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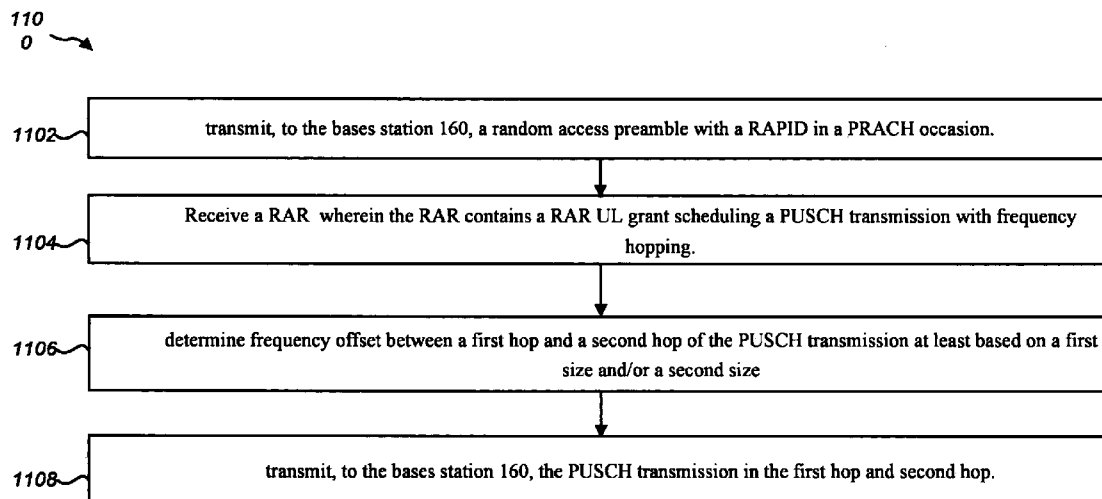


FIG. 11

(57) Abstract: A method by a user equipment (UE) is described. The method includes receiving, from a base station, a random access response (RAR), wherein the RAR contains a RAR uplink (UL) grant scheduling a PUSCH transmission; and determining, for the PUSCH transmission, a frequency hopping mode from two frequency hopping modes, intra-slot frequency hopping and inter-slot frequency hopping, wherein in a first case that the PUSCH transmission is scheduled with repetitions across multi-slots, the inter-slot frequency hopping is determined for the PUSCH transmission, in a second case that the PUSCH transmission is scheduled without repetition, the intra-slot frequency hopping is determined for the PUSCH transmission.



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[DESCRIPTION]

[Title of Invention]

USER EQUIPMENTS, BASE STATIONS, AND METHODS

[Technical Field]

[0001] The present disclosure relates to a user equipment, a base station, and a method.

[Background Art]

[0002] At present, as a radio access system and a radio network technology aimed for the fifth generation cellular system, technical investigation and standard development are being conducted, as extended standards of Long Term Evolution (LTE), on LTE-Advanced Pro (LTE-A Pro) and New Radio technology (NR) in The Third Generation Partnership Project (3GPP).

[0003] In the fifth generation cellular system, three services of enhanced Mobile BroadBand (eMBB) to achieve high-speed and large-volume transmission, Ultra-Reliable and Low Latency Communication (URLLC) to achieve low-latency and high-reliability communication, and massive Machine Type Communication (mMTC) to allow connection of a large number of machine type devices such as Internet of Things (IoT) have been demanded as assumed scenarios.

[0004] For example, wireless communication devices may communicate with one or more devices for multiple service types. For some device types, a lower complexity would be required such as to reduce the Rx/Tx antennas and/or the RF bandwidth to reduce the UE complexity and the UE cost. However, given the reduced antennas and/or the bandwidth, the DL/UL channel coverage and the reception/transmission reliability would be affected and cause an inefficient communication. As illustrated by this discussion, systems and methods according to the present invention, supporting frequency hopping and/or repetitions for transmission/reception, may improve reception/transmission reliability and coverage, and provide the communication flexibility and efficiency.

[Brief Description of the Drawings]

[0005] Figure 1 is a block diagram illustrating one configuration of one or more base stations and one or more user equipments (UEs) in which systems and methods for PUSCH and PUCCH transmission may be implemented;

[0006] Figure 2 is a diagram illustrating one example 200 of a resource grid;

[0007] Figure 3 is a diagram illustrating one example 300 of common resource block grid, carrier configuration and BWP configuration by a UE 102 and a base station 160;

[0008] Figure 4 is a diagram illustrating one 400 example of CORESET configuration in a BWP by a UE 102 and a base station 160;

[0009] Figure 5 is a diagram illustrating one example 500 of DMRS configuration for a PDSCH with PDSCH mapping type A;

[0010] Figure 6 is a diagram illustrating one example 600 of DMRS configuration for a PDSCH with PDSCH mapping type B;

[0011] Figure 7 is a diagram illustrating one example 700 of SS/PBCH block transmission;

[0012] Figure 8 is a diagram illustrating one example 800 of mapping SS/PBCH block indexes to PRACH occasions;

[0013] Figure 9 is a diagram illustrating one 900 example of random access procedure;

[0014] Figure 10 is a diagram illustrating one 1000 example of fields included in an RAR UL grant;

[0015] Figure 11 is a flow diagram illustrating one implementation of a method 1100 for determining frequency hopping for PUSCH scheduled by RAR UL grant by a UE 102;

[0016] Figure 12 is a diagram illustrating one example 1200 of PUSCH transmission/reception with or without frequency hopping by a UE 102 and a base station 160;

[0017] Figure 13 is a diagram illustrating one example of one predefined table 1300 associated to cell specific PUCCH resource configuration;

[0018] Figure 14 is a diagram illustrating one example 1400 of how a cell-specific PUCCH resource is determined by a UE 102 and a base station 160;

[0019] Figure 15 is a flow diagram illustrating one implementation of a method 1500 for determining PUCCH resource by a UE 102;

[0020] Figure 16 illustrates various components that may be utilized in a UE;

[0021] Figure 17 illustrates various components that may be utilized in a base station;

[Description of Embodiments]

[0022] A method by a user equipment (UE) is described. The method includes receiving, from a base station, a random access response (RAR), wherein the RAR contains a RAR uplink (UL) grant scheduling a PUSCH transmission with frequency hopping; and transmitting, to the base station, the PUSCH transmission in a first hop and in a second hop, wherein a frequency offset between the first hop and the second hop is determined based on comparison between the first size and a second size, where the first size is a size of an initial UL BWP in number of resource blocks. The second size is a maximum bandwidth the UE can support in number of resource blocks. The second size is a configured number of resource blocks which is indicated independently of the first size by the base station.

[0023] A method by a base station is described. The method includes transmitting, to a user equipment (UE), a random access response (RAR), wherein the RAR contains a RAR uplink (UL) grant scheduling a PUSCH transmission with frequency hopping; and receiving, from the UE, the PUSCH transmission in a first hop and in a second hop, wherein a frequency offset between the first hop and the second hop is determined based on comparison between the first size and a second size, where the first size is a size of an initial UL BWP in number of resource blocks. The second size is a maximum bandwidth the UE can support in number of resource blocks. The second size is a configured number of resource blocks which is indicated independently of the first size by the base station.

[0024] A user equipment (UE) is described. The UE includes reception circuitry configured to receive, from a base station, a random access response (RAR), wherein the RAR contains a RAR uplink (UL) grant scheduling a PUSCH transmission with frequency hopping; and transmission circuitry configured to transmit, to the base station, the PUSCH transmission in a first hop and in a second hop, wherein a frequency offset between the first hop and the second hop is determined based on comparison between the first size and a second size, where the first size is a size of an initial UL BWP in number of resource blocks. The second size is a maximum bandwidth the UE can

support in number of resource blocks. The second size is a configured number of resource blocks which is indicated independently of the first size by the base station. In a case that the first size is larger than the second size, the frequency offset between the first hop and the second hop is calculated based on the second size. In a case that the first size is equal to or less than the second size, the frequency offset between the first hop and the second hop is calculated based on the first size.

[0025] A base station is described. The base station includes transmission circuitry configured to transmit, to a user equipment (UE), a random access response (RAR), wherein the RAR contains a RAR uplink (UL) grant scheduling a PUSCH transmission with frequency hopping; and reception circuitry configured to receive, from the UE, the PUSCH transmission in a first hop and in a second hop, wherein a frequency offset between the first hop and the second hop is determined based on comparison between the first size and a second size, where the first size is a size of an initial UL BWP in number of resource blocks. The second size is a maximum bandwidth the UE can support in number of resource blocks. The second size is a configured number of resource blocks which is indicated independently of the first size by the base station. In a case that the first size is larger than the second size, the frequency offset between the first hop and the second hop is calculated based on the second size. In a case that the first size is equal to or less than the second size, the frequency offset between the first hop and the second hop is calculated based on the first size.

[0026] 3GPP Long Term Evolution (LTE) is the name given to a project to improve the Universal Mobile Telecommunications System (UMTS) mobile phone or device standard to cope with future requirements. In one aspect, UMTS has been modified to provide support and specification for the Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN). 3GPP NR (New Radio) is the name given to a project to improve the LTE mobile phone or device standard to cope with future requirements. In one aspect, LTE has been modified to provide support and specification (TS 38.331, 38.321, 38.300, 37.300, 38.211, 38.212, 38.213, 38.214, etc) for the New Radio Access (NR) and Next generation – Radio Access Network (NG-RAN).

[0027] At least some aspects of the systems and methods disclosed herein may be described in relation to the 3GPP LTE, LTE-Advanced (LTE-A), LTE-Advanced Pro, New Radio Access (NR), and other 3G/4G/5G standards (e.g., 3GPP Releases 8, 9, 10,

11, 12, 13, 14, 15, and/or 16, and/or Narrow Band-Internet of Things (NB-IoT)). However, the scope of the present disclosure should not be limited in this regard. At least some aspects of the systems and methods disclosed herein may be utilized in other types of wireless communication systems.

[0028] A wireless communication device may be an electronic device used to communicate voice and/or data to a base station, which in turn may communicate with a network of devices (e.g., public switched telephone network (PSTN), the Internet, etc.). In describing systems and methods herein, a wireless communication device may alternatively be referred to as a mobile station, a UE (User Equipment), an access terminal, a subscriber station, a mobile terminal, a remote station, a user terminal, a terminal, a subscriber unit, a mobile device, a relay node, etc. Examples of wireless communication devices include cellular phones, smart phones, personal digital assistants (PDAs), laptop computers, netbooks, e-readers, wireless modems, etc. In 3GPP specifications, a wireless communication device is typically referred to as a UE. However, as the scope of the present disclosure should not be limited to the 3GPP standards, the terms “UE” and “wireless communication device” may be used interchangeably herein to mean the more general term “wireless communication device.”

[0029] In 3GPP specifications, a base station is typically referred to as a gNB, a Node B, an eNB, a home enhanced or evolved Node B (HeNB) or some other similar terminology. As the scope of the disclosure should not be limited to 3GPP standards, the terms “base station,” “gNB,” “Node B,” “eNB,” and “HeNB” may be used interchangeably herein to mean the more general term “base station.” Furthermore, one example of a “base station” is an access point. An access point may be an electronic device that provides access to a network (e.g., Local Area Network (LAN), the Internet, etc.) for wireless communication devices. The term “communication device” may be used to denote both a wireless communication device and/or a base station.

[0030] It should be noted that as used herein, a “cell” may be any communication channel that is specified by standardization or regulatory bodies to be used for International Mobile Telecommunications-Advanced (IMT-Advanced), IMT-2020 (5G) and all of it or a subset of it may be adopted by 3GPP as licensed bands (e.g., frequency bands) to be used for communication between a base station and a UE. It should also be noted that in NR, NG-RAN, E-UTRA and E-UTRAN overall description, as used herein, a “cell” may be defined as “combination of downlink and optionally

uplink resources.” The linking between the carrier frequency of the downlink resources and the carrier frequency of the uplink resources may be indicated in the system information transmitted on the downlink resources.

[0031] “Configured cells” are those cells of which the UE is aware and is allowed by a base station to transmit or receive information. “Configured cell(s)” may be serving cell(s). The UE may receive system information and perform the required measurements on configured cells. “Configured cell(s)” for a radio connection may consist of a primary cell and/or no, one, or more secondary cell(s). “Activated cells” are those configured cells on which the UE is transmitting and receiving. That is, activated cells are those cells for which the UE monitors the physical downlink control channel (PDCCH) and in the case of a downlink transmission, those cells for which the UE decodes a physical downlink shared channel (PDSCH). “Deactivated cells” are those configured cells that the UE is not monitoring the transmission PDCCH. It should be noted that a “cell” may be described in terms of differing dimensions. For example, a “cell” may have temporal, spatial (e.g., geographical) and frequency characteristics.

[0032] The base stations may be connected by the NG interface to the 5G – core network (5G-CN). 5G-CN may be called as to NextGen core (NGC), or 5G core (5GC). The base stations may also be connected by the S1 interface to the evolved packet core (EPC). For instance, the base stations may be connected to a NextGen (NG) mobility management function by the NG-2 interface and to the NG core User Plane (UP) functions by the NG-3 interface. The NG interface supports a many-to-many relation between NG mobility management functions, NG core UP functions and the base stations. The NG-2 interface is the NG interface for the control plane and the NG-3 interface is the NG interface for the user plane. For instance, for EPC connection, the base stations may be connected to a mobility management entity (MME) by the S1-MME interface and to the serving gateway (S-GW) by the S1-U interface. The S1 interface supports a many-to-many relation between MMEs, serving gateways and the base stations. The S1-MME interface is the S1 interface for the control plane and the S1-U interface is the S1 interface for the user plane. The Uu interface is a radio interface between the UE and the base station for the radio protocol.

[0033] The radio protocol architecture may include the user plane and the control plane. The user plane protocol stack may include packet data convergence protocol (PDCP), radio link control (RLC), medium access control (MAC) and physical (PHY)

layers. A DRB (Data Radio Bearer) is a radio bearer that carries user data (as opposed to control plane signaling). For example, a DRB may be mapped to the user plane protocol stack. The PDCP, RLC, MAC and PHY sublayers (terminated at the base station 460a on the network) may perform functions (e.g., header compression, ciphering, scheduling, ARQ and HARQ) for the user plane. PDCP entities are located in the PDCP sublayer. RLC entities may be located in the RLC sublayer. MAC entities may be located in the MAC sublayer. The PHY entities may be located in the PHY sublayer.

[0034] The control plane may include a control plane protocol stack. The PDCP sublayer (terminated in base station on the network side) may perform functions (e.g., ciphering and integrity protection) for the control plane. The RLC and MAC sublayers (terminated in base station on the network side) may perform the same functions as for the user plane. The Radio Resource Control (RRC) (terminated in base station on the network side) may perform the following functions. The RRC may perform broadcast functions, paging, RRC connection management, radio bearer (RB) control, mobility functions, UE measurement reporting and control. The Non-Access Stratum (NAS) control protocol (terminated in MME on the network side) may perform, among other things, evolved packet system (EPS) bearer management, authentication, evolved packet system connection management (ECM)-IDLE mobility handling, paging origination in ECM-IDLE and security control.

[0035] Signaling Radio Bearers (SRBs) are Radio Bearers (RB) that may be used only for the transmission of RRC and NAS messages. Three SRBs may be defined. SRB0 may be used for RRC messages using the common control channel (CCCH) logical channel. SRB1 may be used for RRC messages (which may include a piggybacked NAS message) as well as for NAS messages prior to the establishment of SRB2, all using the dedicated control channel (DCCH) logical channel. SRB2 may be used for RRC messages which include logged measurement information as well as for NAS messages, all using the DCCH logical channel. SRB2 has a lower-priority than SRB1 and may be configured by a network (e.g., base station) after security activation. A broadcast control channel (BCCH) logical channel may be used for broadcasting system information. Some of BCCH logical channel may convey system information which may be sent from the network to the UE via BCH (Broadcast Channel) transport channel. BCH may be sent on a physical broadcast channel (PBCH). Some of BCCH

logical channel may convey system information which may be sent from the network to the UE via DL-SCH (Downlink Shared Channel) transport channel. Paging may be provided by using paging control channel (PCCH) logical channel.

[0036] For example, the DL-DCCH logical channel may be used (but not limited to) for a RRC reconfiguration message, a RRC reestablishment message, a RRC release, a UE Capability Enquiry message, a DL Information Transfer message or a Security Mode Command message. UL-DCCH logical channel may be used (but not limited to) for a measurement report message, a RRC Reconfiguration Complete message, a RRC Reestablishment Complete message, a RRC Setup Complete message, a Security Mode Complete message, a Security Mode Failure message, a UE Capability Information message, a UL Handover Preparation Transfer message, a UL Information Transfer message, a Counter Check Response message, a UE Information Response message, a Proximity Indication message, a RN (Relay Node) Reconfiguration Complete message, an MBMS Counting Response message, an inter Frequency RSTD Measurement Indication message, a UE Assistance Information message, an In-device Coexistence Indication message, an MBMS Interest Indication message, an SCG Failure Information message. DL-CCCH logical channel may be used (but not limited to) for a RRC Connection Reestablishment message, a RRC Reestablishment Reject message, a RRC Reject message, or a RRC Setup message. UL-CCCH logical channel may be used (but not limited to) for a RRC Reestablishment Request message, or a RRC Setup Request message.

[0037] System information may be divided into the MasterInformationBlock (MIB) and a number of SystemInformationBlocks (SIBs).

[0038] The UE may receive one or more RRC messages from the base station to obtain RRC configurations or parameters. The RRC layer of the UE may configure RRC layer and/or lower layers (e.g., PHY layer, MAC layer, RLC layer, PDCP layer) of the UE according to the RRC configurations or parameters which may be configured by the RRC messages, broadcasted system information, and so on. The base station may transmit one or more RRC messages to the UE to cause the UE to configure RRC layer and/or lower layers of the UE according to the RRC configurations or parameters which may be configured by the RRC messages, broadcasted system information, and so on.

[0039] When carrier aggregation is configured, the UE may have one RRC connection with the network. One radio interface may provide carrier aggregation. During RRC establishment, re-establishment and handover, one serving cell may provide Non-Access Stratum (NAS) mobility information (e.g., a tracking area identity (TAI)). During RRC re-establishment and handover, one serving cell may provide a security input. This cell may be referred to as the primary cell (PCell). In the downlink, the component carrier corresponding to the PCell may be the downlink primary component carrier (DL PCC), while in the uplink it may be the uplink primary component carrier (UL PCC).

[0040] Depending on UE capabilities, one or more SCells may be configured to form together with the PCell a set of serving cells. In the downlink, the component carrier corresponding to an SCell may be a downlink secondary component carrier (DL SCC), while in the uplink it may be an uplink secondary component carrier (UL SCC).

[0041] The configured set of serving cells for the UE, therefore, may consist of one PCell and one or more SCells. For each SCell, the usage of uplink resources by the UE (in addition to the downlink resources) may be configurable. The number of DL SCCs configured may be larger than or equal to the number of UL SCCs and no SCell may be configured for usage of uplink resources only.

[0042] From a UE viewpoint, each uplink resource may belong to one serving cell. The number of serving cells that may be configured depends on the aggregation capability of the UE. The PCell may only be changed using a handover procedure (e.g., with a security key change and a random access procedure). A PCell may be used for transmission of the PUCCH. A primary secondary cell (PSCell) may also be used for transmission of the PUCCH. The PSCell may be referred to as a primary SCG cell or SpCell of a secondary cell group. The PCell or PSCell may not be de-activated. Re-establishment may be triggered when the PCell experiences radio link failure (RLF), not when the SCells experience RLF. Furthermore, NAS information may be taken from the PCell.

[0043] The reconfiguration, addition and removal of SCells may be performed by RRC. At handover or reconfiguration with sync, Radio Resource Control (RRC) layer may also add, remove or reconfigure SCells for usage with a target PCell. When adding a new SCell, dedicated RRC signaling may be used for sending all required system

information of the SCell (e.g., while in connected mode, UEs need not acquire broadcasted system information directly from the SCells).

[0044] The systems and methods described herein may enhance the efficient use of radio resources in Carrier aggregation (CA) operation. Carrier aggregation refers to the concurrent utilization of more than one component carrier (CC). In carrier aggregation, more than one cell may be aggregated to a UE. In one example, carrier aggregation may be used to increase the effective bandwidth available to a UE. In traditional carrier aggregation, a single base station is assumed to provide multiple serving cells for a UE. Even in scenarios where two or more cells may be aggregated (e.g., a macro cell aggregated with remote radio head (RRH) cells) the cells may be controlled (e.g., scheduled) by a single base station.

[0045] The systems and methods described herein may enhance the efficient use of radio resources in Carrier aggregation operation. Carrier aggregation refers to the concurrent utilization of more than one component carrier (CC). In carrier aggregation, more than one cell may be aggregated to a UE. In one example, carrier aggregation may be used to increase the effective bandwidth available to a UE. In traditional carrier aggregation, a single base station is assumed to provide multiple serving cells for a UE. Even in scenarios where two or more cells may be aggregated (e.g., a macro cell aggregated with remote radio head (RRH) cells) the cells may be controlled (e.g., scheduled) by a single base station. However, in a small cell deployment scenario, each node (e.g., base station, RRH, etc.) may have its own independent scheduler. To maximize the efficiency of radio resources utilization of both nodes, a UE may connect to two or more nodes that have different schedulers. The systems and methods described herein may enhance the efficient use of radio resources in dual connectivity operation. A UE may be configured multiple groups of serving cells, where each group may have carrier aggregation operation (e.g., if the group includes more than one serving cell).

[0046] In Dual Connectivity (DC) the UE may be required to be capable of UL-CA with simultaneous PUCCH/PUCCH and PUCCH/PUSCH transmissions across cell-groups (CGs). In a small cell deployment scenario, each node (e.g., eNB, RRH, etc.) may have its own independent scheduler. To maximize the efficiency of radio resources utilization of both nodes, a UE may connect to two or more nodes that have different schedulers. A UE may be configured multiple groups of serving cells, where each group may have carrier aggregation operation (e.g., if the group includes more than one

serving cell). A UE in RRC_CONNECTED may be configured with Dual Connectivity or MR-DC, when configured with a Master and a Secondary Cell Group. A Cell Group (CG) may be a subset of the serving cells of a UE, configured with Dual Connectivity (DC) or MR-DC, i.e. a Master Cell Group (MCG) or a Secondary Cell Group (SCG). The Master Cell Group may be a group of serving cells of a UE comprising of the PCell and zero or more secondary cells. The Secondary Cell Group (SCG) may be a group of secondary cells of a UE, configured with DC or MR-DC, comprising of the PSCell and zero or more other secondary cells. A Primary Secondary Cell (PSCell) may be the SCG cell in which the UE is instructed to perform random access when performing the SCG change procedure. "PSCell" may be also called as a Primary SCG Cell. In Dual Connectivity or MR-DC, two MAC entities may be configured in the UE: one for the MCG and one for the SCG. Each MAC entity may be configured by RRC with a serving cell supporting PUCCH transmission and contention based Random Access. In a MAC layer, the term Special Cell (SpCell) may refer to such cell, whereas the term SCell may refer to other serving cells. The term SpCell either may refer to the PCell of the MCG or the PSCell of the SCG depending on if the MAC entity is associated to the MCG or the SCG, respectively. A Timing Advance Group (TAG) containing the SpCell of a MAC entity may be referred to as primary TAG (pTAG), whereas the term secondary TAG (sTAG) refers to other TAGs.

[0047] DC may be further enhanced to support Multi-RAT Dual Connectivity (MR-DC). MR-DC may be a generalization of the Intra-E-UTRA Dual Connectivity (DC) described in 36.300, where a multiple Rx/Tx UE may be configured to utilize resources provided by two different nodes connected via non-ideal backhaul, one providing E-UTRA access and the other one providing NR access. One node acts as a Master Node (MN) and the other as a Secondary Node (SN). The MN and SN are connected via a network interface and at least the MN is connected to the core network. In DC, a PSCell may be a primary secondary cell. In EN-DC, a PSCell may be a primary SCG cell or SpCell of a secondary cell group.

[0048] E-UTRAN may support MR-DC via E-UTRA-NR Dual Connectivity (EN-DC), in which a UE is connected to one eNB that acts as a MN and one en-gNB that acts as a SN. The en-gNB is a node providing NR user plane and control plane protocol terminations towards the UE, and acting as Secondary Node in EN-DC. The eNB is connected to the EPC via the S1 interface and to the en-gNB via the X2 interface. The

en-gNB might also be connected to the EPC via the S1-U interface and other en-gNBs via the X2-U interface.

[0049] A timer is running once it is started, until it is stopped or until it expires; otherwise it is not running. A timer can be started if it is not running or restarted if it is running. A Timer may be always started or restarted from its initial value.

[0050] For NR, a technology of aggregating NR carriers may be studied. Both lower layer aggregation like Carrier Aggregation (CA) for LTE and upper layer aggregation like DC are investigated. From layer 2/3 point of view, aggregation of carriers with different numerologies may be supported in NR.

[0051] The main services and functions of the RRC sublayer may include the following:

- Broadcast of System Information related to Access Stratum (AS) and Non Access Stratum (NAS);
- Paging initiated by CN or RAN;
- Establishment, maintenance and release of an RRC connection between the UE and NR RAN including:
 - Addition, modification and release of carrier aggregation;
 - Addition, modification and release of Dual Connectivity in NR or between LTE and NR;
- Security functions including key management;
- Establishment, configuration, maintenance and release of signaling radio bearers and data radio bearers;
- Mobility functions including:
 - Handover;
 - UE cell selection and reselection and control of cell selection and reselection;
 - Context transfer at handover.
- QoS management functions;
- UE measurement reporting and control of the reporting;
- NAS message transfer to/from NAS from/to UE.

[0052] Each MAC entity of a UE may be configured by RRC with a Discontinuous Reception (DRX) functionality that controls the UE's PDCCH monitoring activity for the MAC entity's C-RNTI (Radio Network Temporary Identifier), CS-RNTI, INT-

RNTI, SFI-RNTI, SP-CSI-RNTI, TPC-PUCCH-RNTI, TPC-PUSCH-RNTI, and TPC-SRS-RNTI. For scheduling at cell level, the following identities are used:

- C (Cell) -RNTI: unique UE identification used as an identifier of the RRC Connection and for scheduling;
- CS (Configured Scheduling) -RNTI: unique UE identification used for Semi-Persistent Scheduling in the downlink;
- INT-RNTI: identification of pre-emption in the downlink;
- P-RNTI: identification of Paging and System Information change notification in the downlink;
- SI-RNTI: identification of Broadcast and System Information in the downlink;
- SP-CSI-RNTI: unique UE identification used for semi-persistent CSI reporting on PUSCH;
- CI-RNTI: Cancellation Indication RNTI for Uplink.

For power and slot format control, the following identities are used:

- SFI-RNTI: identification of slot format;
- TPC-PUCCH-RNTI: unique UE identification to control the power of PUCCH;
- TPC-PUSCH-RNTI: unique UE identification to control the power of PUSCH;
- TPC-SRS-RNTI: unique UE identification to control the power of SRS;

During the random access procedure, the following identities are also used:

- RA-RNTI: identification of the Random Access Response in the downlink;
- Temporary C-RNTI: UE identification temporarily used for scheduling during the random access procedure;
- Random value for contention resolution: UE identification temporarily used for contention resolution purposes during the random access procedure.

For NR connected to 5GC, the following UE identities are used at NG-RAN level:

- I-RNTI: used to identify the UE context in RRC_INACTIVE.

[0053] The size of various fields in the time domain is expressed in time units $T_c = 1/(\Delta f_{\max} \times N_f)$ where $\Delta f_{\max} = 480 \times 10^3$ Hz and $N_f = 4096$. The constant $\kappa = T_s/T_c = 64$ where $T_s = 1/(\Delta f_{\text{ref}} \cdot N_{f,\text{ref}})$, $\Delta f_{\text{ref}} = 15 \cdot 10^3$ Hz and $N_{f,\text{ref}} = 2048$.

[0054] Multiple OFDM numerologies are supported as given by Table 4.2-1 of [TS 38.211] where μ and the cyclic prefix for a bandwidth part are obtained from the higher-layer parameter *subcarrierSpacing* and *cyclicPrefix*, respectively.

[0055] The size of various fields in the time domain may be expressed as a number of time units $T_c = 1/(15000 \times 2048)$ seconds. Downlink and uplink transmissions are organized into frames with $T_f = (\Delta f_{\max} N_f / 100) \cdot T_c = 10$ ms duration, each consisting of ten subframes of $T_{sf} = (\Delta f_{\max} N_f / 1000) \cdot T_c = 1$ ms duration. The number of consecutive OFDM symbols per subframe is $N_{\text{subframe},\mu}^{\text{subframe},\mu} = N_{\text{symbol}}^{\text{slot}} N_{\text{slot}}^{\text{subframe},\mu}$. Each frame is divided into two equally-sized half-frames of five subframes each with half-frame 0 consisting of subframes 0 – 4 and half-frame 1 consisting of subframes 5 – 9.

[0056] For subcarrier spacing (SCS) configuration μ , slots are numbered $n_s^\mu \in \{0, \dots, N_{\text{slot}}^{\text{subframe},\mu} - 1\}$ in increasing order within a subframe and $n_{s,f}^\mu \in \{0, \dots, N_{\text{slot}}^{\text{frame},\mu} - 1\}$ in increasing order within a frame. $N_{\text{slot}}^{\text{subframe},\mu}$ is the number of slots per subframe for subcarrier spacing configuration μ . There are $N_{\text{symbol}}^{\text{slot}}$ consecutive OFDM symbols in a slot where $N_{\text{symbol}}^{\text{slot}}$ depends on the cyclic prefix as given by Tables 4.3.2-1 and 4.3.2-2 of [TS 38.211]. The start of slot n_s^μ in a subframe is aligned in time with the start of OFDM symbol $n_s^\mu N_{\text{symbol}}^{\text{slot}}$ in the same subframe. Subcarrier spacing refers to a spacing (or frequency bandwidth) between two consecutive subcarrier in the frequency domain. For example, the subcarrier spacing can be set to 15kHz (i.e. $\mu=0$), 30kHz (i.e. $\mu=1$), 60kHz (i.e. $\mu=2$), 120kHz (i.e. $\mu=3$), or 240kHz (i.e. $\mu=4$). A resource block is defined as a number of consecutive subcarriers (e.g. 12) in the frequency domain. For a carrier with different frequency, the applicable subcarrier may be different. For example, for a carrier in a frequency rang 1, a subcarrier spacing only among a set of {15kHz, 30kHz, 60kHz} is applicable. For a carrier in a frequency rang 2, a subcarrier spacing only among a set of {60kHz, 120kHz, 240kHz} is applicable. The base station may not configure an inapplicable subcarrier spacing for a carrier.

[0057] OFDM symbols in a slot can be classified as 'downlink', 'flexible', or 'uplink'. Signaling of slot formats is described in subclause 11.1 of [TS 38.213].

[0058] In a slot in a downlink frame, the UE may assume that downlink transmissions only occur in 'downlink' or 'flexible' symbols. In a slot in an uplink frame, the UE may only transmit in 'uplink' or 'flexible' symbols.

[0059] Various examples of the systems and methods disclosed herein are now described with reference to the Figures, where like reference numbers may indicate functionally similar elements. The systems and methods as generally described and illustrated in the Figures herein could be arranged and designed in a wide variety of different implementations. Thus, the following more detailed description of several implementations, as represented in the Figures, is not intended to limit scope, as claimed, but is merely representative of the systems and methods.

[0060] Figure 1 is a block diagram illustrating one configuration of one or more base stations 160 (e.g., eNB, gNB) and one or more user equipments (UEs) 102 in which systems and methods for PUSCH and PUCCH transmission in a set of multiple sets may be implemented. The one or more UEs 102 may communicate with one or more base stations 160 using one or more antennas 122a–n. For example, a UE 102 transmits electromagnetic signals to the base station 160 and receives electromagnetic signals from the base station 160 using the one or more antennas 122a–n. The base station 160 communicates with the UE 102 using one or more antennas 180a–n.

[0061] It should be noted that in some configurations, one or more of the UEs 102 described herein may be implemented in a single device. For example, multiple UEs 102 may be combined into a single device in some implementations. Additionally or alternatively, in some configurations, one or more of the base stations 160 described herein may be implemented in a single device. For example, multiple base stations 160 may be combined into a single device in some implementations. In the context of Figure 1, for instance, a single device may include one or more UEs 102 in accordance with the systems and methods described herein. Additionally or alternatively, one or more base stations 160 in accordance with the systems and methods described herein may be implemented as a single device or multiple devices.

[0062] The UE 102 and the base station 160 may use one or more channels 119, 121 to communicate with each other. For example, a UE 102 may transmit information or data to the base station 160 using one or more uplink (UL) channels 121 and signals.

Examples of uplink channels 121 include a physical uplink control channel (PUCCH) and a physical uplink shared channel (PUSCH), etc. Examples of uplink signals include a demodulation reference signal (DMRS) and a sounding reference signal (SRS), etc. The one or more base stations 160 may also transmit information or data to the one or more UEs 102 using one or more downlink (DL) channels 119 and signals, for instance. Examples of downlink channels 119 include a PDCCH, a PDSCH, etc. A PDCCH can be used to schedule DL transmissions on PDSCH and UL transmissions on PUSCH, where the Downlink Control Information (DCI) on PDCCH includes downlink assignment and uplink scheduling grants. The PDCCH is used for transmitting Downlink Control Information (DCI) in a case of downlink radio communication (radio communication from the base station to the UE). Here, one or more DCIs (may be referred to as DCI formats) are defined for transmission of downlink control information. Information bits are mapped to one or more fields defined in a DCI format. Examples of downlink signals include a primary synchronization signal (PSS), a secondary synchronization signal (SSS), a cell-specific reference signal (CRS), a non-zero power channel state information reference signal (NZP CSI-RS), and a zero power channel state information reference signal (ZP CSI-RS), etc. Other kinds of channels or signals may be used.

[0063] Each of the one or more UEs 102 may include one or more transceivers 118, one or more demodulators 114, one or more decoders 108, one or more encoders 150, one or more modulators 154, one or more data buffers 104 and one or more UE operations modules 124. For example, one or more reception and/or transmission paths may be implemented in the UE 102. For convenience, only a single transceiver 118, decoder 108, demodulator 114, encoder 150 and modulator 154 are illustrated in the UE 102, though multiple parallel elements (e.g., transceivers 118, decoders 108, demodulators 114, encoders 150 and modulators 154) may be implemented.

[0064] The transceiver 118 may include one or more receivers 120 and one or more transmitters 158. The one or more receivers 120 may receive signals (e.g., downlink channels, downlink signals) from the base station 160 using one or more antennas 122a–n. For example, the receiver 120 may receive and downconvert signals to produce one or more received signals 116. The one or more received signals 116 may be provided to a demodulator 114. The one or more transmitters 158 may transmit signals (e.g., uplink channels, uplink signals) to the base station 160 using one or more antennas

122a–n. For example, the one or more transmitters 158 may upconvert and transmit one or more modulated signals 156.

[0065] The demodulator 114 may demodulate the one or more received signals 116 to produce one or more demodulated signals 112. The one or more demodulated signals 112 may be provided to the decoder 108. The UE 102 may use the decoder 108 to decode signals. The decoder 108 may produce one or more decoded signals 106, 110. For example, a first UE-decoded signal 106 may comprise received payload data, which may be stored in a data buffer 104. A second UE-decoded signal 110 may comprise overhead data and/or control data. For example, the second UE-decoded signal 110 may provide data that may be used by the UE operations module 124 to perform one or more operations.

[0066] As used herein, the term “module” may mean that a particular element or component may be implemented in hardware, software or a combination of hardware and software. However, it should be noted that any element denoted as a “module” herein may alternatively be implemented in hardware. For example, the UE operations module 124 may be implemented in hardware, software or a combination of both.

[0067] In general, the UE operations module 124 may enable the UE 102 to communicate with the one or more base stations 160. The UE operations module 124 may include a UE RRC information configuration module 126. The UE operations module 124 may include a UE resource assignment (RA) control module 128. In some implementations, the UE operations module 124 may include physical (PHY) entities, Medium Access Control (MAC) entities, Radio Link Control (RLC) entities, packet data convergence protocol (PDCP) entities, and an Radio Resource Control (RRC) entity. For example, the UE RRC information configuration module 126 may process RRC parameter for random access configurations, initial UL BWP configuration, maximum bandwidth the UE can support, and cell specific PUCCH resource configuration(s). The UE RA control module (processing module) 128 may determine to select a SS/PBCH block for random access based on the measured RSRP value from the UE receiver 178. The UE RA control module 128 may determine a PRACH occasion and a preamble for PRACH transmission based on the processing output from the UE RRC information configuration module 126. The UE RA control module 128 may determine a frequency offset between a first hop and a second hop of a PUSCH scheduled by a RAR UL grant based on comparison between a first size, i.e. an initial

UL BWP size and a second size. The second size may be a maximum bandwidth the UE can support in number of resource blocks or may be a configured number of resource blocks which is indicated independently of the first size by the base station. The first size and the second size are given based on the processing output from the UE RRC information configuration module 126.

[0068] The UE RA control module 128 may determine a first cell specific PUCCH resource set for transmission of HARQ-ACK information on a PUCCH in a case that the system information provides a first RRC parameter and does not provide a second RRC parameter. The UE RA control module 128 may determine a second cell specific PUCCH resource set for transmission of HARQ-ACK information on a PUCCH in a case that the system information provides the second RRC parameter. The first RRC parameter provides the first cell specific PUCCH resource set. The second RRC parameter provides the second cell specific PUCCH resource set.

[0069] The UE operations module 124 may provide information 148 to the one or more receivers 120. For example, the UE operations module 124 may inform the receiver(s) 120 when or when not to receive transmissions based on the Radio Resource Control (RRC) message (e.g, broadcasted system information, RRC reconfiguration message), MAC control element, and/or the DCI (Downlink Control Information). The UE operations module 124 may provide information 148, including the PDCCH monitoring occasions and DCI format size, to the one or more receivers 120. The UE operation module 124 may inform the receiver(s) 120 when or where to receive/monitor the PDCCH candidate for DCI formats with which DCI size.

[0070] The UE operations module 124 may provide information 138 to the demodulator 114. For example, the UE operations module 124 may inform the demodulator 114 of a modulation pattern anticipated for transmissions from the base station 160.

[0071] The UE operations module 124 may provide information 136 to the decoder 108. For example, the UE operations module 124 may inform the decoder 108 of an anticipated encoding for transmissions from the base station 160. For example, the UE operations module 124 may inform the decoder 108 of an anticipated PDCCH candidate encoding with which DCI size for transmissions from the base station 160.

[0072] The UE operations module 124 may provide information 142 to the encoder 150. The information 142 may include data to be encoded and/or instructions for

encoding. For example, the UE operations module 124 may instruct the encoder 150 to encode transmission data 146 and/or other information 142.

[0073] The encoder 150 may encode transmission data 146 and/or other information 142 provided by the UE operations module 124. For example, encoding the data 146 and/or other information 142 may involve error detection and/or correction coding, mapping data to space, time and/or frequency resources for transmission, multiplexing, etc. The encoder 150 may provide encoded data 152 to the modulator 154.

[0074] The UE operations module 124 may provide information 144 to the modulator 154. For example, the UE operations module 124 may inform the modulator 154 of a modulation type (e.g., constellation mapping) to be used for transmissions to the base station 160. The modulator 154 may modulate the encoded data 152 to provide one or more modulated signals 156 to the one or more transmitters 158.

[0075] The UE operations module 124 may provide information 140 to the one or more transmitters 158. This information 140 may include instructions for the one or more transmitters 158. For example, the UE operations module 124 may instruct the one or more transmitters 158 when to transmit a signal to the base station 160. The one or more transmitters 158 may upconvert and transmit the modulated signal(s) 156 to one or more base stations 160.

[0076] The base station 160 may include one or more transceivers 176, one or more demodulators 172, one or more decoders 166, one or more encoders 109, one or more modulators 113, one or more data buffers 162 and one or more base station operations modules 182. For example, one or more reception and/or transmission paths may be implemented in a base station 160. For convenience, only a single transceiver 176, decoder 166, demodulator 172, encoder 109 and modulator 113 are illustrated in the base station 160, though multiple parallel elements (e.g., transceivers 176, decoders 166, demodulators 172, encoders 109 and modulators 113) may be implemented.

[0077] The transceiver 176 may include one or more receivers 178 and one or more transmitters 117. The one or more receivers 178 may receive signals (e.g., uplink channels, uplink signals) from the UE 102 using one or more antennas 180a–n. For example, the receiver 178 may receive and downconvert signals to produce one or more received signals 174. The one or more received signals 174 may be provided to a demodulator 172. The one or more transmitters 117 may transmit signals (e.g., downlink channels, downlink signals) to the UE 102 using one or more antennas 180a–

n. For example, the one or more transmitters 117 may upconvert and transmit one or more modulated signals 115.

[0078] The demodulator 172 may demodulate the one or more received signals 174 to produce one or more demodulated signals 170. The one or more demodulated signals 170 may be provided to the decoder 166. The base station 160 may use the decoder 166 to decode signals. The decoder 166 may produce one or more decoded signals 164, 168. For example, a first base station-decoded signal 164 may comprise received payload data, which may be stored in a data buffer 162. A second base station-decoded signal 168 may comprise overhead data and/or control data. For example, the second base station-decoded signal 168 may provide data (e.g., PUSCH transmission data) that may be used by the base station operations module 182 to perform one or more operations.

[0079] In general, the base station operations module 182 may enable the base station 160 to communicate with the one or more UEs 102. The base station operations module 182 may include a base station RRC information configuration module 194. The base station operations module 182 may include a base station resource assignment (RA) control module 196 (or a base station RA processing module 196). The base station operations module 182 may include PHY entities, MAC entities, RLC entities, PDCP entities, and an RRC entity.

[0080] The base station RA control module 196 may determine, for respective UE, when and where to transmit the preamble, the time and frequency resource of PRACH occasions and input the information to the base station RRC information configuration module 194. The base station RA control module 196 may generate a RAR UL grant to schedule a PUSCH with frequency hopping. The base station RA control module 196 may determine a frequency offset between a first hop and a second hop of the PUSCH scheduled by a RAR UL grant based on comparison between a first size, i.e. an initial UL BWP size and a second size. The second size may be a maximum bandwidth the UE can support in number of resource blocks or may be a configured number of resource blocks which is indicated independently of the first size by the base station. The first size and the second size are given based on the processing output from the base station RRC information configuration module 194.

[0081] The base station RA control module 196 may determine the configuration of a first cell specific PUCCH resource set and/or a second cell specific PUCCH resource set, and input the information to the base station RRC information

configuration module 194. The base station RRC information configuration module 194 may generate a first RRC parameter providing the first cell specific PUCCH resource set and/or a second RRC parameter providing the second cell specific PUCCH resource set.

[0082] The base station RA control module 196 may input the determined information to the base station RRC information configuration module 194. The base station RRC information configuration module 194 may generate RRC parameters for search space configurations and CORESET configuration based on the output from the base station RA control module 196.

[0083] The base station operations module 182 may provide the benefit of performing PDCCH candidate search and monitoring efficiently.

[0084] The base station operations module 182 may provide information 190 to the one or more receivers 178. For example, the base station operations module 182 may inform the receiver(s) 178 when or when not to receive transmissions based on the RRC message (e.g, broadcasted system information, RRC reconfiguration message), MAC control element, and/or the DCI (Downlink Control Information).

[0085] The base station operations module 182 may provide information 188 to the demodulator 172. For example, the base station operations module 182 may inform the demodulator 172 of a modulation pattern anticipated for transmissions from the UE(s) 102.

[0086] The base station operations module 182 may provide information 186 to the decoder 166. For example, the base station operations module 182 may inform the decoder 166 of an anticipated encoding for transmissions from the UE(s) 102.

[0087] The base station operations module 182 may provide information 101 to the encoder 109. The information 101 may include data to be encoded and/or instructions for encoding. For example, the base station operations module 182 may instruct the encoder 109 to encode transmission data 105 and/or other information 101.

[0088] In general, the base station operations module 182 may enable the base station 160 to communicate with one or more network nodes (e.g., a NG mobility management function, a NG core UP functions, a mobility management entity (MME), serving gateway (S-GW), gNBs). The base station operations module 182 may also generate a RRC reconfiguration message to be signaled to the UE 102.

[0089] The encoder 109 may encode transmission data 105 and/or other information 101 provided by the base station operations module 182. For example, encoding the data 105 and/or other information 101 may involve error detection and/or correction coding, mapping data to space, time and/or frequency resources for transmission, multiplexing, etc. The encoder 109 may provide encoded data 111 to the modulator 113. The transmission data 105 may include network data to be relayed to the UE 102.

[0090] The base station operations module 182 may provide information 103 to the modulator 113. This information 103 may include instructions for the modulator 113. For example, the base station operations module 182 may inform the modulator 113 of a modulation type (e.g., constellation mapping) to be used for transmissions to the UE(s) 102. The modulator 113 may modulate the encoded data 111 to provide one or more modulated signals 115 to the one or more transmitters 117.

[0091] The base station operations module 182 may provide information 192 to the one or more transmitters 117. This information 192 may include instructions for the one or more transmitters 117. For example, the base station operations module 182 may instruct the one or more transmitters 117 when to (or when not to) transmit a signal to the UE(s) 102. The base station operations module 182 may provide information 192, including the PDCCH monitoring occasions and DCI format size, to the one or more transmitters 117. The base station operation module 182 may inform the transmitter(s) 117 when or where to transmit the PDCCH candidate for DCI formats with which DCI size. The one or more transmitters 117 may upconvert and transmit the modulated signal(s) 115 to one or more UEs 102.

[0092] It should be noted that one or more of the elements or parts thereof included in the base station(s) 160 and UE(s) 102 may be implemented in hardware. For example, one or more of these elements or parts thereof may be implemented as a chip, circuitry or hardware components, etc. It should also be noted that one or more of the functions or methods described herein may be implemented in and/or performed using hardware. For example, one or more of the methods described herein may be implemented in and/or realized using a chipset, an application-specific integrated circuit (ASIC), a large-scale integrated circuit (LSI) or integrated circuit, etc.

[0093] A base station may generate a RRC message including the one or more RRC parameters, and transmit the RRC message to a UE. A UE may receive, from a base

station, a RRC message including one or more RRC parameters. The term ‘RRC parameter(s)’ in the present disclosure may be alternatively referred to as ‘RRC information element(s)’. A RRC parameter may further include one or more RRC parameter(s). In the present disclosure, a RRC message may include system information. a RRC message may include one or more RRC parameters. A RRC message may be sent on a broadcast control channel (BCCH) logical channel, a common control channel (CCCH) logical channel or a dedicated control channel (DCCH) logical channel.

[0094] In the present disclosure, a description ‘a base station may configure a UE to’ may also imply/refer to ‘a base station may transmit, to a UE, an RRC message including one or more RRC parameters’. Additionally or alternatively, ‘RRC parameter configure a UE to’ may also refer to ‘a base station may transmit, to a UE, an RRC message including one or more RRC parameters’. Additionally or alternatively, ‘a UE is configured to’ may also refer to ‘a UE may receive, from a base station, an RRC message including one or more RRC parameters’.

[0095] Figure 2 is a diagram illustrating one example of a resource grid 200.

[0096] For each numerology and carrier, a resource grid of $N_{grid,x}^{size,\mu} N_{sc}^{RB}$ subcarriers and $N_{symb}^{subframe,\mu}$ OFDM symbols is defined, starting at common resource block $N_{grid}^{start,\mu}$ indicated by higher layer signaling. There is one set of resource grids per transmission direction (uplink or downlink) with the subscript x set to DL and UL for downlink and uplink, respectively. There is one resource grid for a given antenna port p , subcarrier spacing configuration μ , and the transmission direction (downlink or uplink). When there is no risk for confusion, the subscript x may be dropped.

[0097] In the Figure 2, the resource grid 200 includes the $N_{grid,x}^{size,\mu} N_{sc}^{RB}$ (202) subcarriers in the frequency domain and includes $N_{symb}^{subframe,\mu}$ (204) symbols in the time domain. In the Figure 2, as an example for illustration, the subcarrier spacing configuration μ is set to 0. That is, in the Figure 2, the number of consecutive OFDM symbols $N_{symb}^{subframe,\mu}$ (204) per subframe is equal to 14.

[0098] The carrier bandwidth $N_{grid}^{size,\mu}$ ($N_{grid,x}^{size,\mu}$) for subcarrier spacing configuration μ is given by the higher-layer (RRC) parameter *carrierBandwidth* in the *SCS-SpecificCarrier* IE. The starting position $N_{grid}^{start,\mu}$ for subcarrier spacing configuration μ is given by the higher-layer parameter *offsetToCarrier* in the *SCS-SpecificCarrier* IE. The frequency location of a subcarrier refers to the center frequency of that subcarrier.

[0099] In the Figure 2, for example, a value of *offset* is provided by the higher-layer parameter *offsetToCarrier*. That is, $k = 12 \times \text{offset}$ is the lowest usable subcarrier on this carrier.

[0100] Each element in the resource grid for antenna port p and subcarrier spacing configuration μ is called a resource element and is uniquely identified by $(k, l)_{p,\mu}$ where k is the index in the frequency domain and l refers to the symbols position in the time domain relative to same reference point. The resource element consists of one subcarrier during one OFDM symbol.

[0101] A resource block is defined as $N_{sc}^{RB} = 12$ consecutive subcarriers in the frequency domain. As shown in the Figure 2, a resource block 206 includes 12 consecutive subcarriers in the frequency domain. Resource block can be classified as common resource block (CRB) and physical resource block (PRB).

[0102] Common resource blocks are numbered from 0 and upwards in the frequency domain for subcarrier spacing configuration μ . The center of subcarrier 0 of common resource block with index 0 (i.e. CRB0) for subcarrier spacing configuration μ coincides with point A. The relation between the common resource block number n_{CRB}^μ in the frequency domain and resource element (k, l) for subcarrier spacing configuration μ is given by Formula (1) $n_{CRB}^\mu = \text{floor}(k/N_{sc}^{RB})$ where k is defined relative to the point A such that $k=0$ corresponds to the subcarrier centered around the point A. The function $\text{floor}(A)$ hereinafter is to output a maximum integer not larger than the A .

[0103] Point A refers to as a common reference point. Point A coincides with subcarrier 0 (i.e. $k=0$) of a CRB 0 for all subcarrier spacing. Point A can be obtained from a RRC parameter *offsetToPointA* or a RRC parameter *absoluteFrequencyPointA*. The RRC parameter *offsetToPointA* is used for a PCell downlink and represents the frequency offset between point A and the lowest subcarrier of the lowest resource block, which has the subcarrier spacing provided by a higher-layer parameter *subCarrierSpacingCommon* and overlaps with the SS/PBCH block used by the UE for initial cell selection, expressed in units of resource blocks assuming 15 kHz subcarrier spacing for frequency range (FR) 1 and 60 kHz subcarrier spacing for frequency range (FR2). FR1 corresponds to a frequency range between 410MHz and 7125MHz. FR2 corresponds to a frequency range between 24250MHz and 52600MHz. The RRC parameter *absoluteFrequencyPointA* is used for all cases other than the PCell case and

represents the frequency-location of point A expressed as in ARFCN. The frequency location of point A can be the lowest subcarrier of the carrier bandwidth (or the actual carrier). Additionally, point A may be located outside the carrier bandwidth (or the actual carrier).

[0104] As above mentioned, the information element (IE) *SCS-SpecificCarrier* provides parameters determining the location and width of the carrier bandwidth or the actual carrier. That is, a carrier (or a carrier bandwidth, or an actual carrier) is determined (identified, or defined) at least by a RRC parameter *offsetToCarrier*, a RRC parameter *subcarrierSpacing*, and a RRC parameter *carrierBandwidth* in the *SCS-SpecificCarrier* IE.

[0105] The *subcarrierSpacing* indicates (or defines) a subcarrier spacing of the carrier. The *offsetToCarrier* indicates an offset in frequency domain between point A and a lowest usable subcarrier on this carrier in number of resource blocks (e.g. CRBs) using the subcarrier spacing defined for the carrier. The *carrierBandwidth* indicates width of this carrier in number of resource blocks (e.g. CRBs or PRBs) using the subcarrier spacing defined for the carrier. A carrier includes at most 275 resource blocks.

[0106] Physical resource block for subcarrier spacing configuration μ are defined within a bandwidth part and numbered from 0 to $N_{BWP,i}^{size,\mu}$ where i is the number of the bandwidth part. The relation between the physical resource block n_{PRB}^{μ} in bandwidth part (BWP) i and the common resource block n_{CRB}^{μ} is given by Formula (2) $n_{CRB}^{\mu} = n_{PRB}^{\mu} + N_{BWP,i}^{start,\mu}$ where $N_{BWP,i}^{start,\mu}$ is the common resource block where bandwidth part i starts relative to common resource block 0 (CRB0). When there is no risk for confusion the index μ may be dropped.

[0107] A BWP is a subset of contiguous common resource block for a given subcarrier spacing configuration μ on a given carrier. To be specific, a BWP can be identified (or defined) at least by a subcarrier spacing μ indicated by the RRC parameter *subcarrierSpacing*, a cyclic prefix determined by the RRC parameter *cyclicPrefix*, a frequency domain location, a bandwidth, an BWP index indicated by *bwp-Id* and so on. The *locationAndBandwidth* can be used to indicate the frequency domain location and bandwidth of a BWP. The value indicated by the *locationAndBandwidth* is interpreted as resource indicator value (RIV) corresponding to an offset (an starting resource block) RB_{start} and a length L_{RB} in terms of contiguous resource blocks. The offset RB_{start} is a number of CRBs between the lowest CRB of the carrier and the lowest CRB of the

BWP. The $N_{BWP,i}^{start,\mu}$ is given as Formula (3) $N_{BWP,i}^{start,\mu} = O_{carrier} + RB_{start}$. The value of $O_{carrier}$ is provided by *offsetToCarrier* for the corresponding subcarrier spacing configuration μ .

[0108] A UE 102 configured to operation in BWPs of a serving cell, is configured by higher layers for the serving cell a set of at most four BWPs in the downlink for reception. At a given time, a single downlink BWP is active. The base station 160 may not transmit, to the UE 102, PDSCH and/or PDCCH outside the active downlink BWP. A UE 102 configured to operation in BWPs of a serving cell, is configured by higher layers for the serving cell a set of at most four BWPs for transmission. At a given time, a single uplink BWP is active. The UE 102 may not transmit, to the base station 160, PUSCH or PUCCH outside the active BWP. The specific signaling (higher layers signaling) for BWP configurations are described later.

[0109] Figure 3 is a diagram illustrating one example 300 of common resource block grid, carrier configuration and BWP configuration by a UE 102 and a base station 160.

[0110] Point A 301 is a lowest subcarrier of a CRB0 for all subcarrier spacing configurations. The CRB grid 302 and the CRB grid 312 are corresponding to two different subcarrier spacing configurations. The CRB grid 302 is for subcarrier spacing configuration $\mu = 0$ (i.e. the subcarrier spacing with 15kHz). The CRB grid 312 is for subcarrier spacing configuration $\mu = 1$ (i.e. the subcarrier spacing with 30kHz).

[0111] One or more carrier are determined by respective *SCS-SpecificCarrier* IEs, respectively. In the Figure 3, the carrier 304 uses the subcarrier spacing configuration $\mu = 0$. And the carrier 314 uses the subcarrier spacing configuration $\mu = 1$. The starting position $N_{grid}^{start,\mu}$ of the carrier 304 is given based on the value of an offset 303 (i.e. $O_{carrier}$) indicated by an *offsetToCarrier* in an *SCS-SpecificCarrier* IE. As shown in the Figure 3, for example, the *offsetToCarrier* indicates the value of the offset 303 as $O_{carrier} = 3$. That is, the starting position $N_{grid}^{start,\mu}$ of the carrier 304 corresponds to the CRB3 of the CRB grid 302 for subcarrier spacing configuration $\mu = 0$. In the meantime, the starting position $N_{grid}^{start,\mu}$ of the carrier 314 is given based on the value of an offset 313 (i.e. $O_{carrier}$) indicated by an *offsetToCarrier* in another *SCS-SpecificCarrier* IE. For example, the *offsetToCarrier* indicates the value of the offset 313 as $O_{carrier} = 1$. That is, the starting position $N_{grid}^{start,\mu}$ of the carrier 314 corresponds to the CRB1 of the CRB

grid 312 for subcarrier spacing configuration $\mu=1$. A carrier using different subcarrier spacing configurations can occupy different frequency ranges.

[0112] As above-mentioned, a BWP is for a given subcarrier spacing configuration μ . One or more BWPs can be configured for a same subcarrier spacing configuration μ . For example, in the Figure 3, the BWP 306 is identified at least by the $\mu=0$, a frequency domain location, a bandwidth (L_{RB}), and an BWP index (index A). The first PRB (i.e. PRB0) of a BWP is determined at least by the subcarrier spacing of the BWP, an offset derived by the *locationAndBandwidth* and an offset indicated by the *offsetToCarrier* corresponding to the subcarrier spacing of the BWP. An offset 305 (RB_{start}) is derived as 1 by the *locationAndBandwidth*. According to the Formulas (2) and (3), the PRB0 of BWP 306 corresponds to CRB 4 of the CRB grid 302, and the PRB1 of BWP 306 corresponds to CRB 5 of the CRB grid 302, and so on.

[0113] Additionally, in the Figure 3, the BWP 308 is identified at least by the $\mu=0$, a frequency domain location, a bandwidth (L_{RB}), and an BWP index (index B). For example, an offset 307 (RB_{start}) is derived as 6 by the *locationAndBandwidth*. According to the Formulas (2) and (3), the PRB0 of BWP 308 corresponds to CRB 9 of the CRB grid 302, and the PRB1 of BWP 308 corresponds to CRB 10 of the CRB grid 302, and so on.

[0114] Additionally, in the Figure 3, the BWP 316 is identified at least by the $\mu=1$, a frequency domain location, a bandwidth (L_{RB}), and an BWP index (index C). For example, an offset 315 (RB_{start}) is derived as 1 by the *locationAndBandwidth*. According to the Formulas (2) and (3), the PRB0 of BWP 316 corresponds to CRB 2 of the CRB grid 312, and the PRB1 of BWP 316 corresponds to CRB 3 of the CRB grid 312, and so on.

[0115] As shown in the Figure 3, a carrier with the defined subcarrier spacing locate in a corresponding CRB grid with the same subcarrier spacing. A BWP with the defined subcarrier spacing locate in a corresponding CRB grid with the same subcarrier spacing as well.

[0116] A base station may transmit a RRC message including one or more RRC parameters related to BWP configuration to a UE. A UE may receive the RRC message including one or more RRC parameters related to BWP configuration from a base station. For each cell, the base station may configure at least an initial DL BWP and one

initial uplink bandwidth parts (initial UL BWP) to the UE. Furthermore, the base station may configure additional UL and DL BWPs to the UE for a cell.

[0117] A RRC parameters *initialDownlinkBWP* may indicate the initial downlink BWP (initial DL BWP) configuration for a serving cell (e.g., a SpCell and SCell). The base station may configure the RRC parameter *locationAndBandwidth* included in the *initialDownlinkBWP* so that the initial DL BWP contains the entire CORESET 0 of this serving cell in the frequency domain. The *locationAndBandwidth* may be used to indicate the frequency domain location and bandwidth of a BWP. A RRC parameters *initialUplinkBWP* may indicate the initial uplink BWP (initial UL BWP) configuration for a serving cell (e.g., a SpCell and SCell). The base station may transmit *initialDownlinkBWP* and/or *initialUplinkBWP* which may be included in SIB1, RRC parameter *ServingCellConfigCommon*, or RRC parameter *ServingCellConfig* to the UE.

[0118] SIB1, which is a cell-specific system information block (SystemInformationBlock, SIB), may contain information relevant when evaluating if a UE is allowed to access a cell and define the scheduling of other system information. SIB1 may also contain radio resource configuration information that is common for all UEs and barring information applied to the unified access control. The RRC parameter *ServingCellConfigCommon* is used to configure cell specific parameters of a UE's serving cell. The RRC parameter *ServingCellConfig* is used to configure (add or modify) the UE with a serving cell, which may be the SpCell or an SCell of an MCS or SCG. The RRC parameter *ServingCellConfig* herein are mostly UE specific but partly also cell specific.

[0119] The base station may configure the UE with a RRC parameter *BWP-Downlink* and a RRC parameter *BWP-Uplink*. The RRC parameter *BWP-Downlink* can be used to configure an additional DL BWP. The RRC parameter *BWP-Uplink* can be used to configure an additional UL BWP. The base station may transmit the *BWP-Downlink* and the *BWP-Uplink* which may be included in RRC parameter *ServingCellConfig* to the UE.

[0120] If a UE is not configured (provided) *initialDownlinkBWP* from a base station, an initial DL BWP is defined by a location and number of contiguous physical resource blocks (PRBs), starting from a PRB with the lowest index and ending at a PRB with the highest index among PRBs of a CORESET for Type0-PDCCH CSS set (i.e. CORESET 0), and a subcarrier spacing (SCS) and a cyclic prefix for PDCCH reception

in the CORESET for Type0-PDCCH CSS set. If a UE is configured (provided) *initialDownlinkBWP* from a base station, the initial DL BWP is provided by *initialDownlinkBWP*. If a UE is configured (provided) *initialUplinkBWP* from a base station, the initial UL BWP is provided by *initialUplinkBWP*.

[0121] The UE may be configured by the based station, at least one initial BWP and up to 4 additional BWP(s). One of the initial BWP and the configured additional BWP(s) may be activated as an active BWP. The UE may monitor DCI format, and/or receive PDSCH in the active DL BWP. The UE may not monitor DCI format, and/or receive PDSCH in a DL BWP other than the active DL BWP. The UE may transmit PUSCH and/or PUCCH in the active UL BWP. The UE may not transmit PUSCH and/or PUCCH in a BWP other than the active UL BWP.

[0122] As above-mentioned, a UE may monitor DCI format in the active DL BWP. To be more specific, a UE may monitor a set of PDCCH candidates in one or more CORESETs on the active DL BWP on each activated serving cell configured with PDCCH monitoring according to corresponding search space set where monitoring implies decoding each PDCCH candidate according to the monitored DCI formats.

[0123] A set of PDCCH candidates for a UE to monitor is defined in terms of PDCCH search space sets. A search space set can be a CSS set or a USS set. A UE may monitor a set of PDCCH candidates in one or more of the following search space sets

- a Type0-PDCCH CSS set configured by *pdccch-ConfigSIB1* in MIB or by *searchSpaceSIB1* in *PDCCCH-ConfigCommon* or by *searchSpaceZero* in *PDCCCH-ConfigCommon* for a DCI format with CRC scrambled by a SI-RNTI on the primary cell of the MCG
- a Type0A-PDCCH CSS set configured by *searchSpaceOtherSystemInformation* in *PDCCCH-ConfigCommon* for a DCI format with CRC scrambled by a SI-RNTI on the primary cell of the MCG
- a Type1-PDCCH CSS set configured by *ra-SearchSpace* in *PDCCCH-ConfigCommon* for a DCI format with CRC scrambled by a RA-RNTI or a TC-RNTI on the primary cell
- a Type2-PDCCH CSS set configured by *pagingSearchSpace* in *PDCCCH-ConfigCommon* for a DCI format with CRC scrambled by a P-RNTI on the primary cell of the MCG

- a Type3-PDCCH CSS set configured by *SearchSpace* in *PDCCH-Config* with *searchSpaceType* = common for DCI formats with CRC scrambled by INT-RNTI, SFI-RNTI, TPC-PUSCH-RNTI, TPC-PUCCH-RNTI, or TPC-SRS-RNTI and, only for the primary cell, C-RNTI, MCS-C-RNTI, or CS-RNTI(s), and
- a USS set configured by *SearchSpace* in *PDCCH-Config* with *searchSpaceType* = ue-Specific for DCI formats with CRC scrambled by C-RNTI, MCS-C-RNTI, SP-CSI-RNTI, or CS-RNTI(s).

[0124] For a DL BWP, if a UE is configured (provided) one above-described search space set, the UE may determine PDCCH monitoring occasions for a set of PDCCH candidates of the configured search space set. PDCCH monitoring occasions for monitoring PDCCH candidates of a search space set *s* is determined according to the search space set *s* configuration and a CORESET configuration associated with the search space set *s*. In other words, a UE may monitor a set of PDCCH candidates of the search space set in the determined (configured) PDCCH monitoring occasions in one or more configured control resource sets (CORESETs) according to the corresponding search space set configurations and CORESET configuration. A base station may transmit, to a UE, information to specify one or more CORESET configuration and/or search space configuration. The information may be included in MIB and/or SIBs broadcasted by the base station. The information may be included in RRC configurations or RRC parameters. A base station may broadcast system information such as MIB, SIBs to indicate CORESET configuration or search space configuration to a UE. Or the base station may transmit a RRC message including one or more RRC parameters related to CORESET configuration and/or search space configuration to a UE.

[0125] An illustration of search space set configuration is described below.

[0126] A base station may transmit a RRC message including one or more RRC parameters related to search space configuration. A base station may determine one or more RRC parameter(s) related to search space configuration for a UE. A UE may receive, from a base station, a RRC message including one or more RRC parameters related to search space configuration. RRC parameter(s) related to search space configuration (e.g. *SearchSpace*, *searchSpaceZero*) defines how and where to search for PDCCH candidates. 'search/monitor for PDCCH candidate for a DCI format' may also refer to 'monitor/search for a DCI format' for short.

[0127] For example, a RRC parameter *searchSpaceZero* is used to configure a common search space 0 of an initial DL BWP. The *searchSpaceZero* corresponds to 4 bits. The base station may transmit the *searchSpaceZero* via PBCH(MIB) or ServingCell.

[0128] Additionally, a RRC parameter *SearchSpace* is used to define how/where to search for PDCCH candidates. The RRC parameters *search space* may include a plurality of RRC parameters as like, *searchSpaceId*, *controlResourceSetId*, *monitoringSlotPeriodicityAndOffset*, *duration*, *monitoringSymbolsWithinSlot*, *nrofCandidates*, *searchSpaceType*. Some of the above-mentioned RRC parameters may be present or absent in the RRC parameters *SearchSpace*. Namely, the RRC parameter *SearchSpace* may include all the above-mentioned RRC parameters. Namely, the RRC parameter *SearchSpace* may include one or more of the above-mentioned RRC parameters. If some of the parameters are absent in the RRC parameter *SearchSpace*, the UE 102 may apply a default value for each of those parameters.

[0129] Herein, the RRC parameter *searchSpaceId* is an identity or an index of a search space. The RRC parameter *searchSpaceId* is used to identify a search space. Or rather, the RRC parameter *searchSpaceId* provide a search space set index s , $0 \leq s < 40$. Then a search space s hereinafter may refer to a search space identified by index s indicated by RRC parameter *searchSpaceId*. The RRC parameter *controlResourceSetId* concerns an identity of a CORESET, used to identify a CORESET. The RRC parameter *controlResourceSetId* indicates an association between the search space s and the CORESET identified by *controlResourceSetId*. The RRC parameter *controlResourceSetId* indicates a CORESET applicable for the search space. CORESET p hereinafter may refer to a CORESET identified by index p indicated by RRC parameter *controlResourceSetId*. Each search space is associated with one CORESET. The RRC parameter *monitoringSlotPeriodicityAndOffset* is used to indicate slots for PDCCH monitoring configured as periodicity and offset. Specifically, the RRC parameter *monitoringSlotPeriodicityAndOffset* indicates a PDCCH monitoring periodicity of k_s slots and a PDCCH monitoring offset of o_s slots. A UE can determine which slot is configured for PDCCH monitoring according to the RRC parameter *monitoringSlotPeriodicityAndOffset*. The RRC parameter *monitoringSymbolsWithinSlot* is used to indicate a first symbol(s) for PDCCH monitoring in the slots configured for PDCCH monitoring. That is, the parameter

monitoringSymbolsWithinSlot provides a PDCCH monitoring pattern within a slot, indicating first symbol(s) of the CORESET within a slot (configured slot) for PDCCH monitoring. The RRC parameter *duration* indicates a number of consecutive slots T_s that the search space lasts (or exists) in every occasion (PDCCH occasion, PDCCH monitoring occasion).

[0130] The RRC parameter may include *aggregationLevel1*, *aggregationLevel2*, *aggregationLevel4*, *aggregationLevel8*, *aggregationLevel16*. The RRC parameter *nrofCandidates* may provide a number of PDCCH candidates per CCE aggregation level L by *aggregationLevel1*, *aggregationLevel2*, *aggregationLevel4*, *aggregationLevel8*, and *aggregationLevel16*, for CCE aggregation level 1, CCE aggregation level 2, CCE aggregation level 4, for CCE aggregation level 8, and CCE aggregation level 16, respectively. In other words, the value L can be set to either one in the set $\{1, 2, 4, 8, 16\}$. The number of PDCCH candidates per CCE aggregation level L can be configured as 0, 1, 2, 3, 4, 5, 6, or 8. For example, in a case the number of PDCCH candidates per CCE aggregation level L is configured as 0, the UE may not search for PDCCH candidates for CCE aggregation L . That is, in this case, the UE may not monitor PDCCH candidates for CCE aggregation L of a search space set s . For example, the number of PDCCH candidates per CCE aggregation level L is configured as 4, the UE may monitor 4 PDCCH candidates for CCE aggregation level L of a search space set s .

[0131] The RRC parameter *searchSpaceType* is used to indicate that the search space set s is either a CSS set or a USS set. The RRC parameter *searchSpaceType* may include either a *common* or a *ue-Specific*. The RRC parameter *common* configure the search space set s as a CSS set and DCI format to monitor. The RRC parameter *ue-Specific* configures the search space set s as a USS set. The RRC parameter *ue-Specific* may include *dci-Formats*. The RRC parameter *dci-Formats* indicates to monitor PDCCH candidates either for DCI format 0_0 and DCI format 1_0, or for DCI format 0_1 and DCI format 1_1 in search space set s . That is, the RRC parameter *searchSpaceType* indicates whether the search space set s is a CSS set or a USS set as well as DCI formats to monitor for. The RRC parameter *ue-Specific* may further include a new RRC parameter (e.g. *dci-FormatsExt*) in addition to the *dci-Formats*. The RRC parameter *dci-FormatsExt* indicates to monitor PDCCH candidates for DCI format 0_2 and DCI format 1_2, or for DCI format 0_1, DCI format 1_1, DCI format 0_2 and DCI

format 1_2. If the RRC parameter *dci-FormatsExt* is included in the RRC parameter *ue-Specific*, the UE may ignore the RRC parameter *dci-Formats*. That is to say, the UE may not monitor the PDCCH candidates for DCI formats indicated by the RRC parameter *dci-Format*, and may monitor the PDCCH candidates for DCI formats indicated by the RRC parameter *dci-FormatsExt*.

[0132] The UE 102 may monitor PDCCH candidates for DCI format 0_0 and/or DCI format 1_0 in either a CSS or a USS. The UE 102 may monitor PDCCH candidates for DCI format 0_1, DCI format 1_1, DCI format 0_2 and/or DCI format 1_2 only in a USS but cannot monitor PDCCH candidates for DCI format 0_1, DCI format 1_1, DCI format 0_2, and/or DCI format 1_2 in a CSS. The DCI format 0_1 may schedule up to two transport blocks for one PUSCH while the DCI format 0_2 may only schedule one transport blocks for one PUSCH. DCI format 0_2 may not consist of some fields (e.g. 'CBG transmission information' field), which may be present in DCI format 0_1. Similarly, the DCI format 1_1 may schedule up to two transport blocks for one PDSCH while the DCI format 1_2 may only schedule one transport blocks for one PDSCH. DCI format 1_2 may not consist of some fields (e.g., 'CBG transmission information' field), which may be present in DCI format 1_1. The DCI format 1_2 and DCI format 1_1 may consist of one or more same DCI fields (e.g., 'antenna port' field).

[0133] The base station 160 may schedule a UE 102 to receive PDSCH by a downlink control information (DCI). A DCI format provides DCI and includes one or more DCI fields. The one or more DCI fields in a DCI format are mapped to the information bits. As above-mentioned, the UE 102 can be configured by the base station 160 one or more search space sets to monitor PDCCH for detecting corresponding DCI formats. If the UE 102 detects a DCI format (e.g., the DCI format 1_0, the DCI format 1_1, or the DCI format 1_2) in a PDCCH, the UE 102 may be scheduled by the DCI format to receive a PDSCH.

[0134] A USS at CCE aggregation level L is defined by a set of PDCCH candidates for CCE aggregation L . A USS set may be constructed by a plurality of USS corresponding to respective CCE aggregation level L . A USS set may include one or more USS(s) corresponding to respective CCE aggregation level L . A CSS at CCE aggregation level L is defined by a set of PDCCH candidates for CCE aggregation L . A CSS set may be constructed by a plurality of USS corresponding to respective CCE

aggregation level L . A CSS set may include one or more CSS(s) corresponding to respective CCE aggregation level L .

[0135] Herein, 'a UE monitor PDCCH for a search space set s ' also refers to 'a UE may monitor a set of PDCCH candidates of the search space set s '. Alternatively, 'a UE monitor PDCCH for a search space set s ' also refers to 'a UE may attempt to decode each PDCCH candidate of the search space set s according to the monitored DCI formats'. As above-mentioned, the PDCCH is used for transmitting or carrying Downlink Control Information (DCI). Thus, 'PDCCH', 'DCI', 'DCI format', and/or 'PDCCH candidate' are virtually interchangeable. In other words, 'a UE monitors PDCCH' implies 'a UE monitors PDCCH for a DCI format'. That is, 'a UE monitors PDCCH' implies 'a UE monitors PDCCH for detection of a configured DCI format'.

[0136] In the present disclosure, the term "PDCCH search space sets" may also refer to "PDCCH search space". A UE monitors PDCCH candidates in one or more of search space sets. A search space sets can be a common search space (CSS) set or a UE-specific search space (USS) set. In some implementations, a CSS set may be shared/configured among multiple UEs. The multiple UEs may search PDCCH candidates in the CSS set. In some implementations, a USS set is configured for a specific UE. The UE may search one or more PDCCH candidates in the USS set. In some implementations, a USS set may be at least derived from a value of C-RNTI addressed to a UE.

[0137] An illustration of CORESET configuration is described below.

[0138] A base station may configure a UE one or more CORESETs for each DL BWP in a serving cell. For example, a RRC parameter *ControlResourceSetZero* is used to configure CORESET 0 of an initial DL BWP. The RRC parameter *ControlResourceSetZero* corresponds to 4 bits. The base station may transmit *ControlResourceSetZero*, which may be included in MIB or RRC parameter *ServingCellConfigCommon*, to the UE. MIB may include the system information transmitted on BCH(PBCH). A RRC parameter related to initial DL BWP configuration may also include the RRC parameter *ControlResourceSetZero*. RRC parameter *ServingCellConfigCommon* is used to configure cell specific parameters of a UE's serving cell and contains parameters which a UE would typically acquire from SSB, MIB or SIBs when accessing the cell from IDLE.

[0139] Additionally, a RRC parameter *ControlResourceSet* is used to configure a time and frequency CORESET other than CORESET 0. The RRC parameter *ControlResourceSet* may include a plurality of RRC parameters such as, *ControlResourceSetId*, *frequencyDomainResource*, *duration*, *cce-REG-MappingType*, *precoderGranularity*, *tci-PresentInDCI*, *pdccch-DMRS-ScramblingID* and so on.

[0140] Here, the RRC parameter *ControlResourceSetId* is an CORESET index p , used to identify a CORESET within a serving cell, where $0 < p < 12$. The RRC parameter *duration* indicates a number of consecutive symbols of the CORESET $N_{\text{symb}}^{\text{CORESET}}$, which can be configured as 1, 2 or 3 symbols. A CORESET consists of a set of $N_{\text{RB}}^{\text{CORESET}}$ resource blocks (RBs) in the frequency domain and $N_{\text{symb}}^{\text{CORESET}}$ symbols in the time domain. The RRC parameter *frequencyDomainResource* indicates the set of $N_{\text{RB}}^{\text{CORESET}}$ RBs for the CORESET. Each bit in the *frequencyDomainResource* corresponds a group of 6 RBs, with grouping starting from the first RB group in the BWP. The first (left-most / most significant) bit corresponds to the first RB group in the BWP, and so on. The first common RB of the first RB group has common RB index $6 \times \text{ceiling}(N_{\text{BWP}}^{\text{start}}/6)$. A bit that is set to 1 indicates that this RB group belongs to the frequency domain resource of this CORESET. Bits corresponding to a group of RBs not fully contained in the bandwidth part within which the CORESET is configured are set to zero. The ceiling(A) function hereinafter is to output a smallest integer not less than A.

[0141] According to the CORESET configuration, a CORESET (a CORESET 0 or a CORESET p) consists of a set of PRBs with a time duration of 1 to 3 OFDM symbols. The resource units Resource Element Groups (REGs) and Control Channel Elements (CCEs) are defined within a CORESET. A CCE consists of 6 REGs where a REG equals one resource block during one OFDM symbol. Control channels are formed by aggregation of CCE. That is, a PDCCH consists of one or more CCEs. Different code rates for the control channels are realized by aggregating different number of CCE. Interleaved and non-interleaved CCE-to-REG mapping are supported in a CORESET. Each resource element group carrying PDCCH carries its own DMRS.

[0142] Figure 4 is a diagram illustrating one example of CORESET configuration in a BWP by a UE 102 and a base station 160.

[0143] Figure 4 illustrates that a UE 102 is configured with three CORESETs for receiving PDCCH transmission in two BWPs. In the Figure 4, 401 represent point A.

402 is an offset in frequency domain between point A 401 and a lowest usable subcarrier on the carrier 403 in number of CRBs, and the offset 402 is given by the *offsetToCarrier* in the *SCS-SpecificCarrier* IE. The BWP 405 with index A and the carrier 403 are for a same subcarrier spacing configuration μ . The offset 404 between the lowest CRB of the carrier and the lowest CRB of the BWP in number of RBs is given by the *locationAndBandwidth* included in the BWP configuration for BWP A. The BWP 407 with index B and the carrier 403 are for a same subcarrier spacing configuration μ . The offset 406 between the lowest CRB of the carrier and the lowest CRB of the BWP in number of RBs is given by the *locationAndBandwidth* included in the BWP configuration for BWP B.

[0144] For the BWP 405, two CORESETs are configured. As above-mentioned, a RRC parameter *frequencyDomainResource* in respective CORESET configuration indicates the frequency domain resource for respective CORESET. In the frequency domain, a CORESET is defined in multiples of RB groups and each RB group consists of 6 RBs. For example, in the Figure 4, the RRC parameter *frequencyDomainResource* provides a bit string with a fixed size (e.g. 45 bits) as like '11010000...000000' for CORESET#1. That is, the first RB group, the second RB group, and the fourth RB group belong to the frequency domain resource of the CORESET#1. Additionally, the RRC parameter *frequencyDomainResource* provides a bit string with a fixed size (e.g. 45 bits) as like '00101110...000000' for CORESET#2. That is, the third RB group, the fifth RB group, the sixth RB group and the seventh RB group belong to the frequency domain resource of the CORESET#2.

[0145] For the BWP 407, one CORESET is configured. As above-mentioned, a RRC parameter *frequencyDomainResource* in the CORESET configuration indicates the frequency domain resource for the CORESET #3. In the frequency domain, a CORESET is defined in multiples of RB groups and each RB group consists of 6 RBs. For example, in the Figure 4, the RRC parameter *frequencyDomainResource* provides a bit string with a fixed size (e.g. 45 bits) as like '11010000...000000' for CORESET#3. That is, the first RB group, the second RB group, and the fourth RB group belong to the frequency domain resource of the CORESET#3. Although the bit string configured for CORESET#3 is same as that for CORESET#1, the first RB group of the BWP B is different from that of the BWP A in the carrier. Therefore, the frequency domain

resource of the CORESET#3 in the carrier is different from that of the CORESET#1 as well.

[0146] Hereinafter, PUSCH configuration and DMRS configuration are described.

[0147] The base station 160 may transmit, to the UE 102, a PDCCH with a DCI format. A PUSCH is scheduled by the DCI format. Upon detection of the PDCCH with a DCI format carrying DCI, the UE 102 may be scheduled to transmit PUSCH scheduled by the DCI (DCI format) in the PDCCH. The UE 102 may derive, based on the DCI (DCI fields of the DCI format), necessary information for transmission of the PUSCH. For example, the UE 102 may determine, at least based on a time domain resource assignment field, one, more, or all of a starting slot, time domain resource allocation, PUSCH mapping type, a PUSCH repetition number, and so on. The starting slot means a slot where the PUSCH is transmitted by the UE 102. If the UE 102 is configured with PUSCH repetition transmission, the starting slot means a slot where the first repetition of the PUSCH transmission is transmitted by the UE 102.

[0148] The time domain resource allocation means a starting symbol of the allocated PDSCH and a duration of the allocated PUSCH. To be more specific, the UE 102 may at least determine, based on a time domain resource assignment field of the DCI format, a starting symbol S and a number of consecutive symbols L of the PUSCH transmission in the time domain. The number of consecutive symbols L counts from the starting symbol S within the starting slot. The resource allocation allocated for a PUSCH transmission in time domain may refer to as a PUSCH transmission occasion allocated for a PUSCH transmission or as a scheduled PUSCH resource. The PUSCH transmission occasion (or the scheduled PUSCH resource) comprises at least a starting symbol S , and a number of consecutive symbols L counting from the starting symbol S within a slot. In other words, the base station 160 may receive, from the UE 102, the PUSCH in the PUSCH transmission occasion. And the UE 102 may transmit, to a base station 160, the PUSCH in the PUSCH transmission occasion.

[0149] There are two PUSCH mapping types, i.e. one is PUSCH mapping type A and the other one is PUSCH mapping type B. The UE 102 may determine time location of the front-loaded DMRS symbol for the PUSCH depending on the PUSCH mapping type. In the present disclosure, the front-loaded DMRS symbol(s) for a PUSCH can be also referred to as the first DMRS symbol(s) for a PUSCH. Additional DMRS symbol(s) imply DMRS symbol(s) other than the front-loaded DMRS symbol for a

PUSCH. Additional DMRS symbol(s) imply DMRS symbol(s) other than the first DMRS symbol for a PUSCH.

[0150] For PUSCH mapping type A, the front-loaded DMRS symbol (i.e. the first DMRS symbol) is in either a third symbol or a fourth symbol relative to the start of the slot where the PUSCH is transmitted. The base station 160 may use a parameter *dmrs-TypeA-Position* included in the MIB to indicate the position of the front-loaded DMRS symbol (i.e. the first DMRS symbol) to UEs who are camping on the serving cell. When the *dmrs-TypeA-Position* is set to 'pos2', the front-loaded DMRS symbol (i.e. the first DMRS symbol) for a PDSCH with PDSCH mapping type A or for a PUSCH with PUSCH mapping type A is in a third symbol relative to the start of the slot, i.e. the front-loaded DMRS symbol is in a third symbol of the slot. On the other hand, when the *dmrs-TypeA-Position* is set to 'pos3', the front-loaded DMRS symbol for a PDSCH with PDSCH mapping type A or for a PUSCH with PUSCH mapping type A is in a fourth symbol relative to the start of the slot, i.e. the front-loaded DMRS symbol for a PDSCH or PUSCH is in a fourth symbol of the slot. For PUSCH mapping type A, a PUSCH with allocation duration L ranging from 4 symbols to 14 symbols can be scheduled. While the starting symbol S of a PDSCH with PDSCH mapping type A can be scheduled in the first symbol in a slot.

[0151] For PUSCH mapping type B, the front-loaded DMRS symbol (i.e. the first DMRS symbol) may always be in the first symbol of the scheduled PUSCH resources. That is to say, the front-loaded (first) DMRS symbol for a PUSCH with PUSCH mapping type B is in a first symbol of the PUSCH. For PUSCH mapping type B, a PUSCH with allocation duration L ranging from 1 symbols to 14 symbols can be scheduled. While the starting symbol S of a PUSCH with PUSCH mapping type B can be scheduled in any of symbols in a slot.

[0152] In the present disclosure, the base station may configure different DMRS configurations for PUSCH mapping type A and PUSCH mapping type B via RRC parameters.

[0153] A RRC parameter *dmrs-DownlinkForPUSCH-MappingTypeA* is used for DMRS configuration for PUSCH with PUSCH mapping type A. A RRC parameter *dmrs-DownlinkForPUSCH-MappingTypeB* is used for DMRS configuration for PUSCH with PUSCH mapping type B. Each of the RRC parameter *dmrs-DownlinkForPUSCH-MappingTypeA* and the RRC parameter *dmrs-*

DownlinkForPUSCH-MappingTypeB may contain fields as like *dmrs-Type*, *dmrs-AdditinalPosition*, *maxlength*, and so on. The fields *dmrs-Type*, *dmrs-AdditinalPosition*, and *maxlength* may be set differently for the *dmrs-DownlinkForPUSCH-MappingTypeA* and the *dmrs-DownlinkForPUSCH-MappingTypeB*. Additionally or alternatively, the fields *dmrs-Type*, *dmrs-AdditinalPosition*, and *maxlength* can be also set same for the *dmrs-DownlinkForPUSCH-MappingTypeA* and the *dmrs-DownlinkForPUSCH-MappingTypeB*.

[0154] The RRC parameter *dmrs-Type* is used for selection of the DMRS configuration type for uplink. In the present disclosure, two DMRS configuration types i.e. DMRS configuration type 1 and DMRS configuration type 2 are used. To be specific, if the *dmrs-Type* is not configured (i.e. the *dmrs-Type* is absent), the UE 102 uses DMRS configuration type 1. On the other hand, if the RRC parameter *dmrs-Type* is configured, the UE 102 uses DMRS configuration type 2. The difference between the DMRS configuration type 1 and the DMRS configuration type 2 is different densities in the frequency domain. The resource elements used for DMRS configuration type 1 per RB is denser than that used for DMRS configuration type 2 per RB in the frequency domain.

[0155] The RRC parameter *dmrs-AdditinalPosition*, which can be set to 'pos0', 'pos1', or 'pos3' by the base station 160, is used to indicate the position of additional DMRS symbol(s) for PUSCH. If the *dmrs-AdditinalPosition* is not configured (i.e. the *dmrs-AdditinalPosition* is absent), the UE determines the value of the *dmrs-AdditinalPosition* is set to 'pos2'. If *dmrs-AdditinalPosition* is set to 'pos0', there are no additional DMRS present for a PUSCH. If *dmrs-AdditinalPosition* is set to 'pos1', there are up to one additional DMRS present for a PUSCH depending on the allocation duration of the PUSCH. If *dmrs-AdditinalPosition* is set to 'pos2', there are up to two additional DMRS present for a PUSCH depending on the allocation duration of the PUSCH. If *dmrs-AdditinalPosition* is set to 'pos3', there are up to three additional DMRS present for a PUSCH depending on the allocation duration of the PUSCH.

[0156] The RRC parameter *maxlength* is used to indicate the maximum number of OFDM symbols for UL front-loaded DMRS. The *maxlength* can be configured to 'len2' by the base station 160. That is, the UE 102 may determine the front-loaded DMRS is double-symbol front-loaded DMRS. Specifically, in the case that *maxlength* is configured to set to 'len2', the UE 102 may determine the front-loaded DMRS is single-

symbol front-loaded DMRS or double-symbol front-loaded DMRS based on the associated DCI. On the other hand, if the *maxlength* is not configured (i.e. the *maxlength* is absent), the UE 102 determines that the *maxlength* is set to 'len1'. That is, the UE may determine the front-loaded DMRS is single-symbol front-loaded DMRS. Double-symbol front loaded DMRS means front-loaded DMRS with 2 consecutive OFDM symbols. Single-symbol front-loaded DMRS means front-loaded DMRS with 1 OFDM symbol. Both the DMRS configuration type 1 and DMRS configuration type 2 can support the single-symbol front-loaded DMRS and the double-symbol front-loaded DMRS.

[0157] Figure 5 is a diagram illustrating one example 500 of DMRS configuration for a PUSCH with PUSCH mapping type A. PUSCH mapping type for PUSCHs illustrated in the Figure 5 is provided as PUSCH mapping type A by the corresponding DCI formats which scheduled the PDSCHs in the Figure 5, respectively.

[0158] Figure 5(A) is an illustration where the RRC parameter *dmrs-TypeA-Position* is set to 'pos2' and single-symbol front-loaded DMRS is configured. RRC parameter *dmrs-AdditinalPosition* is set to 'pos0', i.e. there are no additional DMRS present for the PDSCH. In Figure 5(A), the UE 102 is scheduled with a PUSCH with allocated resource 502 with PUSCH mapping type A. The position of the single-symbol front-loaded DMRS with one OFDM symbol 504 is in the third symbol relative to the start of the slot, which is indicated by the *dmrs-TypeA-Position*. The starting symbol *S* of the PUSCH with allocated resource 502 is in the first symbol of the slot, and the allocation duration *L* of the PUSCH with allocated resource 502 is 11 OFDM symbols.

[0159] Figure 5(B) is an illustration where the RRC parameter *dmrs-TypeA-Position* is set to 'pos3' and double-symbol front-loaded DMRS is configured. RRC parameter *dmrs-AdditinalPosition* is set to 'pos0', i.e. there are no additional DMRS present for the PUSCH. In Figure 5(B), the UE 102 is scheduled with a PUSCH with allocated resource 506 with PUSCH mapping type A. The double-symbol front-loaded DMRS is with two consecutive OFDM symbols. The position of the first symbol 508 of the double-symbol front-loaded DMRS is in the fourth symbol relative to the start of the slot, which is indicated by the *dmrs-TypeA-Position*. The position of the second symbol 510 of the double-symbol front-loaded DMRS is in the fifth symbol relative to the start of the slot. The starting symbol *S* of the PUSCH with allocated resource 506 is

in the first symbol of the slot, and the allocation duration L of the PUSCH with allocated resource 502 is 11 OFDM symbols.

[0160] Figure 6 is a diagram illustrating one example 600 of DMRS configuration for a PUSCH with PUSCH mapping type B. PUSCH mapping type for PUSCHs illustrated in the Figure 6 is provided as PUSCH mapping type B by the corresponding DCI formats which scheduled the PUSCHs in the Figure 6, respectively.

[0161] Figure 6(A) is an illustration where single-symbol front-loaded DMRS is configured. RRC parameter *dmrs-AdditinalPosition* is set to 'pos0', i.e. there are no additional DMRS present for the PUSCH with mapping type B. In Figure 6 (A), the UE 102 is scheduled with a PUSCH with allocated resource 602 with PUSCH mapping type B. The starting symbol S of the PUSCH with allocated resource 602 is in the eighth symbol of the slot, and the allocation duration L of the PUSCH with allocated resource 602 is 4 OFDM symbols. The position of the single-symbol front-loaded DMRS with one OFDM symbol 604 is in the eighth symbol, which is the first symbol of the allocated PUSCH resource 602.

[0162] Figure 6(B) is an illustration where double-symbol front-loaded DMRS is configured. RRC parameter *dmrs-AdditinalPosition* is set to 'pos0', i.e. there are no additional DMRS present for the PUSCH with mapping type B. In Figure 6 (B), the UE 102 is scheduled with a PUSCH with allocated resource 606 with PUSCH mapping type B. The starting symbol S of the PUSCH with allocated resource 606 is in the seventh symbol of the slot, and the allocation duration L of the PUSCH with allocated resource 502 is 7 OFDM symbols. The double-symbol front-loaded DMRS is with two consecutive OFDM symbols. The position of the first symbol 608 of the double-symbol front-loaded DMRS is in the seventh symbol, which is the first symbol of the allocated PUSCH resource 606. The position of the second symbol 610 of the double-symbol front-loaded DMRS is in the eighth symbol relative to the start of the slot.

[0163] In the present disclosure, the UE 102 may be configured with either of the RRC parameters *dmrs-DownlinkForPUSCH-MappingTypeA* and *dmrs-DownlinkForPUSCH-MappingTypeB* or both the RRC parameters *dmrs-DownlinkForPUSCH-MappingTypeA* and *dmrs-DownlinkForPUSCH-MappingTypeB*.

[0164] As above-mentioned, the UE 102 may receive a PDCCH with a DCI format. Upon detection of the PDCCH with the DCI format, the UE 102 may determine the PUSCH mapping type for the scheduled PUSCH. In a case that the scheduled PUSCH

is with PUSCH mapping type A, the UE 102 may use the DMRS configuration configured by the RRC parameter *dmrs-DownlinkForPUSCH-MappingTypeA* for transmitting the scheduled PUSCH. In a case that the scheduled PUSCH is with PUSCH mapping type B, the UE 102 may use the DMRS configuration configured by the RRC parameter *dmrs-DownlinkForPUSCH-MappingTypeB* for transmitting the scheduled PUSCH.

[0165] Illustration of SS/PBCH blocks is described hereinafter.

[0166] A SS/PBCH block (or a SSB) is a unit block consisting of primary and secondary synchronization signals (PSS, SSS), each occupying 1 symbol and 127 subcarriers and PBCH spanning across 3 OFDM symbols and 240 subcarriers, but on one symbol leaving an unused part in the middle for SSS as show in Figure 7. Figure 7 is a diagram illustrating one example 700 of SS/PBCH block transmission. The UE 102 receives/detect the SS/PBCH block to acquire time and frequency synchronization with a cell and detect the physical layer Cell ID of the cell. The possible time locations of SS/PBCH blocks within a half-frame are determined by subcarrier spacing and the periodicity of the half-frames where SS/PBCH blocks are transmitted is configured by the base station. During a half frame, different SS/PBCH blocks may be transmitted in different spatial directions (i.e. using different beams, spanning the coverage area of a cell). Within the frequency span of a carrier, multiple SS/PBCH blocks can be transmitted. For a half frame with SS/PBCH blocks, the first symbol indexes for candidate SS/PBCH blocks are determined according to the SCS of SS/PBCH blocks as follows, where index 0 corresponds to the first symbol of the first slot in a half-frame.

[0167] Case A-15kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes of $\{2, 8\} + 14 * n$. n can be either $n=0, 1$ or $n=0, 1, 2, 3$ depending on the carrier frequencies.

[0168] Case B-30kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes of $\{4, 8, 16, 20\} + 28 * n$. n can be either $n=0$ or $n=0, 1$ depending on whether the carrier frequencies is larger than 3GHz.

[0169] Case C-30kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes of $\{2, 8\} + 14 * n$. n can be either $n=0, 1$ or $n=0, 1, 2, 3$ depending on the carrier frequencies.

[0170] Case D - 120 kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes $\{4, 8, 16, 20\} + 28 * n$ where $n=0, 1, 2, 3, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, 17, 18$.

[0171] Case E - 240 kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes $\{8, 12, 16, 20, 32, 36, 40, 44\} + 56 \cdot n$ where $n=0,1,2,3,5,6,7,8$.

[0172] The maximum number of the SS/PBCH blocks within a half-frame is different for different carrier frequencies. The candidate SS/PBCH blocks in a half frame are assigned an SS/PBCH block index. The candidate SS/PBCH blocks in a half frame are indexed in an ascending order in time from 0 to $L_{\max}-1$. The UE 102 determines the 2 LSB bits, for $L_{\max}=4$, or the 3 LSB bits, for $L_{\max}>4$, of a SS/PBCH block index per half frame form a one-to-one mapping with an index of the DM-RS sequence transmitted in the PBCH. For $L_{\max}=64$, the UE 102 determines the 3 MSB bits of the SS/PBCH block index per half frame from PBCH payload bits. That is, when the UE 102 detects/receives an SS/PBCH block, the UE 102 calculates an SS/PBCH block index based on PBCH information and/or reference signal information (DMRS sequence) included in the detected SS/PBCH block. Moreover, upon detection of a SS/PBCH block with an index, the UE 102 may determine from the MIB that a CORESET for Type0-PDCCH CSS set, and the Type0-PDCCH CSS set.

[0173] Figure 7 is an example of the Case A. In the Figure 7, a half frame 704 has 5 slot. According to the case A, when $n=0,1$, the base station may transmit SS/PBCH blocks in the first two slots within the half frame 704. When $n=0,1,2,3$, the base station may transmit SS/PBCH blocks in the first four slots within the half frame 704.

[0174] According to the Case A, the index for the first symbol of the first SS/PBCH block with index 0 706 is an index 2 of the first slot 710 in the half-frame 704, the index for the first symbol of the second SS/PBCH block with index 1 708 is an index 8 of the first slot 710 in the half-frame 704, the index for the first symbol of the third SS/PBCH block with index 2 is an index 2 of the second slot 712 in the half-frame 704, and so on.

[0175] The UE can be provided per serving cell by a RRC parameter indicating a periodicity of the half frames 702 for reception of the SS/PBCH blocks for the serving cell. If the UE is not provided by the RRC parameter, the periodicity of the half frames 702 for reception of the SS/PBCH blocks is a periodicity of a half frame. In this case, the 702 is equivalent to the 704. The periodicity is same for all SS/PBCH blocks in the serving cell. For example, the SS/PBCH with index 0 706 is transmitted in the slot 710. A next SS/PBCH with index 0 may be transmitted in a slot 714 after the periodicity of half frames 702 starting from the slot 710.

[0176] Additionally, after performing initial cell selection, the UE may assume that half frames with SS/PBCH blocks occur with a periodicity of 2 frames. That is, the UE may receive a SS/PBCH block with an index in a slot and then may further receive a SS/PBCH block with the same index in a slot after the periodicity of 2 frames.

[0177] The base station may transmit a set of SS/PBCH blocks in a serving cell and indicate the indices of the transmitted SS/PBCH blocks within a half-frame to UEs camping on the serving cell via SIB1. In other words, the base station 160 may indicate the time domain positions of the transmitted SS/PBCH blocks within a half frame. As above-mentioned, upon detection of a SS/PBCH block with an index, a UE may determine from the MIB a CORESET for Type0-PDCCH CSS set and the Type0-PDCCH CSS set. The UE monitors PDCCH in the Type 0-PDCCH CSS set to receive the SIB1. Then according to the received SIB1, the UE may determine, within a half-frame, a set of SS/PBCH blocks which are transmitted by the base station. In other words, the UE may determine, within a half-frame, the time domain positions of a set of SS/PBCH blocks which are transmitted by the base station.

[0178] Hereinafter, random access procedure is described.

[0179] Random access procedure may include the transmission of random access preamble (Msg1 or Message 1) in a PRACH, the reception of random access response (RAR) message with a PDCCH and/or a PDSCH (Msg2, Message 2), the transmission of a PUSCH scheduled by a RAR UL grant (e.g., Msg 3, Message 3), and the reception of PDSCH for contention resolution.

[0180] Before initiating a random access procedure, the UE 102 may, based on the received SIB1, obtain a set of SS/PBCH block indexes. A set of SS/PBCH blocks corresponding to the indexes in the set of SS/PBCH block indexes are transmitted by the base station. The UE 102 may perform reference signal received power (RSRP) measurements for the set of SS/PBCH blocks. On the other hand, the UE 102 may not perform RSRP measurements for those candidate SS/PBCH blocks which are not transmitted by the base station.

[0181] The secondary synchronization signals of a SS/PBCH block is used for the RSRP determination for the corresponding SS/PBCH block. The number of resource elements carrying the secondary synchronization signals of the SS/PBCH block (or the SS/PBCH blocks with the same SS/PBCH block index) within a measurement period may be used by the UE 102 to determine the RSRP of the SS/PBCH block. Additionally,

the demodulation reference signals for PBCH of the SS/PBCH block and/or configured CSI reference signals can also be used by the UE 102 to determine the RSRP of the SS/PBCH block.

[0182] Before initiating a random access procedure, the UE 102 may receive, from the base station 160, the information for the random access procedure. The information (i.e. the random access information) includes the cell-specific random access parameters and/or the dedicated random access parameters. The random access information may be indicated by the broadcasted system information (e.g., MIB, SIB1, and/or other SIBs) and/or RRC message and so on. For example, the information may include the configuration of PRACH transmission parameters such as time resources for PRACH transmission, frequency resources for PRACH transmission, the PRACH preamble format, preamble SCS and so on. The information may also include parameters for determining the root sequences (logical root sequence index, root index) and their cyclic shifts (CSs) in the PRACH preamble sequence set.

[0183] The random access preamble (PRACH preamble, or preamble) sequence is based on the Zadoff-Chu sequence. The logical root for the Zadoff-Chu sequence is provided by the information as above-mentioned. That is, a UE can generate a set of PRACH preamble sequences based on the Zadoff-Chu sequence corresponding to a root sequence indicated by the base station 160. There are two sequence lengths for the preamble. One is 839 and the other one is 139.

[0184] A preamble is transmitted by the UE 102 in a time-frequency PRACH occasion. A PRACH occasion is a time-frequency resource where the base station configures to multiple UEs for preamble transmission. There are 64 preambles defined in each time-frequency PRACH occasion. In other words, the UE 102 may generate 64 preambles for each PRACH occasion. The preambles (e.g. 64 preambles) in one PRACH occasion may be generated by one root Zadoff-Chu sequence or more than one root Zadoff-Chu sequences. The number of preambles generated from a single root Zadoff-Chu sequence at least depends on the sequence length and/or a distance of the cyclic shifts between two preambles with consecutive preamble indices. The distance of the cyclic shifts is provided by the base station 160.

[0185] Therefore, in some cases, the UE 102 can generate 64 preambles from a single root Zadoff-Chu sequence. In some cases, the UE 102 cannot generate 64 preambles from a single root Zadoff-Chu sequence. In these cases, in order to obtain

the 64 preambles in a PRACH occasion, the UE 102 needs to generate the 64 preambles from multiple root Zadoff-Chu sequences with multiple consecutive root indices. The starting root index of the multiple consecutive root indices is indicated by the base station 160. The UE 102 and the base station 160 may enumerate the 64 preambles in increasing order of first increasing cyclic shift (CS) of a logical root Zadoff-Chu sequence, and then in increasing order of the logical root sequence index. The preamble indices for 64 preambles in a PRACH occasion are from 0 to 63.

[0186] The random access information may include a RRC parameter indicating how many SS/PBCH blocks is associated with a PRACH occasion. For example, if a value indicated by the RRC parameter is one half (i.e. 1/2), it implies that one SS/PBCH block is associated with two PRACH occasions. For example, if a value indicated by the RRC parameter is two (i.e. 2), it implies that two SS/PBCH blocks are associated with one PRACH occasion.

[0187] In addition, the random access information may include a RRC parameter indicating how many frequency multiplexed PRACH occasions there are in one time instance. The random access information may include a RRC parameter indicating an offset of lowest PRACH occasion in frequency domain with respect to PRB0 of the active UL BWP. The UE 102 may determine starting symbol of a PRACH occasion, a number of PRACH occasions in time domain within a PRACH slot, a duration in symbols of the PRACH occasion according to the random access information.

[0188] As above-mentioned, SIB1 indicates a set of SS/PBCH blocks which are transmitted by the base station. In other words, the SIB1 provides SS/PBCH block indexes with which a set of SS/PBCH blocks are transmitted by the base station. The base station and/or the UE may only map the SS/PBCH indexes provided in the SIB1 to the PRACH occasions in accordance with the following rules: (i) first, in increasing order of preamble indexes within a single PRACH occasion, (ii) second, in increasing order of frequency resource indexes for frequency multiplexed PRACH occasions, (iii) third, in increasing order of time resource indexes for time multiplexed PRACH occasions within a PRACH slot, (iv) in increasing order of indexes for PRACH slots.

[0189] Figure 8 is a diagram illustrating one example 800 of mapping SS/PBCH block indexes to PRACH occasions.

[0190] In the Figure 8, the random access information indicates that two SS/PBCH blocks are mapped to one PRACH occasion and there are two frequency multiplexed

PRACH occasions in one time instance. And the random access information indicates that there are two time multiplexed PRACH occasions in one PRACH slot.

[0191] Figure 9 is a diagram illustrating one 900 example of random access procedure.

[0192] In S901, the UE 102 may transmit a random access preamble to the base station 160 via a PRACH. The transmitted random access preamble may be referred to as a message 1 (Msg.1). The transmission of the random access preamble (i.e. the transmission of the preamble) can be also referred to as PRACH transmission.

[0193] The UE 102 may randomly select a preamble with a random access preamble identity (RAPID) in a PRACH occasion. There are 64 preambles (preamble index) for each PRACH occasion. To be specific, the UE 102 may first measure the reference signal received power (RSRP) of a set of SS/PBCH blocks. If one or more SS/PBCH blocks with measured RSRP value above a threshold in the set of SS/PBCH blocks are available for the UE 102, the UE 102 may select one from the one or more SS/PBCH blocks. If there is no SS/PBCH block with measure RSRP value above the threshold in the set of SS/PBCH blocks, the UE may select one SS/PBCH block from the set of SS/PBCH blocks. The set of SS/PBCH blocks is provided by the SIB1. The threshold is an RSRP threshold for the selection of the SS/PBCH block and is indicated by the base station 160 for example via the SIB1.

[0194] After selecting the SS/PBCH block, the UE 102 may determine the PRACH occasions corresponding to the selected SS/PBCH block. In a PRACH occasion associated with the selected SS/PBCH block, the UE 102 may randomly select a preamble associated with the selected SS/PBCH block and transmit it to the base station 160.

[0195] In S902, if the base station 160 received a preamble in a PRACH occasion, the base station 160 may generate a transport block in response to the reception of the preamble. The transport block (i.e. a MAC PDU) herein is referred to as a random access response (or a random access response message). That is to say, the base station 160 may transmit a PDCCH with a DCI format 1_0 with CRC scrambled by a RA-RNTI and the transport block in a corresponding PDSCH scheduled by the DCI format 1_0. The value of the RA-RNTI is calculated at least based on the time and frequency information of the PRACH occasion where the preamble is received. For example, the RA-RNTI can be calculated as $RA-RNTI = 1 + s_id + 14 \times t_id + 14 \times 80 \times f_id + 14$

$\times 80 \times 8 \times \text{ul_carrier_id}$. Here, s_id is the index of the first OFDM symbol of the PRACH occasion ($0 \leq s_id < 14$), t_id is the index of the first slot of the PRACH occasion in a system frame ($0 \leq t_id < 80$), f_id is the index of the PRACH occasion in the frequency domain ($0 \leq f_id < 8$), and ul_carrier_id is the UL carrier used for random access preamble transmission (0 for NUL carrier, and 1 for SUL carrier).

[0196] In S902, in response to the transmission of the preamble, the UE 102 may attempt to detect a DCI format 1_0 with CRC scrambled by the RA-RNTI as above-mentioned during a window in the Type1-PDCCH CSS set. The length of the window in number of slots, based on the SCS for Type 1-PDCCH CSS set, is provided by the base station 160 for example via the SIB1. And the window start at the first symbol of the earliest CORESET where the UE 102 is configured to receive PDCCH for Type 1-PDCCH CSS set, that is at least one symbol after the last symbol of the PRACH occasion where the preamble is transmitted. The symbols duration corresponds to the SCS for Type 1-PDCCH CSS set.

[0197] If the UE 102 detects the DCI format 1_0 with CRC scrambled by the RA-RNTI, the UE 102 may receive a transport block in a corresponding PDSCH scheduled by the DCI format 1_0 within the window. The UE may parse the transport block (i.e. the MAC PDU) for a random access preamble identity (RAPID) associated with the transmitted preamble.

[0198] A MAC PDU (random access response, RAR) consists of one or more MAC subPDUs and optionally padding. Each MAC subPDU consists one of the followings: (i) a MAC subheader with Backoff Indicator only, (ii) a MAC subheader with RAPID only, and (iii) a MAC subheader with RAPID and MAC RAR.

[0199] A MAC subheader with Backoff Indicator consists of five header fields E/T/R/R/BI. A MAC subPDU with Backoff Indicator only is placed at the beginning of the MAC PDU, if included. 'MAC subPDU(s) with RAPID only' and 'MAC subPDU(s) with RAPID and MAC RAR' can be placed anywhere between MAC subPDU with Backoff Indicator only (if any) and padding (if any). Padding is placed at the end of the MAC PDU if present. Presence and length of padding is implicit based on TB size and size of MAC subPDUs.

[0200] If the RAPID in RAR message(s) (i.e. MAC RAR(s)) of the transport block is identified, the UE may obtain an uplink grant which is also referred as a RAR UL grant. That is, if there is a MAC subPDU with a RAPID corresponding to the RAPID

of the preamble which is transmitted by the UE 102, the UE 102 may obtain a RAR UL grant provided by the MAC RAR included in the MAC subPDU with the RAPID corresponding to the transmitted preamble. The size of the RAR UL grant is 27bits. The RAR UL grant is used to indicate the resources to be used for the PUSCH transmission. That is, the RAR UL grant is used to schedule a PUSCH transmission for the UE 102. In addition to the RAR UL grant, the MAC subPDU may also provide, to the UE 102, a timing advance command field with 12 bits, a Temporary C-RNTI field with 16bits and a reserved bit with 1bit.

[0201] Figure 10 is a diagram illustrating one 1000 example of fields included in an RAR UL grant. The RAR UL grant may at least include the fields as given in the Figure 10. The fields of the RAR UL grant starts with the MSB of the RAR UL grant and ends with the LSB of the RAR UL grant.

[0202] In a case that the value of a frequency hopping flag is 0, the UE 102 may transmit the PUSCH scheduled by the RAR UL grant without frequency hopping. In a case that the value of a frequency hopping flag is 1, the UE 102 may transmit the PUSCH scheduled by the RAR UL grant with frequency hopping. The 'PUSCH time resource allocation' field is used to indicate resource allocation in the time domain for the PUSCH scheduled by the RAR UL grant. The 'MCS' field is used to determine an MCS index for the PUSCH scheduled by the RAR UL grant. The 'TPC command for PUSCH' field is used for setting the power of the PUSCH scheduled by the RAR UL grant. The 'CSI request' field is reserved. The 'PUSCH frequency resource allocation' field is used to indicate resource allocation in the frequency domain for the PUSCH scheduled by the RAR UL grant .

[0203] On the other hand, if the UE 102 does not detect the DCI format 1_0 with CRC scrambled by the corresponding RA-RNTI within the window, or if the UE 102 does not correctly receive the transport block in the corresponding PDSCH within the window, or if the UE 102 do not identify the RAPID associated with the transmitted preamble from the UE 102, the UE may transmit a PRACH one more time. That is, the UE 102 may perform S901.

[0204] In S903, the UE 102 transmits, to the base station, a transport block in the PUSCH scheduled by the RAR UL grant in the active UL BWP. The transport block may contain a UE identity, for example, a CCCH SDU, a C-RNTI MAC CE. The

PUSCH containing a CCCH SDU or a C-RNTI MAC CE can be also referred to as Msg 3 (Message 3).

[0205] The base station 160 may not successfully decode the transport block which is transmitted by the UE 102 in the PUSCH scheduled by the RAR UL grant. Then, the base station 160 may request the UE 102 to retransmit the transport block. In this case, the base station 160 may generate a DCI format 0_0 with CRC scrambled by the TC-RNTI for a corresponding PUSCH retransmission of the transport block. And the base station 160 may transmit the DCI format 0_0 with CRC scrambled by the TC-RNTI to the UE 102 in S903a. As above-mentioned, the TC-RNTI is provided in the corresponding MAC RAR (RAR message).

[0206] After transmitting the PUSCH scheduled by the RAR UL grant, the UE 102 may receive a PDCCH with a DCI format 0_0 with CRC scrambled by the TC-RNTI. In this case, the UE 102 may perform a corresponding PUSCH retransmission scheduled by the DCI format 0_0 in S903b. The PUSCH retransmission of the transport block is scheduled by the DCI format 0_0 with CRC scrambled by the TC-RNTI.

[0207] In S904, if the base station 160 successfully decoded the transport block, the base station 160 may generate and transmit a DCI format 1_0 with CRC scrambled by the TC-RNTI scheduling a PDSCH that includes a UE contention resolution identity (i.e. a UE contention resolution identity MAC CE). The UE contention resolution identity contains the CCCH SDU transmitted in the S903. The UE resolution identity MAC CE contains part or all of the CCCH SDU transmitted by the UE 102 (UL CCCH SDU). If the UL CCCH SDU is longer than 48bits, the UE resolution identity MAC CE contains the first 48 bits of the UL CCCH SDU

[0208] The UE contention resolution identity contributes to resolving contention between multiples UEs who transmitted a same preamble in a same PRACH occasion. A UE may compare the UE contention resolution identity received in the S904 with the CCCH SDU transmitted in the S903. If the UE contention resolution identity matches the transmitted CCCH SDU, the UE 102 considers the contention resolution successful and considers the random access procedure successfully completed. On the other hand, if the UE contention resolution identity does not match the transmitted CCCH SDU, the UE 102 considers the contention resolution not successful.

[0209] In response to the PDSCH reception with the UE contention resolution identity, the UE 102 may transmit HARQ-ACK information in a PUCCH using

frequency hopping to the base station 160. The UE 102 may generate one HARQ-ACK information bit in response to the PDSCH reception with the UE contention resolution identity. The UE 102 may transmit a PUCCH with the HARQ-ACK information in a cell specific PUCCH resource in the initial UL BWP.

[0210] Compared with the Release 15/16 UEs, cost reduction for a new type UEs (e.g., wearable devices, industrial sensors, video surveillance) is desirable. To reduce the cost and the complexity, the new type UEs would be equipped with less reception antennas and/or the reduced RF bandwidth relative to the Release 15/16 UEs. The reduced reception antennas would result in a reduced power for the received channels/signals. The reduced RF bandwidth would also result in a reduced frequency diversity. For example, maximum bandwidth that UEs with reduced RF bandwidth can support may be 20MHz for FR1 and may be 100MHz for FR2. This kind of new type UEs can be termed 'RedCap UEs'. A UE 102 hereinafter in the present disclosure may refer to the RedCap UEs with reduced RF bandwidth. That is, the maximum bandwidth the UE 102 can support may be 20MHz for FR1 and may be 100MHz for FR2.

[0211] The new type UEs with less reception antennas and/or the reduced RF bandwidth would have a reduced coverage relative to the Release 15/16 UEs. For UEs for which the coverage is issue or some new type UEs which have less reception antennas or reduced RF bandwidth relative to the Release 15/16 UEs, due to the coverage issue or the low capabilities, the performance of the transmission/reception of the UL/DL channels/signals would be affected. Coverage enhancement or coverage recovery for these UEs are necessary. Solutions as like to frequency hopping, repetition transmission/reception would be necessary to provide robustness against transmission/reception errors, to enhance the coverage and to improve the transmission/reception reliability. For example, the frequency hopping can obtain the frequency diversity.

[0212] In order to obtain additional frequency diversity, the base station 160 may enable frequency hopping for a PUSCH scheduled by the RAR UL grant. As depicted in the Figure 10, RAR UL grant contains a frequency hopping flag field. The frequency hopping flag indicates whether the PUSCH scheduled by the RAR UL grant is transmitted with frequency hopping or not. In a case that the value of the frequency hopping flag is set to '0', the UE 102 transmits the PUSCH scheduled by the RAR UL grant without frequency hopping. That is, in this case, the RAR UL grant schedules a

PUSCH transmission without frequency hopping. In a case that the value of the frequency hopping flag is set to '1', the UE 102 transmits the PUSCH scheduled by the RAR UL grant with frequency hopping. That is, in this case, the RAR UL grant schedules a PUSCH transmission with frequency hopping.

[0213] For the PUSCH transmission with frequency hopping, the PUSCH is divided into two hops (or two frequency hops), i.e. the first hop and the second hop. The frequency resource (e.g. a starting RB and a number of allocated resource blocks within the active UL BWP) allocated for the first hop is determined at least based on the PUSCH frequency resource allocation field included in a corresponding RAR UL grant or a corresponding DCI format. The starting RB for the second hop in the frequency domain is given depending on the starting RB for the first hop and a frequency offset. The frequency offset between the first hop and the second hop can be given (or calculated) at least based on the size of the initial UL BWP (i.e. the initial UL BWP size of $N_{\text{BWP}}^{\text{size}}$ RBs). The $N_{\text{BWP}}^{\text{size}}$ herein is the frequency-domain size of the initial UL BWP in units of resource block, i.e. a number of resource blocks of the initial UL BWP. In a case that $N_{\text{BWP}}^{\text{size}}$ is less than 50, two frequency offsets for the second hop, i.e. $\text{floor}(N_{\text{BWP}}^{\text{size}}/2)$ and $\text{floor}(N_{\text{BWP}}^{\text{size}}/4)$ are defined or given. One bit (one hopping bit) of the PUSCH frequency resource allocation field is used to indicate the UE 102 which frequency offset is used for the second hop. In a case that $N_{\text{BWP}}^{\text{size}}$ is equal to or larger than 50, three frequency offsets for the second hop, i.e. $\text{floor}(N_{\text{BWP}}^{\text{size}}/2)$, $\text{floor}(N_{\text{BWP}}^{\text{size}}/4)$ and $-\text{floor}(N_{\text{BWP}}^{\text{size}}/4)$ are defined or given. Two bits (two hopping bits) of the PUSCH frequency resource allocation field is used to indicate the UE 102 which frequency offset is used for the second hop. In the present disclosure, frequency offset between the first hop and the second hop refers to frequency offset for the second hop. Similarly, frequency offset for the second hop refers to frequency offset between the first hop and the second hop.

[0214] However, according to the existing frequency offset values for the second hop, frequency offset between two hops may result in a total frequency bandwidth (region) within which PUSCH transmission in the first hop and the second hop are performed exceeding a maximum bandwidth the UE 102 with reduced RF bandwidth can support. In this case, the UE 102 may need to perform frequency retuning. In the present disclosure, frequency retuning implies that the UE 102 may retune from a frequency to another different frequency. For example, center frequency for a

receiver/transmitter of the UE 102 would be retuned from a frequency to another different frequency for reception or transmission. That is, when frequency retuning operation is performed by the UE 102, the center frequency would be changed for receiving or transmitting. In other words, in the present disclosure, frequency retuning means the UE 102 retunes from a frequency region carrying UL or DL transmission to another different frequency region carrying UL or DL transmission within a BWP. Frequency retuning time is needed for UE to perform the frequency retuning operation. Therefore, the UE 102 may not transmit PUSCH on some symbols among the allocated duration for the PUSCH, which would degrade the transmission performance.

[0215] Figure 11 is a flow diagram illustrating one implementation of a method 1100 for determining frequency hopping for PUSCH scheduled by RAR UL grant by a UE 102. In the implementation of the present disclosure, new method of frequency offset determination for the second hop is illustrated. The new method may ensure a total frequency bandwidth for the PUSCH transmission in the first hop and the second hop to be confined within the maximum bandwidth the UE102 can support. As a consequence, the frequency retuning for the UE 102 is not necessary. The implementation can be applied to intra-slot frequency hopping and/or inter-slot frequency hopping.

[0216] In the implementation of the present disclosure, duration of the PUSCH scheduled by the RAR UL grant is given by the PUSCH time resource allocation field in the RAR UL grant, which can be denoted as $N_{\text{symb}}^{\text{PUSCH}}$. That is, the $N_{\text{symb}}^{\text{PUSCH}}$ is the length of the PUSCH transmission in OFDM symbols in one slot. There are two frequency hopping types (i.e. intra-slot frequency hopping and inter-slot frequency hopping) applied to the PUSCH scheduled by the RAR UL grant and/or the PUSCH scheduled by DCI format 0_0 with CRC scrambled by a TC-RNTI.

[0217] In a case that the intra-slot frequency hopping is enabled, the UE 102 may perform frequency hopping for PUSCH transmission scheduled by the RAR UL grant within a slot. That is, the UE 102 may perform the PUSCH transmission in the first hop and the second hop in one slot. The number of symbols in the first hop is given by $\text{floor}(N_{\text{symb}}^{\text{PUSCH}} / 2)$. That is, in a slot where the PUSCH is transmitted, the first $\text{floor}(N_{\text{symb}}^{\text{PUSCH}} / 2)$ symbol(s) of PUSCH transmission with allocated duration $N_{\text{symb}}^{\text{PUSCH}}$ are symbol(s) in the first hop. While the number of symbols in the second hop is given by $N_{\text{symb}}^{\text{PUSCH}} - \text{floor}(N_{\text{symb}}^{\text{PUSCH}} / 2)$, i.e. $\text{ceiling}(N_{\text{symb}}^{\text{PUSCH}} / 2)$. That is, in

a slot where the PUSCH is transmitted, the last $\text{ceiling}(N_{\text{symb}}^{\text{PUSCH}} / 2)$ symbol(s) of PUSCH transmission with allocated duration $N_{\text{symb}}^{\text{PUSCH}}$ are symbol(s) in the second hop.

[0218] In a case that the inter-slot frequency hopping is enabled, the UE 102 may perform frequency hopping for PUSCH transmission across slots. Herein, the UE 102 may perform PUSCH transmission repetitions across slots, i.e. multi-slot PUSCH transmission. Same symbol allocation (i.e. the starting symbol and the allocated duration for the PUSCH) is applied across slots. For convenience, for one PUSCH transmission among the multi-slot PUSCH transmission which is transmitted in a slot with slot number n_s^{μ} , if $n_s^{\mu} \bmod 2 = 0$, the PUSCH transmission may refer to one first hop of the multi-slot PUSCH transmission. On the other hand, for one PUSCH transmission among the multi-slot PUSCH transmission which is transmitted in a slot with slot number n_s^{μ} , if $n_s^{\mu} \bmod 2 = 1$, the PUSCH transmission may refer to one second hop of the multi-slot PUSCH transmission. Therefore, if the PUSCH transmission scheduled by the RAR UL grant is repeated across more than two slots, the multi-slot PUSCH transmission (i.e. the PUSCH transmission scheduled by the RAR UL grant with repetitions) may consist of more than one first hop and more than one second hop.

[0219] Unless specified, a first hop hereinafter may refer to either a first hop for intra-slot frequency hopping or a first hop for inter-slot frequency hopping. Similarly, a second hop hereinafter may refer to either a second hop for intra-slot frequency hopping or a second hop for inter-slot frequency hopping.

[0220] The UE 102 and/or the base station 160 may determine which frequency hopping type is applied to the PUSCH scheduled by the RAR UL grant (or the PUSCH scheduled by DCI format 0_0 with CRC scrambled by a TC-RNTI) at least based on one, more or all of the broadcasted system information, the transmitted preamble index, the PRACH resource where the preamble is transmitted, the RSRP of the selected SS/PBCH block, one or more RSRP thresholds, a MAC RAR, a MAC subPDU, a RAR UL grant, a DCI format with CRC scrambled by a first RNTI. Here, the broadcasted system information may refer to a MIB, a SIB1, or other SIBs. The one or more RSRP thresholds can be indicated via the broadcasted system information. The MAC RAR means a MAC RAR provided by a MAC subPDU with the RAPID corresponding to the transmitted preamble. The first RNTI can be a SI-RNTI, a RA-RNTI, or a TC-RNTI. The DCI format can be a DCI format 1_0 or a DCI format 0_0. For example, the

broadcasted system information may include a RRC parameter which can be used to indicate which frequency hopping type is applied. For example, a value of a field in the DCI format with CRC scrambled by the first RNTI can be used to indicate which frequency hopping type is applied to the PUSCH scheduled by the RAR UL grant. In a case that the value of the field is set to 0, the UE 102 may determine intra-slot frequency hopping is applied. In a case that the value of the field is set to 1, the UE 102 may determine inter-slot frequency hopping is applied.

[0221] Additionally or alternatively, the UE 102 and/or the base station 160 may determine the inter-slot frequency hopping for PUSCH scheduled by the RAR UL grant with repetitions. On the other hand, the UE 102 and/or the base station 160 may determine the intra-slot frequency hopping for PUSCH scheduled by the RAR UL grant without repetitions. Then a value of a frequency hopping flag field included in the RAR UL grant can be used to indicate whether the determined frequency hopping is enabled or disabled for the PUSCH scheduled by the RAR UL grant. In a case that the value of the frequency hopping flag field is set to 0, the UE 102 may transmit the PUSCH without frequency hopping. In this case, the frequency hopping is disabled for the PUSCH scheduled by the RAR UL grant. In a case that the value of the frequency hopping flag field is set to 1, the UE 102 may transmit the PUSCH with frequency hopping. In this case, the frequency hopping is enabled for the PUSCH scheduled by the RAR UL grant.

[0222] Additionally or alternatively, the UE 102 and/or the base station 160 may determine that frequency hopping type applied to a PUSCH scheduled by DCI format 0_0 with CRC scrambled by a TC-RNTI is same as that applied to a PUSCH scheduled by the RAR UL grant.

[0223] In Figure 11, the UE 102 may transmit 1102, to a base station 160, a random access preamble with a RAPID in a PRACH occasion. If the base station 160 successfully received a preamble in a PRACH occasion, the base station 160 may generate a RAR at least containing a MAC subPDU with RAPID corresponding to the received preamble. The base station 160 may generate a DCI format scheduling the RAR as well and transmit the DCI format (i.e. the DCI format 1_0 with CRC scrambled by the RA-RNTI) and corresponding RAR to UEs.

[0224] The UE 102 may receive 1104, from the base station 160, the RAR. The RAR may include one or more MAC subPDUs. The UE 102 spares the RAR for a

RAPID corresponding to the transmitted preamble. If the RAR contains a MAC subPDU with the RAPID corresponding to the transmitted RAPID which is transmitted by the UE 102 itself, the MAC subPDU provides a MAC RAR including a RAR UL grant to the UE 102. The RAR UL grant is used to schedule a PUSCH. The RAR UL grant includes a frequency hopping flag field, as depicted in the Figure 10, which is used to indicate whether frequency hopping is enabled or disabled for the PUSCH scheduled by the RAR UL grant. In a case that the value of the frequency hopping flag field is set to 0, the UE 102 may transmit the PUSCH without frequency hopping. In this case, the frequency hopping is disabled for the PUSCH scheduled by the RAR UL grant. In a case that the value of the frequency hopping flag field is set to 1, the UE 102 may transmit the PUSCH with frequency hopping. In this case, the frequency hopping is enabled for the PUSCH scheduled by the RAR UL grant. Herein, in 1104, the UE 102 may receive the RAR containing the RAR UL grant scheduling the PUSCH transmission with frequency hopping, i.e. the value of the frequency hopping flag field in the RAR UL grant is set to 1.

[0225] A PUSCH frequency resource allocation field in the RAR UL grant is used to indicate the frequency resource allocation for the PUSCH in the initial UL BWP. The PUSCH frequency resource allocation field consists of a resource indication value (RIV) corresponding to a starting resource block RB_{start} and a length of contiguously allocated resource blocks L_{RBs} within the initial UL BWP. The number of the starting resource block RB_{start} starts from the first (lowest) RB of the initial UL BWP. The RB_{start} is the starting RB for the first hop within the initial UL BWP. The allocated resource blocks L_{RBs} is a number of resource blocks allocated for the first hop in frequency domain.

[0226] Given the UE 102 performs frequency hopping for PUSCH transmission scheduled by the RAR UL grant within a slot or across slots, the UE 102 may need to determine a frequency offset between the first hop and the second hop. Firstly, the UE 102 and/or the base station 160 may determine 1106, a number of frequency offsets between the first hop and the second hop for the PUSCH transmission at least based on a first size (i.e. N_{BWP}^{size}) and/or a second size (i.e. $N_{RF}^{size, \mu}$ or N_{RF}^{size}). In other words, a number of frequency offsets is determined at least based on comparison result between the first size and the second size. Furthermore, values for the frequency offsets may be given at least based on the first size and/or the second size. In other words, the UE 102

and/or the base station may determine a frequency offset between the first hop and the second hop based on comparison between the first size and the second size.

[0227] A value of hopping bit(s) in the PUSCH frequency resource allocation field may indicate the UE 102 which frequency offset among the frequency offsets to be used as a frequency offset for the second hop. In the present disclosure, the first size $N_{\text{BWP}}^{\text{size}}$ is the frequency-domain size of the initial UL BWP in number of resource blocks, i.e. a number of resource blocks of the initial UL BWP. The second size $N_{\text{RF}}^{\text{size}, \mu}$ is the frequency-domain size of the maximum bandwidth the UE 102 can support in number of resource blocks for a subcarrier spacing configuration μ , i.e. a number of resource blocks of the maximum bandwidth the UE 102 can support for a subcarrier spacing configuration μ . For different subcarrier spacing configurations, the number of resource blocks of the maximum bandwidth $N_{\text{RF}}^{\text{size}, \mu}$ is different. The number of resource blocks of the maximum bandwidth per subcarrier spacing configuration μ , i.e. the second size $N_{\text{RF}}^{\text{size}, \mu}$, can be a predefined value in number of RBs. For convenience, $N_{\text{RF}}^{\text{size}}$ without the subscript μ can refer to a frequency-domain size of maximum bandwidth the UE 102 can support in number of resource blocks for the subcarrier spacing configuration of the initial UL BWP. Therefore, the second size may refer to $N_{\text{RF}}^{\text{size}}$. In the present disclosure, for a UE 102 with reduced RF bandwidth, the maximum bandwidth the UE 102 can support may be 20MHz for FR1 and may be 100MHz for FR2.

[0228] Additionally or alternatively, the second size $N_{\text{RF}}^{\text{size}}$ may be a configured number of resource blocks which is indicated independently of the first size $N_{\text{BWP}}^{\text{size}}$ by the base station 160. As above-mentioned, the base station 160 may transmit a RRC parameter *initialUplinkBWP* to indicate the size of the initial UL BWP $N_{\text{BWP}}^{\text{size}}$. The base station 160 may transmit another RRC parameter included in the system information (e.g. MIB, SIB1 or other SIBs) to indicate the second size $N_{\text{RF}}^{\text{size}}$. Additionally or alternatively, another RRC parameter may indicate a set of sizes in number of resource blocks where each size corresponds to a specific subcarrier spacing configuration μ . The UE 102 and/or the base station 160 may determine a size corresponding to subcarrier spacing configuration of the initial UL BWP as the second size $N_{\text{RF}}^{\text{size}}$.

[0229] Additionally or alternatively, in various implementations of the present disclosure, the size $N_{\text{RF}}^{\text{size}}$ may be determined based on the initial UL BWP size.

[0230] In a case that the first size $N_{\text{BWP}}^{\text{size}}$ is larger than the second size $N_{\text{RF}}^{\text{size}}$, a number of one or multiple frequency offsets for the second hop is determined at least based on the second size $N_{\text{RF}}^{\text{size}}$. For example, the $N_{\text{RF}}^{\text{size}}$ is less than 50, the number of one or multiple frequency offsets for the second hop is determined as two frequency offsets, i.e. $\text{floor}(N_{\text{RF}}^{\text{size}}/2)$ and $\text{floor}(N_{\text{RF}}^{\text{size}}/4)$. Then one bit (one hopping bit) of the PUSCH frequency resource allocation field is used to indicate the UE 102 which frequency offset among these two frequency offsets is used for the second hop. Furthermore, values of the two frequency offsets, i.e. $\text{floor}(N_{\text{RF}}^{\text{size}}/2)$ and $\text{floor}(N_{\text{RF}}^{\text{size}}/4)$, are also given (determined or calculated) based on the second size $N_{\text{RF}}^{\text{size}}$. In a case that $N_{\text{RF}}^{\text{size}}$ is equal to or larger than 50, the number of one or multiple frequency offsets for the second hop is determined as three frequency offset, i.e. $\text{floor}(N_{\text{RF}}^{\text{size}}/2)$, $\text{floor}(N_{\text{RF}}^{\text{size}}/4)$ and $-\text{floor}(N_{\text{RF}}^{\text{size}}/4)$. Then two bits (two hopping bits) of the PUSCH frequency resource allocation field is used to indicate the UE 102 which frequency offset among these three frequency offset is used for the second hop. Furthermore, values of these three frequency offsets, i.e. $\text{floor}(N_{\text{RF}}^{\text{size}}/2)$, $\text{floor}(N_{\text{RF}}^{\text{size}}/4)$ and $-\text{floor}(N_{\text{RF}}^{\text{size}}/4)$, are also given (determined or calculated) based on the second size $N_{\text{RF}}^{\text{size}}$. That is, the UE 102 may be provided one or multiple frequency offsets, the number of which is determined (or given) at least based on the second size. A corresponding number of bits included in the PUSCH frequency resource allocation field is used to indicate which one among the one or multiple frequency offset values is used for the frequency offset for the second hop. The indicated frequency offset for the second hop can be denoted as RB_{offset} . The starting RB for the second hop can be given by $(RB_{\text{start}} + RB_{\text{offset}}) \bmod N_{\text{RF}}^{\text{size}}$. The number of resource blocks for the second hop is same as that for the first hop, i.e. L_{RBs} .

[0231] In a case that the first size $N_{\text{BWP}}^{\text{size}}$ is equal to or less than the second size, a number of one or multiple frequency offsets for the second hop is determined at least based on the first size $N_{\text{BWP}}^{\text{size}}$. For example, the $N_{\text{BWP}}^{\text{size}}$ is less than 50, the number of one or multiple frequency offsets for the second hop is determined as two frequency offsets, i.e. $\text{floor}(N_{\text{BWP}}^{\text{size}}/2)$ and $\text{floor}(N_{\text{BWP}}^{\text{size}}/4)$. Then one bit (one hopping bit) of the PUSCH frequency resource allocation field is used to indicate the UE 102 which frequency offset among these two frequency offsets is used for the second hop. Furthermore, values of the two frequency offsets, i.e. $\text{floor}(N_{\text{BWP}}^{\text{size}}/2)$ and $\text{floor}(N_{\text{BWP}}^{\text{size}}/4)$, are also given (determined or calculated) based on the first size $N_{\text{BWP}}^{\text{size}}$.

In a case that $N_{\text{BWP}}^{\text{size}}$ is equal to or larger than 50, the number of one or multiple frequency offsets for the second hop is determined as three frequency offset, i.e. $\text{floor}(N_{\text{BWP}}^{\text{size}}/2)$, $\text{floor}(N_{\text{BWP}}^{\text{size}}/4)$ and $-\text{floor}(N_{\text{BWP}}^{\text{size}}/4)$. Then two bits (two hopping bits) of the PUSCH frequency resource allocation field is used to indicate the UE 102 which frequency offset among these three frequency offset is used for the second hop. Furthermore, values of these three frequency offsets, i.e. $\text{floor}(N_{\text{BWP}}^{\text{size}}/2)$, $\text{floor}(N_{\text{BWP}}^{\text{size}}/4)$ and $-\text{floor}(N_{\text{BWP}}^{\text{size}}/4)$, are also given (determined or calculated) based on the first size $N_{\text{BWP}}^{\text{size}}$. That is, the UE 102 may be provided one or multiple frequency offsets, the number of which is determined (or given) at least based on the first size. A corresponding number of bits included in the PUSCH frequency resource allocation field is used to indicate which one among the one or multiple frequency offset values is used for the frequency offset for the second hop. The indicated frequency offset for the second hop can be denoted as RB_{offset} . The starting RB for the second hop can be given by $(RB_{\text{start}} + RB_{\text{offset}}) \bmod N_{\text{BWP}}^{\text{size}}$. The number of resource blocks for the second hop is same as that for the first hop, i.e. L_{RBs} .

[0232] Additionally or alternatively, in a case that the first size $N_{\text{BWP}}^{\text{size}}$ is equal to the second size, the UE 102 may determine the number of one or multiple frequency offsets for the second hop at least based on either the first size or the second size. The values for the one or multiple frequency offsets can be given based on either the first size or the second size.

[0233] Additionally or alternatively, the UE 102 may always determine a number of one or multiple frequency offsets for the second hop at least based on the second size. That is, the UE 102 may not determine a number of one or multiple frequency offset for the second hop at least based on the first size. The values for the one or multiple frequency offsets can be given based on the second size as well.

[0234] Additionally or alternatively, the base station may configure the UE 102 one or multiple frequency offsets via system information (e.g. MIB, SIB1 or other SIBs). That is, the UE 102 may receive, from the base station, a RRC parameter which is a list of entries wherein each entry indicates a frequency offset in number of resource blocks. That is, the RRC parameter contains one or multiple entries where each entry indicates a frequency offset. one or multiple frequency offsets indicated by the RRC parameter herein can be applied to, for example, a PUSCH scheduled by a RAR UL grant or a PUSCH scheduled by a DCI format 0_0 with CRC scrambled by TC-RNTI.

[0235] In a case that the frequency hopping is enabled for a PUSCH scheduled by the RAR UL grant or a PUSCH scheduled by a DCI format 0_0 with CRC scrambled by TC-RNTI, the UE 102 may need to determine a number of hopping bits in the PUSCH frequency resource allocation field included in the RAR UL grant or in the DCI format 0_0. The UE 102 may not determine the number of hopping bits based on the size of initial UL BWP $N_{\text{BWP}}^{\text{size}}$. The UE 102 may determine a number of hopping bits in the PUSCH frequency resource allocation field included in the RAR UL grant or in the DCI format 0_0 at least based on the total count of the entries in the RRC parameter. For example, the total count of the one or multiple entries in the RRC parameter is N_{total} . The UE 102 may determine the number of hopping bits as $\text{ceiling}(N_{\text{total}}/2)$. That is, the $\text{ceiling}(N_{\text{total}}/2)$ bits of the PUSCH frequency resource allocation field is used to indicate which one among the one or multiple frequency offsets provided by the RRC parameter is used for the frequency offset for the second hop.

[0236] The UE 102 may transmit 1108, to the base station 160, the PUSCH transmission with frequency hopping in the first hop and the second hop.

[0237] In an example of the implementation, frequency retuning may be performed by the UE 102. In a case that a indicated frequency offset for the second hop may result in a total frequency bandwidth, within which the PUSCH transmission in the first hop and in the second hop scheduled by the RAR UL grant is transmitted, being larger than the maximum bandwidth the UE 102 can support. The UE 102 may, in the initial UL BWP, retune from one frequency region where PUSCH in the first hop is transmitted to another frequency region where PUSCH in the second hop is transmitted. These two frequency regions are within a same BWP, for example, the initial UL BWP. In other words, the UE 102 may retune from the first hop of the PUSCH scheduled by the RAR UL grant to the second hop of the PUSCH scheduled by the RAR UL grant within a slot. The UE 102 may retune from a first frequency region carrying PUSCH transmission in the first hop to a second frequency region carrying PUSCH transmission in the second hop within a slot.

[0238] Frequency retuning time is needed for the frequency retuning operation by the UE 102. The UE 102 may need to determine which symbol(s) among the duration of the PUSCH scheduled by the RAR UL grant as the frequency retuning time. The duration of the PUSCH scheduled by the RAR UL grant is given by the PUSCH time resource allocation field in the RAR UL grant, which can be denoted as $N_{\text{symb}}^{\text{PUSCH}}$.

That is, the $N_{\text{symb}}^{\text{PUSCH}}$ is the length of the PUSCH transmission in OFDM symbols in one slot. The number of symbols in the first hop is given by $\text{floor}(N_{\text{symb}}^{\text{PUSCH}} / 2)$. While the number of symbols in the second hop is given by $N_{\text{symb}}^{\text{PUSCH}} - \text{floor}(N_{\text{symb}}^{\text{PUSCH}} / 2)$, i.e. $\text{ceiling}(N_{\text{symb}}^{\text{PUSCH}} / 2)$.

[0239] The frequency retuning time can be predefined in number of OFDM symbols per subcarrier spacing configuration μ . Hereinafter, notation $T_{\text{switching}}$ represents the frequency returning time in OFDM symbols for the subcarrier spacing configuration μ of the initial UL BWP. The UE 102 may determine which symbol(s) among the duration $N_{\text{symb}}^{\text{PUSCH}}$ of the PUSCH as the frequency retuning time $T_{\text{switching}}$.

[0240] The frequency retuning time $T_{\text{switching}}$ can be distributed among the first hop and the second hop. For example, the last $\text{floor}(T_{\text{switching}} / 2)$ symbol(s) of the first hop and the first $\text{ceiling}(T_{\text{switching}} / 2)$ symbol(s) of the second hop can be used as frequency retuning time $T_{\text{switching}}$. That is, the UE 102 may determine the last $\text{floor}(T_{\text{switching}} / 2)$ symbol(s) of the first hop and the first $\text{ceiling}(T_{\text{switching}} / 2)$ symbol(s) of the second hop as the frequency retuning time. In other words, the UE 102 may not transmit the PUSCH and/or associated DMRS on the last $\text{floor}(T_{\text{switching}} / 2)$ symbol(s) of the first hop and may not transmit the PUSCH and/or associated DMRS on the first $\text{ceiling}(T_{\text{switching}} / 2)$ symbol(s) of the second hop. That is to say, the UE 102 may not transmit the last $\text{floor}(T_{\text{switching}} / 2)$ symbols in the first hop and may not transmit the first $\text{ceiling}(T_{\text{switching}} / 2)$ symbol(s) of the second hop. The base station 160 may not receive PUSCH and/or associated DMRS on the last $\text{floor}(T_{\text{switching}} / 2)$ symbols in the first hop and may not receive PUSCH and/or associated DMRS on the first $\text{ceiling}(T_{\text{switching}} / 2)$ symbol(s) of the second hop.

[0241] Figure 12 is a diagram illustrating one example 1200 of PUSCH transmission/reception with or without frequency hopping by a UE 102 and a base station 160. In the Figure 12, PUSCH mapping type for the scheduled PUSCH is given as PUSCH mapping type B. A single-symbol front-loaded DMRS is configured for the scheduled PUSCH. RRC parameter *dmrs-AdditionalPosition* is set to 'pos1', i.e. there are up to one additional DMRS present for the PUSCH with PUSCH mapping type B. Duration allocated for the scheduled PUSCH is 12 symbols, i.e. $N_{\text{symb}}^{\text{PUSCH}} = 12$. In the Figure 12, the PUSCH may be a PUSCH scheduled by the RAR UL grant. Additionally or alternatively, the PUSCH may be a PUSCH scheduled by DCI format 0_0 with CRC scrambled by TC-RNTI. Additionally or alternatively, the PUSCH may be a PUSCH

scheduled by a DCI format with CRC scrambled by a C-RNTI. The DCI format herein may be DCI format 0_0, DCI format 0_1 or DCI format 0_2.

[0242] Figure 12 (A) is an illustration that the PUSCH with allocated duration $N_{\text{symb}}^{\text{PUSCH}}$ 1201 is transmitted by the UE 102 without frequency hopping. The position of the single-symbol front-loaded DMRS is on the first symbol of the scheduled PUSCH. The position of the single-symbol additional DMRS is on the tenth symbol of the scheduled PUSCH. 1202 represents the allocated resource blocks for the PUSCH in number of resource blocks in the frequency domain.

[0243] Figure 12 (B) is an illustration that the PUSCH is transmitted by the UE 102 with frequency hopping. The PUSCH with duration $N_{\text{symb}}^{\text{PUSCH}}$ contains two hops, i.e. the first hop 1203 with duration $\text{floor}(N_{\text{symb}}^{\text{PUSCH}} / 2) = 6$, and the second hop 1204 with duration $N_{\text{symb}}^{\text{PUSCH}} - \text{floor}(N_{\text{symb}}^{\text{PUSCH}} / 2) = 6$. The position of the front-loaded DMRS symbol is on the first symbol relative to the start of each hop in case frequency hopping is enabled. That is, the position of the single-symbol front-loaded DMRS for the first hop is on the first symbol of the first hop. The position of the single-symbol front-loaded DMRS for the second hop is on the first symbol of the second hop. As above-mentioned, if *dmrs-AdditinalPosition* is set to 'pos1', there are up to one additional DMRS present for a PUSCH. The one additional DMRS is present or not depending on the allocation duration of the PUSCH. As given by Table 6.4.1.1.3-6 of [TS 38.211], one additional DMRS is present if duration of a hop for PUSCH transmission is larger than 4 symbols. The one additional DMRS is located on the fifth symbol of the hop with duration larger than 4 symbols. In other words, even if *dmrs-AdditinalPosition* is set to 'pos1', one additional DMRS may be not present if the duration of the hop is equal to or less than 4 symbols. In the Figure 12 (B), for the first hop 1202 with 6 symbols, one additional DMRS is present on the fifth symbol of the first hop. For the second hop 1203 with 6 symbols, one additional DMRS is also present on the fifth symbol of the second hop.

[0244] Figure 12 (C) is an illustration that the PUSCH is transmitted by the UE 102 with frequency hopping and frequency retuning is performed by the UE 102 between these two hops of the PUSCH transmission. In the Figure 12 (C), a total frequency bandwidth 1205 (or frequency offset or frequency distance), within which the PUSCH transmission in the first hop and in the second hop is transmitted, is larger than maximum bandwidth the UE 102 can support. Therefore, the UE 102 may perform

frequency retuning operation. That is, the UE 102 may retune from one frequency region carrying PUSCH in the first hop 1206 to another frequency region carrying PUSCH in the second hop 1207 in order to transmit the second hop of the PUSCH. Herein, for example, the frequency retuning time $T_{\text{switching}}$ is 3 symbols. The last symbol of the first hop 1206 and the first two symbols of the second hop 1207 are used as frequency retuning time $T_{\text{switching}}$. That is, the UE 102 may determine the last one symbol of the first hop and the first two symbols of the second hop as the frequency retuning time.

[0245] The UE 102 may not transmit the last symbol in the first hop and may not transmit the first two symbols in the second hop. The base station 160 may not receive the last symbol in the first hop and may not receive the first two symbols in the second hop. The UE 102 may transmit symbols in the duration 1208 of the first hop 1206 and may transmit symbols in the duration 1209 of the first hop 1207. The duration 1208 is the actual PUSCH transmission duration (actual PUSCH transmission occasion) within the first hop and the duration 1209 is the actual PUSCH transmission duration (actual PUSCH transmission occasion) within the second hop. In the present disclosure, an actual PUSCH transmission duration may refer to an actual PUSCH transmission hop (or an actual hop). That is, one hop of a PUSCH may consist of an actual PUSCH transmission duration and zero, one or multiple symbols used for frequency retuning time. Additionally or alternatively, one hop of a PUSCH may consist of an actual hop and zero, one or multiple symbols used for frequency retuning time. In a case that a hop of a PUSCH does not include one or multiple symbols used for frequency retuning time, the hop is equivalent to an actual hop within the hop.

[0246] In the present disclosure, in a case that the intra-slot frequency hopping is enabled, the position(s) of DMRS(s) including one front-loaded DMRS and/or zero, one or more additional DMRS(s) configured for the PUSCH are determined at least based on an actual PUSCH transmission duration (actual PUSCH transmission occasion) and/or the start of the actual PUSCH transmission duration within each hop but not the duration of each hop and/or the start of each hop. The actual PUSCH transmission duration within a hop is a number of symbols which the UE 102 transmits. The UE 102 may transmit PUSCH and/or DMRS on the symbols of the actual PUSCH transmission duration. That is, in this case, the UE 102 may not determine the position(s) of DMRS(s) including the front-loaded DMRS and zero, one or more

additional DMRS(s) configured for the PUSCH based on the duration of a hop and/or the start of the hop. In other words, for a hop of PUSCH transmission, the position(s) of DMRS(s) including one front-loaded DMRS and/or zero, one or more additional DMRS(s) are determined at least based on the duration of the hop, the number of one or more symbols, and/or the start of the one or more symbols wherein the one or more symbols are used as frequency retuning time. In other words, for a hop of PUSCH transmission, the position(s) of DMRS(s) including one front-loaded DMRS and/or zero, one or more additional DMRS(s) are determined at least based on the duration of the actual hop within the hop and/or the start of the actual hop. Start of a duration (e.g. a hop, an actual PUSCH transmission) means a starting symbol of the duration relative to the start (first symbol) of a slot.

[0247] To be specific, in case frequency hopping is enabled, for a hop of PUSCH transmission, the position of the front-loaded DMRS symbol is determined as the first symbol of an actual PUSCH transmission duration within the hop but not the first symbol of the hop. That is, in case frequency hopping is enabled, for a hop of PUSCH transmission, the position of the front-loaded DMRS symbol within a hop is determined based on the start (first symbol) of an actual PUSCH transmission duration within the hop but not the start (first symbol) of the hop. In a case that frequency hopping is enabled and one additional DMRS is configured, for a hop of PUSCH transmission, the additional DMRS symbol within the hop is present or not at least based on the actual PUSCH transmission duration within the hop but not based on the duration of the hop. Moreover, the position of the additional DMRS symbol within a hop is determined based on the start of the actual PUSCH transmission duration but not the start of the hop.

[0248] As depicted in the Figure 12 (C), the position of the front-loaded DMRS symbol in the first hop is the first symbol relative to the start of the actual transmission duration. And the position of the front-loaded DMRS symbol in the second hop is the first symbol relative to the start of the actual transmission duration 1209. That is, the position of the front-loaded DMRS symbols in a hop is determined as the first symbol of the actual hop within the hop. In other words, the position of the front-loaded DMRS symbols in a hop is in the first symbol relative to the actual hop within the hop. The additional DMRS is present in the first hop with six symbols given the actual PUSCH transmission duration within the first hop is with 5 symbol. However, the additional

DMRS is not present in the second hop with six symbols given the actual PUSCH transmission duration within the second hop is with 4 symbol. That is, whether the additional DMRS is present or not within a hop is determined based on the duration of an actual hop within the hop.

[0249] Additionally or alternatively, the UE 102 may always determine the first $T_{\text{switching}}$ symbol(s) of the second hop as the frequency retuning time. The UE 102 may not transmit the PUSCH and/or associated DMRS in the first $T_{\text{switching}}$ symbol(s) of the second hop. The UE 102 may transmit the PUSCH and/or associated DMRS in the symbols of the first hop and the last ceiling($N_{\text{symb}}^{\text{PUSCH}} / 2$) - $T_{\text{switching}}$ symbol(s) of the second hop.

[0250] As above-mentioned, the UE 102 may not transmit the symbols used for the frequency retuning time in the first hop and in the second hop. For PUSCH transmission in a hop, the symbols used for the frequency retuning time are punctured. That is, a portion of PUSCH which are mapped to the symbols used for the frequency retuning time are punctured, i.e. not transmitted. That is, the last floor($T_{\text{switching}} / 2$) symbol(s) of the PUSCH in the first hop would be punctured, while the first ceiling($T_{\text{switching}} / 2$) symbol(s) of the PUSCH in the second hop would be punctured.

[0251] For an initial PUSCH transmission, systematic bits and then parity bits are sequentially mapped to resource elements allocated for the PUSCH transmission in an increasing order of first the subcarrier index in the frequency domain and then the symbol index in the time domain. Puncturing operation would result in a consequence that a number of coded bits, for example, the systematic bits will be punctured and not be transmitted by the UE 102. Systematic bits are of higher importance than the parity bits. Then due to lack of the punctured systematic bits, the reception performance of the PUSCH by the base station would be degraded.

[0252] Rate matching operation would be beneficial for the case that some symbols of the PUSCH transmission are used for the frequency retuning time. The UE 102 may determine, in each hop of the PUSCH transmission, which symbol(s) are used for the frequency retuning time. The UE 102 may then determine the symbol(s) among the PUSCH duration in the first hop and/or the second hop which are used for the frequency retuning time as unavailable symbols for the PUSCH transmission. The UE 102 may rate match the PUSCH around the symbols used for frequency retuning time in the first hop and/or the second hop. That is, systematic bits and then parity bits are sequentially

mapped to resource elements of symbols which are used for actual PUSCH transmission. In other words, the UE 102 may not map the PUSCH on the symbol(s) used for frequency retuning time. On the contrary, for the puncturing operation, the UE 102 may map the PUSCH on the symbol(s) used for frequency retuning time but not transmit the symbol(s).

[0253] The above-mentioned implementation used for a PUSCH scheduled by the RAR UL grant can equally apply to a PUSCH scheduled by a DCI format 0_0 with CRC scrambled by a TC-RNTI by applying 'PUSCH scheduled by the format 0_0 with CRC scrambled by a TC-RNTI' instead of 'PUSCH scheduled by the RAR UL grant', and/or applying 'the format 0_0 with CRC scrambled by a TC-RNTI' instead of 'RAR UL grant'.

[0254] Hereinafter, cell specific PUCCH configuration is described.

[0255] As above-mentioned, in response to the PDSCH reception with the UE contention resolution identity, the UE 102 may transmit HARQ-ACK information in a PUCCH using frequency hopping to the base station 160. The UE 102 may generate one HARQ-ACK information bit in response to the PDSCH reception with the UE contention resolution identity. The UE 102 may transmit a PUCCH with the HARQ-ACK information in a cell specific PUCCH resource in the initial UL BWP. If the UE 102 has not been configured with dedicated PUCCH resource configuration, the UE 102 may use cell specific PUCCH resource configuration for PUCCH transmission with the HARQ-ACK information in the initial UL BWP.

[0256] The base station 160 may configure a PUCCH resource set, which includes one or multiple cell specific PUCCH resources, within an initial UL BWP for PUCCH transmission with HARQ-ACK information. The base station 160 and the UE 102 may be provided a predefined table associated to cell specific PUCCH resource configuration(s). Each row(entry) of the predefined table configures (or provides) a PUCCH resource set including a set of cell specific PUCCH resources. In other words, each entry of the predefined table configures a set of cell specific PUCCH parameters related to, for example, PUCCH format, first symbol, number of symbols, PRB offset, set of initial CS indexes. Each PUCCH resource corresponds to a PUCCH format, a first symbol, a duration, a PRB offset RB_{BWP}^{offset} , and an initial cyclic shift index in a set of initial cyclic shift indexes. In other words, each PUCCH resource can be

identified by at least a PUCCH format, a first symbol, a duration, a PRB offset RB_{BWP}^{offset} , and an initial cyclic shift index.

[0257] The base station 160 may inform the UE 102 which row of the table is used for PUCCH transmission in the initial UL BWP via a RRC parameter (e.g. *pucch-ResourceCommon*). The RRC parameter *pucch-ResourceCommon* is included in broadcasted system information, for example, SIB1. The RRC parameter *pucch-ResourceCommon* is used to indicate an index corresponding to a row of the table. In other words, the RRC parameter *pucch-ResourceCommon* is used to determine or provide a PUCCH resource set for PUCCH transmission in an initial UL BWP.

[0258] Figure 13 is a diagram illustrating one example of one predefined table 1300 associated to cell specific PUCCH resource configuration(s). The table 1300 contains 16 rows(entries). Each row provides a PUCCH resource set. One PUCCH resource set includes sixteen resources, each corresponding to a PUCCH format, a first symbol, a duration (i.e. a number of symbols configured for each PUCCH resource), a PRB offset RB_{BWP}^{offset} , and a cyclic shift index set for a PUCCH transmission. The base station 160 may use the RRC parameter *pucch-ResourceCommon* to indicate which row is used for determining PUCCH resources (or a PUCCH resource set). For example, if the RRC parameter *pucch-ResourceCommon* is set to 0, the row with index 0 is used to determine a PUCCH resource set for PUCCH transmission with HARQ-ACK information in the initial UL BWP of N_{BWP}^{size} PRBs. N_{BWP}^{size} is a frequency-domain size of the initial UL BWP in unit of resource block, i.e. a number of resource blocks of the initial UL BWP. If the RRC parameter *pucch-ResourceCommon* is set to 8, the row with index 8 is used to determine a PUCCH resource set for PUCCH transmission with HARQ-ACK information in the initial UL BWP of N_{BWP}^{size} PRBs.

[0259] Figure 14 is a diagram illustrating one example 1400 of how a cell-specific PUCCH resource is determined by a UE 102 and a base station 160. As depicted in the Figure 14, one box in the time domain represents one symbol. The total number of the symbols in the time domain is 14 symbols, which is a number of symbols within a slot. In the meantime, one box in the frequency domain represents one resource block (e.g. one PRB). The total number of the resource blocks in the frequency domain is the N_{BWP}^{size} , which is the size of the initial UL BWP.

[0260] In the Figure 14, the RRC parameter *pucch-ResourceCommon* is set to 8. That is, the row with index 8 of Table 1300 is used to provide or configure a PUCCH

resource set. In other words, a PUCCH resource set is provided by the RRC parameter *pucch-ResourceCommon*. The PUCCH resource set can be also referred to as a cell specific PUCCH resource set. The PUCCH resource set includes a plurality of PUCCH resources, for example, sixteen PUCCH resources. The UE 102 may determine a PUCCH resource set for PUCCH transmission in the initial UL BWP of $N_{\text{BWP}}^{\text{size}}$ PRBs at least based on the RRC parameter *pucch-ResourceCommon* and the predefined table associated to the cell specific PUCCH resource configuration.

[0261] According to the row with index 8 of Table 1300, the UE 102 may be provided one PUCCH resource configuration relating to PUCCH format, first symbol, number of symbols, PRB offset, and set of initial CS indexes. To be specific, PUCCH format configured for the PUCCH resources included in the PUCCH resource set is PUCCH format 1. In time domain, each PUCCH resource is configured with 10 symbols and starts from the fifth symbol relative to the first symbol of a slot. That is, the first symbol of each PUCCH resource is a fifth symbol within a slot. PRB offset, i.e. $RB_{\text{BWP}}^{\text{offset}} = 0$, is used to determine the frequency location of PUCCH resources included in the PUCCH resource set. The PRB offset $RB_{\text{BWP}}^{\text{offset}}$ indicates an offset in PRBs relative to PRB0 of the initial UL BWP. $RB_{\text{BWP}}^{\text{offset}} = 0$ means some PUCCH resources are configured in the PRB0 of the initial UL BWP. That is, PRB index for PUCCH resource(s) with certain index(es) is PRB0 of the initial UL BWP. Different PUCCH resources may have different frequency locations (PRB indexes). PRB index of one PUCCH resource may be different from that for another PUCCH resource. Since frequency hopping is used for PUCCH transmission, one PUCCH resource is divided into two hops, i.e. the first hop and the second hop. The frequency offset (frequency distance) between two hops of one PUCCH resource for PUCCH transmission may be configured as large as possible, which can harvest frequency diversity gain as much as possible and can avoid the fragmentation of data transmission. In the present disclosure, two hops of one PUCCH resource may be configured on two edges of the initial UL BWP. To be specific, one hop of one PUCCH resource may be configured on one edge of the initial UL BWP. On the other hand, the other hop of the PUCCH resource may be configured on the other edge of the initial UL BWP.

[0262] According to PUCCH configuration(s) provided by a row of Table 1300, the UE 102 may determine time and frequency resources assigned to a PUCCH resource set by the base station 160. As showed in the Figure 14, the time and frequency resource

assigned to the PUCCH resource set can be further divided into four sets of time and frequency resources, i.e. a set of boxes marked (drew) with horizontal lines, a set of boxes marked with vertical lines, a set of boxes marked with cross, a set of boxes marked with diagonal lines. As above-mentioned, the PUCCH resource set includes sixteen PUCCH resources which can be indexed from 0 to 15. The PUCCH resource index can be denoted as r_{PUCCH} where $0 \leq r_{\text{PUCCH}} \leq 15$. Therefore, each set of time and frequency resources includes four PUCCH resources.

[0263] For PUCCH resource with index r_{PUCCH} where $0 \leq r_{\text{PUCCH}} \leq 7$, the UE 102 may determine PRB index of the PUCCH resources in the first hop as $RB_{\text{BWP}}^{\text{offset}} + \text{floor}(r_{\text{PUCCH}}/N_{\text{CS}})$ and may determine PRB index of the PUCCH resources in the second hop as $N_{\text{BWP}}^{\text{size}} - 1 - RB_{\text{BWP}}^{\text{offset}} - \text{floor}(r_{\text{PUCCH}}/N_{\text{CS}})$. N_{CS} is the total number of initial cyclic shift indexes in the set of initial cyclic shift indexes $\{0, 3, 6, 9\}$, i.e. $N_{\text{CS}} = 4$. For PUCCH resources with index r_{PUCCH} where $0 \leq r_{\text{PUCCH}} \leq 3$, the PRB index of these PUCCH resources in the first hop is PRB 0 of the initial UL BWP, i.e. the boxes marked with horizontal lines in the bottom of the Figure 14. On the other hand, for PUCCH resources with index r_{PUCCH} where $0 \leq r_{\text{PUCCH}} \leq 3$, the PRB index of these PUCCH resources in the second hop is PRB $N_{\text{BWP}}^{\text{size}} - 1$ of the initial UL BWP, i.e. the boxes marked with horizontal lines in the top of the Figure 14. For PUCCH resources with index r_{PUCCH} where $4 \leq r_{\text{PUCCH}} \leq 7$, the PRB index of these PUCCH resources in the first hop is PRB 1 of the initial UL BWP, i.e. the boxes marked with cross in the bottom of the Figure 14. On the other hand, for PUCCH resources with index r_{PUCCH} where $4 \leq r_{\text{PUCCH}} \leq 7$, the PRB index of these PUCCH resources in the second hop is PRB $N_{\text{BWP}}^{\text{size}} - 2$ of the initial UL BWP, i.e. the boxes marked with cross in the top of the Figure 14.

[0264] For PUCCH resource with index r_{PUCCH} where $8 \leq r_{\text{PUCCH}} \leq 15$, the UE 102 may determine PRB index of the PUCCH resources in the first hop as $N_{\text{BWP}}^{\text{size}} - 1 - RB_{\text{BWP}}^{\text{offset}} - \text{floor}((r_{\text{PUCCH}} - 8)/N_{\text{CS}})$ and may determine PRB index of the PUCCH resources in the second hop as $RB_{\text{BWP}}^{\text{offset}} + \text{floor}((r_{\text{PUCCH}} - 8)/N_{\text{CS}})$. For PUCCH resources with index r_{PUCCH} where $8 \leq r_{\text{PUCCH}} \leq 11$, the PRB index of these PUCCH resources in the first hop is PRB $N_{\text{BWP}}^{\text{size}} - 1$ of the initial UL BWP, i.e. the boxes marked with vertical lines in the top of the Figure 14. On the other hand, for PUCCH resources with index r_{PUCCH} where $8 \leq r_{\text{PUCCH}} \leq 11$, the PRB index of these PUCCH resources in the second hop is PRB 0 of the initial UL BWP, i.e. the boxes marked with

vertical lines in the bottom of the Figure 14. For PUCCH resources with index r_{PUCCH} where $12 \leq r_{\text{PUCCH}} \leq 15$, the PRB index of these PUCCH resources in the first hop is PRB $N_{\text{BWP}}^{\text{size}} - 2$ of the initial UL BWP, i.e. the boxes marked with diagonal lines in the top of the Figure 14. On the other hand, for PUCCH resources with index r_{PUCCH} where $12 \leq r_{\text{PUCCH}} \leq 15$, the PRB index of these PUCCH resources in the second hop is PRB 1 of the initial UL BWP, i.e. the boxes marked with diagonal lines in the bottom of the Figure 14.

[0265] For those PUCCH resources assigned in same time and frequency resources, different cyclic shift indexes among the set of initial cyclic shift indexes are used. That is, initial cyclic shift indexes can be used to distinguish each other. The total number of initial cyclic shift indexes in the set of initial cyclic shift indexes, i.e. N_{CS} , determines how many PUCCH resources can be assigned within a same time and frequency resource. For PUCCH resource with index r_{PUCCH} where $0 \leq r_{\text{PUCCH}} \leq 7$, the UE 102 may determine the initial cyclic shift index in the set of initial cyclic shift indexes according to $r_{\text{PUCCH}} \bmod N_{\text{CS}}$. That is, for a PUCCH resource with index r_{PUCCH} where $0 \leq r_{\text{PUCCH}} \leq 7$, the UE 102 may determine the location of the initial cyclic shift index L_{CS} , $0 \leq L_{\text{CS}} < N_{\text{CS}}$, in the set of initial cyclic shift indexes as $r_{\text{PUCCH}} \bmod N_{\text{CS}}$, i.e. $L_{\text{CS}} = r_{\text{PUCCH}} \bmod N_{\text{CS}}$. An initial cyclic shift index with location $L_{\text{CS}} = 0$ means the initial cyclic shift index is the first initial cyclic shift index in the set of initial cyclic shift indexes.

[0266] Similarly, for PUCCH resource with index r_{PUCCH} where $8 \leq r_{\text{PUCCH}} \leq 15$, the UE 102 may determine the initial cyclic shift index in the set of initial cyclic shift indexes according to $(r_{\text{PUCCH}} - 8) \bmod N_{\text{CS}}$. That is, for a PUCCH resource with index r_{PUCCH} where $8 \leq r_{\text{PUCCH}} \leq 15$, the UE 102 may determine the location of the initial cyclic shift index L_{CS} , $0 \leq L_{\text{CS}} < N_{\text{CS}}$, in the set of initial cyclic shift indexes as $(r_{\text{PUCCH}} - 8) \bmod N_{\text{CS}}$, i.e. $L_{\text{CS}} = (r_{\text{PUCCH}} - 8) \bmod N_{\text{CS}}$.

[0267] In response to reception of PDSCH scheduled by a DCI format, the UE 102 may provide HARQ-ACK information in a PUCCH transmission. As above-mentioned, the UE 102 determines a PUCCH resource set at least based on the RRC parameter *pucch-ResourceCommon* and the predefined table associated to the cell specific PUCCH resource configuration. After determining the PUCCH resource set, the UE 102 may determine a PUCCH resource (a PUCCH resource index r_{PUCCH}) from the PUCCH resource set for PUCCH transmission with the HARQ-ACK information. The

UE may determine a PUCCH resource with index r_{PUCCH} based on Formula (4) $r_{\text{PUCCH}} = \text{floor}(2 \times n_{\text{CCE},0} / N_{\text{CCE}}) + 2 \times \Delta_{\text{PRI}}$. Here, N_{CCE} is a number of CCEs in a CORESET where a PDCCH with the DCI format is detected. $n_{\text{CCE},0}$ is the index of a first CCE for the PDCCH reception. Δ_{PRI} is a value of the PUCCH resource indicator (PRI) field in the DCI format scheduling the PDSCH. The UE 102 may transmit PUCCH with the HARQ-ACK information in the determined PUCCH resource with index r_{PUCCH} in the initial UL BWP.

[0268] In the present disclosure, PUCCH support multiple PUCCH formats as like PUCCH formats 0, 1, 2, 3, and 4. For example, for a PUCCH transmission with PUCCH format 0, the number of HARQ-ACK information bits is 1 or 2. A PUCCH resource with PUCCH format 0 can be configured with 1 symbol or 2 symbols in time domain and is configured with 1 RB in frequency domain. A low PAPR sequence (i.e. Zadoff-Chu sequence) with length 12 is used as a base sequence for the PUCCH format 0. UP to 12 different phase rotations i.e. different cyclic shifts in time domain can be applied to a same base sequence. Different cyclic shifts represent different HARQ-ACK information bits. The PUCCH with PUCCH format 0 is transmitted by the UE 102 in one PRB. For a PUCCH transmission with PUCCH format 1, the number of HARQ-ACK information bits is 1 or 2. A PUCCH resource with PUCCH format 1 can be configured with from 4 symbol to 14 symbols in time domain and is configured with 1 RB in frequency domain. Information bit(s) including HARQ-ACK information and/or SR information shall be modulated using BPSK or QPSK, which results in a complex-valued symbol. The complex-valued symbol shall be multiplied with a low PRPR sequence with length 12. The complex-valued symbol(s) and associated DMRS symbol(s) are alternately mapped to the symbols of the PUCCH resource with the PUCCH format 1. To be specific, associated DMRS(s) for PUCCH format 1 are mapped to symbols with even indexes of the PUCCH resource with the PUCCH format 1, e.g. symbols with indexes 0, 2, 4, etc. The complex-valued symbol(s) are mapped to symbols with odd indexes of the PUCCH resource with the PUCCH format 1, e.g. symbols with indexes 1, 3, 5, etc. The PUCCH with PUCCH format 1 is transmitted in one PRB.

[0269] Figure 15 is a flow diagram illustrating one implementation of a method 1500 for determining PUCCH resource by a UE 102.

[0270] In the implementation of the present disclosure, one or two RRC parameters related to cell specific PUCCH resource configuration(s) may be configured to the UE 102. The UE 102 may determine a PUCCH resource set at least based on one, more, or all of a first RRC parameter, a second RRC parameter, and/or a predefined table related to cell specific PUCCH resource configuration(s), which are illustrated hereinafter. In the implementation of the present disclosure, the UE 102 may not have been configured dedicated PUCCH resource configuration(s). IN the implementation of the present disclosure, the UE 102 may perform PUCCH transmission with HARQ-ACK information in response to a PDSCH scheduled by DCI format 1_0 with CRC scrambled by a TC-RNTI. The implementation can be applied to intra-slot frequency hopping and/or inter-slot frequency hopping of a PUCCH transmission.

[0271] In the implementation of the present disclosure, duration of the PUCCH within a slot can be denoted as $N_{\text{symb}}^{\text{PUCCH}}$. In a case that the intra-slot frequency hopping is enabled, the UE 102 may perform frequency hopping for PUCCH transmission. That is, the UE 102 may perform the PUCCH transmission in the first hop and the second hop in one slot. The number of symbols in the first hop is given by $\text{floor}(N_{\text{symb}}^{\text{PUCCH}} / 2)$. That is, in a slot where the PUCCH is transmitted, the first $\text{floor}(N_{\text{symb}}^{\text{PUCCH}} / 2)$ symbol(s) of PUCCH transmission with allocated duration $N_{\text{symb}}^{\text{PUCCH}}$ are symbol(s) in the first hop. While the number of symbols in the second hop is given by $N_{\text{symb}}^{\text{PUCCH}} - \text{floor}(N_{\text{symb}}^{\text{PUCCH}} / 2)$, i.e. $\text{ceiling}(N_{\text{symb}}^{\text{PUCCH}} / 2)$. That is, in a slot where the PUCCH is transmitted, the last $\text{ceiling}(N_{\text{symb}}^{\text{PUCCH}} / 2)$ symbol(s) of PUCCH transmission with allocated duration $N_{\text{symb}}^{\text{PUCCH}}$ are symbol(s) in the second hop.

[0272] In a case that the inter-slot frequency hopping is enabled, the UE 102 may perform frequency hopping for PUCCH transmission across slots. Herein, the UE 102 may perform PUCCH transmission repetitions across slots, i.e. multi-slot PUCCH transmission. Same symbol allocation (i.e. the starting symbol and the allocated duration for the PUCCH) is applied across slots. For convenience, for one PUCCH transmission among the multi-slot PUCCH transmission which is transmitted in a slot with slot number n_s^μ , if $n_s^\mu \bmod 2 = 0$, the PUCCH transmission may refer to one first hop of the multi-slot PUCCH transmission. On the other hand, for one PUCCH transmission among the multi-slot PUCCH transmission which is transmitted in a slot with slot number n_s^μ , if $n_s^\mu \bmod 2 = 1$, the PUCCH transmission may refer to one second

hop of the multi-slot PUCCH transmission. Therefore, if the PUCCH transmission with HARQ-ACK information in response to a PDSCH scheduled by DCI format 1_0 with CRC scrambled by a TC-RNTI is repeated across more than two slots, the multi-slot PUCCH transmission may consist of more than one first hop and more than one second hop.

[0273] Unless specified, a first hop hereinafter may refer to either a first hop for intra-slot frequency hopping or a first hop for inter-slot frequency hopping. Similarly, a second hop hereinafter may refer to either a second hop for intra-slot frequency hopping or a second hop for inter-slot frequency hopping.

[0274] The UE 102 and/or the base station 160 may determine which frequency hopping type is applied to the PUCCH at least based on one, more or all of the broadcasted system information, the transmitted preamble index, the PRACH resource where the preamble is transmitted, the RSRP of the selected SS/PBCH block, one or more RSRP thresholds, a MAC RAR, a MAC subPDU, a RAR UL grant, a DCI format with CRC scrambled by a first RNTI. Here, the broadcasted system information may refer to a MIB, a SIB1, or other SIBs. The one or more RSRP thresholds can be indicated via the broadcasted system information. The MAC RAR means a MAC RAR provided by a MAC subPDU with the RAPID corresponding to the transmitted preamble. The first RNTI can be a SI-RNTI, a RA-RNTI, or a TC-RNTI. The DCI format can be a DCI format 1_0 or a DCI format 0_0. For example, the broadcasted system information may include a RRC parameter which can be used to indicate which frequency hopping type is applied. For example, a value of a field in the DCI format with CRC scrambled by the first RNTI can be used to indicate which frequency hopping type is applied to the PUCCH transmission. In a case that the value of the field is set to 0, the UE 102 may determine intra-slot frequency hopping is applied. In a case that the value of the field is set to 1, the UE 102 may determine inter-slot frequency hopping is applied.

[0275] Additionally or alternatively, the UE 102 and/or the base station 160 may determine the inter-slot frequency hopping for PUCCH transmission with repetitions. On the other hand, the UE 102 and/or the base station 160 may determine the intra-slot frequency hopping for PUCCH transmission without repetitions. A DCI format which schedules the corresponding PDSCH may include a frequency hopping flag field. The frequency hopping flag field can be included in the frequency domain resource

allocation field and can be used to indicate whether the determined frequency hopping is enabled or disabled for the PUCCH transmission. In a case that the value of the frequency hopping flag field is set to 0, the UE 102 may transmit the PUCCH without frequency hopping. In this case, the frequency hopping is disabled for the PUCCH transmission. In a case that the value of the frequency hopping flag field is set to 1, the UE 102 may transmit the PUCCH with frequency hopping. In this case, the frequency hopping is enabled for the PUCCH transmission.

[0276] Additionally or alternatively, the UE 102 and/or the base station 160 may determine that frequency hopping type applied to a PUCCH transmission in response to a PDSCH scheduled by DCI format 1_0 with CRC scrambled by a TC-RNTI is same as that applied to a PUSCH scheduled by the RAR UL grant.

[0277] The UE 102 may receive 1502, from a base station 160, system information including a first RRC parameter. The system information may be the SIB1. Or the system information may be other system information broadcasted by the base station 160. (e.g., MIB or other SIBs). The first RRC parameter is related to a first PUCCH resource set. Or, the first RRC parameter is related to a first cell specific PUCCH resource configuration. The first RRC parameter (e.g. the above-mentioned RRC parameter *pucch-ResourceCommon*) is a cell specific RRC parameter and may indicate an index corresponding to a row of a predefined table associated to cell specific PUCCH resource configuration(s). As above-mentioned, each row of the predefined table 1300 provides a cell specific PUCCH resource configuration, i.e. a PUCCH resource set. Each cell specific PUCCH resource configuration includes information as PUCCH format, first (starting) symbol, number of symbols, PRB offset and set of initial CS indexes. In other words, each row of the predefined table 1300 provides a PUCCH resource set. Therefore, the PUCCH resource set provided by a row of the table 1300 indicated by the first RRC parameter is used for PUCCH transmission with HARQ-ACK information in the initial UL BWP. The HARQ-ACK information, for example, may be one HARQ-ACK information bit in response to PDSCH reception with the UE contention resolution identity. In other words, the first RRC parameter may configure or provide the UE 102 a first PUCCH resource set which may be used for transmission of HARQ-ACK information on a PUCCH in the initial UL BWP.

[0278] The first PUCCH resource set may include a plurality of cell specific PUCCH resources, for example, sixteen cell specific PUCCH resources. Each PUCCH

resource corresponds to a PUCCH format, a first symbol, a duration, a PRB offset, and an initial cyclic shift index in a set of initial cyclic shift indexes. In other words, each PUCCH resource can be identified by at least a PUCCH format, a first (starting) symbol, a duration, a PRB offset, and an initial cyclic shift index in a set of initial cyclic shift indexes.

[0279] The UE 102 may determine 1504, whether the received system information includes a second RRC parameter or not. The second RRC parameter is a cell specific RRC parameter. The second RRC parameter is related to a second PUCCH resource set. Or, the second RRC parameter is related to a second cell specific PUCCH resource configuration. The second RRC parameter may provide a second PUCCH resource set which may be used for transmission of HARQ-ACK information on a PUCCH in the initial UL BWP. Additionally or alternatively, the second RRC parameter may provide a second cell specific PUCCH resource configuration, which includes at least one, more or all of PUCCH format, first (starting) symbol, number of symbols (duration), PRB offset, a set of initial CS indexes, and/or PRB index(es). The PRB index(es) is the PRB index(es) of PUCCH resources for PUCCH transmission in the first hop and/or in the second hop in the initial UL BWP.

[0280] Additionally or alternative, the second RRC parameter (e.g. a RRC parameter *pucch-ResourceCommon-additional*) may indicate an index corresponding to a row of the predefined table 1300 associated to cell specific PUCCH resource configuration(s). The indicated row of the predefined table 1300 provides a cell specific PUCCH resource configuration including information as PUCCH format, first (starting) symbol, number of symbols, PRB offset and set of initial CS indexes for a second PUCCH resource set. Therefore, the second RRC parameter may configure or provide the UE 102 a second PUCCH resource set (or a second PUCCH resource configuration) for PUCCH transmission in the initial UL BWP.

[0281] The second PUCCH resource set may include a plurality of cell specific PUCCH resources, for example, sixteen PUCCH resources. Each PUCCH resource corresponds to a PUCCH format, a first symbol, a duration, a PRB offset, and an initial cyclic shift index in the set of initial cyclic shift indexes. In other words, each PUCCH resource can be identified by at least a PUCCH format, a first symbol, a duration, a PRB offset, and an initial cyclic shift index in the set of initial cyclic shift indexes.

[0282] The UE 102 may determine which PUCCH resource set among the first PUCCH resource set and the second PUCCH resource set is used for transmission of HARQ-ACK information on the PUCCH based on 1504 whether the system information includes the second RRC parameter or not.

[0283] In a first case that the system information includes the second RRC parameter, the UE 102 may determine 1506, the second PUCCH resource set to be used for PUCCH transmission with HARQ-ACK information in the initial UL BWP. That is, if the system information includes the second RRC parameter, the UE 102 may ignore the first RRC parameter and may apply the second RRC parameter to determine a PUCCH resource set, i.e. the second PUCCH resource set, which is used for transmission of HARQ-ACK information on the PUCCH in the initial UL BWP. When the UE 102 received a PDSCH scheduled by a DCI format, the UE 102 may further determine, from the second PUCCH resource set, one PUCCH resource for PUCCH transmission with HARQ-ACK information corresponding to the PDSCH reception. The UE 102 may determine, from the second PUCCH resource set, one PUCCH resource with index r_{PUCCH} for PUCCH transmission with HARQ-ACK information corresponding to the PDSCH reception at least based on a PRI field in the DCI format, a first CCE for PDCCH reception with the DCI format, a total number of CCEs in a CORESET where the DCI format is detected, and so on.

[0284] In a second case that the system information does not include the second RRC parameter, the UE 102 may determine 1508, the first PUCCH resource set to be used for PUCCH transmission with HARQ-ACK information in the initial UL BWP. That is, if the system information does not include the second RRC parameter, the UE 102 may apply the first RRC parameter to determine PUCCH resource set, i.e. the first PUCCH resource set, which is used for transmission of HARQ-ACK information on the PUCCH in the initial UL BWP. When the UE 102 received a PDSCH scheduled by a DCI format, the UE 102 may further determine, from the first PUCCH resource set, one PUCCH resource for PUCCH transmission with HARQ-ACK information corresponding to the PDSCH reception. The UE 102 may determine, from the first PUCCH resource set, one PUCCH resource with index r_{PUCCH} for PUCCH transmission with HARQ-ACK information corresponding to the PDSCH reception at least based on a PRI field in the DCI format, a first CCE for PDCCH reception with the DCI format, a total number of CCEs in a CORESET where the DCI format is detected, and so on.

[0285] In the implementation of the present disclosure, whether to allow a base station 160 to configure one or two RRC parameters would give the base station 160 more flexibility on the cell specific PUCCH configurations for legacy UE and the RedCap UE, which is beneficial for improving wireless communication efficiency of the whole system. In the implementation of the present disclosure, the DCI format herein may be a DCI format 1_0 with CRC scrambled by TC-RNTI. Additionally, the DCI format herein may refer to a DCI format which the UE 102 detected before the UE 102 is provided with dedicated PUCCH resource configuration(s).

[0286] Additionally or alternatively, the base station 160 may transmit the second RRC parameter included in the system information in a case that the size of the initial UL BWP is larger than the size of the maximum bandwidth the UE 102 can support. In other words, the base station 160 may not transmit the second RRC parameter included in the system information in a case that the size of the initial UL BWP is equal to or less than the size of the maximum bandwidth the UE 102 can support.

[0287] Additionally or alternatively, the base station 160 may always transmit the second RRC parameter included in the system information regardless of whether the size of the initial UL BWP is larger than the size of the maximum bandwidth the UE 102 can support or not. The UE 102 with reduced RF bandwidth may determine the PUCCH resource set provided by the second RRC parameter for transmission of HARQ-ACK information on a PUCCH in the initial UL BWP. The UE 102 with reduced RF bandwidth may not determine the PUCCH resource set provided by the first RRC parameter for transmission of HARQ-ACK information on a PUCCH in the initial UL BWP.

[0288] The determination of a PUCCH resource (i.e. the determination of r_{PUCCH}) from the determined PUCCH resource set for PUCCH transmission in the initial UL BWP can be similar as what illustrated above. The UE 102 may transmit a PUCCH in the determined PUCCH resource using frequency hopping in the initial UL BWP in response to a PDSCH reception.

[0289] Frequency offset between two hops of the PUCCH may result in a total frequency bandwidth (region, distance) within which the PUCCH transmission in these two hops are performed exceeding the maximum bandwidth the UE 102 with reduced RF bandwidth can support. When the total frequency bandwidth exceeds the bandwidth the UE 102 can support, frequency retuning may be performed by the UE 102.

[0290] In an example of the implementation, new determination method of PRB indexes of the PUCCH transmission is illustrated. The new determination method of PRB indexes of the PUCCH transmission in the first hop and the second hop may ensure a total frequency bandwidth, within which the PUCCH transmission in both the first hop and the second hop are transmitted, to be confined within the maximum bandwidth the UE102 can support. As a consequence, the frequency retuning for the UE 102 may not be necessary.

[0291] As above-mentioned, PRB offset, e.g. RB_{BWP}^{offset} , is provided by the first RRC parameter or the second RRC parameter. For a PUCCH resource with index r_{PUCCH} where $0 \leq r_{PUCCH} \leq 7$, the existing determination of PRB indexes of the PUCCH transmission is that, PRB index of PUCCH transmission in one hop is determined at least based on the PRB offset as like $RB_{BWP}^{offset} + \text{floor}(r_{PUCCH}/N_{CS})$, and PRB index of PUCCH transmission in the other hop is correspondingly determined at least based on the PRB offset and the size of initial UL BWP as like $N_{BWP}^{size} - 1 - RB_{BWP}^{offset} - \text{floor}(r_{PUCCH}/N_{CS})$. For a PUCCH resource with index r_{PUCCH} where $8 \leq r_{PUCCH} \leq 15$, the existing determination of PRB indexes of the PUCCH transmission is that, PRB index of PUCCH transmission in one hop is determined at least based on the PRB offset as like $RB_{BWP}^{offset} + \text{floor}((r_{PUCCH} - 8)/N_{CS})$, and PRB index of PUCCH transmission in the other hop is correspondingly determined at least based on the PRB offset and the size of initial UL BWP as like $N_{BWP}^{size} - 1 - RB_{BWP}^{offset} - \text{floor}((r_{PUCCH} - 8)/N_{CS})$. Therefore, the frequency offset between these two hops is possibly larger than the maximum bandwidth the UE 102 can support if the size of initial UL BWP is larger than the maximum bandwidth the UE 102 can support.

[0292] In order to avoid the case that the frequency offset (distance) between two hops of PUCCH transmission is larger than the maximum bandwidth the UE 102 can support, the maximum bandwidth the UE 102 can support instead of the size of the initial UL BWP can be used to determine the PRB index of the PUCCH transmission in one hop. That is, the UE 102 may determine a PRB index of the PUCCH transmission in one hop at least based on the PRB offset. The PRB offset can be termed a first PRB offset. To be specific, in the above-mentioned first case, the first PRB offset is provided by the first RRC parameter. In the above-mentioned second case, the first PRB offset is provided by the second RRC parameter. On the other hand, the UE 102 may determine a PRB index of the PUCCH transmission in the other hop at least based on the PRB

offset (i.e. the first PRB offset) and a size of the maximum bandwidth the UE 102 can support. The size of the maximum bandwidth herein is a number of resource blocks of the maximum bandwidth for subcarrier spacing configuration μ of the initial UL BWP. The number of resource blocks of the maximum bandwidth for a subcarrier spacing configuration μ can be denoted as $N_{\text{RF}}^{\text{size}, \mu}$. That is, $N_{\text{RF}}^{\text{size}, \mu}$ is a frequency-domain size of maximum bandwidth the UE 102 can support in number of resource blocks for a subcarrier spacing configuration μ . For different subcarrier spacing configurations, the number of resource blocks of the maximum bandwidth $N_{\text{RF}}^{\text{size}, \mu}$ is different. The number of resource blocks of the maximum bandwidth per subcarrier spacing configuration μ can be a predefined value in number of RBs. For convenience, $N_{\text{RF}}^{\text{size}}$ without the subscript μ can refer to a frequency-domain size of maximum bandwidth the UE 102 can support in number of resource blocks for the subcarrier spacing configuration of the initial UL BWP. For a UE 102 with reduced RF bandwidth, the maximum bandwidth the UE 102 can support may be 20MHz for FR1 and may be 100MHz for FR2.

[0293] Additionally or alternatively, the size $N_{\text{RF}}^{\text{size}}$ may be a configured number of resource blocks which is indicated independently of the initial UL BWP size $N_{\text{BWP}}^{\text{size}}$ by the base station 160. As above-mentioned, the base station 160 may transmit a RRC parameter *initialUplinkBWP* to indicate the size of the initial UL BWP $N_{\text{BWP}}^{\text{size}}$. The base station 160 may transmit another RRC parameter included in the system information (e.g. MIB, SIB1 or other SIBs) to indicate the size $N_{\text{RF}}^{\text{size}}$. Additionally or alternatively, another RRC parameter may indicate a set of sizes in number of resource blocks where each size corresponds to a specific subcarrier spacing configuration μ . The UE 102 and/or the base station 160 may determine a size corresponding to subcarrier spacing configuration of the initial UL BWP as a size of the maximum bandwidth the UE 102 can support, i.e. $N_{\text{RF}}^{\text{size}}$.

[0294] Therefore, in the example, for PUCCH resource with index r_{PUCCH} where $0 \leq r_{\text{PUCCH}} \leq 7$, the UE 102 may determine a PRB index of the PUCCH resource in the first hop as $RB_{\text{BWP}}^{\text{offset}} + \text{floor}(r_{\text{PUCCH}} / N_{\text{CS}})$ and may determine PRB index of the PUCCH resources in the second hop as $N_{\text{RF}}^{\text{size}} - 1 - RB_{\text{BWP}}^{\text{offset}} - \text{floor}(r_{\text{PUCCH}} / N_{\text{CS}})$. $RB_{\text{BWP}}^{\text{offset}}$ herein refers to the first PRB offset. For PUCCH resource with index r_{PUCCH} where $8 \leq r_{\text{PUCCH}} \leq 15$, the UE 102 may determine PRB index of the PUCCH resources in the first hop as $N_{\text{RF}}^{\text{size}} - 1 - RB_{\text{BWP}}^{\text{offset}} - \text{floor}((r_{\text{PUCCH}} - 8) / N_{\text{CS}})$ and may determine

PRB index of the PUCCH resources in the second hop as $RB_{BWP}^{offset} + \text{floor}((r_{PUCCH} - 8)/N_{CS})$. That is, the UE 102 may determine a PRB index of the PUCCH transmission in one hop at least based on the first PRB offset. On the other hand, the UE 102 may determine a PRB index of the PUCCH transmission in the other hop at least based on the first PRB offset and the N_{RF}^{size} . According to the determination of PRB indexes of the PUCCH transmission in the first and second hops, the UE 102 may not need to retune a first frequency region where the first hop is transmitted to a second frequency region where the second hop is transmitted. The first frequency region and the second frequency region herein are within a same BWP (e.g. the initial UL BWP). Both the PUCCH transmissions in the first and second hops can be confined within the maximum bandwidth the UE 102 can support. The frequency offset between the first hop and the second hop of the PUCCH transmission can be given at least based on the size of the maximum bandwidth the UE 102 can support.

[0295] In an example of the implementation, additional third RRC parameter related to PRB offset is introduced to determine the PRB indexes of the PUCCH transmission in the first hop and/or the second hop. The base station 160 may transmit the third RRC parameter included in the system information. The third RRC parameter is a cell specific RRC parameter and is related to a PRB offset. For example, the third RRC parameter may indicate a second PRB offset in number of resource blocks. The second PRB offset in number of resource blocks can be denoted as $RB_{BWP}^{offset2}$. If the base station 160 does not transmit the second RRC parameter in the system information to the UE 102, the UE 102 may determine a PUCCH resource set at least based on the first RRC parameter and the third RRC parameter.

[0296] The UE 102 may determine a PRB index of the PUCCH transmission in one hop at least based on a first PRB offset RB_{BWP}^{offset} which is provided by first RRC parameter (e.g. *pucch-ResourceCommon*) or the second RRC parameter (e.g. *pucch-ResourceCommon-additional*). On the other hand, the UE 102 may determine a PRB index of the PUCCH transmission in the other hop at least based on the first PRB offset RB_{BWP}^{offset} and the second PRB offset $RB_{BWP}^{offset2}$.

[0297] For example, for a PUCCH resource with index r_{PUCCH} where $0 \leq r_{PUCCH} \leq 7$, the UE 102 may determine PRB index of the PUCCH resource in the first hop as $RB_{BWP}^{offset} + \text{floor}(r_{PUCCH}/N_{CS})$ and may determine PRB index of the PUCCH resource in the second hop as $RB_{BWP}^{offset} + \text{floor}(r_{PUCCH}/N_{CS}) + RB_{BWP}^{offset2}$. For a PUCCH

resource with index r_{PUCCH} where $8 \leq r_{\text{PUCCH}} \leq 15$, the UE 102 may determine PRB index of the PUCCH resource in the first hop as $RB_{\text{BWP}}^{\text{offset}} + \text{floor}((r_{\text{PUCCH}} - 8) / N_{\text{CS}}) + RB_{\text{BWP}}^{\text{offset2}}$ and may determine PRB index of the PUCCH resource in the second hop as $RB_{\text{BWP}}^{\text{offset}} + \text{floor}((r_{\text{PUCCH}} - 8) / N_{\text{CS}})$. Additionally or alternatively, for a PUCCH resource with index r_{PUCCH} where $8 \leq r_{\text{PUCCH}} \leq 15$, the UE 102 may determine PRB index of the PUCCH resource in the first hop as $N_{\text{BWP}}^{\text{size}} - 1 - RB_{\text{BWP}}^{\text{offset}} - \text{floor}((r_{\text{PUCCH}} - 8) / N_{\text{CS}})$ and may determine PRB index of the PUCCH resource in the second hop as $N_{\text{BWP}}^{\text{size}} - 1 - RB_{\text{BWP}}^{\text{offset}} - \text{floor}((r_{\text{PUCCH}} - 8) / N_{\text{CS}}) - RB_{\text{BWP}}^{\text{offset2}}$. That is, the UE 102 may determine a PRB index of the PUCCH transmission in one hop at least based on the first PRB offset. On the other hand, the UE 102 may determine a PRB index of the PUCCH transmission in the other hop at least based on the first PRB offset and the second PRB offset. According to the configuration of $RB_{\text{BWP}}^{\text{offset2}}$, the UE 102 may not need to retune a frequency region where the first hop is transmitted to another frequency region where the second hop is transmitted. Both the PUCCH transmissions in the first and second hops can be confined within the maximum bandwidth the UE 102 can support.

[0298] In an example of the implementation, additional fourth RRC parameter related to PRB offset is introduced to determine the PRB indexes of the PUCCH transmission in the first hop and/or the second hop. The base station 160 may transmit the fourth RRC parameter included in the system information. The fourth RRC parameter are a cell specific RRC parameter and is related to PRB offset. The fourth RRC parameter contains two entries where each entry indicates a PRB offset in number of resource blocks. The PRB offset indicated by the first entry in the fourth RRC parameter can be denoted as $RB_{\text{BWP}}^{\text{offset3}}$, and the PRB offset indicated by the second entry in the fourth RRC parameter can be denoted as $RB_{\text{BWP}}^{\text{offset4}}$. The PRB offset $RB_{\text{BWP}}^{\text{offset3}}$ may be used for determining PRB index of PUCCH transmission in a PUCCH resource with index r_{PUCCH} where $0 \leq r_{\text{PUCCH}} \leq 7$. On the other hand, the PRB offset $RB_{\text{BWP}}^{\text{offset4}}$ may be used for determining PRB index of PUCCH transmission in a PUCCH resource with index r_{PUCCH} where $8 \leq r_{\text{PUCCH}} \leq 15$. Additionally or alternatively, the $RB_{\text{BWP}}^{\text{offset3}}$ is used to determine the PRB indexes of PUCCH transmission in a first hop of a PUCCH resource with index r_{PUCCH} where $0 \leq r_{\text{PUCCH}} \leq 7$ and is used to determine the PRB indexes of PUCCH transmission in a second hop of a PUCCH resource with index r_{PUCCH} where $8 \leq r_{\text{PUCCH}} \leq 15$. On the other hand, the

$RB_{BWP}^{offset4}$ is used to determine the PRB indexes of PUCCH transmission in a second hop of a PUCCH resource with index r_{PUCCH} where $0 \leq r_{PUCCH} \leq 7$ and is used to determine the PRB indexes of PUCCH transmission in a first hop of a PUCCH resource with index r_{PUCCH} where $8 \leq r_{PUCCH} \leq 15$. The UE 102 may not apply the first PRB offset for determining the PRB index of PUCCH transmission in the first hop and/or the second hop. For example, for a PUCCH resource with index r_{PUCCH} where $0 \leq r_{PUCCH} \leq 7$, the UE 102 may determine PRB index of the PUCCH resource in the first hop as $RB_{BWP}^{offset3} + \text{floor}(r_{PUCCH}/N_{CS})$ and may determine PRB index of the PUCCH resource in the second hop as $RB_{BWP}^{offset4} + \text{floor}(r_{PUCCH}/N_{CS})$ (or $N_{BWP}^{size} - 1 - RB_{BWP}^{offset4} - \text{floor}(r_{PUCCH}/N_{CS})$). For a PUCCH resource with index r_{PUCCH} where $8 \leq r_{PUCCH} \leq 15$, the UE 102 may determine PRB index of the PUCCH resources in the first hop as $RB_{BWP}^{offset4} + \text{floor}((r_{PUCCH} - 8)/N_{CS})$ (or $N_{BWP}^{size} - 1 - RB_{BWP}^{offset4} - \text{floor}((r_{PUCCH} - 8)/N_{CS})$) and may determine PRB index of the PUCCH resources in the second hop as $RB_{BWP}^{offset3} + \text{floor}((r_{PUCCH} - 8)/N_{CS})$.

[0299] In an example of the implementation, additional fifth RRC parameter related to PRB offset is introduced to determine the PRB indexes of the PUCCH transmission in the first hop and/or the second hop. The base station 160 may transmit the fifth RRC parameter included in the system information. The fifth RRC parameter is a cell specific RRC parameter and is related to PRB offset. For example, the fifth RRC parameter may indicate a second PRB offset in number of resource blocks. The second PRB offset in number of resource blocks can be denoted as $RB_{BWP}^{offset5}$.

[0300] The UE 102 may determine a PRB index of the PUCCH transmission in the first and/or second hop at least based on the PRB offset $RB_{BWP}^{offset5}$ other than the PRB offset RB_{BWP}^{offset} provided by the first RRC parameter (e.g. *pucch-ResourceCommon*) or the second RRC parameter (e.g. *pucch-ResourceCommon-additional*). In other words, the UE102 may not use the PRB offset RB_{BWP}^{offset} to determine PRB index of the PUCCH transmission. To be specific, the UE 102 may determine a PRB index of the PUCCH transmission in one hop at least based on the PRB offset $RB_{BWP}^{offset5}$ and may determine a PRB index of the PUCCH transmission in the other hop at least based on the PRB offset $RB_{BWP}^{offset5}$ and the size of the initial UL BWP.

[0301] For example, for a PUCCH resource with index r_{PUCCH} where $0 \leq r_{PUCCH} \leq 7$, the UE 102 may determine PRB index of the PUCCH resource in the first hop as $RB_{BWP}^{offset5} + \text{floor}(r_{PUCCH}/N_{CS})$ and may determine PRB index of the PUCCH resource

in the second hop as $N_{\text{BWP}}^{\text{size}} - 1 - RB_{\text{BWP}}^{\text{offset5}} - \text{floor}(r_{\text{PUCCH}}/N_{\text{CS}})$. For a PUCCH resource with index r_{PUCCH} where $8 \leq r_{\text{PUCCH}} \leq 15$, the UE 102 may determine PRB index of the PUCCH resources in the first hop as $N_{\text{BWP}}^{\text{size}} - 1 - RB_{\text{BWP}}^{\text{offset5}} - \text{floor}((r_{\text{PUCCH}} - 8)/N_{\text{CS}})$ and may determine PRB index of the PUCCH resources in the second hop as $RB_{\text{BWP}}^{\text{offset5}} + \text{floor}((r_{\text{PUCCH}} - 8)/N_{\text{CS}})$. The UE 102 may not apply the first PRB offset for determining the PRB index of PUCCH transmission in the first hop and/or the second hop. Additionally or alternatively, the $N_{\text{BWP}}^{\text{size}}$ in above PRB index determination may be replaced by $N_{\text{RF}}^{\text{size}}$. According to the configuration of $RB_{\text{BWP}}^{\text{offset5}}$, the UE 102 may not need to retune a frequency region where the first hop is transmitted to another frequency region where the second hop is transmitted. Both the PUCCH transmissions in the first and second hops can be confined within the maximum bandwidth the UE 102 can support.

[0302] In an example of the implementation, frequency retuning for the UE 102 may be necessary. In a case that the frequency offset between the first hop and the second hop for PUCCH transmission exceeds the maximum bandwidth the UE 102 can support, the UE may, in the initial UL BWP, retune from one frequency region where the first hop is transmitted to another frequency region where the second hop is transmitted. These two frequency regions are within a same BWP, for example, within the initial UL BWP. In other words, the UE 102 may retune from the first hop to second hop within a slot. This kind of frequency retuning can be also referred to as Tx-to-Tx frequency retuning.

[0303] Frequency retuning time between two frequency regions is needed. The UE 102 may need to determine which symbol(s) among the PUCCH resource duration to be used for the frequency retuning time. The PUCCH resource duration (i.e. a number of symbols configured for each PUCCH resource in a PUCCH resource set) is provided by the first RRC parameter (e.g. *pucch-ResourceCommon*) or the second RRC parameter (e.g. *pucch-ResourceCommon-additional*), which can be denoted as $N_{\text{symp}}^{\text{PUCCH}}$. The number of symbols in the first hop is given by $\text{floor}(N_{\text{symp}}^{\text{PUCCH}}/2)$. While the number of symbols in the second hop is given by $\text{ceiling}(N_{\text{symp}}^{\text{PUCCH}}/2)$.

[0304] The frequency retuning time can be predefined in OFDM symbols per subcarrier spacing configuration μ . Hereinafter, notation $T_{\text{switching}}$ represents the frequency returning time in OFDM symbols for the subcarrier spacing configuration μ of the initial UL BWP. The UE 102 may determine the last $\text{floor}(T_{\text{switching}}/2)$ symbol(s)

of the first hop and the first ceiling($T_{\text{switching}} / 2$)symbol(s) of the second hop as the frequency retuning time. That is, the last floor($T_{\text{switching}} / 2$) symbol(s) of the first hop and the first ceiling($T_{\text{switching}} / 2$)symbol(s) of the second hop are used for frequency retuning time. In other words, the UE 102 may not transmit the PUCCH and/or associated DMRS in the last floor($T_{\text{switching}} / 2$) symbol(s) of the first hop and the first ceiling($T_{\text{switching}} / 2$)symbol(s) of the second hop.

[0305] Additionally or alternatively, the UE 102 may always determine the last $T_{\text{switching}}$ symbol(s) of the first hop as the frequency retuning time. The UE 102 may not transmit the PUCCH and/or associated DMRS in the last $T_{\text{switching}}$ symbol(s) of the first hop. The UE 102 may transmit the PUCCH and/or associated DMRS in the first floor($N_{\text{symb}}^{\text{PUCCH}} / 2$) - $T_{\text{switching}}$ symbol(s) of the first hop and in the symbols of the second hop.

[0306] Additionally or alternatively, the UE 102 may always determine the first $T_{\text{switching}}$ symbol(s) of the second hop as the frequency retuning time. The UE 102 may not transmit the PUCCH and/or associated DMRS in the first $T_{\text{switching}}$ symbol(s) of the second hop. The UE 102 may transmit the PUCCH and/or associated DMRS in the symbols of the first hop and the last ceiling($N_{\text{symb}}^{\text{PUCCH}} / 2$) - $T_{\text{switching}}$ symbol(s) of the second hop.

[0307] As above-mentioned, complex-valued symbol(s) and associated DMRS symbol(s) are alternately mapped to the symbols of the PUCCH resource with the PUCCH format 1. In the present disclosure, a hop of PUCCH transmission may consist of an actual PUCCH transmission duration within the hop and zero, one or multiple symbols used for frequency retuning time. In a case that a hop of PUCCH transmission with PUCCH format 1 consists of an actual PUCCH transmission duration within the hop and at least one symbol used for frequency retuning time, associated DMRS(s) for PUCCH format 1 are mapped to symbols with even indexes of the actual PUCCH transmission duration within the hop of the PUCCH transmission, e.g. symbols with indexes 0, 2, 4, etc. The complex-valued symbol(s) are mapped to symbols with odd indexes of the actual PUCCH transmission duration within the hop of the PUCCH transmission, e.g. symbols with indexes 1, 3, 5, etc. If one hop of PUCCH transmission does not consist of any symbol(s) used for frequency retuning time, the actual PUCCH transmission duration within the hop is equivalent to the hop. Additionally or alternatively, even in a case that a hop of PUCCH transmission with PUCCH format 1

consists of an actual PUCCH transmission duration within the hop and at least one symbol used for frequency retuning time, associated DMRS(s) for PUCCH format 1 are mapped to symbols with even indexes of the hop of the PUCCH transmission, e.g. symbols with indexes 0, 2, 4, etc. The complex-valued symbol(s) are mapped to symbols with odd indexes of the hop of the PUCCH transmission, e.g. symbols with indexes 1, 3, 5, etc. The complex-valued symbol(s) and/or associated DMRS symbol(s) may be also mapped to symbol(s), which are used for frequency retuning time, within a hop. However, the UE 102 may not transmit the symbol(s).

[0308] In an example of the implementation, the base station 160 may not transmit the second RRC parameter in the system information to the UE 102. The base station 160 may instead transmit a third RRC parameter to the UE 102. The third RRC parameter is related to a PRB offset. The UE 102 may determine a PUCCH resource set at least based on the first RRC parameter and the third RRC parameter. The UE 102 may not apply the PRB offset provided in the row of table 00 indicated by the first RRC parameter. The UE 102 may apply the third RRC parameter to determine the PRB index of the PUCCH transmission. Figure 16 illustrates various components that may be utilized in a UE 1602. The UE 1602 (UE 102) described in connection with Figure 16 may be implemented in accordance with the UE 102 described in connection with Figure 1. The UE 1602 includes a processor 1681 that controls operation of the UE 1602. The processor 1681 may also be referred to as a central processing unit (CPU). Memory 1687, which may include read-only memory (ROM), random access memory (RAM), a combination of the two or any type of device that may store information, provides instructions 1683a and data 1685a to the processor 1681. A portion of the memory 1687 may also include non-volatile random access memory (NVRAM). Instructions 1683b and data 1685b may also reside in the processor 1681. Instructions 1683b and/or data 1685b loaded into the processor 1681 may also include instructions 1683a and/or data 1685a from memory 1687 that were loaded for execution or processing by the processor 1681. The instructions 1683b may be executed by the processor 1681 to implement one or more of the methods 200 described above.

[0309] The UE 1602 may also include a housing that contains one or more transmitters 1658 and one or more receivers 1620 to allow transmission and reception of data. The transmitter(s) 1658 and receiver(s) 1620 may be combined into one or more

transceivers 1618. One or more antennas 1622a–n are attached to the housing and electrically coupled to the transceiver 1618.

[0310] The various components of the UE 1602 are coupled together by a bus system 1689, which may include a power bus, a control signal bus and a status signal bus, in addition to a data bus. However, for the sake of clarity, the various buses are illustrated in Figure 16 as the bus system 1689. The UE 1602 may also include a digital signal processor (DSP) 1691 for use in processing signals. The UE 1602 may also include a communications interface 1693 that provides user access to the functions of the UE 1602. The UE 1602 illustrated in Figure 16 is a functional block diagram rather than a listing of specific components.

[0311] Figure 17 illustrates various components that may be utilized in a base station 1760. The base station 1760 described in connection with Figure 17 may be implemented in accordance with the base station 160 described in connection with Figure 1. The base station 1760 includes a processor 1781 that controls operation of the base station 1760. The processor 1781 may also be referred to as a central processing unit (CPU). Memory 1787, which may include read-only memory (ROM), random access memory (RAM), a combination of the two or any type of device that may store information, provides instructions 1783a and data 1785a to the processor 1781. A portion of the memory 1787 may also include non-volatile random access memory (NVRAM). Instructions 1783b and data 1785b may also reside in the processor 1781. Instructions 1783b and/or data 1785b loaded into the processor 1781 may also include instructions 1783a and/or data 1785a from memory 1787 that were loaded for execution or processing by the processor 1781. The instructions 1783b may be executed by the processor 1781 to implement one or more of the methods 300 described above.

[0312] The base station 1760 may also include a housing that contains one or more transmitters 1717 and one or more receivers 1778 to allow transmission and reception of data. The transmitter(s) 1717 and receiver(s) 1778 may be combined into one or more transceivers 1776. One or more antennas 1780a–n are attached to the housing and electrically coupled to the transceiver 1776.

[0313] The various components of the base station 1760 are coupled together by a bus system 1789, which may include a power bus, a control signal bus and a status signal bus, in addition to a data bus. However, for the sake of clarity, the various buses are illustrated in Figure 17 as the bus system 1789. The base station 1760 may also

include a digital signal processor (DSP) 1791 for use in processing signals. The base station 1760 may also include a communications interface 1793 that provides user access to the functions of the base station 1760. The base station 1760 illustrated in Figure 17 is a functional block diagram rather than a listing of specific components.

[0314] The term “computer-readable medium” refers to any available medium that can be accessed by a computer or a processor. The term “computer-readable medium,” as used herein, may denote a computer- and/or processor-readable medium that is non-transitory and tangible. By way of example, and not limitation, a computer-readable or processor-readable medium may comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer or processor. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray® disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers.

[0315] It should be noted that one or more of the methods described herein may be implemented in and/or performed using hardware. For example, one or more of the methods described herein may be implemented in and/or realized using circuitry, a chipset, an application-specific integrated circuit (ASIC), a large-scale integrated circuit (LSI) or integrated circuit, etc.

[0316] Each of the methods disclosed herein comprises one or more steps or actions for achieving the described method. The method steps and/or actions may be interchanged with one another and/or combined into a single step without departing from the scope of the claims. In other words, unless a specific order of steps or actions is required for proper operation of the method that is being described, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims.

[0317] It is to be understood that the claims are not limited to the precise configuration and components illustrated above. Various modifications, changes and variations may be made in the arrangement, operation and details of the systems, methods and apparatus described herein without departing from the scope of the claims.

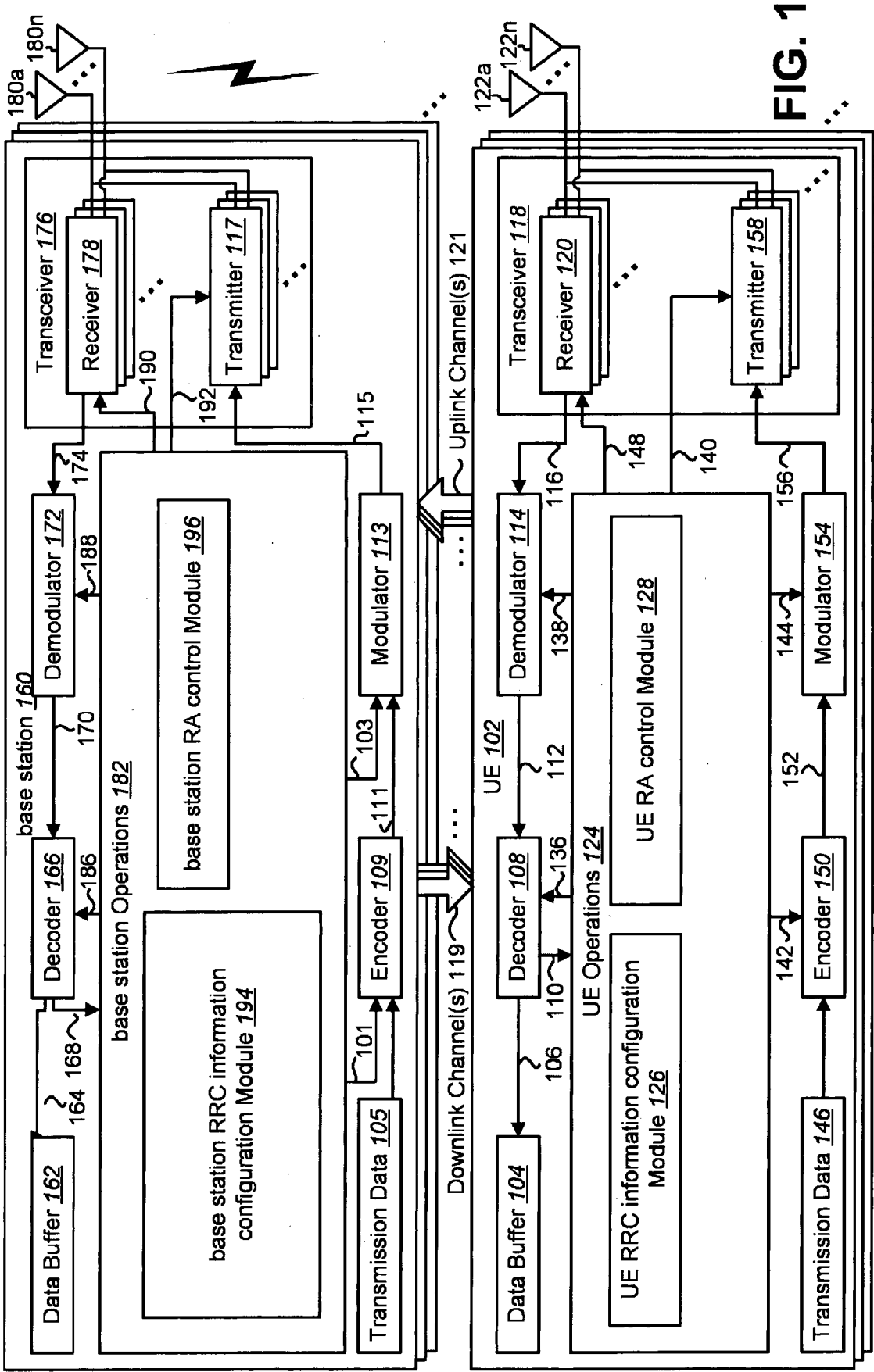
[CLAIMS]

1. A user equipment (UE), comprising:
reception circuitry configured to receive, from a base station, a random access response (RAR), wherein the RAR contains a RAR uplink (UL) grant scheduling a PUSCH transmission; and
control circuitry configured to determine, for the PUSCH transmission, a frequency hopping mode from two frequency hopping modes, intra-slot frequency hopping and inter-slot frequency hopping, wherein
in a first case that the PUSCH transmission is scheduled with repetitions across multi-slots, the inter-slot frequency hopping is determined for the PUSCH transmission,
in a second case that the PUSCH transmission is scheduled without repetition, the intra-slot frequency hopping is determined for the PUSCH transmission.
2. The UE of claim 1, wherein
in the first case, a frequency hopping flag field included in the RAR UL grant is used to indicate whether the determined inter-slot frequency hopping is enabled or disable for the PUSCH transmission,
in the second case, the frequency hopping flag field is used to indicate whether the determined intra-slot frequency hopping is enabled or disable for the PUSCH transmission.
3. A base station, comprising:
transmission circuitry configured to transmit, to a user equipment (UE), a random access response (RAR), wherein the RAR contains a RAR uplink (UL) grant scheduling a PUSCH transmission; and
control circuitry configured to determine, for the PUSCH transmission, a frequency hopping mode from two frequency hopping modes, intra-slot frequency hopping and inter-slot frequency hopping, wherein

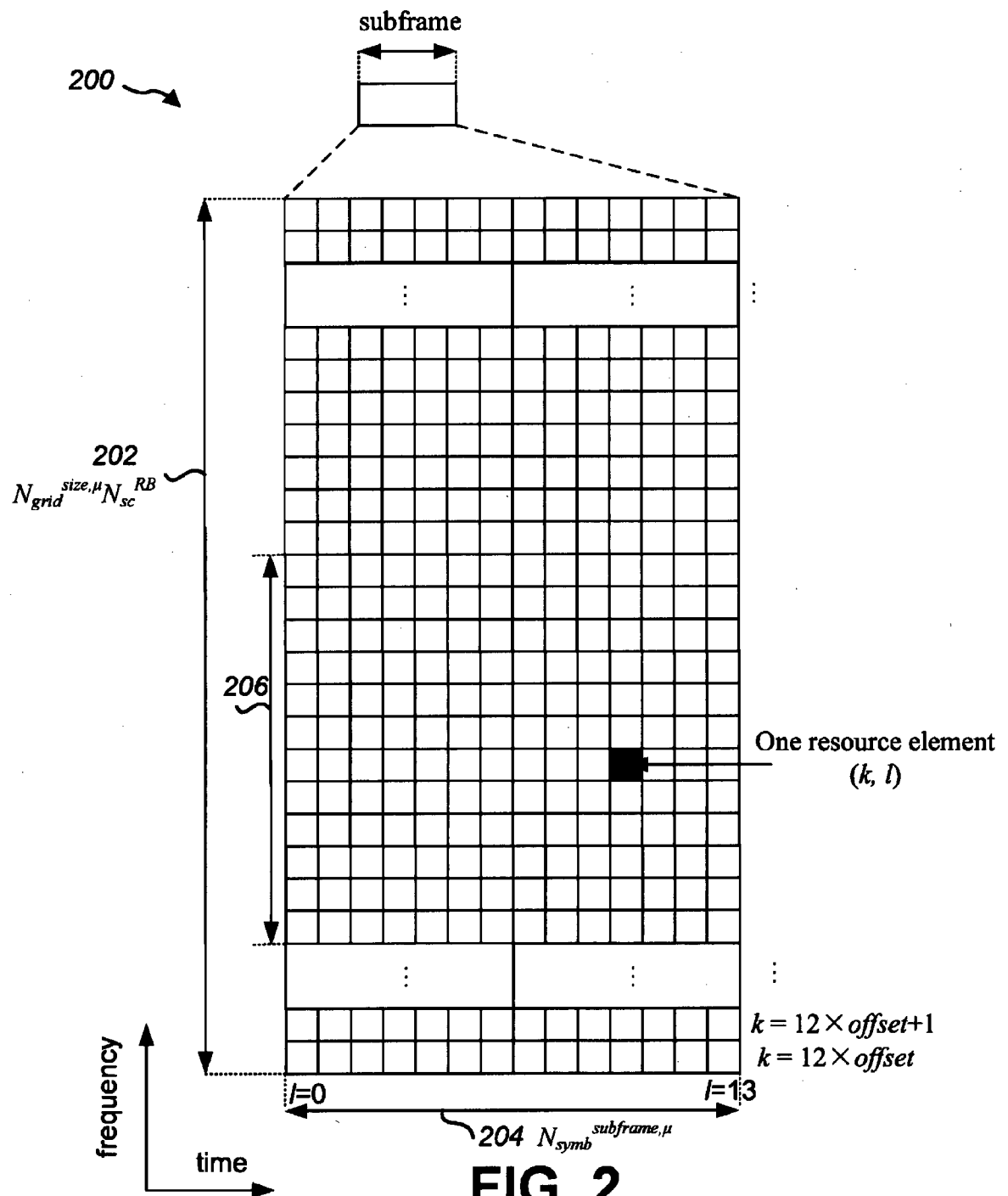
in a first case that the PUSCH transmission is scheduled with repetitions across multi-slots, the inter-slot frequency hopping is determined for the PUSCH transmission,

in a second case that the PUSCH transmission is scheduled without repetition, the intra-slot frequency hopping is determined for the PUSCH transmission.

4. The base station of claim 3, wherein
in the first case, a frequency hopping flag field included in the RAR UL grant is used to indicate whether the determined inter-slot frequency hopping is enabled or disabled for the PUSCH transmission,
in the second case, the frequency hopping flag field is used to indicate whether the determined intra-slot frequency hopping is enabled or disabled for the PUSCH transmission.
5. A method performed by user equipment (UE), comprising:
receiving, from a base station, a random access response (RAR), wherein the RAR contains a RAR uplink (UL) grant scheduling a PUSCH transmission; and
determining, for the PUSCH transmission, a frequency hopping mode from two frequency hopping modes, intra-slot frequency hopping and inter-slot frequency hopping, wherein
in a first case that the PUSCH transmission is scheduled with repetitions across multi-slots, the inter-slot frequency hopping is determined for the PUSCH transmission,
in a second case that the PUSCH transmission is scheduled without repetition, the intra-slot frequency hopping is determined for the PUSCH transmission.



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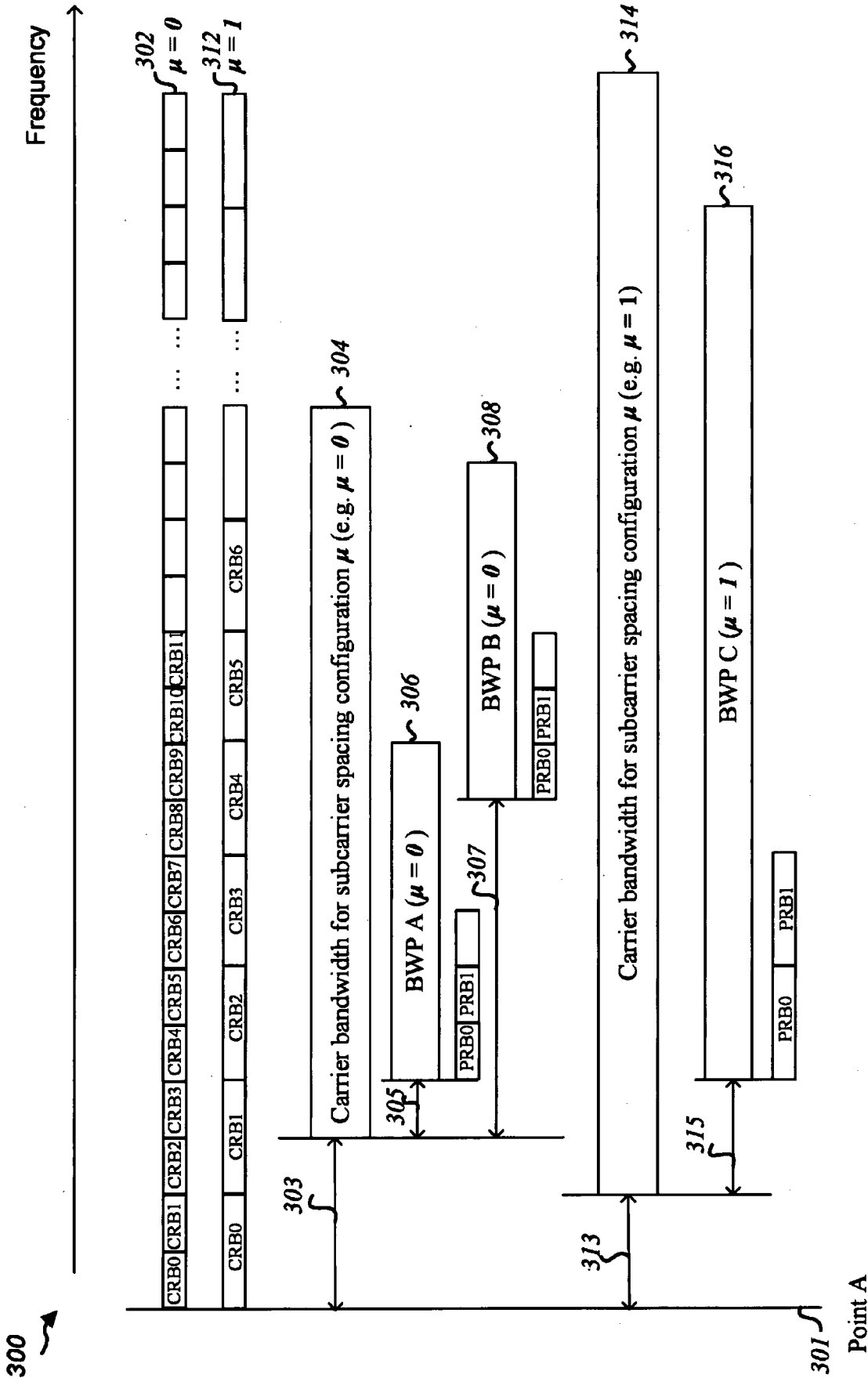


FIG. 3

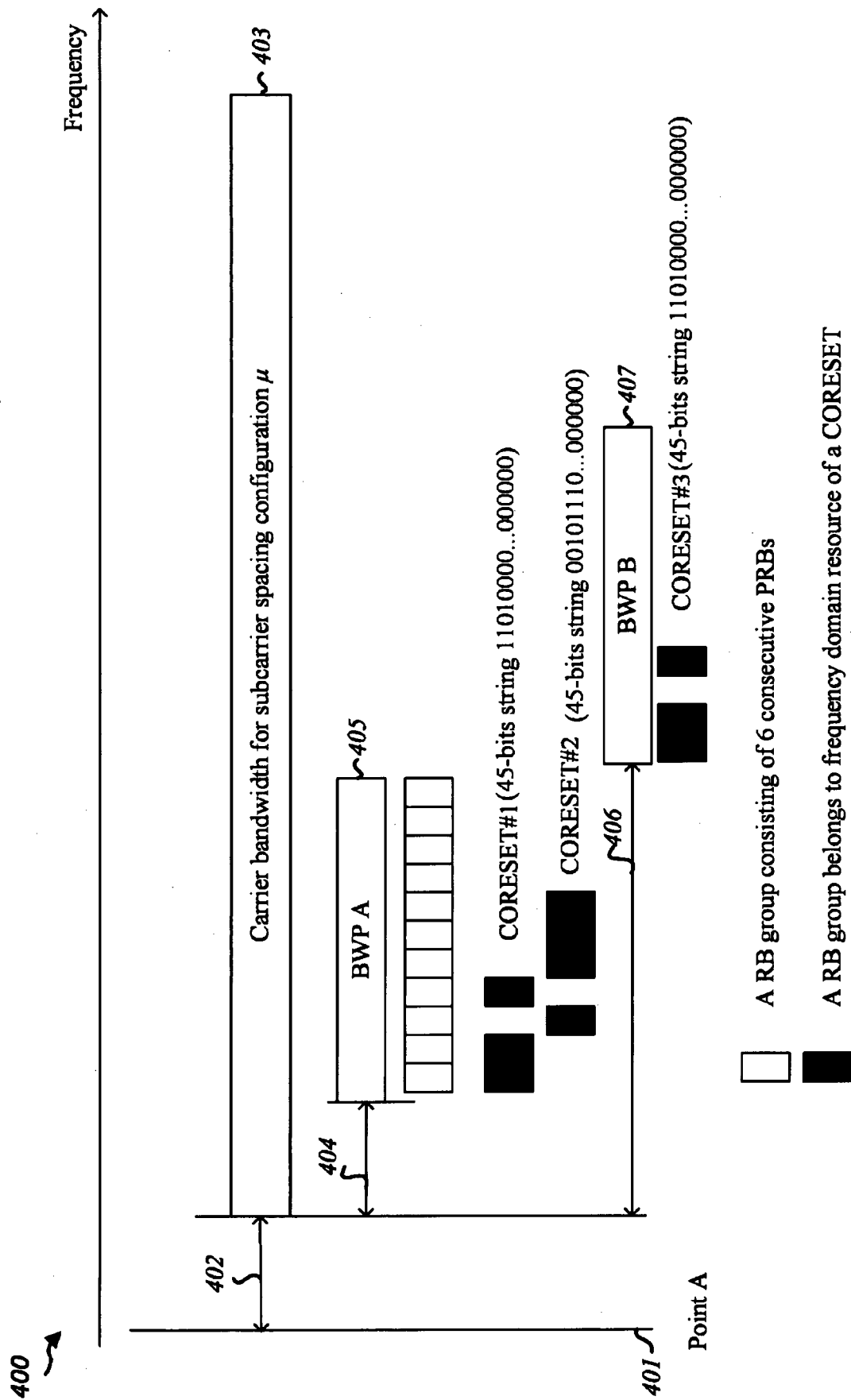


FIG. 4

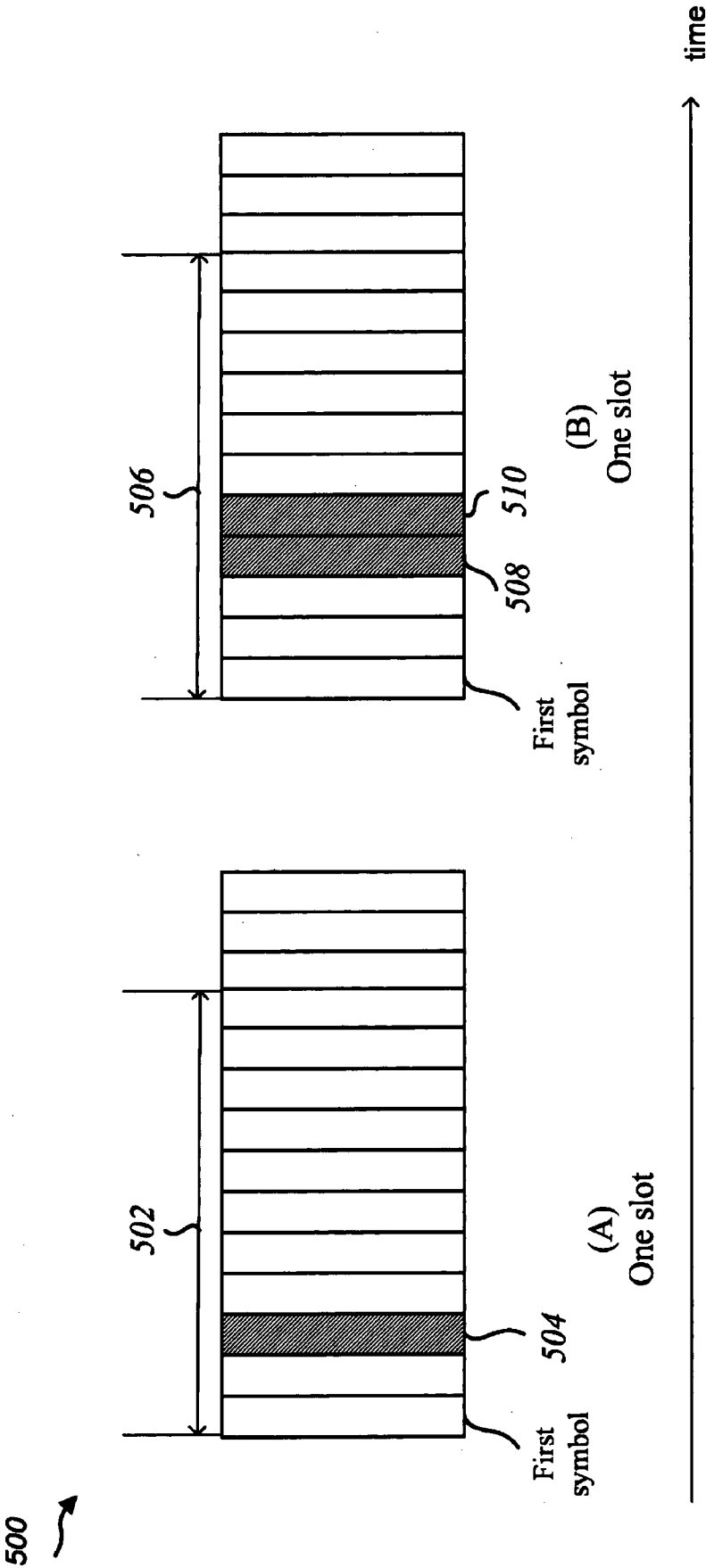


FIG. 5

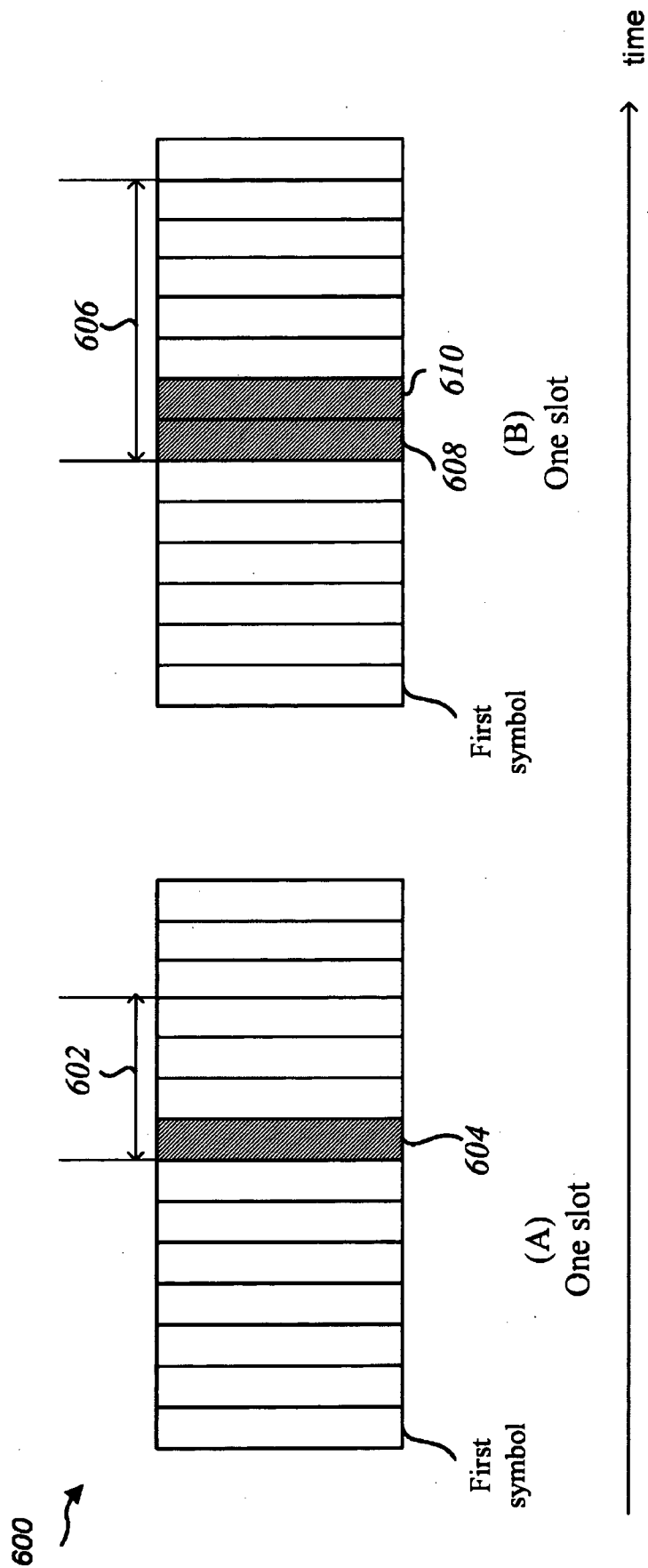


FIG. 6

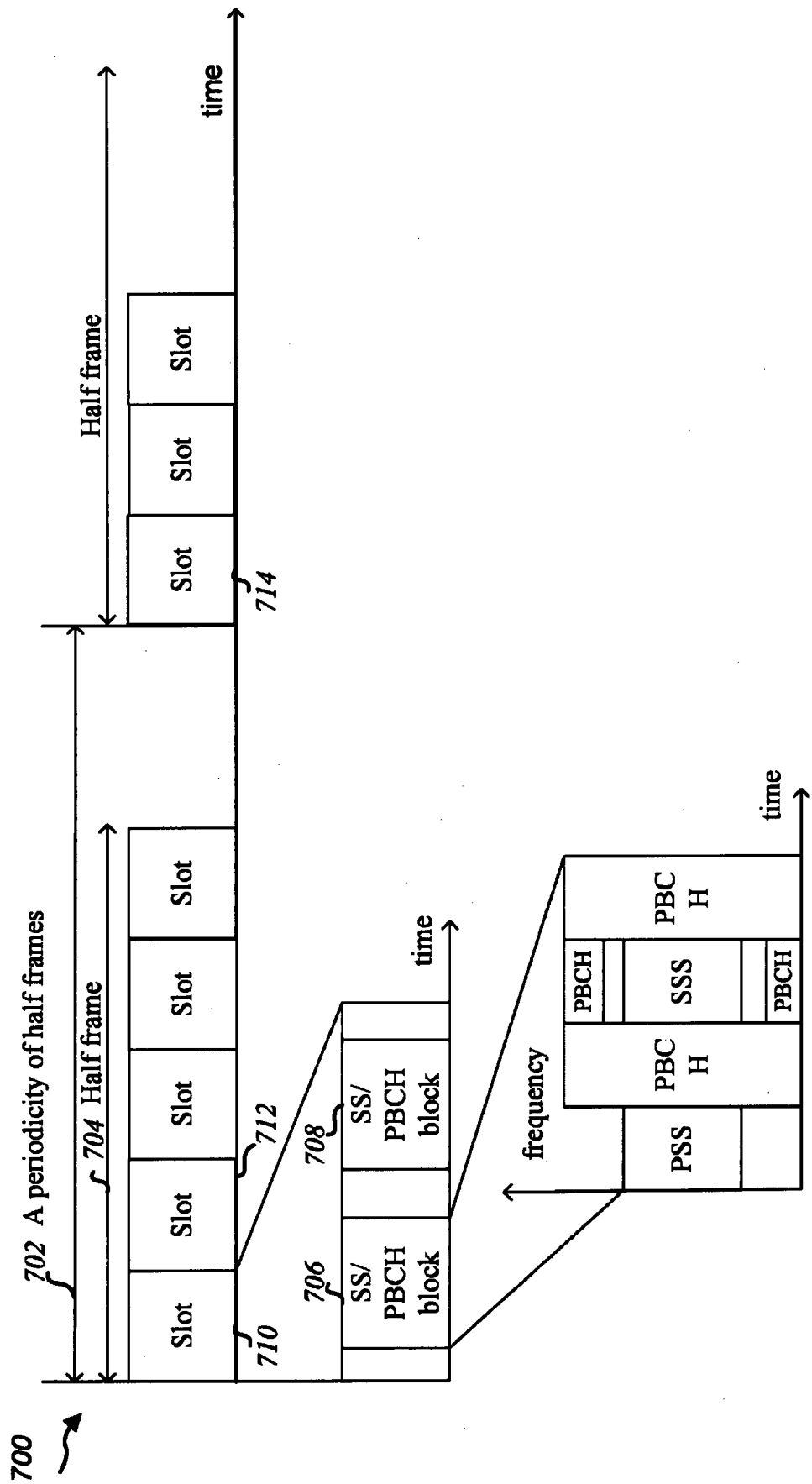


FIG. 7

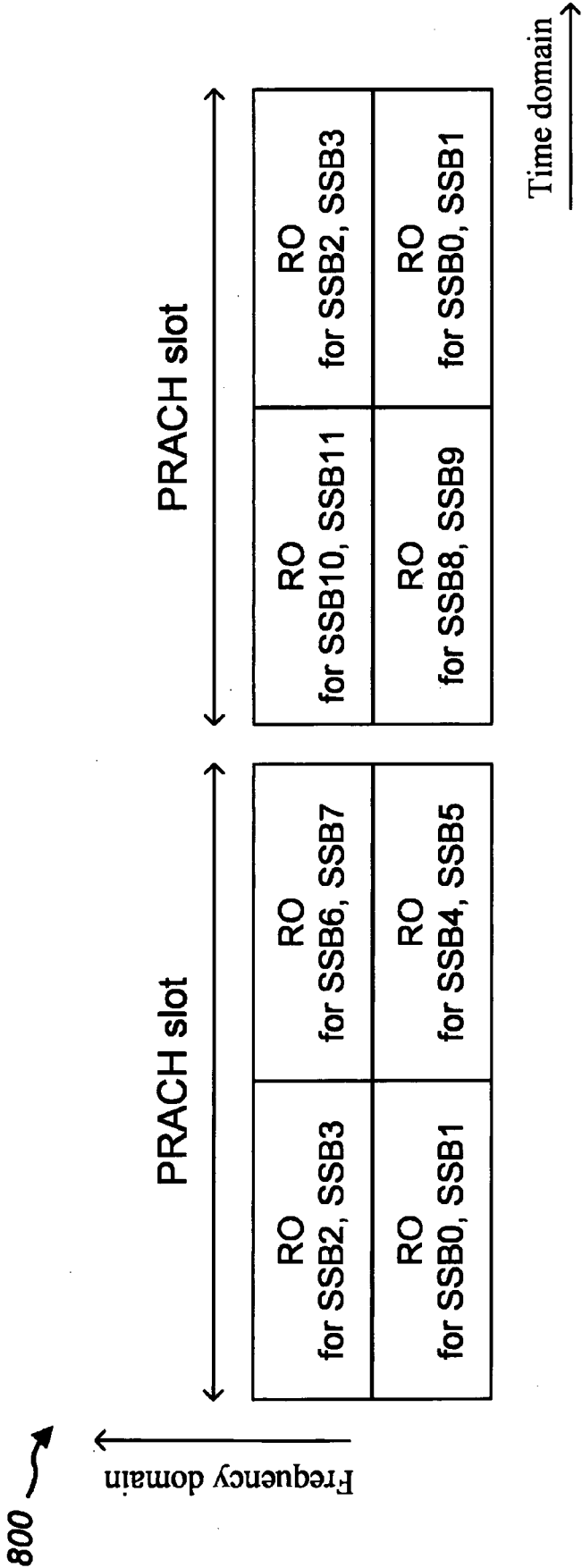
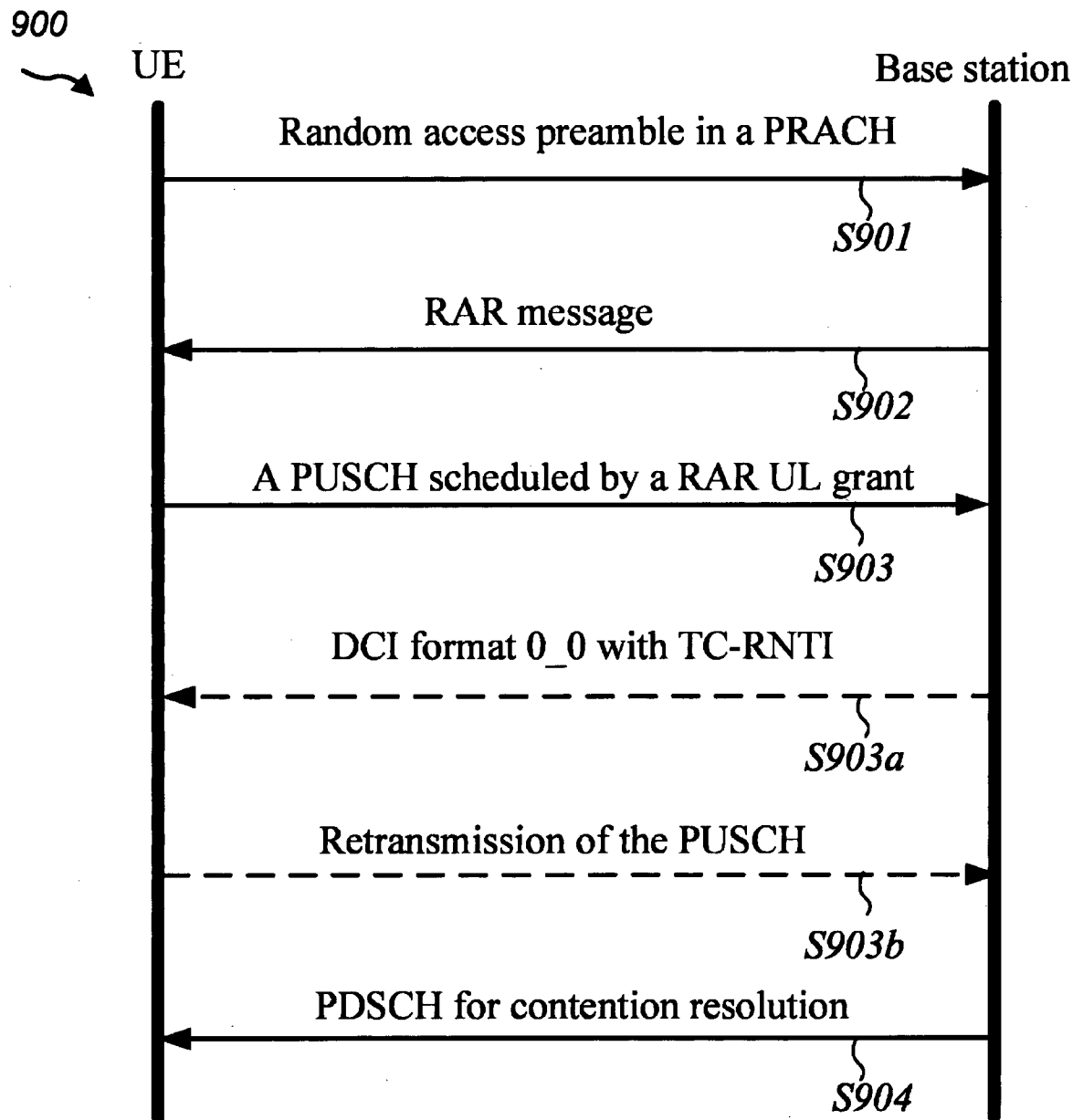


FIG. 8

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**FIG. 9**

100
0
↘

Random Access Response Grant Content field size

RAR grant field	Number of bits
Frequency hopping flag	1
PUSCH frequency resource allocation	14
PUSCH time domain allocation	4
MCS	4
TPC command for PUSCH	3
CSI request	1

FIG. 10

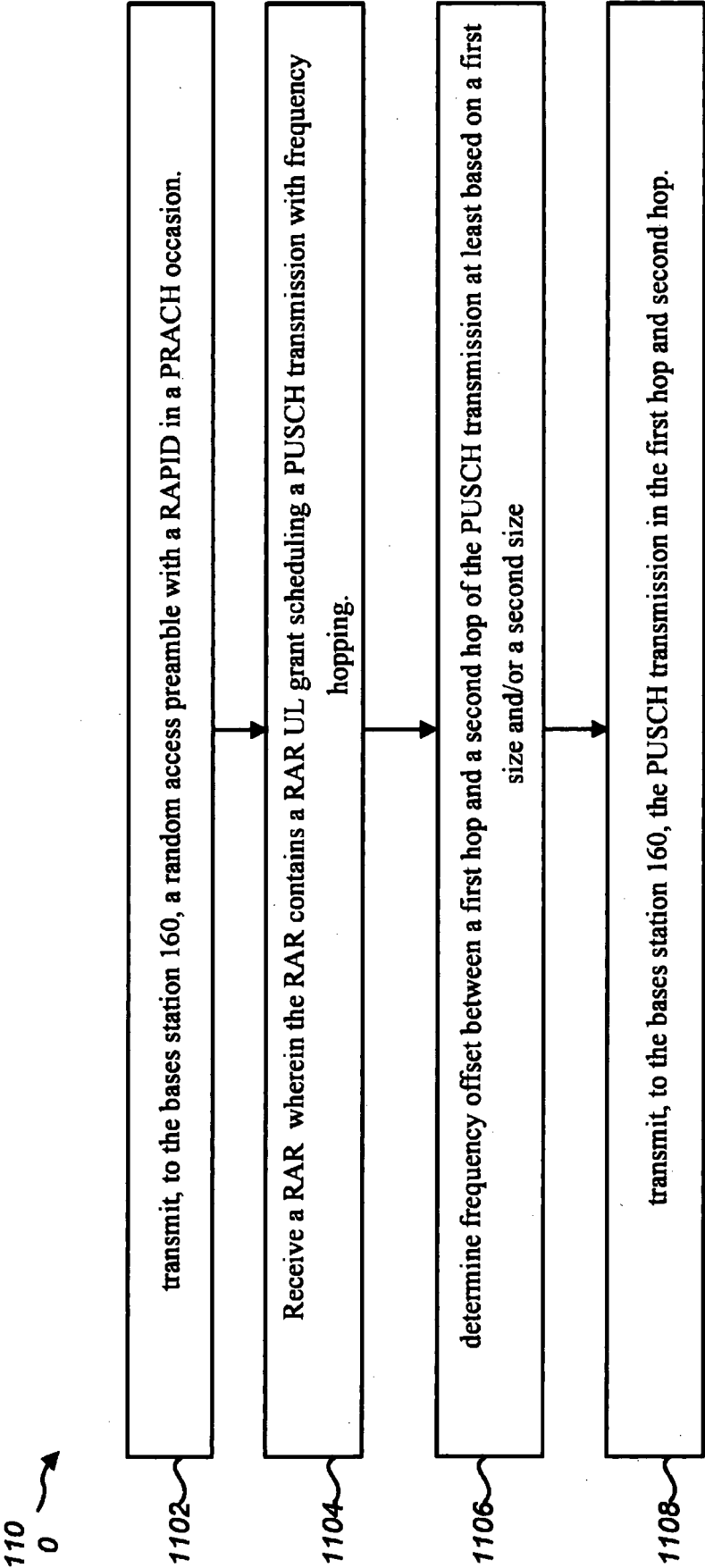
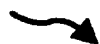


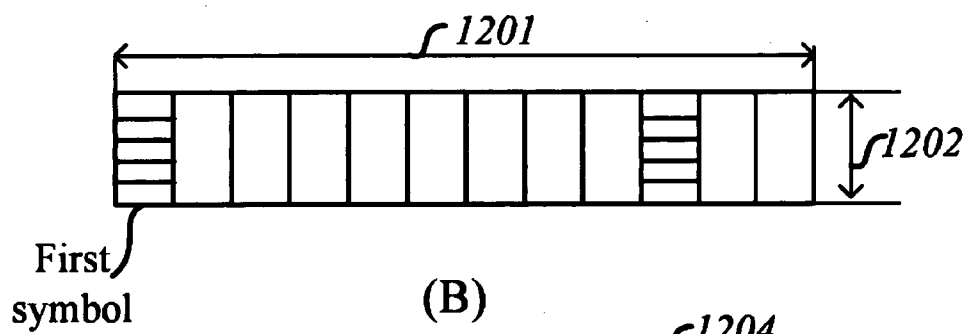
FIG. 11

12/17

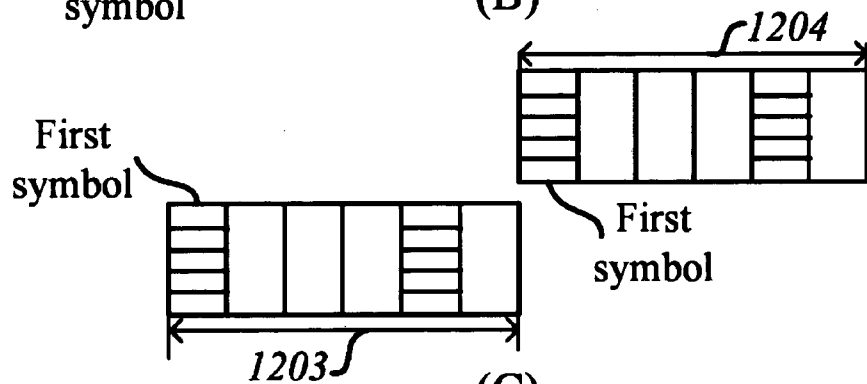
1200



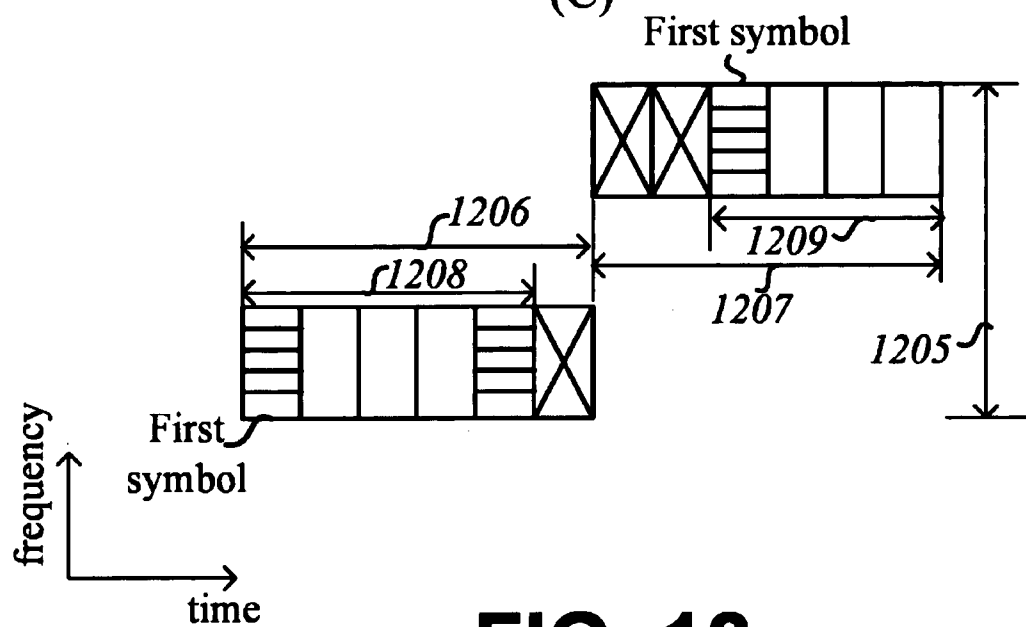
(A)



(B)



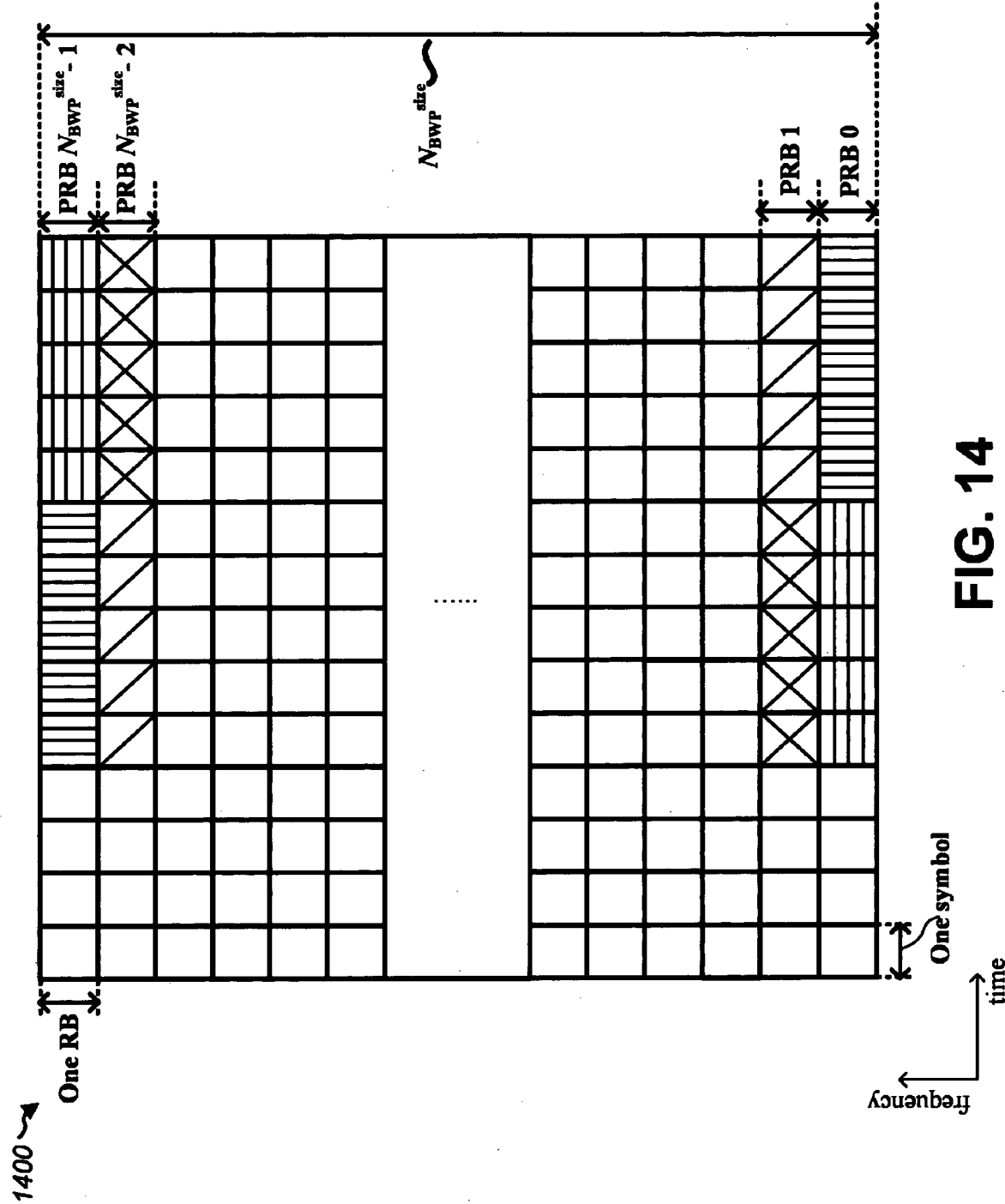
(C)

**FIG. 12**

130
0

Index	PUCCH format	First symbol	Number of symbols	PRB offset RB_{BWP}^{offset}	Set of initial CS indexes
0	0	12	2	0	{0, 3}
1	0	12	2	0	{0, 4, 8}
2	0	12	2	3	{0, 4, 8}
3	1	10	4	0	{0, 6}
4	1	10	4	0	{0, 3, 6, 9}
5	1	10	4	2	{0, 3, 6, 9}
6	1	10	4	4	{0, 3, 6, 9}
7	1	4	10	0	{0, 6}
8	1	4	10	0	{0, 3, 6, 9}
9	1	4	10	2	{0, 3, 6, 9}
10	1	4	10	4	{0, 3, 6, 9}
11	1	0	14	0	{0, 6}
12	1	0	14	0	{0, 3, 6, 9}
13	1	0	14	2	{0, 3, 6, 9}
14	1	0	14	4	{0, 3, 6, 9}
15	1	0	14	$\lfloor N_{BWP}^{size}/4 \rfloor$	{0, 3, 6, 9}

FIG. 13



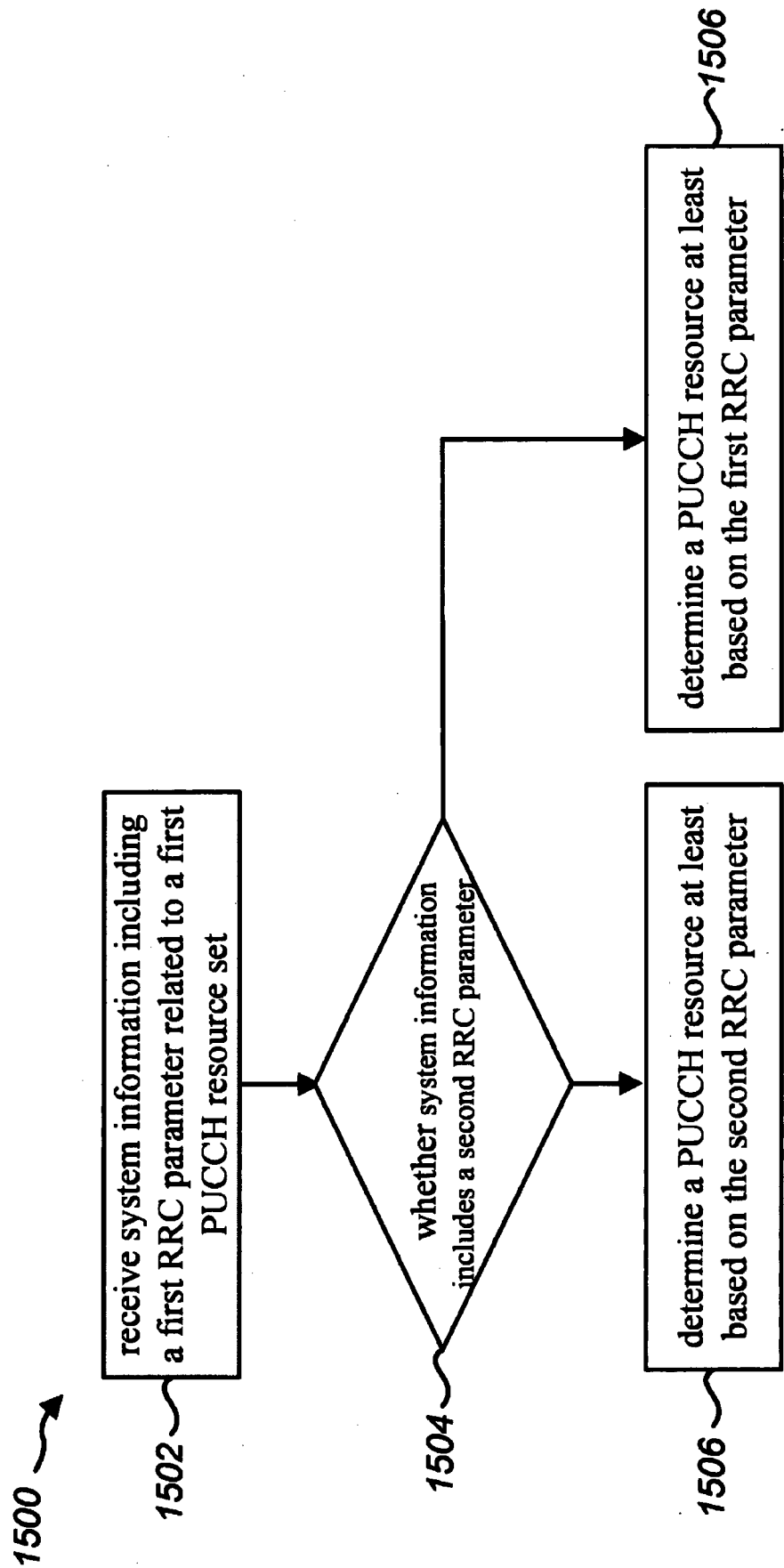


FIG. 15

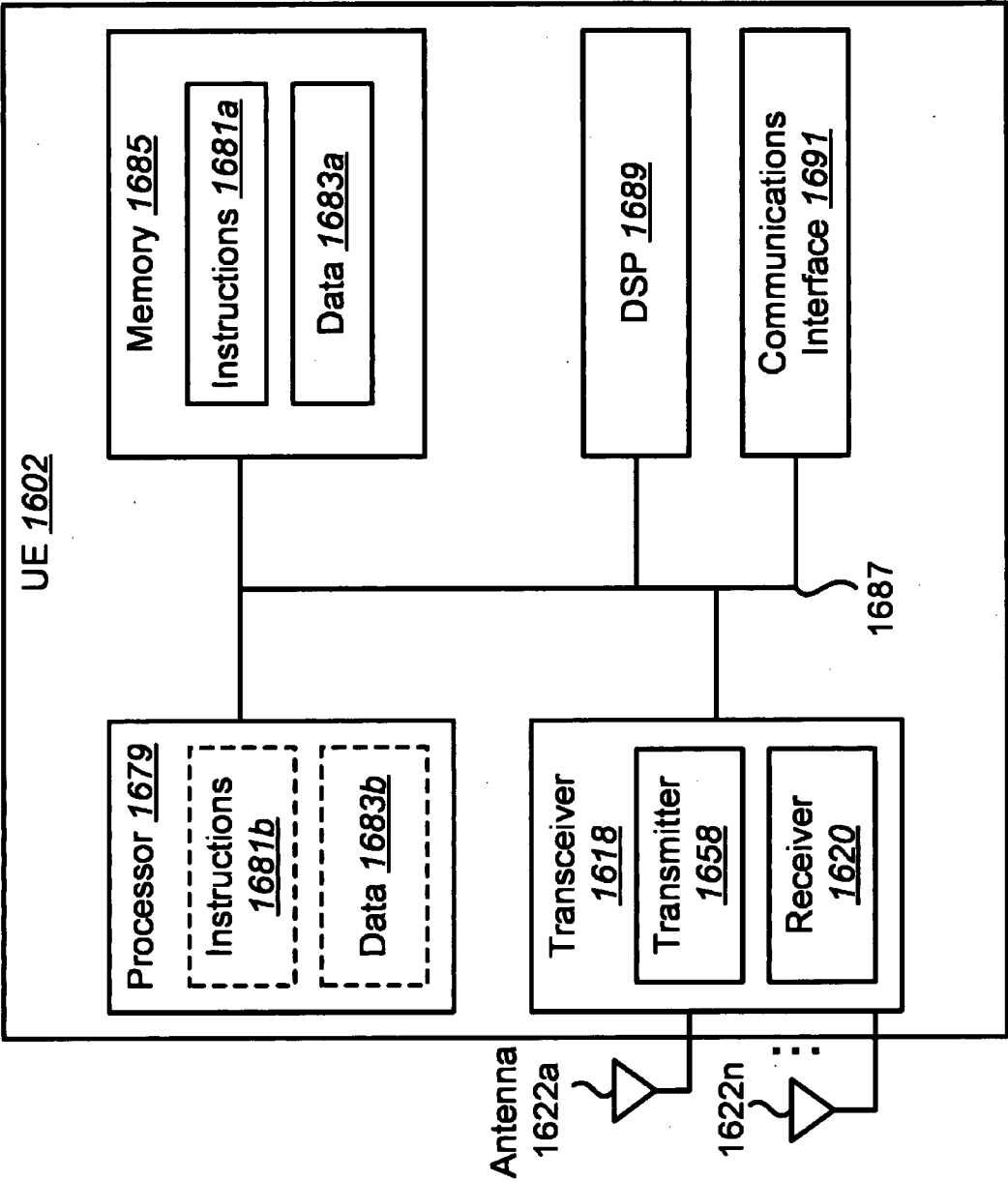


FIG. 16

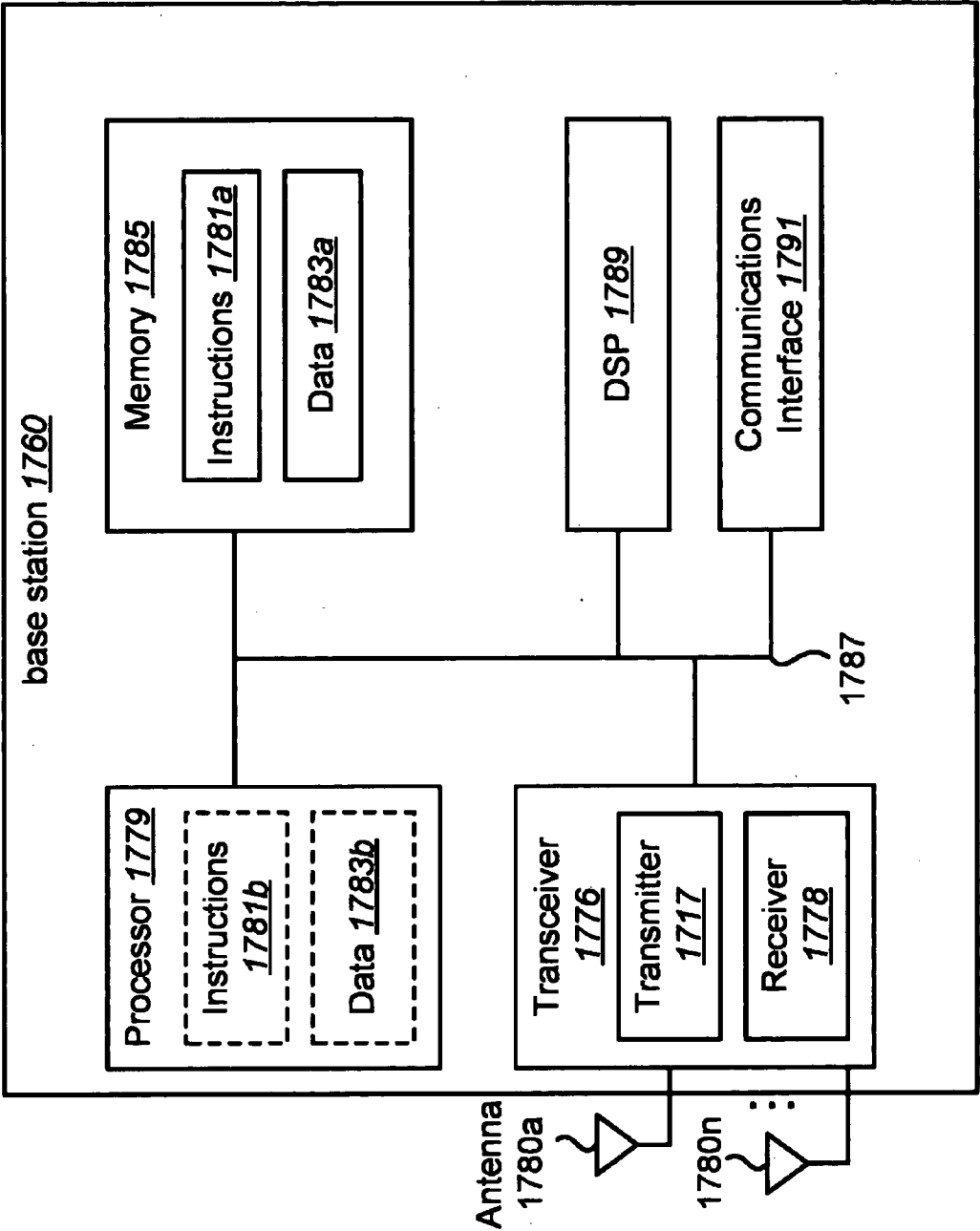


FIG. 17

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2022/016978

A. CLASSIFICATION OF SUBJECT MATTER H04W 72/12 (2009.01)i; H04W 72/14 (2009.01)i; H04W 74/08 (2009.01)i FI: H04W72/14; H04W72/12 150; H04W74/08 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) H04W4/00-99/00 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Published examined utility model applications of Japan 1922-1996 Published unexamined utility model applications of Japan 1971-2022 Registered utility model specifications of Japan 1996-2022 Published registered utility model applications of Japan 1994-2022 Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)																	
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>X</td> <td>Xiaomi, Discussion on Type A PUSCH repetition for Msg3[online], 3GPP TSG RAN WG1 #104-e R1-2101130, 2021.01.18 sections 1, 2.1 and 2.2</td> <td>1-5</td> </tr> <tr> <td colspan="3"> ☐ 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 </td> </tr> <tr> <td colspan="2"> Date of the actual completion of the international search 17 June 2022 </td> <td> Date of mailing of the international search report 28 June 2022 </td> </tr> <tr> <td colspan="2"> Name and mailing address of the ISA/JP Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan </td> <td> Authorized officer Yoshiharu ISHIHARA 5J 3782 Telephone No. +81-3-3581-1101 Ext. 3534 </td> </tr> </tbody> </table>			Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	X	Xiaomi, Discussion on Type A PUSCH repetition for Msg3[online], 3GPP TSG RAN WG1 #104-e R1-2101130, 2021.01.18 sections 1, 2.1 and 2.2	1-5	☐ 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 17 June 2022		Date of mailing of the international search report 28 June 2022	Name and mailing address of the ISA/JP Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan		Authorized officer Yoshiharu ISHIHARA 5J 3782 Telephone No. +81-3-3581-1101 Ext. 3534
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