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Inventor(s)	Yi; Yunjung et al.

Multi-Cell Downlink Control Information

Abstract

A wireless device receives downlink control information (DCI) comprising: a cell index, wherein the cell index indicates one or more cells of a plurality of cells; and a channel state information (CSI) request. The wireless device determines a cell, of the one or more cells, to transmit a CSI based on the CSI request and the cell index of the DCI. The wireless device transmits, via the cell, the CSI.

Inventors: **Yi; Yunjung (Vienna, VA), Dinan; Esmael Hejazi (McLean, VA), Cirik; Ali Cagatay (Chantilly, VA), Park; Jonghyun (Syosset, NY), Zhou; Hua (Vienna, VA)**

Applicant: **Ofinno, LLC** (Reston, VA)

Family ID: **78463886**

Assignee: **Ofinno, LLC (Reston, VA)**

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of U.S. patent application Ser. No. 18/121,509, filed Mar. 14, 2023, which is a continuation of International Application No. PCT/US2021/051202, filed Sep. 21, 2021, which claims the benefit of U.S. Provisional Application No. 63/081,616, filed Sep. 22, 2020, all of which are hereby incorporated by reference in their entireties.

BRIEF DESCRIPTION OF THE DRAWINGS
[0002] Examples of several of the various embodiments of the present disclosure are described herein with reference to the drawings.
[0003] FIG. **1**A and FIG. **1**B illustrate example mobile communication networks in which
[0004] embodiments of the present disclosure may be implemented.
[0005] FIG. **2**A and FIG. **2**B respectively illustrate a New Radio (NR) user plane and control plane protocol stack.
[0006] FIG. **3** illustrates an example of services provided between protocol layers of the NR user plane protocol stack of FIG. **2**A.
[0007] FIG. **4**A illustrates an example downlink data flow through the NR user plane protocol stack of FIG. **2**A.
[0008] FIG. **4**B illustrates an example format of a MAC subheader in a MAC PDU.
[0009] FIG. **5**A and FIG. **5**B respectively illustrate a mapping between logical channels, transport channels, and physical channels for the downlink and uplink.
[0010] FIG. **6** is an example diagram showing RRC state transitions of a UE.
[0011] FIG. **7** illustrates an example configuration of an NR frame into which OFDM symbols are grouped.
[0012] FIG. **8** illustrates an example configuration of a slot in the time and frequency domain for an NR carrier.
[0013] FIG. **9** illustrates an example of bandwidth adaptation using three configured BWPs for an NR carrier.
[0014] FIG. **10**A illustrates three carrier aggregation configurations with two component carriers.
[0015] FIG. **10**B illustrates an example of how aggregated cells may be configured into one or more PUCCH groups.
[0016] FIG. **11**A illustrates an example of an SS/PBCH block structure and location.
[0017] FIG. **11**B illustrates an example of CSI-RSs that are mapped in the time and frequency domains.
[0018] FIG. **12**A and FIG. **12**B respectively illustrate examples of three downlink and uplink beam management procedures.
[0019] FIG. **13**A, FIG. **13**B, and FIG. **13**C respectively illustrate a four-step contention-based random access procedure, a two-step contention-free random access procedure, and another two-step random access procedure.
[0020] FIG. **14**A illustrates an example of CORESET configurations for a bandwidth part.
[0021] FIG. **14**B illustrates an example of a CCE-to-REG mapping for DCI transmission on a CORESET and PDCCH processing.
[0022] FIG. **15** illustrates an example of a wireless device in communication with a base station.
[0023] FIG. **16**A, FIG. **16**B, FIG. **16**C, and FIG. **16**D illustrate example structures for uplink and
[0024] downlink transmission.
[0025] FIG. **17** illustrates an example of various DCI formats used for various purposes.

[0026] FIG. **18** illustrates an example DCI format for scheduling uplink resource of a single cell.
[0027] FIG. **19** illustrates an example DCI format for scheduling downlink resource of a single cell.
[0028] FIG. **20** illustrates an example of dynamic enabling and disabling of a transport block.
[0029] FIG. **21** illustrates an example diagram for a multi-cell scheduling.
[0030] FIG. **22** illustrates an example of an embodiment for determining enabling and disabling of one or more transport blocks of one or more cells based on a DCI.
[0031] FIG. **23** illustrates an example embodiment to disable one or more cells of a plurality of scheduled cells.
[0032] FIG. **24** illustrates an example DCI format for scheduling downlink data based on a multi-cell scheduling.
[0033] FIG. **25** illustrates an example DCI format for scheduling uplink data based on a multi-cell scheduling.
[0034] FIG. **26** illustrates an example flow chart of an embodiment.
[0035] FIG. **27** illustrates an example flow chart of an embodiment.

Description

DETAILED DESCRIPTION
[0036] In the present disclosure, various embodiments are presented as examples of how the disclosed techniques may be implemented and/or how the disclosed techniques may be practiced in environments and scenarios. It will be apparent to persons skilled in the relevant art that various changes in form and detail can be made therein without departing from the scope. In fact, after reading the description, it will be apparent to one skilled in the relevant art how to implement alternative embodiments. The present embodiments should not be limited by any of the described exemplary embodiments. The embodiments of the present disclosure will be described with reference to the accompanying drawings. Limitations, features, and/or elements from the disclosed example embodiments may be combined to create further embodiments within the scope of the disclosure. Any figures which highlight the functionality and advantages, are presented for example purposes only. The disclosed architecture is sufficiently flexible and configurable, such that it may be utilized in ways other than that shown. For example, the actions listed in any flowchart may be re-ordered or only optionally used in some embodiments.
[0037] Embodiments may be configured to operate as needed. The disclosed mechanism may be performed when certain criteria are met, for example, in a wireless device, a base station, a radio environment, a network, a combination of the above, and/or the like. Example criteria may be based, at least in part, on for example, wireless device or network node configurations, traffic load, initial system set up, packet sizes, traffic characteristics, a combination of the above, and/or the like. When the one or more criteria are met, various example embodiments may be applied. Therefore, it may be possible to implement example embodiments that selectively implement disclosed protocols.
[0038] A base station may communicate with a mix of wireless devices. Wireless devices and/or base stations may support multiple technologies, and/or multiple releases of the same technology. Wireless devices may have some specific capability(ies) depending on wireless device category and/or capability(ies). When this disclosure refers to a base station communicating with a plurality of wireless devices, this disclosure may refer to a subset of the total wireless devices in a coverage area. This disclosure may refer to, for example, a plurality of wireless devices of a given LTE or 5G release with a given capability and in a given sector of the base station. The plurality of wireless devices in this disclosure may refer to a selected plurality of wireless devices, and/or a subset of total wireless devices in a coverage area which perform according to disclosed methods, and/or the like. There may be a plurality of base stations or a plurality of wireless devices in a coverage area

that may not comply with the disclosed methods, for example, those wireless devices or base stations may perform based on older releases of LTE or 5G technology.

[0039] In this disclosure, “a” and “an” and similar phrases are to be interpreted as “at least one” and “one or more.” Similarly, any term that ends with the suffix “(s)” is to be interpreted as “at least one” and “one or more.” In this disclosure, the term “may” is to be interpreted as “may, for example.” In other words, the term “may” is indicative that the phrase following the term “may” is an example of one of a multitude of suitable possibilities that may, or may not, be employed by one or more of the various embodiments. The terms “comprises” and “consists of”, as used herein, enumerate one or more components of the element being described. The term “comprises” is interchangeable with “includes” and does not exclude unenumerated components from being included in the element being described. By contrast, “consists of” provides a complete enumeration of the one or more components of the element being described. The term “based on”, as used herein, should be interpreted as “based at least in part on” rather than, for example, “based solely on”. The term “and/or” as used herein represents any possible combination of enumerated elements. For example, “A, B, and/or C” may represent A; B; C; A and B; A and C; B and C; or A, B, and C.

[0040] If A and B are sets and every element of A is an element of B, A is called a subset of B. In this specification, only non-empty sets and subsets are considered. For example, possible subsets of B={cell1, cell2} are: {cell1}, {cell2}, and {cell1, cell2}. The phrase “based on” (or equally “based at least on”) is indicative that the phrase following the term “based on” is an example of one of a multitude of suitable possibilities that may, or may not, be employed to one or more of the various embodiments. The phrase “in response to” (or equally “in response at least to”) is indicative that the phrase following the phrase “in response to” is an example of one of a multitude of suitable possibilities that may, or may not, be employed to one or more of the various embodiments. The phrase “depending on” (or equally “depending at least to”) is indicative that the phrase following the phrase “depending on” is an example of one of a multitude of suitable possibilities that may, or may not, be employed to one or more of the various embodiments. The phrase “employing/using” (or equally “employing/using at least”) is indicative that the phrase following the phrase “employing/using” is an example of one of a multitude of suitable possibilities that may, or may not, be employed to one or more of the various embodiments.

[0041] The term configured may relate to the capacity of a device whether the device is in an operational or non-operational state. Configured may refer to specific settings in a device that effect the operational characteristics of the device whether the device is in an operational or non-operational state. In other words, the hardware, software, firmware, registers, memory values, and/or the like may be “configured” within a device, whether the device is in an operational or nonoperational state, to provide the device with specific characteristics. Terms such as “a control message to cause in a device” may mean that a control message has parameters that may be used to configure specific characteristics or may be used to implement certain actions in the device, whether the device is in an operational or non-operational state.

[0042] In this disclosure, parameters (or equally called, fields, or Information elements: IEs) may comprise one or more information objects, and an information object may comprise one or more other objects. For example, if parameter (IE) N comprises parameter (IE) M, and parameter (IE) M comprises parameter (IE) K, and parameter (IE) K comprises parameter (information element) J. Then, for example, N comprises K, and N comprises J. In an example embodiment, when one or more messages comprise a plurality of parameters, it implies that a parameter in the plurality of parameters is in at least one of the one or more messages, but does not have to be in each of the one or more messages.

[0043] Many features presented are described as being optional through the use of “may” or the use of parentheses. For the sake of brevity and legibility, the present disclosure does not explicitly recite each and every permutation that may be obtained by choosing from the set of optional features. The present disclosure is to be interpreted as explicitly disclosing all such permutations. For example, a system described as having three optional features may be embodied in seven ways, namely with just one of the three possible features, with any two of the three possible features or with three of the three possible features.

[0044] Many of the elements described in the disclosed embodiments may be implemented as modules. A module is defined here as an element that performs a defined function and has a defined interface to other elements. The modules described in this disclosure may be implemented in hardware, software in combination with hardware, firmware, wetware (e.g. hardware with a biological element) or a combination thereof, which may be behaviorally equivalent. For example, modules may be implemented as a software routine written in a computer language configured to be executed by a hardware machine (such as C, C++, Fortran, Java, Basic, Matlab or the like) or a modeling/simulation program such as Simulink, Stateflow, GNU Octave, or LabVIEWMathScript. It may be possible to implement modules using physical hardware that incorporates discrete or programmable analog, digital and/or quantum hardware. Examples of programmable hardware comprise: computers, microcontrollers, microprocessors, application-specific integrated circuits (ASICs); field programmable gate arrays (FPGAs); and complex programmable logic devices (CPLDs). Computers, microcontrollers and microprocessors are programmed using languages such as assembly, C, C++ or the like. FPGAs, ASICs and CPLDs are often programmed using hardware description languages (HDL) such as VHSIC hardware description language (VHDL) or Verilog that configure connections between internal hardware modules with lesser functionality on a programmable device. The mentioned technologies are often used in combination to achieve the result of a functional module.

[0045] FIG. **1**A illustrates an example of a mobile communication network **100** in which embodiments of the present disclosure may be implemented. The mobile communication network **100** may be, for example, a public land mobile network (PLMN) run by a network operator. As illustrated in FIG. **1**A, the mobile communication network **100** includes a core network (CN) **102**, a radio access network (RAN) **104**, and a wireless device **106**.

[0046] The CN **102** may provide the wireless device **106** with an interface to one or more data networks (DNS), such as public DNS (e.g., the Internet), private DNs, and/or intra-operator DNs. As part of the interface functionality, the CN **102** may set up end-to-end connections between the wireless device **106** and the one or more DNs, authenticate the wireless device **106**, and provide charging functionality.

[0047] The RAN **104** may connect the CN **102** to the wireless device **106** through radio communications over an air interface. As part of the radio communications, the RAN **104** may provide scheduling, radio resource management, and retransmission protocols. The communication direction from the RAN **104** to the wireless device **106** over the air interface is known as the downlink and the communication direction from the wireless device **106** to the RAN **104** over the air interface is known as the uplink. Downlink transmissions may be separated from uplink transmissions using frequency division duplexing (FDD), time-division duplexing (TDD), and/or some combination of the two duplexing techniques.

[0048] The term wireless device may be used throughout this disclosure to refer to and encompass any mobile device or fixed (non-mobile) device for which wireless communication is needed or usable. For example, a wireless device may be a telephone, smart phone, tablet, computer, laptop, sensor, meter, wearable device, Internet of Things (IoT) device, vehicle road side unit (RSU), relay node, automobile, and/or any combination thereof. The term wireless device encompasses other terminology, including user equipment (UE), user terminal (UT), access terminal (AT), mobile station, handset, wireless transmit and receive unit (WTRU), and/or wireless communication device.

[0049] The RAN **104** may include one or more base stations (not shown). The term base station may be used throughout this disclosure to refer to and encompass a Node B (associated with

UMTS and/or 3G standards), an Evolved Node B (eNB, associated with E-UTRA and/or 4G standards), a remote radio head (RRH), a baseband processing unit coupled to one or more RRHs, a repeater node or relay node used to extend the coverage area of a donor node, a Next Generation Evolved Node B (ng-eNB), a Generation Node B (gNB, associated with NR and/or 5G standards), an access point (AP, associated with, for example, WiFi or any other suitable wireless communication standard), and/or any combination thereof. A base station may comprise at least one gNB Central Unit (gNB-CU) and at least one a gNB Distributed Unit (gNB-DU).

[0050] A base station included in the RAN **104** may include one or more sets of antennas for communicating with the wireless device **106** over the air interface. For example, one or more of the base stations may include three sets of antennas to respectively control three cells (or sectors). The size of a cell may be determined by a range at which a receiver (e.g., a base station receiver) can successfully receive the transmissions from a transmitter (e.g., a wireless device transmitter) operating in the cell. Together, the cells of the base stations may provide radio coverage to the wireless device **106** over a wide geographic area to support wireless device mobility.

[0051] In addition to three-sector sites, other implementations of base stations are possible. For example, one or more of the base stations in the RAN **104** may be implemented as a sectored site with more or less than three sectors. One or more of the base stations in the RAN **104** may be implemented as an access point, as a baseband processing unit coupled to several remote radio heads (RRHs), and/or as a repeater or relay node used to extend the coverage area of a donor node. A baseband processing unit coupled to RRHs may be part of a centralized or cloud RAN architecture, where the baseband processing unit may be either centralized in a pool of baseband processing units or virtualized. A repeater node may amplify and rebroadcast a radio signal received from a donor node. A relay node may perform the same/similar functions as a repeater node but may decode the radio signal received from the donor node to remove noise before amplifying and rebroadcasting the radio signal.

[0052] The RAN **104** may be deployed as a homogenous network of macrocell base stations that have similar antenna patterns and similar high-level transmit powers. The RAN **104** may be deployed as a heterogeneous network. In heterogeneous networks, small cell base stations may be used to provide small coverage areas, for example, coverage areas that overlap with the comparatively larger coverage areas provided by macrocell base stations. The small coverage areas may be provided in areas with high data traffic (or so-called “hotspots”) or in areas with weak macrocell coverage. Examples of small cell base stations include, in order of decreasing coverage area, microcell base stations, picocell base stations, and femtocell base stations or home base stations.

[0053] The Third-Generation Partnership Project (3GPP) was formed in 1998 to provide global standardization of specifications for mobile communication networks similar to the mobile communication network **100** in FIG. **1**A. To date, 3GPP has produced specifications for three generations of mobile networks: a third generation (3G) network known as Universal Mobile Telecommunications System (UMTS), a fourth generation (4G) network known as Long-Term Evolution (LTE), and a fifth generation (5G) network known as 5G System (5GS). Embodiments of the present disclosure are described with reference to the RAN of a 3GPP 5G network, referred to as next-generation RAN (NG-RAN). Embodiments may be applicable to RANs of other mobile communication networks, such as the RAN **104** in FIG. **1**A, the RANs of earlier 3G and 4G networks, and those of future networks yet to be specified (e.g., a 3GPP 6G network). NG-RAN implements 5G radio access technology known as New Radio (NR) and may be provisioned to implement 4G radio access technology or other radio access technologies, including non-3GPP radio access technologies.

[0054] FIG. **1**B illustrates another example mobile communication network **150** in which embodiments of the present disclosure may be implemented. Mobile communication network **150** may be, for example, a PLMN run by a network operator. As illustrated in FIG. **1**B, mobile communication network **150** includes a 5G core network (5G-CN) **152**, an NG-RAN **154**, and UEs **156**A and **156**B (collectively UEs **156**). These components may be implemented and operate in the same or similar manner as corresponding components described with respect to FIG. **1**A.

[0055] The 5G-CN **152** provides the UEs **156** with an interface to one or more DNs, such as public DNS (e.g., the Internet), private DNs, and/or intra-operator DNs. As part of the interface functionality, the 5G-CN **152** may set up end-to-end connections between the UEs **156** and the one or more DNs, authenticate the UEs **156**, and provide charging functionality. Compared to the CN of a 3GPP 4G network, the basis of the 5G-CN **152** may be a service-based architecture. This means that the architecture of the nodes making up the 5G-CN **152** may be defined as network functions that offer services via interfaces to other network functions. The network functions of the 5G-CN **152** may be implemented in several ways, including as network elements on dedicated or shared hardware, as software instances running on dedicated or shared hardware, or as virtualized functions instantiated on a platform (e.g., a cloud-based platform).

[0056] As illustrated in FIG. **1**B, the 5G-CN **152** includes an Access and Mobility Management Function (AMF) **158**A and a User Plane Function (UPF) **158**B, which are shown as one component AMF/UPF **158** in FIG. **1**B for ease of illustration. The UPF **158**B may serve as a gateway between the NG-RAN **154** and the one or more DNs. The UPF **158**B may perform functions such as packet routing and forwarding, packet inspection and user plane policy rule enforcement, traffic usage reporting, uplink classification to support routing of traffic flows to the one or more DNs, quality of service (QOS) handling for the user plane (e.g., packet filtering, gating, uplink/downlink rate enforcement, and uplink traffic verification), downlink packet buffering, and downlink data notification triggering. The UPF **158**B may serve as an anchor point for intra-/inter-Radio Access Technology (RAT) mobility, an external protocol (or packet) data unit (PDU) session point of interconnect to the one or more DNs, and/or a branching point to support a multi-homed PDU session. The UEs **156** may be configured to receive services through a PDU session, which is a logical connection between a UE and a DN.

[0057] The AMF **158**A may perform functions such as Non-Access Stratum (NAS) signaling termination, NAS signaling security, Access Stratum (AS) security control, inter-CN node signaling for mobility between 3GPP access networks, idle mode UE reachability (e.g., control and execution of paging retransmission), registration area management, intra-system and inter-system mobility support, access authentication, access authorization including checking of roaming rights, mobility management control (subscription and policies), network slicing support, and/or session management function (SMF) selection. NAS may refer to the functionality operating between a CN and a UE, and AS may refer to the functionality operating between the UE and a RAN.

[0058] The 5G-CN **152** may include one or more additional network functions that are not shown in FIG. **1**B for the sake of clarity. For example, the 5G-CN **152** may include one or more of a Session Management Function (SMF), an NR Repository Function (NRF), a Policy Control Function (PCF), a Network Exposure Function (NEF), a Unified Data Management (UDM), an Application Function (AF), and/or an Authentication Server Function (AUSF).

[0059] The NG-RAN **154** may connect the 5G-CN **152** to the UEs **156** through radio communications over the air interface. The NG-RAN **154** may include one or more gNBs, illustrated as gNB **160**A and gNB **160**B (collectively gNBs **160**) and/or one or more ng-eNBs, illustrated as ng-eNB **162**A and ng-eNB **162**B (collectively ng-eNBs **162**). The gNBs **160** and ng-eNBs **162** may be more generically referred to as base stations. The gNBs **160** and ng-eNBs **162** may include one or more sets of antennas for communicating with the UEs **156** over an air interface. For example, one or more of the gNBs **160** and/or one or more of the ng-eNBs **162** may include three sets of antennas to respectively control three cells (or sectors). Together, the cells of the gNBs **160** and the ng-eNBs **162** may provide radio coverage to the UEs **156** over a wide geographic area to support UE mobility.

[0060] As shown in FIG. **1**B, the gNBs **160** and/or the ng-eNBs **162** may be connected to the 5G-

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

[0061] The gNBs **160** and/or the ng-eNBs **162** may be connected to one or more AMF/UPF functions of the 5G-CN **152**, such as the AMF/UPF **158**, by means of one or more NG interfaces. For example, the gNB **160**A may be connected to the UPF **158**B of the AMF/UPF **158** by means of an NG-User plane (NG-U) interface. The NG-U interface may provide delivery (e.g., non-guaranteed delivery) of user plane PDUs between the gNB **160**A and the UPF **158**B. The gNB **160**A may be connected to the AMF **158**A by means of an NG-Control plane (NG-C) interface. The NG-C interface may provide, for example, NG interface management, UE context management, UE mobility management, transport of NAS messages, paging, PDU session management, and configuration transfer and/or warning message transmission.

[0062] The gNBs **160** may provide NR user plane and control plane protocol terminations towards the UEs **156** over the Uu interface. For example, the gNB **160**A may provide NR user plane and control plane protocol terminations toward the UE **156**A over a Uu interface associated with a first protocol stack. The ng-eNBs **162** may provide Evolved UMTS Terrestrial Radio Access (E-UTRA) user plane and control plane protocol terminations towards the UEs **156** over a Uu interface, where E-UTRA refers to the 3GPP 4G radio-access technology. For example, the ng-eNB **162**B may provide E-UTRA user plane and control plane protocol terminations towards the UE **156**B over a Uu interface associated with a second protocol stack.

[0063] The 5G-CN **152** was described as being configured to handle NR and 4G radio accesses. It will be appreciated by one of ordinary skill in the art that it may be possible for NR to connect to a 4G core network in a mode known as “non-standalone operation.” In non-standalone operation, a 4G core network is used to provide (or at least support) control-plane functionality (e.g., initial access, mobility, and paging). Although only one AMF/UPF **158** is shown in FIG. **1**B, one gNB or ng-eNB may be connected to multiple AMF/UPF nodes to provide redundancy and/or to load share across the multiple AMF/UPF nodes.

[0064] As discussed, an interface (e.g., Uu, Xn, and NG interfaces) between the network elements in FIG. **1**B may be associated with a protocol stack that the network elements use to exchange data and signaling messages. A protocol stack may include two planes: a user plane and a control plane. The user plane may handle data of interest to a user, and the control plane may handle signaling messages of interest to the network elements.

[0065] FIG. **2**A and FIG. **2**B respectively illustrate examples of NR user plane and NR control plane protocol stacks for the Uu interface that lies between a UE **210** and a gNB **220**. The protocol stacks illustrated in FIG. **2**A and FIG. **2**B may be the same or similar to those used for the Uu interface between, for example, the UE **156**A and the gNB **160**A shown in FIG. **1**B.

[0066] FIG. **2**A illustrates a NR user plane protocol stack comprising five layers implemented in the UE **210** and the gNB **220**. At the bottom of the protocol stack, physical layers (PHYs) **211** and **221** may provide transport services to the higher layers of the protocol stack and may correspond to layer 1 of the Open Systems Interconnection (OSI) model. The next four protocols above PHYs **211** and **221** comprise media access control layers (MACs) **212** and **222**, radio link control layers (RLCs) **213** and **223**, packet data convergence protocol layers (PDCPs) **214** and **224**, and service data application protocol layers (SDAPs) **215** and **225**. Together, these four protocols may make up

layer 2, or the data link layer, of the OSI model.
[0067] FIG. **3** illustrates an example of services provided between protocol layers of the NR user plane protocol stack. Starting from the top of FIG. **2**A and FIG. **3**, the SDAPs **215** and **225** may perform QoS flow handling. The UE **210** may receive services through a PDU session, which may be a logical connection between the UE **210** and a DN. The PDU session may have one or more QoS flows. A UPF of a CN (e.g., the UPF **158**B) may map IP packets to the one or more QoS flows of the PDU session based on QoS requirements (e.g., in terms of delay, data rate, and/or error rate). The SDAPs **215** and **225** may perform mapping/de-mapping between the one or more QoS flows and one or more data radio bearers. The mapping/de-mapping between the QoS flows and the data radio bearers may be determined by the SDAP **225** at the gNB **220**. The SDAP **215** at the UE **210** may be informed of the mapping between the QoS flows and the data radio bearers through reflective mapping or control signaling received from the gNB **220**. For reflective mapping, the SDAP **225** at the gNB **220** may mark the downlink packets with a QoS flow indicator (QFI), which may be observed by the SDAP **215** at the UE **210** to determine the mapping/de-mapping between the QoS flows and the data radio bearers.
[0068] The PDCPs **214** and **224** may perform header compression/decompression to reduce the amount of data that needs to be transmitted over the air interface, ciphering/deciphering to prevent unauthorized decoding of data transmitted over the air interface, and integrity protection (to ensure control messages originate from intended sources. The PDCPs **214** and **224** may perform retransmissions of undelivered packets, in-sequence delivery and reordering of packets, and removal of packets received in duplicate due to, for example, an intra-gNB handover. The PDCPs **214** and **224** may perform packet duplication to improve the likelihood of the packet being received and, at the receiver, remove any duplicate packets. Packet duplication may be useful for services that require high reliability.
[0069] Although not shown in FIG. **3**, PDCPs **214** and **224** may perform mapping/de-mapping between a split radio bearer and RLC channels in a dual connectivity scenario. Dual connectivity is a technique that allows a UE to connect to two cells or, more generally, two cell groups: a master cell group (MCG) and a secondary cell group (SCG). A split bearer is when a single radio bearer, such as one of the radio bearers provided by the PDCPs **214** and **224** as a service to the SDAPs **215** and **225**, is handled by cell groups in dual connectivity. The PDCPs **214** and **224** may map/de-map the split radio bearer between RLC channels belonging to cell groups.
[0070] The RLCs **213** and **223** may perform segmentation, retransmission through Automatic Repeat Request (ARQ), and removal of duplicate data units received from MACs **212** and **222**, respectively. The RLCs **213** and **223** may support three transmission modes: transparent mode (TM); unacknowledged mode (UM); and acknowledged mode (AM). Based on the transmission mode an RLC is operating, the RLC may perform one or more of the noted functions. The RLC configuration may be per logical channel with no dependency on numerologies and/or Transmission Time Interval (TTI) durations. As shown in FIG. **3**, the RLCs **213** and **223** may provide RLC channels as a service to PDCPs **214** and **224**, respectively.
[0071] The MACs **212** and **222** may perform multiplexing/demultiplexing of logical channels and/or mapping between logical channels and transport channels. The multiplexing/demultiplexing may include multiplexing/demultiplexing of data units, belonging to the one or more logical channels, into/from Transport Blocks (TBs) delivered to/from the PHYs **211** and **221**. The MAC **222** may be configured to perform scheduling, scheduling information reporting, and priority handling between UEs by means of dynamic scheduling. Scheduling may be performed in the gNB **220** (at the MAC **222**) for downlink and uplink. The MACs **212** and **222** may be configured to perform error correction through Hybrid Automatic Repeat Request (HARQ) (e.g., one HARQ entity per carrier in case of Carrier Aggregation (CA)), priority handling between logical channels of the UE **210** by means of logical channel prioritization, and/or padding. The MACs **212** and **222** may support one or more numerologies and/or transmission timings. In an example, mapping

restrictions in a logical channel prioritization may control which numerology and/or transmission timing a logical channel may use. As shown in FIG. **3**, the MACs **212** and **222** may provide logical channels as a service to the RLCs **213** and **223**.
[0072] The PHYs **211** and **221** may perform mapping of transport channels to physical channels and digital and analog signal processing functions for sending and receiving information over the air interface. These digital and analog signal processing functions may include, for example, coding/decoding and modulation/demodulation. The PHYs **211** and **221** may perform multi-antenna mapping. As shown in FIG. **3**, the PHYs **211** and **221** may provide one or more transport channels as a service to the MACs **212** and **222**.
[0073] FIG. **4**A illustrates an example downlink data flow through the NR user plane protocol stack. FIG. **4**A illustrates a downlink data flow of three IP packets (n, n+1, and m) through the NR user plane protocol stack to generate two TBs at the gNB **220**. An uplink data flow through the NR user plane protocol stack may be similar to the downlink data flow depicted in FIG. **4**A.
[0074] The downlink data flow of FIG. **4**A begins when SDAP **225** receives the three IP packets from one or more QoS flows and maps the three packets to radio bearers. In FIG. **4**A, the SDAP **225** maps IP packets n and n+1 to a first radio bearer **402** and maps IP packet m to a second radio bearer **404**. An SDAP header (labeled with an "H" in FIG. **4**A) is added to an IP packet. The data unit from/to a higher protocol layer is referred to as a service data unit (SDU) of the lower protocol layer and the data unit to/from a lower protocol layer is referred to as a protocol data unit (PDU) of the higher protocol layer. As shown in FIG. **4**A, the data unit from the SDAP **225** is an SDU of lower protocol layer PDCP **224** and is a PDU of the SDAP **225**.
[0075] The remaining protocol layers in FIG. **4**A may perform their associated functionality (e.g., with respect to FIG. **3**), add corresponding headers, and forward their respective outputs to the next lower layer. For example, the PDCP **224** may perform IP-header compression and ciphering and forward its output to the RLC **223**. The RLC **223** may optionally perform segmentation (e.g., as shown for IP packet m in FIG. **4**A) and forward its output to the MAC **222**. The MAC **222** may multiplex a number of RLC PDUs and may attach a MAC subheader to an RLC PDU to form a transport block. In NR, the MAC subheaders may be distributed across the MAC PDU, as illustrated in FIG. **4**A. In LTE, the MAC subheaders may be entirely located at the beginning of the MAC PDU. The NR MAC PDU structure may reduce processing time and associated latency because the MAC PDU subheaders may be computed before the full MAC PDU is assembled.
[0076] FIG. **4**B illustrates an example format of a MAC subheader in a MAC PDU. The MAC subheader includes: an SDU length field for indicating the length (e.g., in bytes) of the MAC SDU to which the MAC subheader corresponds; a logical channel identifier (LCID) field for identifying the logical channel from which the MAC SDU originated to aid in the demultiplexing process; a flag (F) for indicating the size of the SDU length field; and a reserved bit (R) field for future use.
[0077] FIG. **4**B further illustrates MAC control elements (CEs) inserted into the MAC PDU by a MAC, such as MAC **212** or MAC **222**. For example, FIG. **4**B illustrates two MAC CEs inserted into the MAC PDU. MAC CEs may be inserted at the beginning of a MAC PDU for downlink transmissions (as shown in FIG. **4**B) and at the end of a MAC PDU for uplink transmissions. MAC CEs may be used for in-band control signaling. Example MAC CEs include: scheduling-related MAC CEs, such as buffer status reports and power headroom reports; activation/deactivation MAC CEs, such as those for activation/deactivation of PDCP duplication detection, channel state information (CSI) reporting, sounding reference signal (SRS) transmission, and prior configured components; discontinuous reception (DRX) related MAC CEs; timing advance MAC CEs; and random access related MAC CEs. A MAC CE may be preceded by a MAC subheader with a similar format as described for MAC SDUs and may be identified with a reserved value in the LCID field that indicates the type of control information included in the MAC CE.
[0078] Before describing the NR control plane protocol stack, logical channels, transport channels, and physical channels are first described as well as a mapping between the channel types. One or

more of the channels may be used to carry out functions associated with the NR control plane protocol stack described later below.

[0079] FIG. 5A and FIG. 5B illustrate, for downlink and uplink respectively, a mapping between logical channels, transport channels, and physical channels. Information is passed through channels between the RLC, the MAC, and the PHY of the NR protocol stack. A logical channel may be used between the RLC and the MAC and may be classified as a control channel that carries control and configuration information in the NR control plane or as a traffic channel that carries data in the NR user plane. A logical channel may be classified as a dedicated logical channel that is dedicated to a specific UE or as a common logical channel that may be used by more than one UE. A logical channel may also be defined by the type of information it carries. The set of logical channels defined by NR include, for example: [0080] a paging control channel (PCCH) for carrying paging messages used to page a UE whose location is not known to the network on a cell level; [0081] a broadcast control channel (BCCH) for carrying system information messages in the form of a master information block (MIB) and several system information blocks (SIBs), wherein the system information messages may be used by the UEs to obtain information about how a cell is configured and how to operate within the cell; [0082] a common control channel (CCCH) for carrying control messages together with random access; [0083] a dedicated control channel (DCCH) for carrying control messages to/from a specific the UE to configure the UE; and [0084] a dedicated traffic channel (DTCH) for carrying user data to/from a specific the UE.

[0085] Transport channels are used between the MAC and PHY layers and may be defined by how the information they carry is transmitted over the air interface. The set of transport channels defined by NR include, for example: [0086] a paging channel (PCH) for carrying paging messages that originated from the PCCH; [0087] a broadcast channel (BCH) for carrying the MIB from the BCCH; [0088] a downlink shared channel (DL-SCH) for carrying downlink data and signaling messages, including the SIBs from the BCCH; [0089] an uplink shared channel (UL-SCH) for carrying uplink data and signaling messages; and [0090] a random access channel (RACH) for allowing a UE to contact the network without any prior scheduling.

[0091] The PHY may use physical channels to pass information between processing levels of the PHY. A physical channel may have an associated set of time-frequency resources for carrying the information of one or more transport channels. The PHY may generate control information to support the low-level operation of the PHY and provide the control information to the lower levels of the PHY via physical control channels, known as L1/L2 control channels. The set of physical channels and physical control channels defined by NR include, for example: [0092] a physical broadcast channel (PBCH) for carrying the MIB from the BCH; [0093] a physical downlink shared channel (PDSCH) for carrying downlink data and signaling messages from the DL-SCH, as well as paging messages from the PCH; [0094] a physical downlink control channel (PDCCH) for carrying downlink control information (DCI), which may include downlink scheduling commands, uplink scheduling grants, and uplink power control commands; [0095] a physical uplink shared channel (PUSCH) for carrying uplink data and signaling messages from the UL-SCH and in some instances uplink control information (UCI) as described below; [0096] a physical uplink control channel (PUCCH) for carrying UCI, which may include HARQ acknowledgments, channel quality indicators (CQI), pre-coding matrix indicators (PMI), rank indicators (RI), and scheduling requests (SR); and [0097] a physical random access channel (PRACH) for random access.

[0098] Similar to the physical control channels, the physical layer generates physical signals to support the low-level operation of the physical layer. As shown in FIG. 5A and FIG. 5B, the physical layer signals defined by NR include: primary synchronization signals (PSS), secondary synchronization signals (SSS), channel state information reference signals (CSI-RS), demodulation reference signals (DMRS), sounding reference signals (SRS), and phase-tracking reference signals (PT-RS). These physical layer signals will be described in greater detail below.

[0099] FIG. 2B illustrates an example NR control plane protocol stack. As shown in FIG. 2B, the

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

[0100] The NAS protocols **217** and **237** may provide control plane functionality between the UE **210** and the AMF **230** (e.g., the AMF **158**A) or, more generally, between the UE **210** and the CN. The NAS protocols **217** and **237** may provide control plane functionality between the UE **210** and the AMF **230** via signaling messages, referred to as NAS messages. There is no direct path between the UE **210** and the AMF **230** through which the NAS messages can be transported. The NAS messages may be transported using the AS of the Uu and NG interfaces. NAS protocols **217** and **237** may provide control plane functionality such as authentication, security, connection setup, mobility management, and session management.

[0101] The RRCs **216** and **226** may provide control plane functionality between the UE **210** and the gNB **220** or, more generally, between the UE **210** and the RAN. The RRCs **216** and **226** may provide control plane functionality between the UE **210** and the gNB **220** via signaling messages, referred to as RRC messages. RRC messages may be transmitted between the UE **210** and the RAN using signaling radio bearers and the same/similar PDCP, RLC, MAC, and PHY protocol layers. The MAC may multiplex control-plane and user-plane data into the same transport block (TB). The RRCs **216** and **226** may provide control plane functionality such as: broadcast of system information related to AS and NAS; paging initiated by the CN or the RAN; establishment, maintenance and release of an RRC connection between the UE **210** and the RAN; security functions including key management; establishment, configuration, maintenance and release of signaling radio bearers and data radio bearers; mobility functions; QoS management functions; the UE measurement reporting and control of the reporting; detection of and recovery from radio link failure (RLF); and/or NAS message transfer. As part of establishing an RRC connection, RRCs **216** and **226** may establish an RRC context, which may involve configuring parameters for communication between the UE **210** and the RAN.

[0102] FIG. **6** is an example diagram showing RRC state transitions of a UE. The UE may be the same or similar to the wireless device **106** depicted in FIG. **1**A, the UE **210** depicted in FIG. **2**A and FIG. **2**B, or any other wireless device described in the present disclosure. As illustrated in FIG. **6**, a UE may be in at least one of three RRC states: RRC connected **602** (e.g., RRC_CONNECTED), RRC idle **604** (e.g., RRC_IDLE), and RRC inactive **606** (e.g., RRC_INACTIVE).

[0103] In RRC connected **602**, the UE has an established RRC context and may have at least one RRC connection with a base station. The base station may be similar to one of the one or more base stations included in the RAN **104** depicted in FIG. **1**A, one of the gNBs **160** or ng-eNBs **162** depicted in FIG. **1**B, the gNB **220** depicted in FIG. **2**A and FIG. **2**B, or any other base station described in the present disclosure. The base station with which the UE is connected may have the RRC context for the UE. The RRC context, referred to as the UE context, may comprise parameters for communication between the UE and the base station. These parameters may include, for example: one or more AS contexts; one or more radio link configuration parameters; bearer configuration information (e.g., relating to a data radio bearer, signaling radio bearer, logical channel, QoS flow, and/or PDU session); security information; and/or PHY, MAC, RLC, PDCP, and/or SDAP layer configuration information. While in RRC connected **602**, mobility of the UE may be managed by the RAN (e.g., the RAN **104** or the NG-RAN **154**). The UE may measure the signal levels (e.g., reference signal levels) from a serving cell and neighboring cells and report these measurements to the base station currently serving the UE. The UE's serving base station may request a handover to a cell of one of the neighboring base stations based on the reported measurements. The RRC state may transition from RRC connected **602** to RRC idle **604** through a connection release procedure **608** or to RRC inactive **606** through a connection inactivation procedure **610**.

[0104] In RRC idle **604**, an RRC context may not be established for the UE. In RRC idle **604**, the UE may not have an RRC connection with the base station. While in RRC idle **604**, the UE may be in a sleep state for the majority of the time (e.g., to conserve battery power). The UE may wake up periodically (e.g., once in every discontinuous reception cycle) to monitor for paging messages from the RAN. Mobility of the UE may be managed by the UE through a procedure known as cell reselection. The RRC state may transition from RRC idle **604** to RRC connected **602** through a connection establishment procedure **612**, which may involve a random access procedure as discussed in greater detail below.

[0105] In RRC inactive **606**, the RRC context previously established is maintained in the UE and the base station. This allows for a fast transition to RRC connected **602** with reduced signaling overhead as compared to the transition from RRC idle **604** to RRC connected **602**. While in RRC inactive **606**, the UE may be in a sleep state and mobility of the UE may be managed by the UE through cell reselection. The RRC state may transition from RRC inactive **606** to RRC connected **602** through a connection resume procedure **614** or to RRC idle **604** though a connection release procedure **616** that may be the same as or similar to connection release procedure **608**.

[0106] An RRC state may be associated with a mobility management mechanism. In RRC idle **604** and RRC inactive **606**, mobility is managed by the UE through cell reselection. The purpose of mobility management in RRC idle **604** and RRC inactive **606** is to allow the network to be able to notify the UE of an event via a paging message without having to broadcast the paging message over the entire mobile communications network. The mobility management mechanism used in RRC idle **604** and RRC inactive **606** may allow the network to track the UE on a cell-group level so that the paging message may be broadcast over the cells of the cell group that the UE currently resides within instead of the entire mobile communication network. The mobility management mechanisms for RRC idle **604** and RRC inactive **606** track the UE on a cell-group level. They may do so using different granularities of grouping. For example, there may be three levels of cell-grouping granularity: individual cells; cells within a RAN area identified by a RAN area identifier (RAI); and cells within a group of RAN areas, referred to as a tracking area and identified by a tracking area identifier (TAI).

[0107] Tracking areas may be used to track the UE at the CN level. The CN (e.g., the CN **102** or the 5G-CN **152**) may provide the UE with a list of TAIs associated with a UE registration area. If the UE moves, through cell reselection, to a cell associated with a TAI not included in the list of TAIs associated with the UE registration area, the UE may perform a registration update with the CN to allow the CN to update the UE's location and provide the UE with a new the UE registration area.

[0108] RAN areas may be used to track the UE at the RAN level. For a UE in RRC inactive **606** state, the UE may be assigned a RAN notification area. A RAN notification area may comprise one or more cell identities, a list of RAIs, or a list of TAIs. In an example, a base station may belong to one or more RAN notification areas. In an example, a cell may belong to one or more RAN notification areas. If the UE moves, through cell reselection, to a cell not included in the RAN notification area assigned to the UE, the UE may perform a notification area update with the RAN to update the UE's RAN notification area.

[0109] A base station storing an RRC context for a UE or a last serving base station of the UE may be referred to as an anchor base station. An anchor base station may maintain an RRC context for the UE at least during a period of time that the UE stays in a RAN notification area of the anchor base station and/or during a period of time that the UE stays in RRC inactive **606**.

[0110] A gNB, such as gNBs **160** in FIG. **1**B, may be split in two parts: a central unit (gNB-CU), and one or more distributed units (gNB-DU). A gNB-CU may be coupled to one or more gNB-DUs using an F1 interface. The gNB-CU may comprise the RRC, the PDCP, and the SDAP. A gNB-DU may comprise the RLC, the MAC, and the PHY.

[0111] In NR, the physical signals and physical channels (discussed with respect to FIG. **5**A and FIG. **5**B) may be mapped onto orthogonal frequency divisional multiplexing (OFDM) symbols. OFDM is a multicarrier communication scheme that transmits data over F orthogonal subcarriers (or tones). Before transmission, the data may be mapped to a series of complex symbols (e.g., M-quadrature amplitude modulation (M-QAM) or M-phase shift keying (M-PSK) symbols), referred to as source symbols, and divided into F parallel symbol streams. The F parallel symbol streams may be treated as though they are in the frequency domain and used as inputs to an Inverse Fast Fourier Transform (IFFT) block that transforms them into the time domain. The IFFT block may take in F source symbols at a time, one from each of the F parallel symbol streams, and use each source symbol to modulate the amplitude and phase of one of F sinusoidal basis functions that correspond to the F orthogonal subcarriers. The output of the IFFT block may be F time-domain samples that represent the summation of the F orthogonal subcarriers. The F time-domain samples may form a single OFDM symbol. After some processing (e.g., addition of a cyclic prefix) and up-conversion, an OFDM symbol provided by the IFFT block may be transmitted over the air interface on a carrier frequency. The F parallel symbol streams may be mixed using an FFT block before being processed by the IFFT block. This operation produces Discrete Fourier Transform (DFT)-precoded OFDM symbols and may be used by UEs in the uplink to reduce the peak to average power ratio (PAPR). Inverse processing may be performed on the OFDM symbol at a receiver using an FFT block to recover the data mapped to the source symbols.

[0112] FIG. **7** illustrates an example configuration of an NR frame into which OFDM symbols are grouped. An NR frame may be identified by a system frame number (SFN). The SFN may repeat with a period of 1024 frames. As illustrated, one NR frame may be 10 milliseconds (ms) in duration and may include 10 subframes that are 1 ms in duration. A subframe may be divided into slots that include, for example, 14 OFDM symbols per slot.

[0113] The duration of a slot may depend on the numerology used for the OFDM symbols of the slot. In NR, a flexible numerology is supported to accommodate different cell deployments (e.g., cells with carrier frequencies below 1 GHz up to cells with carrier frequencies in the mm-wave range). A numerology may be defined in terms of subcarrier spacing and cyclic prefix duration. For a numerology in NR, subcarrier spacings may be scaled up by powers of two from a baseline subcarrier spacing of 15 kHz, and cyclic prefix durations may be scaled down by powers of two from a baseline cyclic prefix duration of 4.7 μs. For example, NR defines numerologies with the following subcarrier spacing/cyclic prefix duration combinations: 15 kHz/4.7 μs; 30 kHz/2.3 μs; 60 kHz/1.2 μs; 120 kHz/0.59 μs; and 240 kHz/0.29 μs.

[0114] A slot may have a fixed number of OFDM symbols (e.g., 14 OFDM symbols). A numerology with a higher subcarrier spacing has a shorter slot duration and, correspondingly, more slots per subframe. FIG. **7** illustrates this numerology-dependent slot duration and slots-per-subframe transmission structure (the numerology with a subcarrier spacing of 240 kHz is not shown in FIG. **7** for ease of illustration). A subframe in NR may be used as a numerology-independent time reference, while a slot may be used as the unit upon which uplink and downlink transmissions are scheduled. To support low latency, scheduling in NR may be decoupled from the slot duration and start at any OFDM symbol and last for as many symbols as needed for a transmission. These partial slot transmissions may be referred to as mini-slot or subslot transmissions.

[0115] FIG. **8** illustrates an example configuration of a slot in the time and frequency domain for an NR carrier. The slot includes resource elements (REs) and resource blocks (RBs). An RE is the smallest physical resource in NR. An RE spans one OFDM symbol in the time domain by one subcarrier in the frequency domain as shown in FIG. **8**. An RB spans twelve consecutive REs in the frequency domain as shown in FIG. **8**. An NR carrier may be limited to a width of 275 RBs or

275×12=3300 subcarriers. Such a limitation, if used, may limit the NR carrier to 50, 100, 200, and 400 MHz for subcarrier spacings of 15, 30, 60, and 120 kHz, respectively, where the 400 MHz bandwidth may be set based on a 400 MHz per carrier bandwidth limit.

[0116] FIG. **8** illustrates a single numerology being used across the entire bandwidth of the NR carrier. In other example configurations, multiple numerologies may be supported on the same carrier.

[0117] NR may support wide carrier bandwidths (e.g., up to 400 MHz for a subcarrier spacing of 120 kHz). Not all UEs may be able to receive the full carrier bandwidth (e.g., due to hardware limitations). Also, receiving the full carrier bandwidth may be prohibitive in terms of UE power consumption. In an example, to reduce power consumption and/or for other purposes, a UE may adapt the size of the UE's receive bandwidth based on the amount of traffic the UE is scheduled to receive. This is referred to as bandwidth adaptation.

[0118] NR defines bandwidth parts (BWPs) to support UEs not capable of receiving the full carrier bandwidth and to support bandwidth adaptation. In an example, a BWP may be defined by a subset of contiguous RBs on a carrier. A UE may be configured (e.g., via RRC layer) with one or more downlink BWPs and one or more uplink BWPs per serving cell (e.g., up to four downlink BWPs and up to four uplink BWPs per serving cell). At a given time, one or more of the configured BWPs for a serving cell may be active. These one or more BWPs may be referred to as active BWPs of the serving cell. When a serving cell is configured with a secondary uplink carrier, the serving cell may have one or more first active BWPs in the uplink carrier and one or more second active BWPs in the secondary uplink carrier.

[0119] For unpaired spectra, a downlink BWP from a set of configured downlink BWPs may be linked with an uplink BWP from a set of configured uplink BWPs if a downlink BWP index of the downlink BWP and an uplink BWP index of the uplink BWP are the same. For unpaired spectra, a UE may expect that a center frequency for a downlink BWP is the same as a center frequency for an uplink BWP.

[0120] For a downlink BWP in a set of configured downlink BWPs on a primary cell (PCell), a base station may configure a UE with one or more control resource sets (CORESETs) for at least one search space. A search space is a set of locations in the time and frequency domains where the UE may find control information. The search space may be a UE-specific search space or a common search space (potentially usable by a plurality of UEs). For example, a base station may configure a UE with a common search space, on a PCell or on a primary secondary cell (PSCell), in an active downlink BWP.

[0121] For an uplink BWP in a set of configured uplink BWPs, a BS may configure a UE with one or more resource sets for one or more PUCCH transmissions. A UE may receive downlink receptions (e.g., PDCCH or PDSCH) in a downlink BWP according to a configured numerology (e.g., subcarrier spacing and cyclic prefix duration) for the downlink BWP. The UE may transmit uplink transmissions (e.g., PUCCH or PUSCH) in an uplink BWP according to a configured numerology (e.g., subcarrier spacing and cyclic prefix length for the uplink BWP).

[0122] One or more BWP indicator fields may be provided in Downlink Control Information (DCI). A value of a BWP indicator field may indicate which BWP in a set of configured BWPs is an active downlink BWP for one or more downlink receptions. The value of the one or more BWP indicator fields may indicate an active uplink BWP for one or more uplink transmissions.

[0123] A base station may semi-statically configure a UE with a default downlink BWP within a set of configured downlink BWPs associated with a PCell. If the base station does not provide the default downlink BWP to the UE, the default downlink BWP may be an initial active downlink BWP. The UE may determine which BWP is the initial active downlink BWP based on a CORESET configuration obtained using the PBCH.

[0124] A base station may configure a UE with a BWP inactivity timer value for a PCell. The UE may start or restart a BWP inactivity timer at any appropriate time. For example, the UE may start or restart the BWP inactivity timer (a) when the UE detects a DCI indicating an active downlink BWP other than a default downlink BWP for a paired spectra operation; or (b) when a UE detects a DCI indicating an active downlink BWP or active uplink BWP other than a default downlink BWP or uplink BWP for an unpaired spectra operation. If the UE does not detect DCI during an interval of time (e.g., 1 ms or 0.5 ms), the UE may run the BWP inactivity timer toward expiration (for example, increment from zero to the BWP inactivity timer value, or decrement from the BWP inactivity timer value to zero). When the BWP inactivity timer expires, the UE may switch from the active downlink BWP to the default downlink BWP.

[0125] In an example, a base station may semi-statically configure a UE with one or more BWPs. A UE may switch an active BWP from a first BWP to a second BWP in response to receiving a DCI indicating the second BWP as an active BWP and/or in response to an expiry of the BWP inactivity timer (e.g., if the second BWP is the default BWP).

[0126] Downlink and uplink BWP switching (where BWP switching refers to switching from a currently active BWP to a not currently active BWP) may be performed independently in paired spectra. In unpaired spectra, downlink and uplink BWP switching may be performed simultaneously. Switching between configured BWPs may occur based on RRC signaling, DCI, expiration of a BWP inactivity timer, and/or an initiation of random access.

[0127] FIG. **9** illustrates an example of bandwidth adaptation using three configured BWPs for an NR carrier. A UE configured with the three BWPs may switch from one BWP to another BWP at a switching point. In the example illustrated in FIG. **9**, the BWPs include: a BWP **902** with a bandwidth of 40 MHz and a subcarrier spacing of 15 kHz; a BWP **904** with a bandwidth of 10 MHz and a subcarrier spacing of 15 kHz; and a BWP **906** with a bandwidth of 20 MHz and a subcarrier spacing of 60 kHz. The BWP **902** may be an initial active BWP, and the BWP **904** may be a default BWP. The UE may switch between BWPs at switching points. In the example of FIG. **9**, the UE may switch from the BWP **902** to the BWP **904** at a switching point **908**. The switching at the switching point **908** may occur for any suitable reason, for example, in response to an expiry of a BWP inactivity timer (indicating switching to the default BWP) and/or in response to receiving a DCI indicating BWP **904** as the active BWP. The UE may switch at a switching point **910** from active BWP **904** to BWP **906** in response receiving a DCI indicating BWP **906** as the active BWP. The UE may switch at a switching point **912** from active BWP **906** to BWP **904** in response to an expiry of a BWP inactivity timer and/or in response receiving a DCI indicating BWP **904** as the active BWP. The UE may switch at a switching point **914** from active BWP **904** to BWP **902** in response receiving a DCI indicating BWP **902** as the active BWP.

[0128] If a UE is configured for a secondary cell with a default downlink BWP in a set of configured downlink BWPs and a timer value, UE procedures for switching BWPs on a secondary cell may be the same/similar as those on a primary cell. For example, the UE may use the timer value and the default downlink BWP for the secondary cell in the same/similar manner as the UE would use these values for a primary cell.

[0129] To provide for greater data rates, two or more carriers can be aggregated and simultaneously transmitted to/from the same UE using carrier aggregation (CA). The aggregated carriers in CA may be referred to as component carriers (CCs). When CA is used, there are a number of serving cells for the UE, one for a CC. The CCs may have three configurations in the frequency domain.

[0130] FIG. **10**A illustrates the three CA configurations with two CCs. In the intraband, contiguous configuration **1002**, the two CCs are aggregated in the same frequency band (frequency band A) and are located directly adjacent to each other within the frequency band. In the intraband, non-contiguous configuration **1004**, the two CCs are aggregated in the same frequency band (frequency band A) and are separated in the frequency band by a gap. In the interband configuration **1006**, the two CCs are located in frequency bands (frequency band A and frequency band B).

[0131] In an example, up to 32 CCs may be aggregated. The aggregated CCs may have the same or different bandwidths, subcarrier spacing, and/or duplexing schemes (TDD or FDD). A serving cell for a UE using CA may have a downlink CC. For FDD, one or more uplink CCs may be optionally configured for a serving cell. The ability to aggregate more downlink carriers than uplink carriers may be useful, for example, when the UE has more data traffic in the downlink than in the uplink.

[0132] When CA is used, one of the aggregated cells for a UE may be referred to as a primary cell (PCell). The PCell may be the serving cell that the UE initially connects to at RRC connection establishment, reestablishment, and/or handover. The PCell may provide the UE with NAS mobility information and the security input. UEs may have different PCells. In the downlink, the carrier corresponding to the PCell may be referred to as the downlink primary CC (DL PCC). In the uplink, the carrier corresponding to the PCell may be referred to as the uplink primary CC (UL PCC). The other aggregated cells for the UE may be referred to as secondary cells (SCells). In an example, the SCells may be configured after the PCell is configured for the UE. For example, an SCell may be configured through an RRC Connection Reconfiguration procedure. In the downlink, the carrier corresponding to an SCell may be referred to as a downlink secondary CC (DL SCC). In the uplink, the carrier corresponding to the SCell may be referred to as the uplink secondary CC (UL SCC).

[0133] Configured SCells for a UE may be activated and deactivated based on, for example, traffic and channel conditions. Deactivation of an SCell may mean that PDCCH and PDSCH reception on the SCell is stopped and PUSCH, SRS, and CQI transmissions on the SCell are stopped. Configured SCells may be activated and deactivated using a MAC CE with respect to FIG. **4**B. For example, a MAC CE may use a bitmap (e.g., one bit per SCell) to indicate which SCells (e.g., in a subset of configured SCells) for the UE are activated or deactivated. Configured SCells may be deactivated in response to an expiration of an SCell deactivation timer (e.g., one SCell deactivation timer per SCell).

[0134] Downlink control information, such as scheduling assignments and scheduling grants, for a cell may be transmitted on the cell corresponding to the assignments and grants, which is known as self-scheduling. The DCI for the cell may be transmitted on another cell, which is known as cross-carrier scheduling. Uplink control information (e.g., HARQ acknowledgments and channel state feedback, such as CQI, PMI, and/or RI) for aggregated cells may be transmitted on the PUCCH of the PCell. For a larger number of aggregated downlink CCs, the PUCCH of the PCell may become overloaded. Cells may be divided into multiple PUCCH groups.

[0135] FIG. **10**B illustrates an example of how aggregated cells may be configured into one or more PUCCH groups. A PUCCH group **1010** and a PUCCH group **1050** may include one or more downlink CCs, respectively. In the example of FIG. **10**B, the PUCCH group **1010** includes three downlink CCs: a PCell **1011**, an SCell **1012**, and an SCell **1013**. The PUCCH group **1050** includes three downlink CCs in the present example: a PCell **1051**, an SCell **1052**, and an SCell **1053**. One or more uplink CCs may be configured as a PCell **1021**, an SCell **1022**, and an SCell **1023**. One or more other uplink CCs may be configured as a primary Scell (PSCell) **1061**, an SCell **1062**, and an SCell **1063**. Uplink control information (UCI) related to the downlink CCs of the PUCCH group **1010**, shown as UCI **1031**, UCI **1032**, and UCI **1033**, may be transmitted in the uplink of the PCell **1021**. Uplink control information (UCI) related to the downlink CCs of the PUCCH group **1050**, shown as UCI **1071**, UCI **1072**, and UCI **1073**, may be transmitted in the uplink of the PSCell **1061**. In an example, if the aggregated cells depicted in FIG. **10**B were not divided into the PUCCH group **1010** and the PUCCH group **1050**, a single uplink PCell to transmit UCI relating to the downlink CCs, and the PCell may become overloaded. By dividing transmissions of UCI between the PCell **1021** and the PSCell **1061**, overloading may be prevented.

[0136] A cell, comprising a downlink carrier and optionally an uplink carrier, may be assigned with a physical cell ID and a cell index. The physical cell ID or the cell index may identify a downlink carrier and/or an uplink carrier of the cell, for example, depending on the context in which the physical cell ID is used. A physical cell ID may be determined using a synchronization signal transmitted on a downlink component carrier. A cell index may be determined using RRC messages. In the disclosure, a physical cell ID may be referred to as a carrier ID, and a cell index may be referred to as a carrier index. For example, when the disclosure refers to a first physical cell ID for a first downlink carrier, the disclosure may mean the first physical cell ID is for a cell comprising the first downlink carrier. The same/similar concept may apply to, for example, a carrier activation. When the disclosure indicates that a first carrier is activated, the specification may mean that a cell comprising the first carrier is activated.

[0137] In CA, a multi-carrier nature of a PHY may be exposed to a MAC. In an example, a HARQ entity may operate on a serving cell. A transport block may be generated per assignment/grant per serving cell. A transport block and potential HARQ retransmissions of the transport block may be mapped to a serving cell.

[0138] In the downlink, a base station may transmit (e.g., unicast, multicast, and/or broadcast) one or more Reference Signals (RSs) to a UE (e.g., PSS, SSS, CSI-RS, DMRS, and/or PT-RS, as shown in FIG. **5**A). In the uplink, the UE may transmit one or more RSs to the base station (e.g., DMRS, PT-RS, and/or SRS, as shown in FIG. **5**B). The PSS and the SSS may be transmitted by the base station and used by the UE to synchronize the UE to the base station. The PSS and the SSS may be provided in a synchronization signal (SS)/physical broadcast channel (PBCH) block that includes the PSS, the SSS, and the PBCH. The base station may periodically transmit a burst of SS/PBCH blocks.

[0139] FIG. **11**A illustrates an example of an SS/PBCH block's structure and location. A burst of SS/PBCH blocks may include one or more SS/PBCH blocks (e.g., 4 SS/PBCH blocks, as shown in FIG. **11**A). Bursts may be transmitted periodically (e.g., every 2 frames or 20 ms). A burst may be restricted to a half-frame (e.g., a first half-frame having a duration of 5 ms). It will be understood that FIG. **11**A is an example, and that these parameters (number of SS/PBCH blocks per burst, periodicity of bursts, position of burst within the frame) may be configured based on, for example: a carrier frequency of a cell in which the SS/PBCH block is transmitted; a numerology or subcarrier spacing of the cell; a configuration by the network (e.g., using RRC signaling); or any other suitable factor. In an example, the UE may assume a subcarrier spacing for the SS/PBCH block based on the carrier frequency being monitored, unless the radio network configured the UE to assume a different subcarrier spacing.

[0140] The SS/PBCH block may span one or more OFDM symbols in the time domain (e.g., 4 OFDM symbols, as shown in the example of FIG. **11**A) and may span one or more subcarriers in the frequency domain (e.g., **240** contiguous subcarriers). The PSS, the SSS, and the PBCH may have a common center frequency. The PSS may be transmitted first and may span, for example, 1 OFDM symbol and 127 subcarriers. The SSS may be transmitted after the PSS (e.g., two symbols later) and may span 1 OFDM symbol and 127 subcarriers. The PBCH may be transmitted after the PSS (e.g., across the next 3 OFDM symbols) and may span 240 subcarriers.

[0141] The location of the SS/PBCH block in the time and frequency domains may not be known to the UE (e.g., if the UE is searching for the cell). To find and select the cell, the UE may monitor a carrier for the PSS. For example, the UE may monitor a frequency location within the carrier. If the PSS is not found after a certain duration (e.g., 20 ms), the UE may search for the PSS at a different frequency location within the carrier, as indicated by a synchronization raster. If the PSS is found at a location in the time and frequency domains, the UE may determine, based on a known structure of the SS/PBCH block, the locations of the SSS and the PBCH, respectively. The SS/PBCH block may be a cell-defining SS block (CD-SSB). In an example, a primary cell may be associated with a CD-SSB. The CD-SSB may be located on a synchronization raster. In an example, a cell selection/search and/or reselection may be based on the CD-SSB.

[0142] The SS/PBCH block may be used by the UE to determine one or more parameters of the cell. For example, the UE may determine a physical cell identifier (PCI) of the cell based on the sequences of the PSS and the SSS, respectively. The UE may determine a location of a frame boundary of the cell based on the location of the SS/PBCH block. For example, the SS/PBCH block may indicate that it has been transmitted in accordance with a transmission pattern, wherein a SS/PBCH block in the transmission pattern is a known distance from the frame boundary.

[0143] The PBCH may use a QPSK modulation and may use forward error correction (FEC). The FEC may use polar coding. One or more symbols spanned by the PBCH may carry one or more DMRSs for demodulation of the PBCH. The PBCH may include an indication of a current system frame number (SFN) of the cell and/or a SS/PBCH block timing index. These parameters may facilitate time synchronization of the UE to the base station. The PBCH may include a master information block (MIB) used to provide the UE with one or more parameters. The MIB may be used by the UE to locate remaining minimum system information (RMSI) associated with the cell. The RMSI may include a System Information Block Type 1 (SIB1). The SIB1 may contain information needed by the UE to access the cell. The UE may use one or more parameters of the MIB to monitor PDCCH, which may be used to schedule PDSCH. The PDSCH may include the SIB1. The SIB1 may be decoded using parameters provided in the MIB. The PBCH may indicate an absence of SIB1. Based on the PBCH indicating the absence of SIB1, the UE may be pointed to a frequency. The UE may search for an SS/PBCH block at the frequency to which the UE is pointed.

[0144] The UE may assume that one or more SS/PBCH blocks transmitted with a same SS/PBCH block index are quasi co-located (QCLed) (e.g., having the same/similar Doppler spread, Doppler shift, average gain, average delay, and/or spatial Rx parameters). The UE may not assume QCL for SS/PBCH block transmissions having different SS/PBCH block indices.

[0145] SS/PBCH blocks (e.g., those within a half-frame) may be transmitted in spatial directions (e.g., using different beams that span a coverage area of the cell). In an example, a first SS/PBCH block may be transmitted in a first spatial direction using a first beam, and a second SS/PBCH block may be transmitted in a second spatial direction using a second beam.

[0146] In an example, within a frequency span of a carrier, a base station may transmit a plurality of SS/PBCH blocks. In an example, a first PCI of a first SS/PBCH block of the plurality of SS/PBCH blocks may be different from a second PCI of a second SS/PBCH block of the plurality of SS/PBCH blocks. The PCIs of SS/PBCH blocks transmitted in different frequency locations may be different or the same.

[0147] The CSI-RS may be transmitted by the base station and used by the UE to acquire channel state information (CSI). The base station may configure the UE with one or more CSI-RSs for channel estimation or any other suitable purpose. The base station may configure a UE with one or more of the same/similar CSI-RSs. The UE may measure the one or more CSI-RSs. The UE may estimate a downlink channel state and/or generate a CSI report based on the measuring of the one or more downlink CSI-RSs. The UE may provide the CSI report to the base station. The base station may use feedback provided by the UE (e.g., the estimated downlink channel state) to perform link adaptation.

[0148] The base station may semi-statically configure the UE with one or more CSI-RS resource sets. A CSI-RS resource may be associated with a location in the time and frequency domains and a periodicity. The base station may selectively activate and/or deactivate a CSI-RS resource. The base station may indicate to the UE that a CSI-RS resource in the CSI-RS resource set is activated and/or deactivated.

[0149] The base station may configure the UE to report CSI measurements. The base station may configure the UE to provide CSI reports periodically, aperiodically, or semi-persistently. For periodic CSI reporting, the UE may be configured with a timing and/or periodicity of a plurality of CSI reports. For aperiodic CSI reporting, the base station may request a CSI report. For example, the base station may command the UE to measure a configured CSI-RS resource and provide a CSI report relating to the measurements. For semi-persistent CSI reporting, the base station may configure the UE to transmit periodically, and selectively activate or deactivate the periodic reporting. The base station may configure the UE with a CSI-RS resource set and CSI reports using

RRC signaling.

[0150] The CSI-RS configuration may comprise one or more parameters indicating, for example, up to 32 antenna ports. The UE may be configured to employ the same OFDM symbols for a downlink CSI-RS and a control resource set (CORESET) when the downlink CSI-RS and CORESET are spatially QCLed and resource elements associated with the downlink CSI-RS are outside of the physical resource blocks (PRBs) configured for the CORESET. The UE may be configured to employ the same OFDM symbols for downlink CSI-RS and SS/PBCH blocks when the downlink CSI-RS and SS/PBCH blocks are spatially QCLed and resource elements associated with the downlink CSI-RS are outside of PRBs configured for the SS/PBCH blocks.

[0151] Downlink DMRSs may be transmitted by a base station and used by a UE for channel estimation. For example, the downlink DMRS may be used for coherent demodulation of one or more downlink physical channels (e.g., PDSCH). An NR network may support one or more variable and/or configurable DMRS patterns for data demodulation. At least one downlink DMRS configuration may support a front-loaded DMRS pattern. A front-loaded DMRS may be mapped over one or more OFDM symbols (e.g., one or two adjacent OFDM symbols). A base station may semi-statically configure the UE with a number (e.g. a maximum number) of front-loaded DMRS symbols for PDSCH. A DMRS configuration may support one or more DMRS ports. For example, for single user-MIMO, a DMRS configuration may support up to eight orthogonal downlink DMRS ports per UE. For multiuser-MIMO, a DMRS configuration may support up to 4 orthogonal downlink DMRS ports per UE. A radio network may support (e.g., at least for CP-OFDM) a common DMRS structure for downlink and uplink, wherein a DMRS location, a DMRS pattern, and/or a scrambling sequence may be the same or different. The base station may transmit a downlink DMRS and a corresponding PDSCH using the same precoding matrix. The UE may use the one or more downlink DMRSs for coherent demodulation/channel estimation of the PDSCH.

[0152] In an example, a transmitter (e.g., a base station) may use a precoder matrices for a part of a transmission bandwidth. For example, the transmitter may use a first precoder matrix for a first bandwidth and a second precoder matrix for a second bandwidth. The first precoder matrix and the second precoder matrix may be different based on the first bandwidth being different from the second bandwidth. The UE may assume that a same precoding matrix is used across a set of PRBs. The set of PRBs may be denoted as a precoding resource block group (PRG).

[0153] A PDSCH may comprise one or more layers. The UE may assume that at least one symbol with DMRS is present on a layer of the one or more layers of the PDSCH. A higher layer may configure up to 3 DMRSs for the PDSCH.

[0154] Downlink PT-RS may be transmitted by a base station and used by a UE for phase-noise compensation. Whether a downlink PT-RS is present or not may depend on an RRC configuration. The presence and/or pattern of the downlink PT-RS may be configured on a UE-specific basis using a combination of RRC signaling and/or an association with one or more parameters employed for other purposes (e.g., modulation and coding scheme (MCS)), which may be indicated by DCI. When configured, a dynamic presence of a downlink PT-RS may be associated with one or more DCI parameters comprising at least MCS. An NR network may support a plurality of PT-RS densities defined in the time and/or frequency domains. When present, a frequency domain density may be associated with at least one configuration of a scheduled bandwidth. The UE may assume a same precoding for a DMRS port and a PT-RS port. A number of PT-RS ports may be fewer than a number of DMRS ports in a scheduled resource. Downlink PT-RS may be confined in the scheduled time/frequency duration for the UE. Downlink PT-RS may be transmitted on symbols to facilitate phase tracking at the receiver.

[0155] The UE may transmit an uplink DMRS to a base station for channel estimation. For example, the base station may use the uplink DMRS for coherent demodulation of one or more uplink physical channels. For example, the UE may transmit an uplink DMRS with a PUSCH and/or a PUCCH. The uplink DM-RS may span a range of frequencies that is similar to a range of frequencies associated with the corresponding physical channel. The base station may configure the UE with one or more uplink DMRS configurations. At least one DMRS configuration may support a front-loaded DMRS pattern. The front-loaded DMRS may be mapped over one or more OFDM symbols (e.g., one or two adjacent OFDM symbols). One or more uplink DMRSs may be configured to transmit at one or more symbols of a PUSCH and/or a PUCCH. The base station may semi-statically configure the UE with a number (e.g. maximum number) of front-loaded DMRS symbols for the PUSCH and/or the PUCCH, which the UE may use to schedule a single-symbol DMRS and/or a double-symbol DMRS. An NR network may support (e.g., for cyclic prefix orthogonal frequency division multiplexing (CP-OFDM)) a common DMRS structure for downlink and uplink, wherein a DMRS location, a DMRS pattern, and/or a scrambling sequence for the DMRS may be the same or different.

[0156] A PUSCH may comprise one or more layers, and the UE may transmit at least one symbol with DMRS present on a layer of the one or more layers of the PUSCH. In an example, a higher layer may configure up to three DMRSs for the PUSCH.

[0157] Uplink PT-RS (which may be used by a base station for phase tracking and/or phase-noise compensation) may or may not be present depending on an RRC configuration of the UE. The presence and/or pattern of uplink PT-RS may be configured on a UE-specific basis by a combination of RRC signaling and/or one or more parameters employed for other purposes (e.g., Modulation and Coding Scheme (MCS)), which may be indicated by DCI. When configured, a dynamic presence of uplink PT-RS may be associated with one or more DCI parameters comprising at least MCS. A radio network may support a plurality of uplink PT-RS densities defined in time/frequency domain. When present, a frequency domain density may be associated with at least one configuration of a scheduled bandwidth. The UE may assume a same precoding for a DMRS port and a PT-RS port. A number of PT-RS ports may be fewer than a number of DMRS ports in a scheduled resource. For example, uplink PT-RS may be confined in the scheduled time/frequency duration for the UE.

[0158] SRS may be transmitted by a UE to a base station for channel state estimation to support uplink channel dependent scheduling and/or link adaptation. SRS transmitted by the UE may allow a base station to estimate an uplink channel state at one or more frequencies. A scheduler at the base station may employ the estimated uplink channel state to assign one or more resource blocks for an uplink PUSCH transmission from the UE. The base station may semi-statically configure the UE with one or more SRS resource sets. For an SRS resource set, the base station may configure the UE with one or more SRS resources. An SRS resource set applicability may be configured by a higher layer (e.g., RRC) parameter. For example, when a higher layer parameter indicates beam management, an SRS resource in a SRS resource set of the one or more SRS resource sets (e.g., with the same/similar time domain behavior, periodic, aperiodic, and/or the like) may be transmitted at a time instant (e.g., simultaneously). The UE may transmit one or more SRS resources in SRS resource sets. An NR network may support aperiodic, periodic and/or semi-persistent SRS transmissions. The UE may transmit SRS resources based on one or more trigger types, wherein the one or more trigger types may comprise higher layer signaling (e.g., RRC) and/or one or more DCI formats. In an example, at least one DCI format may be employed for the UE to select at least one of one or more configured SRS resource sets. An SRS trigger type 0 may refer to an SRS triggered based on a higher layer signaling. An SRS trigger type 1 may refer to an SRS triggered based on one or more DCI formats. In an example, when PUSCH and SRS are transmitted in a same slot, the UE may be configured to transmit SRS after a transmission of a PUSCH and a corresponding uplink DMRS.

[0159] The base station may semi-statically configure the UE with one or more SRS configuration parameters indicating at least one of following: a SRS resource configuration identifier; a number of SRS ports; time domain behavior of an SRS resource configuration (e.g., an indication of periodic, semi-persistent, or aperiodic SRS); slot, mini-slot, and/or subframe level periodicity;

offset for a periodic and/or an aperiodic SRS resource; a number of OFDM symbols in an SRS resource; a starting OFDM symbol of an SRS resource; an SRS bandwidth; a frequency hopping bandwidth; a cyclic shift; and/or an SRS sequence ID.

[0160] An antenna port is defined such that the channel over which a symbol on the antenna port is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed. If a first symbol and a second symbol are transmitted on the same antenna port, the receiver may infer the channel (e.g., fading gain, multipath delay, and/or the like) for conveying the second symbol on the antenna port, from the channel for conveying the first symbol on the antenna port. A first antenna port and a second antenna port may be referred to as quasi co-located (QCLed) if one or more large-scale properties of the channel over which a first symbol on the first antenna port is conveyed may be inferred from the channel over which a second symbol on a second antenna port is conveyed. The one or more large-scale properties may comprise at least one of: a delay spread; a Doppler spread; a Doppler shift; an average gain; an average delay; and/or spatial Receiving (Rx) parameters.

[0161] Channels that use beamforming require beam management. Beam management may comprise beam measurement, beam selection, and beam indication. A beam may be associated with one or more reference signals. For example, a beam may be identified by one or more beamformed reference signals. The UE may perform downlink beam measurement based on downlink reference signals (e.g., a channel state information reference signal (CSI-RS)) and generate a beam measurement report. The UE may perform the downlink beam measurement procedure after an RRC connection is set up with a base station.

[0162] FIG. **11**B illustrates an example of channel state information reference signals (CSI-RSs) that are mapped in the time and frequency domains. A square shown in FIG. **11**B may span a resource block (RB) within a bandwidth of a cell. A base station may transmit one or more RRC messages comprising CSI-RS resource configuration parameters indicating one or more CSI-RSs. One or more of the following parameters may be configured by higher layer signaling (e.g., RRC and/or MAC signaling) for a CSI-RS resource configuration: a CSI-RS resource configuration identity, a number of CSI-RS ports, a CSI-RS configuration (e.g., symbol and resource element (RE) locations in a subframe), a CSI-RS subframe configuration (e.g., subframe location, offset, and periodicity in a radio frame), a CSI-RS power parameter, a CSI-RS sequence parameter, a code division multiplexing (CDM) type parameter, a frequency density, a transmission comb, quasi co-location (QCL) parameters (e.g., QCL-scramblingidentity, crs-portscount, mbsfn-subframeconfiglist, csi-rs-configZPid, qcl-csi-rs-configNZPid), and/or other radio resource parameters.

[0163] The three beams illustrated in FIG. **11**B may be configured for a UE in a UE-specific configuration. Three beams are illustrated in FIG. **11**B (beam #**1**, beam #**2**, and beam #**3**), more or fewer beams may be configured. Beam #**1** may be allocated with CSI-RS **1101** that may be transmitted in one or more subcarriers in an RB of a first symbol. Beam #**2** may be allocated with CSI-RS **1102** that may be transmitted in one or more subcarriers in an RB of a second symbol. Beam #**3** may be allocated with CSI-RS **1103** that may be transmitted in one or more subcarriers in an RB of a third symbol. By using frequency division multiplexing (FDM), a base station may use other subcarriers in a same RB (for example, those that are not used to transmit CSI-RS **1101**) to transmit another CSI-RS associated with a beam for another UE. By using time domain multiplexing (TDM), beams used for the UE may be configured such that beams for the UE use symbols from beams of other UEs.

[0164] CSI-RSs such as those illustrated in FIG. **11**B (e.g., CSI-RS **1101**, **1102**, **1103**) may be transmitted by the base station and used by the UE for one or more measurements. For example, the UE may measure a reference signal received power (RSRP) of configured CSI-RS resources. The base station may configure the UE with a reporting configuration and the UE may report the RSRP measurements to a network (for example, via one or more base stations) based on the reporting configuration. In an example, the base station may determine, based on the reported measurement results, one or more transmission configuration indication (TCI) states comprising a number of reference signals. In an example, the base station may indicate one or more TCI states to the UE (e.g., via RRC signaling, a MAC CE, and/or a DCI). The UE may receive a downlink transmission with a receive (Rx) beam determined based on the one or more TCI states. In an example, the UE may or may not have a capability of beam correspondence. If the UE has the capability of beam correspondence, the UE may determine a spatial domain filter of a transmit (Tx) beam based on a spatial domain filter of the corresponding Rx beam. If the UE does not have the capability of beam correspondence, the UE may perform an uplink beam selection procedure to determine the spatial domain filter of the Tx beam. The UE may perform the uplink beam selection procedure based on one or more sounding reference signal (SRS) resources configured to the UE by the base station. The base station may select and indicate uplink beams for the UE based on measurements of the one or more SRS resources transmitted by the UE.

[0165] In a beam management procedure, a UE may assess (e.g., measure) a channel quality of one or more beam pair links, a beam pair link comprising a transmitting beam transmitted by a base station and a receiving beam received by the UE. Based on the assessment, the UE may transmit a beam measurement report indicating one or more beam pair quality parameters comprising, e.g., one or more beam identifications (e.g., a beam index, a reference signal index, or the like), RSRP, a precoding matrix indicator (PMI), a channel quality indicator (CQI), and/or a rank indicator (RI).

[0166] FIG. **12**A illustrates examples of three downlink beam management procedures: P**1**, P**2**, and P**3**. Procedure P**1** may enable a UE measurement on transmit (Tx) beams of a transmission reception point (TRP) (or multiple TRPs), e.g., to support a selection of one or more base station Tx beams and/or UE Rx beams (shown as ovals in the top row and bottom row, respectively, of P**1**). Beamforming at a TRP may comprise a Tx beam sweep for a set of beams (shown, in the top rows of P**1** and P**2**, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). Beamforming at a UE may comprise an Rx beam sweep for a set of beams (shown, in the bottom rows of P**1** and P**3**, as ovals rotated in a clockwise direction indicated by the dashed arrow). Procedure P**2** may be used to enable a UE measurement on Tx beams of a TRP (shown, in the top row of P**2**, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). The UE and/or the base station may perform procedure P**2** using a smaller set of beams than is used in procedure P**1**, or using narrower beams than the beams used in procedure P**1**. This may be referred to as beam refinement. The UE may perform procedure P**3** for Rx beam determination by using the same Tx beam at the base station and sweeping an Rx beam at the UE.

[0167] FIG. **12**B illustrates examples of three uplink beam management procedures: U**1**, U**2**, and U**3**. Procedure U**1** may be used to enable a base station to perform a measurement on Tx beams of a UE, e.g., to support a selection of one or more UE Tx beams and/or base station Rx beams (shown as ovals in the top row and bottom row, respectively, of U**1**). Beamforming at the UE may include, e.g., a Tx beam sweep from a set of beams (shown in the bottom rows of U**1** and U**3** as ovals rotated in a clockwise direction indicated by the dashed arrow). Beamforming at the base station may include, e.g., an Rx beam sweep from a set of beams (shown, in the top rows of U**1** and U**2**, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). Procedure U**2** may be used to enable the base station to adjust its Rx beam when the UE uses a fixed Tx beam. The UE and/or the base station may perform procedure U**2** using a smaller set of beams than is used in procedure P**1**, or using narrower beams than the beams used in procedure P**1**. This may be referred to as beam refinement The UE may perform procedure U**3** to adjust its Tx beam when the base station uses a fixed Rx beam.

[0168] A UE may initiate a beam failure recovery (BFR) procedure based on detecting a beam failure. The UE may transmit a BFR request (e.g., a preamble, a UCI, an SR, a MAC CE, and/or the like) based on the initiating of the BFR procedure. The UE may detect the beam failure based on a determination that a quality of beam pair link(s) of an associated control channel is unsatisfactory (e.g., having an error rate higher than an error rate threshold, a received signal power lower than a received signal power threshold, an expiration of a timer, and/or the like).

[0169] The UE may measure a quality of a beam pair link using one or more reference signals (RSs) comprising one or more SS/PBCH blocks, one or more CSI-RS resources, and/or one or more demodulation reference signals (DMRSs). A quality of the beam pair link may be based on one or more of a block error rate (BLER), an RSRP value, a signal to interference plus noise ratio (SINR) value, a reference signal received quality (RSRQ) value, and/or a CSI value measured on RS resources. The base station may indicate that an RS resource is quasi co-located (QCLed) with one or more DM-RSs of a channel (e.g., a control channel, a shared data channel, and/or the like). The RS resource and the one or more DMRSs of the channel may be QCLed when the channel characteristics (e.g., Doppler shift, Doppler spread, average delay, delay spread, spatial Rx parameter, fading, and/or the like) from a transmission via the RS resource to the UE are similar or the same as the channel characteristics from a transmission via the channel to the UE.

[0170] A network (e.g., a gNB and/or an ng-eNB of a network) and/or the UE may initiate a random access procedure. A UE in an RRC_IDLE state and/or an RRC_INACTIVE state may initiate the random access procedure to request a connection setup to a network. The UE may initiate the random access procedure from an RRC_CONNECTED state. The UE may initiate the random access procedure to request uplink resources (e.g., for uplink transmission of an SR when there is no PUCCH resource available) and/or acquire uplink timing (e.g., when uplink synchronization status is non-synchronized). The UE may initiate the random access procedure to request one or more system information blocks (SIBs) (e.g., other system information such as SIB2, SIB3, and/or the like). The UE may initiate the random access procedure for a beam failure recovery request. A network may initiate a random access procedure for a handover and/or for establishing time alignment for an SCell addition.

[0171] FIG. **13**A illustrates a four-step contention-based random access procedure. Prior to initiation of the procedure, a base station may transmit a configuration message **1310** to the UE. The procedure illustrated in FIG. **13**A comprises transmission of four messages: a Msg 1 **1311**, a Msg 2 **1312**, a Msg 3 **1313**, and a Msg 4 **1314**. The Msg 1 **1311** may include and/or be referred to as a preamble (or a random access preamble). The Msg 2 **1312** may include and/or be referred to as a random access response (RAR).

[0172] The configuration message **1310** may be transmitted, for example, using one or more RRC messages. The one or more RRC messages may indicate one or more random access channel (RACH) parameters to the UE. The one or more RACH parameters may comprise at least one of following: general parameters for one or more random access procedures (e.g., RACH-configGeneral); cell-specific parameters (e.g., RACH-ConfigCommon); and/or dedicated parameters (e.g., RACH-configDedicated). The base station may broadcast or multicast the one or more RRC messages to one or more UEs. The one or more RRC messages may be UE-specific (e.g., dedicated RRC messages transmitted to a UE in an RRC_CONNECTED state and/or in an RRC_INACTIVE state). The UE may determine, based on the one or more RACH parameters, a time-frequency resource and/or an uplink transmit power for transmission of the Msg 1 **1311** and/or the Msg 3 **1313**. Based on the one or more RACH parameters, the UE may determine a reception timing and a downlink channel for receiving the Msg 2 **1312** and the Msg 4 **1314**.

[0173] The one or more RACH parameters provided in the configuration message **1310** may indicate one or more Physical RACH (PRACH) occasions available for transmission of the Msg 1 **1311**. The one or more PRACH occasions may be predefined. The one or more RACH parameters may indicate one or more available sets of one or more PRACH occasions (e.g., prach-ConfigIndex). The one or more RACH parameters may indicate an association between (a) one or more PRACH occasions and (b) one or more reference signals. The one or more RACH parameters may indicate an association between (a) one or more preambles and (b) one or more reference signals. The one or more reference signals may be SS/PBCH blocks and/or CSI-RSs. For example, the one or more RACH parameters may indicate a number of SS/PBCH blocks mapped to a PRACH occasion and/or a number of preambles mapped to a SS/PBCH blocks.

[0174] The one or more RACH parameters provided in the configuration message **1310** may be used to determine an uplink transmit power of Msg 1 **1311** and/or Msg 3 **1313**. For example, the one or more RACH parameters may indicate a reference power for a preamble transmission (e.g., a received target power and/or an initial power of the preamble transmission). There may be one or more power offsets indicated by the one or more RACH parameters. For example, the one or more RACH parameters may indicate: a power ramping step; a power offset between SSB and CSI-RS; a power offset between transmissions of the Msg 1 **1311** and the Msg 3 **1313**; and/or a power offset value between preamble groups. The one or more RACH parameters may indicate one or more thresholds based on which the UE may determine at least one reference signal (e.g., an SSB and/or CSI-RS) and/or an uplink carrier (e.g., a normal uplink (NUL) carrier and/or a supplemental uplink (SUL) carrier).

[0175] The Msg 1 **1311** may include one or more preamble transmissions (e.g., a preamble transmission and one or more preamble retransmissions). An RRC message may be used to configure one or more preamble groups (e.g., group A and/or group B). A preamble group may comprise one or more preambles. The UE may determine the preamble group based on a pathloss measurement and/or a size of the Msg 3 **1313**. The UE may measure an RSRP of one or more reference signals (e.g., SSBs and/or CSI-RSs) and determine at least one reference signal having an RSRP above an RSRP threshold (e.g., rsrp-ThresholdSSB and/or rsrp-ThresholdCSI-RS). The UE may select at least one preamble associated with the one or more reference signals and/or a selected preamble group, for example, if the association between the one or more preambles and the at least one reference signal is configured by an RRC message.

[0176] The UE may determine the preamble based on the one or more RACH parameters provided in the configuration message **1310**. For example, the UE may determine the preamble based on a pathloss measurement, an RSRP measurement, and/or a size of the Msg 3 **1313**. As another example, the one or more RACH parameters may indicate: a preamble format; a maximum number of preamble transmissions; and/or one or more thresholds for determining one or more preamble groups (e.g., group A and group B). A base station may use the one or more RACH parameters to configure the UE with an association between one or more preambles and one or more reference signals (e.g., SSBs and/or CSI-RSs). If the association is configured, the UE may determine the preamble to include in Msg 1 **1311** based on the association. The Msg 1 **1311** may be transmitted to the base station via one or more PRACH occasions. The UE may use one or more reference signals (e.g., SSBs and/or CSI-RSs) for selection of the preamble and for determining of the PRACH occasion. One or more RACH parameters (e.g., ra-ssb-OccasionMskIndex and/or ra-OccasionList) may indicate an association between the PRACH occasions and the one or more reference signals.

[0177] The UE may perform a preamble retransmission if no response is received following a preamble transmission. The UE may increase an uplink transmit power for the preamble retransmission. The UE may select an initial preamble transmit power based on a pathloss measurement and/or a target received preamble power configured by the network. The UE may determine to retransmit a preamble and may ramp up the uplink transmit power. The UE may receive one or more RACH parameters (e.g., PREAMBLE_POWER_RAMPING_STEP) indicating a ramping step for the preamble retransmission. The ramping step may be an amount of incremental increase in uplink transmit power for a retransmission. The UE may ramp up the uplink transmit power if the UE determines a reference signal (e.g., SSB and/or CSI-RS) that is the same as a previous preamble transmission. The UE may count a number of preamble transmissions and/or retransmissions (e.g., PREAMBLE_TRANSMISSION_COUNTER). The UE may determine that a random access procedure completed unsuccessfully, for example, if the number of preamble transmissions exceeds a threshold configured by the one or more RACH parameters (e.g., preambleTransMax).

[0178] The Msg 2 **1312** received by the UE may include an RAR. In some scenarios, the Msg 2 **1312** may include multiple RARs corresponding to multiple UEs. The Msg 2 **1312** may be received after or in response to the transmitting of the Msg 1 **1311**. The Msg 2 **1312** may be scheduled on the DL-SCH and indicated on a PDCCH using a random access RNTI (RA-RNTI). The Msg 2 **1312** may indicate that the Msg 1 **1311** was received by the base station. The Msg 2 **1312** may include a time-alignment command that may be used by the UE to adjust the UE's transmission timing, a scheduling grant for transmission of the Msg 3 **1313**, and/or a Temporary Cell RNTI (TC-RNTI). After transmitting a preamble, the UE may start a time window (e.g., ra-ResponseWindow) to monitor a PDCCH for the Msg 2 **1312**. The UE may determine when to start the time window based on a PRACH occasion that the UE uses to transmit the preamble. For example, the UE may start the time window one or more symbols after a last symbol of the preamble (e.g., at a first PDCCH occasion from an end of a preamble transmission). The one or more symbols may be determined based on a numerology. The PDCCH may be in a common search space (e.g., a Type1-PDCCH common search space) configured by an RRC message. The UE may identify the RAR based on a Radio Network Temporary Identifier (RNTI). RNTIs may be used depending on one or more events initiating the random access procedure. The UE may use random access RNTI (RA-RNTI). The RA-RNTI may be associated with PRACH occasions in which the UE transmits a preamble. For example, the UE may determine the RA-RNTI based on: an OFDM symbol index; a slot index; a frequency domain index; and/or a UL carrier indicator of the PRACH occasions. An example of RA-RNTI may be as follows:

[0179] $\text{RA-RNTI}=1+s\_id+14\times t\_id+14\times 80\times f\_id+14\times 80\times 8\times ul\_carrier\_id$, where s_id may be an index of a first OFDM symbol of the PRACH occasion (e.g., $0\leq s\_id<14$), t_id may be an index of a first slot of the PRACH occasion in a system frame (e.g., $0\leq t\_id<80$), f_id may be an index of the PRACH occasion in the frequency domain (e.g., $0\leq f\_id<8$), and ul_carrier_id may be a UL carrier used for a preamble transmission (e.g., 0 for an NUL carrier, and 1 for an SUL carrier).

[0180] The UE may transmit the Msg 3 **1313** in response to a successful reception of the Msg 2 **1312** (e.g., using resources identified in the Msg 2 **1312**). The Msg 3 **1313** may be used for contention resolution in, for example, the contention-based random access procedure illustrated in FIG. **13**A. In some scenarios, a plurality of UEs may transmit a same preamble to a base station and the base station may provide an RAR that corresponds to a UE. Collisions may occur if the plurality of UEs interpret the RAR as corresponding to themselves. Contention resolution (e.g., using the Msg 3 **1313** and the Msg 4 **1314**) may be used to increase the likelihood that the UE does not incorrectly use an identity of another the UE. To perform contention resolution, the UE may include a device identifier in the Msg 3 **1313** (e.g., a C-RNTI if assigned, a TC-RNTI included in the Msg 2 **1312**, and/or any other suitable identifier).

[0181] The Msg 4 **1314** may be received after or in response to the transmitting of the Msg 3 **1313**. If a C-RNTI was included in the Msg 3 **1313**, the base station will address the UE on the PDCCH using the C-RNTI. If the UE's unique C-RNTI is detected on the PDCCH, the random access procedure is determined to be successfully completed. If a TC-RNTI is included in the Msg 3 **1313** (e.g., if the UE is in an RRC_IDLE state or not otherwise connected to the base station), Msg 4 **1314** will be received using a DL-SCH associated with the TC-RNTI. If a MAC PDU is successfully decoded and a MAC PDU comprises the UE contention resolution identity MAC CE that matches or otherwise corresponds with the CCCH SDU sent (e.g., transmitted) in Msg 3 **1313**, the UE may determine that the contention resolution is successful and/or the UE may determine that the random access procedure is successfully completed.

[0182] The UE may be configured with a supplementary uplink (SUL) carrier and a normal uplink (NUL) carrier. An initial access (e.g., random access procedure) may be supported in an uplink carrier. For example, a base station may configure the UE with two separate RACH configurations: one for an SUL carrier and the other for an NUL carrier. For random access in a cell configured with an SUL carrier, the network may indicate which carrier to use (NUL or SUL). The UE may determine the SUL carrier, for example, if a measured quality of one or more reference signals is lower than a broadcast threshold. Uplink transmissions of the random access procedure (e.g., the Msg 1 **1311** and/or the Msg 3 **1313**) may remain on the selected carrier. The UE may switch an uplink carrier during the random access procedure (e.g., between the Msg 1 **1311** and the Msg 3 **1313**) in one or more cases. For example, the UE may determine and/or switch an uplink carrier for the Msg 1 **1311** and/or the Msg 3 **1313** based on a channel clear assessment (e.g., a listen-before-talk).

[0183] FIG. **13**B illustrates a two-step contention-free random access procedure. Similar to the four-step contention-based random access procedure illustrated in FIG. **13**A, a base station may, prior to initiation of the procedure, transmit a configuration message **1320** to the UE. The configuration message **1320** may be analogous in some respects to the configuration message **1310**. The procedure illustrated in FIG. **13**B comprises transmission of two messages: a Msg 1 **1321** and a Msg 2 **1322**. The Msg 1 **1321** and the Msg 2 **1322** may be analogous in some respects to the Msg 1 **1311** and a Msg 2 **1312** illustrated in FIG. **13**A, respectively. As will be understood from FIGS. **13**A and **13**B, the contention-free random access procedure may not include messages analogous to the Msg 3 **1313** and/or the Msg 4 **1314**.

[0184] The contention-free random access procedure illustrated in FIG. **13**B may be initiated for a beam failure recovery, other SI request, SCell addition, and/or handover. For example, a base station may indicate or assign to the UE the preamble to be used for the Msg 1 **1321**. The UE may receive, from the base station via PDCCH and/or RRC, an indication of a preamble (e.g., ra-PreambleIndex).

[0185] After transmitting a preamble, the UE may start a time window (e.g., ra-Response Window) to monitor a PDCCH for the RAR. In the event of a beam failure recovery request, the base station may configure the UE with a separate time window and/or a separate PDCCH in a search space indicated by an RRC message (e.g., recoverySearchSpaceId). The UE may monitor for a PDCCH transmission addressed to a Cell RNTI (C-RNTI) on the search space. In the contention-free random access procedure illustrated in FIG. **13**B, the UE may determine that a random access procedure successfully completes after or in response to transmission of Msg 1 **1321** and reception of a corresponding Msg 2 **1322**. The UE may determine that a random access procedure successfully completes, for example, if a PDCCH transmission is addressed to a C-RNTI. The UE may determine that a random access procedure successfully completes, for example, if the UE receives an RAR comprising a preamble identifier corresponding to a preamble transmitted by the UE and/or the RAR comprises a MAC sub-PDU with the preamble identifier. The UE may determine the response as an indication of an acknowledgement for an SI request.

[0186] FIG. **13**C illustrates another two-step random access procedure. Similar to the random access procedures illustrated in FIGS. **13**A and **13**B, a base station may, prior to initiation of the procedure, transmit a configuration message **1330** to the UE. The configuration message **1330** may be analogous in some respects to the configuration message **1310** and/or the configuration message **1320**. The procedure illustrated in FIG. **13**C comprises transmission of two messages: a Msg A **1331** and a Msg B **1332**.

[0187] Msg A **1331** may be transmitted in an uplink transmission by the UE. Msg A **1331** may comprise one or more transmissions of a preamble **1341** and/or one or more transmissions of a transport block **1342**. The transport block **1342** may comprise contents that are similar and/or equivalent to the contents of the Msg 3 **1313** illustrated in FIG. **13**A. The transport block **1342** may comprise UCI (e.g., an SR, a HARQ ACK/NACK, and/or the like). The UE may receive the Msg B **1332** after or in response to transmitting the Msg A **1331**. The Msg B **1332** may comprise contents that are similar and/or equivalent to the contents of the Msg 2 **1312** (e.g., an RAR) illustrated in FIGS. **13**A and **13**B and/or the Msg 4 **1314** illustrated in FIG. **13**A.

[0188] The UE may initiate the two-step random access procedure in FIG. **13**C for licensed spectrum and/or unlicensed spectrum. The UE may determine, based on one or more factors, whether to initiate the two-step random access procedure. The one or more factors may be: a radio access technology in use (e.g., LTE, NR, and/or the like); whether the UE has valid TA or not; a cell size; the UE's RRC state; a type of spectrum (e.g., licensed vs. unlicensed); and/or any other suitable factors.

[0189] The UE may determine, based on two-step RACH parameters included in the configuration message **1330**, a radio resource and/or an uplink transmit power for the preamble **1341** and/or the transport block **1342** included in the Msg A **1331**. The RACH parameters may indicate a modulation and coding schemes (MCS), a time-frequency resource, and/or a power control for the preamble **1341** and/or the transport block **1342**. A time-frequency resource for transmission of the preamble **1341** (e.g., a PRACH) and a time-frequency resource for transmission of the transport block **1342** (e.g., a PUSCH) may be multiplexed using FDM, TDM, and/or CDM. The RACH parameters may enable the UE to determine a reception timing and a downlink channel for monitoring for and/or receiving Msg B **1332**.

[0190] The transport block **1342** may comprise data (e.g., delay-sensitive data), an identifier of the UE, security information, and/or device information (e.g., an International Mobile Subscriber Identity (IMSI)). The base station may transmit the Msg B **1332** as a response to the Msg A **1331**. The Msg B **1332** may comprise at least one of following: a preamble identifier; a timing advance command; a power control command; an uplink grant (e.g., a radio resource assignment and/or an MCS); a UE identifier for contention resolution; and/or an RNTI (e.g., a C-RNTI or a TC-RNTI). The UE may determine that the two-step random access procedure is successfully completed if: a preamble identifier in the Msg B **1332** is matched to a preamble transmitted by the UE; and/or the identifier of the UE in Msg B **1332** is matched to the identifier of the UE in the Msg A **1331** (e.g., the transport block **1342**).

[0191] A UE and a base station may exchange control signaling. The control signaling may be referred to as L1/L2 control signaling and may originate from the PHY layer (e.g., layer 1) and/or the MAC layer (e.g., layer 2). The control signaling may comprise downlink control signaling transmitted from the base station to the UE and/or uplink control signaling transmitted from the UE to the base station.

[0192] The downlink control signaling may comprise: a downlink scheduling assignment; an uplink scheduling grant indicating uplink radio resources and/or a transport format; a slot format information; a preemption indication; a power control command; and/or any other suitable signaling. The UE may receive the downlink control signaling in a payload transmitted by the base station on a physical downlink control channel (PDCCH). The payload transmitted on the PDCCH may be referred to as downlink control information (DCI). In some scenarios, the PDCCH may be a group common PDCCH (GC-PDCCH) that is common to a group of UEs.

[0193] A base station may attach one or more cyclic redundancy check (CRC) parity bits to a DCI in order to facilitate detection of transmission errors. When the DCI is intended for a UE (or a group of the UEs), the base station may scramble the CRC parity bits with an identifier of the UE (or an identifier of the group of the UEs). Scrambling the CRC parity bits with the identifier may comprise Modulo-2 addition (or an exclusive OR operation) of the identifier value and the CRC parity bits. The identifier may comprise a 16-bit value of a radio network temporary identifier (RNTI).

[0194] DCIs may be used for different purposes. A purpose may be indicated by the type of RNTI used to scramble the CRC parity bits. For example, a DCI having CRC parity bits scrambled with a paging RNTI (P-RNTI) may indicate paging information and/or a system information change notification. The P-RNTI may be predefined as “FFFE” in hexadecimal. A DCI having CRC parity bits scrambled with a system information RNTI (SI-RNTI) may indicate a broadcast transmission of the system information. The SI-RNTI may be predefined as “FFFF” in hexadecimal. A DCI having CRC parity bits scrambled with a random access RNTI (RA-RNTI) may indicate a random access response (RAR). A DCI having CRC parity bits scrambled with a cell RNTI (C-RNTI) may indicate a dynamically scheduled unicast transmission and/or a triggering of PDCCH-ordered random access. A DCI having CRC parity bits scrambled with a temporary cell RNTI (TC-RNTI) may indicate a contention resolution (e.g., a Msg 3 analogous to the Msg 3 **1313** illustrated in FIG. **13**A). Other RNTIs configured to the UE by a base station may comprise a Configured Scheduling RNTI (CS-RNTI), a Transmit Power Control-PUCCH RNTI (TPC-PUCCH-RNTI), a Transmit Power Control-PUSCH RNTI (TPC-PUSCH-RNTI), a Transmit Power Control-SRS RNTI (TPC-SRS-RNTI), an Interruption RNTI (INT-RNTI), a Slot Format Indication RNTI (SFI-RNTI), a Semi-Persistent CSI RNTI (SP-CSI-RNTI), a Modulation and Coding Scheme Cell RNTI (MCS-C-RNTI), and/or the like.

[0195] Depending on the purpose and/or content of a DCI, the base station may transmit the DCIs with one or more DCI formats. For example, DCI format 0_0 may be used for scheduling of PUSCH in a cell. DCI format 0_0 may be a fallback DCI format (e.g., with compact DCI payloads). DCI format 0_1 may be used for scheduling of PUSCH in a cell (e.g., with more DCI payloads than DCI format 0_0). DCI format 1_0 may be used for scheduling of PDSCH in a cell. DCI format 1_0 may be a fallback DCI format (e.g., with compact DCI payloads). DCI format 1_1 may be used for scheduling of PDSCH in a cell (e.g., with more DCI payloads than DCI format 1_0). DCI format 2_0 may be used for providing a slot format indication to a group of UEs. DCI format 2_1 may be used for notifying a group of UEs of a physical resource block and/or OFDM symbol where the UE may assume no transmission is intended to the UE. DCI format 2_2 may be used for transmission of a transmit power control (TPC) command for PUCCH or PUSCH. DCI format 2_3 may be used for transmission of a group of TPC commands for SRS transmissions by one or more UEs. DCI format(s) for new functions may be defined in future releases. DCI formats may have different DCI sizes, or may share the same DCI size.

[0196] After scrambling a DCI with a RNTI, the base station may process the DCI with channel coding (e.g., polar coding), rate matching, scrambling and/or QPSK modulation. A base station may map the coded and modulated DCI on resource elements used and/or configured for a PDCCH. Based on a payload size of the DCI and/or a coverage of the base station, the base station may transmit the DCI via a PDCCH occupying a number of contiguous control channel elements (CCEs). The number of the contiguous CCEs (referred to as aggregation level) may be 1, 2, 4, 8, 16, and/or any other suitable number. A CCE may comprise a number (e.g., 6) of resource-element groups (REGs). A REG may comprise a resource block in an OFDM symbol. The mapping of the coded and modulated DCI on the resource elements may be based on mapping of CCEs and REGs (e.g., CCE-to-REG mapping).

[0197] FIG. **14**A illustrates an example of CORESET configurations for a bandwidth part. The base station may transmit a DCI via a PDCCH on one or more control resource sets (CORESETs). A CORESET may comprise a time-frequency resource in which the UE tries to decode a DCI using one or more search spaces. The base station may configure a CORESET in the time-frequency domain. In the example of FIG. **14**A, a first CORESET **1401** and a second CORESET **1402** occur at the first symbol in a slot. The first CORESET **1401** overlaps with the second CORESET **1402** in the frequency domain. A third CORESET **1403** occurs at a third symbol in the slot. A fourth CORESET **1404** occurs at the seventh symbol in the slot. CORESETs may have a different number of resource blocks in frequency domain.

[0198] FIG. **14**B illustrates an example of a CCE-to-REG mapping for DCI transmission on a CORESET and PDCCH processing. The CCE-to-REG mapping may be an interleaved mapping (e.g., for the purpose of providing frequency diversity) or a non-interleaved mapping (e.g., for the purposes of facilitating interference coordination and/or frequency-selective transmission of control channels). The base station may perform different or same CCE-to-REG mapping on different CORESETs. A CORESET may be associated with a CCE-to-REG mapping by RRC configuration. A CORESET may be configured with an antenna port quasi co-location (QCL) parameter. The antenna port QCL parameter may indicate QCL information of a demodulation reference signal

(DMRS) for PDCCH reception in the CORESET.

[0199] The base station may transmit, to the UE, RRC messages comprising configuration parameters of one or more CORESETs and one or more search space sets. The configuration parameters may indicate an association between a search space set and a CORESET. A search space set may comprise a set of PDCCH candidates formed by CCEs at a given aggregation level. The configuration parameters may indicate: a number of PDCCH candidates to be monitored per aggregation level; a PDCCH monitoring periodicity and a PDCCH monitoring pattern; one or more DCI formats to be monitored by the UE; and/or whether a search space set is a common search space set or a UE-specific search space set. A set of CCEs in the common search space set may be predefined and known to the UE. A set of CCEs in the UE-specific search space set may be configured based on the UE's identity (e.g., C-RNTI).

[0200] As shown in FIG. **14**B, the UE may determine a time-frequency resource for a CORESET based on RRC messages. The UE may determine a CCE-to-REG mapping (e.g., interleaved or non-interleaved, and/or mapping parameters) for the CORESET based on configuration parameters of the CORESET. The UE may determine a number (e.g., at most 10) of search space sets configured on the CORESET based on the RRC messages. The UE may monitor a set of PDCCH candidates according to configuration parameters of a search space set. The UE may monitor a set of PDCCH candidates in one or more CORESETs for detecting one or more DCIs. Monitoring may comprise decoding one or more PDCCH candidates of the set of the PDCCH candidates according to the monitored DCI formats. Monitoring may comprise decoding a DCI content of one or more PDCCH candidates with possible (or configured) PDCCH locations, possible (or configured) PDCCH formats (e.g., number of CCEs, number of PDCCH candidates in common search spaces, and/or number of PDCCH candidates in the UE-specific search spaces) and possible (or configured) DCI formats. The decoding may be referred to as blind decoding. The UE may determine a DCI as valid for the UE, in response to CRC checking (e.g., scrambled bits for CRC parity bits of the DCI matching a RNTI value). The UE may process information contained in the DCI (e.g., a scheduling assignment, an uplink grant, power control, a slot format indication, a downlink preemption, and/or the like).

[0201] The UE may transmit uplink control signaling (e.g., uplink control information (UCI)) to a base station. The uplink control signaling may comprise hybrid automatic repeat request (HARQ) acknowledgements for received DL-SCH transport blocks. The UE may transmit the HARQ acknowledgements after receiving a DL-SCH transport block. Uplink control signaling may comprise channel state information (CSI) indicating channel quality of a physical downlink channel. The UE may transmit the CSI to the base station. The base station, based on the received CSI, may determine transmission format parameters (e.g., comprising multi-antenna and beamforming schemes) for a downlink transmission. Uplink control signaling may comprise scheduling requests (SR). The UE may transmit an SR indicating that uplink data is available for transmission to the base station. The UE may transmit a UCI (e.g., HARQ acknowledgements (HARQ-ACK), CSI report, SR, and the like) via a physical uplink control channel (PUCCH) or a physical uplink shared channel (PUSCH). The UE may transmit the uplink control signaling via a PUCCH using one of several PUCCH formats.

[0202] There may be five PUCCH formats and the UE may determine a PUCCH format based on a size of the UCI (e.g., a number of uplink symbols of UCI transmission and a number of UCI bits). PUCCH format 0 may have a length of one or two OFDM symbols and may include two or fewer bits. The UE may transmit UCI in a PUCCH resource using PUCCH format 0 if the transmission is over one or two symbols and the number of HARQ-ACK information bits with positive or negative SR (HARQ-ACK/SR bits) is one or two. PUCCH format 1 may occupy a number between four and fourteen OFDM symbols and may include two or fewer bits. The UE may use PUCCH format 1 if the transmission is four or more symbols and the number of HARQ-ACK/SR bits is one or two. PUCCH format 2 may occupy one or two OFDM symbols and may include more than two bits.

The UE may use PUCCH format 2 if the transmission is over one or two symbols and the number of UCI bits is two or more. PUCCH format 3 may occupy a number between four and fourteen OFDM symbols and may include more than two bits. The UE may use PUCCH format 3 if the transmission is four or more symbols, the number of UCI bits is two or more and PUCCH resource does not include an orthogonal cover code. PUCCH format 4 may occupy a number between four and fourteen OFDM symbols and may include more than two bits. The UE may use PUCCH format 4 if the transmission is four or more symbols, the number of UCI bits is two or more and the PUCCH resource includes an orthogonal cover code.

[0203] The base station may transmit configuration parameters to the UE for a plurality of PUCCH resource sets using, for example, an RRC message. The plurality of PUCCH resource sets (e.g., up to four sets) may be configured on an uplink BWP of a cell. A PUCCH resource set may be configured with a PUCCH resource set index, a plurality of PUCCH resources with a PUCCH resource being identified by a PUCCH resource identifier (e.g., pucch-Resourceid), and/or a number (e.g. a maximum number) of UCI information bits the UE may transmit using one of the plurality of PUCCH resources in the PUCCH resource set. When configured with a plurality of PUCCH resource sets, the UE may select one of the plurality of PUCCH resource sets based on a total bit length of the UCI information bits (e.g., HARQ-ACK, SR, and/or CSI). If the total bit length of UCI information bits is two or fewer, the UE may select a first PUCCH resource set having a PUCCH resource set index equal to “0”. If the total bit length of UCI information bits is greater than two and less than or equal to a first configured value, the UE may select a second PUCCH resource set having a PUCCH resource set index equal to “1”. If the total bit length of UCI information bits is greater than the first configured value and less than or equal to a second configured value, the UE may select a third PUCCH resource set having a PUCCH resource set index equal to “2”. If the total bit length of UCI information bits is greater than the second configured value and less than or equal to a third value (e.g., 1406), the UE may select a fourth PUCCH resource set having a PUCCH resource set index equal to “3”.

[0204] After determining a PUCCH resource set from a plurality of PUCCH resource sets, the UE may determine a PUCCH resource from the PUCCH resource set for UCI (HARQ-ACK, CSI, and/or SR) transmission. The UE may determine the PUCCH resource based on a PUCCH resource indicator in a DCI (e.g., with a DCI format 1_0 or DCI for 1_1) received on a PDCCH. A three-bit PUCCH resource indicator in the DCI may indicate one of eight PUCCH resources in the PUCCH resource set. Based on the PUCCH resource indicator, the UE may transmit the UCI (HARQ-ACK, CSI and/or SR) using a PUCCH resource indicated by the PUCCH resource indicator in the DCI.

[0205] FIG. **15** illustrates an example of a wireless device **1502** in communication with a base station **1504** in accordance with embodiments of the present disclosure. The wireless device **1502** and base station **1504** may be part of a mobile communication network, such as the mobile communication network **100** illustrated in FIG. **1**A, the mobile communication network **150** illustrated in FIG. **1**B, or any other communication network. Only one wireless device **1502** and one base station **1504** are illustrated in FIG. **15**, but it will be understood that a mobile communication network may include more than one UE and/or more than one base station, with the same or similar configuration as those shown in FIG. **15**.

[0206] The base station **1504** may connect the wireless device **1502** to a core network (not shown) through radio communications over the air interface (or radio interface) **1506**. The communication direction from the base station **1504** to the wireless device **1502** over the air interface **1506** is known as the downlink, and the communication direction from the wireless device **1502** to the base station **1504** over the air interface is known as the uplink. Downlink transmissions may be separated from uplink transmissions using FDD, TDD, and/or some combination of the two duplexing techniques.

[0207] In the downlink, data to be sent to the wireless device **1502** from the base station **1504** may be provided to the processing system **1508** of the base station **1504**. The data may be provided to the processing system **1508** by, for example, a core network. In the uplink, data to be sent to the base station **1504** from the wireless device **1502** may be provided to the processing system **1518** of the wireless device **1502**. The processing system **1508** and the processing system **1518** may implement layer 3 and layer 2 OSI functionality to process the data for transmission. Layer 2 may include an SDAP layer, a PDCP layer, an RLC layer, and a MAC layer, for example, with respect to FIG. **2**A, FIG. **2**B, FIG. **3**, and FIG. **4**A. Layer 3 may include an RRC layer as with respect to FIG. **2**B.

[0208] After being processed by processing system **1508**, the data to be sent to the wireless device **1502** may be provided to a transmission processing system **1510** of base station **1504**. Similarly, after being processed by the processing system **1518**, the data to be sent to base station **1504** may be provided to a transmission processing system **1520** of the wireless device **1502**. The transmission processing system **1510** and the transmission processing system **1520** may implement layer 1 OSI functionality. Layer 1 may include a PHY layer with respect to FIG. **2**A, FIG. **2**B, FIG. **3**, and FIG. **4**A. For transmit processing, the PHY layer may perform, for example, forward error correction coding of transport channels, interleaving, rate matching, mapping of transport channels to physical channels, modulation of physical channel, multiple-input multiple-output (MIMO) or multi-antenna processing, and/or the like.

[0209] At the base station **1504**, a reception processing system **1512** may receive the uplink transmission from the wireless device **1502**. At the wireless device **1502**, a reception processing system **1522** may receive the downlink transmission from base station **1504**. The reception processing system **1512** and the reception processing system **1522** may implement layer 1 OSI functionality. Layer 1 may include a PHY layer with respect to FIG. **2**A, FIG. **2**B, FIG. **3**, and FIG. **4**A. For receive processing, the PHY layer may perform, for example, error detection, forward error correction decoding, deinterleaving, demapping of transport channels to physical channels, demodulation of physical channels, MIMO or multi-antenna processing, and/or the like.

[0210] As shown in FIG. **15**, a wireless device **1502** and the base station **1504** may include multiple antennas. The multiple antennas may be used to perform one or more MIMO or multi-antenna techniques, such as spatial multiplexing (e.g., single-user MIMO or multi-user MIMO), transmit/receive diversity, and/or beamforming. In other examples, the wireless device **1502** and/or the base station **1504** may have a single antenna.

[0211] The processing system **1508** and the processing system **1518** may be associated with a memory **1514** and a memory **1524**, respectively. Memory **1514** and memory **1524** (e.g., one or more non-transitory computer readable mediums) may store computer program instructions or code that may be executed by the processing system **1508** and/or the processing system **1518** to carry out one or more of the functionalities discussed in the present application. Although not shown in FIG. **15**, the transmission processing system **1510**, the transmission processing system **1520**, the reception processing system **1512**, and/or the reception processing system **1522** may be coupled to a memory (e.g., one or more non-transitory computer readable mediums) storing computer program instructions or code that may be executed to carry out one or more of their respective functionalities.

[0212] The processing system **1508** and/or the processing system **1518** may comprise one or more controllers and/or one or more processors. The one or more controllers and/or one or more processors may comprise, for example, a general-purpose processor, a digital signal processor (DSP), a microcontroller, an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) and/or other programmable logic device, discrete gate and/or transistor logic, discrete hardware components, an on-board unit, or any combination thereof. The processing system **1508** and/or the processing system **1518** may perform at least one of signal coding/processing, data processing, power control, input/output processing, and/or any other functionality that may enable the wireless device **1502** and the base station **1504** to operate in a wireless environment.

[0213] The processing system **1508** and/or the processing system **1518** may be connected to one or more peripherals **1516** and one or more peripherals **1526**, respectively. The one or more peripherals **1516** and the one or more peripherals **1526** may include software and/or hardware that provide features and/or functionalities, for example, a speaker, a microphone, a keypad, a display, a touchpad, a power source, a satellite transceiver, a universal serial bus (USB) port, a hands-free headset, a frequency modulated (FM) radio unit, a media player, an Internet browser, an electronic control unit (e.g., for a motor vehicle), and/or one or more sensors (e.g., an accelerometer, a gyroscope, a temperature sensor, a radar sensor, a lidar sensor, an ultrasonic sensor, a light sensor, a camera, and/or the like). The processing system **1508** and/or the processing system **1518** may receive user input data from and/or provide user output data to the one or more peripherals **1516** and/or the one or more peripherals **1526**. The processing system **1518** in the wireless device **1502** may receive power from a power source and/or may be configured to distribute the power to the other components in the wireless device **1502**. The power source may comprise one or more sources of power, for example, a battery, a solar cell, a fuel cell, or any combination thereof. The processing system **1508** and/or the processing system **1518** may be connected to a GPS chipset **1517** and a GPS chipset **1527**, respectively. The GPS chipset **1517** and the GPS chipset **1527** may be configured to provide geographic location information of the wireless device **1502** and the base station **1504**, respectively.

[0214] FIG. **16**A illustrates an example structure for uplink transmission. A baseband signal representing a physical uplink shared channel may perform one or more functions. The one or more functions may comprise at least one of: scrambling; modulation of scrambled bits to generate complex-valued symbols; mapping of the complex-valued modulation symbols onto one or several transmission layers; transform precoding to generate complex-valued symbols; precoding of the complex-valued symbols; mapping of precoded complex-valued symbols to resource elements; generation of complex-valued time-domain Single Carrier-Frequency Division Multiple Access (SC-FDMA) or CP-OFDM signal for an antenna port; and/or the like. In an example, when transform precoding is enabled, a SC-FDMA signal for uplink transmission may be generated. In an example, when transform precoding is not enabled, an CP-OFDM signal for uplink transmission may be generated by FIG. **16**A. These functions are illustrated as examples and it is anticipated that other mechanisms may be implemented in various embodiments.

[0215] FIG. **16**B illustrates an example structure for modulation and up-conversion of a baseband signal to a carrier frequency. The baseband signal may be a complex-valued SC-FDMA or CP-OFDM baseband signal for an antenna port and/or a complex-valued Physical Random Access Channel (PRACH) baseband signal. Filtering may be employed prior to transmission.

[0216] FIG. **16**C illustrates an example structure for downlink transmissions. A baseband signal representing a physical downlink channel may perform one or more functions. The one or more functions may comprise: scrambling of coded bits in a codeword to be transmitted on a physical channel; modulation of scrambled bits to generate complex-valued modulation symbols; mapping of the complex-valued modulation symbols onto one or several transmission layers; precoding of the complex-valued modulation symbols on a layer for transmission on the antenna ports; mapping of complex-valued modulation symbols for an antenna port to resource elements; generation of complex-valued time-domain OFDM signal for an antenna port; and/or the like. These functions are illustrated as examples and it is anticipated that other mechanisms may be implemented in various embodiments.

[0217] FIG. **16**D illustrates another example structure for modulation and up-conversion of a baseband signal to a carrier frequency. The baseband signal may be a complex-valued OFDM baseband signal for an antenna port. Filtering may be employed prior to transmission.

[0218] A wireless device may receive from a base station one or more messages (e.g. RRC messages) comprising configuration parameters of a plurality of cells (e.g. primary cell, secondary cell). The wireless device may communicate with at least one base station (e.g. two or more base stations in dual-connectivity) via the plurality of cells. The one or more messages (e.g. as a part of the configuration parameters) may comprise parameters of physical, MAC, RLC, PCDP, SDAP, RRC layers for configuring the wireless device. For example, the configuration parameters may comprise parameters for configuring physical and MAC layer channels, bearers, etc. For example, the configuration parameters may comprise parameters indicating values of timers for physical, MAC, RLC, PCDP, SDAP, RRC layers, and/or communication channels.

[0219] A timer may begin running once it is started and continue running until it is stopped or until it expires. A timer may be started if it is not running or restarted if it is running. A timer may be associated with a value (e.g. the timer may be started or restarted from a value or may be started from zero and expire once it reaches the value). The duration of a timer may not be updated until the timer is stopped or expires (e.g., due to BWP switching). A timer may be used to measure a time period/window for a process. When the specification refers to an implementation and procedure related to one or more timers, it will be understood that there are multiple ways to implement the one or more timers. For example, it will be understood that one or more of the multiple ways to implement a timer may be used to measure a time period/window for the procedure. For example, a random access response window timer may be used for measuring a window of time for receiving a random access response. In an example, instead of starting and expiry of a random access response window timer, the time difference between two time stamps may be used. When a timer is restarted, a process for measurement of time window may be restarted. Other example implementations may be provided to restart a measurement of a time window.

[0220] In an example, a base station and a wireless device may use a plurality of downlink control information (DCI) formats to communicate control information to schedule downlink data and/or uplink data or to deliver control information. For example, a DCI format 0_0 may be used to schedule an uplink resource for a PUSCH over a cell. A DCI format 0_1 may be used to schedule one or more PUSCHs in one cell or may be used to indicate downlink feedback information for configured grant PUSCH (CG-DFI). A DCI format 0_2 may be used to schedule a resource for a PUSCH in one cell. Similarly, for downlink scheduling, a DCI format 1_0 may schedule a resource for a PDSCH in one cell. A DCI format 1_1 may be used to schedule a PDSCH in one cell or trigger one shot HARQ-ACK feedback. A DCI format 1_2 may be used to schedule a resource for a PDSCH in one cell. There are one or more DCI formats carrying non-scheduling information. For example, a DCI format 2_0 may be used to indicate a slot formation information for one or more slots of one or more cells. A DCI format 2_2 may be used to indicate one or more transmit power control commands for PUCCH and PUSCH. A DCI format 2_3 may be used to indicate one or more transmit power control for SRS. A DCI format 2_4 may be used to indicate an uplink cancellation information. A DCI format 2_5 may be used to indicate a preemption information. A DCI format 2_6 may be used to indicate a power saving state outside of DRX active time. A DCI format 3_0 or 3_1 may be used to schedule NR sidelink resource or LTE sidelink resource in one cell.

[0221] FIG. **17** illustrates example cases of various DCI formats. In an example, a DCI format 0_0 and a DCI format 1_0 may be referred as a fallback DCI format for scheduling uplink and downlink respectively. In an example, a DCI format 0_1 and a DCI format 1_1 may be referred as a non-fallback DCI format scheduling uplink and downlink respectively. In an example, a DCI format 0_2 and a DCI format 1_2 may be referred as a compact DCI format for scheduling uplink and downlink respectively. A base station may configure one or more DCI formats for scheduling downlink and/or uplink resources. FIG. **17** illustrates that a DCI format 0_0, 0_1 and 0_2 may be used to schedule uplink resource(s) for one or more PUSCHs. A DCI format 1_0, 1_1 and 1_2 may be used to schedule downlink resource(s) for one or more PDSCHs. A DCI format 2_0, 2_1, 2_2, 2_3, 2_4, 2_5 and 2_6 may be used for a group-common DCI transmission. Each format of DCI format 2_x may be used for different information. For example, the DCI format 2_4 may be used to indicate uplink resources for a group of wireless devices. In response to receiving a DCI based on the DCI format 2_4, a wireless device may cancel any uplink resource, scheduled prior to the receiving, when the uplink resource may be overlapped with the indicated uplink resources.

[0222] A DCI format may comprise one or more DCI fields. A DCI field may have a DCI size. A wireless device may determine one or more bitfield sizes of one or more DCI fields of the DCI format based on one or more radio resource control (RRC) configuration parameters by a base station. For example, the one or more RRC configuration parameters may be transmitted via master information block (MIB). For example, the one or more RRC configuration parameters may be transmitted via system information blocks (SIBs). For example, the one or more RRC configuration parameters may be transmitted via one or more a wireless device specific messages. For example, the wireless device may determine one or more DCI sizes of one or more DCI fields of a DCI format 0_0 based on the one or more RRC configuration parameters transmitted via the MIB and/or the SIBs. The wireless device may be able to determine the one or more DCI sizes of the DCI format 0_0 without receiving any the wireless device specific message. Similarly, the wireless device may determine one or more DCI sizes of one or more second DCI fields of a DCI format 1_0 based on the one or more RRC configuration parameters transmitted via the MIB and/or the SIBs.

[0223] For example, the wireless device may determine one or more first DCI sizes of one or more first DCI fields of a DCI format 0_1 based on one or more RRC configuration parameters transmitted via the MIB and/or the SIBs and/or the wireless device specific RRC message(s). The wireless device may determine one or more bitfield sizes of the one or more first DCI fields based on the one or more RRC configuration parameters. For example, FIG. **19** may illustrate the one or more first DCI fields of the DCI format 0_1. In FIG. **19**, there are one or more second DCI fields that may present in the DCI format 0_1 regardless of the wireless device specific RRC message(s). For example, the DCI format 0_1 may comprise a 1-bit DL/UL indicator where the bit is configured with zero (‘0’) to indicate an uplink grant for the DCI format 0_1. DCI field(s) shown in dotted boxes may not be present or a size of the DCI field(s) may be configured as zero. For example, a carrier indicator may be present when the DCI format 0_1 is used to schedule a cell based on cross-carrier scheduling. The carrier indicator may indicate a cell index of a scheduled cell by the cross-carrier scheduling. For example, UL/SUL indicator (shown UL/SUL in FIG. **18**) may indicate whether a DCI based the DCI format 0_1 schedules a resource for an uplink carrier or a supplemental uplink. The UL/SUL indicator field may be present when the wireless device is configured with a supplemental uplink for a scheduled cell of the DCI. Otherwise, the UL/SUL indicator field may not be present.

[0224] A field of BWP index may indicate a bandwidth part indicator. The base station may transmit configuration parameters indicating one or more uplink BWPs for the scheduled cell. The wireless device may determine a bit size of the field of BWP index based on a number of the one or more uplink BWPs. For example, 1 bit may be used. The number of the one or more uplink BWPs (excluding an initial UL BWP) is two. The field of BWP index may be used to indicate an uplink BWP switching. The wireless device may switch to a first BWP in response to receiving the DCI indicating an index of the first BWP. The first BWP is different from an active uplink BWP (active before receiving the DCI).

[0225] A DCI field of frequency domain resource allocation (frequency domain RA in FIGS. **18-19**) may indicate uplink resource(s) of the scheduled cell. For example, the base station may transmit configuration parameters indicating a resource allocation type 0. With the resource allocation type 0, a bitmap over one or more resource block groups (RBGs) may schedule the uplink resource(s). With a resource allocation type 1, a starting PRB index and a length of the scheduled uplink resource(s) may be indicated. The base station may transmit configuration parameters indicating a dynamic change between the resource allocation type 0 and the resource allocation type 1 (e.g., ‘dynamicswitch’). The wireless device may determine a field size of the frequency domain RA field based on the configured resource allocation type and a bandwidth of an active UL BWP of the scheduled cell. For example, when the resource allocation type 0 is configured, the bitmap may indicate each of the one or more RBGs covering the bandwidth of the active UL BWP. A size of the bitmap may be determined based on a number of the one or more RBGs of the active UL BWP. For example, the wireless device may determine the size of the frequency domain RA field based on the resource allocation type 1 based on the bandwidth of the active uplink BWP (e.g., ceil (log 2(BW(BW+1)/2), wherein BW is the bandwidth of the active uplink BWP).

[0226] The wireless device may determine a resource allocation indicator value (RIV) table, where an entry of the table may comprise a starting PRB index and a length value. For example, when the dynamic change between the resource allocation type 0 and the resource allocation type 1 is used, a larger size between a first size based on the resource allocation type 0 (e.g., the bitmap size) and a second size based on the resource allocation type 1 (e.g., the RIV table size) with additional 1 bit indication to indicate either the resource allocation type 0 or the resource allocation type 1. For example, the frequency domain RA field may indicate a frequency hopping offset. The base station may use K (e.g., 1 bit for two offset values, 2 bits for up to four offset values) bit(s) to indicate the frequency hopping offset from one or more configured offset values, based on the resource allocation type 1. The base station may use ceil (log 2(BW(BW+1)/2)−K bits to indicate the uplink resource(s) based on the resource allocation type 1, when frequency hopping is enabled.

[0227] A DCI field of time domain resource allocation (time domain RA shown in FIG. **18**) may indicate time domain resource of one or more slots of the scheduled cell. The base station may transmit configuration parameters indicating one or more time domain resource allocation lists of a time domain resource allocation table for an uplink BWP of the scheduled cell. The wireless device may determine a bit size of the time domain RA field based on a number of the one or more time domain resource allocation lists of the time domain resource allocation table. The base station may indicate a frequency hopping flag by a FH flag (shown as FH in FIG. **18**). For example, the FH flag may present when the base station may enable a frequency hopping of the scheduled cell or the active UL BWP of the scheduled cell. A DCI field of modulation and coding scheme (MCS) (shown as MCS in FIG. **18**) may indicate a coding rate and a modulation scheme for the scheduled uplink data. A new data indicator (NDI) field may indicate whether the DCI schedules the uplink resource(s) for a new/initial transmission or a retransmission. A redundancy version (RV) field may indicate one or more RV values (e.g., a RV value may be 0, 2, 3, or 1) for one or more PUSCHs scheduled over the one or more slots of the scheduled cells. For example, the DCI may schedule a single PUSCH via one slot, a RV value is indicated. For example, the DCI may schedule two PUSCHs via two slots, two RV values may be indicated. A number of PUSCHs scheduled by a DCI may be indicated in a time domain resource allocation list of the one or more time domain resource allocation lists.

[0228] A DCI field of hybrid automatic repeat request (HARQ) process number (HARQ process # in FIG. **18**) may indicate an index of a HARQ process used for the one or more PUSCHs. The wireless device may determine one or more HARQ processes for the one or more PUSCHs based on the index of the HARQ process. The wireless device may determine the index for a first HARQ process of a first PUSCH of the one or more PUSCHs and select a next index as a second HARQ process of a second PUSCH of the one or more PUSCHs and so on. The DCI format 0_1 may have a first downlink assignment index (1.sup.st DAI) and/or a second DAI (2.sup.nd DAI). The first DAI may be used to indicate a first size of bits of first HARQ-ACK codebook group. The second DAI may be present when the base station may transmit configuration parameters indicating a plurality of HARQ-ACK codebook groups. When there is no HARQ-ACK codebook group configured, the wireless device may assume the first HARQ-ACK codebook group only. The second DAI may indicate a second size of bits of second HARQ-ACK codebook group. The first DAI may be 1 bit when a semi-static HARQ-ACK codebook generation mechanism is used. The first DAI may be 2 bits or 4 bits when a dynamic HARQ-ACK codebook generation mechanism is used.

[0229] A field of transmission power control (TPC shown in FIG. **18**) may indicate a power offset value to adjust transmission power of the one or more scheduled PUSCHs. A field of sounding reference signal (SRS) resource indicator (SRI) may indicate an index of one or more configured SRS resources of an SRS resource set. A field of precoding information and number of layers (shown as PMI in FIG. **18**) may indicate a precoding and a MIMO layer information for the one or more scheduled PUSCHs. A field of antenna ports may indicate DMRS pattern(s) for the one or more scheduled PUSCHs. A field of SRS request may indicate to trigger a SRS transmission of a SRS resource or skip SRS transmission. A field of CSI request may indicate to trigger a CSI feedback based on a CSI-RS configuration or skip CSI feedback. A field of code block group (CBG) transmission information (CBGTI) may indicate HARQ-ACK feedback(s) for one or more CBGs. A field of phase tracking reference signal (PTRS)-demodulation reference signal (DMRS) association (shown as PTRS in FIG. **18**) may indicate an association between one or more ports of PTRS and one or more ports of DM-RS. The one or more ports may be indicated in the field of antenna ports. A field of beta_offset indicator (beta offset in FIG. **18**) may indicate a code rate for transmission of uplink control information (UCI) via a PUSCH of the one or more scheduled PUSCHs. A field of DM-RS sequence initialization (shown as DMRS in FIG. **18**) may present based on a configuration of transform precoding. A field of UL-SCH indicator (UL-SCH) may indicate whether a UCI may be transmitted via a PUSCH of the one or more scheduled PUSCHs or not. A field of open loop power control parameter set indication (open loop power in FIG. **18**) may indicate a set of power control configuration parameters. The wireless device is configured with one or more sets of power control configuration parameters. A field of priority indicator (priority) may indicate a priority value of the one or more scheduled PUSCHs. A field of invalid symbol pattern indicator (invalid OS) may indicate one or more unavailable/not-available OFDM symbols to be used for the one or more scheduled PUSCHs. A field of SCell dormancy indication (Scell dormancy) may indicate transitioning between a dormant state and a normal state of one or more secondary cells.

[0230] Note that additional DCI field(s), though not shown in FIG. **18**, may present for the DCI format 0_1. For example, a downlink feedback information (DFI) field indicating for one or more configured grant resources may present for an unlicensed/shared spectrum cell. For example, the unlicensed/shared spectrum cell is a scheduled cell. When the DCI format 0_1 is used for indicating downlink feedback information for the one or more configured grant resources, other DCI fields may be used to indicate a HARQ-ACK bitmap for the one or more configured grant resources and TPC commands for a scheduled PUSCH. Remaining bits may be reserved and filled with zeros (‘0’s).

[0231] FIG. **18** shows an example of a DCI format 1_1. For example, the DCI format 1_1 may schedule a downlink resource for a scheduled downlink cell. The DCI format 1_1 may comprise one or more DCI fields such as an identifier for DCI formats (DL/UL), a carrier indicator, bandwidth part indicator (BWP index), a frequency domain resource assignment (frequency domain RA), a time domain resource assignment (time domain RA), a virtual resource block to physical resource block mapping (VRB-PRB), Physical resource block (PRB) bundling size indicator (PRB bundle), rate matching indicator (rate matching), zero power CSI-RS (ZP-CSI), a MCS, a NDI, a RV, a HARQ process number, a downlink assignment index (DAI), a TPC command for a PUCCH, a PUCCH resource indicator (PUCCH-RI), a PDSCH-to-HARQ_feedback timing indicator (PDSCH-to-HARQ in FIG. **18**), an antenna ports, a transmission configuration indication (TCI), a SRS request, a CBG transmission information (CBGTI), a CBG flushing out information (CBGFI), DMRS sequence initialization (DMRS), a priority indicator (priority), and a minimum applicable scheduling offset indicator.

[0232] For example, the VRB-PRB field may indicate whether a mapping is based on a virtual RB or a physical RB. For example, the PRB bundle may indicate a size of PRB bundle when a dynamic PRB bundling is enabled. For example, the rate matching may indicate one or more rate matching resources where the scheduled data may be mapped around based on the rate matching. For example, the ZP-CSI field may indicate a number of aperiodic ZP CSI-RS resource sets configured by the base station. For example, the DCI format 1_1 may also include MCS, NDI and RV for a second transport block, in response to a max number of codewords scheduled by DCI may be configured as two. The DCI format 1_1 may not include MCS, NDI and RV field for the second transport block, in response to the max number of codewords scheduled by DCI may be configured as one. For example, the DAI field may indicate a size of bits of HARQ-ACK codebook. The TPC field may indicate a power offset for the scheduled PUCCH. The wireless device may transmit the scheduled PUCCH comprising HARQ-ACK bit(s) of the scheduled downlink data by the DCI. The PUCCH-RI may indicate a PUCCH resource of one or more PUCCH resources configured by the base station. The PDSCH-to-HARQ field may indicate a timing offset between an end of a scheduled PDSCH by the DCI and a starting of the scheduled PUCCH. The field of antenna ports may indicate DMRS patterns for the scheduled PDSCH. The TCI field may indicate a TCI code point of one or more active TCI code points/active TCI states. The base station may transmit configuration parameters indicating one or more TCI states for the scheduled cell. The base station may active one or more second TCI states of the one or more TCI states via one or more MAC CEs/DCIs. The wireless device may map an active TCI code point of the one or more active TCI code points to an active TCI of the one or more second TCI states. For example, the CBGTI may indicate whether to flush a soft buffer corresponding to a HARQ process indicated by the HARQ process #. For example, the Min scheduling field may indicate enable or disable applying a configured minimum scheduling offset (e.g., when a minimum scheduling offset is configured) or select a first minimum scheduling offset or a second minimum scheduling offset (e.g., when the first minimum scheduling offset and the second minimum scheduling offset are configured).

[0233] For example, the wireless device may determine one or more first DCI sizes of one or more first DCI fields of a DCI format 0_2 based on one or more RRC configuration parameters transmitted via the MIB and/or the SIBs and/or the wireless device specific RRC message(s). The wireless device may determine one or more bitfield sizes of the one or more first DCI fields based on the one or more RRC configuration parameters. For example, there are one or more second DCI fields that may present in the DCI format 0_2 regardless of the wireless device specific RRC message(s). For example, the one or more second DCI fields may comprise at least one of DL/UL indicator, frequency domain resource allocation, MCS, NDI, and TPC fields. For example, the one or more first DCI fields may comprise the one or more second DCI fields and one or more third DCI fields. A DCI field of the one or more third DCI fields may be present or may not be present based on one or more configuration parameters transmitted by the base station. For example, the one or more third DCI fields may comprise at least one of a BWP index, RV, HARQ process #, PMI, antenna ports, and/or beta offset.

[0234] For example, the DCI format 0_2 may comprise a 1-bit DL/UL indicator where the bit is configured with zero ('0') to indicate an uplink grant for the DCI format 0_2. For example, a carrier indicator may be present when the DCI format 0_2 is used to schedule a cell based on cross-carrier scheduling. The carrier indicator may indicate a cell index of a scheduled cell by the cross-carrier scheduling. For example, UL/SUL indicator (shown UL/SUL in FIG. **18**) may indicate whether a DCI based the DCI format 0_2 schedules a resource for an uplink carrier or a supplemental uplink. The UL/SUL indicator field may be present when the wireless device is configured with a supplemental uplink for a scheduled cell of the DCI. Otherwise, the UL/SUL indicator field is not present.

[0235] A field of BWP index may indicate a bandwidth part indicator. The base station may transmit configuration parameters indicating one or more uplink BWPs for the scheduled cell. The wireless device may determine a bit size of the field of BWP index based on a number of the one or more uplink BWPs. For example, 1 bit may be used. The number of the one or more uplink BWPs (excluding an initial UL BWP) is two. The field of BWP index may be used to indicate an uplink BWP switching. The wireless device may switch to a first BWP in response to receiving the DCI indicating an index of the first BWP. The first BWP is different from an active uplink BWP (active before receiving the DCI).

[0236] A DCI field of frequency domain resource allocation (frequency domain RA in FIG. **18**) may indicate uplink resource(s) of the scheduled cell. For example, the base station may transmit configuration parameters indicating a resource allocation type 0. With the resource allocation type 0, a bitmap over one or more resource block groups (RBGs) may schedule the uplink resource(s). With a resource allocation type 1, a starting PRB index and a length of the scheduled uplink resource(s) may be indicated. In an example, a length may be a multiple of K1 resource blocks. For example, the configuration parameters may comprise a resource allocation type1 granularity for the DCI format 0_2 (e.g., K1). A default value of the K1 may be one ('1'). The base station may transmit configuration parameters indicating a dynamic change between the resource allocation type 0 and the resource allocation type 1 (e.g., 'dynamicswitch'). The wireless device may determine a field size of the frequency domain RA field based on the configured resource allocation type and a bandwidth of an active UL BWP of the scheduled cell. The wireless device may further determine the field size of the frequency domain RA field based on the K1 value, when the resource allocation type 1 may be used/configured. For example, when the resource allocation type 0 is configured, the bitmap may indicate each of the one or more RBGs covering the bandwidth of the active UL BWP. A size of the bitmap may be determined based on a number of the one or more RBGs of the active UL BWP. For example, the wireless device may determine the size of the frequency domain RA field based on the resource allocation type 1 based on the bandwidth of the active uplink BWP (e.g., ceil (log 2(BW/K1 (BW/K1+1)/2) and the resource allocation type1 granularity. E.g., the BW is the bandwidth of the active uplink BWP. E.g., the K1 is the resource allocation type1 granularity.).

[0237] The wireless device may determine a resource allocation indicator value (RIV) table, where an entry of the table may comprise a starting PRB index and a length value. The wireless device may determine the RIV table based on the resource allocation type1 granularity. For example, when the dynamic change between the resource allocation type 0 and the resource allocation type 1 is used, a larger size between a first size based on the resource allocation type 0 (e.g., the bitmap size) and a second size based on the resource allocation type 1 (e.g., the RIV table size) with additional 1 bit indication to indicate either the resource allocation type 0 or the resource allocation type 1. For example, the frequency domain RA field may indicate a frequency hopping offset. The base station may use K (e.g., 1 bit for two offset values, 2 bits for up to four offset values) bit(s) to indicate the frequency hopping offset from one or more configured offset values, based on the resource allocation type 1. The base station may use ceil (log 2(BW/K1(BW/K1+1)/2)−K bits to indicate the uplink resource(s) based on the resource allocation type 1, when frequency hopping is enabled. Otherwise, the base station/wireless device may use ceil (log 2(BW/K1(BW/K1+1)/2) bits to indicate the uplink resource(s) based on the resource allocation type 1.

[0238] In an example, a base station may transmit one or more messages comprising configuration parameters of a BWP of a cell. The configuration parameters may comprise a resource allocation type for one or more PUSCHs scheduled by one or more DCIs, based on a first RNTI. The resource allocation type may be a resource allocation type 0 or a resource allocation type 1 or a dynamic switching between the resource allocation type 0 and the resource allocation type 1. For example, the first RNTI is a C-RNTI. The configuration parameters may comprise a configured grant configuration or a SPS configuration. The configuration parameters may indicate a resource allocation type for the configured grant configuration or the SPS configuration. The resource allocation type may be a resource allocation type 0 or a resource allocation type 1 or a dynamic switching between the resource allocation type 0 and the resource allocation type 1.

[0239] A DCI field of time domain resource allocation (time domain RA shown in FIG. **18**) may indicate time domain resource of one or more slots of the scheduled cell. The base station may transmit configuration parameters indicating one or more time domain resource allocation lists of a time domain resource allocation table for an uplink BWP of the scheduled cell. The wireless device may determine a bit size of the time domain RA field based on a number of the one or more time domain resource allocation lists of the time domain resource allocation table. The base station may indicate a frequency hopping flag by a FH flag (shown as FH in FIG. **18**). For example, the FH flag may present when the base station may enable a frequency hopping of the scheduled cell or the active UL BWP of the scheduled cell. A DCI field of modulation and coding scheme (MCS) (shown as MCS in FIG. **18**) may indicate a coding rate and a modulation scheme for the scheduled uplink data. In an example, a bit size of the MCS field may be predetermined as a constant (e.g., 5 bits). A new data indicator (NDI) field may indicate whether the DCI schedules the uplink resource(s) for a new/initial transmission or a retransmission. A bit size of the NDI may be fixed as a constant value (e.g., 1 bit). A redundancy version (RV) field may indicate one or more RV values (e.g., a RV value may be 0, 2, 3, or 1) for one or more PUSCHs scheduled over the one or more slots of the scheduled cells. For example, the DCI may schedule a single PUSCH via one slot, a RV value is indicated. For example, the DCI may schedule two PUSCHs via two slots, two RV values may be indicated. A number of PUSCHs scheduled by a DCI may be indicated in a time domain resource allocation list of the one or more time domain resource allocation lists. The configuration parameters may comprise a bit size of the RV field. For example, the bit size may be 0, 1 or 2 bits for a single PUSCH. When the bit size is configured as zero (‘0’), the wireless device may apply a RV=0 for any uplink resource scheduled by a DCI based on the DCI format 0_2.

[0240] A DCI field of hybrid automatic repeat request (HARQ) process number (HARQ process # in FIG. **18**) may indicate an index of a HARQ process used for the one or more PUSCHs. The wireless device may determine one or more HARQ processes for the one or more PUSCHs based on the index of the HARQ process. The wireless device may determine the index for a first HARQ process of a first PUSCH of the one or more PUSCHs and select a next index as a second HARQ process of a second PUSCH of the one or more PUSCHs and so on. The configuration parameters may comprise a bit size for the HARQ process # field. For example, the bit size may be 0, 1, 2, 3 or 4 bits for a single PUSCH. The wireless device may assume that a HARQ process index=0 in case the bit size is configured as zero. The wireless device may assume that a HARQ process index in a range of [0, 1] when the bit size is configured as one. The wireless device may assume that a HARQ process index in a range of [0, . . . , 3] when the bit size is configured as two. The wireless device may assume that a HARQ process index in a range of [0, . . . , 7] when the bit size is configured as three. For the 4 bits of bit size, the wireless device may use a HARQ process in a range of [0, . . . , 15].

[0241] The DCI format 0_2 may have a first downlink assignment index (1.sup.st DAI) and/or a second DAI (2.sup.nd DAI). The configuration parameters may comprise a parameter to indicate whether to use DAI for the DCI format 0_2 (e.g., DownlinkassignmentindexForDCIFormat0_2). The first DAI may be used to indicate a first size of bits of first HARQ-ACK codebook group. The second DAI may be present when the base station may transmit configuration parameters indicating a plurality of HARQ-ACK codebook groups. When there is no HARQ-ACK codebook group configured, the wireless device may assume the first HARQ-ACK codebook group only. The second DAI may indicate a second size of bits of second HARQ-ACK codebook group. The first DAI may be 1 bit when a semi-static HARQ-ACK codebook generation mechanism is used. The first DAI may be 2 bits or 4 bits when a dynamic HARQ-ACK codebook generation mechanism is used.

[0242] A field of transmission power control (TPC shown in FIG. **18**) may indicate a power offset value to adjust transmission power of the one or more scheduled PUSCHs. A field of sounding reference signal (SRS) resource indicator (SRI) may indicate an index of one or more configured

SRS resources of an SRS resource set. A field of precoding information and number of layers (shown as PMI in FIG. **18**) may indicate a precoding and a MIMO layer information for the one or more scheduled PUSCHs. A field of antenna ports may indicate DMRS pattern(s) for the one or more scheduled PUSCHs. A field of SRS request may indicate to trigger a SRS transmission of a SRS resource or skip SRS transmission. A field of CSI request may indicate to trigger a CSI feedback based on a CSI-RS configuration or skip CSI feedback. A field of phase tracking reference signal (PTRS)-demodulation reference signal (DMRS) association (shown as PTRS in FIG. **18**) may indicate an association between one or more ports of PTRS and one or more ports of DM-RS. The one or more ports may be indicated in the field of antenna ports. A field of beta_offset indicator (beta offset in FIG. **18**) may indicate a code rate for transmission of uplink control information (UCI) via a PUSCH of the one or more scheduled PUSCHs. A field of DM-RS sequence initialization (shown as DMRS in FIG. **18**) may present based on a configuration of transform precoding. A field of UL-SCH indicator (UL-SCH) may indicate whether a UCI may be transmitted via a PUSCH of the one or more scheduled PUSCHs or not. A field of open loop power control parameter set indication (open loop power in FIG. **18**) may indicate a set of power control configuration parameters. The wireless device is configured with one or more sets of power control configuration parameters. A field of priority indicator (priority) may indicate a priority value of the one or more scheduled PUSCHs. A field of invalid symbol pattern indicator (invalid OS) may indicate one or more unavailable/not-available OFDM symbols to be used for the one or more scheduled PUSCHs.

[0243] Note that additional DCI field(s), though not shown in FIG. **18**, may present for the DCI format 0_1/0_2. For example, a downlink feedback information (DFI) field indicating for one or more configured grant resources may present for an unlicensed/shared spectrum cell. For example, the unlicensed/shared spectrum cell is a scheduled cell. When the DCI format 0_2 is used for indicating downlink feedback information for the one or more configured grant resources, other DCI fields may be used to indicate a HARQ-ACK bitmap for the one or more configured grant resources and TPC commands for a scheduled PUSCH. Remaining bits may be reserved and filled with zeros (‘0’s).

[0244] FIG. **19** shows an example of a DCI format 1_1 and/or 1_2. For example, the DCI format 1_1 or 1_2 may schedule a downlink resource for a scheduled downlink cell. The DCI format 1_1 or 1_2 may comprise one or more DCI fields such as an identifier for DCI formats (DL/UL), a carrier indicator, bandwidth part indicator (BWP index), a frequency domain resource assignment (frequency domain RA), a time domain resource assignment (time domain RA), a virtual resource block to physical resource block mapping (VRB-PRB), Physical resource block (PRB) bundling size indicator (PRB bundle), rate matching indicator (rate matching), zero power CSI-RS (ZP-CSI), a MCS, a NDI, a RV, a HARQ process number, a downlink assignment index (DAI), a TPC command for a PUCCH, a PUCCH resource indicator (PUCCH-RI), a PDSCH-to-HARQ_feedback timing indicator (PDSCH-to-HARQ in FIG. **19**), an antenna ports, a transmission configuration indication (TCI), a SRS request, DMRS sequence initialization (DMRS), and a priority indicator (priority).

[0245] The base station may transmit one or more messages indicating configuration parameters for the DCI format 1_2. The configuration parameters may comprise one or more DCI bit sizes and/or related configuration parameters/values for the one or more DCI fields.

[0246] For example, the VRB-PRB field may indicate whether a mapping is based on a virtual RB or a physical RB. For example, the PRB bundle may indicate a size of PRB bundle when a dynamic PRB bundling is enabled. For example, the rate matching may indicate one or more rate matching resources where the scheduled data may be mapped around based on the rate matching. For example, the ZP-CSI field may indicate a number of aperiodic ZP CSI-RS resource sets configured by the base station. For example, the DCI format 1_2 may also include MCS, NDI and RV for a second transport block, in response to a max number of codewords scheduled by DCI may be configured as two. The DCI format 1_2 may not include MCS, NDI and RV field for the second transport block. For example, the DAI field may indicate a size of bits of HARQ-ACK codebook. The TPC field may indicate a power offset for the scheduled PUCCH. The wireless device may transmit the scheduled PUCCH comprising HARQ-ACK bit(s) of the scheduled downlink data by the DCI. The PUCCH-RI may indicate a PUCCH resource of one or more PUCCH resources configured by the base station. The PDSCH-to-HARQ field may indicate a timing offset between an end of a scheduled PDSCH by the DCI and a starting of the scheduled PUCCH. The field of antenna ports may indicate DMRS patterns for the scheduled PDSCH. The TCI field may indicate a TCI code point of one or more active TCI code points/active TCI states. The base station may transmit configuration parameters indicating one or more TCI states for the scheduled cell. The base station may active one or more second TCI states of the one or more TCI states via one or more MAC CEs/DCIs. The wireless device may map an active TCI code point of the one or more active TCI code points to an active TCI of the one or more second TCI states.

[0247] In an example, a base station may transmit one or more RRC messages indicating configuration parameters. The configuration parameters may comprise a parameter of a number of code words scheduled by a DCI (e.g., maxNrofCodeWordsScheduledByDCI). The number of code words scheduled by a DCI may indicate a maximum number of transport block(s) schedulable by a single DCI. The parameter may indicate two, where a wireless device may expect that a single DCI may schedule up to two transport blocks by the single DCI. When the number of code words scheduled by a DCI is configured greater than one or the number of code words scheduled by a DCI is configured via the one or more RRC messages, the wireless device may determine a downlink scheduling DCI and/or an uplink grant DCI comprising a first MCS field and a second MCS field. For example, the first MCS field may indicate a MCS value corresponding to a first transport block of the up to two transport blocks (TBs). The second MCS field may indicate a MCS value corresponding to a second TB of the up to two transport blocks.

[0248] For example, when a number of code words scheduled by a DCI is K, the wireless device may expect that K number of MCS fields carried via the DCI. For example, each MCS field of the K number of MCS fields may correspond to each TB of up to K TBs.

[0249] Additionally, the downlink scheduling DCI and/or the uplink grant DCI may comprise a first NDI field for the first TB and a second NDI field for the second TB. The downlink scheduling DCI and/or the uplink grant DCI may comprise a first RV field for the first TB and a second RV field for the second TB. The base station may schedule up to K TBs via a single DCI, where K is a value indicated by the number of code words scheduled by a DCI. When the number of code words scheduled by a DCI (e.g., maxNrofCodeWordsScheduledByDCI) is not present or is not configured or is not explicitly transmitted via one or more RRC messages, the wireless device may assume that K is 1. Based on a parameter of maxNrofCodeWordsScheduledByDCI, the wireless device may determine a first DCI format of a downlink scheduling DCI and/or a second DCI format of an uplink scheduling DCI. For example, the wireless device may determine that the first DCI format and/or the second DCI format comprises K number of MCS fields, where each MCS field of the K number of MCS fields correspond to each TB of up to K TBs. For example, the wireless device may determine that the first DCI format and/or the second DCI format comprises K number of RV fields, where each RV field of the K number of RV fields correspond to each TB of up to K TBs. For example, the wireless device may determine that the first DCI format and/or the second DCI format comprises K number of NDI fields, where each NDI field of the K number of NDI fields correspond to each TB of up to K TBs.

[0250] The base station may set a first MCS field of a first DCI based on the first DCI format with a first value and set a first RV field of the first DCI with a second value. For example, the first MCS field and the first RV field of the first DCI may correspond to a first TB of the up to K TBs. For example, the first value is a first predefined value (e.g., 26). For example, the second value may be a second predefined value (e.g., 1). The wireless device may determine whether the first

MCS field of the first DCI is equal to the first predefined value and the first RV field of the first DCI is equal to the second predefined value. Based on the determining, the wireless device may consider a corresponding TB, of the up to K TBs, of the first RV field and the first MCS field is disabled. The wireless device may consider that the first DCI has not scheduled the corresponding TB based on the considering the corresponding TB is disabled. The wireless device may not perform a HARQ combining operation or a HARQ operation (e.g., store in a HARQ buffer) for the disabled TB. For example, the wireless device may skip performing decoding the disabled transport block. The wireless device may generate acknowledgement for the disabled transport block for a HARQ feedback. The wireless device may skip transmission of a HARQ feedback bit corresponding to the disabled transport block. The wireless device may skip generating a HARQ feedback bit corresponding to the disabled transport block.

[0251] In an example, the base station may not disable a first transport block of up to K transport blocks scheduled by a DCI. The first transport block is scheduled by a first MCS field, a first RV field and a first NDI field. For example, the first MCS field may present, in the DCI, before one or more MCS fields for one or more TBs of the up to K TBs. For example, the first NDI field may present, in the DCI, before one or more NDI fields for the one or more TBs of the up to K TBs. In an example, the base station may not disable a second TB and may enable a third TB via a second DCI, where corresponding DCI fields of the second TB may present before DCI fields of the second TB. The base station may disable one or more second TBs of the up to K TBs from a last transport block. For example, the base station may disable one or more last TBs of the up to K TBs based on setting a MCS field, for a TB of the one or more last TBs, to a first predefined value and a RV field, for a TB of the one or more last TBs, to a second predefined value.

[0252] FIG. **20** illustrates an example of a disabling one or more transport blocks by a DCI based on a DCI format. In an example, the DCI may schedule resources for a cell, where the DCI may schedule up to K TBs for the cell. The DCI format may support scheduling information up to K TBs for the cell. For example, the DCI format may be a DCI format 1_1. For example, the DCI format may be a DCI format 0_1. For example, the DCI format may be a DCI format 1_2. For example, the DCI format may be a DCI format 0_2. For example, the DCI format may be a DCI format 3_0. For example, the DCI format may be a DCI format 3_1. The DCI format may comprise one or more DCI fields that are common to each TB of the up to K TBs. For example, FIG. **20** illustrates that a BWP index, a frequency domain resource assignment (frequency domain RA), a time domain resource assignment (time domain RA), a downlink assignment index (DAI), and/or DCI field of a DM-RS (DM-RS) are common to the up to K TBs scheduled by the DCI. The DCI format may have one or more second DCI fields separate for each TB of the up to K TBs. For example, the one or more second DCI fields may comprise an MCS field. The one or more second DCI fields may comprise an NDI field. The one or more second DCI fields may comprise a RV field.

[0253] For example, a base station may set a first MCS field (e.g., MCS #**2**) to a first predefined value for a second TB (TB #**2**) and set a first RV field (e.g., RV #**2**) to a second predefined value for the second TB. A wireless device may determine the first MCS field being set to the first predefined value and the first RV field set to the second predefined value. In response to the determining, the wireless device may determine that the second TB (TB #**2**) is disabled or deactivated or not scheduled by the DCI. In FIG. **20**, the wireless device determines that the second TB (TB #**2**) is disabled based on the MCS #**2** being set to ‘a’ and RV #**2** being se to ‘b’. For example, a value of ‘a’ is 26. For example, a value of ‘b’ is 1. The wireless device may consider a first TB (TB #**1**) is enabled in response to a value of MCS field (MCS #**1**) being different from the first predefined value (e.g., a first value) and a value of RV field (RV #**1**) being different form the second predefined value.

[0254] FIG. **21** illustrates an example of embodiments of a multi-carrier or multi-cell scheduling. When a wireless device is configured with a multi-carrier or multi-cell scheduling for a plurality of serving cells of configured serving cells, the wireless device may receive a DCI that indicates resource assignment(s) and/or CSI/SRS requests for at least one cell of the plurality of serving cells. The DCI may indicate resource assignments for the plurality of serving cells. The DCI may indicate a CSI request for one or more cells of the plurality of serving cells. The DCI may indicate a SRS request for one or more second cells of the plurality of serving cells. The DCI may schedule one or more transport blocks for one or more third cells of the plurality of serving cells. The DCI may schedule downlink data for the plurality of serving cells. The DCI may schedule uplink data for the plurality of serving cells.

[0255] Based on the DCI, the wireless device may receive a first transport block (e.g., TB #**1**) via a first downlink carrier or a first cell (e.g., cell **2**). The wireless device may receive a second transport block (e.g., TB #**2**) via a second downlink carrier or a second cell (e.g., cell **3**). When the DCI may schedule uplink data, the wireless device may transmit a first TB via a first uplink carrier and may transmit a second TB via a second uplink carrier based on the DCI. The base station may transmit one or more radio resource control (RRC) messages indicating/comprising configuration parameters for a multi-carrier/multi-cell scheduling. The configuration parameters may comprise/indicate a plurality of serving cells scheduled by a DCI. The configuration parameters may indicate to enable or disable the multi-carrier/multi-cell scheduling. The configuration parameters may indicate a scheduling cell for the multi-carrier/multi-cell scheduling for the plurality of serving cells. For example, FIG. **21** illustrates an example of the configuration parameters indicating a first downlink carrier/cell (e.g. cell **2**) and a second downlink carrier/cell (e.g., cell **3**). The configuration parameters may indicate/comprise a scheduling cell (e.g., cell **1** in FIG. **21**) for the multi-carrier/multi-cell scheduling. For example, the scheduling cell may be same to one cell of the plurality of serving cells. For example, the scheduling cell may be different from any cell of the plurality of serving cells.

[0256] For example, the first carrier/cell may be associated with a first transmission and reception point (TRP) or a first coreset pool/group or a first group or a first TCI group. The second carrier/cell may be associated with a second TRP or a second coreset pool/group or a second group or a second TCI group. The first cell may be same to the second cell (e.g., a first physical cell identifier of the first cell may be same as a second physical cell identifier of the second cell). The first cell may be different from the second cell (e.g., a first physical cell identifier of the first cell may be different from a second physical cell identifier of the second cell).

[0257] In an example, the configuration parameters may indicate a multi-carrier scheduling or a multi-carrier repetition scheduling. A DCI, based on the multi-carrier repetition scheduling, may comprise resource assignments of a plurality of cells for a number of repetitions of a TB over the plurality of cells. A DCI, based on the multi-carrier scheduling, may comprise resource assignments of a plurality of cells for a plurality of transport blocks (TBs) over the plurality of cells. FIG. **21** shows a first transmission of an RRC signaling for configuring the multi-carrier/cell scheduling to the wireless device. A multi-carrier or a multi-cell DCI (M-DCI) may represent a DCI based on the multi-carrier scheduling or the multi-carrier repetition scheduling. For example, the one or more configuration parameters may comprise one or more control resource set (coreset) s and/or one or more search spaces. The DCI of the multi-carrier scheduling may be transmitted via the one or more coresets and/or the one or more search spaces. The one or more configuration parameters may comprise a RNTI that may be used for the DCI of the multi-carrier scheduling. The RNTI may be different from a C-RNTI.

[0258] The base station may transmit one or more MAC CEs/one or more DCIs to activate the multi-carrier scheduling. FIG. **21** shows a second message of activation wherein the second message of the activation may be optional. For example, the one or more MAC CEs may comprise a MAC CE activating and/or deactivating one or more secondary cells. The base station may transmit one or more DCIs. The one or more DCIs may indicate a BWP switching from a first BWP to a second BWP of a cell. The first BWP is an active BWP of the cell. The first BWP may not comprise one or more coresets of the multi-carrier scheduling. The second BWP may comprise one or more second coresets of the multi-carrier scheduling. For example, the one or more MAC CEs may comprise indication(s) of activating and/or deactivating a multi-carrier scheduling of a cell for one or more cells. For example, the one or more DCIs may comprise an indication to activate or deactivate the multi-carrier scheduling of the cell of the one or more cells.

[0259] The wireless device may activate the multi-carrier scheduling in response to receiving the one or more RRC messages. The one or more MAC CEs/the one or more DCIs may be optional. The base station may reconfigure to deactivate or activate the multi-carrier scheduling of a cell via RRC signaling. In response to activating the multi-carrier scheduling, the base station may transmit a DCI, based on the multi-carrier scheduling, comprising resource assignments for the first downlink/uplink carrier/cell (e.g., cell **2**) and for the second downlink/uplink carrier/cell (e.g., cell **3**). FIG. **21** illustrates a third transmission from the base station to the wireless device for the DCI scheduling a first TB for the first cell and a second TB for the second cell. The DCI may be cyclic redundancy check (CRC) scrambled with the RNTI. The DCI may be transmitted via the one or more coresets and/or the one or more search spaces. The DCI may indicate a plurality of downlink/uplink resources for a repetition of the first TB via the first downlink/uplink carrier/cell. The DCI may indicate one downlink/uplink resource for a repetition of the second TB via the second downlink/uplink carrier/cell. The configuration parameters may comprise/indicate a first number of repetition via the first cell. The configuration parameters may comprise/indicate a second number of repetition via the second cell. The base station may transmit the first TB based on the first number of repetitions via the first cell. The base station may transmit the second TB based on the second number of repetitions via the second cell. When a multi-carrier/cell repetition is configured/used, the first TB may be same as the second TB. FIG. **21** illustrates that a box of TB #**1** corresponds to a PDSCH. In FIG. **21**, the base station transmits a first PDSCH (a first box via the cell **2**) comprising the first TB via the first cell (cell **2**) and a second PDSCH (a second box via cell **3**) comprising the second TB via the second cell (cell **3**). For example, the first PDSCH may transmit a first RV of the first TB with a first HARQ process ID. The second PDSCH may transmit a second RV of the second TB with a second HARQ process ID.

[0260] For example, the DCI may comprise a RV field indicating an index of the first RV. For example, the second RV may be determined based on the first RV and one or more configuration parameters. The configuration parameters may comprise/indicate a RV offset. The second RV may be determined as the index of (the first RV+the RV offset) mod K. The K is a number of RVs (e.g., K=4). An index of RV may be determined as an order in the RV sequence. For example, an index of RV **3** is 3, and an index of RV **1** is 4. Similarly, the DCI may comprise a HARQ process ID field indicating an index of the first HARQ process ID. The wireless device may determine the second HARQ process ID based on the first RV and one or more configuration parameters. The configuration parameters may comprise/indicate a HARQ process ID offset or a list of HARQ process IDs of the first cell and the second cell.

[0261] For example, the DCI may comprise a first RV field and a second RV field. The wireless device may determine the first RV based on the first RV field. The wireless device may determine the second RV based on the second RV field. The DCI may comprise a plurality of RV fields. A RV field of the plurality of RV fields may correspond to a cell of the plurality of serving cells. For example, the DCI may comprise a RV field for a TB scheduled via a cell of the plurality of serving cells. Similarly, the DCI may comprise a plurality of HARQ process ID fields for the plurality of serving cells. Each HARQ process ID field of the plurality of HARQ process ID fields may correspond to each cell of the plurality of serving cells.

[0262] In an example, the DCI may comprise a first NDI bit for the first cell of the plurality of serving cells. The DCI may comprise a second NDI bit for the second cell of the plurality of serving cells. The DCI may comprise a plurality of NDI bits for the plurality of serving cells. Each NDI bit of the plurality of NDI bits may correspond to each cell of the plurality of serving cells.

The DCI may comprise a plurality of NDI bits for a cell of the plurality of cells in response to the DCI schedules a multi-slot (e.g., multi-TTI) scheduling. The wireless device may receive, based on the DCI, a plurality of resources of a plurality of slots for one or more transport blocks based on the multi-slot/multi-TTI scheduling.

[0263] For example, the DCI may comprise a first frequency domain resource assignment field and a second frequency domain resource assignment field. The first frequency domain resource assignment field may indicate first resource(s) of the first cell/carrier in frequency domain. The second frequency domain resource assignment field may indicate a second resource of the second cell/carrier in frequency domain. For example, the DCI may comprise a first frequency domain resource assignment (RA) field. The first frequency domain RA field may indicate an entry of one or more frequency domain resource allocation lists. The entry may comprise a first field indicating first resource(s) of the first cell/carrier and a second field indicating second resource(s) of the second cell/carrier. An entry of the one or more frequency domain resource allocation lists may comprise a plurality of fields/sub-entries. A field/sub-entry may correspond to an uplink carrier. Embodiments may allow a low overhead DCI signaling while maintaining flexibility in assigning frequency domain resources over a plurality of cells.

[0264] For example, the DCI may comprise a first time domain resource assignment field and a second time frequency domain resource assignment field. The first time domain resource assignment field may indicate first resource(s) of the first cell/carrier in time domain. The second time domain resource assignment field may indicate a second resource of the second cell/carrier in time domain. For example, the DCI may comprise a first time domain resource assignment (RA) field. The first time domain RA field may indicate an entry of one or more time domain resource allocation lists. The entry may comprise a first field indicating first resource(s) of the first cell/carrier and a second field indicating second resource(s) of the second cell/carrier. An entry of the one or more time domain resource allocation lists may comprise a plurality of fields/sub-entries. A field/sub-entry may correspond to an uplink carrier. Embodiments may allow a low overhead DCI signaling while maintaining flexibility in assigning time domain resources over a plurality of cells.

[0265] In an example, a physical downlink control channel (PDCCH) may comprise one or more control-channel elements (CCEs). For example, the PDCCH may comprise one CCE, that may correspond to an aggregation level (AL)=1. For example, the PDCCH may comprise two CCEs, that may correspond to an AL of two (AL=2). For example, the PDCCH may comprise four CCEs, that may correspond to an AL of four (AL=4). For example, the PDCCH may comprise eight CCEs, that may correspond to an AL of eight (AL=8). For example, the PDCCH may comprise sixteen CCEs, that may correspond to an AL of sixteen (AL=16).

[0266] In an example, a PDCCH may be carried over one or more control resource set (coreset). A coreset may comprise N_rb_coreset resource blocks (RBs) in the frequency domain and N_symbol_coreset symbols in the time domain. For example, the N_rb_coreset may be multiple of 6 RBs (e.g., 6, 12, 18, . . .). For example, N_symbol_coreset may be 1, 2 or 3. A CCE may comprise M (e.g., M=6) resource-element groups (REGs). For example, one REG may comprise one RB during one OFDM symbol. REGs within the coreset may be ordered/numbered in increasing order in a time-first manner, starting with 0 for a first OFDM symbol and a lowest number (e.g., a lowest frequency) RB in the coreset. The wireless device may increase the numbering in the first OFDM symbol by increasing a frequency location or a RB index. The wireless device may move to a next symbol in response to all RBs of the first symbol may have been indexed. The wireless device may map one or more REG indices for one or more 6 RBs of N_rb_coreset RBs within N_symbol_coreset OFDM symbols of the coreset.

[0267] In an example, a wireless device may receive configuration parameters from a base station. The configuration parameters may comprise one or more coresets. One coreset may be associated with one CCE-to-REG mapping. For example, a single coreset may have a single CCE mapping to physical RBs/resources of the single coreset. For example, a CCE-to-REG of a coreset may be interleaved or non-interleaved. For example, a REG bundle may comprise L consecutive REGs (e.g., iL, iL+1, . . . , iL+L−1). For example, L may be a REG bundle size (e.g., L=2 or 6 for N_symbol_coreset=1 and L=N_symbol_coreset or 6 when N_symbol_coreset is 2 or 3). A index of a REG bundle (e.g., i), may be in a range of [0, 1, ... N_reg_coreset/L−1]. For example, N_reg_coreset may be defined as N_rb_coreset*N_symbol_coreset (e.g., a total number of REGs in the single coreset). For example, a j-th indexed CCE may comprise one or more REG bundles of {f(6j/L), f(6j/L+1), . . . , f(6j/L+6/L−1)}. For example, f(x) may be an interleaver function. In an example, f(x) may be x (e.g., j-th CCE may comprise 6j/L, 6j/L+1, . . . , and 6j/L+6/L−1), when the CCE-to-REG mapping may be non-interleaved. When the CCE-to-REG mapping may be interleaved, L may be defined as one of {2, 6} when N_symbol_coreset is 1 or may be defined as one of {N_symbol_coreset, 6} when N_symbol_coreset is 2 or 3. When the CCE-to-REG mapping may be interleaved, the function f(x) may be defined as (rC+c+n_shift) mod (N_reg_coreset/L), wherein x=cR+r, r=0, 1, . . . , R−1, c=0, 1, . . . , C−1, C=N_reg_coreset/(L*R), and R is one of {2, 3, 6}.

[0268] For example, the configuration parameters may comprise a frequencyDomainResources that may define N_rb_coreset. The configuration parameters may comprise duration that may define N_symbol_coreset. The configuration parameters may comprise cce-REG-MappingType that may be selected between interleaved or non-interleaved mapping. The configuration parameters may comprise reg-BundleSize that may define a value for L for the interleaved mapping. For the non-interleaved mapping, L=6 may be predetermined. The configuration parameters may comprise shfitIndex that may determine n_shift as one of {0, 1, . . . , 274}. The wireless device may determine/assume a same precoding for REGs within a REG bundle when precorder granularity (e.g., a precoderGranularity indicated/configured by the configuration parameters) is configured as sameAsREG-bundle. The wireless device may determine/assume a same precoding for all REGs within a set of contiguous RBs of a coreset when the precoderGranularity is configured as allContiguousRBs.

[0269] For a first coreset (e.g., CORESET #**0**) may be defined/configured with L=6, R=2, n_shift=cell ID, and precoderGranularity=sameAsREG-bundle.

[0270] In existing technologies, a base station may enable a multi-carrier/multi-cell scheduling.

[0271] Based on the multi-carrier/multi-cell scheduling, the base station may transmit a single DCI that may indicate a plurality of resources of a plurality of carriers/cells. When the multi-carrier/multi-cell scheduling is configured/enabled, the base station may need to schedule a second DCI that may indicate resource(s) of a single carrier/cell. For example, the base station may not have data to be scheduled via the plurality of carriers/cells. For example, the base station may need to perform retransmission only for a single cell of the plurality of carriers/cells. For example, the base station may have resources available only for a cell of the plurality of carriers/cells.

[0272] In existing technologies, a base station may transmit a first DCI of a multi-carrier/multi-cell scheduling via a first search space of a first cell. For example, the first cell may be a scheduling cell for the multi-carrier/multi-cell scheduling. The base station may transmit a second DCI of a single cell scheduling via a second search space of the first cell. For example, the first search space is different from the second search space. To support the multi-carrier/multi-cell scheduling and the single cell scheduling simultaneously via the first cell, a wireless device may need to support the first search space and the second search space. This may require the wireless device to support a greater number of search spaces than the case where the wireless device may support the single cell scheduling only. This may increase implementation complexity of the wireless device. In an example, the first search space may be the same as the second search space. In that case, the base station may scramble a CRC of the first DCI based on a first RNTI (e.g., M-C-RNTI). The base station may scramble a CRC of the second DCI based on a second RNTI (e.g., C-RNTI). This may increase a number of blind decodings of the wireless device for monitoring control channel candidates as the wireless device may need to support a first DCI size of the first DCI and a second DCI size of the second DCI via a control channel candidate. This may lead to increase the complexity of the wireless device.

[0273] Embodiments of the present disclosure are directed to a method and apparatus for using a DCI format to support both single cell and multi-carrier/multi cell scheduling. For example, a wireless device may receive a DCI, with the DCI format, from a base station. The DCI may comprise a plurality of first DCI fields for a first cell and a plurality of second DCI fields for a second cell. The wireless device may receive, based on the DCI, at least one transport block scheduled for the first cell. For example, the wireless device may receive the at least one transport block in response to a first DCI field of the plurality of first DCI fields having a first value and a second DCI field of the plurality of first DCI fields having a second value. The wireless device may determine, based on the DCI, whether at least one additional transport block is scheduled for the second cell. For example, the wireless device may determine that no additional transport block is scheduled for the second cell in response to a first DCI field of the plurality of second DCI fields having a first predetermined value and a second DCI field of the plurality of DCI fields having a second predetermined value. The wireless device may alternatively determine that one or more additional transport blocks are scheduled for the second cell in response to a first DCI field of the plurality of second DCI fields not having a first predetermined value or a second DCI field of the plurality of DCI fields not having a second predetermined value. In other examples, the wireless device may determine that no additional transport block is scheduled for the second cell in response to DCI fields of the plurality of second DCI fields meeting a rule (or one or more rules). Because the wireless device may monitor a wireless channel for reception of a DCI, with the DCI format, for both single cell and multi-carrier/multi cell scheduling, complexity of the wireless device may be reduced when the wireless device provides support for both single cell and multi-carrier/multi cell scheduling.

[0274] For example, the above mentioned rule may be determined as follows. A first DCI field of the DCI format corresponding to a first cell may be set to a first predefined value. A second DCI field of the DCI format corresponding to the first cell may be set to a second predefined value. For example, the first DCI field may be a MCS field. For example, the first predefined value may be 26. For example, the second DCI field may be a RV field. For example, the second predefined value may be 1. In an example, a wireless device may receive a DCI comprising a plurality of first DCI fields for a first cell and a plurality of second DCI fields for a second cell. The wireless device may receive, based on the DCI, at least one transport block scheduled for the first cell in response to a first DCI field of the plurality of first DCI fields having a first value and a second DCI field of the plurality of first DCI fields having a second value. For example, the first value may be different from a first predefined value. For example, the second value may be different from a second predefined value. The wireless device may determine, based on the DCI, no transport block is scheduled for the second cell in response to a first DCI field of the plurality of second DCI fields having the first predefined value and a second DCI field of the plurality of second DCI fields having the second predefined value. For example, the first DCI field may be a MCS field. For example, the second DCI field may be a RV field.

[0275] In an example, a multi-carrier/multi-cell DCI format may comprise a list of {a first DCI field, a second DCI field}, where each of {the first DCI field, the second DCI field} may correspond to each cell of the plurality of scheduled carriers/cells. A base station may set, to disable scheduling of a transport block for a cell, the first DCI field, corresponding to the cell, to a first predefined value and a second DCI field, corresponding to the cell, to a second predefined value. The base station may set, to enable scheduling of a transport block for a second cell, the first DCI field, corresponding to the second cell, to a first value different from the first predefined value and/or set the second DCI field, corresponding to the second cell, to a second value different from the second predefined value.

[0276] Based on a rule, a base station may enable or disable scheduling one or more transport blocks for a cell of a plurality of scheduled cells based on a single DCI format. Embodiments may allow lower complexity of a wireless device to support a single cell and a multi-carrier/multi-cell scheduling simultaneously with lower number of DCI formats and/or lower number of DCI sizes.

[0277] In an example, a base station may transmit one or more RRC messages indicating/comprising configuration parameters. The configuration parameters may indicate/comprise enabling of a multi-carrier/multi-cell scheduling. The configuration parameters may indicate/comprise a scheduling cell for the multi-carrier/multi-cell scheduling. The configuration parameters may comprise one or more scheduled cells for the multi-carrier/multi-cell scheduling. For example, the scheduling cell may be included as one of the one or more scheduled cells without explicit configuration parameters. For example, the configuration parameters may indicate whether the multi-carrier/multi-cell scheduling is based on a self-carrier or a cross-carrier scheduling. When the self-carrier scheduling is based, a wireless device may consider that the scheduling cell is a scheduled cell. When the cross-carrier scheduling is based, the wireless device may consider that the one or more scheduled cells may not comprise the scheduling cell.

[0278] FIG. **22** illustrates an example diagram of an embodiment of coexistence of a multi-carrier/multi-cell scheduling and a single cell scheduling based on a rule. For example, the base station may transmit one or more first RRC messages indicating configuration parameters for a multi-carrier/multi-cell scheduling. For example, the configuration parameters may comprise/indicate a scheduling cell (e.g., Cell **1** in FIG. **22**), and a plurality of scheduled cells (e.g., Cell **2** and Cell **3** in FIG. **22**). The configuration parameters may also comprise/indicate parameters needed for the multi-carrier/multi-cell scheduling. For example, the configuration parameters may comprise a first RNTI used for a DCI for the multi-carrier/multi-cell scheduling. The first RNTI may be different from a cell-RNTI (e.g., C-RNTI). The first RNTI may be the C-RNTI. The configuration parameters may comprise a list of time domain resource allocations, where an entry of the list of time domain resource allocation may comprise one or more time domain resources for the plurality of scheduled cells. The configuration parameters may comprise a list of frequency domain resource allocations, where an entry of the list of frequency domain resource allocation may comprise one or more frequency domain resources for the plurality of scheduled cells.

[0279] The base station may transmit one or more second RRC messages comprising/indicating second configuration parameters. The second configuration parameters may comprise/indicate a number of code words/transport blocks for a cell schedulable by a DCI. For example, the DCI may be a multi-carrier/multi-cell DCI based on a multi-carrier/multi-cell DCI format. For example, the second configuration parameters in FIG. **22** may indicate that up to two TBs are scheduled for each of the plurality of scheduled cells. For example, the second configuration parameters may indicate a first number of TBs for a first cell of the plurality of cells. The second configuration parameters may indicate a second number of TBs for a second cell of the plurality of cells. The number of TBs may indicate one or two. The number of TBs may indicate more than one. When a cell is schedulable with up to one transport block, the second configuration parameters may not indicate/comprise a number of TBs for the cell. The wireless device may determine as a default value a single TB for a cell. For example, when a maximum number of transport block for Cell **2** and Cell **3** is one, the base station may not transmit the one or more second RRC messages indicating the number of code words/transport blocks. Based on the absence of the one or more second RRC messages, the wireless device may determine a single TB as the maximum number of transport block for Cell **2** and Cell **3**. In an example, the wireless device may determine a maximum number of transport block for a cell based on a configuration parameter of a number of code words/transport blocks configured for the cell regardless whether the cell is scheduled via the multi-carrier/multi-cell scheduling.

[0280] The wireless device may receive a DCI indicating based on the multi-carrier/multi-cell DCI format. The multi-carrier/multi-cell DCI format may comprise one or more first DCI fields for a first cell of the plurality of cells. The multi-carrier/multi-cell DCI format may comprise one or more second DCI fields for a second cell of the plurality of cells. The multi-carrier/multi-cell DCI format may comprise one or more DCI fields for the plurality of cells. For example, the one or more first DCI fields may be same as the one or more second DCI fields. For example, the one or more first DCI fields may comprise a MCS field and a RV field. For example, the one or more first DCI fields may comprise a MCS field, a RV field and a NDI field. For example, the one or more first DCI fields may comprise a MCS field, a RV field, a NDI field and a HARQ process ID field. A same set of the one or more first DCI fields may be present for the one or more second DCI fields for the second cell. In an example, the one or more first DCI fields may be different from the one or more second DCI fields. For example, the one or more second DCI fields may comprise a HARQ process ID field and a NDI field. For example, the one or more first DCI fields may comprise a MCS field, a RV field, a NDI field and a HARQ process ID field. Various combinations for the one or more first DCI fields are considered. Various combinations for the one or more second DCI fields are considered. For example, a DCI field may comprise a first DCI bit(s) and a second DCI bit(s). The first DCI bit(s) may correspond to the one or more first DCI fields even though the DCI format may have the DCI field. The second DCI bit(s) may correspond to the one or more second DCI fields. For example, the DCI field may belong to the one or more first DCI fields and the one or more second DCI fields. For example, the DCI format may have a single NDI field, where the single NDI field may comprise a plurality of NDI bits. Each NDI bit of the plurality of NDI bits may correspond to a transport block of a cell of the plurality of scheduled cells. For example, the DCI format may have a single RV DCI field, where the single RV DCI field may comprise a plurality of RV fields/bits. Each RV field/bit of the plurality of RV fields/bits may correspond to a transport block of a cell of the plurality of scheduled cells. For example, the DCI format may have a RV field, where the RV field may indicate an entry of one or more RV entries for a plurality of TBs of the plurality of scheduled cells. A value of RV field may indicate an entry, where the entry may include/comprise/indicate a second predefined value (e.g., 1). Based on the entry indicating the second predefined value for a transport block of a cell of the plurality of scheduled cells, the wireless device may determine that the RV field for the cell is set to the second predefined value.

[0281] Various implementation of DCI fields for the plurality of scheduled cells are possible. For example, a separate DCI field, with a same label (e.g., a separate RV field) may be present for each cell of the plurality of scheduled cells. For example, a DCI field may comprise a plurality of sub-DCI fields, where each sub-DCI field correspond to each cell of the plurality of scheduled cells (e.g., a NDI field comprises N NDI bits where N correspond to a number of transport blocks schedulable via the plurality of scheduled cells). For example, a DCI field may indicate an entry of a table. An entry of the table may indicate/comprise a plurality of values, where each value of the plurality of values may correspond to each cell of the plurality of scheduled cells. The table may be explicitly configured by a base station or implicitly determined by a wireless device based on a functionality.

[0282] In FIG. **22**, the wireless device receives a DCI, indicating resources for Cell **2** and Cell **3**, scheduling up to four transport blocks via Cell **2** and Cell **3**. The DCI may comprise one or more first DCI fields corresponding to Cell **2**. The DCI may additionally comprise one or more second DCI fields corresponding to Cell **3**. The DCI may comprise one or more DCI fields applied for both Cell **2** and Cell **3**. For example, the one or more first DCI fields may comprise a MCS and a RV field. For example, the one or more second DCI fields may comprise a MCS and a RV field. The wireless device may determine that a first DCI field of the one or more first DCI fields having a first value. The first value may be different from a first predefined value. The wireless device may determine that a second DCI field of the one or more DCI fields having a second value. The second value may be different form a second predefined value. Based on determining the first value being different from the first predefined value and the second value being different from the second predefined value, the wireless device may determine that the DCI schedules at least one transport block for Cell **2**. The wireless device may determine a first DCI field of the one or more second DCI fields having the first predefined value. The wireless device may further determine a second DCI field of the one or more second DCI fields having the second predefined value. Based on both determining, the wireless device may determine that the DCI may not schedule a transport block for Cell **3**.

[0283] In an example, the DCI may schedule a first TB and a second TB for Cell **3**. The one or more second DCI fields may have a first DCI field and a second DCI field corresponding to the first TB for Cell **3** and a third DCI field and a fourth DCI field corresponding to the second TB. In response to the first DCI field setting to the first predefined value and the second DCI field setting to the second predefined value, the wireless device may determine that the first TB for Cell **3** is disabled or not scheduled. In response to the third DCI field setting to the first predefined value and the fourth DCI field setting to the second predefined value, the wireless device may determine that the second TB for Cell **3** is disabled or not scheduled. For example, the first DCI field and the third DCI field is a MCS field. For example, the second DCI field and the fourth DCI field is a RV field. For example, the first predefined value may be 26. For example, the second predefined value may be 1. Based on the determining which cell(s) and/or which transport blocks are scheduled by the DCI, the wireless device may receive the determined transport blocks via the determined cells.

[0284] Similarly, a wireless device may receive an uplink grant based on a DCI format for a multi-carrier/multi-cell scheduling. The uplink grant may schedule one or more transport blocks of one or more cells of a plurality of scheduled cells. The wireless device may determine the one or more transport blocks and/or the one or more cells based on a rule. For example, the rule may be same between an uplink grant (e.g., a second DCI) and a downlink scheduling DCI (e.g., a first DCI). For example, the wireless device may determine a transport block for a cell is scheduled in response to a first DCI field corresponding to the transport block for the cell having a first value different from a first predefined value or a second DCI field corresponding to the transport block of the cell having a second value different form a second predefined vale. The wireless device may determine a second transport block for a second cell is disabled or not scheduled in response to a first DCI field corresponding to the second transport block for the second cell having the first predefined value and a second DCI field corresponding to the second transport block for the second cell having the second predefined value.

[0285] In an example, a base station may transmit one or more RRC messages indicating/comprising configuration parameters. The configuration parameters may comprise/indicate a multi-carrier/multi-cell scheduling for downlink data scheduling. The configuration parameters may not indicate a multi-carrier/multi-cell scheduling for uplink data scheduling (e.g., uplink grants). A wireless device may determine a first DCI format for downlink data scheduling based on the multi-carrier/multi-cell scheduling. The first DCI format may comprise one or more first DCI fields for a first cell of a plurality of scheduled cells. The first DCI format may comprise one or more second DCI fields for a second cell of the plurality of scheduled cells. The wireless device may determine a second DCI format for uplink data scheduling based on a single cell scheduling. The second DCI format may comprise one or more DCI fields for a scheduled cell.

[0286] For example, a first cell may be a scheduling cell for the multi-carrier/multi-cell scheduling. The plurality of scheduled cells may comprise a second cell and a third cell. The second cell may be same as the first cell. The second cell may be different from the first cell. For the second DCI format for the second cell, the wireless device may determine that the first cell is a scheduling cell for the single cell uplink data scheduling for the second cell. The wireless device may determine that the second cell is a scheduling cell for the single cell uplink scheduling for the second cell. The wireless device may monitor the first DCI format for the second cell and the second DCI format for the second cell via the first cell. When the wireless device may need to perform a DCI size alignment between the first DCI format and the second DCI format, the wireless device may append zeros or predefined values to either the first DCI format or the second DCI format until the first DCI format and the second DCI format have a same size. For example, the wireless device may monitor a third DCI format via the first cell. The third DCI format may schedule a single cell uplink scheduling data for the third cell. The wireless device may perform a DCI size alignment between the first DCI format, the second DCI format and the third DCI format in that case. The wireless device may select a largest size among the first DCI format, the second DCI format and the third DCI format. The wireless device may append zeros or predefined value to each DCI format until a size of the each DCI format becomes the largest size.

[0287] FIG. **23** illustrates an example of a rule to determine whether a DCI schedule one or more TBs for a cell of a plurality of cells when a multi-carrier/multi-cell scheduling is enabled. For example, in the example, a base station may configure up to one transport block, for each cell of the plurality of cells, schedulable by a DCI of the multi-carrier/multi-cell scheduling. Based on the rule, the wireless device may determine whether the one transport block is scheduled for the cell or not. In the example, the plurality of cells may comprise a Cell i and Cell j. The DCI may transmit one or more values of one or more DCI fields based on a DCI format. The DCI format may comprise one or more DCI fields common for the plurality of cells. The one or more DCI fields may comprise a frequency domain resource assignment (e.g., frequency domain RA), a time domain resource assignment (e.g., time domain RA), a downlink assignment index (e.g., DIA), a DM-RS (e.g., DM-RS). The DCI format may comprise one or more first DCI fields corresponding to a first cell (e.g., Cell i) of the plurality of cells. The one or more first DCI fields may comprise at least one of a first MCS field (e.g., MCS #k), a first NDI field (e.g., NDI #k), a first RV field (e.g., RV #k) and a first HARQ process ID field (e.g., HARQ ID #k). The one or more second DCI fields may comprise at least one of a second MCS field (e.g., MCS #m), a second NDI field (e.g., NDI #m), a second RV field (e.g., RV #m) and a second HARQ process ID field (e.g., HARQ ID #m). The wireless device may determine the first MCS field being set to a first predetermined value (e.g., a, 26) and the first RV field being set to a second predetermined value (e.g., b, 1). In response to the determining, the wireless device may determine that a first transport block for Cell i is disabled or deactivated or not scheduled. The wireless device may not receive the first transport block via Cell i in response to the determining. When the first MCS field having a first value different from the first predetermined value or the first RV field having a second value different from the second predetermined value, the wireless device may determine the DCI schedules the first transport block via Cell i. The wireless device may determine the second MCS field being set to the first predetermined value and the second RV field being set to the second predetermined value. In response to the determining, the wireless device may determine that a second TB via Cell j is disabled or deactivated or not scheduled. The wireless device may not receive the second transport block via Cell j in response to the determining. When the second MCS field having a first value different from the first predetermined value or the second RV field having a second value different from the second predetermined value, the wireless device may determine the DCI schedules the second transport block via Cell j.

[0288] In an example, a wireless device may receive a DCI based on a multi-carrier/multi-cell DCI format. The DCI format may comprise one or more first DCI fields for a first cell. The DCI format may comprise one or more second DCI fields for a second cell. The multi-carrier/multi-cell DCI format may schedule resources for a plurality of cells. The plurality of cells may comprise the first cell and the second cell. In an example, the wireless device may determine a first field of the one or more first DCI fields of the DCI being set to a first predefined value. In response to the determining, the wireless device may determine that the DCI may not schedule a transport block for the first cell. For example, the first field may be a MCS field. The first predefined value may be 26. For example, the first field may be a RV field. The first predefined value may be 1. For example, the first field may be a HARQ process ID field. The first predefined value may be zeros or a constant. The wireless device may determine a first field of the one or more second DCI fields of the DCI having a first value different from the first predefined value. Based on the determining, the wireless device may determine that the DCI may schedule a transport block for the second cell.

[0289] In an example, the wireless device may determine a first field of the one or more first DCI fields of the DCI being set to a first predefined value and a second field of the one or more first DCI fields of the DCI being set to a second predefined value. In response to the determining, the wireless device may determine that the DCI may not schedule a transport block for the first cell. For example, the first field may be a MCS field. The second field may be a RV field. For example, the first field may be a RV field. The second field may be a HARQ process ID field. For example, the first field may be a MCS field. The second field may be a frequency domain resource assignment. The first predefined value may be 26 or 1 or zeros. The second predefined value may be 1 or 26 or zeros. The wireless device may determine a first field of the one or more second DCI fields of the DCI having a first value different from the first predefined value or a second field of the one or more second DCI fields of the DCI having a second value different from the second predefined value. Based on the determining, the wireless device may determine that the DCI may schedule a transport block for the second cell.

[0290] In an example, the wireless device may determine a first field of the one or more first DCI fields of the DCI being set to a first predefined value and a second field of the one or more first DCI fields of the DCI being set to a second predefined value and a third field of the one or more first DCI fields of the DCI being set to a third predefined value. In response to the determining, the wireless device may determine that the DCI may not schedule a transport block for the first cell. For example, the first field may be a MCS field. The second field may be a RV field. The third field may be a HARQ process ID field. For example, the first field may be a RV field. The second field may be a HARQ process ID field. The third field may be a frequency domain resource assignment field. For example, the first field may be a MCS field. The second field may be a frequency domain resource assignment. The third field may be a time domain resource assignment field. The first predefined value may be 26 or 1 or zeros or all ones or all zeros or 1 for most significant bit with zeros for others or 0 for most significant bit with ones for others. The second predefined value may be 1 or 26 or zeros or zeros or all ones or all zeros or 1 for most significant bit with zeros for others or 0 for most significant bit with ones for others. The third predefined value may be 1 or 26 or zeros or zeros or all ones or all zeros or 1 for most significant bit with zeros for others or 0 for most significant bit with ones for others. The wireless device may determine a first field of the one or more second DCI fields of the DCI having a first value different from the first predefined value or a second field of the one or more second DCI fields of the DCI having a second value different from the second predefined value or a third field of the one or more second DCI fields of the DCI having a third value different from the third predefined value. Based on the determining, the wireless device may determine that the DCI may schedule a transport block for the second cell.

[0291] In an example, a base station may transmit one or more RRC messages indicating/comprising configuration parameters for a multi-carrier/multi-cell scheduling. The configuration parameters may comprise a plurality of scheduled cells. The configuration parameters may comprise a scheduling cell. The configuration parameters may comprise a parameter of a number of code words or transport block for a cell of the plurality of scheduled cells. The parameter may indicate a maximum number of transport blocks schedulable to a wireless device for each cell of the plurality of scheduled cells based on the multi-carrier/multi-cell scheduling. In an example, the configuration parameters may comprise a number of code words or transport blocks for each cell of the plurality of scheduled cells. The configuration parameters may comprise a plurality of parameters of a number of code words or transport blocks for the plurality of scheduled cells. The wireless device may apply each of the plurality of parameters for each cell of the plurality of scheduled cells. The configuration parameters may be absent a number of code words or transport blocks for a first cell of the plurality of scheduled cells. The wireless device may consider up to one transport block may be scheduled for the first cell in response to the absence

The wireless device may apply a number of code words or transport blocks configured for the first cell, for a single cell scheduling, in response to the absence of the number of code words or transport blocks for the multi-carrier/multi-cell scheduling.

[0292] In an example, the wireless device may use or apply a number of code words or transport blocks configured for a cell for a single celling for a multi-carrier/multi-cell scheduling as well.

[0293] Based on a number of code words/transport blocks for each cell of the plurality of scheduled cells, the wireless device may determine a DCI format for the multi-carrier/multi-cell scheduling. For example, the wireless device may determine a NDI bit or a NDI field corresponding to a transport block of a cell of the plurality of scheduled cells. When the cell has up to k number of code words or transport blocks, the wireless device may determine k NDI bits or k NDI fields for the cell. In an example, the wireless device may determine a first DCI bit(s) or a first DCI field corresponding to each transport block of each cell of the plurality of scheduled cells. For example, the first DCI field may comprise a NDI field. For example, the first DCI field may comprise a RV field. For example, the first DCI field may comprise a HARQ process ID field. For example, the first DCI field may comprise a MCS field. The first DCI bit(s) of a DCI field may comprise at least one of a NDI bit, a RV bits, and/or a HARQ process ID bits. Other DCI fields, e.g., frequency domain resource assignment, time domain resource assignment, a rate matching indicator, a DM-RS and/or like, may be considered for the first DCI field or the first DCI bits.

[0294] In an example, a base station may transmit one or more RRC messages comprising/indicating configuration parameters. The configuration parameters may indicate/comprise a first DCI format for scheduling downlink resources for one or more first scheduled cells. The configuration parameters may indicate/comprise a second DCI format for scheduling uplink resources for one or more second scheduled cells. The base station may transmit a first DCI based on the first DCI format via a first cell. The base station may transmit a second DCI based on the second DCI format via the first cell. The configuration parameters may comprise/indicate a first RNTI used for scheduling a single cell via the first DCI format or the second DCI format. The configuration parameters may comprise/indicate a second RNTI used for scheduling a plurality of cells via the first DCI format or the second DCI format. For example, the plurality of cells may comprise a second cell and a third cell. For example, the single cell may be the second cell or the third cell. The wireless device may receive a first DCI based on the first DCI format using the first RNTI. In response to the first DCI, the wireless device may determine/interpret the first DCI format for a single cell scheduling. For example, the wireless device may determine the first DCI based on the first DCI format based on a number of code words/transport blocks configured for the single cell. When two code words/transport blocks are configured for the single cell, the wireless device may determine/interpret that the first DCI format has two MCS fields, one for each code word/transport block, and two RV fields, one for each code word/transport block, and two NDI fields, one for each code word/transport block.

[0295] The wireless device may receive a second DCI based on the first DCI format using the second RNTI. In response to the second DCI, the wireless device may determine/interpret the first DCI format for a multi-carrier/multi-cell scheduling. For example, the wireless device may determine the second DCI based on the first DCI format based on a number of scheduled cells supported by the multi-carrier/multi-cell scheduling. When two scheduled cells (e.g., a first cell and a second cell) are configured, the wireless device may determine/interpret that the first DCI format has two MCS fields, one for each cell of the number of scheduled cells, and two RV fields, one for each cell of the number of scheduled cells, and two NDI fields, one for each cell of the number of scheduled cells.

[0296] In an example, the wireless device may determine a first DCI size of the first DCI format based on a single cell scheduling. For example, a number of code words/transport blocks may be used to determine the first DCI size. The wireless device may determine a second DCI size of the first DCI format based on a multi-carrier/multi-cell scheduling. For example, a number of scheduled cells may be used to determine the second DCI size. The wireless device may determine a larger size between the first DCI size and the second DCI size. The wireless device may assume that the first DCI size is equal to the second DCI size. The wireless device may add zeros or predefined values to one or more DCI fields of the single cell scheduling (if the first DCI size is smaller) to have same field size(s) to the one or more DCI fields of the multi-carrier/multi-cell scheduling. The wireless device may add zeros or predefined values to one or more second DCI fields of the multi-carrier/multi-cell scheduling (if the second DCI size is smaller) to have same field size(s) to the one or more second DCI fields of the single cell scheduling. The wireless device may decode a DCI of a search space candidate based on the first RNTI and the second RNTI. In response to decoding successfully with the first RNTI, the wireless device may determine the DCI is a single cell scheduling DCI. In response to decoding successfully with the second RNTI, the wireless device may determine the DCI is a multi-carrier/multi-cell scheduling DCI.

[0297] In an example, a wireless device may receive a configuration parameter of a number of code words/transport blocks (e.g., maxNrofCodeWordsScheduledByDCI) schedulable to a first cell, based on a single cell scheduling. When the base station indicates the first cell as one of scheduled cells of a multi-carrier/multi-cell scheduling by a second DCI, the wireless device may determine a number of code words/transport blocks schedulable to the first cell, based on the multi-carrier/multi-cell scheduling is 1 (one). For example, the wireless device may not expect a plurality of code words/transport blocks scheduled by a single multi-carrier/multi-cell DCI for a cell. The wireless device may assume that at most one transport block may be scheduled to each cell of a plurality of scheduled cells via a multi-carrier/multi-cell DCI.

[0298] FIG. **24** illustrates an example DCI format supported for a multi-carrier/multi-cell scheduling of downlink resources. For example, the multi-carrier/multi-cell may schedule a first cell and a second cell. A DCI format scheduling downlink data (e.g., DCI format 1_1, DCI format 1_2) may comprise a DL/UL indicator, and optionally a carrier indicator. A BWP index field of the DCI format may indicate one or more first downlink BWPs of the first cell and/or one or more second downlink BWPs of the second cell. For example, a size of the BWP index may be determined based on a total number of the one or more first downlink BWPs and the one or more second downlink BWPs, when the first cell and the second cell are configured with a plurality of downlink BWPs. Otherwise, the size of BWP index may be determined based on a larger number between the one or more first downlink BWPs and the one or more second downlink BWPs. For example, when a number of the one or more first downlink BWPs is three and a number of the one or more second downlink BWPs is one, the total number is three. For example, when a number of the one or more first downlink BWPs is three and a number of the one or more second downlink BWPs is two, the total number is five. The size of BWP index may be determined based on the total number. A value of the BWP index may indicate a BWP of the one or more first downlink BWPs and the one or more second downlink BWPs. In an example, the BWP index may comprise a first sub BWP index field for the one or more first downlink BWPs, if a number of the one or more first downlink BWPs is larger than 1. The BWP index may comprise a second sub BWP index for the one or more second downlink BWPs, if a number of the one or more second downlink BWPs is larger than 1. When a number of downlink BWPs of a cell is 1, a sub BWP index field is not present. Based on the first sub BWP index and the second sub BWP index, the BWP index may be determined (e.g., combined). For example, a size of the first sub BWP index is 1 and a size of the second sub BWP index is 2, a size of the BWP index is 3.

[0299] The DCI format may comprise a frequency domain resource assignment. The wireless device may determine one or more first frequency resources for the first cell based on the frequency domain resource assignment. The wireless device may determine one or more second frequency resources for the second cell based on the frequency domain resource assignment. The DCI format may comprise a time domain resource assignment. The wireless device may determine one or more first time resources for the first cell based on the time domain resource assignment.

The wireless device may determine one or more second time resources for the second cell based on the time domain resource assignment. The DCI format may comprise a first MCS field, a first RV field, a first NDI field and a first HARQ process ID field for the first cell. The DCI format may comprise a second MCS field, a second RV field, a second NDI field, and a second HARQ process ID field for the second cell. The DCI format may have a DAI field, a TPC field, a PUCCH resource indicator, and a PDSCH-to-HARQ timing offset. The DCI format may indicate one or more antenna ports for the first cell and/or the second cell. The TCI state may indicate one or more TCI state for the first cell and/or the second cell. The SRS request may indicate one or more SRS request for the first cell and/or the second cell. Similar to the BWP index, the wireless device may determine a single SRS request field covering one or more first SRS configurations of the first cell and one or more second SRS configuration of the second cell. For the TCI state, the base station may transmit one or more RRC messages indicating/comprising configuration parameters. The configuration parameters may indicate/comprise a TCI state in a DCI for the first cell and a TCI state in the DCI for the second cell separately. When the TCI state in the DCI for the first cell is configured/enabled/activated, one or more DCI bits for the first cell is determined for the TCI state field. When the TCI state in the DCI for the second cell is configured/enabled/activated, one or more second bits fo the second cell is determined for the TCI state field. A size of the TCI state may be determined based on the TCI state in the DCI for the first cell and the TCI state in the DCI for the second cell. The TCI state in the DCI for the first cell, wherein the DCI is a multi-carrier/multi-cell scheduling, may be configured differently from a TCI state in a second DCI for the first cell, wherein the second DCI is a single cell scheduling. The TCI state in the DCI for the second cell, wherein the DCI is the multi-carrier/multi-cell scheduling, may be configured differently from a TCI state in a third DCI for the second cell, wherein the third DCI is a single cell scheduling.

[0300] For example, the DCI format may comprise a CBGTI for the first cell or the second cell. The CBGTI may have a single bit to indicate the first cell or the second cell wherein the CBGTI may be applied. For example, the base station may configure a CBG feedback either for the first cell or the second cell. The CBGTI may indicate a CBG bitmap for a cell configured with the CBG feedback. Similarly, CBGFI may be applied for the first cell or the second cell. Or, the CBGFI may be N bits, where 1 bit correspond to a cell of a plurality of scheduled cells. Minimum scheduling field may be used commonly for the first cell and the second cell. For example, a value of the minimum scheduling field may be applied for the first cell and the second cell based on a first scheduling offset configured for the first cell and a second scheduling offset configured for the second cell. For example, the configuration parameters may indicate one or more first scheduling offset values for the first cell. The configuration parameters may indicate one or more second scheduling offset values for the second cell. Based on a value of the minimum scheduling offset (e.g., 0 for a first value of the one or more first scheduling offset values for the first cell and a first value of the one or more second scheduling offset values for the second cell, 1 for a second value of the one or more first scheduling offset values for the first cell and a second value of the one or more second scheduling offset values for the second cell), the wireless device may determine a scheduling offset value for each cell. The base station may not configure any scheduling offset value for a cell. The wireless device may ignore the minimum scheduling field for the cell. The base station may configure a single scheduling offset value for a cell. The wireless device may consider ‘0’ (e.g., no scheduling offset) may be configured as a second value for the cell in additional to the single scheduling offset value.

[0301] FIG. **25** illustrates an example DCI format supported for a multi-carrier/multi-cell scheduling of uplink resources. For example, the multi-carrier/multi-cell may schedule a first carrier/cell and a second carrier/cell. A DCI format scheduling uplink data may comprise a DL/UL indicator, and optionally a carrier indicator. The DCI format may not comprise a UL/SUL DCI field. For example, a cell with an uplink carrier and a supplemental uplink carrier may not be configured as a single cell of the multi-carrier/multi-cell scheduling. A DCI of the multi-carrier/multi-cell may schedule resources for the uplink carrier and the supplemental uplink carrier of the cell. The DCI may schedule resources for both of the uplink carrier and the supplemental uplink carrier or one of the uplink carrier and the supplemental uplink carrier. The DCI format may comprise/indicate a cell index or a carrier index, indicating a UL carrier of a cell or a SUL carrier of the cell instead of a UL/SUL indicator.

[0302] A BWP index field of the DCI format (e.g., DCI format 0_1, DCI format 0_2) scheduling uplink data may be determined similarly as to determination of a BWP index of a DCI format scheduling downlink data (e.g., DCI format 1_1, DCI format 1_2). Based on a number of one or more first uplink BWPs of the first carrier/cell and a number of one or more second uplink BWPs of the second carrier/cell, the wireless device may determine a size of the BWP index field. The BWP index field may comprise a single field to cover the one or more first uplink BWPs and the one or more second uplink BWPs. The BWP index field may comprise a first sub BWP index field for the first carrier/cell and a second sub BWP index field for the second carrier/cell. The DCI format may comprise a frequency domain resource assignment field. The DCI format may comprise a time domain resource assignment field. For example, a frequency hopping field (e.g., FH) may comprise a number of bits, where each bit of the number of bits may comprise to each uplink carrier/cell of a plurality of scheduled carriers/cells. For example, a frequency hopping field may comprise a single bit indicating frequency hopping occurred over the plurality of carriers/cells or not. When the frequency hopping is enabled, the wireless device may apply the frequency hopping for each of the plurality of carriers/cells. When the frequency hopping is disabled, the wireless device may not apply the frequency hopping for any of the plurality of carriers/cells. The DCI format may have a first MCS field, a first NDI field, a first RV field and a first HARQ process ID field for the first carrier/cell. The DCI format may have a second MCS field, a second NDI field, a second RV field and a second HARQ process ID field for the second carrier/cell.

[0303] In an example, the DCI format may have a single first DAI field. The first DAI field may be applied to a first PUSCH via the first carrier/cell or a second PUSCH via the second carrier/cell. For example, the wireless device may receive a first DCI based on the DCI format comprising/indicating resources for the first PUSCH via the first carrier/cell and the second PUSCH via the second carrier/cell. The wireless device may not expect that the wireless device may piggyback a first UCI via the first PUSCH and a second UCI via the second PUSCH. The wireless device may perform a UCI piggybacking for either the first PUSCH or the second PUSCH. For example, the wireless device may select a PUSCH between the first PUSCH and the second PUSCH, when the first PUSCH and the second PUSCH are overlapped in time, based on a cell/carrier index of the first carrier/cell and the second carrier/cell. For example, when the first carrier may be an uplink carrier and the second carrier may be a supplemental uplink carrier, the wireless device may select the uplink carrier for the piggybacking. For example, the wireless device may select a lower indexed cell or carrier between the first uplink carrier/cell and the second uplink carrier/cell. For example, a first numerology of the first carrier/cell may be smaller than a second numerology of the second carrier/cell. For example, the first numerology of the first carrier/cell may be larger than the second numerology of the second carrier/cell. For example, a first duration of the first PUSCH may be smaller than a second duration of the second PUSCH. For example, the first duration of the first PUSCH may be larger than the second duration of the second PUSCH. A combination of one or more conditions (e.g., a first select based on a numerology and then index) may be considered.

[0304] The wireless device may apply a value of the first DAI field to a PUSCH determined for the UCI piggybacking. Similar behavior may be applied for a second DAI field if present. Similarly, a beta offset may be used for a single PUSCH determined for the UCI piggybacking. The wireless device may apply a same beta offset value for the first PUSCH and the second PUCH when the wireless device may determine to piggyback a first UCI via the first PUSCH and a second UCI via the second PUCH.

[0305] In an example, the DCI format may have a single TPC field. For example, a value of the single TPC field may be applied to a first PUSCH of the first carrier/cell and a second PUSCH of the second carrier/cell, where the first PUSCH and the second PUSCH are scheduled by a DCI of the multi-carrier/multi-cell scheduling. In an example, a first TPC field with 2 or 3 bits may be present in the DCI format. The first TPC field may comprise a value for the first carrier/cell. The DCI format may comprise a second TPC field with 1 or 2 bits. The second field may comprise a value for the second carrier/cell. A transmission power adjustment for the first carrier/cell may be determined based on the first TPC field. A transmission power adjustment for the second carrier/cell may be determined based on the first TPC field and the second TPC field. For example, the value of the first TCP field may be added with the value of the second TCP field. The transmission power adjustment for the second carrier/cell may be a sum of the value of the first TPC field and the value of the second TPC field.

[0306] In an example, a UL-SCH (indicating a PUSCH without data) may indicate a PUSCH via the first carrier/cell. For example, the DCI format has a single UL-SCH bit/field. When the UL-SCH field is indicated as enabled via a first DCI of the multi-carrier/multi-cell scheduling, the wireless device may consider that the first DCI schedules a single PUSCH via the first carrier/cell. The first carrier/cell may have a lower carrier index or cell index compared to one or more scheduled carriers/cells. For example, the first carrier may be an uplink carrier while the second carrier may be a supplemental uplink carrier. For example, the first cell may have a lower index than the second cell. For example, a first numerology of the first carrier/cell may be smaller than a second numerology of the second carrier/cell. For example, the first numerology of the first carrier/cell may be larger than the second numerology of the second carrier/cell. A combination of one or more conditions (e.g., a first select based on a numerology and then index) may be considered. The wireless device may assume that transport blocks are disabled for other carriers/cells than the selected carrier/cell of the plurality of scheduled carriers/cells.

[0307] Similar to the TPC field, different options for SRI field, PMI field or antenna ports field may be considered. For a SRS request, a CSI request, or a CBGTI, the DCI format may comprise/indicate a cell index. The cell index may indicate one cell of the plurality of scheduled cells (e.g., either the first carrier/cell or the second carrier/cell) where the wireless device may apply a value of the SRS request field, a value of the CSI request field and/or a value of the CBGTI. In an example, a priority of the DCI format may represent a single priority value for the first PUSCH and the second PSCH. For example, the DCI format may have a first priority field for the first PUSCH of the first carrier/cell and a second priority field for the second PUSCH of the second carrier/cell.

[0308] In the specification, a cell and a carrier may be interchangeably used. Embodiments for a cell may be applied for a carrier. Embodiments for a carrier may be applied for a cell.

[0309] FIG. **26** illustrates an example flow chart of an embodiment. A base station may transmit one or more RRC messages comprising/indicating configuration parameters related to a multi-carrier/multi-cell scheduling. For example, the configuration parameters may indicated/comprise a first cell and a second cell as scheduled cells by the multi-carrier/multi-cell scheduling. The configuration parameters may indicate/comprise a scheduling cell. The configuration parameters may indicate/comprise a first number of code words/transport blocks schedulable by a DCI for the first cell. The configuration parameters may indicated/comprise a second number of code words/transport blocks schedulable by the DCI for the second cell. A wireless device may determine a DCI format for the multi-carrier/multi-cell scheduling based on the configuration parameters. For example, the DCI format may comprise/indicate one or more cells of the scheduled cells via a cell index or a combination of one or more DCI fields. For example, FIG. **26** illustrates an example that the wireless device may receive a DCI based on the multi-carrier/multi-cell scheduling. The wireless device may determine whether the DCI indicates at least one transport block is scheduled for the first cell or at least one resource is scheduled for the first cell (e.g., 1.sup.st cell is indicated?). When the DCI comprises/indicates information that the DCI may indicate resource(s) for the first cell or transport block(s) for the first cell, the wireless device may determine a first DCI field for the first cell being set to a first predefined value and a second DCI field for the first cell being set to a second predefined value. In response to the determining, the wireless device may determine that the DCI may not comprise/indicate a transport block for the first cell. For example, the wireless device may determine that the DCI deactivates or disables one or more transport blocks for the first cell. Otherwise, the wireless device may determine that the DCI may schedule resource(s) or transport block(s) for the first cell. The wireless device may determine that the DCI schedules for the first cell. The wireless device may determine whether the DCI indicates at least one transport block is scheduled for the second cell or at least one resource is scheduled for the second cell (e.g., 2.sup.nd cell is indicated?). When the DCI comprises/indicates information that the DCI may indicate resource(s) for the second cell or transport block(s) for the second cell, the wireless device may determine a first DCI field for the second cell being set to the first predefined value and a second DCI field for the second cell being set to the second predefined value. In response to the determining, the wireless device may determine that the DCI may not comprise/indicate a transport block for the second cell. For example, the wireless device may determine that the DCI deactivates or disables one or more transport blocks for the second cell. Otherwise, the wireless device may determine that the DCI may schedule resource(s) or transport block(s) for the second cell. The wireless device may determine that the DCI schedules for the second cell.

[0310] For example, the first DCI field may be a MCS field. For example, the first predefined value is 26. For example, the second DCI field may be a RV field. For example, the second predefined value is 1. For example, the wireless device may determine whether the first cell is indicated based on a value of a cell index field. For example, the cell index field may indicate a value of the first cell only, the second cell only, both the first cell and the second cell or reserved. For example, the wireless device may determine whether the first cell is indicated based on a RNTI of the DCI. For example, when the RNTI is a first RNTI, the wireless device may determine that the DCI schedules the first cell. When the RNTI is a second RNTI, the wireless device may determine that the DCI may not schedule the first cell.

[0311] In an example, FIG. **27** illustrates an example where a DCI format of a multi-carrier/multi-cell scheduling may not comprise a field to indicate whether a DCI is for a first cell or a second cell or both the first cell and the second cell. FIG. **27** shows a similar process to that of FIG. **26**. A wireless device may consider that a DCI based on the DCI format may indicate resource(s) for the first cell and the second cell. For example, the first cell and the second cell may be scheduled cells of the multi-carrier/multi-cell scheduling.

[0312] In an example, a wireless device may receive a downlink control information (DCI). The DCI comprises a plurality of first DCI fields for a first cell and a plurality of second DCI fields for a second cell. The wireless device may receive, based on the DCI, at least one transport block scheduled for the first cell in response to a first DCI field of the plurality of first DCI fields having a first value and a second DCI field of the plurality of first DCI fields having a second value. The wireless device may determine, based on the DCI, no transport block is scheduled for the second cell in response to a first DCI field of the plurality of second DCI fields having a first predetermined value and a second DCI field of the plurality of second DCI fields having a second predetermined value.

[0313] According to an example embodiment, the first DCI field may be a redundancy version field. The second DCI field may be a modulation and coding scheme field. For example, the first predetermined value may be zero or one. For example, the second predefined value may be 26 or zeros or all ones. According to an example embodiment, the determining no transport block being scheduling for the second cell may be further in response to a third DCI field of the plurality of second DCI fields having a third predetermined value. For example, third DCI field may be a hybrid automatic repeat request (HARQ) process identifier field. The third predetermined value may be zero or all ones or all zeros or one.

[0314] According to an example embodiment, the wireless device may receive one or more RRC messages indicating configuration parameters. The configuration parameters may indicate a third cell scheduling a first DCI comprising resource assignment for the first cell and the second cell. The wireless device may determine at most one transport block may be scheduled by the first DCI for the first cell in response to the configuration parameters. The wireless device may determine that at most one transport block may be scheduled by the first DCI for the second cell in response to the configuration parameters. The configuration parameters may further indicate at most one transport block for the first cell via the first DCI and at most one transport block for the second cell via the first DCI. For example, the DCI and the first DCI may be based on a DCI format of a multi-carrier/multi-cell scheduling. For example, the DCI format may comprise one or more DCI fields, wherein one or more values of the one or more DCI fields may be applied to the first cell and the second cell.

[0315] In an example, the wireless device may receive one or more radio resource control messages indicating configuration parameters. The configuration parameters may indicate a third cell scheduling a first DCI comprising resource assignments for the first cell and the second cell, a first number of transport block(s) scheduled for the first cell via the first DCI, and a second number of transport block(s) scheduled for the second cell via the first DCI. The wireless device may determine a plurality of DCI fields of a DCI format used for the first DCI based on the first number and the second number. The one or more DCI fields may comprise the first DCI field and the second DCI field. For example, the wireless device may determine the first number of the first DCI field for the first cell and the first number of the second DCI field for the first cell in the DCI format. The wireless device may determine the second number of the first DCI fields for the second cell and the second number of the second DCI fields for the second cell in the DCI format.

[0316] In an example, a wireless device may receive a downlink control information. The DCI may comprise a plurality of first DCI fields for a first cell and a plurality of second DCI fields for a second cell. The wireless device may determine, based on the DCI, at least one transport block being scheduled for the first cell in response to: a first value of a first DCI field of the plurality of first DCI fields being different from a first predetermined value; or a second value of a second DCI field of the plurality of first DCI fields being different from a second predetermined value.

[0317] The wireless device may determine, based on the DCI, disabling scheduling for the second cell in response to a third value of the first DCI field of the plurality of second DCI fields being equal to the first predetermined value and a fourth value of the second DCI field of the plurality of second DCI fields being equal to a second predetermined value.

[0318] In an example, a wireless device may receive a downlink control information (DCI). The DCI may comprise a cell index indicating one or more cells of a plurality of cells. The DCI may comprise a SRS request field and a CSI request field. The wireless device may determine one or more first cells to transmit a SRS based on the SRS request field and the cell index. The wireless device may determine one or more second cells to transmit a CSI based on the CSI request field and the cell index. The one or more first cells may be same as the one or more second cells. The one or more first cells may be empty when the SRS request may be not indicated as enabled. The one or more second cells may be empty when the CSI request field may be not indicated as enabled.

[0319] The wireless device may determine a cell of the plurality of cells to transmit a physical uplink shared channel with an uplink control information based on a rule. The wireless device may determine a cell of the plurality of cells to transmit a PUSCH in response to the DCI comprising/indicating an uplink shared channel being enabled. The wireless device may transmit the PUSCH via the cell. The wireless device may not transmit a PUSCH via other cell of the plurality of cells based on the DCI.

Claims

1. A wireless device comprising: one or more processors; and memory storing instructions that, when executed by the one or more processors, cause the wireless device to receive downlink control information (DCI) comprising: a cell index, wherein the cell index indicates one or more cells of a plurality of cells; and a channel state information (CSI) request; determine a cell, of the one or more cells, to transmit a CSI based on the CSI request and the cell index of the DCI; and transmit, via the cell, the CSI.
2. The wireless device of claim 1, wherein the cell is further determined by determining a second cell, of the cells, to transmit the CSI based on the CSI request and the cell index.
3. The wireless device of claim 2, wherein the instructions further cause the wireless device to transmit the CSI via the second cell based on the determining.
4. The wireless device of claim 1, wherein the cells are a plurality of cells.
5. The wireless device of claim 1, wherein the CSI request indicates: to transmit the CSI; or to skip transmission of the CSI.
6. The wireless device of claim 1, wherein the instructions further cause the wireless device to receive a second DCI comprising: the cell index; and the CSI request.
7. The wireless device of claim 6, wherein the instructions further cause the wireless device to determine at least one of the cells to not transmit the CSI based on the CSI request and the cell index.
8. The wireless device of claim 6, wherein the instructions further cause the wireless device transmit, via one or more of the plurality of cells indicated by the cell index, the CSI based on the second DCI.
9. A base station comprising: one or more processors; and memory storing instructions that, when executed by the one or more processors, cause the base station to: transmit, to a wireless device, downlink control information (DCI) comprising: a cell index, wherein the cell index indicates one or more cells of a plurality of cells; and a channel state information (CSI) request, wherein the DCI indicates a cell, of the one or more cells, for the wireless device to transmit a CSI based on the CSI request and the cell index of the DCI; and receive, via the cell, the CSI.
10. The base station of claim 9, wherein the DCI indicates a second cell, of the cells, for the wireless device to transmit the CSI based on the CSI request and the cell index.
11. The base station of claim 10, wherein the instructions further cause the base station to receive the CSI via the second cell based on the DCI.
12. The base station of claim 9, wherein the cells are a plurality of cells.
13. The base station of claim 9, wherein the CSI request indicates: to transmit the CSI; or to skip transmission of the CSI.
14. The base station of claim 9, wherein the instructions further cause the base station to transmit a second DCI comprising: the cell index; and the CSI request.
15. The base station of claim 10, wherein the instructions further cause the base station to receive, via one or more of the plurality of cells indicated by the cell index, the CSI based on the second DCI.
16. A non-transitory computer-readable medium comprising instructions that, when executed by one or more processors, cause the one or more processors to: receive downlink control information (DCI) comprising: a cell index, wherein the cell index indicates one or more cells of a plurality of cells; and a channel state information (CSI) request; determine a cell, of the one or more cells, to transmit a CSI based on the CSI request and the cell index of the DCI; and transmit, via the cell, the CSI.

17. The non-transitory computer-readable medium of claim 16, wherein the cell is further determined by determining a first cell, of the cells, to transmit the CSI based on the CSI request and the cell index.
18. The non-transitory computer-readable medium claim 17, wherein the instructions further cause the one or more processors to transmit the CSI via the second cell based on the determining.
19. The non-transitory computer-readable medium of claim 16, wherein the CSI request indicates: to transmit the CSI; or to skip transmission of the CSI.
20. The non-transitory computer-readable medium of claim 16, wherein the instructions further cause the one or more processors to receive a second DCI comprising: the cell index; and the CSI request.