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**Yi et al.**

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(54) **SEMI-PERSISTENT SCHEDULING IN HIGH FREQUENCY**(71) Applicant: **Ofinno, LLC**, Reston, VA (US)(72) Inventors: **Yunjung Yi**, Vienna, VA (US); **Nazanin Rastegardoost**, McLean, VA (US); **Esmael Hejazi Dinan**, McLean, VA (US); **Hua Zhou**, Vienna, VA (US); **Ali Cagatay Cirik**, Chantilly, VA (US); **Jonghyun Park**, Syosset, NY (US); **Hyoungsuk Jeon**, Centreville, VA (US)(73) Assignee: **Ofinno, LLC**, Reston, VA (US)

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(21) Appl. No.: **17/719,611**(22) Filed: **Apr. 13, 2022**(65) **Prior Publication Data**

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**Related U.S. Application Data**

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(51) **Int. Cl.****H04W 72/56** (2023.01)  
**H04L 1/1812** (2023.01)

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(52) **U.S. Cl.**CPC ..... **H04W 72/56** (2023.01); **H04L 1/1812** (2013.01); **H04L 5/0053** (2013.01);  
(Continued)(58) **Field of Classification Search**

CPC ..... H04W 72/56; H04W 72/0446; H04W 72/1263; H04L 27/26025; H04L 72/23; H04L 1/1812; H04L 5/0053

See application file for complete search history.

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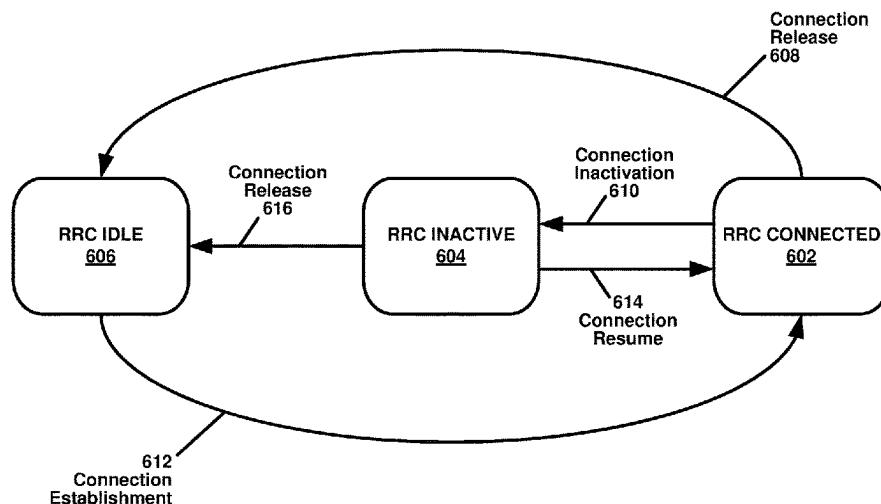
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*Primary Examiner* — Shukri Taha(74) *Attorney, Agent, or Firm* — Matthew Fernandez; Kavon Nasabzadeh; Jacob L. Mangan(57) **ABSTRACT**

A base station may transmit, to a wireless device, configuration parameters for semi-persistent scheduling (SPS), indicating periodic downlink resources for SPS physical downlink shared channel (PDSCH) transmissions. The base station may transmit, to the wireless device, a downlink control information (DCI). The DCI may indicate: an activation of the periodic downlink resources, a PUCCH resource for receiving feedback information corresponding to a plurality of SPS PDSCH transmissions via the periodic downlink resources, and a total downlink assignment index (DAI) incremented based on a number of the plurality of SPS PDSCH transmissions corresponding to the PUCCH resource. The base station may receive, from the wireless device via the PUCCH resource, feedback information bits for the plurality of SPS PDSCH transmissions based on the total DAI.

**20 Claims, 48 Drawing Sheets**

- (51) **Int. Cl.**
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  - H04L 27/26** (2006.01)
  - H04W 72/0446** (2023.01)
  - H04W 72/1263** (2023.01)
  - H04W 72/23** (2023.01)
- (52) **U.S. Cl.**
- CPC ... **H04L 27/26025** (2021.01); **H04W 72/0446** (2013.01); **H04W 72/1263** (2013.01); **H04W 72/23** (2023.01)

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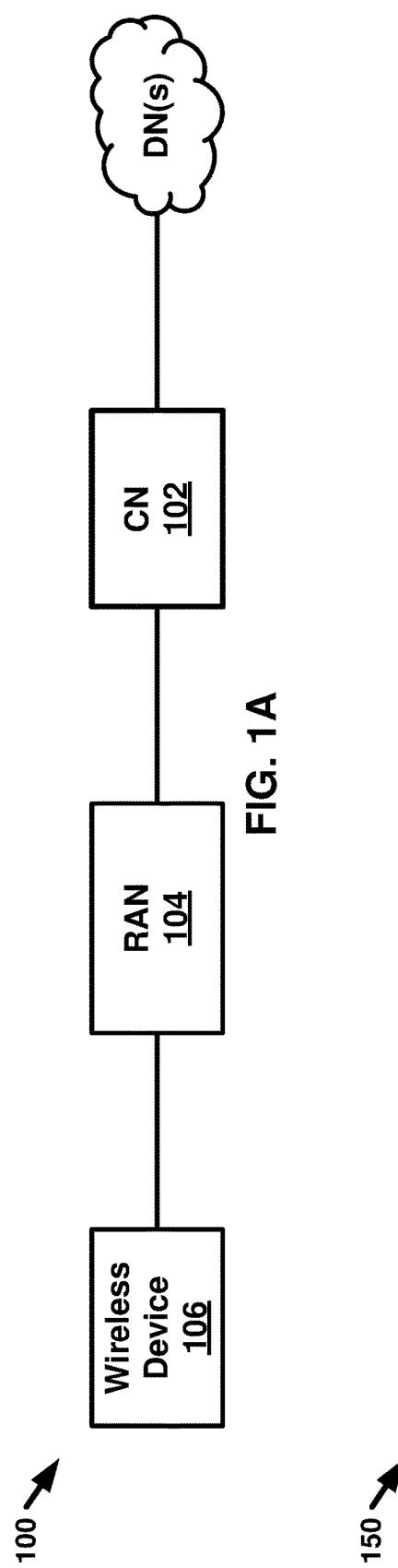


FIG. 1A

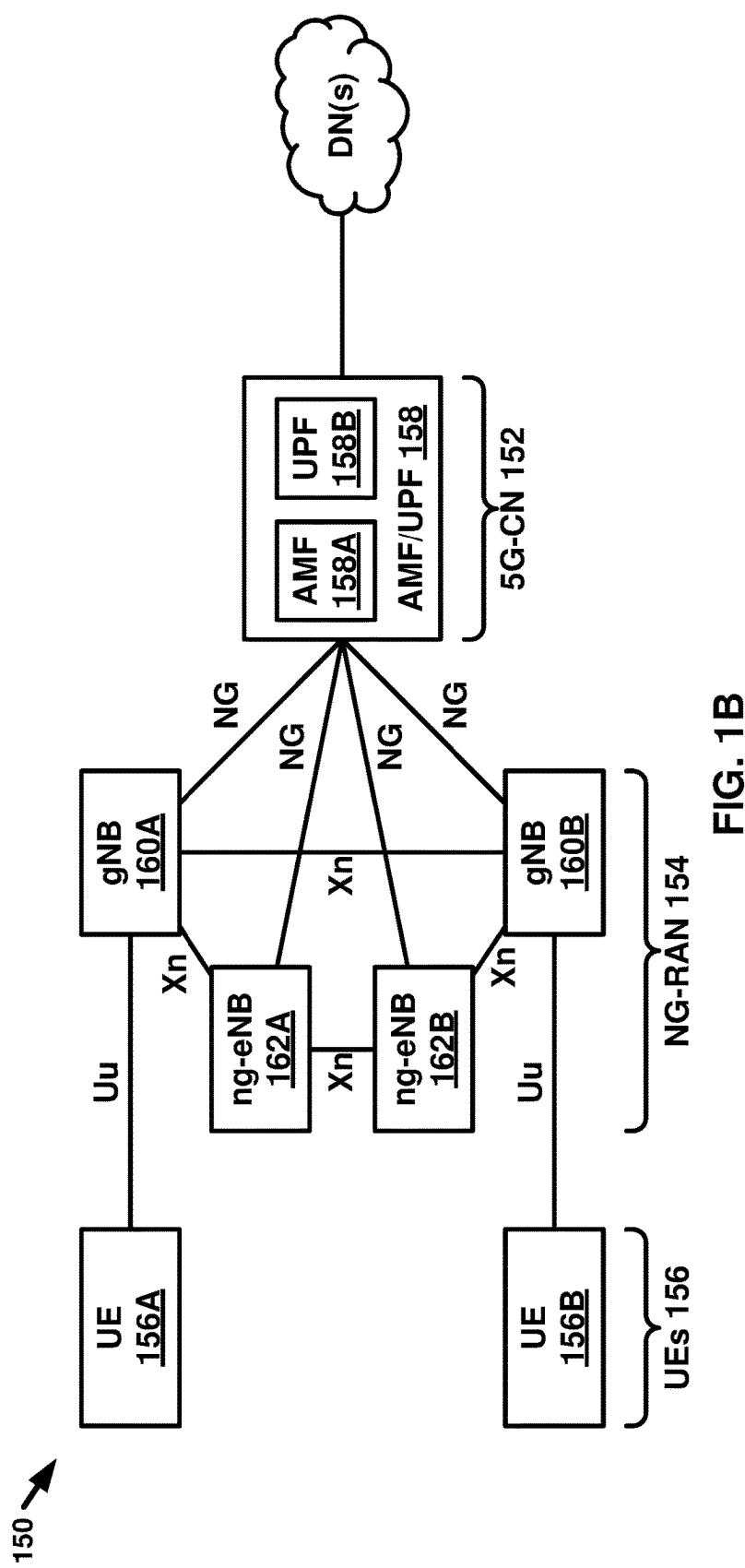


FIG. 1B

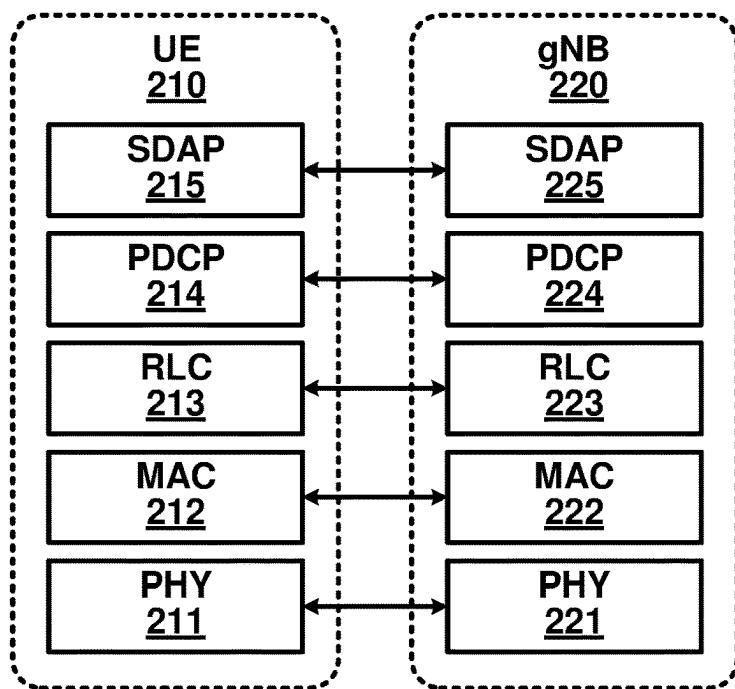


FIG. 2A

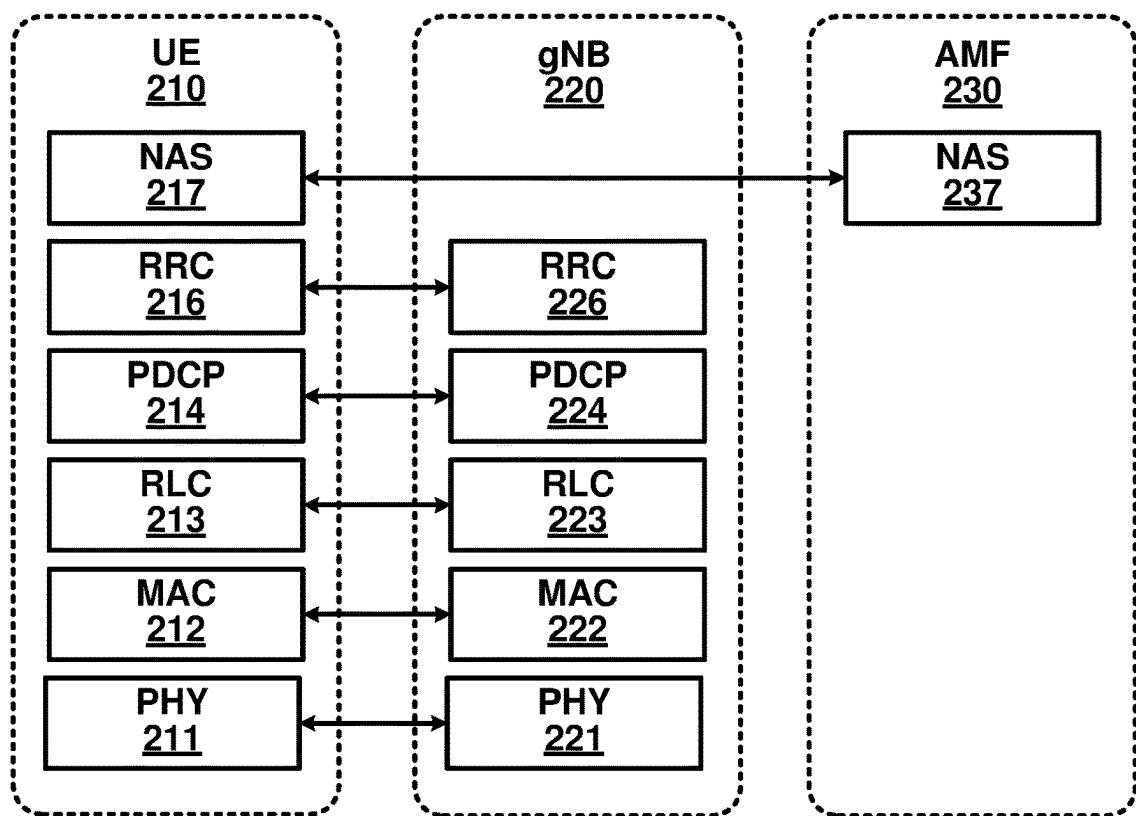
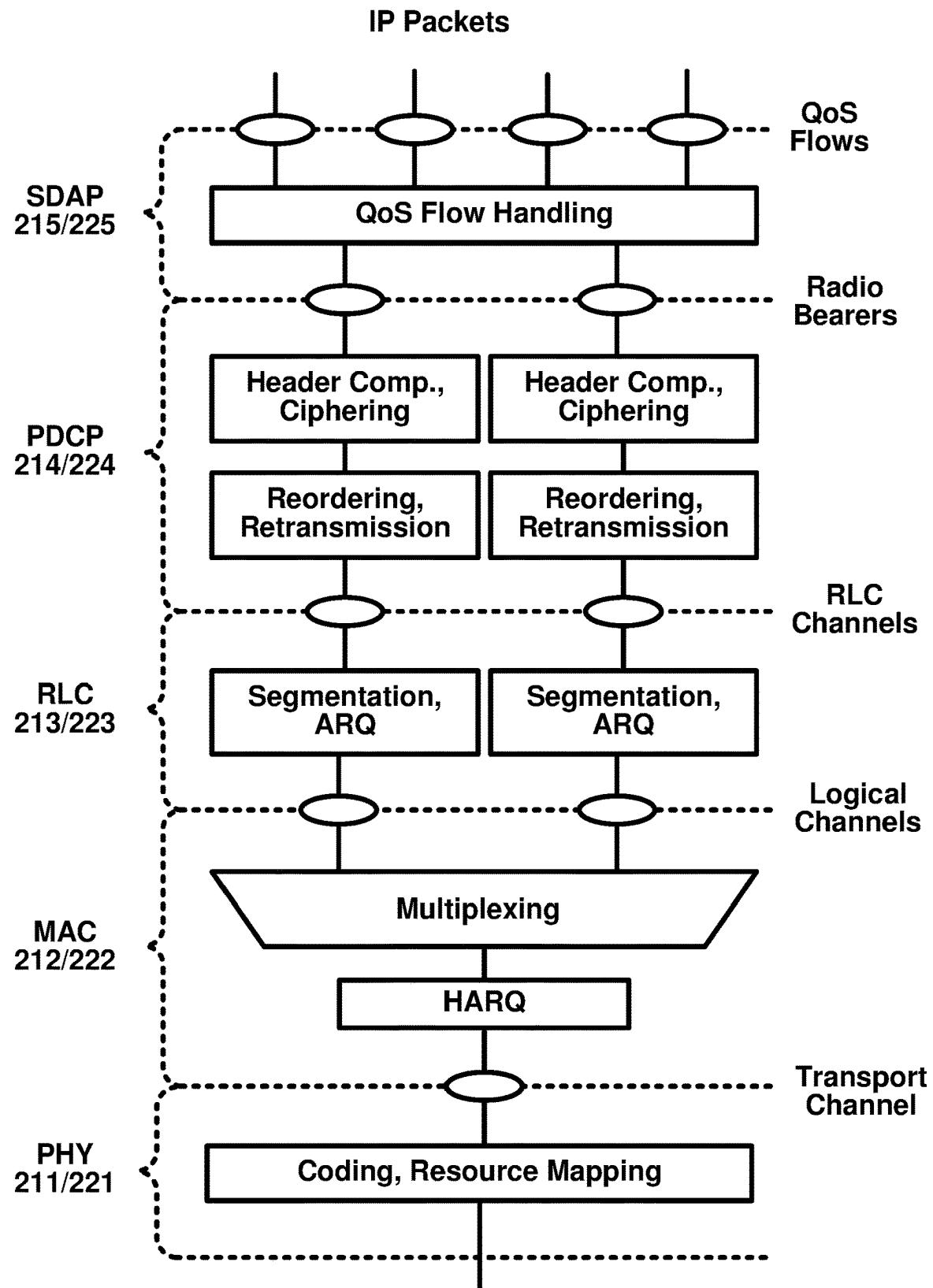


FIG. 2B

**FIG. 3**

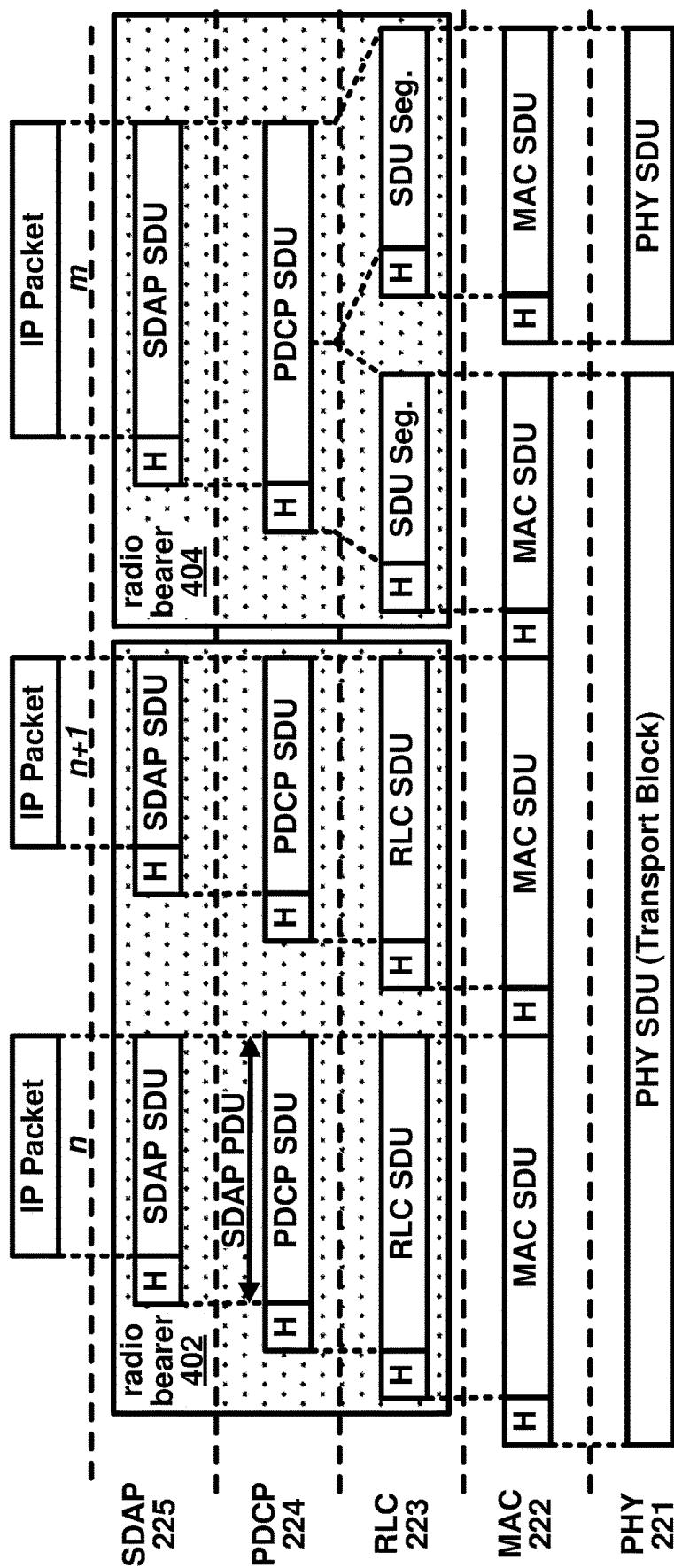
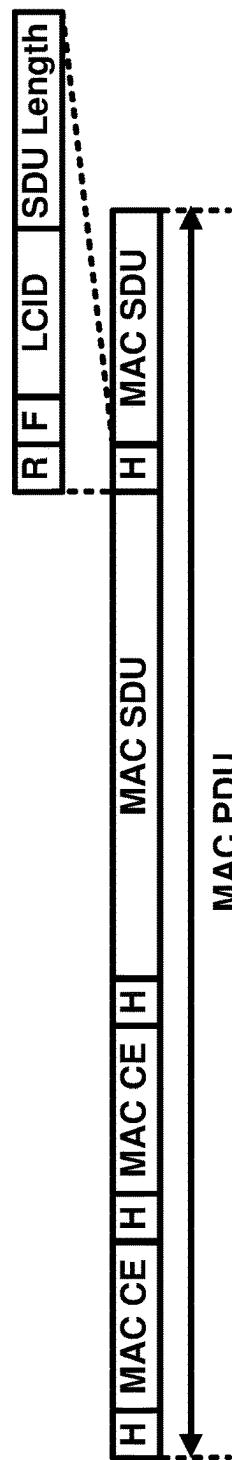


FIG. 4A

MAC PDU  
FIG. 4B

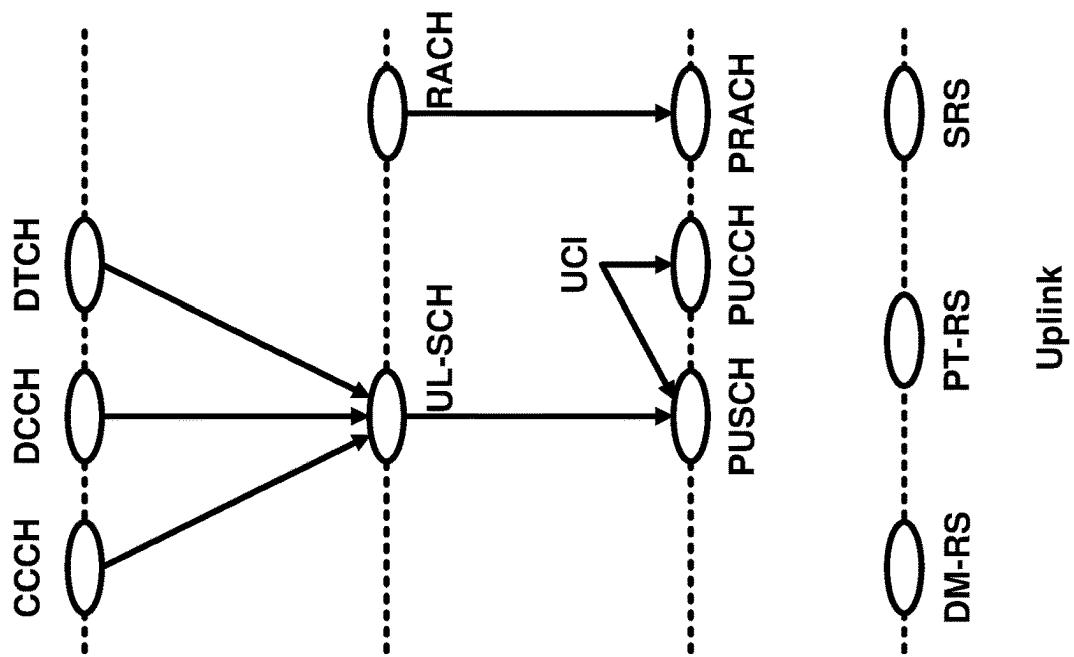


FIG. 5B

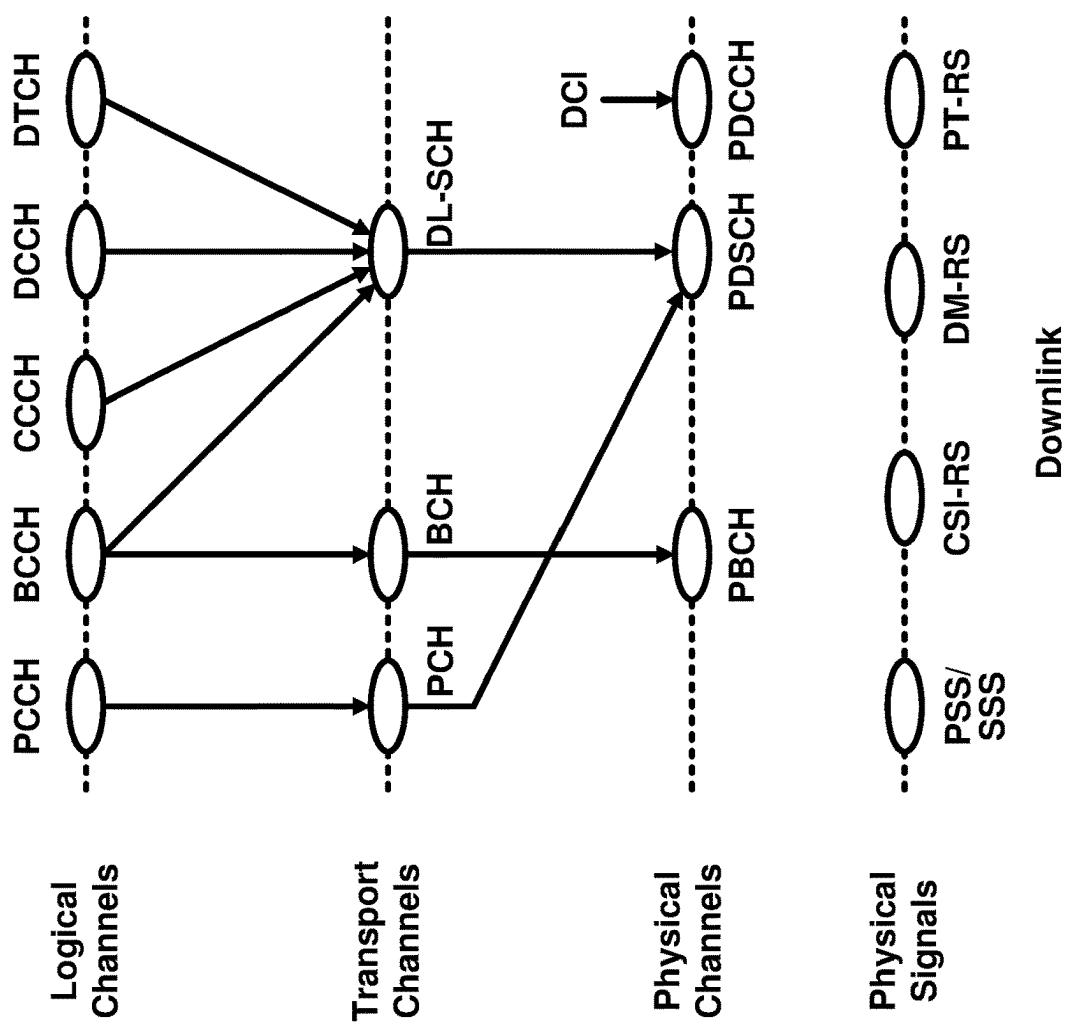


FIG. 5A

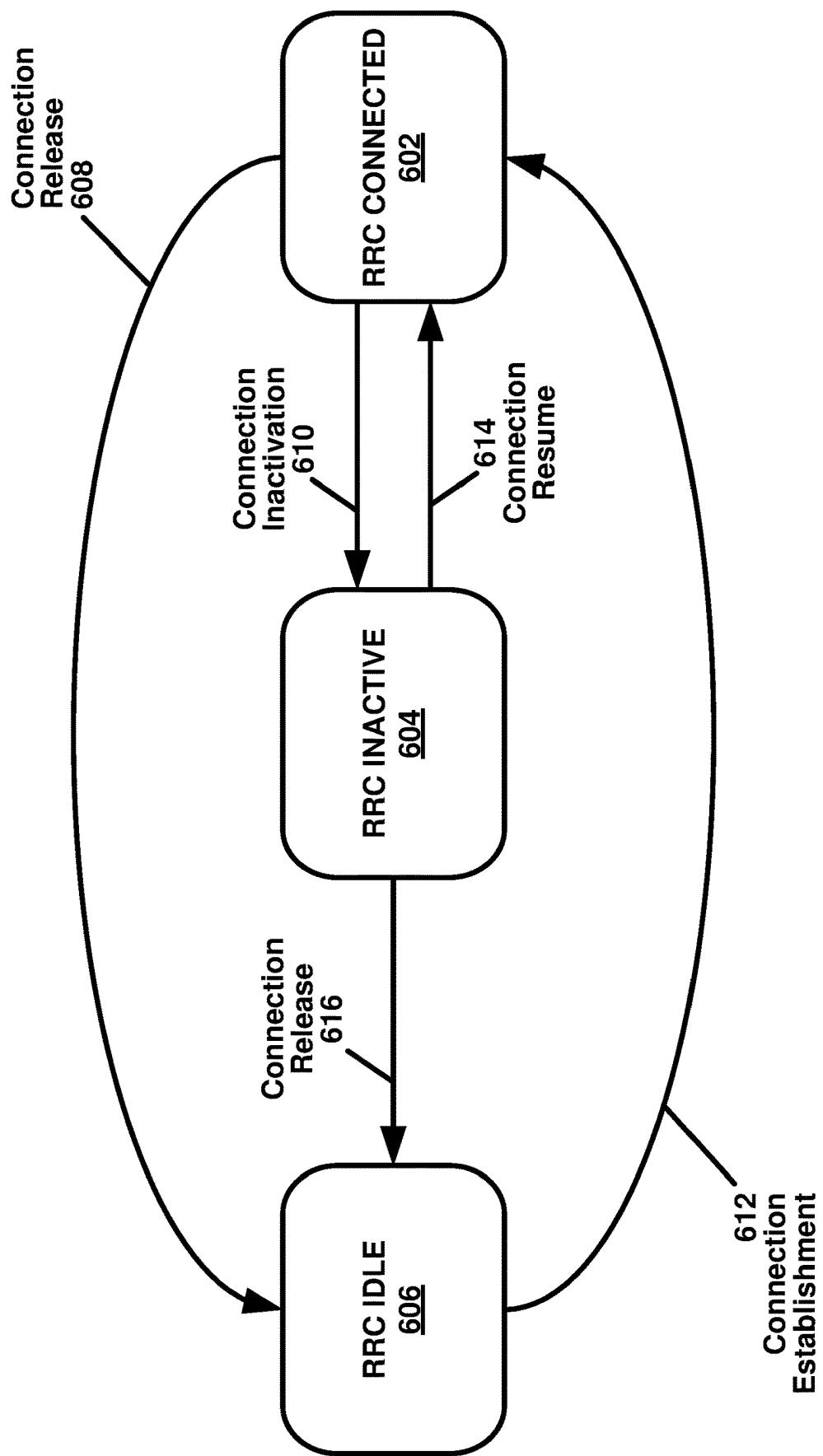


FIG. 6

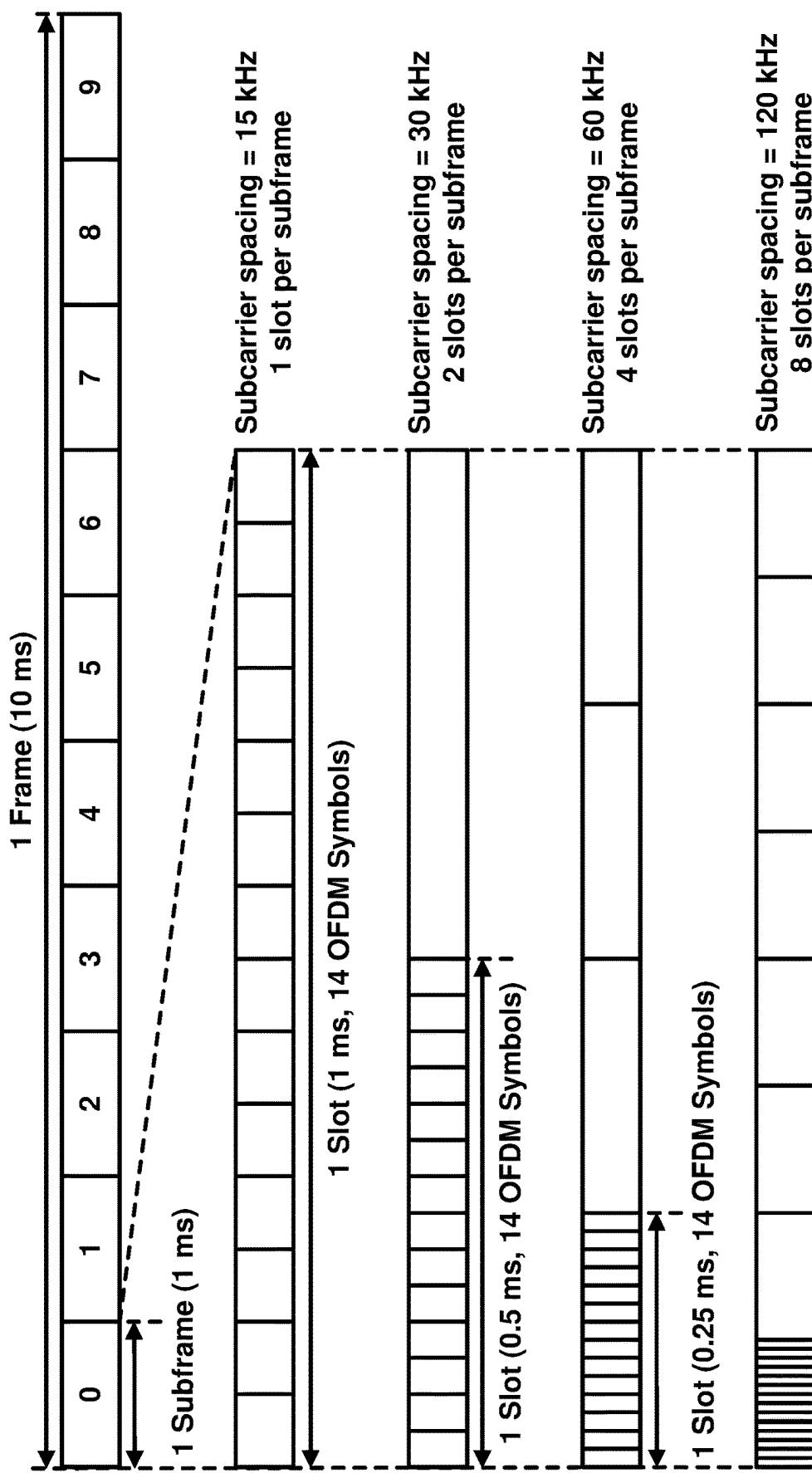


FIG. 7

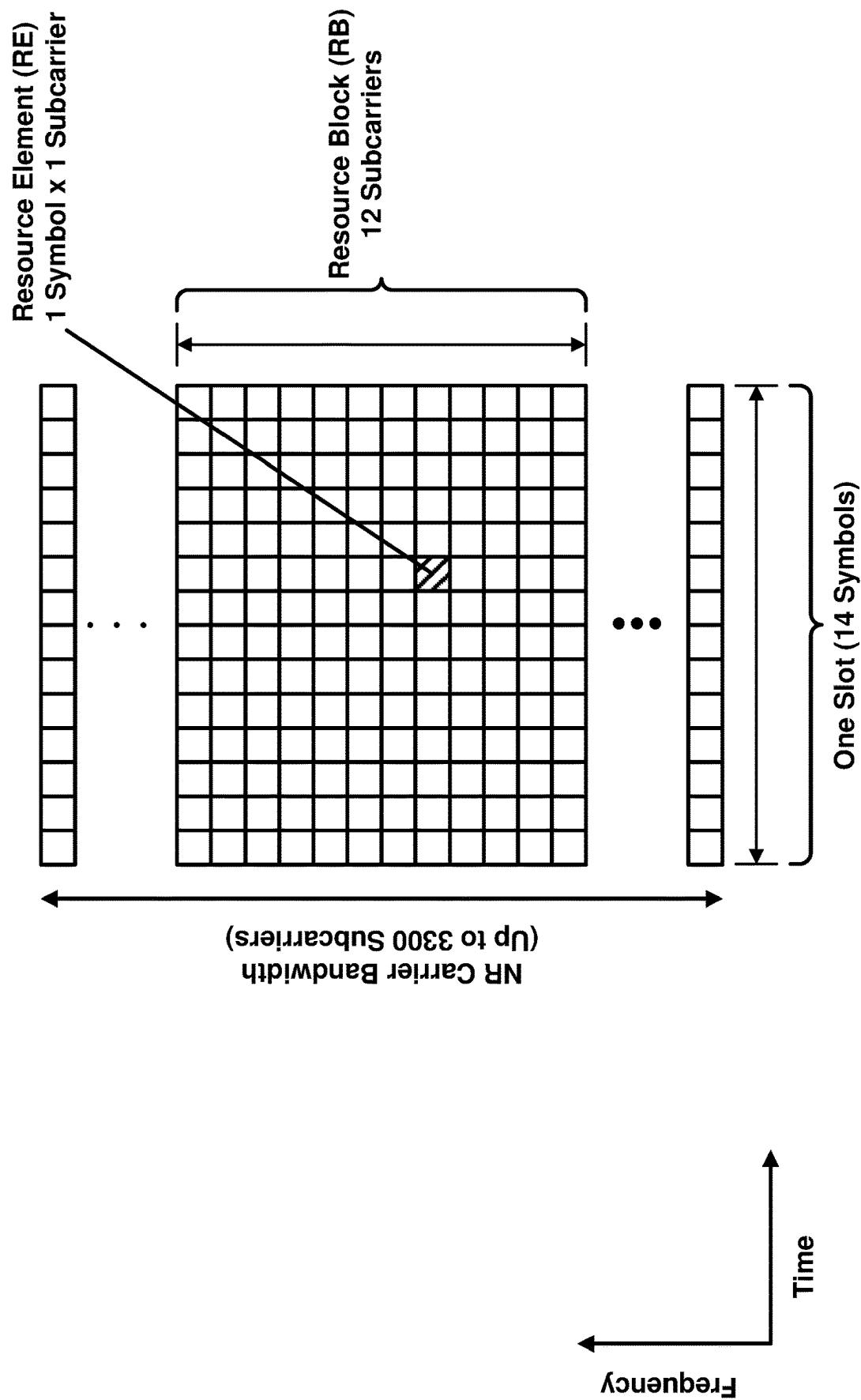


FIG. 8

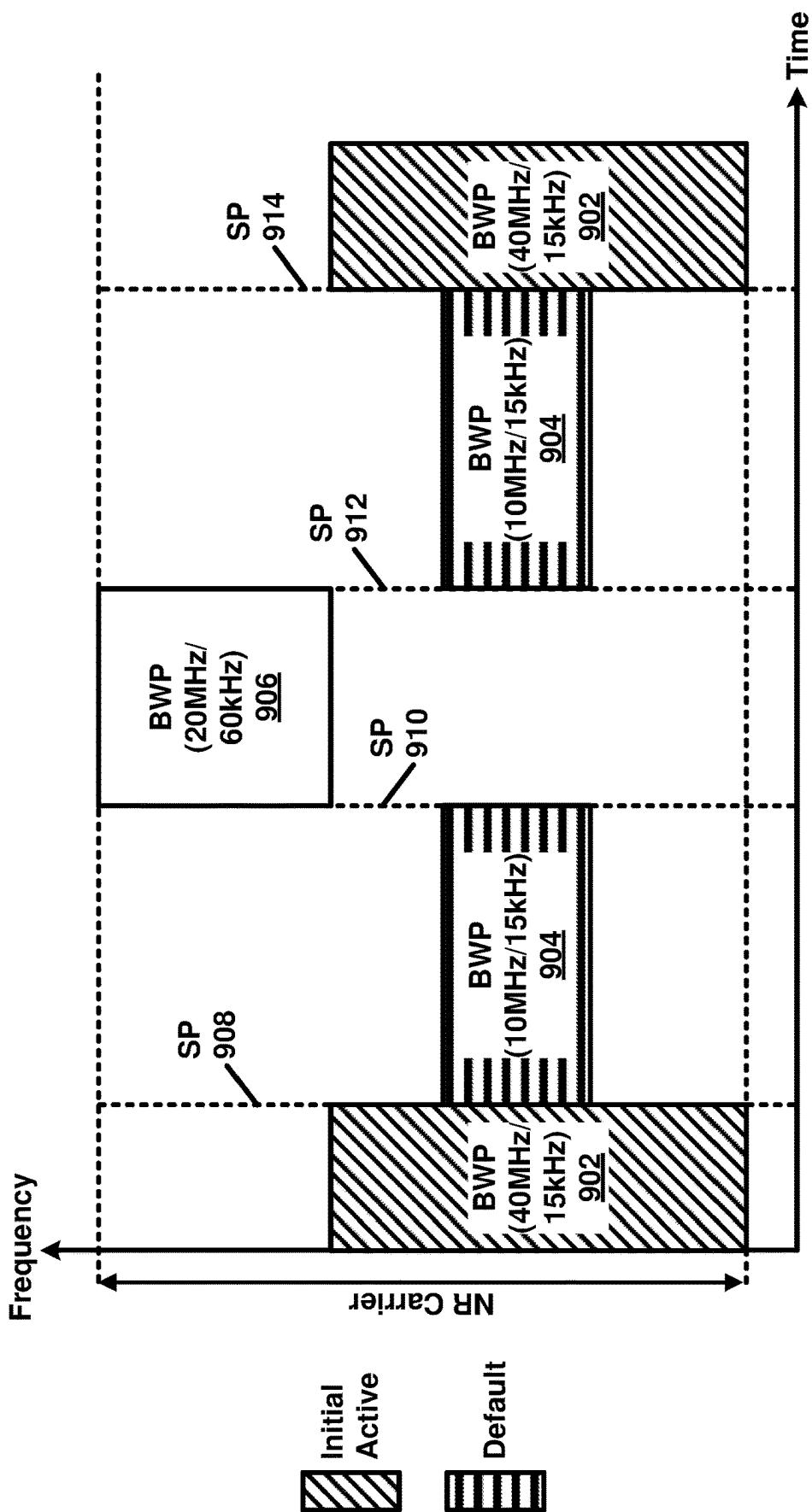


FIG. 9

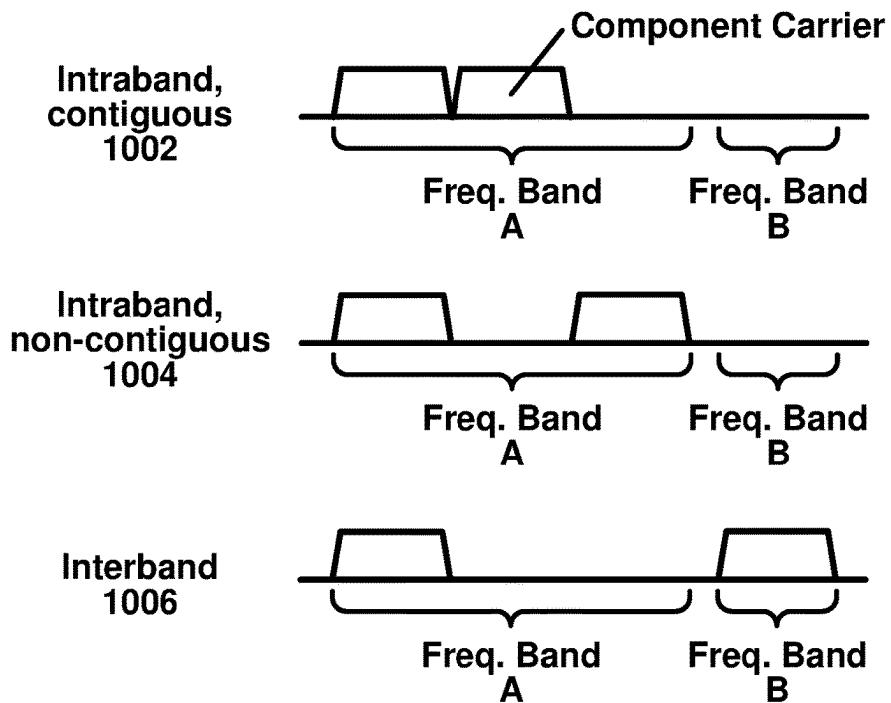


FIG. 10A

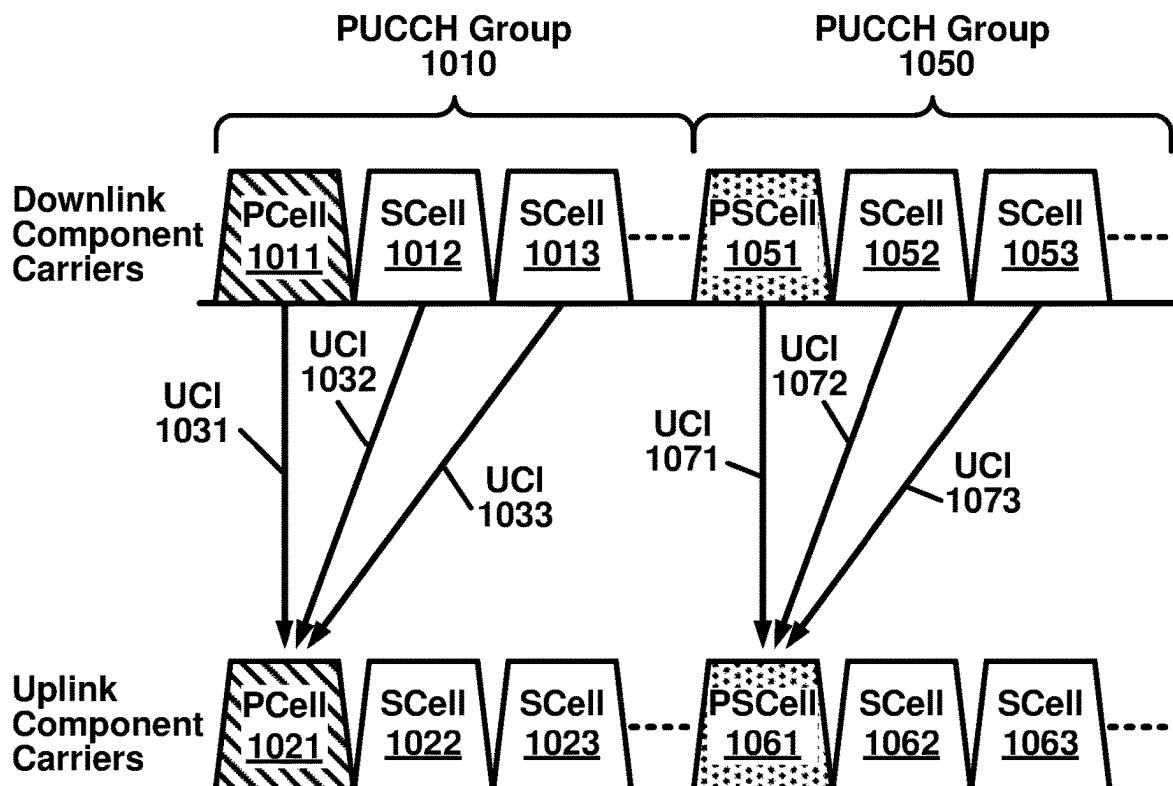


FIG. 10B

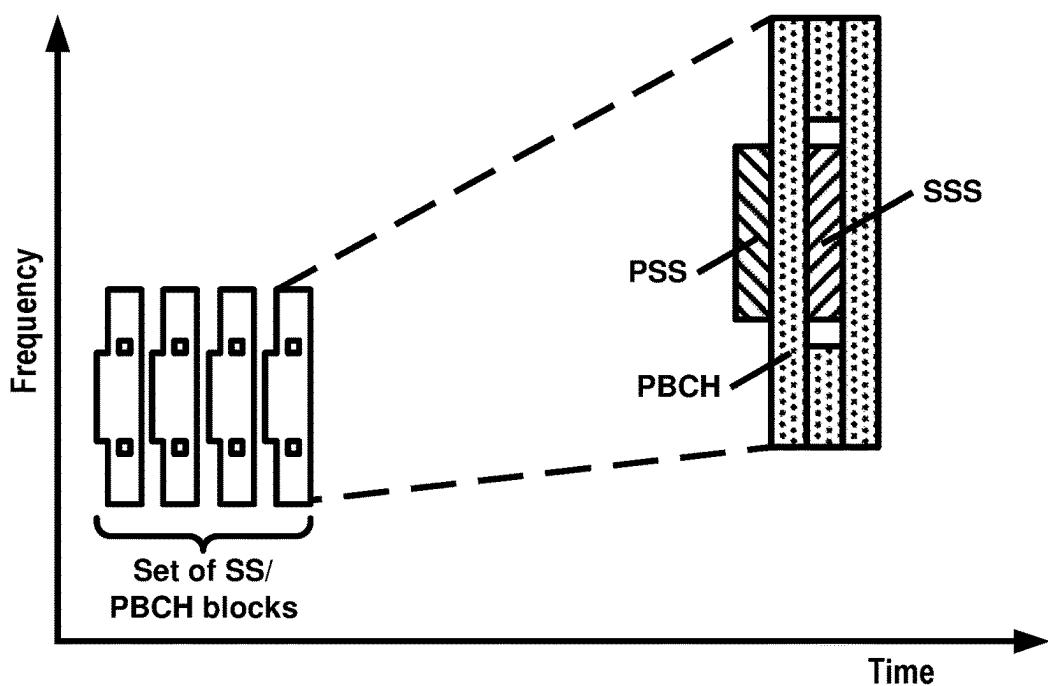


FIG. 11A

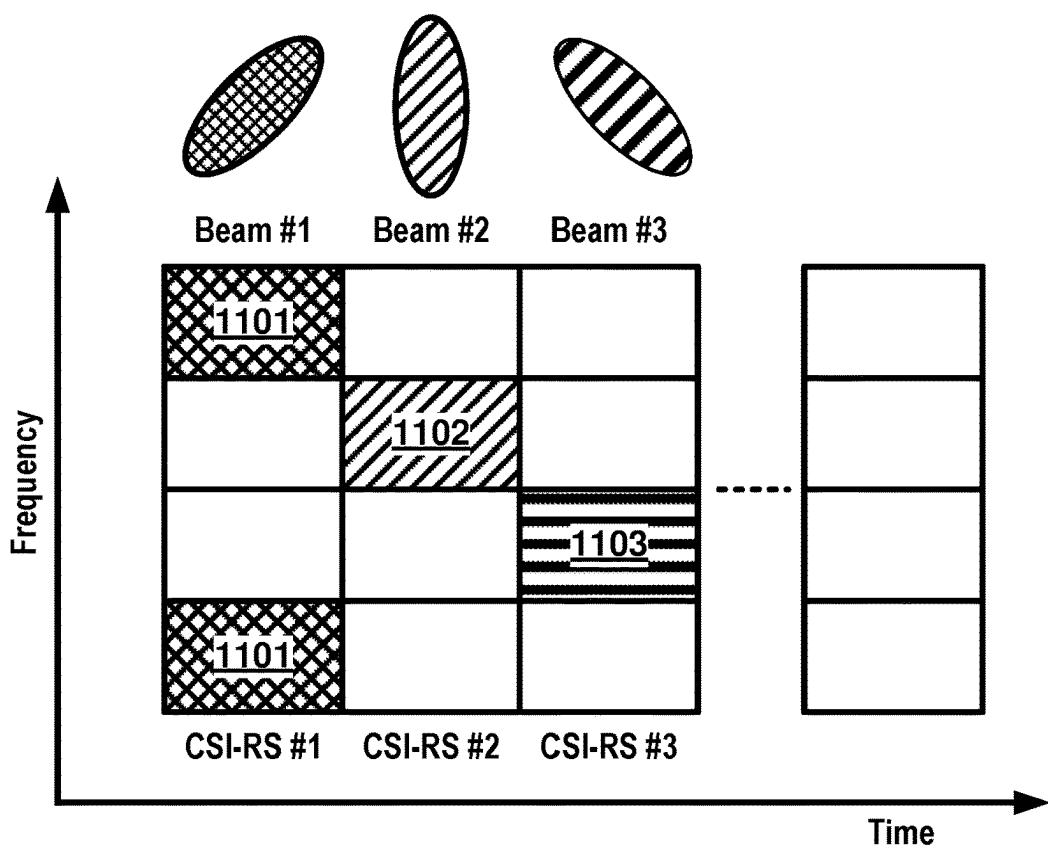


FIG. 11B

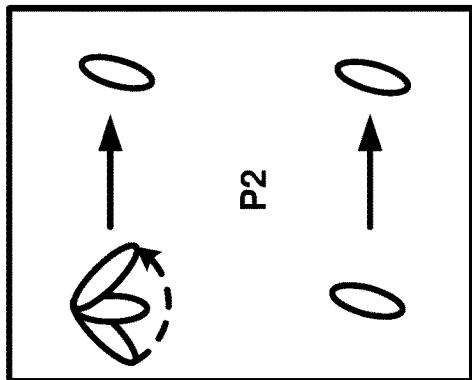
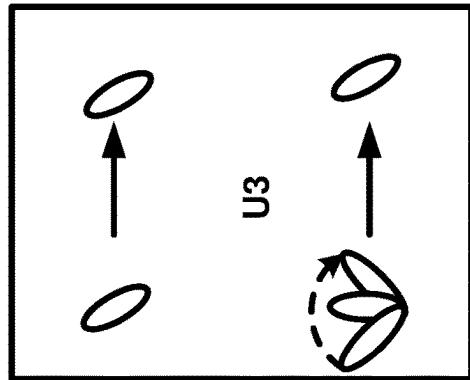
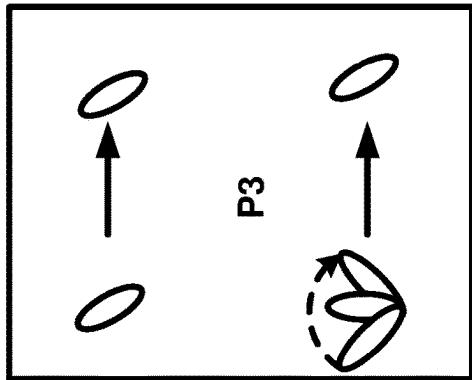


FIG. 12A

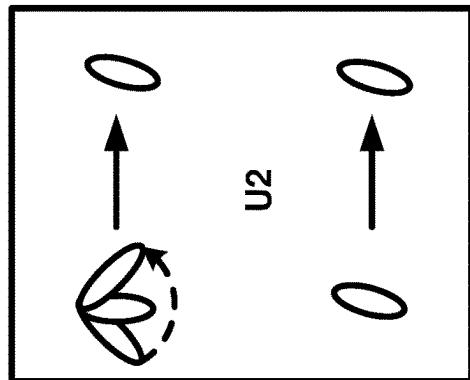
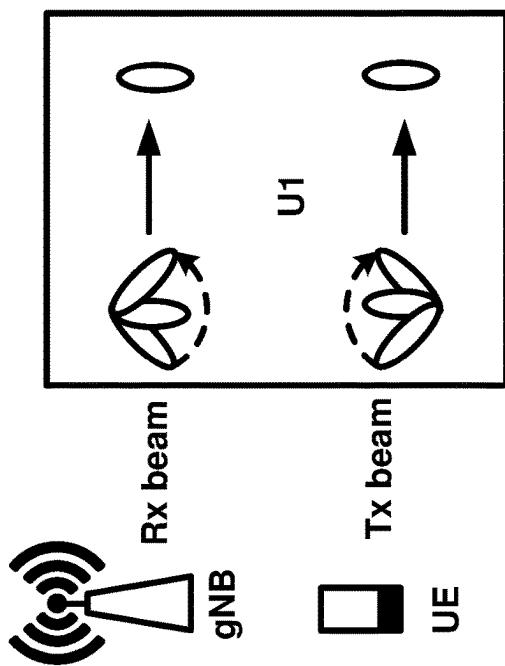
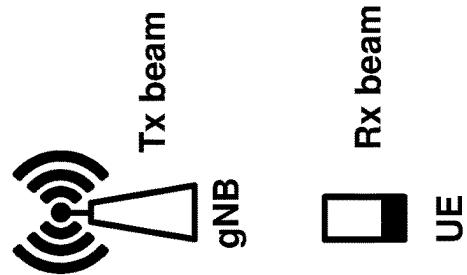
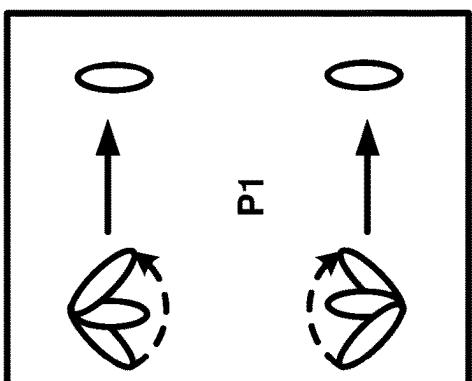


FIG. 12B



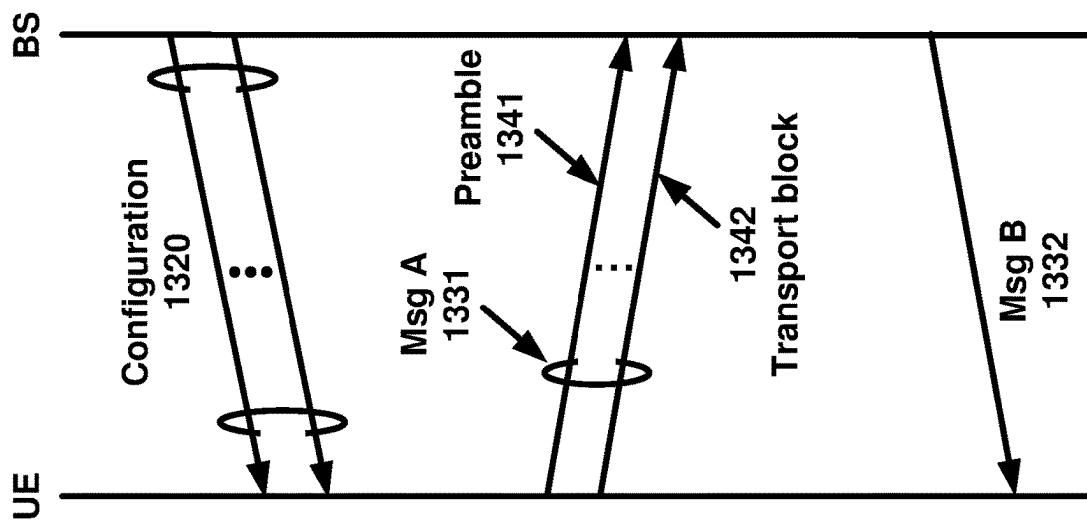


FIG. 13C

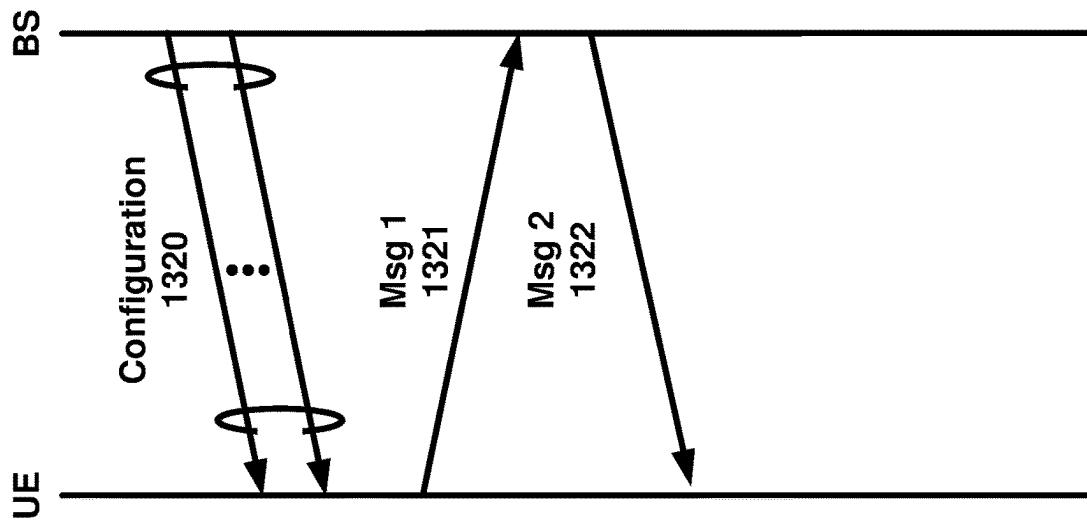


FIG. 13B

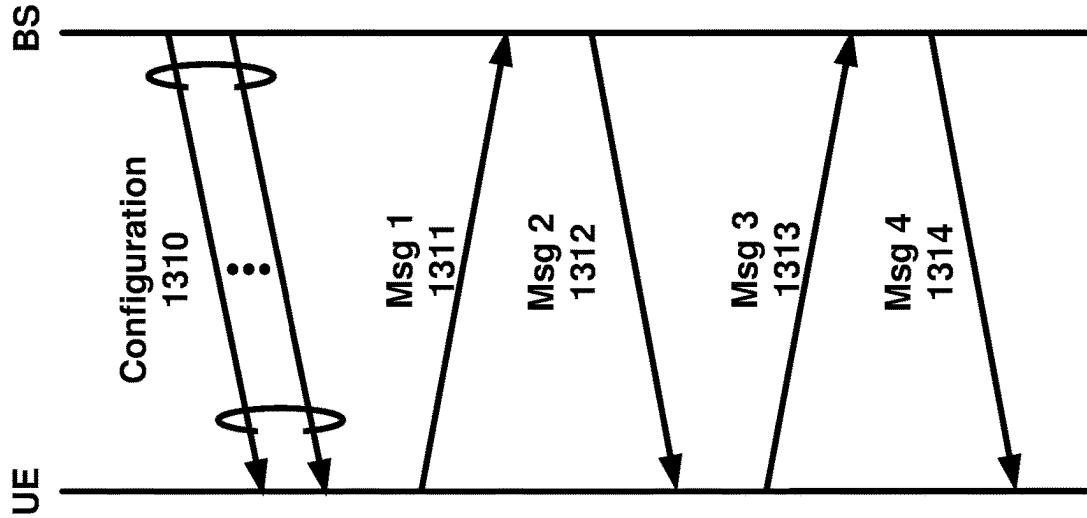


FIG. 13A

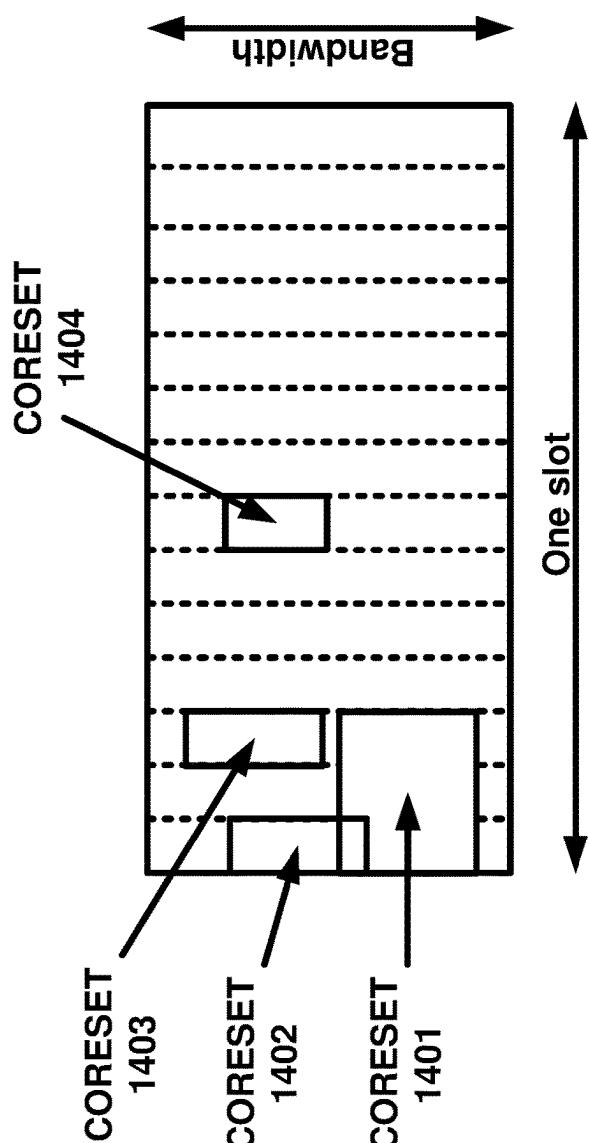


FIG. 14A

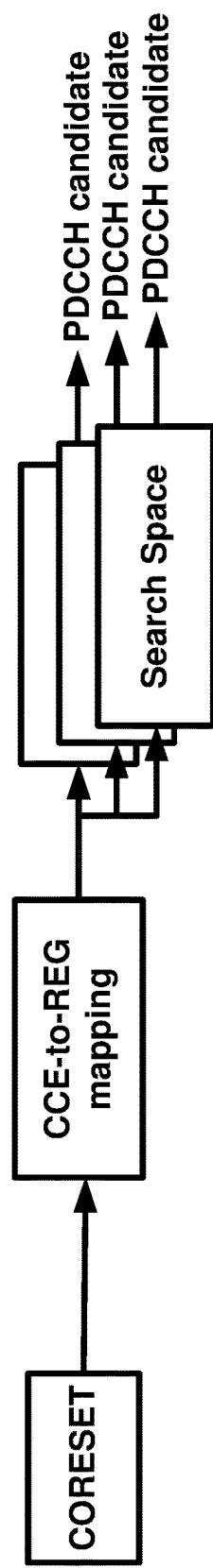


FIG. 14B

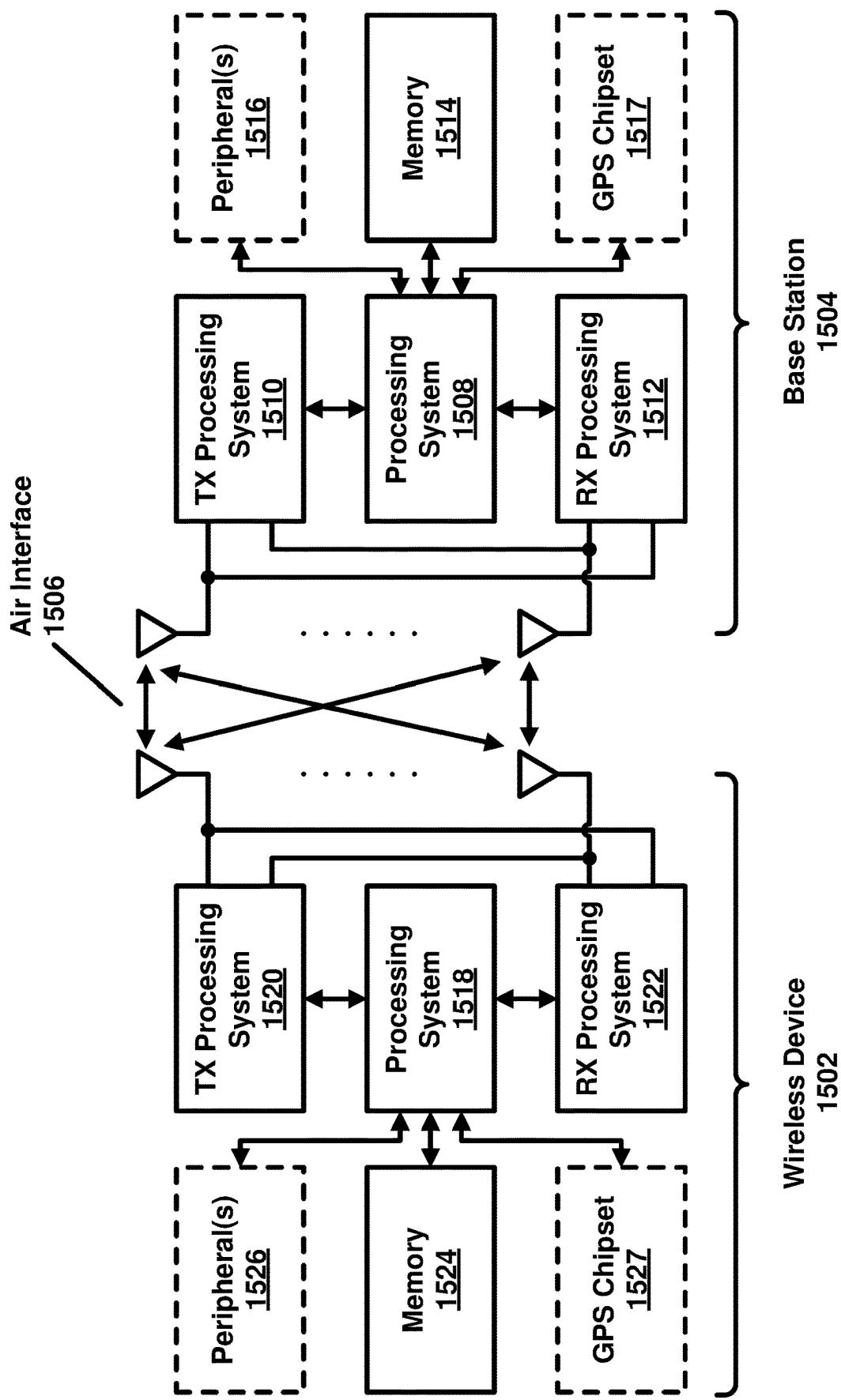


FIG. 15

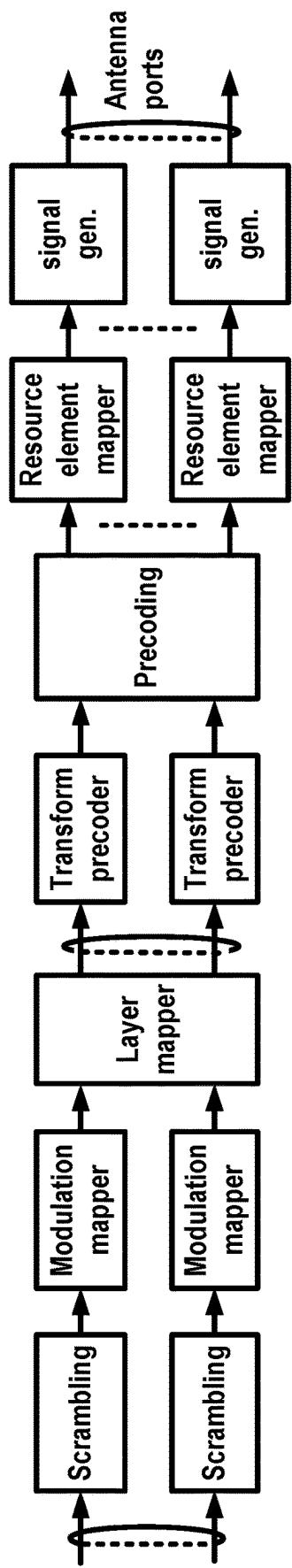


FIG. 16A

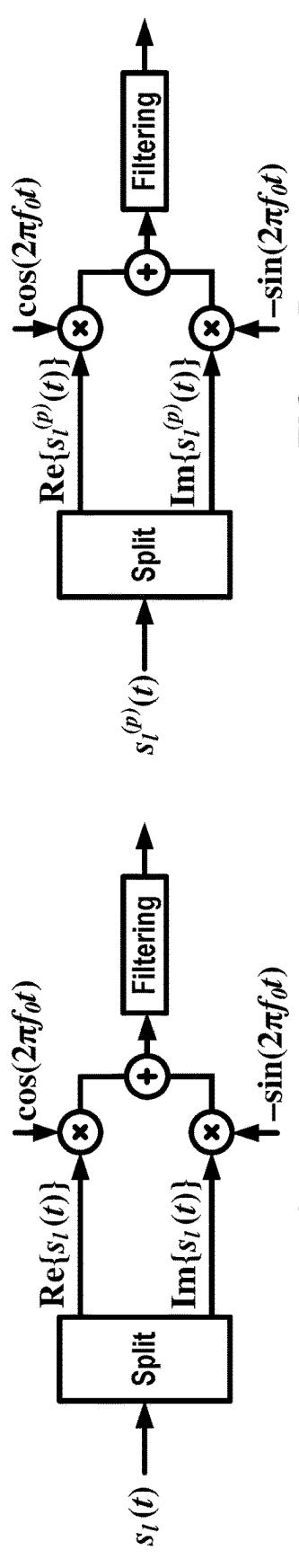


FIG. 16D

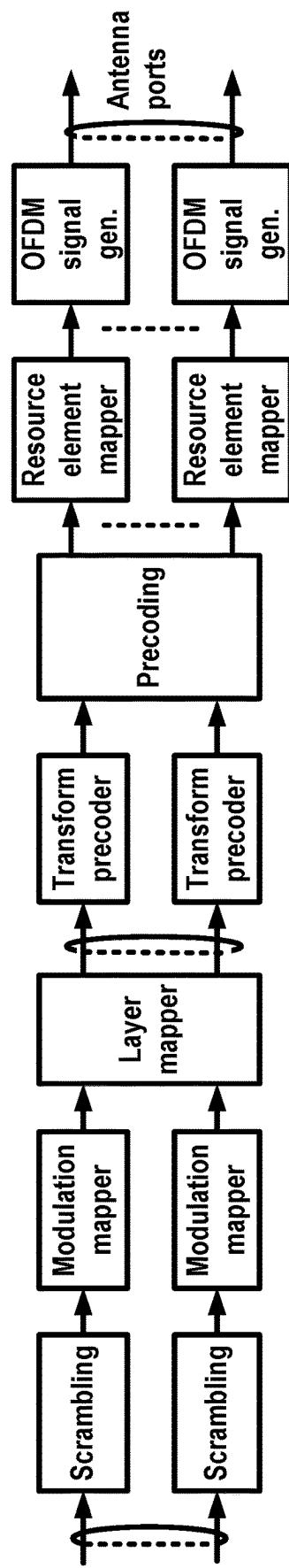


FIG. 16C

DCI format	Usage
0_0	Scheduling of PUSCH in one cell
0_1	Scheduling of one or multiple PUSCH in one cell, or indicating downlink feedback information for configured grant PUSCH (CG-DFI)
0_2	Scheduling of PUSCH in one cell
1_0	Scheduling of PDSCH in one cell
1_1	Scheduling of PDSCH in one cell, and/or triggering one shot HARQ-ACK codebook feedback
1_2	Scheduling of PDSCH in one cell
2_0	Notifying a group of UEs of the slot format, available RB sets, COT duration and search space set group switching
2_1	Notifying a group of UEs of the PRB(s) and OFDM symbol(s) where UE may assume no transmission is intended for the UE
2_2	Transmission of TPC commands for PUCCH and PUSCH
2_3	Transmission of a group of TPC commands for SRS transmissions by one or more UEs
2_4	Notifying a group of UEs of the PRB(s) and OFDM symbol(s) where UE cancels the corresponding UL transmission from the UE
2_5	Notifying the availability of soft resources as defined in Clause [x.x] of [10, TS 38.473]
2_6	Notifying the power saving information outside DRX Active Time for one or more UEs
3_0	Scheduling of NR sidelink in one cell
3_1	Scheduling of LTE sidelink in one cell

FIG. 17

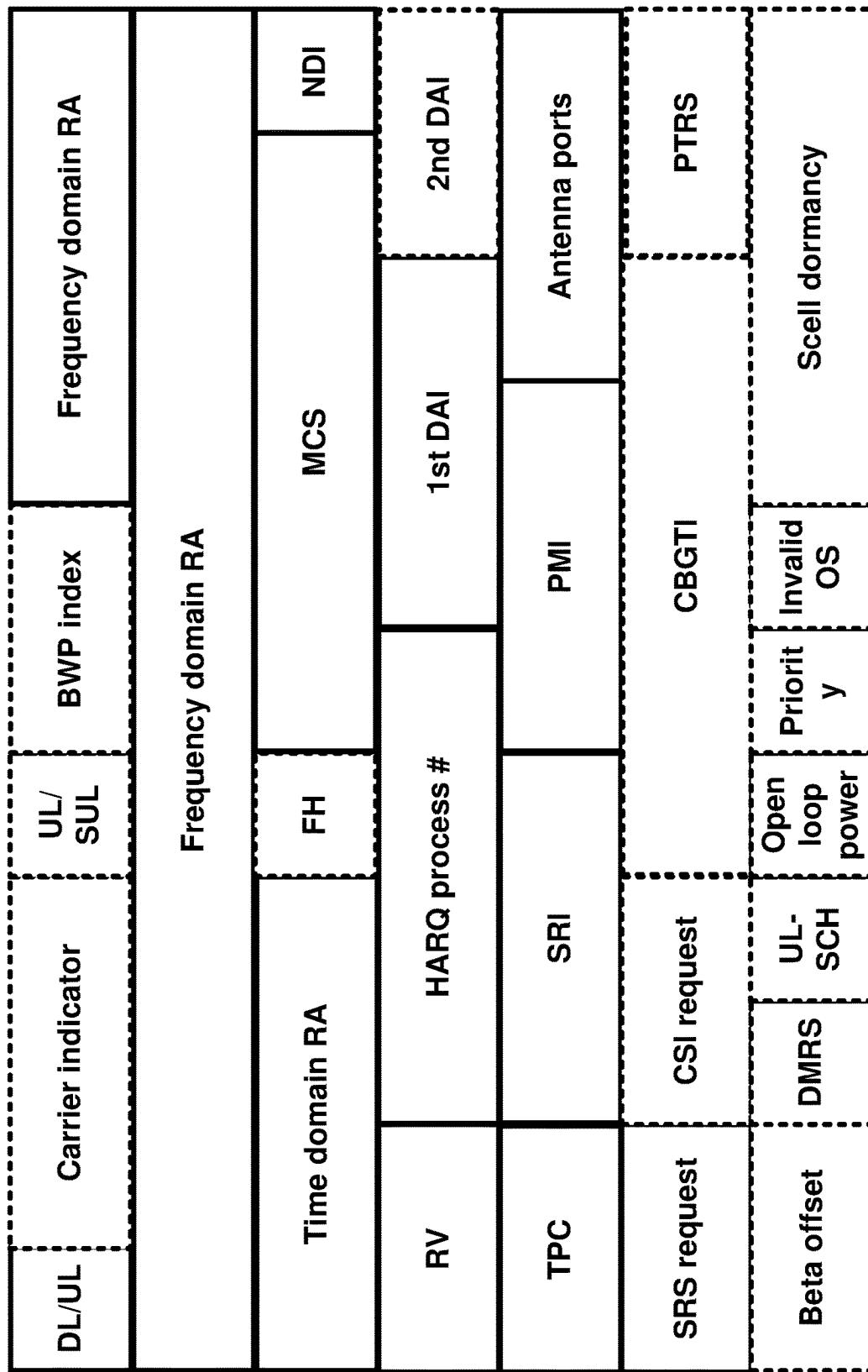


FIG. 18

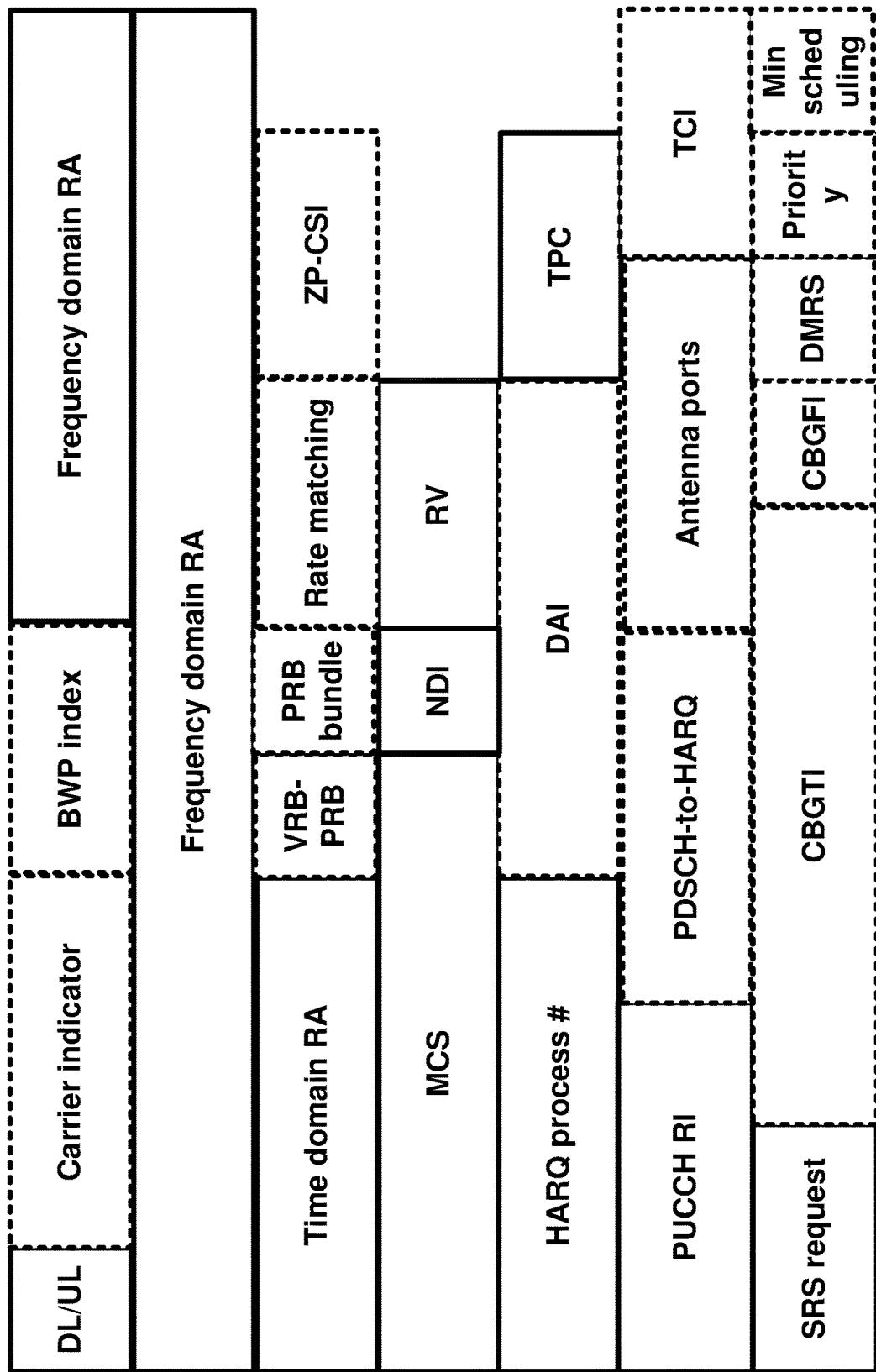


FIG. 19

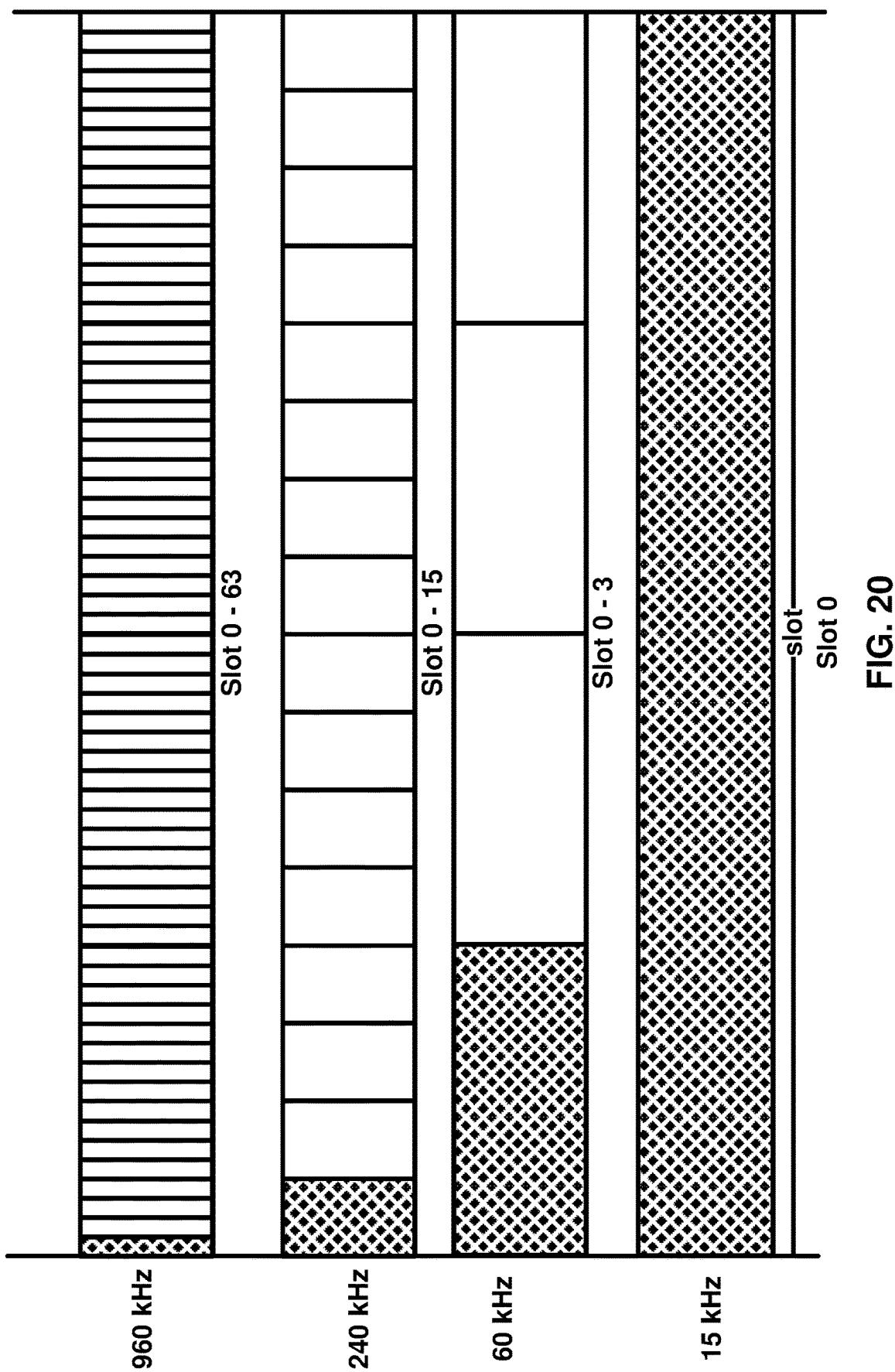


FIG. 20

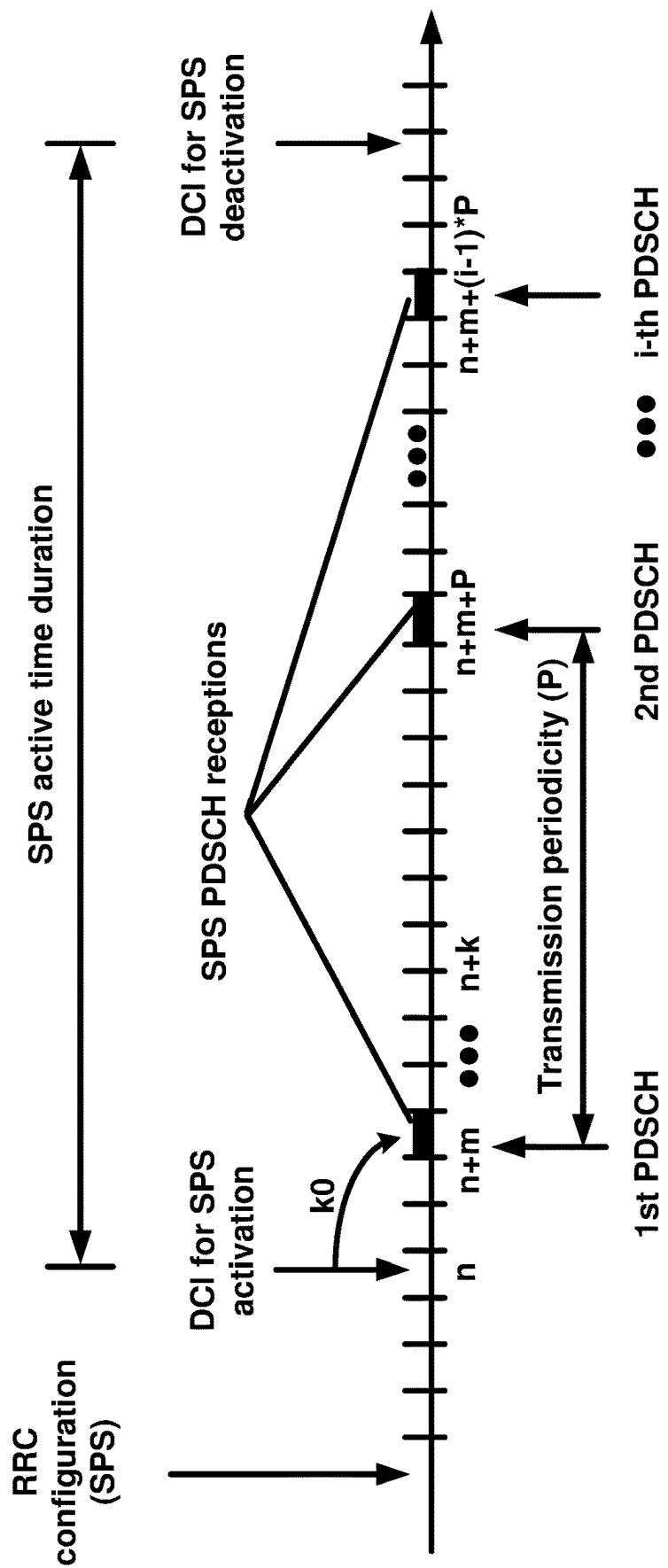


FIG. 21

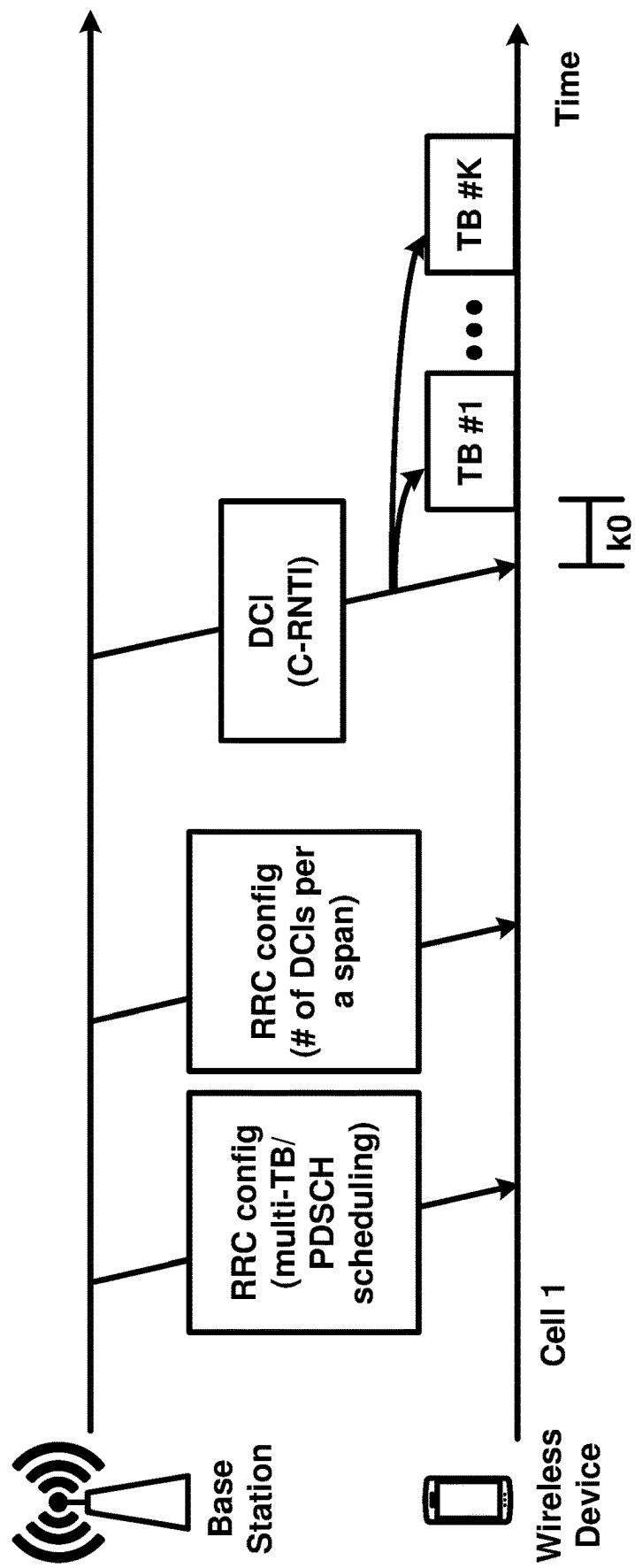


FIG. 22

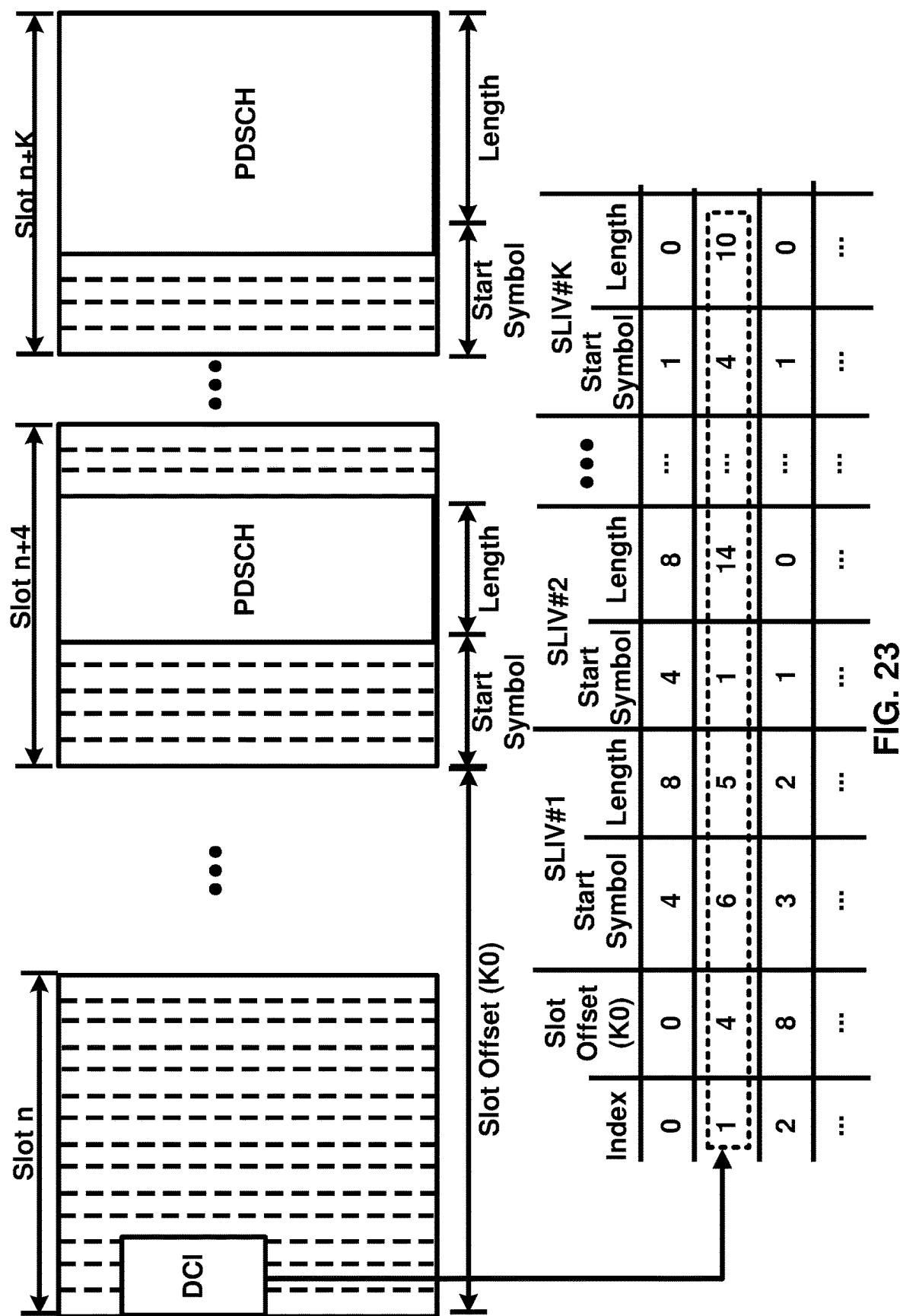


FIG. 23

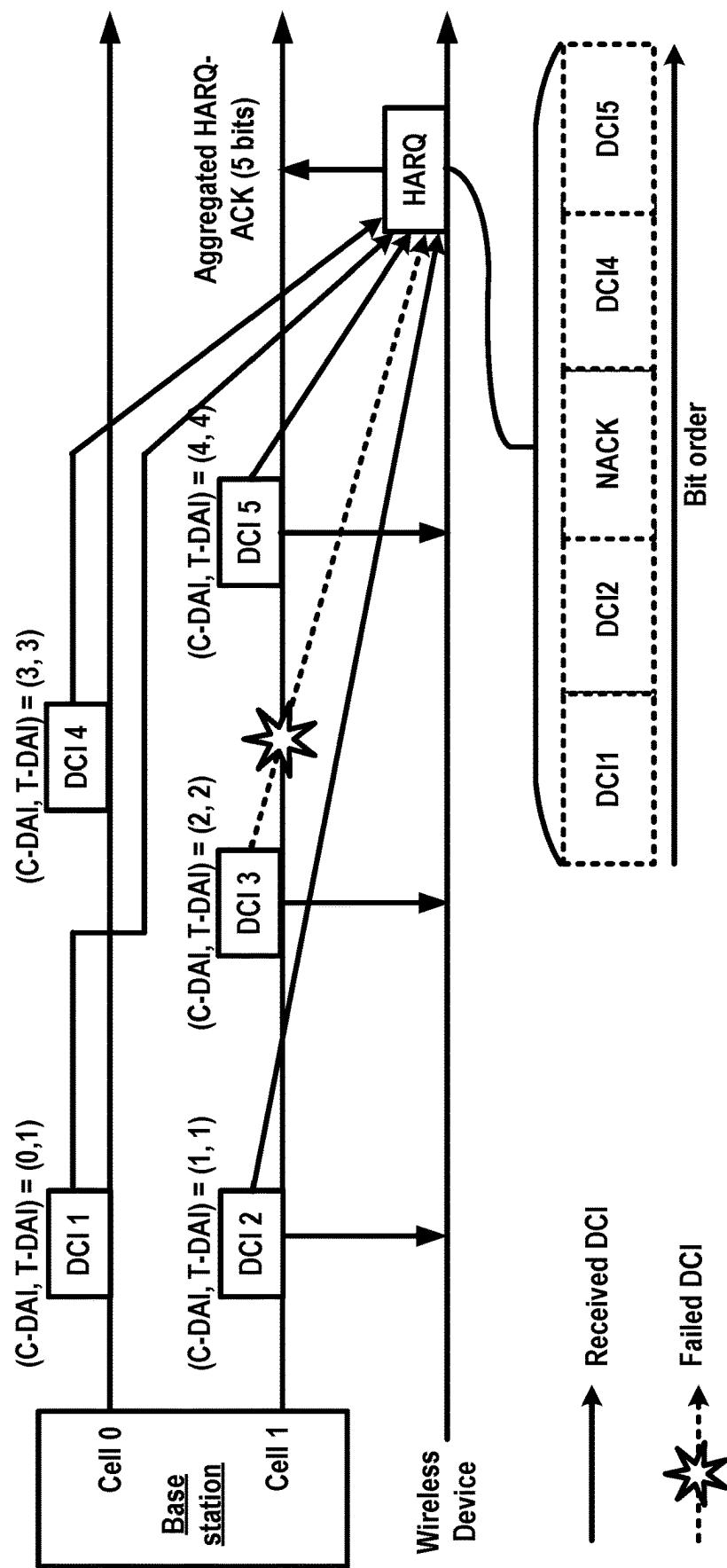


FIG. 24

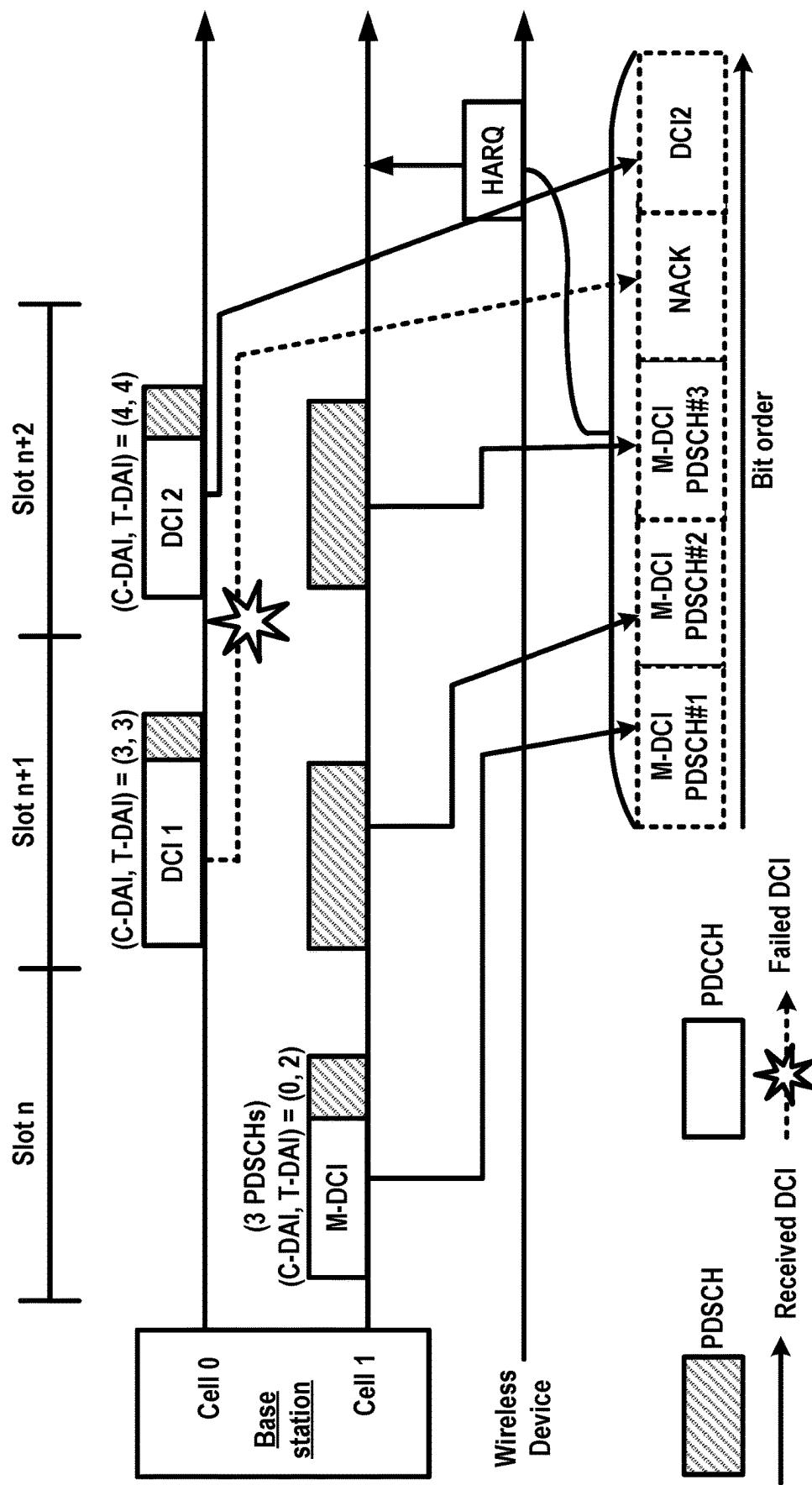
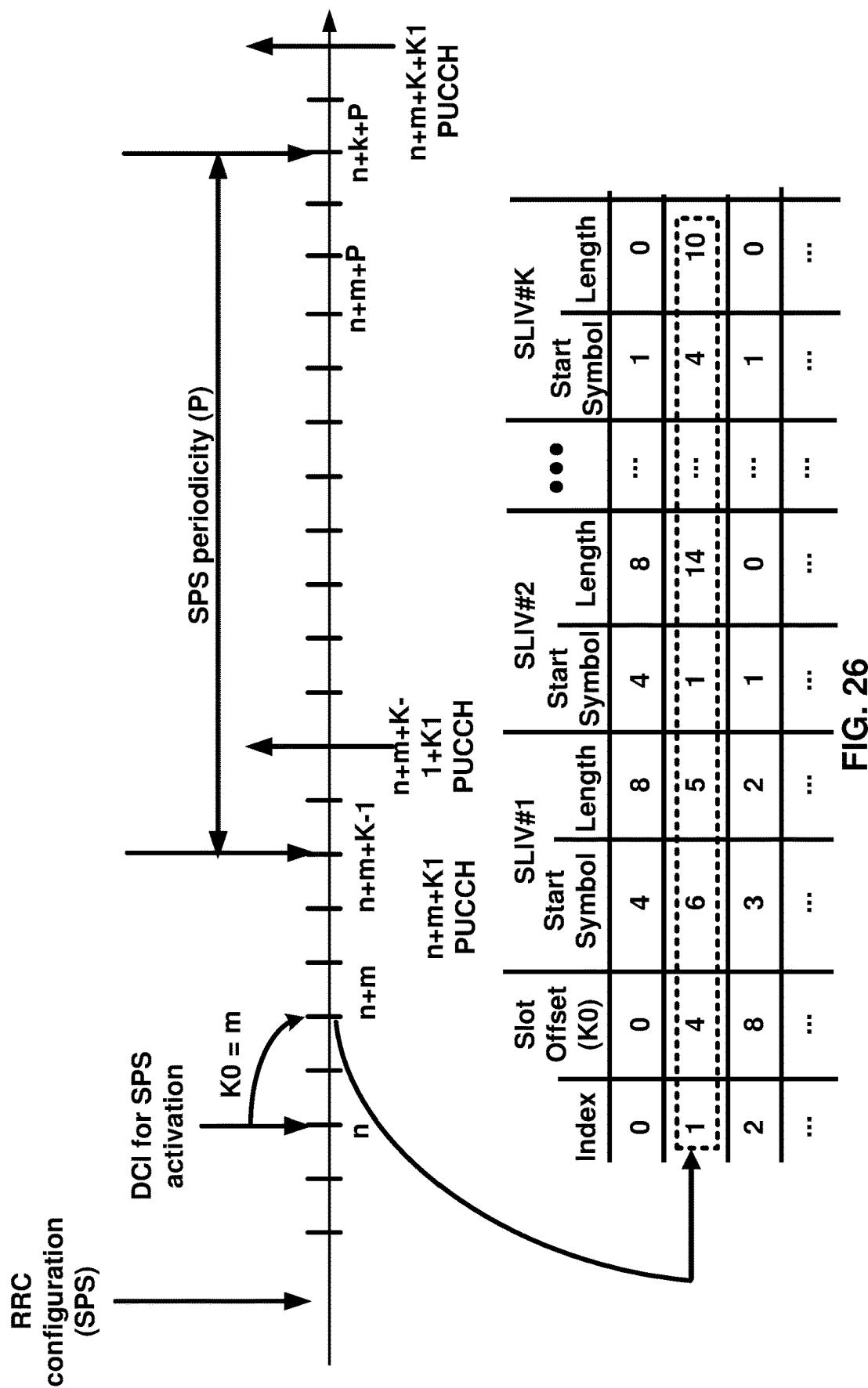


FIG. 25



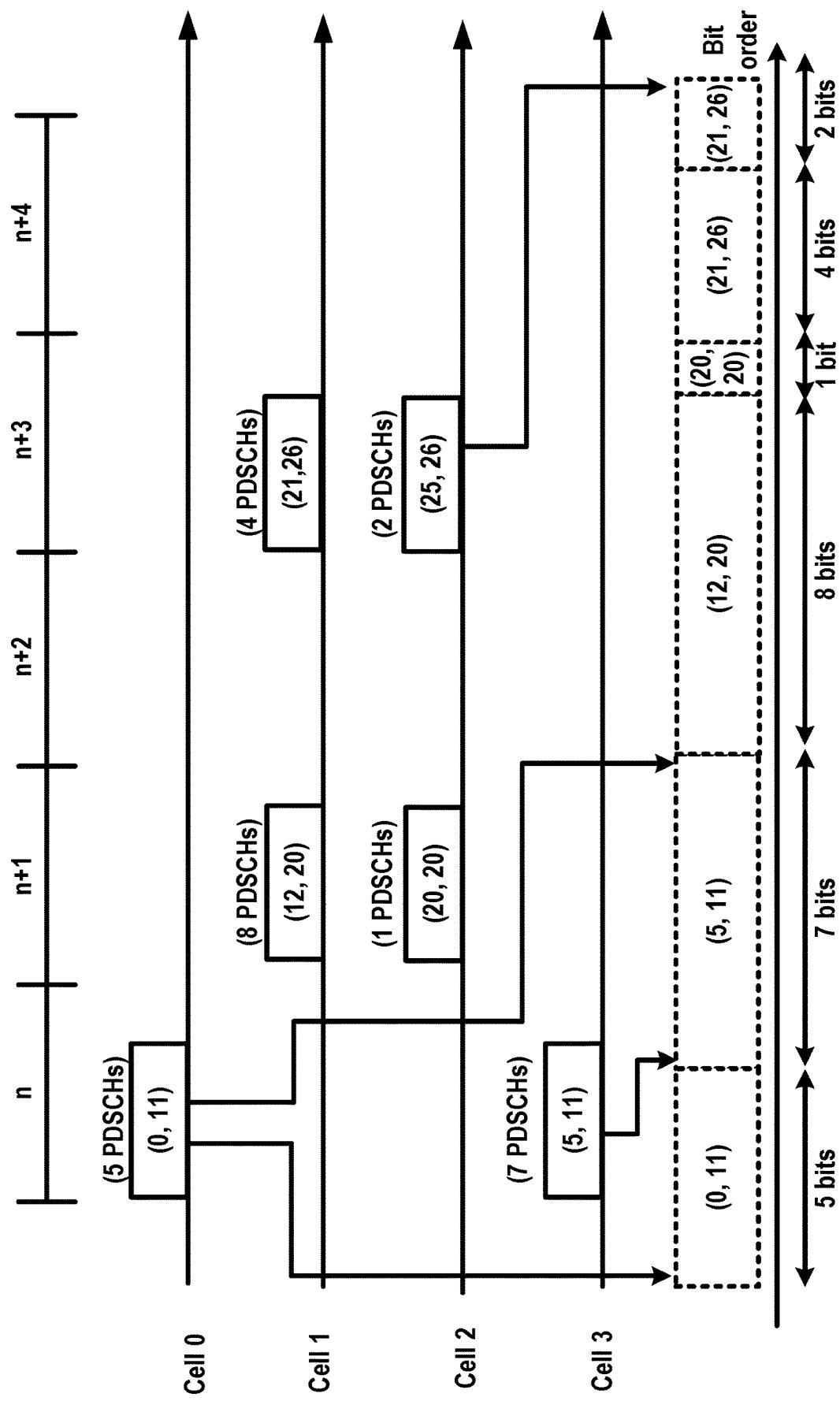
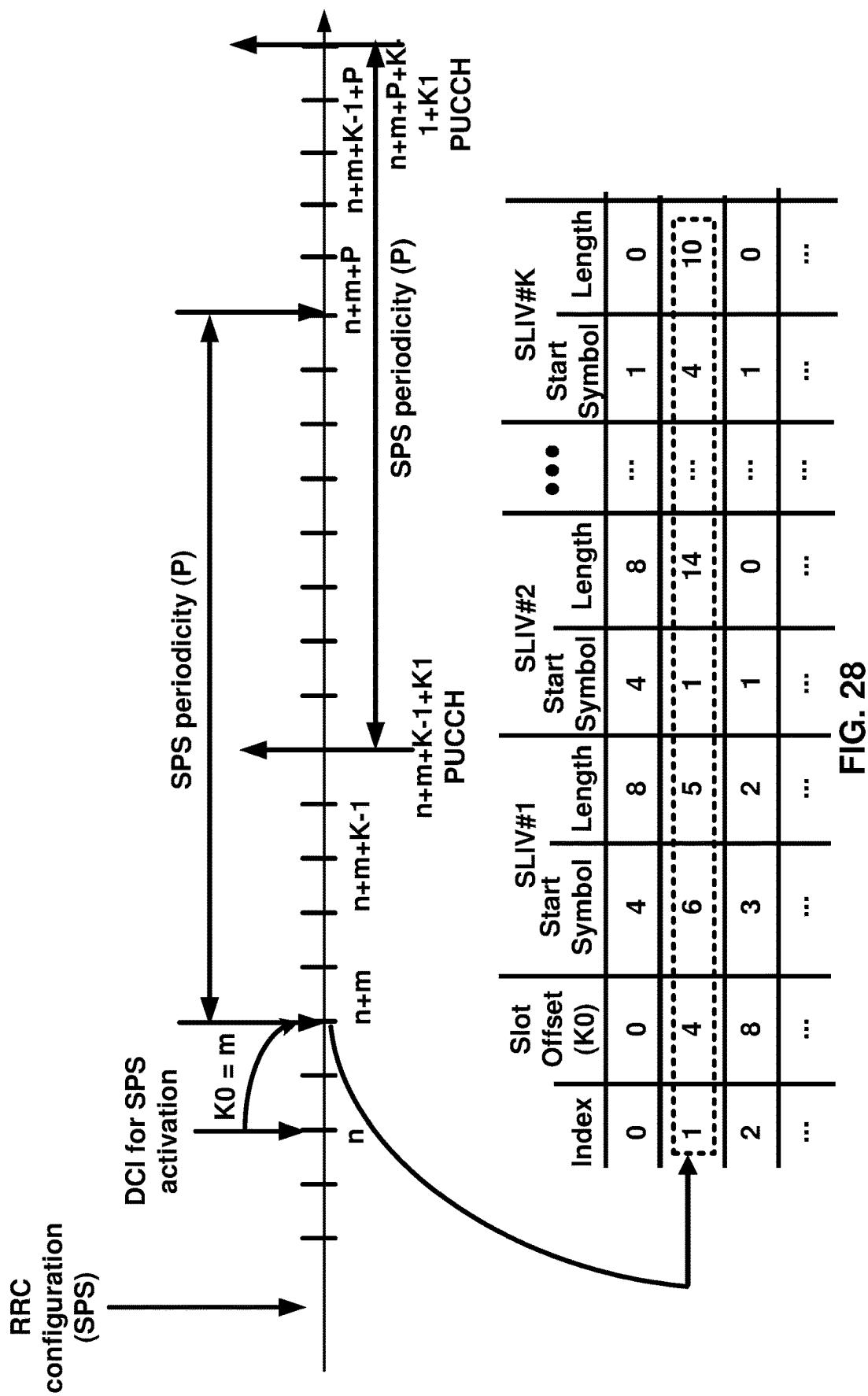


FIG. 27



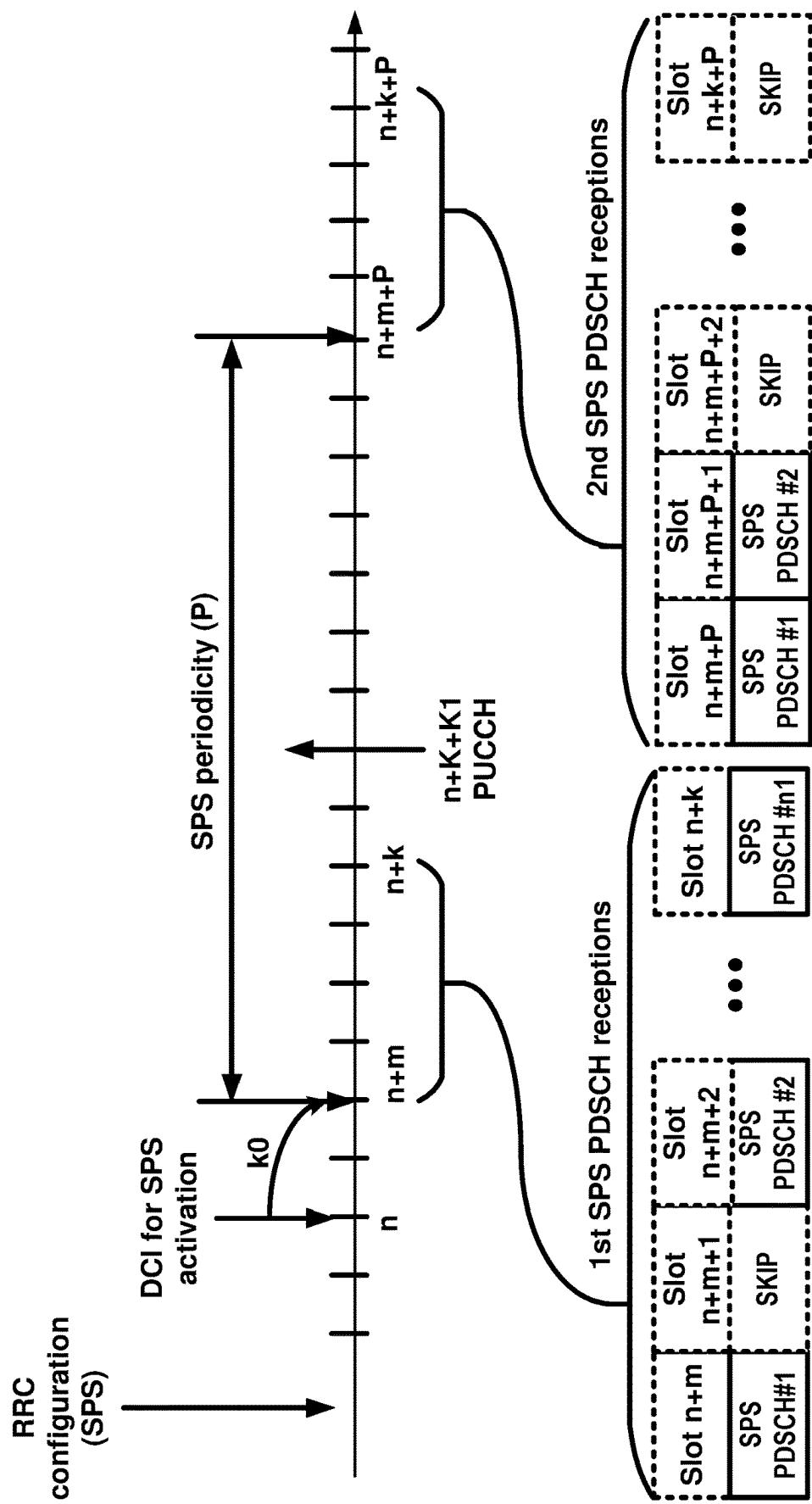


FIG. 29

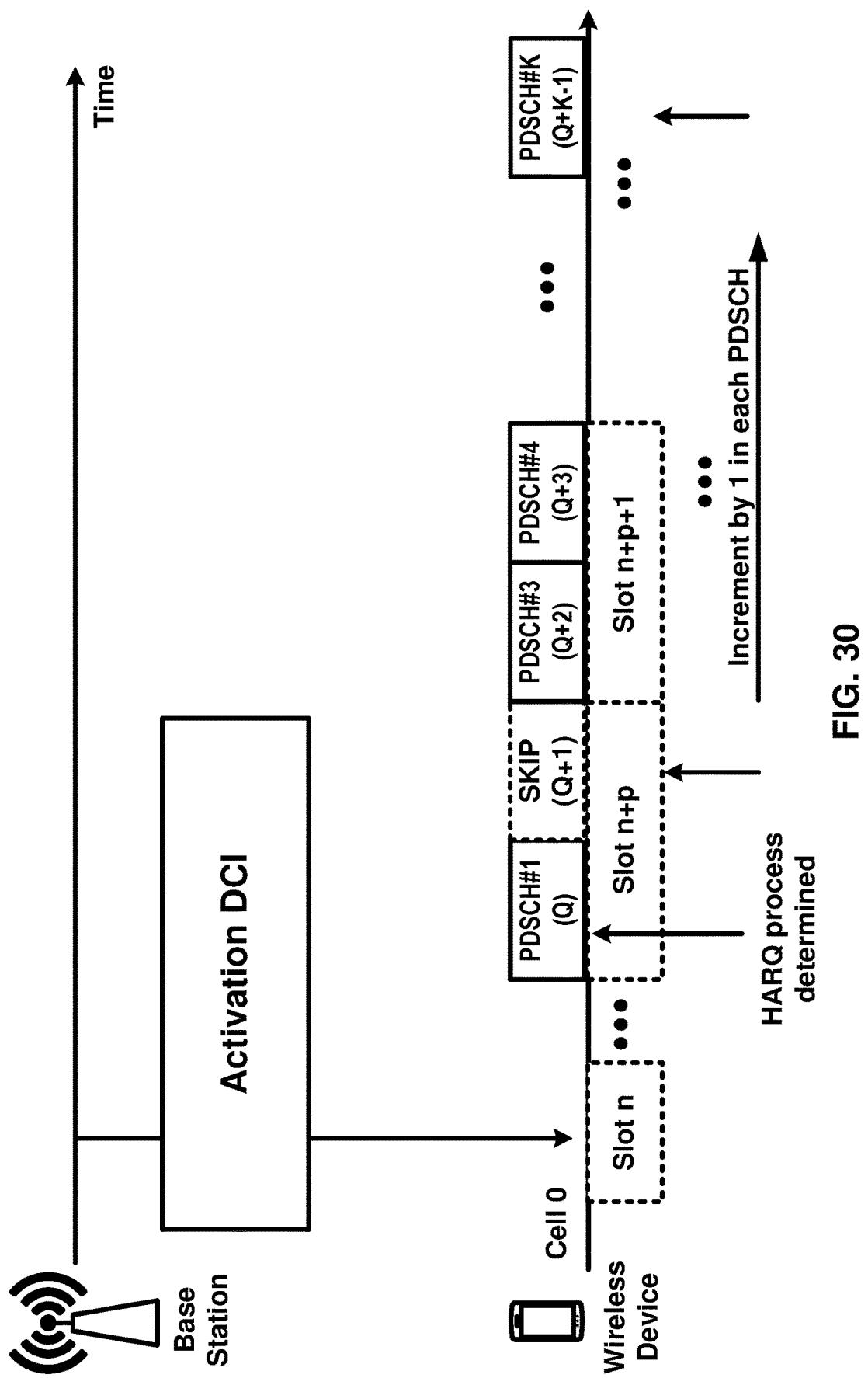


FIG. 30

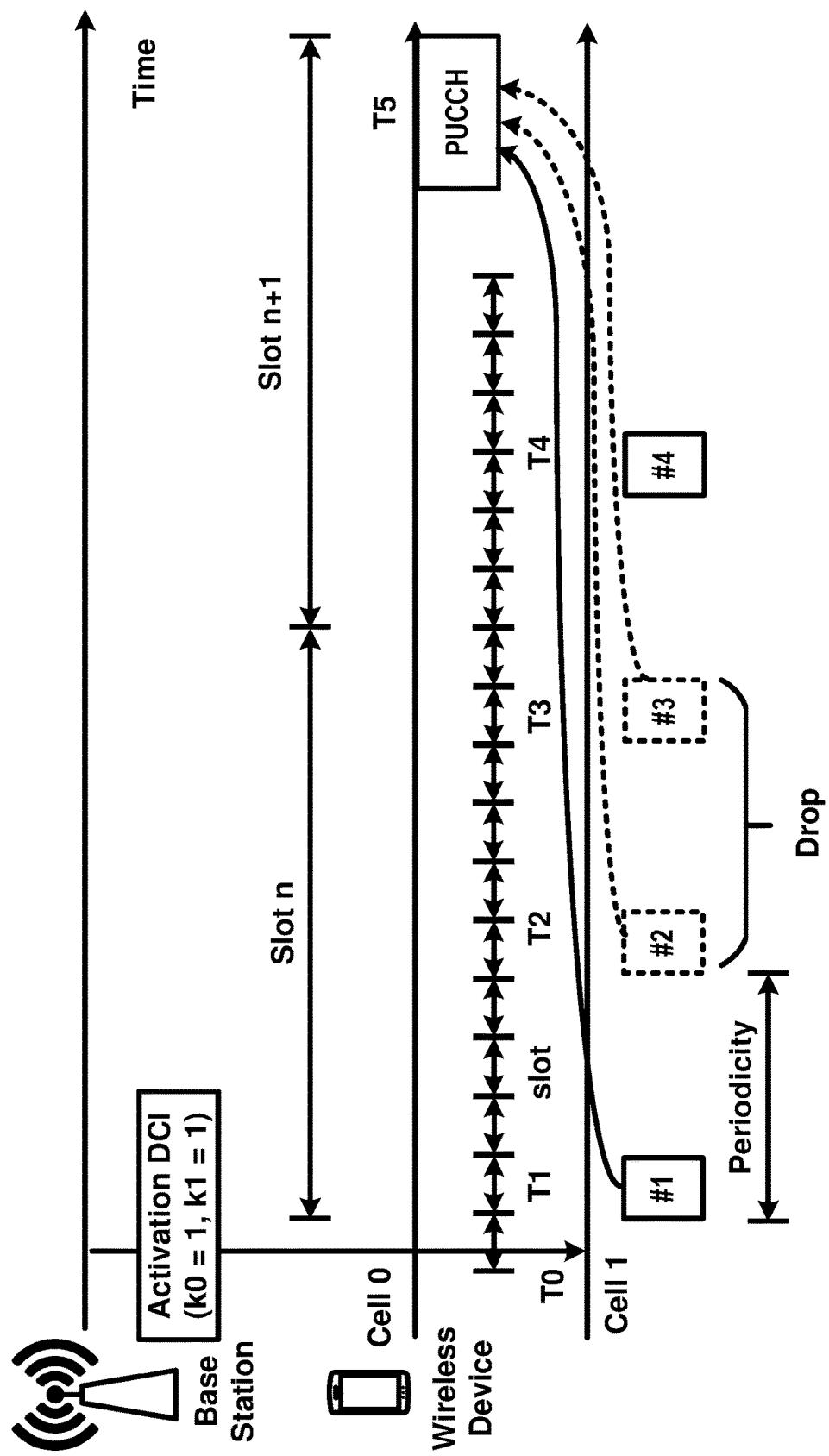


FIG. 31

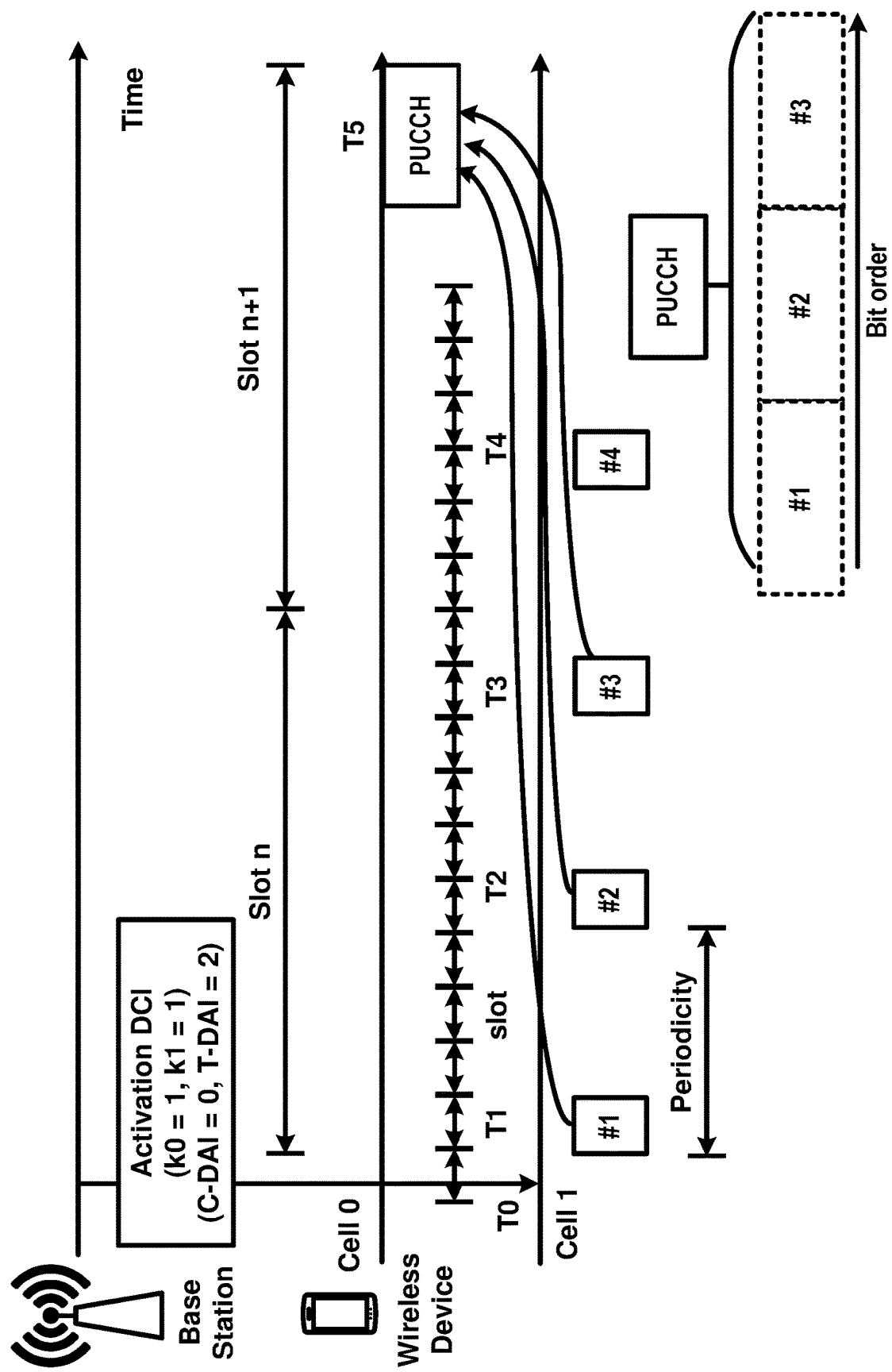


FIG. 32

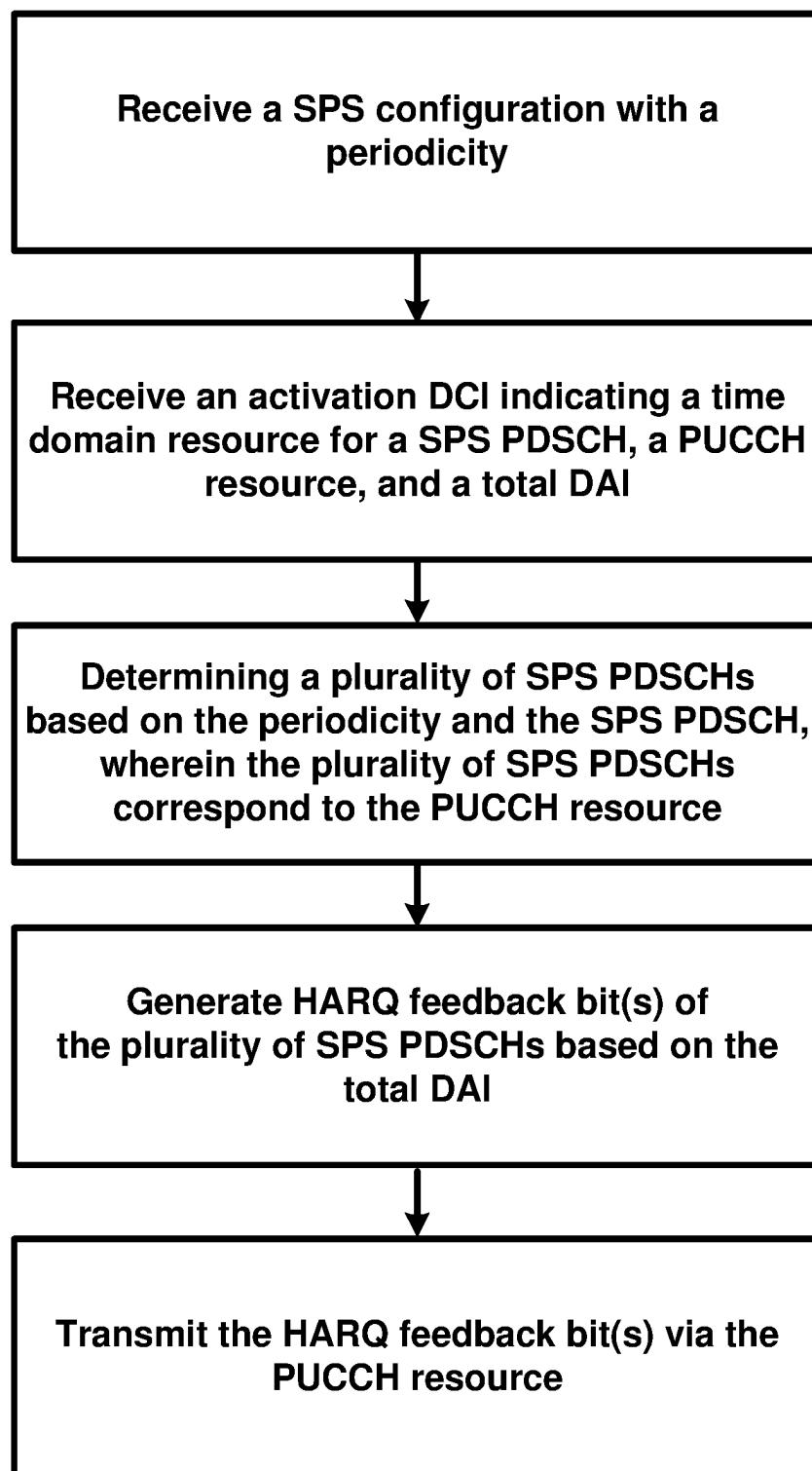


FIG. 33

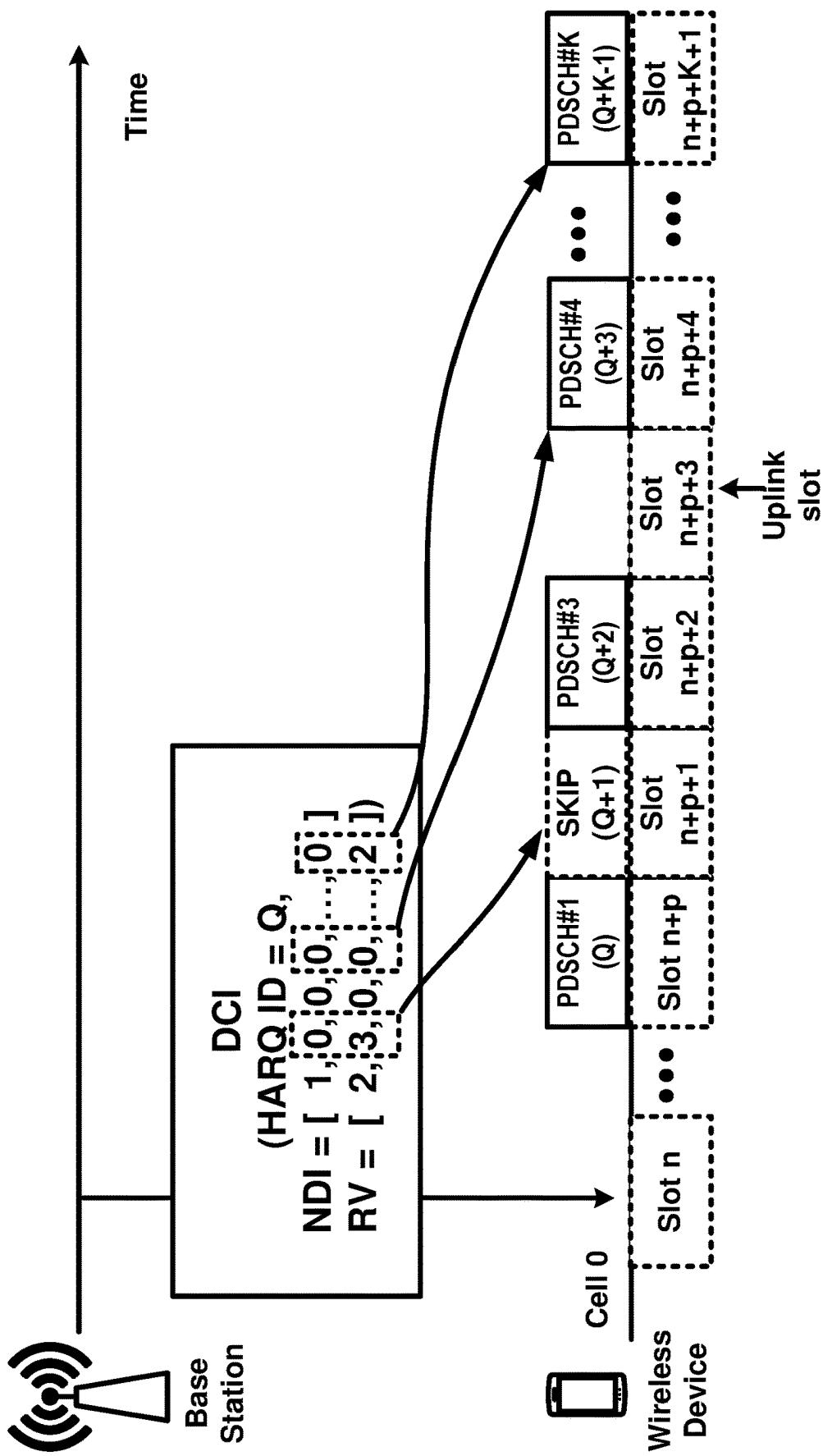


FIG. 34

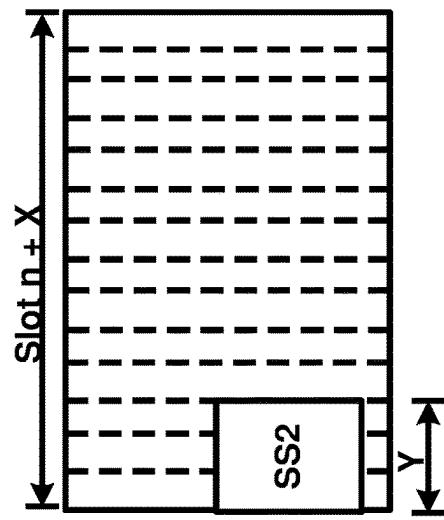


FIG. 35A

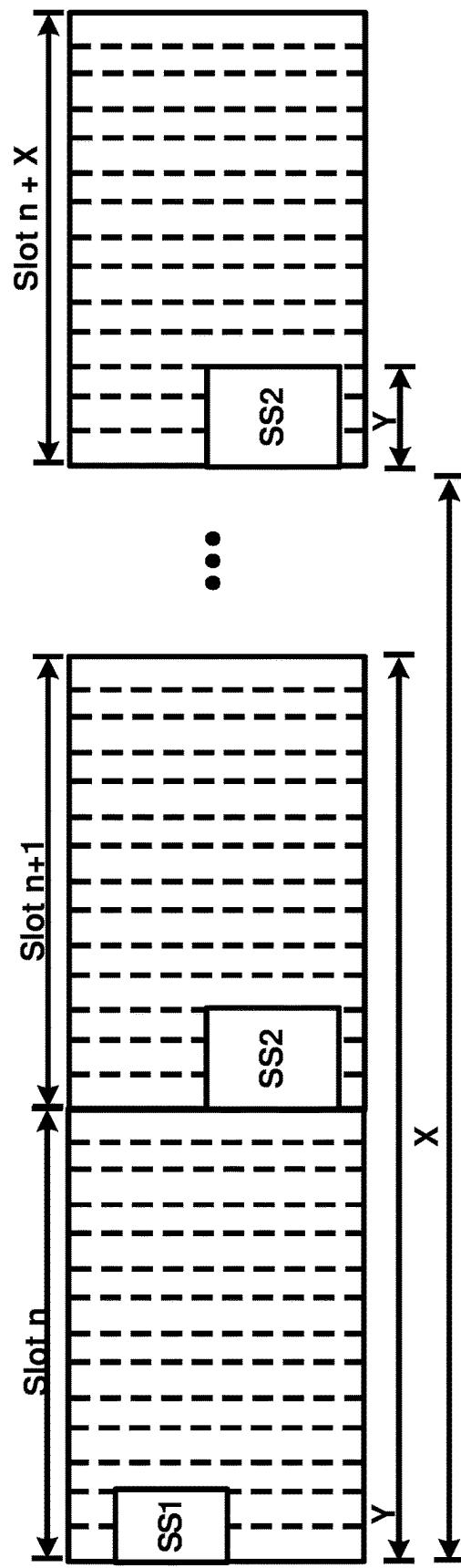
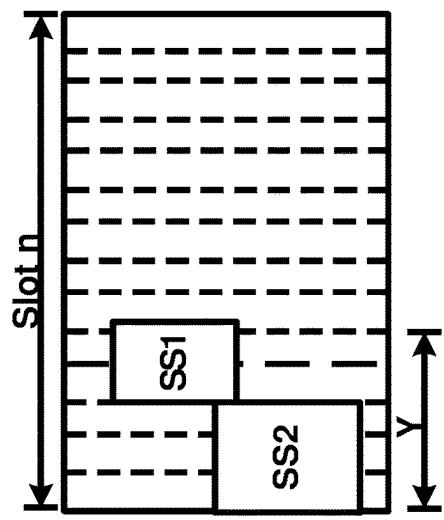


FIG. 35B

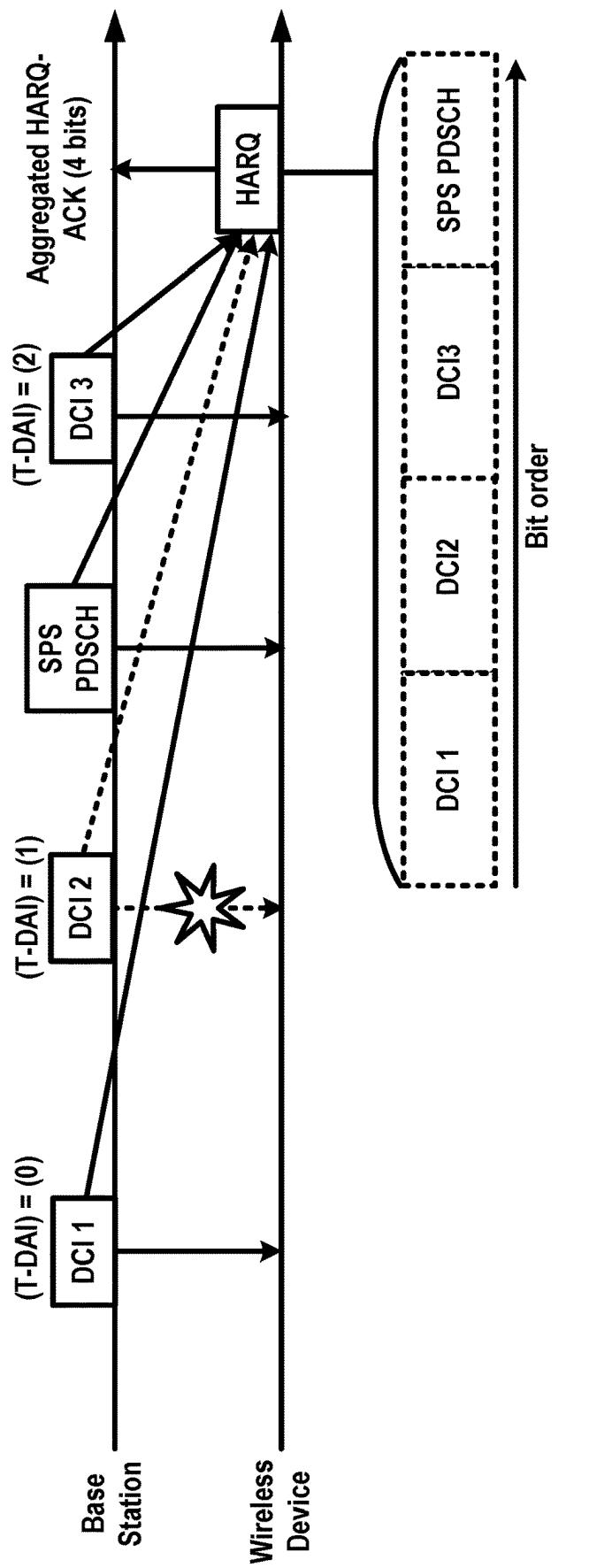


FIG. 36

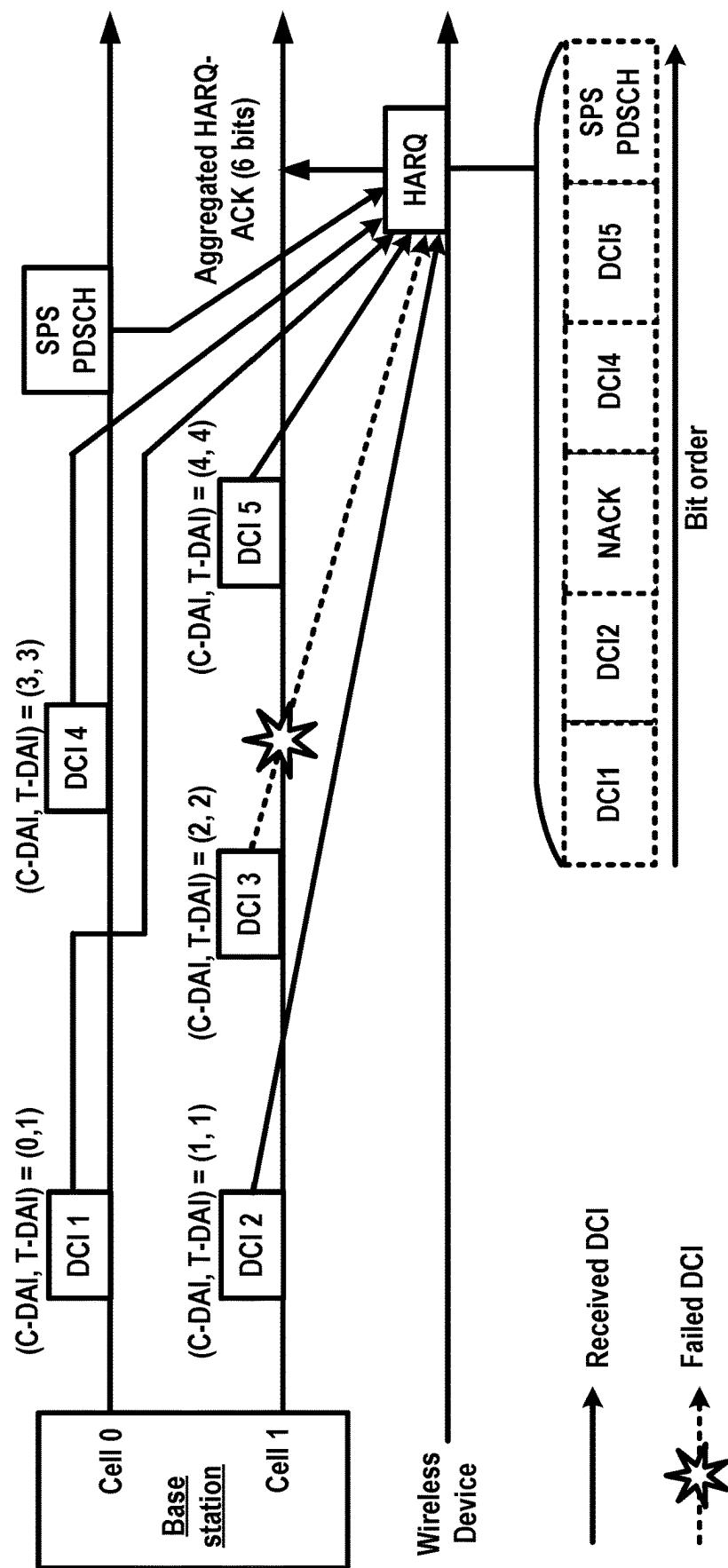


FIG. 37

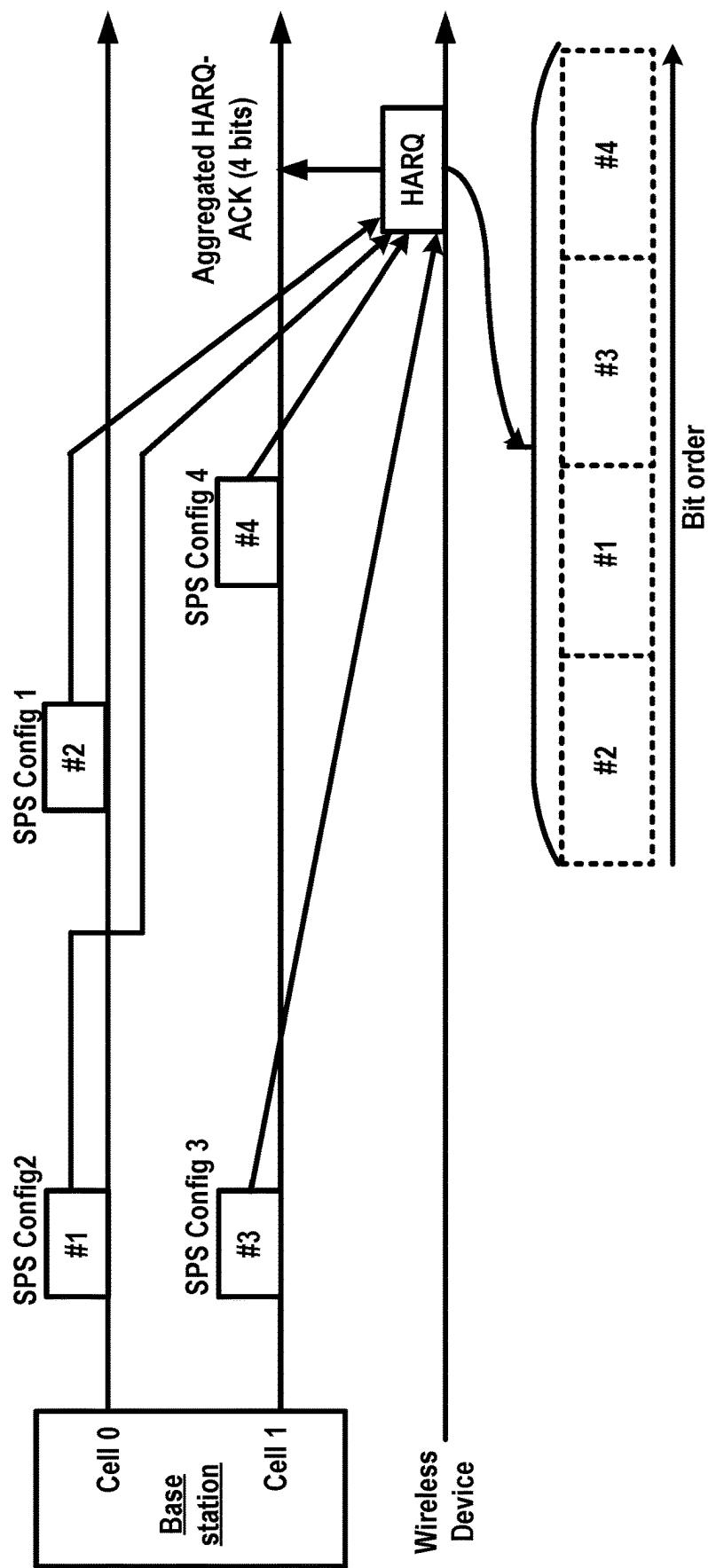


FIG. 38

```
Set  $N_{\text{cells}}^{\text{DL}}$  to the number of serving cells configured to the UE
Set  $N_c^{\text{SPS}}$  to the number of SPS PDSCH configuration configured to the UE for serving cell  $c$ 
Set  $N_c^{\text{DL}}$  to the number of DL slots for SPS PDSCH reception on serving cell  $c$  with HARQ-ACK
information multiplexed on the PUCCH
Set  $j = 0$  – HARQ-ACK information bit index
Set  $c = 0$  – serving cell index: lower indexes correspond to lower RRC indexes of corresponding cell
while  $c < N_{\text{cells}}^{\text{DL}}$ 
    Set  $s = 0$  – SPS PDSCH configuration index: lower indexes correspond to lower RRC indexes of
    corresponding SPS configurations
    while  $s < N_c^{\text{SPS}}$ 
        Set  $n_D = 0$  – slot index
        while  $n_D < N_c^{\text{DL}}$ 
            if a SPS PDSCH reception is scheduled
                 $\tilde{o}_j^{\text{ACK}} = \text{HARQ-ACK information bit for this SPS PDSCH reception}$ 
                 $j = j + 1;$ 
            end if
             $n_D = n_D + 1;$ 
        end while
         $s = s + 1;$ 
    end while
     $c = c + 1;$ 
end while
```

FIG. 39

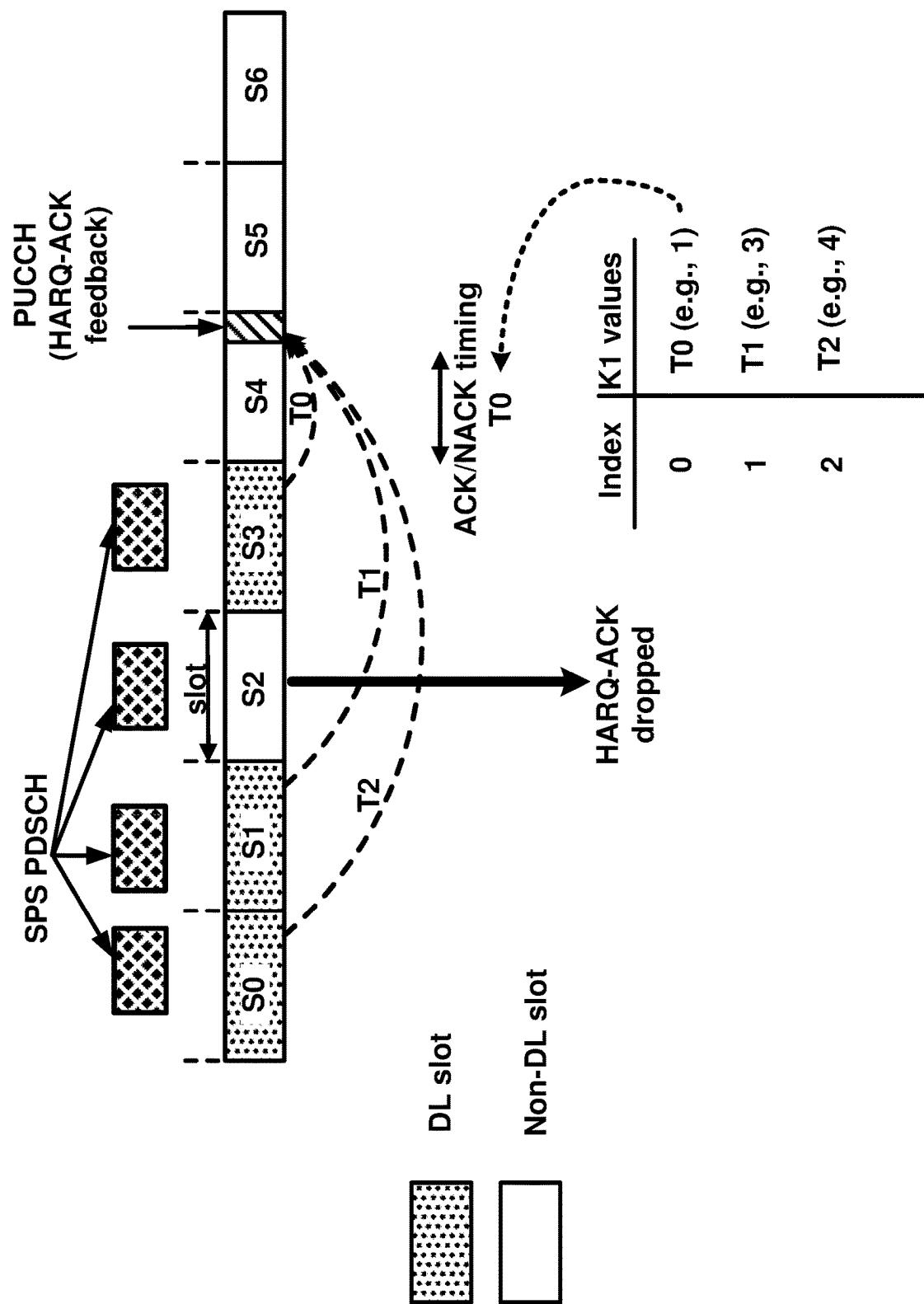


FIG. 40

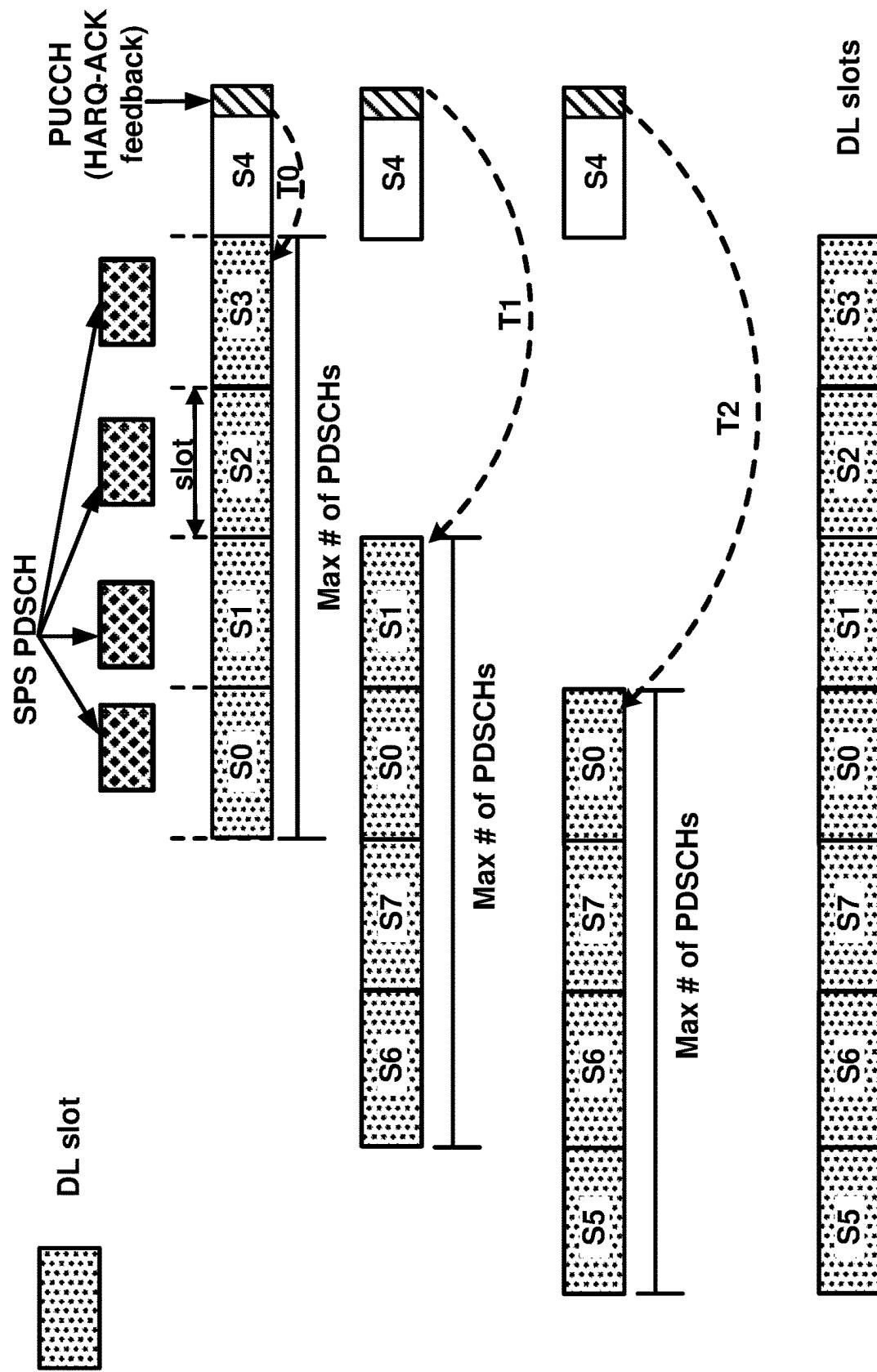


FIG. 41

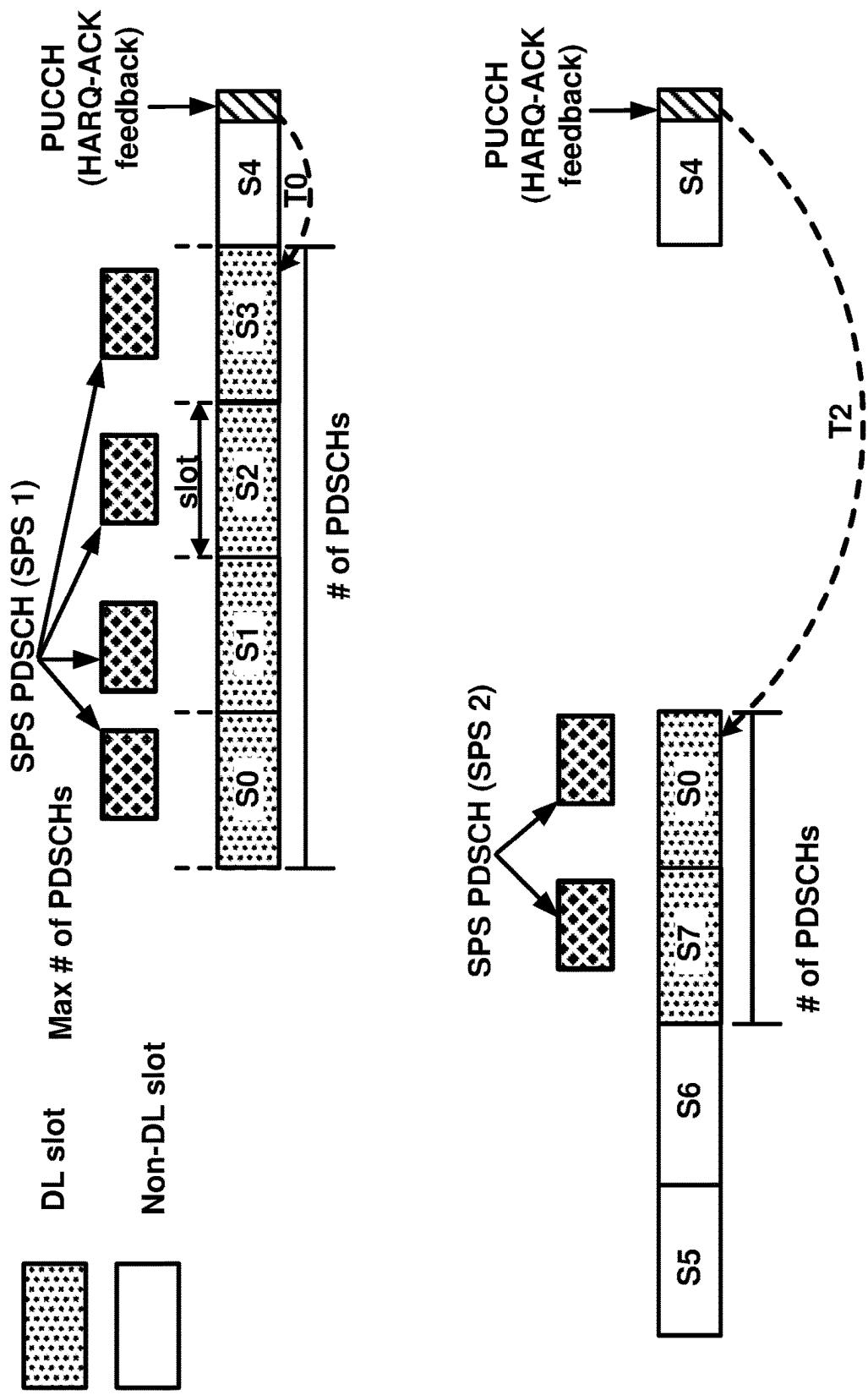


FIG. 42

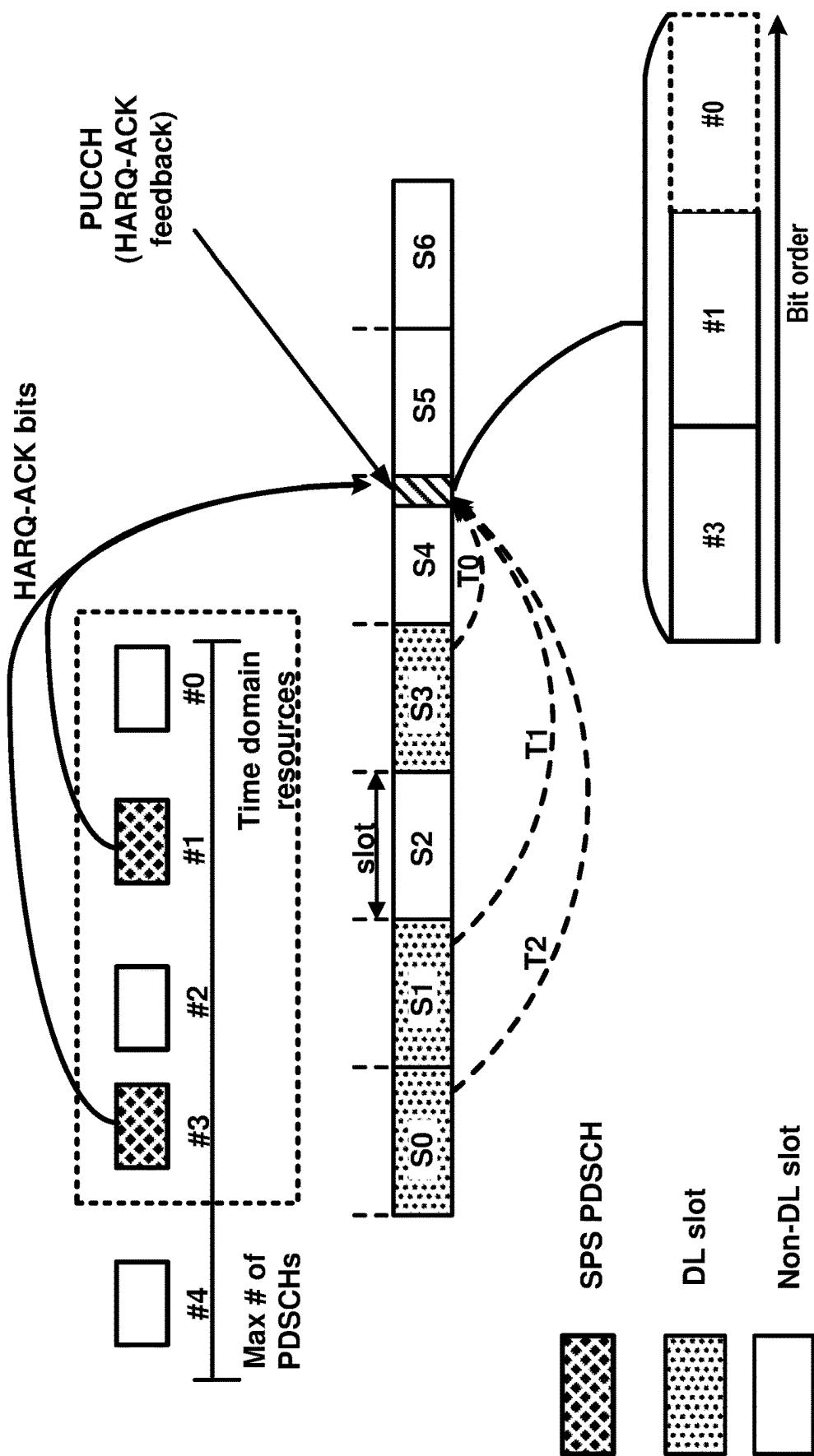


FIG. 43

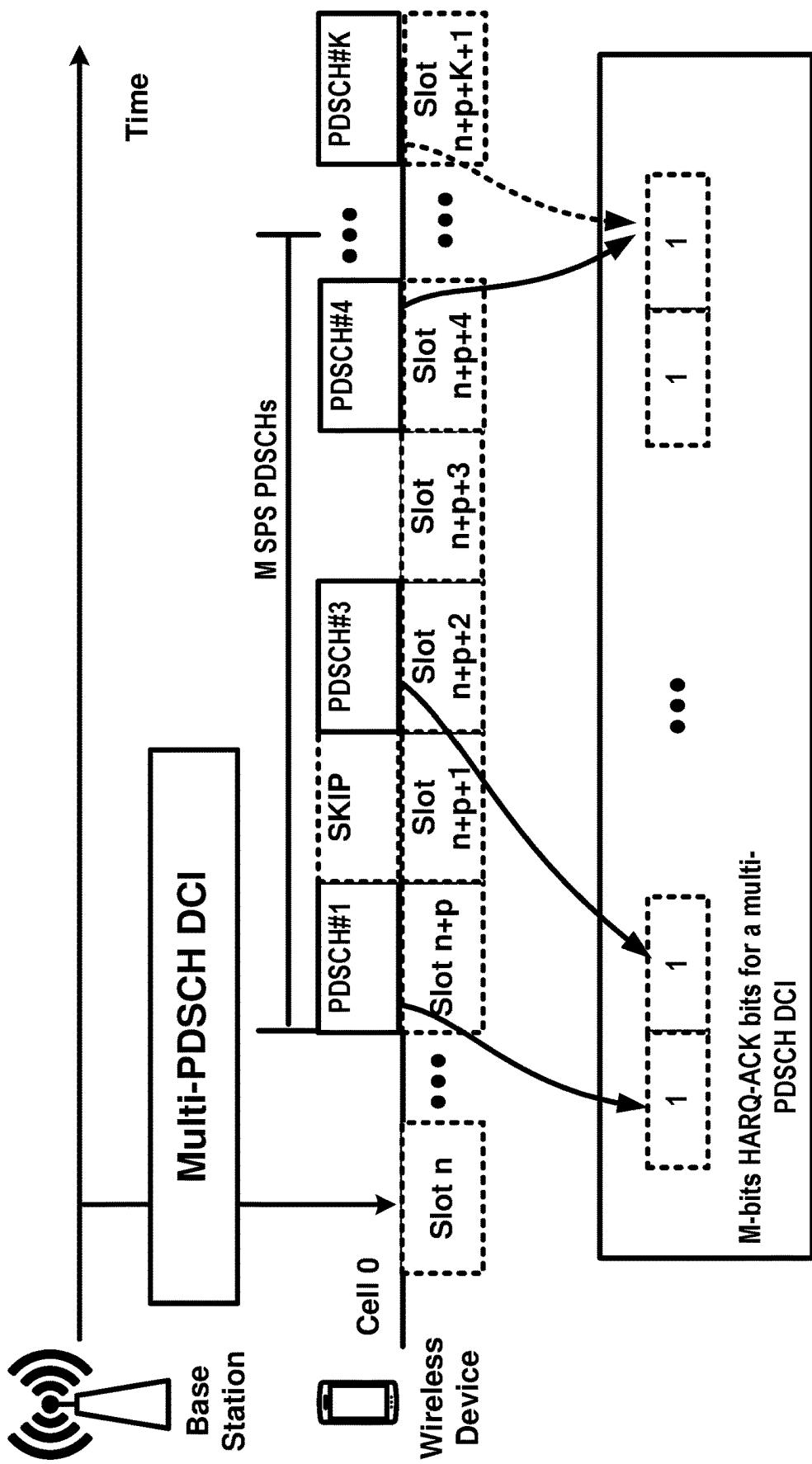


FIG. 44

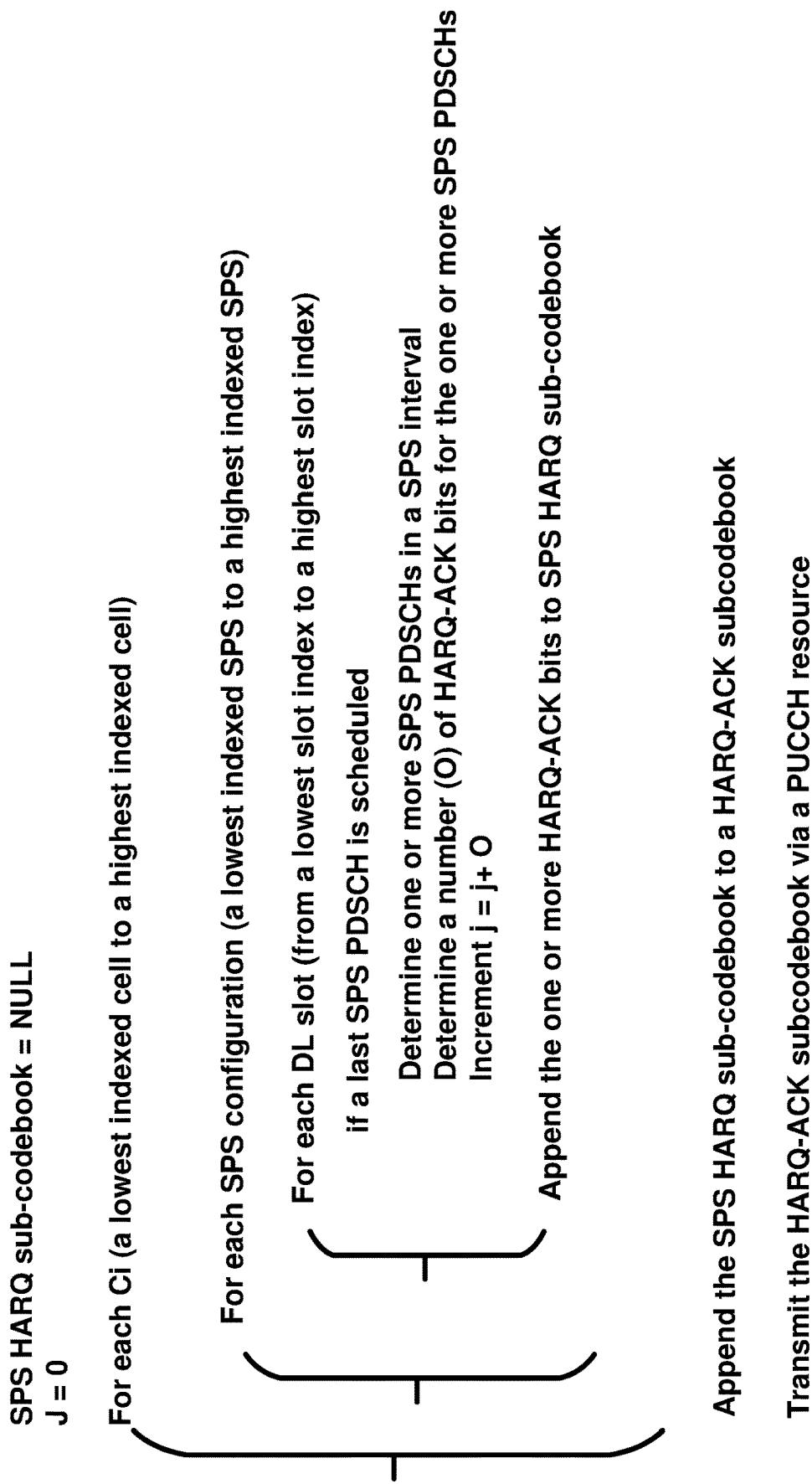


FIG. 45

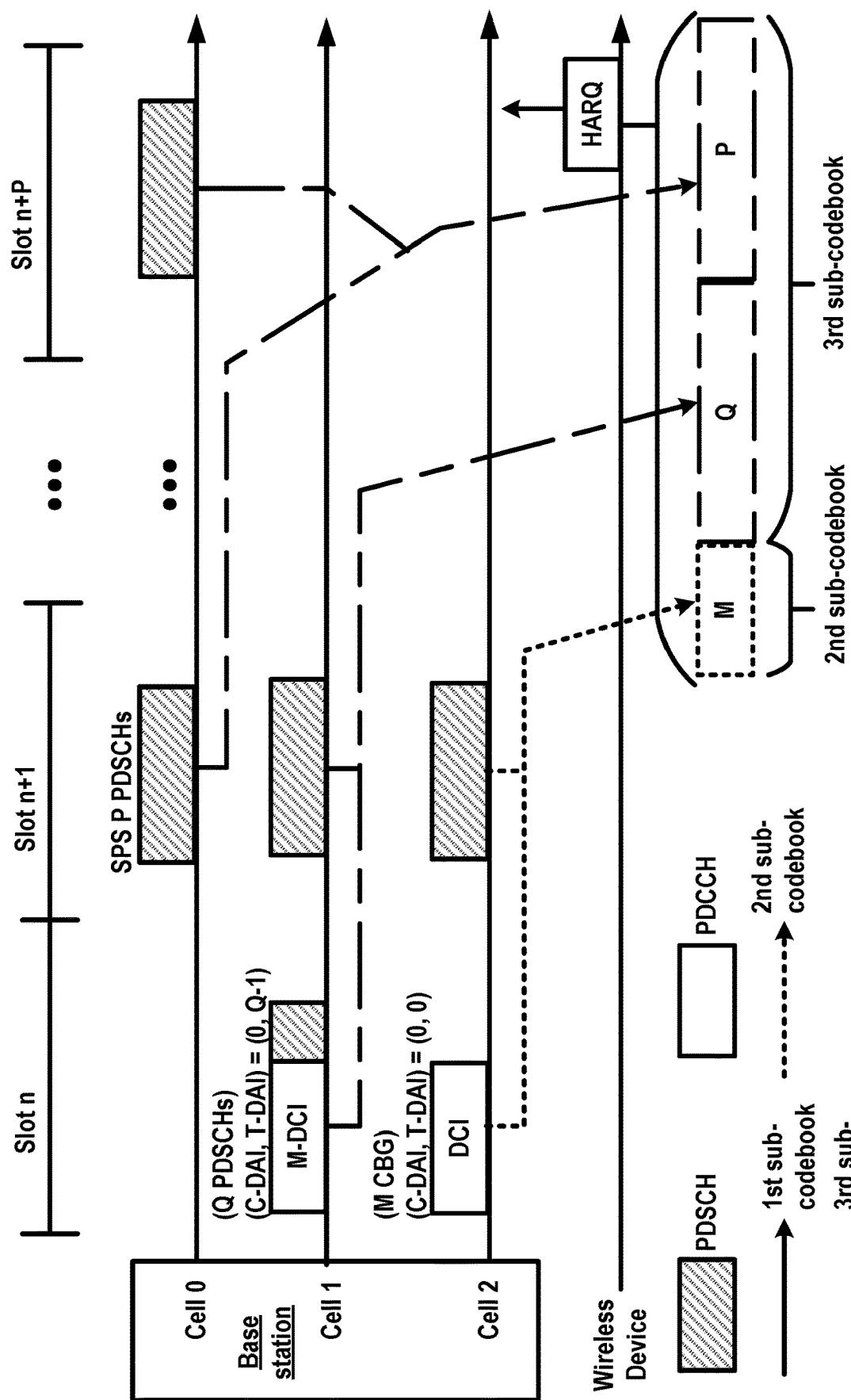
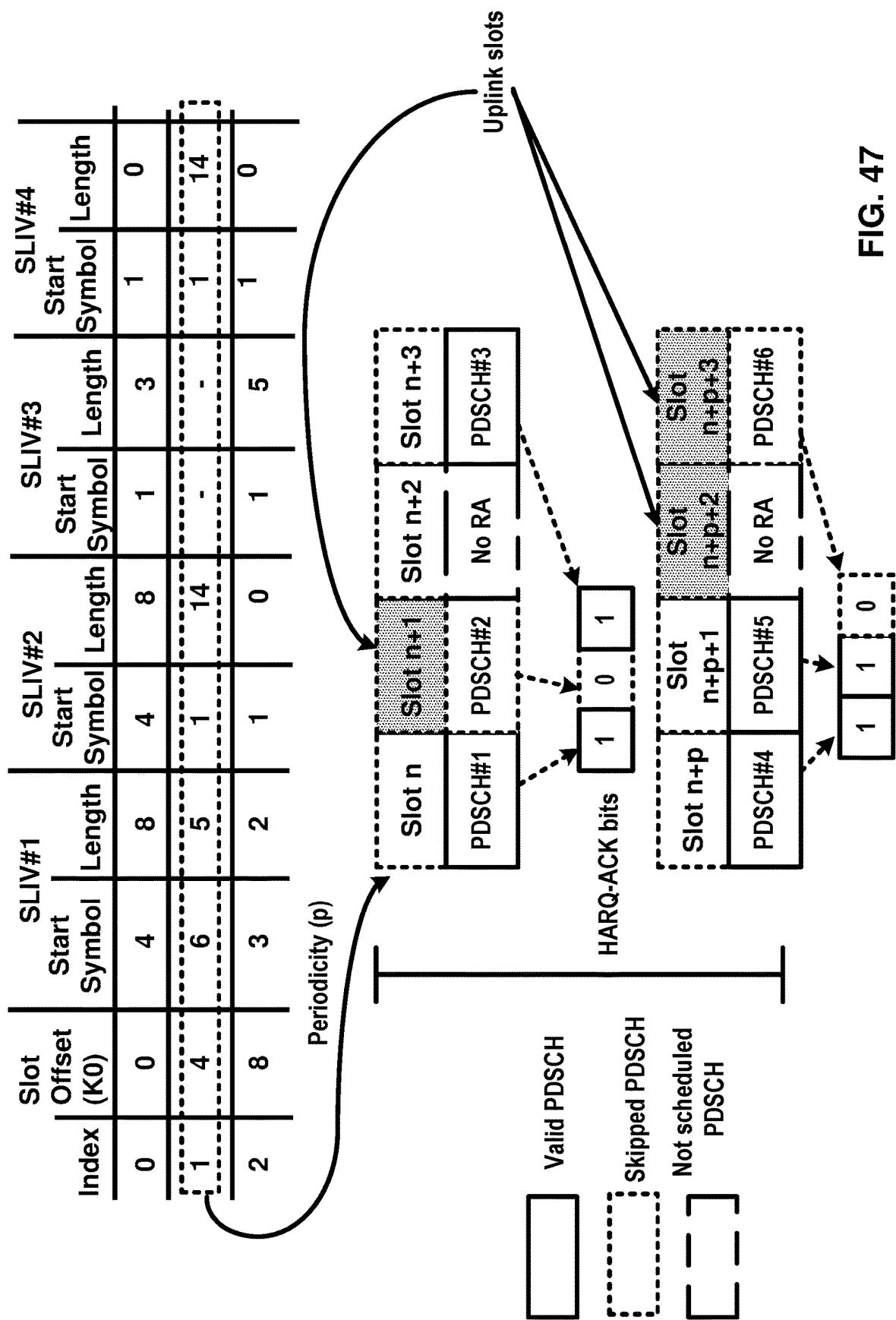


FIG. 46



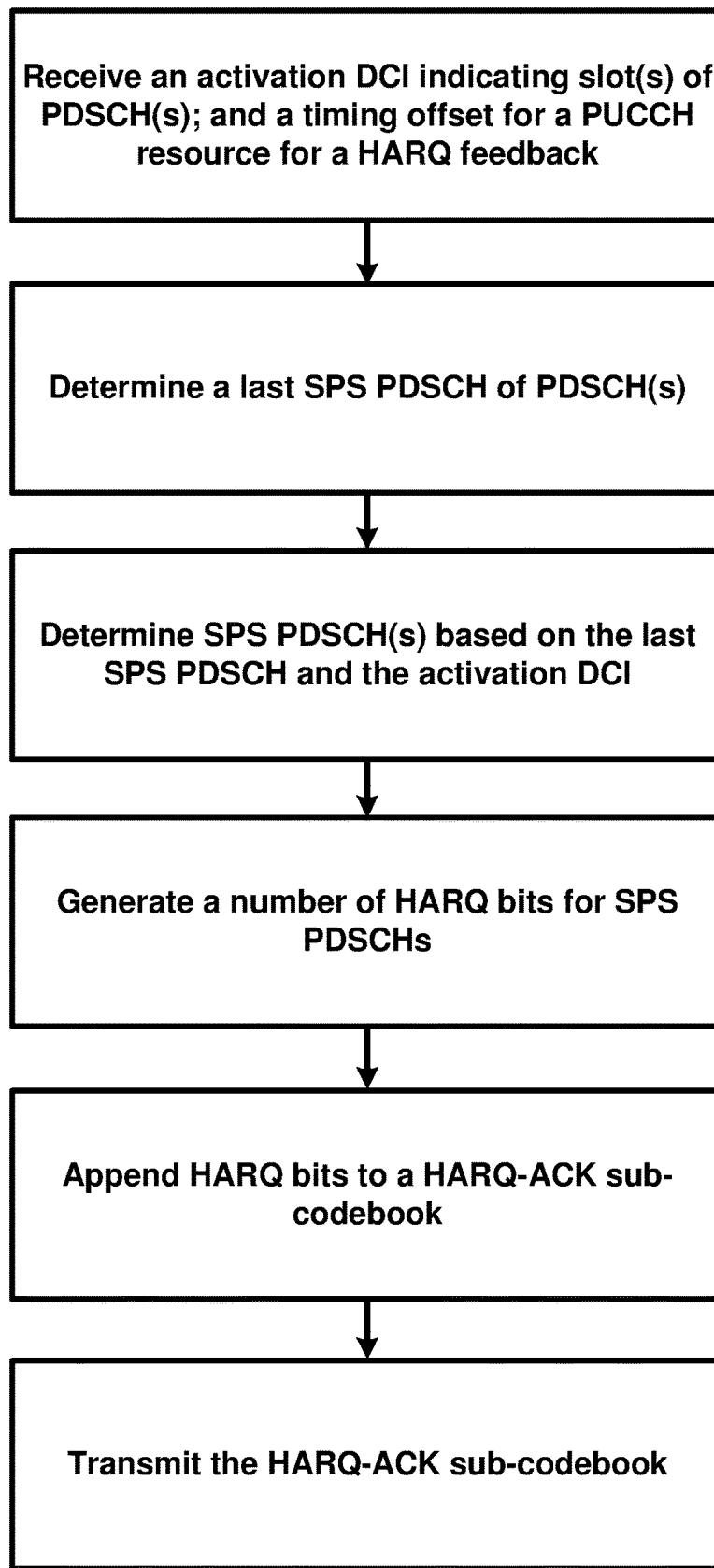


FIG. 48

## SEMI-PERSISTENT SCHEDULING IN HIGH FREQUENCY

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 63/175,610, filed Apr. 16, 2021, and U.S. Provisional Application No. 63/180,739, filed Apr. 28, 2021, all of which are hereby incorporated by reference in their entireties.

### BRIEF DESCRIPTION OF THE DRAWINGS

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

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

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

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

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

FIG. 4B illustrates an example format of a MAC sub-header in a MAC PDU.

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

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

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

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

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

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

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

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

FIG. 11B illustrates an example of CSI-RSSs that are mapped in the time and frequency domains.

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

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

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

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

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

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

FIG. 17 illustrates an example of various DCI formats used for various purposes.

FIG. 18 illustrates an example DCI format for scheduling uplink resource of a single cell.

FIG. 19 illustrates an example DCI format for scheduling downlink resource of a single cell.

FIG. 20 illustrates an example of different numerologies as per an aspect of an embodiment of the present disclosure.

FIG. 21 illustrates a SPS configuration as per an aspect of an embodiment of the present disclosure.

FIG. 22 illustrates an example of embodiments of a multi-PDSCH scheduling as per an aspect of an embodiment of the present disclosure.

FIG. 23 illustrates a time domain resource allocation mechanism for downlink data as per an aspect of an embodiment of the present disclosure.

FIG. 24 illustrates an example of HARQ feedback determination with a plurality of serving cells as per an aspect of an embodiment of the present disclosure.

FIG. 25 illustrates an example embodiment of a DAI counter procedure with a multi-PDSCH scheduling as per an aspect of an embodiment of the present disclosure.

FIG. 26 illustrates example embodiment of a DAI counter procedure for a multi-PDSCH scheduling as per an aspect of an embodiment of the present disclosure.

FIG. 27 illustrates an example of a SPS configuration activation based on a multi-PDSCH DCI as per an aspect of an embodiment of the present disclosure.

FIG. 28 illustrates an example of a PUCCH resource determination for a SPS configuration as per an aspect of an embodiment of the present disclosure.

FIG. 29 illustrates an example of a SPS configuration activation based on a multi-PDSCH DCI as per an aspect of an embodiment of the present disclosure.

FIG. 30 illustrates an example of HARQ process ID determination as per an aspect of an embodiment of the present disclosure.

FIG. 31 illustrates an example of a single HARQ-ACK bit of a plurality of SPS PDSCH receptions as per an aspect of an embodiment of the present disclosure.

FIG. 32 illustrates an example DAI mechanism for a plurality of SPS PDSCH receptions as per an aspect of an embodiment of the present disclosure.

FIG. 33 illustrates a flow diagram of an example embodiment as per an aspect of an embodiment of the present disclosure.

FIG. 34 illustrates an example embodiment for a HARQ process ID for a multi-PDSCH/multi-PUSCH scheduling as per an aspect of an embodiment of the present disclosure.

FIG. 35A illustrates an example of a multi-slot span as per an aspect of an embodiment of the present disclosure.

FIG. 35B illustrates an example of a multi-slot span as per an aspect of an embodiment of the present disclosure.

FIG. 36 illustrates an example of a HARQ-ACK codebook determination as per an aspect of an embodiment of the present disclosure.

FIG. 37 illustrates an example of HARQ feedback determination with a plurality of serving cells as per an aspect of an embodiment of the present disclosure.

FIG. 38 illustrates an example of a HARQ-ACK codebook determination of SPS configurations as per an aspect of an embodiment of the present disclosure.

FIG. 39 illustrates a pseudo code of a HARQ-ACK codebook determination of SPS configurations as per an aspect of an embodiment of the present disclosure.

FIG. 40 illustrates an example embodiment of DL slot determination as per an aspect of an embodiment of the present disclosure.

FIG. 41 illustrates an example embodiment of DL slot determination as per an aspect of an embodiment of the present disclosure.

FIG. 42 illustrates an example embodiment of DL slot determination as per an aspect of an embodiment of the present disclosure.

FIG. 43 illustrates an example embodiment of generating HARQ-ACK bits for a SPS configuration as per an aspect of an embodiment of the present disclosure.

FIG. 44 illustrates an example of a HARQ-ACK aggregation as per an aspect of an embodiment of the present disclosure.

FIG. 45 illustrates an example pseudo code as per an aspect of an embodiment of the present disclosure.

FIG. 46 shows an example embodiment of a HARQ-ACK sub-codebook as per an aspect of an embodiment of the present disclosure.

FIG. 47 illustrates an example of HARQ-ACK bits of a SPS configuration as per an aspect of an embodiment of the present disclosure.

FIG. 48 illustrates a flow diagram as per an aspect of an embodiment of the present disclosure.

#### DETAILED DESCRIPTION

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.

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.

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.

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.

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 on”) 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.

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 charac-

teristics or may be used to implement certain actions in the device, whether the device is in an operational or non-operational state.

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.

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.

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.

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

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.

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.

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.

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).

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.

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 central-

ized 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.

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.

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

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

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).

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

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

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

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

As shown in FIG. 1B, the gNBs 160 and/or the ng-eNBs 162 may be connected to the 5G-CN 152 by means of an NG interface and to other base stations by an Xn interface. The NG and Xn interfaces may be established using direct physical connections and/or indirect connections over an underlying transport network, such as an internet protocol (IP) transport network. The gNBs 160 and/or the ng-eNBs 162 may be connected to the UEs 156 by means of a Uu interface. For example, as illustrated in FIG. 1B, gNB 160A

may be connected to the UE **156A** by means of a Uu interface. The NG, Xn, and Uu interfaces are associated with a protocol stack. The protocol stacks associated with the interfaces may be used by the network elements in FIG. 1B to exchange data and signaling messages and may include two planes: a user plane and a control plane. The user plane may handle data of interest to a user. The control plane may handle signaling messages of interest to the network elements.

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

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

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

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

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

FIG. 2A illustrates a NR user plane protocol stack comprising five layers implemented in the UE **210** and the gNB **220**. At the bottom of the protocol stack, physical layers (PHYS) **211** and **221** may provide transport services to the higher layers of the protocol stack and may correspond to

layer 1 of the Open Systems Interconnection (OSI) model. The next four protocols above PHYS **211** and **221** comprise media access control layers (MACs) **212** and **222**, radio link control layers (RLCs) **213** and **223**, packet data convergence protocol layers (PDCPs) **214** and **224**, and service data application protocol layers (SDAPs) **215** and **225**. Together, these four protocols may make up layer 2, or the data link layer, of the OSI model.

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

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.

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.

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

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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.

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.

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.

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

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

The remaining protocol layers in FIG. 4A may perform their associated functionality (e.g., with respect to FIG. 3), add corresponding headers, and forward their respective outputs to the next lower layer. For example, the PDCP 224 may perform IP-header compression and ciphering and forward its output to the RLC 223. The RLC 223 may optionally perform segmentation (e.g., as shown for IP packet m in FIG. 4A) and forward its output to the MAC 222. The MAC 222 may multiplex a number of RLC PDUs and may attach a MAC subheader to an RLC PDU to form a transport block. In NR, the MAC subheaders may be distributed across the MAC PDU, as illustrated in FIG. 4A.

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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.

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

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

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.

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

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

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

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

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

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

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

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.

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

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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.

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

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.

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

In RRC connected 602, the UE has an established RRC context and may have at least one RRC connection with a base station. The base station may be similar to one of the one or more base stations included in the RAN 104 depicted in FIG. 1A, one of the gNBs 160 or ng-eNBs 162 depicted in FIG. 1B, the gNB 220 depicted in FIG. 2A and FIG. 2B, or any other base station described in the present disclosure. The base station with which the UE is connected may have the RRC context for the UE. The RRC context, referred to as the UE context, may comprise parameters for communication between the UE and the base station. These parameters may include, for example: one or more AS contexts; one or more radio link configuration parameters; bearer configuration information (e.g., relating to a data radio bearer, signaling radio bearer, logical channel, QoS flow, and/or PDU session); security information; and/or PHY, MAC, RLC, PDCP, and/or SDAP layer configuration information.

mation. 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.

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.

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.

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).

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.

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 10 perform a notification area update with the RAN to update the UE's RAN notification area.

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 15 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.

A gNB, such as gNBs 160 in FIG. 1B, may be split in two 20 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.

In NR, the physical signals and physical channels (discussed with respect to FIG. 5A and FIG. 5B) may be mapped onto orthogonal frequency divisional multiplexing (OFDM) symbols. OFDM is a multicarrier communication scheme that transmits data over F orthogonal subcarriers (or tones). 25 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 30 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 35 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 40 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 45 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 50 FFT block to recover the data mapped to the source symbols.

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, 55 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.

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  $\mu$ s. For example, NR defines numerologies with the following subcarrier spacing/cyclic prefix duration combinations: 15 kHz/4.7  $\mu$ s; 30 kHz/2.3  $\mu$ s; 60 kHz/1.2  $\mu$ s; 120 kHz/0.59  $\mu$ s; and 240 kHz/0.29  $\mu$ s.

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.

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  $275 \times 12 = 3300$  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.

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.

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.

NR defines bandwidth parts (BWP)s 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.

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.

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 (CORE-SETs) 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.

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).

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.

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.

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.

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).

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.

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.

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.

#### 4.2 Carrier Aggregation

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.

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

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.

When CA is used, one of the aggregated cells for a UE 5 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 10 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 15 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 20 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).

Configured SCells for a UE may be activated and deactivated based on, for example, traffic and channel conditions. 25 Deactivation of an SCell may mean that PDCCH and PDSCH reception on the SCell is stopped and PUSCH, SRS, and CQI transmissions on the SCell are stopped. Configured SCells may be activated and deactivated using a MAC CE with respect to FIG. 4B. For example, a MAC CE may use 30 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).

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.

FIG. 10B illustrates an example of how aggregated cells 50 may be configured into one or more PUCCH groups. A PUCCH group 1010 and a PUCCH group 1050 may include one or more downlink CCs, respectively. In the example of FIG. 10B, the PUCCH group 1010 includes three downlink CCs: a Pcell1011, an Scell1012, and an Scell1013. The PUCCH group 1050 includes three downlink CCs in the present example: a Pcell1051, an Scell1052, and an Scell1053. One or more uplink CCs may be configured as a Pcell1021, an Scell1022, and an Scell1023. One or more other uplink CCs may be configured as a primary SCell (PSCell) 1061, an Scell1062, and an Scell1063. 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 Pcell1021. 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 PSCell1061. In an example, if the aggregated cells depicted 60 in FIG. 10B were not divided into the PUCCH group 1010 and the PUCCH group 1050, a single uplink PCell to

transmit UCI relating to the downlink CCs, and the PCell may become overloaded. By dividing transmissions of UCI between the Pcell1021 and the PScell1161, overloading may be prevented.

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.

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.

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

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

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

127 subcarriers. The PBCH may be transmitted after the PSS (e.g., across the next 3 OFDM symbols) and may span 240 subcarriers.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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).

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.

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.

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.

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.

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.

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.

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.

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.

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.

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

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

beams used for the UE may be configured such that beams for the UE use symbols from beams of other UEs.

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

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).

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

FIG. 12B illustrates examples of three uplink beam management procedures: U1, U2, and U3. Procedure U1 may be

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

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).

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.

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.

FIG. 13A illustrates a four-step contention-based random access procedure. Prior to initiation of the procedure, a base

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

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**.

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.

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).

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.

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.

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).

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:

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

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).

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

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.

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).

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

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

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

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

Msg A **1320** may be transmitted in an uplink transmission by the UE. Msg A **1320** may comprise one or more transmissions of a preamble **1341** and/or one or more transmissions of a transport block **1342**. The transport block **1342** may comprise contents that are similar and/or equivalent to the contents of the Msg **3 1313** illustrated in FIG. **13A**. The transport block **1342** may comprise UCI (e.g., an SR, a HARQ ACK/NACK, and/or the like). The UE may receive the Msg B **1350** after or in response to transmitting the Msg A **1320**. The Msg B **1350** may comprise contents that are similar and/or equivalent to the contents of the Msg **2 1312** (e.g., an RAR) illustrated in FIGS. **13A** and **13B** and/or the Msg **4 1314** illustrated in FIG. **13A**.

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

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 **1350**.

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**).

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.

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.

- 5 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).
- 10 DCIs may be used for different purposes. A purpose may be indicated by the type of RNTI used to scramble the CRC parity bits. For example, a DCI having CRC parity bits scrambled with a paging RNTI (P-RNTI) may indicate paging information and/or a system information change notification. The P-RNTI may be predefined as "FFFE" in hexadecimal. A DCI having CRC parity bits scrambled with a system information RNTI (SI-RNTI) may indicate a broadcast transmission of the system information. The SI-RNTI may be predefined as "FFFF" in hexadecimal. A DCI having CRC parity bits scrambled with a random access RNTI (RA-RNTI) may indicate a random access response (RAR). A DCI having CRC parity bits scrambled with a cell RNTI (C-RNTI) may indicate a dynamically scheduled unicast transmission and/or a triggering of PDCCH-ordered random access. A DCI having CRC parity bits scrambled with a temporary cell RNTI (TC-RNTI) may indicate a contention resolution (e.g., a Msg **3** analogous to the Msg **3 1313** illustrated in FIG. **13A**). Other RNTIs configured to the UE by a base station may comprise a Configured Scheduling RNTI (CS-RNTI), a Transmit Power Control-PUCCH RNTI (TPC-PUCCH-RNTI), a Transmit Power Control-PUSCH RNTI (TPC-PUSCH-RNTI), a Transmit Power Control-SRS RNTI (TPC-SRS-RNTI), an Interruption RNTI (INT-RNTI), a Slot Format Indication RNTI (SFI-RNTI), a Semi-Persistent CSI RNTI (SP-CSI-RNTI), a Modulation and Coding Scheme Cell RNTI (MCS-C-RNTI), and/or the like.
- 15
- 20
- 25
- 30
- 35
- 40

- 45 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.
- 50
- 55
- 60
- 65

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).

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

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

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).

As shown in FIG. 14B, the UE may determine a time-frequency resource for a CORESET based on RRC messages. The UE may determine a CCE-to-REG mapping (e.g., interleaved or non-interleaved, and/or mapping parameters) for the CORESET based on configuration parameters of the CORESET. The UE may determine a number (e.g., at most 10) of search space sets configured on the CORESET based

on the RRC messages. The UE may monitor a set of PDCCH candidates according to configuration parameters of a search space set. The UE may monitor a set of PDCCH candidates in one or more CORESETS for detecting one or more DCIs. 5 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 10 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 15 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 20 downlink preemption, and/or the like).

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 25 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 30 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 35 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 40 uplink control signaling via a PUCCH using one of several PUCCH formats.

There may be five PUCCH formats and the UE may 45 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 50 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 55 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 60 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 65 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.

bols, the number of UCI bits is two or more and the PUCCH resource includes an orthogonal cover code.

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".

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.

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

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.

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

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

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

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.

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.

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 micro-controller, 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.

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.

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

FIG. 16B illustrates an example structure for modulation and up-conversion of a baseband signal to a carrier frequency. The baseband signal may be a complex-valued

SC-FDMA or CP-OFDM baseband signal for an antenna port and/or a complex-valued Physical Random Access Channel (PRACH) baseband signal. Filtering may be employed prior to transmission.

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

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

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.

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.

In carrier aggregation (CA), two or more component carriers (CCs) may be aggregated. A wireless device may simultaneously receive or transmit on one or more CCs, depending on capabilities of the wireless device, using the

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technique of CA. In an example, a wireless device may support CA for contiguous CCs and/or for non-contiguous CCs. CCs may be organized into cells. For example, CCs may be organized into one primary cell (PCell) and one or more secondary cells (SCells).

When configured with CA, a wireless device may have one RRC connection with a network. During an RRC connection establishment/re-establishment/handover, a cell providing NAS mobility information may be a serving cell. During an RRC connection re-establishment/handover procedure, a cell providing a security input may be a serving cell. In an example, the serving cell may denote a PCell. In an example, a gNB may transmit, to a wireless device, one or more messages comprising configuration parameters of a plurality of one or more SCells, depending on capabilities of the wireless device.

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

In an example, a wireless device may activate/deactivate an SCell in response to receiving an SCell Activation/Deactivation MAC CE.

In an example, a gNB may transmit, to a wireless device, one or more messages comprising an SCell timer (e.g., sCellDeactivationTimer). In an example, a wireless device may deactivate an SCell in response to an expiry of the SCell timer.

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

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

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

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device may: suspend one or more configured uplink grants of a configured uplink grant Type 1 associated with the activated SCell; and/or flush HARQ buffers associated with the activated SCell.

5 In an example, when an SCell is deactivated, a wireless device may not perform operations comprising: transmitting SRS on the SCell; reporting CQI/PMI/RI/CRI for the SCell; transmitting on UL-SCH on the SCell; transmitting on RACH on the SCell; monitoring at least one first PDCCH on the SCell; monitoring at least one second PDCCH for the SCell; and/or transmitting a PUCCH on the SCell.

In an example, when at least one first PDCCH on an activated SCell indicates an uplink grant or a downlink assignment, a wireless device may restart a first SCell timer (e.g., sCellDeactivationTimer) associated with the activated SCell. In an example, when at least one second PDCCH on a serving cell (e.g. a PCell or an SCell configured with PUCCH, i.e. PUCCH SCell) scheduling the activated SCell indicates an uplink grant or a downlink assignment for the activated SCell, a wireless device may restart the first SCell timer (e.g., sCellDeactivationTimer) associated with the activated SCell.

In an example, when an SCell is deactivated, if there is an ongoing random access procedure on the SCell, a wireless device may abort the ongoing random access procedure on the SCell.

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 L1 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.

55 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.

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.

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.

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).

A DCI field of frequency domain resource allocation (frequency domain RA in FIG. 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.,  $\text{ceil}(\log 2(\text{BW}(\text{BW}+1)/2))$ , wherein BW is the bandwidth of the active uplink BWP).

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  $\text{ceil}(\log 2(\text{BW}(\text{BW}+1)/2)-K)$  bits to indicate the uplink resource(s) based on the resource allocation type 1, when frequency hopping is enabled.

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 sched-

ules 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.

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</sup> DAI) and/or a second DAI (2<sup>nd</sup> 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.

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.

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).

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.

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 CBGTTI 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).

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.

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.

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).

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.).

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.

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.

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.

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].

The DCI format 0\_2 may have a first downlink assignment index (1<sup>st</sup> DAI) and/or a second DAI (2<sup>nd</sup> DAI). The configuration parameters may comprise a parameter to indicate whether to use DAI for the DCI format 0\_2 (e.g., 5 DownlinkAssignmentIndex-ForDCIFormat0\_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.

A field of transmission power control (TPC shown in FIG. 20 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 25 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 30 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. 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 35 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.

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 40 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 45 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).

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).

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.

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.

In a NR system, in order to support wide bandwidth operation, a gNB may transmit one or more PDCCH in different control resource sets. A gNB may transmit one or more RRC message comprising configuration parameters of one or more control resource sets. At least one of the one or more control resource sets may comprise at least one of: a first OFDM symbol; a number of consecutive OFDM symbols; a set of resource blocks; a CCE-to-REG mapping; and a REG bundle size, in case of interleaved CCE-to-REG mapping.

A base station (gNB) may configure a wireless device (UE) with uplink (UL) bandwidth parts (BWP)s and downlink (DL) BWP>s to enable bandwidth adaptation (BA) on a PCCell. If carrier aggregation is configured, the gNB may further configure the UE with at least DL BWP(s) (i.e., there may be no UL BWP>s in the UL) to enable BA on an SCell. For the PCCell, an initial active BWP may be a first BWP used for initial access. For the SCell, a first active BWP may be a second BWP configured for the UE to operate on the SCell upon the SCell being activated.

In paired spectrum (e.g., FDD), a gNB and/or a UE may independently switch a DL BWP and an UL BWP. In unpaired spectrum (e.g. TDD), a gNB and/or a UE may simultaneously switch a DL BWP and an UL BWP.

In an example, a gNB and/or a UE may switch a BWP between configured BWPs by means of a DCI or a BWP inactivity timer. When the BWP inactivity timer is configured for a serving cell, the gNB and/or the UE may switch an active BWP to a default BWP in response to an expiry of the BWP inactivity timer associated with the serving cell. The default BWP may be configured by the network.

In an example, for FDD systems, when configured with BA, one UL BWP for each uplink carrier and one DL BWP may be active at a time in an active serving cell. In an example, for TDD systems, one DL/UL BWP pair may be active at a time in an active serving cell. Operating on the one UL BWP and the one DL BWP (or the one DL/UL pair) may improve UE battery consumption. BWPs other than the one active UL BWP and the one active DL BWP that the UE may work on may be deactivated. On deactivated BWPs, the UE may: not monitor PDCCH; and/or not transmit on PUCCH, PRACH, and UL-SCH.

In an example, a serving cell may be configured with at most a first number (e.g., four) of BWPs. In an example, for an activated serving cell, there may be one active BWP at any point in time.

In an example, a BWP switching for a serving cell may be used to activate an inactive BWP and deactivate an active BWP at a time. In an example, the BWP switching may be controlled by a PDCCH indicating a downlink assignment or an uplink grant. In an example, the BWP switching may be controlled by a BWP inactivity timer (e.g., bwp-Inactivity-Timer). In an example, the BWP switching may be controlled by a MAC entity in response to initiating a Random Access procedure. Upon addition of an SpCell or activation of an SCell, one BWP may be initially active without receiving a PDCCH indicating a downlink assignment or an uplink grant. The active BWP for a serving cell may be indicated by RRC and/or PDCCH. In an example, for unpaired spectrum, a DL BWP may be paired with a UL BWP, and BWP switching may be common for both UL and DL.

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

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

In an example, if a MAC entity receives a PDCCH for a BWP switching of a serving cell while a Random Access procedure associated with this serving cell is not ongoing, a UE may perform the BWP switching to a BWP indicated by the PDCCH.

In an example, if a bandwidth part indicator field is configured in DCI format 1\_1, the bandwidth part indicator field value may indicate the active DL BWP, from the configured DL BWP set, for DL receptions. In an example, if a bandwidth part indicator field is configured in DCI format 0\_1, the bandwidth part indicator field value may indicate the active UL BWP, from the configured UL BWP set, for UL transmissions.

In an example, for a primary cell, a UE may be provided by a higher layer parameter Default-DL-BWP a default DL BWP among the configured DL BWPs. If a UE is not provided a default DL BWP by the higher layer parameter Default-DL-BWP, the default DL BWP is the initial active DL BWP.

In an example, a UE may be provided by higher layer parameter bwp-InactivityTimer, a timer value for the primary cell. If configured, the UE may increment the timer, if running, every interval of 1 millisecond for frequency range 1 or every 0.5 milliseconds for frequency range 2 if the UE may not detect a DCI format 1\_1 for paired spectrum operation or if the UE may not detect a DCI format 1\_1 or DCI format 0\_1 for unpaired spectrum operation during the interval.

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

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

In an example, a wireless device may transmit one or more uplink control information (UCI) via one or more PUCCH resources to a base station. The one or more UCI may comprise at least one of: HARQ-ACK information; scheduling request (SR); and/or CSI report. In an example, a PUCCH resource may be identified by at least: frequency location (e.g., starting PRB); and/or a PUCCH format associated with initial cyclic shift of a base sequence and time domain location (e.g., starting symbol index). In an example, a PUCCH format may be PUCCH format 0, PUCCH format 1, PUCCH format 2, PUCCH format 3, or PUCCH format 4. A PUCCH format 0 may have a length of 1 or 2 OFDM symbols and be less than or equal to 2 bits. A PUCCH format 1 may occupy a number between 4 and 14 of OFDM symbols and be less than or equal to 2 bits. A PUCCH format 2 may occupy 1 or 2 OFDM symbols and be greater than 2 bits. A PUCCH format 3 may occupy a number between 4 and 14 of OFDM symbols and be greater than 2 bits. A PUCCH format 4 may occupy a number between 4 and 14 of OFDM symbols and be greater than 2 bits. The PUCCH resource may be configured on a PCell, or a PUCCH secondary cell.

In an example, when configured with multiple uplink BWPs, a base station may transmit to a wireless device, one

or more RRC messages comprising configuration parameters of one or more PUCCH resource sets (e.g., at most 4 sets) on an uplink BWP of the multiple uplink BWPs. Each PUCCH resource set may be configured with a PUCCH resource set index, a list of PUCCH resources with each PUCCH resource being identified by a PUCCH resource identifier (e.g., pucch-Resourceid), and/or a maximum number of UCI information bits a wireless device may transmit using one of the plurality of PUCCH resources in the PUCCH resource set.

In an example, when configured with one or more PUCCH resource sets, a wireless device may select one of the one or more PUCCH resource sets based on a total bit length of UCI information bits (e.g., HARQ-ARQ bits, SR, and/or CSI) the wireless device will transmit. In an example, when the total bit length of UCI information bits is less than or equal to 2, the wireless device may select a first PUCCH resource set with the PUCCH resource set index equal to "0". In an example, when the total bit length of UCI information bits is greater than 2 and less than or equal to a first configured value, the wireless device may select a second PUCCH resource set with the PUCCH resource set index equal to "1". In an example, when 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 wireless device may select a third PUCCH resource set with the PUCCH resource set index equal to "2". In an example, when 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., 1706), the wireless device may select a fourth PUCCH resource set with the PUCCH resource set index equal to "3".

In an example, a wireless device may determine, based on a number of uplink symbols of UCI transmission and a number of UCI bits, a PUCCH format from a plurality of PUCCH formats comprising PUCCH format 0, PUCCH format 1, PUCCH format 2, PUCCH format 3 and/or PUCCH format 4. In an example, the wireless device may transmit UCI in a PUCCH using PUCCH format 0 if the transmission is over 1 symbol or 2 symbols and the number of HARQ-ACK information bits with positive or negative SR (HARQ-ACK/SR bits) is 1 or 2. In an example, the wireless device may transmit UCI in a PUCCH using PUCCH format 1 if the transmission is over 4 or more symbols and the number of HARQ-ACK/SR bits is 1 or 2. In an example, the wireless device may transmit UCI in a PUCCH using PUCCH format 2 if the transmission is over 1 symbol or 2 symbols and the number of UCI bits is more than 2. In an example, the wireless device may transmit UCI in a PUCCH using PUCCH format 3 if the transmission is over 4 or more symbols, the number of UCI bits is more than 2 and PUCCH resource does not include an orthogonal cover code. In an example, the wireless device may transmit UCI in a PUCCH using PUCCH format 4 if the transmission is over 4 or more symbols, the number of UCI bits is more than 2 and the PUCCH resource includes an orthogonal cover code.

In an example, in order to transmit HARQ-ACK information on a PUCCH resource, a wireless device may determine the PUCCH resource from a PUCCH resource set. The PUCCH resource set may be determined as mentioned above. The wireless device may determine the PUCCH resource based on a PUCCH resource indicator field in a DCI (e.g., with a DCI format 1\_0 or DCI for 1\_1) received on a PDCCH. A 3-bit PUCCH resource indicator field in the DCI may indicate one of eight PUCCH resources in the PUCCH resource set. The wireless device may

transmit the HARQ-ACK information in a PUCCH resource indicated by the 3-bit PUCCH resource indicator field in the DCI.

In an example, the wireless device may transmit one or more UCI bits via a PUCCH resource of an active uplink BWP of a PCell or a PUCCH secondary cell. Since at most one active uplink BWP in a cell is supported for a wireless device, the PUCCH resource indicated in the DCI is naturally a PUCCH resource on the active uplink BWP of the cell.

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

In an example, during a DRX mode, the UE may power down most of its circuitry when there are no packets to be received. The UE may monitor PDCCCH discontinuously in the DRX mode. The UE may monitor the PDCCCH continuously when a DRX operation is not configured. During this time the UE listens to the downlink (DL) (or monitors PDCCCHs) which is called DRX Active state. In a DRX mode, a time during which UE does not listen/monitor PDCCCH is called DRX Sleep state.

In an example, a frequency range of 52.6 to 71 GHz (e.g., a frequency region 3, a frequency range 3, a third frequency range, a third frequency region) may support additional numerologies. For example, the additional numerologies may comprise a 120 kHz subcarrier spacing with a normal CP. For example, the additional numerologies may comprise a 240 kHz subcarrier spacing with the normal CP. For example, the additional numerologies may comprise a 480 kHz subcarrier spacing with the normal CP and/or an extended CP. For example, the additional numerologies may comprise a 960 kHz subcarrier spacing with the normal CP and/or the extended CP.

FIG. 20 illustrates an example of different numerologies that the wireless device may support for one or more cells in different frequency ranges. For example, 15 kHz subcarrier spacing with the normal CP and/or the extended CP may be supported in a frequency region 1 (e.g., FR1). For example, 60 kHz (and/or 120 kHz) subcarrier spacing with the normal CP and/or the extended CP may be supported in a frequency region 2 (e.g., FR2). For example, 240 kHz and/or 480 kHz and/or 960 kHz subcarrier spacings with the normal CP and/or the extended CP may be supported in a frequency region 3 (e.g., FR3).

A length of a slot with the 15 kHz subcarrier spacing may be 1 msec. A length of a slot with a subcarrier spacing that is 15 kHz\*2<sup>u</sup> (e.g., 15\*2<sup>u</sup>) may be ½<sup>u</sup> (½<sup>u</sup>) msec. For example, a length of the slot with a subcarrier spacing 120 kHz is ½=0.125 msec. A length of a slot with a subcarrier spacing 240 kHz is ¼=62.5 us. A length of a slot with a subcarrier spacing 960 kHz is ¼=16 us.

In a millisecond, one slot may be present with a subcarrier spacing of 15 kHz, 4 slots with 60 kHz subcarrier spacing, 16 slots with 240 kHz subcarrier spacing and 64 slots with 960 kHz subcarrier spacing.

In an example, a base station may transmit a DCI to a UE to activate or release a Semi-Persistent Scheduling (SPS) assignment/configuration or a configured grant (CG) assignment/configuration. The SPS configuration or the CG configuration may be configured to support some types (e.g., VoIP, V2X) of applications.

A SPS configuration or a CG configuration may allow a wireless device to determine resources without receiving a dynamic grant, via a control channel, for each data transmission (e.g., before each time the data transmission occurs). The SPS configuration or CG configuration may reduce a DCI overhead.

FIG. 21 illustrates a SPS configuration as per an aspect of an embodiment of the present disclosure.

The base station may transmit one or more RRC messages comprising/indicating configuration parameters. The configuration parameters may comprise/indicate a SPS configuration. For example, the SPS configuration may comprise a periodicity (P). For example, the SPS configuration may comprise a resource allocation type. For example, the SPS configuration may comprise one or more parameters to receive a SPS PDSCH based on the SPS configuration (e.g., PDSCH-Config).

The base station may transmit a DCI at a slot n. The DCI may activate the SPS configuration. For example, the wireless device may validate the DCI based on a first DCI field of the DCI being set to a first predetermined value and a second DCI field of the DCI being set to a second predetermined value. The DCI may be called/referred as an activation DCI in response to validating the DCI and determining that the DCI activating the SPS configuration. For example, the first DCI field may be a HARQ process ID field. The first predetermined value may be zero or all zeros. The second DCI field may be a RV field. The second predetermined value may be zeros or all zeros.

Based on the validating the DCI as an activation DCI, the wireless device may activate the SPS configuration. The wireless device may determine a first SPS PDSCH reception (e.g., first PDSCH) based on a slot offset indicated by the activation DCI.

A SPS PDSCH reception may refer to resources scheduled for a SPS PDSCH based on a SPS configuration. A SPS PDSCH reception may refer to a scheduled time/frequency domain resource for a PDSCH comprising a transport block based on a SPS configuration. A SPS PDSCH reception may refer to an occasion or a periodic resource scheduled for a SPS PDSCH. A (SPS) PDSCH reception may refer to a time domain resource (in a slot or in a sub-slot) in which a PDSCH transmission may be received/scheduled from e.g., a base station. A SPS PDCH may refer to a PDSCH configured via a SPS configuration. A SPS PDSCH may be a PDSCH scheduled periodically. A SPS PDSCH may be a PDSCH.

In an example, the wireless device may determine whether the DCI indicates the activation, the release or the retransmission for the one or more CG configurations or for the one or more SPS configurations based on determining one or more values of one or more DCI fields of the DCI format used for the DCI. For example, the wireless device may determine the DCI indicates the activation in response to receiving the DCI with a HARQ process ID (HARQ process #) field of the DCI format indicating zero(s) (e.g., '0, ..., 0') and a RV (redundancy version) field of the DCI indicating zero(s). The wireless device may first determine whether an NDI field of the DCI may indicate a new data or not. In response to receiving the DCI with the NDI field of the new data, the wireless device may further

determine the HARQ process number field and the redundancy version field of the DCI. In response to determining the HARQ process number field being set to a predetermined value (e.g., zero(s)) and the redundancy version field being set to a predetermined value (e.g., zero(s)), the wireless device may determine the DCI may indicate the activation or the release of at least one CG configuration or at least one SPS configuration. For example, the wireless device may further check/determine a MCS (modulation and coding scheme) field of the DCI and/or a FDRA (frequency domain resource assignment) field of the DCI to differentiate between the activation and the release. In response to the MCS field being set to a second predetermined value (e.g., one(s), '1, . . . , 1') and the FDRA field being set to a third predetermined value (e.g., zero(s) for resource allocation type 0 or a resource allocation type 2 with mu=1, one(s) for resource allocation type 1 or the resource allocation type 2 with mu=0), the wireless device may determine the DCI indicates the release for the at least one CG configuration or the at least one SPS configuration. In response to the MCS field being set to different value from the second predetermined value and/or the FDRA field being set to the third predetermined value, the wireless device may determine the DCI may indicate the activation for the at least one CG configuration or the at least one SPS configuration.

For example, a DCI format 0\_0/0\_1/0\_2, CRC scrambled with the first RNTI, may be used to indicate an activation, a release and/or retransmission for a configured grant (CG) based on setting one or more DCI fields with one or more predetermined values. For example, a DCI format 1\_0/1\_2, CRC scrambled with a third RNTI (e.g., SPS-RNTI), may be used to indicate an activation, a release and/or retransmission for a semi-persistent scheduling (SPS) on setting the one or more DCI fields with one or more predetermined values.

In an example, a DCI activating a SPS configuration or a CG configuration may be referred as an activation DCI. A DCI releasing one or more SPS configurations or one or more CG configurations may be referred as a release DCI or a DCI with a SPS (or CG) release.

For example, FIG. 21 illustrates k0 is m. The wireless device may determine the first SPS PDSCH reception at a slot n+m.

The wireless device may determine a second SPS PDSCH reception (e.g., second PDSCH) based on the first SPS PDSCH Hand a periodicity of the SPS configuration. For example, the wireless device may determine the second SPS PDSCH at a slot n+m+P (e.g., P slots after the first SPS PDSCH).

The wireless device may determine i-th SPS PDSCH based on the first SPS PDSCH and the periodicity. For example, the wireless device may determine i-th SPS PDSCH at a slot n+m+(i-1)\*P (e.g., (i-1)\*P slots after the first SPS PDSCH).

The wireless device may receive a second DCI releasing the SPS configuration. For example, the wireless device may deactivate the SPS configuration in response to the second DCI. The wireless device may assume that no more SPS PDSCH reception, determined based on the SPS configuration, after deactivating the SPS configuration.

The wireless device may determine a transport block may be transmitted in each periodicity. Each SPS PDSCH reception may carry at most one transport block. Each SPS PDSCH reception may be configured with a repetition. For example, in each SPS PDSCH reception, one or more repetitions may be transmitted via one or more PDSCHs.

Each SPS PDSCH reception with or without repetition may comprise a transport block in each periodicity/interval.

FIG. 22 illustrates an example of embodiments of a multi-PDSCH scheduling as per an aspect of an embodiment 5 of the present disclosure. When a wireless device is configured with a multi-PDSCH scheduling for a serving cell, the wireless device may receive a DCI that indicates resource assignment(s) and/or CSI/SRS requests for one or more PDSCHs via the serving cell. The DCI may indicate 10 resources for the one or more PDSCHs via consecutive one or more slots. The DCI may indicate resources for the one or more PDSCHs via non-consecutive one or more slots.

Each PDSCH of the one or more PDSCHs may comprise one or more transport blocks. One or more first transport 15 blocks of a first PDSCH of the one or more PDSCHs may be different from one or more second transport blocks of a second PDSCH of the one or more PDSCHs. One or more first transport blocks of a first PDSCH of the one or more PDSCHs may be same to one or more second transport 20 blocks of a second PDSCH of the one or more PDSCHs (e.g., each PDSCH may carry repetitions of one or more transport blocks).

A first PDSCH of the one or more PDSCHs may comprise 25 a first transport block. A second PDSCH of the one or more PDSCHs may comprise a second transport block. The first transport block may be different from the second transport block. The second transport block may be repetition of the first transport block. The DCI may comprise one or more NDI bits or one or more NDI fields. Each NDI bit of the one 30 or more NDI bits or each NDI field of the one or more NDI fields may correspond to each of the one or more PDSCHs. The DCI may comprise one or more RV bits or one or more RV fields. Each RV bit of the one or more RV bits or each RV field of the one or more RV fields may correspond to the 35 each of the one or more PDSCHs.

In an example, a multi-PDSCH scheduling may be configured for a cell based on a cross-carrier scheduling and/or a self-carrier scheduling. For example, when the cross-carrier scheduling is used, a second cell is a scheduled cell 40 by a first cell. For example, when the self-carrier scheduling is used, a scheduling cell may be same to a scheduled cell. FIG. 22 shows an example of a self-carrier scheduling for a cell (Cell 1).

For example, when a cross-carrier scheduling is used, the 45 first cell (e.g., scheduling cell) may operate with a first numerology (e.g., 15 kHz with a normal CP). The second cell (e.g., scheduled cell) may operate with a second numerology (e.g., 960 kHz with an extended CP or 480 kHz with an extended CP). During 1 msec, the first cell may have 1 50 slot. During 1 msec, the second cell may have a plurality of slots (e.g., 32 slots with 480 kHz, 64 slots with 960 kHz).

The base station may transmit one or more RRC messages indicating configuration parameters. The configuration parameters may comprise/indicate a multi-PDSCH scheduling 55 for the scheduled cell (e.g., cell 1). The configuration parameters may comprise/indicate a number of PDSCHs schedulable by a single DCI. For example, a maximum number of PDSCHs by a single DCI may be indicated by the configuration parameters. A DCI, of a multi-PDSCH scheduling, may comprise resource assignment(s) for one or more PDSCHs, where a number of the one or more PDSCHs or one or more slots scheduled with the one or more PDSCHs is less than or equal to the maximum number of PDSCHs.

For example, the configuration parameters may comprise/ 60 indicate a number of DCIs that may be transmitted/scheduled via a span or a PDCCH monitoring occasion or a slot of the scheduling cell. The base station may transmit one or

more second RRC messages indicating second configuration parameters. The second configuration parameters may comprise/indicate a cross-carrier scheduling for the scheduled cell. For example, the first cell is indicated as a scheduling cell. The first cell may schedule the second cell.

The DCI may be CRC-scrambled with a first RNTI (e.g., C-RNTI, CS-RNTI). The DCI may schedule a first TB (TB #1) via a first PDSCH, a second TB (TB #2) via a second PDSCH, and so on. For example, FIG. 22 illustrates that up to K TBs via K PDSCHs are scheduled by the DCI. FIG. 22 illustrates that the DCI schedules the TB #1 to TB #K. For example, one or more slots of the one or more PDSCHs may be contiguous in time domain. For example, the one or more slots may be non-contiguous in time domain. The DCI may comprise a time domain resource allocation field that indicates time domain resources indicating the one or more slots. The time domain resource allocation field may indicate a starting symbol and a duration in each slot of the one or more slots. A first slot of the one or more slots may have a first starting symbol and a first duration. A second slot of the one or more slots may have a second starting symbol and a second duration. The first starting symbol may be different from the second starting symbol. The first duration may be different from the second duration.

The time domain resource allocation field may indicate a starting symbol and a duration for each PDSCH of the one or more PDSCHs.

The configuration parameters may indicate to enable or disable the multi-PDSCH scheduling. The second cell may operate with a plurality of TRPs/coreset pools. The one or more TBs or the one or more PDSCHs may be scheduled via the plurality of TRPs/coreset pools.

For example, a first PDSCH of the one or more PDSCHs may be associated with a first transmission and reception point (TRP) or a first coresset pool/group or a first group or a first TCI group. The second PDSCH of the one or more PDSCHs may be associated with a second TRP or a second coresset pool/group or a second group or a second TCI group. When the scheduled cell is operating with a single TRP, the first TRP may be same as the second TRP. The first TRP or the first coresset pool is assumed to be present as a default for the single TRP operation. A wireless device may determine a coresset pool index as zero when a coresset pool is not configured/provided to the wireless device.

FIG. 22 illustrates that a first PDSCH of the one or more PDSCHs is determined based on a slot/scheduling offset (e.g., k0) of a time domain resource allocation field of the DCI. The first PDSCH may start in a slot where the slot occurs k0 slots after a first slot of the DCI. For example, k0 may be 1 slot.

The wireless device may determine slot(s) for the one or more PDSCHs based on the slot/scheduling offset and the time domain resource allocation field of the DCI. The wireless device may map the one or more PDSCHs sequentially starting from the first PDSCH based on the slot/scheduling offset. The wireless device may map the one or more PDSCHs based on an TDRA entry indicated by the time domain resource allocation field of the DCI.

A multi-PDSCH DCI or a multi-TB DCI (e.g., DCI-M, M-DCI, Multi-PDSCH DCI, m-DCI, mDCI) may represent a DCI based on a multi-PDSCH scheduling (e.g., a multi-TTI scheduling, a multi-transport blocks scheduling, or a multi-TB scheduling). For example, the one or more configuration parameters may comprise one or more control resource set (coresets) and/or one or more search spaces. The DCI of the multi-PDSCH 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/indicate one or more RNTIs that may be used for the DCI of the multi-PDSCH scheduling. The one or more RNTIs may not comprise a C-RNTI. The one or more RNTIs may comprise the C-RNTI.

The base station may transmit one or more MAC CEs/ one or more DCIs to activate the multi-PDSCH scheduling. 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-PDSCH scheduling. The second BWP may comprise one or more second coresets of the multi-PDSCH scheduling. For example, the one or more MAC CEs may comprise indication(s) of activating and/or deactivating a multi-PDSCH scheduling. For example, the one or more DCIs may comprise an indication to activate or deactivate the multi-PDSCH scheduling of the second cell. For example, the configuration parameters may comprise/ indicate a plurality of BWPs. A first BWP of the plurality of BWPs may comprise/indicate a first DCI format that is used for a multi-PDSCH scheduling. A second BWP of the plurality of BWPs may comprise/indicate a second DCI format that is used for a single-PDSCH scheduling. The wireless device may determine the multi-PDSCH scheduling is activated in response to the first BWP being an active BWP of the second cell. The wireless device may determine the multi-PDSCH scheduling is deactivated in response to the second BWP being an active BWP of the second cell.

Similar mechanisms may be applied for a PUSCH scheduling. Similarly, a multi-PUSCH scheduling (e.g., a multi-TTI scheduling, multi-TB scheduling, multi-uplink scheduling) may be used for scheduling one or more PUSCHs via a single DCI (e.g., a multi-PUSCH DCI, a M-DCI, DCI-M, mDCI, m-DCI, multi-TTI DCI). For a cell, the multi-PDSCH scheduling and the multi-PUSCH scheduling may be configured/activated/deactivated simultaneously or may be independently configured/activated/deactivated. For example, when a first DCI format used for scheduling PDSCH(s) for a cell may be size-aligned with a second DCI format used for scheduling PUSCH(s) for the cell. When the first DCI format and the second DCI format are size-aligned, the multi-PDSCH and the multi-PUSCH scheduling may be both activated or both deactivated.

The wireless device may activate the multi-PDSCH (and/ or multi-PUSCH) 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-PDSCH (or the multi-PUSCH) scheduling of a cell via RRC signaling. In response to activating the multi-PDSCH (or the multi-PUSCH) scheduling, the base station may transmit a DCI, based on the multi-PDSCH (or the multi-PUSCH) scheduling, comprising resource assignments for the first downlink/uplink carrier/cell (e.g., cell 1). The DCI may indicate a plurality of downlink/uplink resources for a repetition of a TB via one or more slots (e.g., TB #1, . . . TB #K are same).

In an example, a DCI, of a multi-PDSCH and/or a multi-PUSCH scheduling, may comprise a MCS field or one or more MCS fields. A value of the MCS field or one or more values of the one or more MCS fields may be applied to each of the one or more PDSCHs. The one or more values of the one or more MCS fields may be applied for one or more TBs scheduled via each PDSCH of the one or more PDSCHs. For example, the DCI may comprise a first MCS field indicating

a value of MCS values (e.g., 32 values). The DCI may additionally comprise one or more second MCS fields where each of the one or more second MCS fields indicates a gap/offset compared to the first MCS field. For example, the each of the one or more second MCS fields may have k1 bits (e.g., k1=2) that is smaller than k2 bits of the first MCS field (e.g., k2=5).

In an example, the DCI may comprise one or more MCS fields where each of the one or more MCS fields may correspond to each of the one or more PDSCHs.

In an example, the DCI may comprise a first RV field indicating an index of a redundancy version for a first PDSCH. When two TBs may be scheduled for the first PDSCH, the first RV field may comprise two RV values where each RV value corresponds to a first TB and a second TB of the two TBs.

The wireless device may determine one or more second RV values for one or more second PDSCHs of the one or more PDSCHs. The one or more second PDSCHs may be present when the one or more PDSCHs comprise additional PDSCHs than the first PDSCH. The wireless device may determine the one or more second RVs based on configuration parameters configured by the base station. For example, the configuration parameters may comprise a list of RV values, where each entry of the list of RV values comprises a set of RV values {the first RV value, a second RV value, a third RV value, and so on}. The first RV value is determined based on the first RV field. The second RV value may correspond to a second PDSCH of the one or more PDSCHs. The second PDSCH is a PDSCH occurring in a second earliest (e.g., a next one after the earliest) among the one or more PDSCHs. The third RV value may be applied or correspond to a third PDSCH (e.g., a third earliest PDSCH, a next after the second PDSCH) of the one or more PDSCHs.

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 HARQ process ID 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 one or more PDSCHs. For example, the wireless device may increment the HARQ process ID for each PDSCH of the one or more PDSCHs.

For example, the wireless device may apply the HARQ process ID indicated by the DCI for an earliest PDSCH of the one or more PDSCHs. The wireless device may increment the HARQ process ID for a second earliest PDSCH of the one or more PDSCHs. The wireless device may determine a HARQ process ID of a PDSCH of the one or more PDSCHs as (HARQ process ID+i) % MAX HARQ process ID where i is an order of the PDSCH among the one or more PDSCHs or i is a slot offset of the PDSCH from a first slot of the earliest PDSCH of the one or more PDSCHs. The MAX HARQ process ID may represent a number of maximum HARQ processes that the wireless device is configured with or supports for the cell. The MAX HARQ process ID may represent a number of maximum HARQ processes that

the wireless device is configured with or supports for one or more PDSCHs/TBs scheduled by the DCI.

For example, when the DCI may be used for an activation of a SPS PDSCH configuration, MAX HARQ process ID may represent a number of HARQ processes configured for the SPS PDSCH configuration or one or more SPS PDSCH configuration of the cell.

In an example, the DCI may comprise a first NDI bit for the first PDSCH of the one or more PDSCHs. The DCI may comprise a second NDI bit for the second PDSCH of the one or more PDSCHs. The DCI may comprise one or more NDI bits for the one or more PDSCHs. Each NDI bit of the one or more of NDI bits may correspond to each PDSCH of the one or more PDSCHs.

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 TRP/coreset pool in frequency domain. The second frequency domain resource assignment field may indicate a second resource of the second TRP/coreset pool 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 TRP/coreset pool and a second field indicating second resource(s) of the second TRP/coreset pool.

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 TRP/coreset pool in time domain. The second time domain resource assignment field may indicate a second resource of the second TRP/coreset pool 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 TRP/coreset pool and a second field indicating second resource(s) of the second TRP/coreset pool. An entry of the one or more time domain resource allocation lists may comprise a plurality of fields/sub-entries.

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).

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 coresets. 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 coresets.

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.,  $iL, iL+1, \dots, iL+L-1$ ). 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  $[0, 1, \dots, N_{reg\_coreset}/L-1]$ . For example,  $N_{reg\_coreset}$  may be defined as  $N_{ib\_coreset} * N_{symbol\_coreset}$  (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  $\{f(6j/L), f(6j/L+1), \dots, f(6j/L+6/L-1)\}$ . For example,  $f(x)$  may be an interleaver function. In an example,  $f(x)$  may be  $x$  (e.g., j-th CCE may comprise  $6j/L, 6j/L+1, \dots, 6j/L+6/L-1$ ), 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  $(rC+c+n\_shift) \bmod (N_{reg\_coreset}/L)$ , wherein  $x=cR+r$ ,  $r=0, 1, \dots, R-1$ ,  $c=0, 1, \dots, C-1$ ,  $C=N_{reg\_coreset}/(L*R)$ , and R is one of  $\{2, 3, 6\}$ .

For example, the configuration parameters may comprise a frequencyDomainResources that may define  $N_{ib\_coreset}$ . 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 shiftIndex that may determine n\_shift as one of  $\{0, 1, \dots, 274\}$ . The wireless device may determine/assume a same precoding for REGs within a REG bundle when precoder 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 coresset when the precoderGranularity is configured as all-ContiguousRBs.

For a first coresset (e.g., CORESET #0) may be defined/configured with  $L=6$ ,  $R=2$ ,  $n\_shift=cell$  ID, and  $precoderGranularity=sameAsREG\_bundle$ .

In an example, a wireless device may receive up to M DCIs via a slot or a PDCCH monitoring occasion or a span of a scheduling cell. Each DCI of the M DCIs may schedule one or more PDSCHs for a scheduled cell. The wireless device may inform a wireless device capability of the M for a band/band combination or for each numerology pair between a scheduling cell and a scheduled cell.

In an example, two downlink resource allocation schemes, type 0 and type 1, are supported. A wireless device may determine a frequency domain resource based on a DCI based on a fallback DCI format such as DCI format 0\_1 based on a resource allocation type 1. A base station may transmit configuration parameters indicating a dynamic switch between the type 0 and the type 1 resource allocation via an indication in a DCI. The configuration parameters may comprise 'dynamicswitch' to enable dynamic switching between the type 0 and the type 1 via the DCI. The dynamic switching may be supported for a DCI based on a non-fallback DCI format such as DCI format 1\_1 or DCI format 1\_2. The configuration parameters may comprise/indicate either the type 0 or the type 1 as a resource allocation type via an RRC signaling. The wireless device may determine a frequency domain resource based on a DCI based on the resource allocation configured via the RRC signaling, in response to 'dynamicswitch' being not configured. The wireless device may determine a frequency domain resource based on a frequency domain resource assignment field of a DCI based on an active downlink BWP of a cell. The cell is a scheduled cell. The DCI may indicate a BWP index. The wireless device may determine the frequency domain resource based on one or more configuration parameters of an indicated BWP by the BWP index. For a PDSCH scheduled with a DCI based on a fallback DCI format (e.g., DCI format 1\_0) via any common search space, a RB numbering, to determine a frequency domain resource, may start from a lowest RB of a coresset. For example, the DCI has been received via the coresset. In other cases, the RB numbering may start from a lowest RB of an active BWP of the scheduled cell.

For example, a resource allocation type 0 may use a bitmap to indicate a frequency domain resource. The bitmap may indicate one or more resource block groups (RBGs) that may allocate the frequency domain resource. One RBG may represent a set of consecutive virtual resource blocks defined by a rbg-Size. For example, the rbg-Size may be indicated as a parameter of a PDSCH-Config under a servingCellConfig. For example, the rbg-Size may be determined based on a parameter of 'Configuration 1' or 'Configuration 2' and a bandwidth of an active BWP of a scheduled cell. For example, when the bandwidth of the active BWP is between 1 to 36 RBs, 'Configuration 1' indicates the rbg-Size of 2 and 'Configuration 2' indicates the rbg-Size of 4. For example, when the bandwidth of the active BWP is between 37 to 72 RBs, 'Configuration 1' indicates the rbg-Size of 4 and 'Configuration 2' indicates the rbg-Size of 8. For example, when the bandwidth of the active BWP is between 73 to 144 RBs, 'Configuration 1' indicates the rbg-Size of 8 and 'Configuration 2' indicates the rbg-Size of 16. For example, when the bandwidth of the active BWP is between 145 to 275 (or 550) RBs, 'Configuration 1' indicates the rbg-Size of 16 and 'Configuration 2' indicates the rbg-Size of 16. A number of RBGs ( $N_{RBG}$ ) for a downlink BWP may present. A DCI field size of a frequency domain resource allocation based on the resource allocation type 0 would be  $\text{ceil}(N_{RBG} + (N_{start\_BWP} \text{ mode } P))/P$  where a size of a first RBG is  $P - N_{start\_BWP} \text{ mode } P$ , a size of a last RBG is  $(N_{start\_BWP} + \text{bandwidth}) \text{ mode } P$  wherein is  $(N_{start\_BWP} + \text{bandwidth}) \text{ mode } P$  is greater than zero, a size of other RBGs are  $P$ , and  $P$  is the rbg-Size. The bitmap of  $N_{RBG}$  bits with one bitmap bit per a corresponding RBG, such that the corresponding RBG may be scheduled. The one or more RBGs may be indexed in an order of increasing frequency, and indexing may start from a lowest frequency of the active BWP. The order of the bitmap may

be determined such that RBG #0 to RBG # N\_RBGS-1 may be mapped to most significant bit to least significant bit of the bitmap. The wireless device may assume an RBG is allocated in response to a corresponding bit of the bitmap being allocated/assigned as 1. The wireless device may assume a second RBG is not allocated in response to a corresponding bit of the bitmap being allocated/assigned as 0.

When a virtual RB to a physical RB mapping is enabled, the wireless device may determine one or more physical RBGs based on the indicated bitmap for the virtual RBGs. Otherwise, the indicated bitmap may determine the one or more physical RBGs.

For example, a resource allocation type 1, a frequency domain resource allocation may indicate a set of contiguously allocated non-interleaved or interleaved virtual resource blocks within an active bandwidth part of a scheduled cell. For example, a DCI may be scheduled via a USS. The frequency domain resource allocation field based on the resource allocation type 1 may use a resource allocation value (RIV). The RIV may indicate a starting virtual RB (RB\_start) and a length in terms of contiguously allocated virtual RBs (L\_rbs). The RIV value may be determined as the RIV=bandwidth (L\_rbs-1)+RB\_start when (L\_rbs-1) is smaller than or equal to floor (bandwidth/2), or the RIV=bandwidth (bandwidth-L\_rbs+1)+(bandwidth-1-RB\_start) otherwise. The bandwidth may represent a bandwidth of the active BWP.

A base station may enable a PRB bundling. A wireless device may assume a same precoding over a number RBs of the PRB bundle (e.g., two PRBs, four PRBs or the bandwidth). The base station may schedule the PRB bundle or not, and may not schedule partial PRB bundle to the wireless device.

Similar to downlink, for an uplink transmission, a few resource allocation types are supported. For the uplink transmission, a resource allocation type 0, resource allocation type 1 or resource allocation type 2 may be supported. The resource allocation type 0 may be used in response to a transform precoding being disabled. The resource allocation type 1 or the resource allocation type 2 may be used in response to the transform precoding being enabled or being disabled. For the uplink transmission, a ‘dynamicswitch’ may be configured. In response to the ‘dynamicswitch’, the wireless device may switch between the resource allocation type 0 and the resource allocation type 1 based on a DCI. The base station may configure a resource allocation type via an RRC signaling in response to the ‘dynamicswitch’ being not configured/enabled. The resource allocation type 2 may be used in response to an interlaced PUSCH being enabled. The wireless device may apply the resource allocation type 1 for a DCI based on a fallback DCI format such as a DCI format 0\_0. The interlaced PUSCH is disabled for the fallback DCI format. When the interlaced PUSCH is enabled, the wireless device may apply the resource allocation type 2 for the DCI. The wireless device may determine a frequency domain resource based on a frequency domain resource allocation field of a DCI based on an active uplink BWP of a scheduled cell. The DCI may not comprise a BWP index. The wireless device may determine the frequency domain resource based on an indicated BWP by a BWP index when the DCI comprises the BWP index.

In an example, a resource allocation type 0 for an uplink transmission may use a bitmap indicating one or more RBGs within an active UL BWP of a scheduled cell. One RBG may represent a set of consecutive virtual resource blocks defined by a rbg-Size. The rbg-Size may be indicated as a parameter

of a PUSCH-Config under a servingCellConfig. For example, the rbg-Size may be determined based on a parameter of ‘Configuration 1’ or ‘Configuration 2’ and a bandwidth of an active UL BWP of a scheduled cell. For example, when the bandwidth of the active UL BWP is between 1 to 36 RBs, ‘Configuration 1’ indicates the rbg-Size of 2 and ‘Configuration 2’ indicates the rbg-Size of 4. For example, when the bandwidth of the active UL BWP is between 37 to 72 RBs, ‘Configuration 1’ indicates the rbg-Size of 4 and ‘Configuration 2’ indicates the rbg-Size of 8. For example, when the bandwidth of the active UL BWP is between 73 to 144 RBs, ‘Configuration 1’ indicates the rbg-Size of 8 and ‘Configuration 2’ indicates the rbg-Size of 16. For example, when the bandwidth of the active UL BWP is between 145 to 275 (or 550) RBs, ‘Configuration 1’ indicates the rbg-Size of 16 and ‘Configuration 2’ indicates the rbg-Size of 16. A number of RBGs (N\_RBGS) for an uplink BWP may present. Determination of a bit of the bitmap of the uplink resource allocation type 1 is same as that of the downlink resource allocation type 1. In frequency range 1 (e.g., below 7 GHz), almost contiguous allocation may be supported. In frequency range 2 (e.g., above 7 GHz and below 52.6 GHz), contiguous resource allocation may be supported.

The resource allocation type 0 for an uplink transmission may follow similar procedure to the resource allocation type 0 for a downlink transmission.

The resource allocation type 2 may be used to indicate an interlaced resource allocation, wherein M is a number of interlaces. For example, a frequency domain resource allocation field may comprise a RIV. For the RIV between 0 and M (M+1)/2 (e.g., 0<=RIV<M(M+1)/2), the RIV may indicate a starting interlace index m\_0 and a number of contiguous interlace indices L (L>=1). For example, when (L-1)<=floor (M/2), the RIV may define M (L-1)+m\_0. Otherwise, the RIV may define M (M-L+1)+(M-1-m\_0). For the RIV larger than or equal to M(M+1)/2 (e.g., RIV>=M(M+1)/2), the RIV may indicate a starting interlace index m\_0 and a set of values 1 based on one or more set of values. For example, an entry may represent {RIV-M(M+1)/2, m\_0, 1}. For example, the one or more set of values may comprise {0, 0, {0, 5}}, {1, 0, {0, 1, 5, 6}}, {2, 1, {0, 5}}, {3, 1, {0, 1, 3, 5, 6, 7, 8}}, {4, 2, {0, 5}}, {5, 2, {0, 2, 5, 6, 7}}, {6, 3, {0, 5}}, and/or {7, 4, {0, 5}}.

Resource allocation type and mechanism based on a DCI may be also applied to a configured grant configuration or semi-persistent scheduling configuration.

In an example, a base station may transmit a DCI. The DCI may comprise a time domain resource allocation field. A value of the time domain resource allocation field (e.g., m) may indicate a row index m+1 of a time domain resource allocation lists/a time domain resource allocation table. The base station may transmit configuration parameters indicating one or more time domain resource allocation tables. For example, a first time domain resource allocation table may be used for a fallback DCI format scheduled via a CSS. For example, a second time domain resource allocation table may be used for a fallback DCI format and/or a non-fallback DCI format via a USS. The wireless device may determine a time domain resource allocation table from the one or more time domain resource allocation tables for the DCI in response to receiving the DCI. The configuration parameters may comprise one or more time domain resource allocation entries for a time domain resource allocation table. One time domain resource allocation entry may comprise a starting and a length indicator value (SLIV), a PUSCH mapping type, and K2 value. The K2 may represent a scheduling

offset between a scheduling DCI of a PUSCH and a starting slot index of the PUSCH. The one time domain resource allocation (TDRA) entry may comprise a repetition number (numberOfRepetitions). The one TDRA entry may comprise a starting symbol (startSymbol) and a length addition to the SLIV. For a PUSCH, scheduled by a non-fallback DCI format such as DCI format 0\_1, a base station may transmit, to a wireless device, configuration parameters indicating PUSCHRepTypeIndicator-ForDCIFormat0\_1 to ‘puschRepTypeB’ indicating a repetition type B. In response to being configured with ‘puschRepTypeB’, the wireless device may determine a resource based on a procedure for the repetition type B and a time domain resource allocation field of a DCI based on the DCI format 0\_1. Similarly, the configuration parameters may comprise PUSCHRepTypeIndicator-ForDCIFormat0\_2 to ‘puschRepTypeB’ to apply the repetition type B for a second DCI based on a DCI format 0\_2. When the base station may not configure PUSCHRepTypeIndicator-ForDCIFormat0\_1 indicating ‘puschRepTypeB’, the wireless device may determine a time domain resource based on a DCI based on a repetition type A.

For example, when the repetition type A is configured/ enabled, the wireless device may determine a starting symbol S in a starting slot and a number of consecutive symbols L from the starting symbol S based on a SLIV value. For example, the SLIV value may define  $SLIV=14*(L-1)+S$  when  $(L-1)$  is smaller than or equal to 7 (half slot based on a normal CP). The SLF value may define  $SLIV=14*(14-L+1)+(14-1-S)$  when  $(L-1)$  is larger than 7. For example, L would be greater than 0, and may be smaller than or equal to 14-S. In an uplink BWP with an extended CP, 12 OFDM symbols may be assumed for a slot. A SLIV value may be determined by  $12*(L-1)+S$  or  $12*(12-L+1)+(14-1-S)$  respectively based on  $L-1$  being smaller than/equal to 6 or larger than 6. For the repetition type A, the configuration parameters may comprise/indicate a TypeA or Type B for a PUSCH mapping type. For example, the base station may determine a first OFDM symbol comprising a DM-RS based on a fixed location (e.g., a first symbol of a slot) when the TypeA is configured for the PUSCH mapping type. For example, the base station may determine a first OFDM symbol comprising a DM-RS based on a starting OFDM symbol of the PUSCH in response to the typeB being configured for the PUSCH mapping type.

For example, when the repetition type B is configured/ enabled, the wireless device may determine a starting OFDM symbol S in a starting slot, and a number of consecutive OFDM symbols L based on a row of a time domain resource allocation table. For example, the row of the time domain resource allocation table may comprise startSymbol for the starting OFDM symbol S and length for the number of consecutive OFDM symbols L. For the repetition type B, the wireless device may assume that the TypeB is configured for the PUSCH mapping type. For example, when a TypeA is configured for a PUSCH mapping type, a starting OFDM symbol S, a length L, and S+L may represent one or more values. For example, {S, L, S+L} may be {0, {4, . . . , 14}, {4, . . . , 14}} for a normal CP, and {0, {4, . . . , 12}, {4, . . . , 12}} for an extended CP. When a TypeB is configured for the PUSCH mapping type, {S, L, S+L} may be {{0, . . . , 13}, {1, . . . , 14}, {1, . . . , 14}} for a repetition type A, {1, . . . , 27} for a repetition type B for the normal CP, and {{0, . . . , 11}, {1, . . . , 12}, {1, . . . , 12}} for the extended CP.

For a repetition type A, a wireless device may determine a repetition number K based on a row of a time domain

resource allocation table. The row may comprise a number of repetitions. The wireless device may determine based on an RRC parameter, ‘puschAggregationFactor’ when the row may not comprise the number of repetitions. The wireless device may determine a single transmission based on the row may not comprise the number of repetitions nor the ‘puschAggregationFactor’ is not configured. The wireless device may determine the single transmission for a PUSCH scheduled by a fallback DCI such as a DCI format 0\_0.

For a repetition type A with a repetition number K being larger than 1, a wireless device may apply a starting OFDM symbol S and a length L in a slot across K consecutive slots based on a single transmission layer. The wireless device may repeat a TB across the K consecutive slots applying same OFDM symbols in each slot. A redundancy version (RV) applied on a i-th transmission of the K consecutive slots may be determined based on a repetition type. For example, when a RV value indicated by a DCI is 0, a second RV value for i-th transmission occasion (when a repetition type A is configured) or i-th actual repetition (when a repetition type B is configured) may be determined as 0 for  $i \bmod 4=0, 2$  for  $i \bmod 4=1, 3$  for  $i \bmod 4=2, 4$  for  $i \bmod 4=3$ . When the RV value is 2, the second RV value may be determined as 2 for  $i \bmod 4=0, 3$  for  $i \bmod 4=1, 1$  for  $i \bmod 4=2, 0$  for  $i \bmod 4=3$ . When the RV value is 3, the second RV value may be determined as 3 for  $i \bmod 4=0, 1$  for  $i \bmod 4=1, 0$  for  $i \bmod 4=2, 0$  for  $i \bmod 4=3$ . When the RV value is 1, the second RV value may be determined as 1 for  $i \bmod 4=0, 0$  for  $i \bmod 4=1, 2$  for  $i \bmod 4=2, 3$  for  $i \bmod 4=3$ .

For a repetition type A, a PUSCH transmission of a slot over a plurality of slots may be omitted when the slot may not have a sufficient number of uplink OFDM symbols for the PUSCH transmission. For a repetition type B, a wireless device may determine one or more slots for a number of nominal repetition number N. For a i-th nominal repetition, wherein i is 0, . . . , N-1, wherein N may be configured by a base station via an RRC signaling or a time domain resource allocation of a DCI. The wireless device may determine a slot. The i-th nominal repetition may start, wherein a slot index would be  $K_s + \text{floor}((S+iL)/N_{\text{slot\_symbol}})$ , and a starting symbol in the slot may be given by  $\text{mod}(S+iL, N_{\text{slot\_symbol}})$ . The  $N_{\text{slot\_symbol}}$  may be 14 with a normal CP and 12 with an extended CP. The S may represent a starting OFDM symbol indicated by a time domain resource allocation field of a DCI and L may represent a length indicated by the time domain resource allocation field of the DCI. The wireless device may determine a second slot wherein the i-th nominal repetition may end wherein a second slot index of the second slot may be determined as  $K_s + \text{floor}((S+(i+1)*L-1)/N_{\text{slot\_symbol}})$ , and an ending symbol in the second slot may be determined as  $\text{mod}(S+(i+1)*L-1, N_{\text{slot\_symbol}})$ . The  $K_s$  may be determined as a starting slot indicated by the time domain resource allocation field of the DCI.

When the wireless device is configured with the repetition type B, the wireless device may determine invalid OFDM symbol for PUSCH repetitions based on a tdd-UL-DL-ConfigurationCommon/a tdd-UL-DL-ConfigurationDedicated and/or an InvalidSymbolPattern indicated by an RRC signaling. For example, the wireless device may determine a downlink symbol based on the tdd-UL-DL-ConfigurationCommon or the tdd-UL-DL-ConfigurationDedicated as an invalid OFDM symbol for the repetition type B. The base station may transmit the InvalidSymbolPattern, a bitmap of OFDM symbols over one slot or two slots. A bit of the bitmap may indicate ‘1’ to invalidate a corresponding

OFDM symbol. The base station may further configure periodicityAndPattern. A bit of the periodicityAndPattern may correspond to a unit equal to a duration of the bitmap of the InvalidSymbolPattern. The wireless device may determine invalid OFDM symbol(s) based on the InvalidSymbolPattern and the periodicityAndPattern. For example, when a PUSCH is scheduled/activated by a non-fallback DCI format such as a DCI format 0\_1/0\_2 and InvalidSymbolPatternIndicator-ForDCIFormat0\_1/0\_2 is configured, a invalid symbol pattern indicator field may indicate 1, the wireless device may apply an invalid symbol pattern (e.g., InvalidSymbolPattern). Otherwise, the wireless device may not apply the invalid symbol pattern. When the InvalidSymbolPatternIndicator-ForDCIFormat0\_1/0\_2 is not configured, the wireless device may not apply the invalid symbol pattern. The wireless device may determine remaining OFDM symbols. The remaining OFDM symbols may not comprise invalid OFDM symbol(s), the wireless device may consider the remaining OFDM symbols as valid OFDM symbols. When there is a sufficient number of valid OFDM symbols in a slot to transmit a PUSCH based on a scheduling DCI, the wireless device may determine an actual repetition of a slot wherein the slot may have consecutive sufficient valid consecutive OFDM symbols. The wireless device may skip the actual repetition based on a slot formation indication. The wireless device may apply a redundancy version based on the actual repetition.

In an example, a row of a time domain resource allocation may comprise one or more resource assignments for one or more contiguous PUSCHs. A K2 of the row may indicate a first PSCH of the one or more contiguous PUSCHs. Each PUSCH of the one or more contiguous PUSCHs may be indicated/scheduled with a separate SLIV value and a PUSCH mapping type.

A similar mechanism may be used to schedule a time domain resource for a downlink data.

FIG. 23 illustrates a time domain resource allocation mechanism for downlink data as per an aspect of an embodiment of the present disclosure. A base station may transmit one or more RRC messages comprising/indicating configuration parameters. The configuration parameters may comprise/indicate a list of time domain resource allocation or a time domain resource allocation (TDRA) table. The list of TDRA or the TDRA table may comprise one or more entries/rows of TDRA. Each entry/row TDRA of the list of TDRA or the TDRA table comprises a slot offset (e.g., a scheduling offset, K0, k0) and one or more SLIV values (e.g., indicating a starting symbol and a length). The each entry/row may comprise additionally/optionally a PDSCH mapping type (e.g., type A or type B).

A SLIV value may be jointly encoded a starting symbol and a length. For example, a SLIV value m may represent a starting symbol index s and a length l. The wireless device may determine the SLIV value m, with a normal CP, as  $m=14*(l-1)+s$  when l is smaller than 9, and  $m=14*(14-l)+(14-1-s)$  when l is between [9, 14]. Instead of 14, 12 may be used in case of extended CP.

A reserved SLIV value (e.g., 0) may be reserved to indicate no resource allocation in a slot. For example, FIG. 23 show an index 2 of a TDRA entry comprises a SLIV #2 being set with the reserved SLIV value (e.g., length is zero or one). The wireless device may not expect any resource or schedule in the slot n+5 when the DCI indicates the index 2 via a time domain resource allocation.

Each TDRA entry may have one or more SLIV values, where each SLIV value may correspond to a slot. Each TDRA may have one or more SLIV values, where each

SLIV value may correspond to a valid slot. For example, a valid slot may be determined as a slot comprising at least C (e.g., C=2 or 3) valid symbols. Valid symbols may comprise downlink or flexible symbol for downlink TDRA table. 5 Valid symbols may comprise uplink or flexible symbol for uplink TDRA table.

A first TDRA entry may have a first number of SLIV values, scheduling up to the first number of PDSCHs. A DCI, indicating the first TDRA entry, may schedule up to the 10 first number of PDSCH(s).

A second TDRA entry may have a second number of SLIV values, scheduling up to the second number of PDSCHs. A DCI, indicating the second TDRA entry, may schedule up to the 15 second number of PDSCH(s). The first number may be different from the second number.

A TDRA entry may have a K SLIV values, where each SLIV value of K SLIV values may be set to the reserved SLIV value or may be set to a valid (s, l). A wireless device 20 may determine no scheduling in a slot configured/indicated with the reserved SLIV value.

For example, FIG. 23 shows that a TDRA entry with index 0, does not schedule a PDSCH in a slot n-K, when the DCI indicates the index 0 for the TDRA resource allocation. For example, the TDRA entry with index 0 may not have a 25 SLIV entry corresponding to the slot n+K.

For example, FIG. 23 shows that a TDRA entry with index 2, does not schedule a PDSCH in slots between [n+9, . . . , n+8+K], when the DCI indicates the index 2 for the TDRA resource allocation. For example, the TDRA entry with index 2 may have a single SLIV value corresponding to a first PDSCH/slot.

In an example, a TDRA entry may comprise a set of {a SLIV value, a mapping type, a number of repetition} and a scheduling/slot offset (e.g., k0, k2) for one or more PDSCHs 35 or one or more PUSCHs.

In an example, a TDRA entry may comprise a set of {a SLIV value, a mapping type, a k0 or k2 scheduling/slot offset} for one or more PDSCHs or one or more PUSCHs.

In an example, a TDRA entry may comprise a set of {a 40 SLIV value} and a scheduling/slot offset (e.g., k0, k2).

For example, each row may have an index that may be determined based on an order of the each row. For example, the index may be configured via the configuration parameters.

Based on the configuration parameters, the wireless device may determine a time domain resource allocation table shown in FIG. 23. For example, the time domain resource allocation (TDRA) table has a list of entries. Each entry comprises an index (e.g., an index of the entry, an index of a row of the entry in the time domain resource allocation table), a scheduling offset (or a slot offset, K0, k0), one or more SLIV (e.g., a starting symbol and a length) values (and a mapping type (e.g., PDSCH Mapping Type)). The wireless device may receive the DCI, scheduling one or 50 more PDSCHs, in a slot n. The DCI may indicate an index=1 for the TDRA table. The wireless device may determine a scheduling offset value 4. The wireless device may determine a first slot of first PDSCH in a slot n+4 based on the scheduling offset. The wireless device may determine, for the first PDSCH, a starting symbol of 6 and a length of 5 based on an index=1 of the TDRA table. The wireless device may decode a transport block carried via the first PDSCH based on the receiving the first PDSCH.

The wireless device may determine resource for a second 60 PDSCH of the one or more PDSCHs (e.g., based on SLIV #2), where starting symbol is 1 and length is 14 for the second PDSCH.

The wireless device may determine resource for K-th PDSCH of the one or more PDSCHs (e.g., based on SLIV #K), where starting symbol is 4 and length is 10 for the K-th PDSCH.

In an example, a TDRA table (e.g., PUSCH-TimeDomainResourceAllocationList, PDSCH-TimeDomainResourceAllocationList) may comprise one or more entries of TDRA. Each TDRA entry may comprise a scheduling offset (e.g., k<sub>2</sub>-r<sub>17</sub> for PUSCH, k<sub>0</sub>-r<sub>17</sub> for PDSCH) and one or more indexes to the list of SLIV values. Each of the one or more indexes may correspond to each PDSCH of one or more PDSCHs scheduled by a DCI or each PSCH of one or more PUSCHs scheduled by a DCI.

For example, a first entry (e.g., PUSCH-SLIVList[0], PDSCH-SLIVList[0]) of the list of SLIV values may be reserved for a skipping (e.g., a duration is 0 or a starting symbol is a last symbol of a slot).

In an example, the subset of SLIV values may comprise a reserved state or a duration of zero. For example, a first SLIV value of the subset of SLIV values (e.g., a SLIV value with index=0 or index=1) may be reserved for indicating zero duration or no resource allocation. When the reserved state or the first SLIV value is indicated by a DCI for a PDSCH or a slot n, the wireless device may determine that resource is not allocated for the PDSCH or the slot n. The wireless device may determine to skip the PDSCH or the slot.

For example, a DCI, of a multi-PDSCH scheduling, may comprise K indexes of SLIV values for K PDSCHs or K slots. When i-th index of the K indexes indicates the reserved state or the first SLIV value with duration 0, the wireless device may determine that i-th PDSCH is skipped or i-th slot (a slot with index n+i, where the first slot has a slot index n) is skipped.

The wireless device may determine that one or more slots or one or more PDSCHs are skipped for a multi-PDSCH scheduling based on one or more SLIV values corresponding to the one or more slots or the one or more PDSCHs. The wireless device may determine that a PDSCH or a slot is skipped in response to a SLIV value, corresponding to the PDSCH or the slot, being set to a reserved value (e.g., a duration is zero, a stating symbol is a last symbol) or an index of the SLIV value being a predetermined value (e.g., 0 or 1).

In an example, a DCI, of a multi-PDSCH or a multi-PUSCH scheduling, may comprise one or more NDI bits/fields, where each of the one or more NDI bits/fields corresponds to each PDSCH of one or more PDSCHs scheduled by the DCI or each PUSCH of one or more PUSCHs scheduled by the DCI. The DCI may also comprise one or more RV fields/bits, where each of the one or more RV bits/fields corresponds to the each PDSCH or the each PUSCH.

The wireless device may determine whether a PDSCH of the one or more PDSCHs or a PUSCH of the one or more PUSCHs is scheduled or is skipped in a slot based on a NDI bit/field of the one or more NDI bits/fields and a RV bit/field of the one or more RV bits/fields. For example, the NDI bit/field corresponds to the PDSCH or the PUSCH. The RV bit/field corresponds to the PDSCH or the PUSCH. For example, when the NDI bit/field is set to a first predetermined value and the RV bit/field is set to a second predetermined value, the wireless device may determine that the PDSCH or the PUSCH is skipped. For example, when the NDI bit/field is toggled (e.g., indicates a new data) and the RV bit/field is set to a second predetermined value, the wireless device may determine that the PDSCH or the

PUSCH is skipped. For example, the first predetermined value may be 0 (or 1). For example, the second predetermined value may be RV=2 (or RV=3 or RV=1).

The wireless device may determine whether a PDSCH or a PUSCH is skipped or not based on a first field and a second field. A DCI, of a multi-PDSCH or a multi-PUSCH scheduling, may comprise the first field and the second field. The first field and the second field may correspond to the PDSCH or the PUSCH.

10 The wireless device may determine that the PDSCH or the PUSCH is skipped in response to the first field being set to a first predetermined value (or toggled or non-toggled) and the second field being set to a second predetermined value (or toggled or non-toggled). Examples of the first field may comprise at least one of a NDI field, a RV field, a MCS field, a HARQ process ID field, a TPC field. Examples of the second field may comprise at least one of a NDI field, a RV field, a MCS field, a HARQ process ID field, a TPC field. The first field and the second field may be different.

15 In an example, a DCI, of a multi-PDSCH or a multi-PUSCH scheduling, may comprise a HARQ process identifier (a HARQ ID). The DCI may comprise resources for one or more PDSCHs via one or more slots. The DCI may comprise resources for one or more PUSCHs via one or more second slots.

20 The wireless device may determine a HARQ process ID of a PDSCH of the one or more PDSCHs based on the HARQ ID and a gap between a second slot and a first slot. For example, the first slot is a slot where an earliest PDSCH 30 of the one or more PDSCHs start. For example, the wireless device may determine the first slot based on a scheduling offset indicated by the DCI. The second slot is a slot where the PDSCH of the one or more PDSCHs is scheduled or mapped or determined.

25 The wireless device may determine, the DCI schedules K slots/PDSCHs with k<sub>0</sub>=p. The wireless device may determine an earliest slot (the first slot) as n+p where the wireless device receives the DCI in the slot n. The DCI indicates HARQ ID=Q. The wireless device may determine a HARQ process ID of a first 40 PDSCH (e.g., an earliest PDSCH) of the one or more PDSCHs as Q. The wireless device may determine a HARQ process ID of a second PDSCH or a next slot (e.g., n+p+1) as a Q+1. The wireless device may determine a HARQ process ID of a i-th PDCCH or a i-th next slot (e.g., n+p+i) as a Q+i.

35 The wireless device may increment a HARQ process ID by 1 in every slot between an earliest slot and a latest slot of the one or more slots scheduled by the DCI.

40 The wireless device may determine one or more second PDSCHs of the one or more PDSCHs being skipped based on one or more rules in the specification. The wireless device may continue incrementing HARQ process IDs across the one or more second PDSCHs regardless the one or more second PDSCHs being skipped.

45 The wireless device may continue incrementing HARQ process ID based on a slot index or over contiguous slots starting from a first slot (or an earliest slot) determined based on a time domain resource allocation field of a DCI, regardless of whether the wireless device may not have any data scheduled in one or more slots of the contiguous slots.

50 For example, the wireless device may not continue incrementing HARQ process IDs over slot(s) that are configured as uplink slots or the wireless device may not expect to receive any downlink data via the slot(s) as resources are indicated as uplink.

55 For example, the wireless device may increment a HARQ process ID in a slot that is skipped based on the one or more

rules in the specification. The wireless device may not increment the HARQ process ID in the slot if the slot is skipped due to slot formation information or due to resource conflict (e.g., uplink resource for the downlink data).

In an example, the wireless device may increment the HARQ process ID in the slot even if the slot is skipped due to the resource conflict.

In an example, the wireless device may increment a HARQ process ID per each PDSCH, where example embodiments based on a slot may be applied to a PDSCH of one or more PDSCHs scheduled by the DCI.

In an example, a wireless device may be, via RRC signaling, configured with a first cell group comprising one or more serving cells. The wireless device may be, via RRC signaling, configured with a second cell group comprising one or more second serving cells. The wireless device may perform a hybrid automatic repeat request (HARQ) feedback procedure for the first cell group independently from a second HARQ feedback procedure for the second cell group. A cell group may be a master cell group or a secondary cell group. A cell group may be a first PUCCH cell group comprising a primary cell. A cell group may be a second PUCCH cell group not comprising the primary cell. A cell group may comprise one or more serving cells among a plurality of serving cells configured to the wireless device. A cell group may also represent one or more serving cells associated with a first service or a first link (e.g., sidelink, multicast, broadcast, MBSM, D2D, V2X, V2P, V2I, V2N, and/or the like).

A cell group may represent one or more second serving cells associated with a second service or a second link (e.g., downlink/uplink, cellular communication, location service, and/or the like). The wireless device may be configured with, via RRC signaling, a first set of PUCCH resources for the first cell group. The wireless device may be configured with, via RRC signaling, a second set of PUCCH resources for the second cell group. The wireless device may determine a first PUCCH for the first cell group based on the HARQ feedback procedure. The wireless device may determine a second PUCCH for the second cell group based on the second HARQ feedback procedure. For example, the first PUCCH and the second PUCCH may overlap in time and/or frequency domain. The wireless device may determine the first PUCCH or the second PUCCH based on a priority of the first PUCCH and a second priority of the second PUCCH. For example, the wireless device may determine the first PUCCH or the second PUCCH based on a priority of the first PUCCH and a threshold for the first PUCCH. A base station may configure the threshold for the first cell group via RRC signaling.

In an example, a wireless device may be provided with a coresset pool index for one or more coresets of an active bandwidth part of a serving cell. The wireless device may determine a coresset pool index of a coresset as zero in response to the coresset pool index has not been provided for the coresset. The coresset pool index may be zero or one. The base station may transmit one or more RRC messages indicating configuration parameters. The configuration parameters may indicate/comprise a ACKNACKFeedbackMode between SeparateFeedback or JointFeedback. For example, when ACKNACKFeedbackMode is indicated as SeparateFeedback, the wireless device may determine first HARQ feedback bits corresponding to a first coresset pool index (or coressets of the first coresset pool index). The wireless device may determine second HARQ feedback bits, independently from the first HARQ feedback bits, corresponding to a second coresset pool index (or coressets of the

second coresset pool index). When ACKNACKFeedbackMode is indicated as JointFeedback, the wireless device may generate/determine HARQ feedback bits for both coreset pool indexes jointly. When ACKNACKFeedbackMode is indicated as SeparateFeedback, the wireless device may perform a first HARQ feedback process for the first coresset pool independently from a second HARQ feedback process for the second coresset pool.

In an example, a wireless device may determine a priority index of a PUSCH or a PUCCH transmission. For example, the wireless device may determine the priority index of the PUSCH based on a DCI scheduling uplink resource(s) for the PUSCH. The DCI may comprise or indicate the priority index. In response to the DCI does not comprise a priority index field, the wireless device may determine the priority index of the PUSCH is zero (0). The wireless device may determine a priority index of a PUCCH transmission based on one or more priorities of corresponding PDSCH(s) and/or SPS PDSCH(s) or SPS PDSCH release(s) that the PUCCH transmission carries HARQ feedback bits for the corresponding PDSCH(s) and/or SPS PDSCH(s) or SPS PDSCH release(s). In an example, the base station may transmit one or more RRC messages comprising configuration parameters. The configuration parameters may indicate a harq-CodebookID for a SPS configuration, wherein the harq-CodebookID may be used to determine a priority value of a SPS PDSCH or a SPS PDSCH release based on the SPS configuration. The wireless device may receive a second DCI scheduling a PDSCH of the corresponding PDSCH(s). The wireless device may determine a priority of the PDSCH based on the second DCI. For example, the second DCI may comprise/indicate a priority index field indicating the priority. For example, the wireless device may determine the priority as zero (0) in response to the second DCI does not comprise/indicate the priority for the PDSCH.

In an example, a base station may schedule a PUSCH with a first priority that may be used to piggyback/carry HARQ feedback bits with a second priority. The first priority and the second priority may be different or same. The wireless device may determine a prioritization of an overlapping PUSCH with a first priority and a PUCCH with a second priority based on a rule. For example, the rule is that the wireless device may determine or resolve conflict/overlapping between one or more PUCCHs and one or more PUSCHs with a same priority. For example, based on the determining the conflict/overlapping, the wireless device may have a first PUCCH with a high priority (e.g., larger priority index) and either a PUSCH or a second PUCCH with a low priority (e.g., lower priority index) where the first PUCCH overlaps with either the PUSCH or the second PUCCH.

The wireless device may determine to transmit the first PUCCH and may cancel either the PUSCH or the second PUCCH before a first symbol overlapping with the first PUCCH transmission. The wireless device may expect that a transmission of the first PUCCH may not start before Tproc+d1 after a last symbol of a first PDCCH reception. The first PDCCH is a DCI scheduling the first PUCCH. For example, Tproc is a processing delay and d1 is a processing offset. For example, based on the determining the conflict/overlapping, the wireless device may have a PUSCH with a larger priority index scheduled by a first DCI format via a first PDCCH repetition and a PUCCH of a smaller priority index.

The wireless device may determine to transmit the PUSCH and may cancel the PUCCH. The PUSCH and the PUCCH may overlap in time. The wireless device may

cancel a transmission of the PUCCH before a first symbol overlapping with a transmission of the PUSCH. The wireless device may expect that the transmission of the PUSCH may not start before  $T_{proc}+d_1$  after a last symbol of the first PDCCH reception. For example,  $d_1$  may be determined based on a UE capability.

When a wireless device may detect a first DCI format (or a first DCI) scheduling a PUCCH with a larger priority index or a PUSCH transmission with a larger priority index that may overlap with a second PUCCH with a smaller priority index or a second PUSCH with a smaller priority index, the wireless device may not expect to receive a second DCI format (or a second DCI), after receiving the first DCI format (or the first DCI), scheduling resource(s) mapped to/fully overlapped to the second PUSCH or the second PUCCH. The base station may not reschedule or reclaim the resource(s) of the second PUSCH or the second PUCCH that are cancelled by a prioritization.

In an example, a wireless device may receive a first DCI format (or a first DCI) in a first PDCCH reception scheduling a first PUCCH or a first PUSCH with a higher priority index. The wireless device may receive a second DCI format (or a second DCI) in a second PDCCH reception scheduling a second PUCCH or a second PUSCH with a smaller priority index. The first PUCCH or the first PUSCH may overlap with the second PUCCH or the second PUSCH. The wireless device may determine  $T_{proc}$  based on a numerology of a smaller subcarrier spacing between a first numerology of the first PDCCH and a second numerology of the second PDCCH and a third numerology of the first PUCCH or the first PUSCH and a fourth numerology of the second PUCCH or the second PUSCH.

In an example, a base station may not schedule a first PUCCH or a first PUSCH with a smaller priority index that may overlap with a second PUCCH with a larger priority index with a HARQ feedback bits corresponding to a SPS PDSCH reception only. The base station may not schedule a first PUCCH with a smaller priority index that may overlap in time with a PUSCH with a larger priority index and comprises SP-CSI report(s) without a corresponding scheduling DCI/PDCCH.

In an example, when a wireless device multiplex UCI(s) with a first priority to a PUCCH or a PUSCH, the wireless device may assume that a priority of the PUCCH or the PUSCH may have a same priority to the first priority. A base station may schedule to multiplex the UCI(s) with the first priority to the PUCCH or the PUSCH with the same priority (e.g., the first priority). In an example, when a wireless device may be scheduled with a PUSCH without UL-SCH (e.g., data) and the PUSCH may overlap with a PUCCH comprising a positive SR, the wireless device may drop/cancel a transmission of the PUSCH.

In an example, a wireless device may multiplex HARQ feedback bits in a PUSCH transmission via a configured grant resource that comprises a CG-UCI based on a cg-CG-UCI-Multiplexing configuration parameter. For example, the wireless device may multiple the HARQ feedback bits to the PUSCH with the CG-UCI when the cg-CG-UCI-Multiplexing is provided or indicated or enabled. Otherwise, the wireless device may not multiplex. The wireless device may multiplex the HARQ feedback bits to another transmission of a second PUSCH or a PUCCH.

In an example, a base station may transmit one or more RRC messages comprising configuration parameters. The configuration parameters may comprise/indicate pdsch-HARQ-ACK-Codebook-List. The pdsch-HARQ-ACK-Codebook-List may indicate whether the wireless device

needs to generate one HARQ codebook or two HARQ codebook. When the wireless device generates one HARQ codebook, the wireless device may multiplex in a single HARQ codebook of HARQ feedback bits associated with a same priority index. When the wireless device generates two HARQ codebooks, the wireless device may generate a first HARQ codebook for a PUCCH of a first priority index (e.g., priority index 0). The wireless device may generate a second HARQ codebook for a second PUCCH of a second priority index (e.g., priority index 1). For each HARQ codebook, the configuration parameters may indicate PUCCH-Config, UCI-OnPUSCH, and/or PDSCH-codeBlockGroupTransmission.

In an example, a wireless device may generate a positive acknowledgement (ACK) when the wireless device detects a DCI format that may schedule a transport block or indicates a SPS release and the wireless device detects the transport block or the SPS release successfully. Otherwise, the wireless device may generate a negative acknowledgement (NACK). For example, a value 0 may indicate an ACK. A value 1 may indicate an NACK.

In an example, the configuration parameters may indicate PDSCH-CodeBlockGroupTransmission for a serving cell to enable a code block group (CBG) based HARQ feedback. The wireless device may generate N bits of HARQ feedback bits for a transport block when the CBG based HARQ feedback is enabled. For example, N is a number of HARQ feedback bits (e.g., number of CBGs) for a transport block. The wireless device may determine M number of code blocks per each CBG based on a total number of code blocks of the transport block. The wireless device may generate an ACK for a CBG in response to the wireless device correctly receive all code blocks of the CBG. Otherwise, the wireless device may generate an NACK for the CBG. When a wireless device receives two transport blocks by a DCI or a DCI format, the wireless device may generate one or more HARQ feedback bits for a first transport block of the two transport blocks first and then generate one or more second HARQ feedback bits for a second transport block of the two transport blocks. In general, the wireless device may generate HARQ feedback bits for one or more CBGs of a transport block first and then generate next HARQ feedback bits for one or more next transport block and so on.

In an example, a base station may transmit one or more RRC messages comprising/indicating configuration parameters. The configuration parameters may indicate a semi-static HARQ feedback mode (e.g., pdsch-HARQ-ACK-Codebook=semi-static) or a dynamic HARQ feedback mode (e.g., pdsch-HARQ-ACK-Codebook=dynamic).

In an example, a wireless device may be configured with dynamic HARQ feedback mode or HARQ-ACK codebook determination. Based on the dynamic HARQ feedback mode, the wireless device may multiplex of one or more HARQ-ACK feedback bits based on a PDSCH scheduled by a DCI format that does not include/comprise a counter DAI field. In an example, a wireless device may determine monitoring occasions for receiving DCI(s) of PDCCH(s) with one or more DCI formats scheduling PDSCH or SPS PDSCH release via an active downlink BWP of a serving cell. The wireless device may determine one or more HARQ-ACK/HARQ feedback bits in a same PUCCH in a slot n based on (1) a value of a PDSCH-to-HARQ feedback timing indicator field of a DCI format scheduling a PDSCH reception or a SPS PDSCH release; and (2) a slot offsets or timing offsets between a PDCCH/DCI and a PDSCH (e.g., K0) provided by a time domain resource assignment filed in a DCI format scheduling a PDSCH or a SPS PDSCH

release; and (3) a number of slot aggregations for the PDSCH or the SPS PDSCH release.

For example, a wireless device may determine a set of PDCCH monitoring occasions for one or more DCI format that may schedule a PDSCH reception or a SPS PDSCH release. A PDCCH monitoring occasion may be a monitoring occasion in a slot, in a min-slot, a sub-frame, a frame or a span. The set of PDCCH monitoring occasions may comprise one or more monitoring occasions based on one or more search spaces of an active DL BWPs of configured serving cells. The one or more monitoring occasions may be indexed in an ascending order of a start time of a search space associated or determining a PDCCH monitoring occasion. A cardinality of the set of PDCCH monitoring occasions may be defined as a total number M of the one or more monitoring occasions. A value of a counter DAI field in one or more DCI formats may represent an accumulative number of {serving cell, PDCCH monitoring occasion}-pair(s) where PDSCH reception or SPS PDSCH release associated with the one or more DCI formats up to a current PDCCH monitoring occasion.

A base station may update (e.g., increment by 1) a counter DAI value for each PDCCH monitoring occasion to indicate accumulative number of PDSCH receptions and/or SPS PDSCH release up to the each PDCCH monitoring occasion. The wireless device may determine an order of a DCI, based on the counter DAI in each PDCCH monitoring occasion.

When a wireless device may support more than a PDSCH reception per each PDCCH monitoring occasion (e.g., PDSCH-Number-perMOperCell is larger than 1), the wireless device may order (e.g., list) one or more PDSCH reception starting time for a same {serving cell, PDCCH monitoring occasion} pair. The wireless device may then order (e.g., list out in an order) PDCCH monitoring occasion or PDSCH receptions based on a serving cell index. The wireless device may then order PDCCH monitoring occasion index (based on a starting time of PDCCH monitoring occasion). When a wireless device is provided with ACKNACKFeedbackMode=JointFeedback, a first coreset pool index may be ordered first than a second coreset pool index for a same serving cell.

In an example, a value of a total DAI may denote/represent a total number of {serving, PDCCH monitoring occasion}-pair(s) up to a current PDCCH monitoring occasion across one or more serving cells.

FIG. 24 illustrates an example of HARQ feedback/code-book determination when a wireless device is configured with a plurality of serving cells. For example, the wireless device may be configured with a first cell (Cell 0) and a second cell (Cell 1). For example, the wireless device may receive a first DCI via the first cell (DCI 1) that may indicate a DAI=0 and a T-DAI=1. The base station may determine a C-DAI (or DAI) and/or T-DAI for a DCI.

The T-DAI may accumulate a number of PDCCH monitoring occasions and/or a number of DCIs, across all serving cells, up to a current PDCCH monitoring occasion. A first monitoring occasion of the first cell may overlap and may have a same starting time to a first monitoring occasion of the second cell. A base station may set the T-DAI of the first DCI being two. The base station may set a T-DAI of a second DCI (DCI 2) via the second cell.

A DAI value of the second DCI may be set to 1 (e.g., counter DAI). For example, the base station may set the DAI value of the second DCI to 1. The wireless device may not receive successfully a third DCI (DCI3) that may indicate a T-DAI=2 and DAI=2. The wireless device may receive a fourth DCI (DCI4) with a T-DAI=3 and DAI=3.

The wireless device may receive a fifth DCI (DCI5) with a T-DAI=4 and DAI=4.

A value of a T-DAI may be wrapped around (e.g., modulo operation, such as a modulo n, which may be expressed as a mode n or a % n) when it reaches a maximum value (e.g., n) or a threshold (e.g., a maximum value=4 based on 2 bits of T-DAI field, a maximum value= $2^K$  or  $2^K-1$  where K is a number of bits used for a T-DAI field in a DCI format). The wireless device may determine HARQ-ACK bits as follows.

- 10 For example, actual value of T-DAI and C-DAI vale may be 0 for the fifth DCI based on the wrapping up mechanism (e.g.,  $4 \bmod 4=0$ ,  $4\% 4=0$  when n is 4, an actual value may be determined based on modulo n, where n is  $2^K$  with K bits used for a DAI field).

15 For example, for each PDCCH monitoring occasion (e.g., a first PDCCH monitoring occasion is a first time when the wireless device may monitor a first monitoring occasion via the first cell and a first monitoring occasion via the second cell), the wireless device may determine a number of 20 HARQ-ACK feedback bits for each serving cell based on a cell index (e.g., determine the first cell and then determine the second cell when an index of the first cell is lower than an index of the second cell).

25 For example, a PDCCH monitoring occasion may indicate a starting time in a slot where a wireless device may start monitoring one or more PDCCH candidates via a monitoring occasion of a serving cell. For example, a PDCCH monitoring occasion may indicate a monitoring occasion determined/configured based on a search space configuration.

30 For example, the wireless device may determine a number of HARQ-ACK bits for a serving cell based on a DAI field of the each PDCCH monitoring occasion. For example, the wireless device may determine a bit index among HARQ-35 ACK bits to put ACK or NACK for a transport block or a SPS PDSCH release scheduled by a DCI for the serving cell, where the wireless device may receive the DCI via the each PDCCH monitoring occasion.

35 The wireless device may determine a first HARQ-ACK 40 bit for a transport block of the first cell at the first PDCCH monitoring occasion. The wireless device may determine a second HARQ-ACK bit for a transport block of the second cell at the first PDCCH monitoring occasion. The wireless device may move to a next PDCCH monitoring occasion 45 which occurs after the first monitoring occasion but occur before other monitoring occasions.

In FIG. 24, the wireless device may determine a second 50 monitoring occasion via the first cell as the wireless device may not detect any DCI via a second monitoring occasion via the second cell. The wireless device may determine a third HARQ ACK bit corresponding to a PDSCH or a SPS PDSCH release scheduled via the fourth DCI (DCI 4). The wireless device may move to a next PDCCH monitoring occasion, where the wireless device receives a DCI with a 55 DAI value. For example, the wireless device may determine a third monitoring occasion via the second cell as the next PDCCH monitoring occasion. The wireless device may determine a fourth HARQ ACK bit corresponding to a PDSCH or a SPS PDSCH scheduled by the fifth DCI (DCI5).

60 The wireless device may determine a total DAI value for a PUCCH resource, based on a last DCI received for the PUCCH resource. For example, the fifth DCI may be a last DCI that the wireless device receives for the PUCCH resource in FIG. 26. The fifth DCI indicates a T-DAI=4 that may indicate five DCIs have been scheduled up to the current PDCCH monitoring occasion.

The wireless device may determine a number of HARQ-ACK bits based on the T-DAI of the last DCI.

The wireless device may determine an order (e.g., a bit order) of each DCI or a PDSCH scheduled by the each DCI based on a C-DAI value of the each DCI. For example, a bit order of the fourth DCI (DCI 4) is 3, the wireless device may place a HARQ-ACK bit for the fourth DCI in a bit with index 3 as shown in FIG. 26.

The wireless device may determine NACK for a missed DCI between the second DCI and the fourth DCI. The wireless device may generate aggregated HARQ-ACK feedback by ascending order of a start time of a PDCCH monitoring occasion (e.g., the first DCI, the second DCI, the third DCI, the fourth DCI, the fifth DCI) and for each PDCCH monitoring occasion based on a cell index (e.g., the first cell, the second cell in the first monitoring occasion).

The wireless device may determine whether a SPS PDSCH reception based on a SPS configuration is mapped to the PUCCH resource. When a single SPS PDSCH reception across cells is mapped to the PUCCH resource, the wireless device may generate a HARQ-ACK bit corresponding to the SPS PDSCH reception. The wireless device may append the HARQ-ACK bit after the aggregated HARQ-ACK feedback based on one or more PDCCH monitoring occasions.

In FIG. 24, the wireless device may append a HARQ-ACK bit for the SPS PDSCH after five bits of HARQ-ACK bits. The wireless device may transmit the appended HARQ-ACK bits via the PUCCH resource.

The wireless device may determine a bit order of HARQ-ACK feedback for one or more DCIs/PDSCHs based on C-DAI/T-DAI values of the one or more DCIs.

If the wireless device may be configured with a plurality of coreset pool indexes for a serving cell, the wireless device may further order based on a coreset pool index (e.g., a first coresset pool, a second coresset pool). When a wireless device may be configured with a plurality of transport blocks for any serving cell, the wireless device may determine two ACK and/or NACK bits for each PDCCH monitoring occasion of a serving cell. The wireless device may transmit 5 bits of HARQ ACK feedback corresponding to an order of DCI1, DCI2, DCI3, DCI4 and DCI5.

In an example, a wireless device may transmit a HARQ-ACK information (e.g., a HARQ-ACK codebook, one or more HARQ-ACK codebooks, and/or the like) in a PUCCH resource in a slot n. The wireless device may determine a bitmap of ACK-NACK information. The bitmap of ACK-NACK information may comprise a HARQ-ACK codebook, where the HARQ-ACK codebook may comprise one or more HARQ-ACK sub-codebooks. For example. The bitmap of ACK-NACK information may comprise one or more HARQ-ACK codebooks.

For example, the wireless device may generate a first bitmap for a first HARQ-ACK sub-codebook. The wireless device may generate a second bitmap for a second HARQ-ACK sub-codebook. For example, the wireless device may generate the first bitmap for a first HARQ-ACK codebook. The wireless device may generate the second bitmap for a second HARQ-ACK codebook. A PUCCH may comprise a HARQ-ACK codebook comprising one or more HARQ-ACK sub-codebooks. A PUCCH may comprise one or more HARQ-ACK codebooks.

For example, a wireless device may perform encoding based on a HARQ-ACK codebook. When a HARQ-ACK codebook comprises a plurality of HARQ-ACK sub-code-

books, the wireless device may append the plurality of HARQ-ACK sub-codebooks before performing encoding.

Example embodiments may generate a plurality of HARQ-ACK sub-codebooks for a HARQ-ACK codebook. Example embodiments may generate a plurality of HARQ-ACK codebooks, where each HARQ-ACK codebook, of the plurality of HARQ-ACK codebooks, may correspond to a HARQ-ACK sub-codebook of the examples.

In an example, a wireless device may generate a HARQ-ACK codebook comprising one or more HARQ-ACK sub-codebooks. The wireless device may encode the HARQ-ACK codebook and may transmit the encoded bits via a PUCCH resource.

For example, a first HARQ-ACK sub-codebook (e.g., a codebook, a sub-codebook, a first HARQ-ACK codebook) may correspond to one or more downlink channels (e.g., PDSCH), where each downlink channel carries one or more transport blocks. A second HARQ-ACK sub-codebook may correspond to one or more second downlink channels (e.g., PDSCH), where each second downlink channel carries one or more code block groups (CBGs).

For the first HARQ-ACK sub-codebook, the wireless device may generate P1 bits of ACK-NACK bits for a downlink channel of the one or more downlink channels. For example, P1 may be 1 in response to a number of transport block for a slot (e.g., maxNrofCodeWordsScheduledByDCI=1) being one. For example, P1 may be 2 in response to a number of transport block for a slot (e.g., maxNrofCodeWordsScheduledByDCI=2) being two. For example, the wireless device may generate P1 bits of ACK-NACK bit(s) for each DAI value based on counter DAI and/or T-DAI for the first HARQ-ACK sub-codebook.

For the second HARQ-ACK sub-codebook, the wireless device may generate P2 bits of ACK-NACK bits for a downlink channel of the one or more second downlink channels. For example, P2 may be M in response to a number of transport block for a slot (e.g., maxNrofCodeWordsScheduledByDCI=1) being one and a number of maximum CBGs configured to a serving cell being M. For example, P2 may be 2\*M in response to a number of transport block for a slot (e.g., maxNrofCodeWordsScheduledByDCI=2) being two and a number of maximum CBGs configured to a serving cell being M. For example, the wireless device may generate P2 bits of ACK-NACK bit(s) for each DAI value based on counter DAI and/or T-DAI for the second HARQ-ACK sub-codebook.

In an example, the wireless device may determine a first C-DAI/T-DAI for the first HARQ-ACK sub-codebook. The wireless device may determine a second C-DAI/T-DAI for the second HARQ-ACK sub-codebook.

In an example, a wireless device may be configured with a first cell and a second cell. The first cell and the second cell may be activated. A base station may transmit one or more RRC messages indicating configuration parameters. The configuration parameters may indicate/comprise a number of CBGs for the second cell. The wireless device may determine a DCI format, for the second cell, comprising a CBG transmission information (CBGTI). The CBGTI may be a bitmap, where each bit may correspond to each CBG of one or more CBGs, where a number of the one or more CBGs may be limited by the number of CBGs configured for the second cell. The base station may not configure a CBG transmission for the first cell. The base station may transmit a second DCI format, for the first cell, based on a transport block transmission.

The wireless device may not be configured with a third DCI format, for the second cell, where the third DCI format may schedule resources of the second cell based on a transport block transmission.

The wireless device may receive a first DCI indicating downlink resources, of a first downlink channel, of the first cell with a PUCCH resource. The wireless device may receive a second DCI indicating second downlink resources, of a second downlink channel, of the second cell with the PUCCH resource. The wireless device may determine a first HARQ-ACK sub-codebook comprising ACK-NACK bit(s) corresponding to the first downlink channel. The wireless device may determine a second HARQ-ACK sub-codebook comprising ACK-NACK bit(s) corresponding to the second downlink channel. The wireless device may append the second HARQ-ACK sub-codebook to the first HARQ-ACK sub-codebook. The wireless device may transmit the appended bits via the PUCCH resource.

In an example, the wireless device may generate a HARQ-ACK bit for a semi-persistent scheduling (SPS) PDSCH reception based on a SPS PDSCH configuration. The wireless device may append the HARQ-ACK bit to the first HARQ-ACK sub-codebook, before appending the second HARQ-ACK sub-codebook to the first HARQ-ACK sub-codebook. The wireless device may place the HARQ-ACK bit of the SPS PDSCH reception via the first HARQ-ACK sub-codebook.

When semipersistent scheduling is activated, a wireless device may periodically receive downlink data transmissions (e.g., SPS PDSCH transmissions, via SPS PDSCH receptions, via SPS PDSCH occasions). The periodicity of receiving the downlink data transmissions may RRC-configured (e.g., based on one or more periodicity parameters received through RRC signaling). First resource of periodic resources may be scheduled via a downlink control channel. The wireless device may activate the first resource and a semi-persistent scheduling based on the downlink control channel. The wireless device may receive downlink data transmission via periodic resources other than first resource without receiving downlink control channel(s).

In an example, a wireless device may be configured with one or more serving cells. The wireless device may receive one or more RRC messages indicating configuration parameters. The configuration parameters may indicate/comprise one or more SPS PDSCH configurations (e.g., SPS PDSCH configs, SPS configs, SPS configurations) for a cell of the one or more serving cells. The wireless device may receive a DCI activating a single SPS PDSCH configuration of the one or more SPS PDSCH configurations. The DCI may comprise/indicate a slot offset/scheduling offset ( $kW$ ) for receiving a first SPS PDSCH. The wireless device may determine the first SPS PDSCH reception based on the DCI and the slot offset ( $k0$ ). For example, a slot  $n$  of the first SPS PDSCH is after  $k0$  slots from the DCI (e.g., a first slot of the DCI).

The wireless device may determine one or more SPS PDSCH receptions where each of the one or more SPS PDSCH receptions may occur at a slot  $n+i*P$ , where  $i$  is 1, 2, . . . , and  $P$  is a periodicity of the SPS configuration. An SPS PDSCH reception may be a resource (e.g., time-domain, frequency-domain, and/or spatial-domain) in the PDSCH or an SPS PDSCH during which the base station may, or may not, transmit a transport block to the wireless device. The SPS PDSCH reception may refer to resources of a SPS transmission by the base station.

The wireless device may determine a PUCCH resource of the first SPS PDSCH based on a PDSCH-to-HARQ feed-

back timing (e.g.,  $k1$ ) indicated by the DCI. The wireless device may transmit a HARQ-ACK feedback for the first SPS PDSCH via the PUCCH resource. The wireless device may determine one or more PUCCH resources of the one or more SPS PDSCH receptions where each PUCCH resource of the one or more PUCCH resources may occur in a slot  $n+i*P+k1$ . A same timing/scheduling offset/gap between a SPS PDSCH reception and a PUCCH resource may be repeated for each periodicity. The wireless device may transmit a HARQ-ACK feedback of each SPS PDSCH via each PUCCH resource of the one or more PUCCH resources.

The wireless device may determine a PUCCH resource in a slot  $n$ . The wireless device may determine a number of SPS PDSCH configuration(s), where a HARQ-ACK feedback corresponding to a SPS PDSCH, of one or more SPS PDSCH configurations, is scheduled via the PUCCH resource. For example, the wireless device may determine the one or more SPS configurations based on periodicity(s) and/or PDSCH-to-HARQ\_feedback timing values and/or a repetition of each SPS PDSCH.

The wireless device may determine HARQ-ACK feedbacks of a plurality of SPS PDSCH configurations may be mapped/respond to a PUCCH resource (e.g., a same PUCCH resource).

FIG. 25 illustrates an example embodiment of a DAI counter procedure with a multi-PDSCH scheduling as per an aspect of an embodiment of the present disclosure.

A base station may transmit one or more RRC messages comprising/indicating configuration parameters. A wireless device may be configured with two serving cells comprising a first cell (Cell 0) and a second cell (Cell 1). The second cell may be configured with a multi-PDSCH scheduling. The first cell may be configured with a multi-PDSCH scheduling. The first cell may not be configured with a multi-PDSCH scheduling.

For example, a multi-PDSCH DCI format may refer a DCI format used for a multi-PDSCH scheduling. For example, the multi-PDSCH DCI format may be a non-fallback DCI format (e.g., DCI format 1\_1). For example, the multi-PDSCH DCI format may be a DCI format 1\_3. The multi-PDSCH DCI format may comprise a plurality of NDI bits, where each of the plurality of NDI bits corresponds to each PDSCH of one or more PDSCHs scheduled by a DCI based on the multi-PDSCH DCI format. The multi-PDSCH DCI format may comprise a plurality of RV fields/bits, where each of the plurality of RV fields/bits corresponds to each PDSCH of the one or more PDSCHs.

For example, a single-PDSCH DCI format may refer a DCI format used for a single-PDSCH scheduling. For example, the single-PDSCH DCI format may be a non-fallback DCI format (e.g., DCI format 1\_1). For example, the multi-PDSCH DCI format may be a DCI format 1\_2. For example, the single PDSCH DCI format may be a fallback DCI format (e.g., DCI format 1\_0). The single-PDSCH DCI format may comprise a single NDI bit for a single PDSCH.

In an example, a base station and a wireless device may determine a counter DAI of a DCI based on a number of PDSCHs, SPS PDSCH release, and/or a SCell dormancy indication scheduled by a previous DCI and a first counter DAI value of the previous DCI.

The base station may increment by the number of PDSCHs, SPS PDSCH release, and/or a SCell dormancy indication scheduled by the previous DCI from the first counter DAI value.

In an example, a base station and a wireless device may determine a counter DAI of a DCI based on an accumulation

of a number of PDSCHs, SPS PDSCH release, and/or a SCell dormancy indication scheduled up to the DCI via {serving cell, a current PDCCH monitoring occasion}-pair (refer to FIG. 26).

In an example, a base station and a wireless device may determine a counter DAI of a DCI based on an accumulation of a number of transport block(s), SPS PDSCH release(s), and/or a SCell dormancy indication scheduled up to the DCI via {serving cell, a current PDCCH monitoring occasion}-pair (refer to FIG. 26).

The DCI and the previous DCI may share (e.g., count, consider, use) a DAI counter procedure that was used by the base station. The base station may have used the same DAI counter procedure to update the C-DAI value and the T-DAI value of the DCI compared to (or from) the previous DCI. The previous DCI may be a DCI that occurs in a same PDCCH monitoring occasion or previous PDCCH monitoring occasion than the DCI. The base station may not schedule any DCI, based on the DAI counter, between the previous DCI and the DCI.

The base station and the wireless device may determine a total DAI of a DCI, in a PDCCH monitoring occasion, based on a number of PDSCH(s), SPS PDSCH release, and/or a SCell dormancy indication scheduled by one or more DCIs up to the PDCCH monitoring occasion. The one or more DCIs may comprise the DCI. The base station may increment, by  $P_{accu}$ , the total DAI of the DCI from a previous DCI in a previous PDCCH monitoring occasion. For example, the previous PDCCH monitoring occasion occurs immediacy before the PCCH monitoring occasion. For example, the previous DCI may occur before the DCI.

The wireless device may determine  $P_{accu}$  as a sum/accumulation of one or more number of one or more PDSCHs, SPS PDSCH release, and/or a SCell dormancy indication scheduled via one or more second DCIs, in the PDCCH monitoring occasion. For example, the base station schedules the DCI and a second DCI in the PDCCH monitoring occasion, where the DCI schedules P1 PDSCHs, and the second DCI schedules P2 PDSCHs. The  $P_{accu}$  is  $P1+P2$  in that case.

In an example, a base station and a wireless device may determine a counter DAI of a DCI based on a number of HARQ-ACK bits for one or more PDSCHs, SPS PDSCH release(s), SCell dormancy indication scheduled by a previous DCI and a first counter DAI value of the previous DCI.

The number of HARQ-ACK bits may be determined based on a number of transport blocks scheduled via the one or more PDSCHs.

The number of HARQ-ACK bits may be determined based on a number of SPS PDSCH release(s) (e.g., 1) via the previous DCI.

The number of HARQ-ACK bits may be determined based on a number of SCell dormancy indication (e.g., 1) via the previous DCI.

For example, the configuration parameters may comprise/indicate a maximum number ( $M_{harq}$ ) of HARQ-ACK bits for a multi-PDSCH DCI. For example, when a multi-PDSCH DCI schedules P PDSCHs, where P may be larger than  $M_{harq}$  the wireless device may generate up to  $M_{harq}$  HARQ-ACK bits for the P PDSCHs. The base station may increment  $M_{harq}$ , instead of P, for a next DCI after the multi-PDSCH DCI based on the maximum number of HARQ-ACK bits.

For example, the base station and the wireless device may determine a total DAI of the DCI based on a sum of one or more number of HARQ-ACK bits based on one or more DCIs in the PDCCH monitoring occasion. The one or more

DCIs may comprise the DCI. When a number of PDSCHs scheduled by a second DCI is smaller than M, a number of HARQ-ACK bits, for the second DCI, may be same as the number of PDSCHs for the second DCI.

5 In an example, the configuration parameters may indicate maxNrofCodeWordsScheduledByDCI=2 for the second cell with a multi-PDSCH scheduling. Each PDSCH may indicate/comprise up to two TBs. When maxNrofCodeWordsScheduledByDCI=2 is configured for a cell with a multi-PDSCH scheduling, the base station and the wireless device may determine/increment a DAI counter based on a number of HARQ-ACK bits. For example, when a multi-PDSCH DCI schedules one or more PDSCHs with a second TB enabled, a number of HARQ\_ACK bits may be twice of a number of the one or more PDSCHs. For example, when a multi-PDSCH DCI schedules one or more PDSCHs with a second TB disabled, a number of HARQ\_ACK bits may be same as a number of the one or more PDSCHs

The wireless device may determine a number of HARQ-ACK bits based on a number of scheduled PDSCH(s), a number of TBs in each PDSCH of the scheduled PDSCH(s), and/or a CBG transmission for any TB of the TB(s) via the scheduled PDSCH(s). For example, when a CBG transmission is configured for the cell, a number of HARQ-ACK bits may be  $P*T*M$ , where P is a number of scheduled PDSCHs, T is a number of TBs scheduled for a PDSCH, and M is a maximum number of CBGs (or configured number of CBGs).

The wireless device may determine a HARQ-ACK bit for 30 a DCI indicating a SPS PDSCH release, or a SCell dormancy indication.

For example, the base station and the wireless device may determine a number of HARQ-ACK bits  $num_{harq\_bits}=$ , where  $T_i$  is a number of TBs via a PDSCH with index i (or 35 i-th PDSCH) and  $M_i$  is a number of CBGs transmitted for TB(s) via the PDSCH with index i.

When a maximum number of HARQ-ACK bits ( $M_{harq}$ ) is configured, the wireless device may determine a number of HARQ-ACK bits as  $\max(M_{harq}, num_{harq\_bits})$ .

40 The wireless device may determine a number of PDSCHs of the one or more PDSCHs based on the first DCI. For example, the wireless device may determine a number of slots, where the one or more PDSCHs are scheduled. For example, when the first DCI schedules resources from slot n to slot  $n+K$  for the one or more PDSCHs, the wireless device may determine the number of PDSCHs as  $K+1$ . The wireless device may count a number of consecutive slots of first PDSCH, of the one or more PDSCHs, and last PDSCH of the one or more PDSCHs. The wireless may count a number of slots, where any PDSCH of the one or more PDSCHs is scheduled. The wireless device may count a number of the one or more PDSCHs, where the first DCI indicates resources for each of the one or more PDSCHs.

The wireless device may count a number of one or more 55 second PDSCHs of the one or more PDSCHs, where each of the one or more second PDSCHs comprises a transport block (e.g., the each of the one or more second PDSCHs is not skipped).

The wireless device may determine a PDSCH is skipped 60 based on a SLIV entry corresponding to the PDSCH or based on a combination of one or more DCI fields. The wireless device may count the number of un-skipped (e.g., non-skipped, delivered, transmitted) or transmitted PDSCHs. The wireless device may determine the number of PDSCHs based on a field by the first DCI. the first DCI may comprise the field indicating the number of PDSCHs scheduled by the first DCI.

In FIG. 25, a DAI counter procedure may be shared/used between the first DCI, the second DCI and the third DCI. The first DCI may comprise a C-DAI value of 0 and a T-DAI value of 2. The base station may reset the C-DAI for the first DCI as the first DCI is an earliest DCI indicating a PUCCH resource. The base station may set the T-DAI of the first DCI as 2 based on accumulated number of PDSCHs up to a first PDCCH monitoring occasion. The wireless device may monitor the first DCI via the first PDCCH monitoring occasion.

The base station may determine a C-DAI value of the second DCI as 3 (e.g., a number of PDSCHs/a number of HARQ-ACK bits for the first DCI is 3). The base station may increment the C-DAI value of the second DCI by the number of PDSCHs scheduled by the first DCI. The base station may determine a T-DAI of the second DCI as 3 as a sum of a number of PDSCHs by the first DCI and a second number of PDSCH scheduled by the second DCI (e.g., 3+1).

The base station may determine a C-DAI value of the third DCI as 4 (e.g., increment by a number of PDSCH(s) scheduled by the second DCI, from the C-DAI value of the second DCI). The base station may determine a T-DAI value of the third DCI as 4 (e.g., a sum of all PDSCHs scheduled up to a third PDCCH monitoring occasion). The wireless device may monitor the third DCI via the third PDCCH monitoring occasion.

The wireless device may determine first bit index or a starting bit index in a HARQ-ACK sub-codebook, for one or more PDSCHs scheduled by a DCI, based on a C-DAI value of the DCI. For example, the first bit or the starting bit of the three PDSCHs by the first DCI is 0 based on the C-DAI being 0.

The wireless device may map three HARQ-ACK bits for the three PDSCHs by the first DCI starting from 1<sup>st</sup> bit of the HARQ-ACK sub-codebook to 3<sup>rd</sup> bit of the HARQ-ACK codebook. For example, the wireless device may generate a HARQ-ACK bit for a first PDSCH of the three PDSCHs (M-DCI PDSCH #1) and put in 1<sup>st</sup> bit. The wireless device may put a HARQ-ACK bit for a second PDSCH of the three PDSCHs (M-DCI PDSCH #2) in 2<sup>nd</sup> bit. The wireless device may put a HARQ-ACK bit for a third PDSCH of the three PDSCHs (M-DCI PDSCH #3) in 3<sup>rd</sup> bit. The wireless device may generate HARQ-ACK bits for one or more PDSCHs scheduled by a multi-PDSCH DCI based on ascending order of reception timing. The wireless device may generate first HARQ-ACK bit for an earliest PDSCH of the one or more PDSCHs, and may generate last HARQ-ACK bit for a latest PDSCH of the one or more PDSCHs.

The first bit or the starting bit of a first PDSCH scheduled by the second DCI is 3 (e.g., 4<sup>th</sup> bit) based on the C-DAI being 3.

The wireless device may map a HARQ-ACK bit for the first PDSCH at the 4<sup>th</sup> bit.

The first bit or the starting bit of a second PDSCH scheduled by the third DCI is 4 (e.g., 5<sup>th</sup> bit) based on the C-DAI being 4.

The wireless device may miss receiving the second DCI. The wireless device may fail to decode the second DCI. The wireless device may not receive the first PDSCH. The wireless device may generate NACK for the 4<sup>th</sup> bit of the HARQ-ACK sub-codebook.

The wireless device may map a HARQ-ACK bit for the second PDSCH at the 5<sup>th</sup> bit.

When a dynamic HARQ-ACK codebook (e.g., Type-2 HARQ-ACK codebook determination) is configured for the wireless device, the wireless device may expect a C-DAI and/or T-DAI field in a DCI. A single-PDSCH DCI format

may comprise K bits of C-DAI field and K bits of T-DAI field. A multi-PDSCH DCI format may comprise M bits of C-DAI field and M bits of T-DAI field. For example, M is larger than K. For example, K is 2. For example, M is 4 or 5.

The wireless device and the base station may determine a first DAI counter procedure for a single-PDSCH scheduling. The wireless device and the base station may determine a second DAI counter procedure for a multi-PDSCH scheduling.

FIG. 26 illustrates example embodiment of a DAI counter procedure for a multi-PDSCH scheduling as per an aspect of an embodiment of the present disclosure.

The base station may configure four serving cells to the wireless device. A first cell (Cell 0), a second cell (Cell 1), a third cell (Cell 2) and a fourth cell (Cell 3) may be configured with a multi-PDSCH scheduling. For example, a first DCI, via the first cell, may schedule 5 PDSCHs, and is an earliest DCI indicating a PUCCH resource. The base station may set a C-DAI of the first DCI as zero based on the earliest DCI. The base station may determine a T-DAI of the first DCI as 11 (e.g., 12 counter) based on a sum of a first number of PDSCHs by the first DCI and a second number of PDSCHs scheduled by a second DCI. The wireless device may receive the second DCI via the fourth cell. The second DCI may schedule 7 PDSCHs. The sum of PDSCHs scheduled by both DCIs in a PDCCH monitoring occasion may be 12.

Each PDCCH monitoring occasion may be determined as a slot.

The base station may increment by the first number for a C-DAI of the second DCI. The C-DAI of the second DCI is set to 5.

The base station may increment by a second number for a C-DAI of a third DCI, via the second cell in a slot n+1.

The base station may determine a total DAI (T-DAI) of the third DCI based on an accumulated number of PDSCHs up to a second PDCCH monitoring occasion.

The base station may schedule the third DCI and the fourth DCI via the second PDCCH monitoring occasion. The base station may add the first number, the second number, a third number (a number of PDSCHs scheduled by the third DCI), and a fourth number (a number of PDSCHs scheduled by the fourth DCI).

The base station may determine the total DAI of the third DCI and the fourth DCI based on adding the first number, the second number, the third number and the fourth number (e.g., 5+7+8+1=21). The total DAI value of the third DCI and the fourth DCI is set to 20.

Similarly, a fifth DCI, via the first cell, in a slot n+3, may indicate a C-DAI=21 and a T-DAI=26. A sixth DCI may indicate a C-DAI=25 and a T-DAI=26.

In an example, the wireless device and the base station may determine to increment a counter-DAI and/or a total-DAI for the activation DCI. The wireless device and the base station may determine the counter-DAI and/or the total-DAI based on a single SPS PDSCH regardless of time domain resources indicated by the activation DCI.

In an example, to avoid ambiguity in a number of HARQ-ACK bits due to multiple SPS PDSCH receptions may occur before a first PUCCH resource based on an activation DCI, the wireless device and the base station may determine a counter-DAI and/or a total-DAI, of the activation DCI, based on a number of multiple SPS PDSCH receptions. For example, when M number of SPS PDSCH receptions may correspond to the first PUCCH resource based on the activation DCI, the base station may determine the counter-

DAI and/or the total-DAI based on the M. When the wireless device misses (e.g., fails to decode and/or receive) the activation DCI, the wireless device may determine M NACK bits. When the wireless device receives the activation DCI, the wireless device may determine M HARQ-ACK bits corresponding to the M SPS PDSCH receptions.

Example embodiments may reduce an ambiguity in a HARQ-ACK codebook size regardless of missing an activation DCI for the SPS configuration.

In an example, the base station may skip transmitting the multiple SPS PDSCH receptions except for a first/earliest SPS PDSCH reception. The wireless device may determine a single HARQ-ACK bit for the first/earliest SPS PDSCH reception. This may reduce an ambiguity in a HARQ-ACK codebook size due to multiple SPS PDSCH reception occasions based on the activation DCI.

In existing technologies, a HARQ process identifier of a transport block via a SPS PDSCH reception may be determined based on time domain resource of the SPS PDSCH reception. When a multi-PDSCH DCI activates a SPS configuration, implementation of existing technologies may generate a same HARQ process for two consecutive SPS PDSCH receptions (e.g., two consecutive SPS PDSCH receptions are in a same slot). Enhancement in a HARQ process identifier may be needed.

In an example, a wireless device may determine one or more SPS PDSCH receptions in each interval/periodicity. The wireless device may determine a first HARQ process identifier for a first/earliest SPS PDSCH reception of the one or more SPS PDSCH reception. The wireless device may increment a HARQ process ID by 1 in each of the one or more SPS PDSCH receptions except for the first/earliest SPS PDSCH reception. This may allow efficient HARQ process identifier for the SPS configuration activated multiple resources in each interval/periodicity.

In an example, a wireless device may receive one or more RRC messages comprising/indicating configuration parameters. The configuration parameters may indicate a serving cell. The configuration parameters may indicate a multi-PDSCH scheduling configured for the serving cell. The configuration parameters may indicate a DCI format for the multi-PDSCH scheduling of the serving cell. The configuration parameters may indicate a maximum number (e.g., M) of PDSCHs/slots scheduled by a DCI based on the multi-PDSCH scheduling. The configuration parameters may indicate a TDRA table comprising one or more TDRA entries. Each TDRA entry of the one or more TDRA entries may indicate resources for one or more PDSCHs/slots.

The configuration parameters may indicate/comprise a SPS configuration for the serving cell.

For example, the wireless device may receive a DCI, based on a multi-PDSCH scheduling or a multi-PDSCH DCI format, activating a SPS configuration. For example, the multi-PDSCH DCI format may indicate a plurality of time domain resources (e.g., a plurality of SLIV values) where each time domain resource (e.g., the start and length values of the SLIV) of the plurality of time domain resources corresponds to a PDSCH or a slot (e.g., a slot in which a PDSCH transmission is to be received). For example, the multi-PDSCH DCI format may comprise a bitmap of NDI field, where each bit of the bitmap corresponds to each PDSCH of one or more PDSCHs or each slot of one or more slots. A DCI based on the multi-PDSCH DCI may schedule the one or more PDSCHs or the one or more slots.

The wireless device may determine a SPS PDSCH reception from the one or more PDSCHs. For example, the wireless device may determine a latest or last PDSCH of the

one or more PDSCHs. The wireless device may determine a latest or last SLIV of the plurality of SLIV for the SPS PDSCH reception. The wireless device may determine a latest or last time domain resource of the plurality of time domain resources for the SPS PDSCH reception.

The wireless device may determine a SPS PDSCH reception from the one or more PDSCHs. For example, the wireless device may determine an earliest or first PDSCH of the one or more PDSCHs. The wireless device may determine an earliest or first SLIV of the plurality of SLIV for the SPS PDSCH reception. The wireless device may determine an earliest or first time domain resource of the plurality of time domain resources for the SPS PDSCH reception.

The DCI may be scrambled with a second RNTI. For example, the second RNTI may comprise a CS-RNTI, a SPS-C-RNTI, or a SPS-RNTI. For example, the second RNTI may be used for a SPS configuration and/or a CG configuration. The second RNTI may be configured to the wireless device for activating/releasing one or more SPS configurations and/or one or more CG configurations. The second RNTI may be configured to the wireless device for scheduling resources for retransmission of transport block(s), where initial transmission of the transport block(s) may have been scheduled via the one or more SPS configurations and/or the one or more CG configurations.

The DCI may be based on a multi-PDSCH DCI format (e.g., a DCI format 1\_1, a DCI format 1\_2). The multi-PDSCH DCI format may comprise a plurality of NDI fields/bits and/or a plurality of RV fields/bits. The multi-PDSCH DCI format may indicate a TDRA entry of a TDRA table, where at least one entry of the TDRA table comprises a plurality of SLIV values/time domain resources. The TDRA table may be configured for a multi-PDSCH scheduling of the serving cell.

The DCI may be based on a fallback DCI format. The fallback DCI format (e.g., DCI format 1\_0) may indicate a multi-PDSCH scheduling or may be considered as a multi-PDSCH DCI format. For example, the fallback DCI format may comprise a time domain resource allocation field indicating an entry of the TDRA table configured for the multi-PDSCH scheduling for the serving cell.

A serving cell or a cell may be referred as an active (downlink) BWP of the serving cell or the cell in the specification. For example, configuration parameters may be configured for a BWP of the serving cell. The configuration parameters may be referred as configuration parameters of an active BWP of the serving cell.

The DCI may comprise a time domain resource allocation field indicating one or more SLIV values and/or one or more slots. For example, each of the one or more SLIV values or each of the one or more slots may correspond to a PDSCH. The DCI may schedule resources for one or more PDSCHs.

The DCI may comprise a first field setting to a first predetermined value. For example, the first field may be a HARQ process ID field. The first predetermined value may be all zeros. The DCI may comprise a second field setting to a second predetermined value. For example, the second field may be one or more RV fields. The second predetermined value may be all zeros. One or more bits of the one or more RV fields may be set to all zeros.

The wireless device may validate the DCI in response to the first field setting to the first predetermined value and the second field setting to the second predetermined value. The wireless device may determine the DCI activating the SPS configuration of the serving cell in response to a third DCI field (e.g., a MCS field) not setting to a third predetermined value (e.g., all ones).

The wireless device may determine a first SPS PDSCH reception based on the DCI and the SPS configuration. For example, the first SPS PDSCH may be a SPS PDSCH in a first interval/periodicity. The wireless device may determine an earliest or a latest time domain resource of the one or more time domain resources indicated by the DCI as the first SPS PDSCH.

The wireless device may determine one or more periodic SPS PDSCH receptions based on the first SPS PDSCH reception and a periodicity of the SPS configuration.

The wireless device may activate or determine a SPS PDSCH reception/occasion in each periodicity based on the periodicity of the SPS configuration.

In an example, a wireless device may receive an activation DCI, for a SPS configuration, indicating a TDRA entry of a TDRA table. The TDRA entry may comprise a plurality of SLIV values, where each of the plurality of SLIV values may correspond to a slot of a plurality of slots. The wireless device may determine earliest slot or first SLIV value of the plurality of SLIV values. The wireless device may determine the activation DCI may schedule resources of the earliest slot for a single SPS PDSCH. The wireless device may ignore resources indicated by the plurality of SLIV values other than the first SLIV value. The wireless device may consider the resources not indicated by the DCI in response to ignoring. For example, the wireless device may not account information of the plurality of SLIV values other than the first value. The wireless device may determine an activation DCI may schedule a single SPS PDSCH in each periodicity of the SPS configuration.

In another example, the wireless device may determine latest slot or last SLIV value of the plurality of SLIV values. The wireless device may determine the activation DCI may schedule resources of the latest slot for a single SPS PDSCH. The wireless device may ignore resources indicated by the plurality of SLIV values other than the last SLIV value. The wireless device may determine an activation DCI may schedule a single SPS PDSCH in each periodicity of the SPS configuration.

In another example, the wireless device may determine latest slot or last SLIV value of the plurality of SLIV values. The wireless device may determine the activation DCI may schedule resources of the latest slot for a single SPS PDSCH. The wireless device may ignore resources indicated by the plurality of SLIV values other than the last SLIV value. The wireless device may determine an activation DCI may schedule a single SPS PDSCH in each periodicity of the SPS configuration.

For example, the wireless device may determine additional resources in each periodicity based on additional configuration parameters (e.g., sps-nofSlots, sps-nofsub-slots).

For example, when the wireless device is not configured with the additional configuration parameters, the wireless device may determine a single SPS PDSCH in each periodicity. The wireless device may determine a PUCCH resource for the SPS configuration based on the earliest slot of the plurality of slots and a PDSCH-to-HARQ\_feedback timing indicator (e.g., k1). For example, the wireless device may determine the PUCCH resource occurring after k1 offset from the earliest slot. The wireless device may determine a PUCCH resource for the SPS configuration based on a slot offset (e.g., k0) indicated by the activation DCI and the k1 value (e.g., the PDSCH-to-HARQ\_feedback timing indicator indicated by the DCI). For example, the wireless device may determine the PUCCH resource occurring after k0+k1 from a slot when the wireless device receives the

activation DCI. The wireless device may determine a PUCCH resource based on k0 value, a first/earliest SLIV value of one or more SLIV values and k1 value indicated by an activation DCI.

5 The wireless device may determine a PUCCH resource for each periodicity based on a last slot, indicated by an activation DCI, of each periodicity. For example, the wireless device may determine a last slot in each periodicity/interval based on the activation DCI and the periodicity. The 10 wireless device may determine a PUCCH resource based on the last slot of each periodicity/interval.

FIG. 27 illustrates an example of a SPS configuration activation based on a multi-PDSCH DCI as per an aspect of an embodiment of the present disclosure.

15 The base station may transmit one or more RRC configuration (RRC configuration (SPS)) indicating a SPS configuration for a cell. The SPS configuration may be configured for an active BWP of the cell. The SPS configuration may be configured for the cell that may be active for any BWP of the 20 serving cell.

The one or more RRC configurations may indicate a number of SPSs in a slot (e.g., sps-nofsub-slots) or a number of SPSs in consecutive slots (e.g., sps-nofSlots). When the 25 number of SPSs in the slot or the number of SPSs in consecutive slots is not configured or is absent, the wireless device may assume that a single SPS PDSCH reception is determined in each interval/periodicity based on the SPS configuration.

The wireless device may receive a DCI activating the SPS 30 configuration at a slot n. The DCI may indicate a slot/scheduling offset (k0) for which the corresponding PDSCH transmission may be received. The wireless device may determine one or more time domain resources based on the slot/scheduling offset and a time domain resource allocation field in the DCI. For example, the time domain resource allocation field may indicate an index=1, which may indicate to use a TDRA entry with an index=1 of a TDRA table. In FIG. 27, the wireless device may determine a first SLIV value of {6, 5} for a starting symbol and a length based on 35 the index=1 TDRA entry. The wireless device may determine a second SLIV value of {1, 14}. The wireless device may determine K SLIV values based on the TDRA entry.

The wireless device may determine K time domain 40 resources based on the K SLIV values and the k0 offset. For example, a first (e.g., an earliest) time domain resource may occur in between symbols [6, 11] in a slot n+m. The wireless device may determine the slot n+m based on the slot offset and a first slot where the wireless device receives the DCI (e.g., the slot n). The first time domain resource may occur 45 in the slot/scheduling offset after the first slot.

The wireless device may determine a second time domain 50 resource occurring in a slot n+m+1 symbol [1-14] based on the second SLIV value. The wireless device may determine a last (e.g., K-th) time domain resource in a slot n+m+K-1 between symbol [4-14].

The SPS configuration is configured (e.g., comprises, includes, points to, etc.) with a periodicity (P). The wireless device may determine a first SPS PDSCH reception based on the DCI. The DCI may indicate resources between [slot 55 n+m, . . . , slot n+k]. The wireless device may determine a time domain resource of the resources for the first SPS PDSCH reception.

The wireless device may determine a first SPS PDSCH 60 reception based on the DCI and one or more configuration parameters. The wireless device may determine a SPS PDSCH reception or a SPS PDSCH in each interval/period based on the SPS configuration. A SPS PDSCH reception

may refer to resources scheduled for a SPS PDSCH based on a SPS configuration. A SPS PDSCH reception may refer to a scheduled time/frequency domain resource for a PDSCH comprising a transport block based on a SPS configuration. A SPS PDSCH reception may refer to an occasion or a periodic resource scheduled for a SPS PDSCH. A (SPS) PDSCH reception may refer to a time domain resource (in a slot or in a sub-slot) in which a PDSCH transmission may be received/scheduled from e.g., a base station. A SPS PDCH may refer to a PDSCH configured via a SPS configuration. A SPS PDSCH may be a PDSCH scheduled periodically. A SPS PDSCH may be a PDSCH. The first SPS PDSCH reception may refer a SPS PDSCH in first interval/period based on the DCI (e.g., based on the activated SPS configuration).

The wireless device may determine a first SPS PDSCH reception based on the earliest time domain resource by the DCI. The wireless device may determine a first SPS PDSCH reception (or first SPS PDSCH) based on a latest (or last) time domain resource by the DCI. The wireless device may determine a first SPS PDSCH reception (or first SPS PDSCH) based on a latest (or last) time domain resource by the DCI and one or more configuration parameters.

The one or more configuration parameters may comprise a number of sub-slots (e.g., sps-nofsub-Slots N1) for a SPS configuration. For example, the wireless device may determine resources of N1 consecutive SPS PDSCHs in a slot based on resources for the first SPS PDSCH reception. The slot is when the wireless device is scheduled with the first SPS PDSCH reception. For example, a symbol 1-3 may be scheduled for the first SPS PDSCH reception in a slot n+m in FIG. 27, and N1 is 2, the wireless device may determine symbol 4-6 as a second SPS PDSCH reception. The wireless device may determine the one or more first SPS PDSCH receptions comprise the first SPS PDSCH reception and the second SPS PDSCH reception.

The one or more configuration parameters may comprise a number of slots (e.g., sps-nofSlots, N2) for a SPS resource. For example, the wireless device may determine resources of N1 SPS PDSCH receptions via N1 consecutive slots based on resources for the first SPS PDSCH reception. For example, the wireless device may determine N1 consecutive slots starting from a slot when the wireless device is scheduled with the first SPS PDSCH reception by the activation DCI. The wireless device may determine a same set of time and/or frequency domain resources to the first SPS PDSCH reception for one or more following SPS PDSCHs receptions.

For example, a symbol 1-8 may be scheduled for the first SPS PDSCH reception in a slot n+m in FIG. 27, and N2 is 4, the wireless device may determine symbol 1-8 in a slot n+m+1 for a second SPS PDSCH reception, symbol 1-8 in a slot n+m+2 for a third SPS PDSCH reception, symbol 1-8 in a slot n+m+3 for a fourth SPS PDSCH reception. The wireless device may determine the one or more first SPS PDSCH receptions comprise the first SPS PDSCH reception, the second SPS PDSCH reception, the third SPS PDSCH reception and the fourth SPS PDSCH reception. The wireless device may determine resources for the one or more SPS PDSCHs based on one or more SLIV values indicated by the DCI (e.g., activation DCI) and the SPS configuration. The wireless device may determine resources for the one or more SPS PDSCHs based on a first (e.g., earliest) SLIV value or a last (e.g., latest) SLIV value of one or more SLIV values indicated by the DCI (e.g., activation DCI) and one or more configuration parameters (e.g., sps-nofsub-Slots, sps-nofSlots).

For example, the wireless device may determine the first SPS PDSCH reception in the slot n+m. For example, the wireless device may determine the first SPS PDSCH reception in an earliest time domain resource of the one or more second time domain resources. The one or more time domain resources may comprise the one or more second time domain resources. The one or more second time domain resources may not overlap with uplink resource.

The wireless device may determine a first (e.g., an earliest) available time domain resource (e.g., downlink and/or flexible resource) as the first SPS PDSCH reception.

In an example, the wireless device may assume that resources indicated by the DCI (e.g., an activation DCI) for the first SPS PDSCH reception are downlink resources.

15 The wireless device may determine i-th SPS PDSCH reception in an i-th interval/periodicity as time domain resource in a slot q+i\*P, where a slot q is when the wireless device determines the first SPS PDSCH reception and P is the periodicity. The wireless device may determine, for the 20 i-th SPS PDSCH reception, a same set of symbols in the slot q+i\*P as the first SPS PDSCH reception.

For example, in FIG. 27, the wireless device may determine a last time domain resource for the first SPS PDSCH reception. The wireless device may determine the first SPS PDSCH reception in a slot n+m+K-1. The wireless device may determine a symbol [4-14] as time domain resource for the first SPS PDSCH reception. This may reduce ambiguity in determining a HARQ-ACK/PUCCH resource. Based on example embodiments, the wireless device may determine 30 periodic PUCCH resources for the SPS configuration in different interval/periods.

The wireless device may determine a last PDSCH occasion scheduled by the DCI as the first SPS PDSCH reception. The wireless device may determine a PDSCH occasion/resource, used for determining a PUCCH resource corresponding to the DCI, as the first SPS PDSCH reception. For example, when a second last time domain resource (e.g., a second last PDSCH occasion/resource or a second last SLIV value of the one or more SLIV values, resources determined based on a penultimate SLIV value of the TDRA entry indicated by the DCI). The wireless device may determine the first SPS PDSCH reception based on a resource used for determining a PUCCH resource for a DCI based on multi-PDSCH scheduling.

45 The wireless device may determine a PUCCH resource for each interval/periodicity based on a SPS PDSCH reception in the interval/periodicity. The wireless device may determine a PUCCH resource for the first SPS PDSCH reception based on a last time domain resource of the one or 50 more time domain resources indicated by the DCI.

For example, when the first SPS PDSCH reception is determined as the first SLIV/first time domain resource in FIG. 27, the wireless device may determine a PUCCH resource based on the last SLIV/last time domain resource in 55 a slot n+m+K-1. The wireless device may determine a PUCCH resource based on a PDSCH-to-HARQ\_feedback timing (e.g., k1) indicated by the DCI and the last time domain resource. The wireless device may determine a slot n+K-1+K1.

60 FIG. 28 illustrates an example of a PUCCH resource determination for a SPS configuration as per an aspect of an embodiment of the present disclosure.

In an example, a wireless device may be configured with a SPS configuration with a periodicity P. The wireless device may receive an activation DCI at a slot n. The activation DCI may indicate a slot/scheduling offset (k0) being as m (e.g., k0=m). The activation DCI may indicate a PDSCH-to-

HARQ\_feedback timing offset (k1) being as K1 (e.g., k1=K1). The activation DCI may indicate a TDRA entry with an index=1 (e.g., a TDRA entry shown in dotted box is indicated).

The wireless device may determine the activation DCI indicates multiple time domain resources based on the indicated TDRA entry. The wireless device may determine a first SPS PDSCH reception via resources determined based on first SLIV value or first time domain resource and the slot/scheduling offset. The first SLIV value may determine resources in a slot indicated by the slot/scheduling offset. For example, in FIG. 28, a slot n+m may be determined as the slot based on the k0 value and the slot n.

The wireless device may determine symbols [6, 11] as the first time domain resource based on the first SLIV value (start symbol=6 and the length=5). The start value and the length value of the SLIV value may be jointly encoded.

The wireless device may determine the first SPS PDSCH reception in the slot n+m.

The wireless device may determine periodic SPS PDSCH receptions based on the first SPS PDSCH reception and the periodicity. For example, a second SPS PDSCH reception of a second interval/period may occur in a slot n+m+P.

The wireless device may determine a PUCCH resource for the first SPS PDSCH based on a last (e.g., latest) time domain resource indicated by the DCI. For example, the last time domain resource of the TDRA entry may be determined based on the SLIV #K (e.g., K-th SLIV value, or last SLIV value). In the example, each SLIV may correspond to a slot, where each SLIV may be determined for each slot of a plurality of slots starting from the slot n+m. For example, the K-th SLIV may correspond to a slot n+m+K-1.

The wireless device may determine the slot n+m+K-1 as the last time domain resource. The wireless device may determine symbols [4-14] in the slot n+m+K-1 as the last time domain resource.

The wireless device may determine the PUCCH resource based on the last time domain resource. The wireless device may determine the PUCCH resource that occurs K1 slots/ sub-slots after the last time domain resource.

For example, a sub-slot may comprise 2 symbols, 4 symbols or 7 symbols. A slot may comprise two or more sub-slots.

The wireless device may determine a slot n+m+K-1+K1 for the PUCCH resource.

The wireless device may determine a k1 offset value (PDSCH-to-HARQ\_feedback timing) as K1+a gap.

The K1 may represent a value indicated by a PDSCH-to-HARQ\_feedback timing indicator field or an offset value configured by a RRC signaling. For example, the offset may indicate a timing offset between a PDSCH to a PUCCH resource. In FIG. 28, the K1 is indicated by the activation DCI.

The gap may represent a number of slots/sub-slots between a first slot/sub-slot of the first SPS PDSCH and a second slot/sub-slot of the last time domain resource. For example, in FIG. 28, the fist slot/sub-slot is a slot n+m. The second slot/sub-slot is a slot n+m+K-1. The gap may be K-1. The wireless device may determine the PDSCH-to-HARQ\_feedback timing (k1) as K1+K-1.

The wireless device may sum a value indicated by the PDSCH-to-HARQ\_feedback timing indicator field by the activation DCI and a gap between the first SPS PDSCH reception and the last time domain resource indicated by the activation DCI. The wireless device may determine the PUCCH resource based on the summing.

The wireless device may determine the PUCCH resource in the slot n+m+K1+K-1.

Similarly, for the second SPS PDSCH reception, the wireless device may determine a second PUCCH resource for the second SPS PDSCH reception in a second slot after K1+K-1 since the second SPS PDSCH reception. The wireless device may determine the second PUCCH at a slot n+m+P+K1+K-1.

Example embodiments allow the wireless device to determine a PUCCH resource of a SPS PDSCH reception in an interval/period based on one or more configured k1 values. The wireless device may determine a PUCCH resource for a multi-PDSCH DCI based on a last PDSCH scheduled by the multi-PDSCH DCI. Example embodiments may allow alignment of PUCCH resources between a SPS configuration and a multi-PDSCH DCI scheduled PDSCH(s). Example embodiments may allow periodic resources of PUCCH resources aligned with periodic SPS PDSCH receptions.

In an example, the wireless device may determine a PUCCH resource based on a last SPS PDSCH reception of one or more SPS PDSCH receptions in an interval/period, in response to sps-nofsub-slots or sps-nofslots being greater than 1. For example, when the wireless device determines a plurality of SPS PDSCH receptions, of a SPS configuration based on one or more configuration parameters, in a period/interval, the wireless device may determine a PUCCH resource based on a last (or a latest) SPS PDSCH reception of the plurality of SPS PDSCH receptions.

The wireless device may determine a PUCCH resource based on a last time domain resource indicated by the activation DCI otherwise. For example, when sps-nofsub-slots or sps-nofslots is not configured, or sps-nofsub-slots or sps-nofslots is configured as 1, the wireless device may determine the PUCCH resource based on the last time domain resource indicated by the activation DCI.

The activation DCI may refer a DCI activating a SPS configuration. The wireless device may determine a DCI as an activation DCI in response to a first field of the DCI being set to a first predetermined value and a second field of the DCI being set to a second predetermined value.

A wireless device may receive configuration parameters (e.g., via RRC signaling) indicating whether a SPS configuration is based on a slot as an unit or a sub-slot as an unit. When the configuration parameters may not be present, the wireless device may determine a slot is used for determining time domain resources (e.g., time domain resource(s) for SPS PDSCH reception, PUCCH resource, periodicity).

When the sub-slot is indicated as a unit, the wireless device may determine offset value(s) (e.g., slot/scheduling offset, PDSCH-to-HARQ\_feedback timing offset, SPS periodicity) based on the sub-slot.

The wireless device may be configured a unit for each offset value independently (e.g., slot/scheduling offset is based on a slot, a PUCCH resource is determined based on a sub-slot).

When a sub-slot is configured/determined/used for determining a PUCCH resource, the wireless device may determine a first sub-slot where a reference time domain resource (e.g., a first SPS PDSCH, last time domain resource) occurs.

The wireless device may determine a PUCCH resource occurring after k1 offset value since the first sub-slot.

For example, the first sub-slot may be determined based on a first symbol (e.g., earliest symbol) of the first SPS PDSCH reception or the last time domain resource.

For example, the first sub-slot may be determined based on a last symbol (e.g., latest symbol) of the first SPS PDSCH reception or the last time domain resource.

For example, the first sub-slot may be determined based on a last symbol of a PDSCH, where the PUCCH resource corresponds to a HARQ-ACK feedback of the PDSCH.

The wireless device may determine the first sub-slot that is overlapping with the first symbol or the last symbol of the first SPS PDSCH reception or the last time domain resource or the PDSCH. When a DCI may schedule multiple PDSCHs for a same PUCCH resource, a last PDSCH of the multiple PDSCHs may be used to determine the first sub-slot.

Similarly for i-th SPS PDSCH reception, the wireless device may determine a sub-slot of the i-th SPS PDSCH reception based on a first symbol (or a last symbol) of the i-th SPS PDSCH reception. The wireless device may determine a i-th PUCCH resource for the i-th SPS PDSCH reception based on a k1 offset determination and the sub-slot.

In an example, when a wireless device may determine a counter-DAI and/or a total-DAI based on a number of SPS PDSCH receptions in each period/interval or a number of SPS PDSCH receptions of a first period/interval indicated by the DCI and/or RRC configuration parameter.

For example, when the wireless device and the base station may indicate a single SPS PDSCH in each period/interval, the wireless device may determine a C-DAI/T-DAI based on 1 PDSCH (e.g., a T-DAI may be incremented by 1, a second C-DAI of a next DCI may be incremented by 1).

For example, when the base station configures a sps-nofsub-slots or a sps-nofslots (>1), the wireless device and the base station may determine the T-DAI incremented by the sps-nofsub-slots or the sps-nofslots. When a HARQ-ACK bit for the sps-nofusb-slots or the sps-nofslots is produced, the T-DAI may be incremented by 1. The second C-DAI of the next DCI may be incremented by the sps-nofusb-slots or the sps-nofslots. The wireless device and the base station may determine DAI value(s) based on a number of HARQ-ACK bits needed for the one or more SPS PDSCH receptions activated by the DCI for the first period/interval.

The wireless device and the base station may determine DAI value(s) based on a number of HARQ-ACK bits needed for one or more SPS PDSCH receptions mapping to a same PUCCH resource based on the SPS configuration. More details may be referred to FIG. 32.

In an example, a wireless device may receive an activation DCI, based on a multi-PDSCH scheduling or a multi-PDSCH DCI format, activating a SPS configuration.

The wireless device may determine one or more first SPS PDSCH receptions based on the activation DCI and the SPS configuration.

The wireless device may determine one or more second SPS PDSCH receptions based on the one or more first SPS PDSCH receptions and a periodicity of the SPS configuration.

The wireless device may activate or determine one or more SPS PDSCH reception occasions in each periodicity based on the periodicity of the SPS configuration.

FIG. 29 illustrates an example of a SPS configuration activation based on a multi-PDSCH DCI as per an aspect of an embodiment of the present disclosure.

The base station may transmit one or more RRC configuration (RRC configuration (SPS)) indicating a SPS configuration for a cell. The one or more RRC configurations may indicate a number of SPSs in a slot (e.g., sps-nofsub-slots) or a number of SPSs in consecutive slots (e.g., sps-nofSlots).

The wireless device may receive a DCI activating the SPS configuration at a slot n. The DCI may indicate a slot/scheduling offset (k0) for which the corresponding PDSCH transmission may be received. The wireless device may determine an earliest SPS PDSCH reception (e.g., first SPS PDSCH) based on the slot offset. For example, if k0 is m, the wireless device may determine the earliest SPS PDSCH reception at a slot n+m based on the DCI and the slot offset.

The SPS configuration is configured (e.g., comprises, includes, points to, etc.) with a periodicity (P). The wireless device may determine one or more first SPS PDSCH receptions based on the DCI. For example, the one or more first SPS PDSCH receptions (first SPS PDSCH receptions in FIG. 29) may be determined based on resource allocations of the DCI. For example, the DCI may indicate resources between [slot n+m, . . . , slot n+k].

The wireless device may determine one or more first SPS PDSCH receptions based on the DCI and one or more configuration parameters.

20 The wireless device may determine one or more first SPS PDSCH receptions (or first SPS PDSCHs) based on the earliest SPS PDSCH indicated by the DCI and one or more configuration parameters.

25 For example, the wireless device may determine the earliest SPS PDSCH reception in the slot n+m. For example, the wireless device may expect an earliest slot indicated by the DCI may not be uplink slot. The wireless device may assume that resources indicated by the DCI (e.g., an activation DCI) for the earliest SPS PDSCH reception are 30 downlink resources. The wireless device may determine a second slot (next slot of the earliest slot) is an uplink slot or not valid for a downlink SPS PDSCH reception. The wireless device may skip the slot n+m+1. The wireless device may map one or more SPS PDSCHs via one or more valid 35 slots in sequence based on reception timing. For example, the wireless device may map first SPS PDSCH in the slot n+m, second SPS PDSCH in slot n+m+2 (as slot n+m+1 is skipped), and map s1-th SPS PDSCH in a slot n+k. The wireless device may determine s1 numbers of SPS PDSCHs 40 mapped in a first periodicity/interval between [slot n+m, slot n+k].

The wireless device may determine one or more second SPS PDSCH receptions between [slot n+m+P, slot n+k+P]. The wireless device may determine an earliest slot of a 45 second periodicity based on the earliest slot of the first periodicity and the periodicity value P. The one or more second SPS PDSCH receptions may occur after P slots from the one or more first SPS PDSCH receptions. The wireless device may determine s2 number of SPS PDSCH receptions in the second periodicity. The s2 may be determined based on one or more valid slots between [slot n+m+P, slot n+k+P].

For example, the wireless device may determine first SPS PDSCH of the second periodicity in a slot n+m+P. The 55 wireless device may determine second SPS PDSCH Hof the second periodicity in a slot n+m+P+1. The wireless device may skip a slot n+m+P+2 as the slot n+m+P+2 is an uplink slot.

The wireless device may skip a slot n+k+P as the slot may be an uplink.

The wireless device may determine a number of one or more SPS PDSCH receptions in each periodicity based on slot formation information of one or more slots mapped to each periodicity.

65 The wireless device may determine a PUCCH resource for each periodicity based on a last SPS PDSCH of each periodicity. For example, the wireless device may determine

one or more slots of each periodicity based on the activation DCI. The wireless device may determine a last SPS PDSCH reception that is latest PDSCH in each interval/periodicity. For example, in the first periodicity, a SPS PDSCH #s1 (s1-th SPS PDSCH reception, s1-th SPS PDSCH) in the first periodicity is last SPS PDSCH of the first periodicity.

For example, in the second periodicity, a SPS PDSCH #s2 (s2-th SPS PDSCH reception) in the second periodicity is last SPS PDSCH of the second periodicity. For example, when all slots shown between slot n+m+P+2 to slot n+k+P are uplink slots in FIG. 29, SPS PDSCH #2 in the second SPS PDSCH receptions is the last SPS PDSCH of the second periodicity.

The wireless device may determine a first PUCCH resource for the one or more first SPS PDSCH receptions/SPS PDSCHs based on the last SPS PDSCH of the first periodicity. The wireless device may determine a second PUCCH resource for the one or more second SPS PDSCH receptions/SPS PDSCHs based on the last SPS PDSCH of the second periodicity. The second PUCCH resource may not occur after P from the first PUCCH resource based on example embodiments. Example embodiments may enable to determine a PUCCH resource occurring with a PDSCH-to-HARQ\_feedback timing (k1) offset from a last SPS PDSCH of each interval. Example embodiments may determine an earliest PUCCH resource based on the k1 offset.

The wireless device may determine a PUCCH resource for each periodicity based on a last slot, indicated by an activation DCI, of each periodicity. For example, the wireless device may determine a last slot in each periodicity/interval based on the activation DCI and the periodicity. The wireless device may determine a PUCCH resource based on the last slot of each periodicity/interval.

For example, a slot n+k is a last slot of the first periodicity. The wireless device may determine a PUCCH resource in a slot n+k+k1 for the first periodicity.

For example, a slot n+k+P is a last slot of the second periodicity. The wireless device may determine a PUCCH resource in a slot n+k+P+k1 for the second periodicity.

Each PUCCH resource of each periodicity may occur periodically based on the periodicity regardless of actual SPS PDSCH(s) in each periodicity.

FIG. 29 illustrates that the wireless device may transmit a PUCCH for the first SPS PDSCH receptions in a slot n+k+k1 where k1 is indicated by the activation DCI as a PDSCH-to-HARQ\_feedback timing offset.

The wireless device may determine one or more SPS PDSCH receptions/SPS PDSCHs in each periodicity based on slot formation information and/or resource assignment by the activation DCI (e.g., refer to FIG. 23). The wireless device may determine one or more slots of each periodicity based on resource assignment of the activation DCI and the periodicity of the SPS configuration. The wireless device may determine one or more SPS PDSCH receptions in each periodicity based on the one or more slots of the each periodicity and slot formation information.

For example, the wireless device may skip mapping a SPS PDSCH in a slot which may not have downlink/flexible resources in overlapped time domain of a resource allocation in that slot for the SPS PDSCH.

In an example, the wireless device may determine one or more HARQ-ACK bits for the one or more SPS PDSCH receptions in each periodicity. The wireless device may determine a single PUCCH resource for the one or more SPS PDSCH receptions based on a last PDSCH or a last slot of the each periodicity and k1 offset indicated by an activation

DCI. The wireless device may transmit the one or more HARQ-ACK bits via the single PUCCH resource.

In an example, a wireless device may receive one or more RRC messages indicating/comprising configuration parameters. The configuration parameters may indicate a SPS configuration of a cell. The SPS configuration may comprise a periodicity. The SPS configuration may comprise one or more parameters to receive one or more SPS PDSCHs based on the SPS configuration.

10 The configuration parameters may indicate a multi-PDSCH DCI scheduling for the cell. The configuration parameters may indicate one or more search spaces with a multi-PDSCH DCI format. The wireless device may receive a DCI, based on the multi-PDSCH DCI format, scheduling one or more PDSCHs for the cell. The one or more PDSCHs may comprise one or more transport blocks for the cell.

15 The configuration parameters may indicate the SPS configuration may be activated with one or more DCIs based on the multi-PDSCH DCI format. For example, the configuration parameters may indicate to use a time domain resource allocation table, configured for a multi-PDSCH scheduling of the cell, for the SPS configuration.

20 For example, the configuration parameters may indicate a DCI based on the multi-PDSCH DCI format may activate or release or schedule resources for retransmission of one or more transport blocks scheduled via the SPS configuration.

25 The wireless device may receive a DCI activating the SPS configuration. The DCI may indicate a slot offset (k0) for a starting SPS PDSCH reception. The DCI may indicate one or more time domain resources (e.g., slots, SLIV values based on a TypeB PDSCH mapping type, SLIV values based on a TypeA PDSCH mapping type), where each of the one or more time domain resources corresponds to a PDSCH.

30 The DCI may schedule one or more PDSCHs via the one or more time domain resources. The DCI may indicate a frequency domain resource. The frequency domain resource may be applied to each PDSCH or each slot or each SLIV time domain resource.

35 Example embodiments in the specification may be applied for each slot. For example, a slot may be mapped to at most one PDSCH. Example embodiments in the specification may be applied for each PDSCH or each time domain resource. For example, a slot may be mapped to one or more PDSCHs. Each time domain resource (e.g., SLIV) may indicate a starting symbol and a length for a PDSCH. Each time domain resource (e.g., SLIV) may indicate a starting symbol, a length for a PDSCH and a repetition.

40 In an example, a wireless device may determine multiple SPS configurations are activated based on an activation DCI comprising/indicating a plurality of time domain resources. For example, each time domain resource of the plurality of time domain resources may be activated for a SPS configuration. The wireless device may determine a SPS configuration index based on an index of the SPS configuration, where each of the multiple SPS configurations may have the index of the SPS configuration added by K. For example, K may refer an order of a SPS PDSCH, for a second SPS configuration of the multiple SPS configurations, among the plurality of SPS PDSCHs scheduled by the activation DCI.

45 For example, in FIG. 29, a first SPS configuration may refer the SPS configuration with the index. A second SPS configuration may refer a second SPS configuration based on a second SPS PDCH reception (e.g., SPS PDSCH #2) with an index incremented by 1 from the index of the SPS configuration. A third SPS configuration may refer a third SPS configuration based on a third SPS reception (e.g., SPS PDSCH #3) with an index incremented by 2 from the index

of the SPS configuration. The K may refer an order -1 of a SPS PDSCH for the corresponding SPS configuration.

// HARQ ID

In an example, a wireless device may determine a HARQ process identifier of a SPS PDSCH reception based on a slot index and/or a symbol index where the SPS PDSCH reception occurs.

For example, the wireless device may determine a HARQ process ID of a SPS PDSCH reception based on HARQ Process ID=[floor (CURRENT\_slotx10/(numberOfSlotsPerFrame×periodicity))] modulo nrofHARQ-Processes. The current\_slot may be determined as [(SFN×numberOfSlotsPerFrame)+slot number in the frame], where for example SFN indicates system frame number corresponding to resources of the SPS PDSCH reception. numberOfSlotsPerFrame may refer a number of consecutive slots in a system frame that may be determined based on a subcarrier spacing of a cell where a SPS configuration for the SPS PDSCH reception is configured. For example, the numberOfSlotsPerFrame may be 10 for 15 kHz, and  $10 \times 2^u$  for  $15 \times 2^u$  subcarrier spacing.

nrofHARQ-Processes may refer a number of HARQ processes configured for the wireless device for one or more SPS configurations.

A module B (A % B) may refer a remainder of A divided by B.

When an activation DCI and/or RRC configuration (e.g., sps-nofslots) may activate a plurality of SPS PDSCH receptions in each interval/period, the wireless device may determine a plurality of HARQ process IDs for the plurality of SPS PDSCH receptions based on a first HARQ process ID of a first SPS PDSCH reception. For example, the first SPS PDSCH reception may refer a first/earliest (or a last/latest) SPS PDSCH reception of the plurality of SPS PDSCH receptions.

The wireless device may increment a HARQ process ID for a next SPS PDSCH reception (or a previous SPS PDSCH reception) based on the first AHRQ process ID of the first SPS PDSCH reception.

For example, the wireless device may determine a first HARQ process ID for the first SPS PDSCH (e.g., SPS PDSCH #1). The wireless device may increment the first HARQ process ID for the SPS PDSCH #2.

The wireless device may increment by 1 for a HARQ process ID in each time domain resource indicated by the activation DCI.

The wireless device may increment by 1 for a HARQ process ID in each valid SPS PDSCH reception.

The wireless device may increment a HARQ process ID by 1 in every slot between an earliest slot and a latest slot of the one or more slots scheduled by the DCI. The wireless device may continue incrementing HARQ process IDs across the plurality of SPS PDSCH receptions regardless of whether each of the plurality of SPS PDSCH receptions is skipped or not (e.g., valid or invalid, scheduled or not scheduled).

In an example, an activation DCI may indicate a TDRA entry that may determine a plurality of time domain resources in a slot. For example, the TDRA entry may comprise, in a first slot, a first SLIV value and a second SLIV value. The first SLIV value and the second SLIV value may be based on a PDSCH mapping type B.

FIG. 30 illustrates an example of HARQ process ID determination as per an aspect of an embodiment of the present disclosure.

The wireless device may be configured with a TDA table comprising one or more TDRA entries. A TDRA entry of the

one or more TDRA entries may comprise one or more SLIV values. The base station may transmit one or more RRC messages indicating configuration parameters. The configuration parameters may indicate a time domain resource allocation unit for each TDRA entry of the one or more TDRA entries. For example, the time domain resource allocation unit may be a slot or a sub-slot. When the sub-slot is indicated as the time domain resource allocation unit, a size of the sub-slot may be indicated. A unit may be configured a number of symbols used in each SLIV value.

For example, a sub-slot may be 2 symbols, 4 symbols or 7 symbols. Based on a size of the sub-slot, the wireless device may determine a number of sub-slots in a slot (e.g., 7 sub-slots in case of 2 symbols, 3 (or 4) sub-slots in case of 3 symbols, 2 sub-slots in case of 7 symbols). Each SLIV value of the TDRA entry may be applied to each subslot sequentially. For example, the TDRA entry may comprise 2 SLIV values. The wireless device may determine a first time domain resource within a first sub-slot that is determined based on a slot/scheduling offset. The first time domain resource (e.g., symbols) within the first sub-slot may be determined based on a first SLIV value of the two SLIV values. The wireless device may determine a second time domain resource in a second sub-slot that is a next sub-slot of the first sub-slot. The wireless device may determine the second time domain resource based on a second SLIV value of the two SLIV values.

The wireless device may determine a sub-slot or slot based on a PDSCH mapping associated with a SLIV value. The TDRA entry may comprise a set of {a PDSCH mapping type, a SLIV value}. The wireless device may determine a first slot based on a slot/scheduling offset of an activation DCI. The wireless device may determine a time domain resource based on the PDSCH mapping type and the SLIV value. For example, a {a PDSCH mapping type, a SLIV value} may be assumed to be mapped to a slot. A slot may correspond to at most one {a PDSCH mapping type, a SLIV value}. For example, the wireless device may map more than one {a PDSCH mapping type, a SLIV value} to a slot.

For example, the TDRA entry may comprise {mapping type B, [1-5]} and {mapping type B, [6-10]} that indicates a first PDSCH and a second PDSCH are scheduled with a PDSCH mapping type B. The first PDSCH may occur in symbol [1-5] (e.g., starting symbol is 1 and a length is 5). The second PDSCH may occur in symbols [6-10] (e.g., starting symbol is 6 and length is 5). The wireless device may determine the first SPS and the second SPS in a same slot.

The wireless device may determine whether to determine multiple time domain resources in a slot based on one or more RRC signaling. For example, the one or more RRC signaling may comprise a unit used for a time domain resource (e.g., sub-slot). For example, the one or more RRC signaling may indicate a number of schedulable PDSCHs in a slot (e.g., greater than 1).

When the wireless device may not support receiving more than one PDSCH of a cell in a slot, the wireless device may determine a time domain resource based on a unit size of a slot. When the one or more RRC signaling is not available, the wireless device may determine a time domain resource based on a unit size of a slot.

In FIG. 30, the wireless device may receive an activation DCI (DCI) activating a SPS configuration at a slot n. The activation DCI may indicate a slot offset (k0=p). The wireless device may determine a first slot where the wireless device receives a first SPS PDSCH reception as a slot n+p (e.g., k0 offset after the DCI).

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The DCI may indicate a TDRA entry that may comprise K SLIV values.

For example, K SLIV values may comprise 1<sup>st</sup> SLIV value, 2<sup>nd</sup> SLIV value, . . . , and K-th SLIV value. The TDRA entry may be indicated with a unit of a sub-slot (e.g., 7 symbols based on NCP, 6 symbols based on ECP). The wireless device may determine maximum two PDSCHs of two sub-slots in a slot.

The wireless device may determine a first time domain resource in a first sub-slot of the slot n+p based on the 1<sup>st</sup> SLIV value.

The wireless device may determine a second time domain resource in a second sub-slot of the slot n+p based on 2<sup>nd</sup> SLIV value.

The wireless device may determine a third/a fourth time domain resources in a slot n+p+1 based on 3<sup>rd</sup>/4<sup>th</sup> SLIV values.

The wireless device may determine a PDSCH or a SPS PDSCH reception based on a time domain resource.

The wireless device may determine K SPS PDSCH receptions or PDSCHs based on the K SLIV values.

The wireless device may determine K SPS PDSCH receptions as first SPS PDSCH receptions in a first interval/period of the SPS configuration.

The wireless device may determine a first HARQ process ID based on the first time domain resource of a first SPS PDSCH reception. The first SPS PDSCH receptions comprise the first SPS PDSCH reception. The first SPS PDSCH reception may refer an earliest SPS PDSCH reception among the first SPS PDSCH receptions.

The wireless device may determine the first HARQ process ID based on a starting symbol and/or a slot where the first time domain resource occurs.

The wireless device may determine a i-th SPS PDSCH reception of the first SPS PDSCH receptions as (the first HARQ process ID+(i-1)) modulo nrofHARQ-Proceses.

For example, as shown in FIG. 30, the wireless device may determine the first HARQ process ID as Q. The wireless device may increment by 1 in each PDSCH such that a HARQ process ID is increased by 1 in a SPS PDSCH reception compared to immediately previous SPS PDSCH reception. For example, a PDSCH #4 (4<sup>th</sup> SPS PDSCH reception) may have a HARQ process ID of Q+3.

The wireless device may determine or increment the HARQ process ID regardless of whether a SPS PDSCH reception may be skipped or dropped (e.g., due to conflict with uplink resources, e.g., due to a prioritization among different channels/signals).

The wireless device may determine second SPS PDSCH receptions based on the first SPS PDSCH receptions and a periodicity of the SPS configuration.

The wireless device may determine a second HARQ process ID based on an earliest SPS PDSCH reception of the second SPS PDSCH receptions. The wireless device may increment by 1 in each SPS PDSCH reception of the second SPS PDSCH receptions based on a timing order of resources of the each SPS PDSCH reception (e.g., from earliest resource to latest resource).

In an example, a wireless device may determine a HARQ process ID of a SPS PDSCH reception based on a time resource of the SPS PDSCH reception. When the SPS PDSCH reception may be scheduled based on a unit of a sub-slot, the wireless device may determine the HARQ process ID as HARQ Process ID=[floor(CURRENT\_symbol/periodicity)] modulo nrofHARQ-Proceses. For example, the wireless device may determine CURRENT\_symbol as (SFN×numberOfSlotsPerFrame×numberofSymbolPerSlot+slot number in the frame×numberofSymbolsPerSlot×symbol number in the slot). For example, numberofSymbolsPerSlot may be 14 based on a normal CP of a numerology of a cell. For example, numberofSymbolsPerSlot may be 12 based on an extended CP of a numerology of a cell. The cell may refer a serving cell configured with a SPS configuration for the SPS PDSCH reception.

In an example, a wireless device may be configured with a first serving cell and a second serving cell. The first serving cell may comprise one or more PUCCH resources. The wireless device may receive one or more RRC messages indicating configuration parameters. The configuration parameters may comprise/indicate a SPS configuration of the second serving cell. A first active BWP of the first serving cell may be based on a first subcarrier spacing (e.g., 15 kHz). A second active BWP of the second serving cell may be based on a second subcarrier spacing (e.g., 960 kHz).

The configuration parameters may indicate a periodicity of the SPS configuration. For example, the periodicity may be M slots based on the second subcarrier spacing. For example, the periodicity may be smaller than a slot duration of the first serving cell. For example, the periodicity may be 16 slots. For example, a first slot of the first active BWP may overlap with 64 second slots of the second active BWP. Within the first slot, potentially 4 SPS PDSCH periods/intervals of the SPS configuration may occur.

The wireless device may receive an activation DCI activating the SPS configuration of the second serving cell. The wireless device may determine to activate the SPS configuration in response to receiving the activation DCI. The activation DCI may indicate a PDSCH-to-HARQ\_feedback timing offset (e.g., k1) as K1 (e.g., K 1=1).

The wireless device may determine a slot of the first active BWP for a PUCCH resource for the activation DCI. For example, the wireless device may determine a first slot of the first active BWP (e.g., an active BWP of a PUCCH cell) that overlaps with a PDSCH of a scheduled cell for a PUCCH resource. The PDSCH may refer a SPS PDSCH reception of the second cell for the PUCCH resource, where the wireless device may transmit a HARQ-ACK feedback corresponding to the SPS PDSCH reception via the PUCCH resource.

The wireless device may apply the K1 based on the first slot. The wireless device may determine a next slot of the first active BWP that has a slot index incremented by 1 from the first slot of the first active BWP.

The wireless device may activate a first SPS PDSCH reception based on a slot/scheduling offset (e.g., k0) indicated by the activation DCI. For example, the wireless device may determine a slot m as the first SPS PDSCH reception. The wireless device may determine a plurality of SPS PDSCH receptions of a plurality of interval/periods, where each of the plurality of SPS PDSCH receptions may correspond to each interval/period of the plurality of interval/periods. The plurality of interval/periods may comprise first time domain resource/period indicated by the activation DCI. The plurality of SPS PDSCH receptions may comprise the first SPS PDSCH reception indicated by the activation DCI.

In an example, the wireless device may be configured with a sps-nofslots or a sps-nofsub-slots that may determine a plurality of SPS PDSCH receptions in a period/interval.

The wireless device may need to determine a plurality of HARQ-ACK bits corresponding to the plurality of SPS PDSCH receptions. For example, the wireless device may determine a HARQ-ACK bit (or two HARQ-ACK bits if

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two codewords are scheduled per each SPS PDSCH reception) for a SPS PDSCH reception.

In an example, the wireless device may receive the activation DCI. The wireless device may be able to determine a number of HARQ-ACK bits for a PUCCH resource based on the SPS configuration and the activation DCI.

In an example, the wireless device may miss or fail to receive the activation DCI. For example, a channel condition may be poor so that the wireless device may fail to decode the activation DCI successfully. When the wireless device misses the activation DCI, the wireless device may not know whether there is a plurality of SPS PDSCHs scheduled/indicated by the activation DCI (e.g., based on a short periodicity and/or based on a number of SPS receptions (e.g., sps-nofsub-slots, sps-nofslots) configured via a RRC signaling.

The wireless device may not know whether the base station activates the SPS configuration.

The wireless device may not be able to determine a number of HARQ-ACK bits corresponding to the activation DCI when the wireless device misses the activation DCI.

The base station may need to determine a bit size of a HARQ-ACK codebook comprising HARQ-ACK feedback for the activation DCI based on at least two conditions. For example, one condition may be based on a case that the wireless device has successfully received the activation DCI. The wireless device may generate a number of HARQ-ACK bits (e.g., M) based on a plurality of SPS PDSCH receptions. Another condition may be based on a case that the wireless device has not successfully received the activation DCI. The wireless device may generate a single HARQ-ACK bit corresponding to the activation DCI.

This may increase complexity at the base station. This may reduce reliability of the HARQ-ACK codebook. For example, when the base station determines M as the HARQ-ACK codebook size whereas the wireless device may transmits 1 bit, the base station may fail to successfully decode the HARQ-ACK codebook. With failure of HARQ-ACK codebook decoding, the base station may need to retransmit all data scheduled/feedbacked via the HARQ-ACK codebook. This may increase the retransmission overhead and may reduce reliability and may increase latency in data transmission.

In an example, the base station and the wireless device may determine a single HARQ-ACK bit corresponding to the activation DCI regardless of a number of SPS PDSCH receptions activated by the activation DCI.

FIG. 31 illustrates an example of a single HARQ-ACK bit of a plurality of SPS PDSCH receptions as per an aspect of an embodiment of the present disclosure.

The wireless device may be configured with a first cell (cell 0) and a second cell (cell 1). The wireless device may be configured with PUCCH resources via the first cell. The wireless device may be configured with a SPS configuration via the second cell. The first cell may operate in a first subcarrier spacing (e.g., 15 kHz, 30 kHz). The second cell may operate in a second subcarrier spacing (e.g., 480 kHz, 960 kHz, 120 kHz).

The second cell may be configured with a multi-PDSCH scheduling. The second cell may be configured with a single-PDSCH scheduling. The SPS configuration may be configured with a sps-nofsub-slots or a sps-nofslots for determining a plurality of SPS PDSCH receptions in a period/interval. The wireless device may be configured with configuration parameters via a RRC signaling (e.g., one or more RRC messages may indicate the configuration parameters).

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The wireless device may receive an activation DCI via the second cell at a first time (T0). The activation DCI may indicate a slot offset (k0) as 1. The activation DCI may indicate a PDSCH-to-HARQ\_feedback timing (k1) as 1.

5 For example, the wireless device may determine a slot of a first SPS PDSCH reception (#1) based on the slot offset (k0) and a first slot when the wireless device receives the activation DCI.

10 The wireless device may determine the slot at a second time (T2) as the first SPS PDSCH reception. The activation DCI may schedule one or more time domain resources based on a multi-PDSCH DCI format. The wireless device may determine a single time domain resource of the one or more time domain resources for the first SPS PDSCH reception. For example, the wireless device may determine first/earliest time domain resource of the one or more time domain resources as resources for the first SPS PDSCH reception. For example, the wireless device may determine last/latest time domain resource of the one or more time domain resources as resources for the first SPS PDSCH reception.

15 The wireless device may determine a PUCCH resource in a slot n+1 based on the slot where the wireless device is scheduled to receive the first SPS PDSCH or a last time domain resource of the one or more time domain resources and the k1. For example, the wireless device may determine a second slot of the first cell, where the second slot overlaps with the slot or the last time domain resource. The wireless device may determine a slot n as the second slot of the first cell.

20 25 The wireless device may determine a slot n+1 of the first cell as a third slot for the PUCCH resource based on the k1 (e.g., one slot after the a slot of the first slot, where the slot overlaps with a corresponding PDSCH for a HARQ-ACK feedback via the PUCCH resource).

30 The wireless device may determine a second SPS PDSCH reception (#2) in a second period/interval at a third time (T2) based on a periodicity of the SPS configuration.

35 The wireless device may determine a third SPS PDSCH reception (#3) and a fourth SPS PDSCH reception (#4) based on the periodicity and the first SPS PDSCH reception (e.g., an i-th SPS PDSCH reception occurs at i\*P slots/sub-slots/time units after the first SPS PDSCH reception). A time unit may be used for a periodicity/k0/k1 offset based on a sub-slot or slot or M slots or K sub-slots or Q symbols or a combination of symbols, sub-slots and/or slots.

40 The third SPS PDSCH reception and the fourth SPS PDSCH reception may occur at T3 and T4 respectively.

45 The wireless device may determine the PUCCH resource in the slot n+1 that may occur in a few last symbols of the slot n+1. The wireless device may determine the PUCCH resource occurring at T5.

50 The wireless device may determine a second PUCCH resource of the second SPS PDSCH reception based on the k1 value indicated by the activation DCI. The wireless device may determine a same k1 value is applied for the second SPS PDSCH reception to determine the second PUCCH resource. The wireless device may determine the slot n overlaps with a third slot of the second SPS PDSCH reception. The wireless device may determine the slot n+1 as the second PUCCH resource based on the k1 value and the slot n. The wireless device may determine the second PUCCH resource being same as the PUCCH resource.

55 60 Similarly, the wireless device may determine a third PUCCH resource for the third SPS PDSCH reception occurring at the slot n+1 (e.g., based on the third SPS PDSCH reception overlapping with the slot n and k1 value).

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The wireless device may determine the third PUCCH resource same as the PUCCH resource.

The wireless device may determine that three SPS PDSCH receptions (#1, #2 and #3) are mapping/associated with the PUCCH resource in the slot n+1.

In an example, the wireless device may determine a HARQ-ACK bit for a plurality of SPS PDSCH receptions corresponding to a PUCCH resource. For example, the wireless device may determine the HARQ-ACK bit for a first/earliest SPS PDSCH of the plurality of SPS PDSCH receptions. For example, the wireless device may determine the HARQ-ACK bit for a last/latest SPS PDSCH reception of the plurality of SPS PDSCH receptions. The plurality of SPS PDSCH receptions may comprise the first/earliest SPS PDSCH reception activated by the activation DCI. For example, resources of the first/earliest SPS PDSCH reception may be determined based on a slot/scheduling offset and a first SLIV value indicated by the activation DCI.

The wireless device may determine the base station transmits a single SPS PDSCH transmission based on the activation DCI until it receives a HARQ-ACK feedback via the PUCCH resource. The base station may skip transmission of the plurality of SPS PDSCH receptions except for the first/earliest SPS PDSCH reception or the last/latest SPS PDSCH reception until the HARQ-ACK feedback. For example, the base station may transmit a single SPS PDSCH of the plurality of SPS PDSCH receptions and may skip remaining SPS PDSCH receptions of the plurality of SPS PDSCH receptions. In FIG. 31, the base station may transmit a transport block via a PDSCH via the first SPS PDSCH reception. The base station may skip transmission of the second SPS PDSCH reception and the third SPS PDSCH reception.

The base station may transmit a second transport block via the fourth SPS PDSCH reception as a fourth PUCCH resource of the fourth SPS PDSCH reception may be different from the PUCCH resource.

In an example, the base station may transmit data via the second SPS PDSCH reception and the third SPS PDSCH reception. The wireless device may determine a single HARQ-ACK bit for a plurality of transport blocks via the three SPS PDSCH receptions. For example, the wireless device may determine a ACK in response to the wireless device receiving data successfully via the three SPS PDSCH receptions. The wireless device may determine a NACK otherwise. For example, the wireless device may determine a ACK in response to receiving data successfully via at least one SPS PDSCH reception among the three SPS PDSCH receptions. The wireless device may determine a NACK otherwise. For example, the wireless device may determine ACK or NACK for the first (or a last/latest) SPS PDSCH of the three SPS PDSCH receptions. The wireless device may ignore remained SPS PDSCH receptions/SPS PDSCHs in generating HARQ-ACK feedback.

In an example, the base station may activate the SPS activation after receiving the HARQ-ACK feedback corresponding to the activation DCI. For example, the base station may start transmission of one or more SPS PDSCH receptions after receiving the HARQ-ACK feedback. The wireless device may determine a PUCCH resource for the activation DCI based on a last time domain resource indicated by the activation DCI. For example, when the activation DCI indicates a plurality of time domain resources based on a plurality of SLIV values, the wireless device may determine a PUCCH resource based on the last time domain resource of the plurality of time domain resources.

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The wireless device may determine a HARQ-ACK bit for a plurality of transport blocks via a plurality of SPS PDSCH receptions, where the plurality of SPS PDSCH receptions may comprise a first (e.g., an activated) SPS PDSCH reception. The first or the activated SPS PDSCH reception may refer a SPS PDSCH reception that is determined/activated by the activation DCI. For example, when the wireless device determines resources based on a first SLIV value and a slot/scheduling offset indicated by the activation DCI, the activated SPS PDSCH reception may be determined based on the resources. For example, the first SLIV value may be an earliest SLIV value of one or more SLIV values indicated by the activation DCI. For example, when the wireless device determines resources, for the first SPS PDSCH, based on a last SLIV value of the plurality of SLIV values, the resources may be referred as the activated SPS PDSCH reception.

The wireless device may determine the first SPS PDSCH reception or the activated SPS PDSCH reception that is an earliest SPS PDSCH reception of first interval/period of the SPS configuration. When there are a plurality of SPS PDSCH receptions in the first period/interval, earliest SPS PDSCH reception may be referred as the first SPS PDSCH reception or the activated SPS PDSCH reception.

In an example, a base station may configure an additional slot offset (k0\_offset) for a SPS configuration. A wireless device may determine a time domain resource of an activated SPS PDSCH in response to receiving an activation DCI based on a slot offset (k0) indicated by the activation DCI and the additional slot offset (k0\_offset). For example, the wireless device may determine the time domain resource may occur k0+k0\_offset after a time when the wireless device receives the activation DCI. This may allow the base station to schedule a first SPS PDSCH reception such that a single SPS PDSCH may be determined based on the activation DCI (e.g., schedule the activated SPS PDSCH close to a PUCCH resource).

In an example, a base station may indicate a number of HARQ-ACK bits corresponding to a number of a plurality of SPS PDSCH receptions comprising an activated SPS PDSCH reception via a counter-DAI and/or a total-DAI. The plurality of SPS PDSCH receptions may be determined based on a SPS configuration. An activation DCI of the SPS configuration may comprise the counter-DAI and/or the total DAI.

For example, the base station may indicate a number of scheduled SPS PDSCH receptions since the activation DCI, where HARQ-ACK feedback(s) of the scheduled SPS PDSCH receptions correspond to a PUCCH resource.

FIG. 32 illustrates an example DAI mechanism for a plurality of SPS PDSCH receptions as per an aspect of an embodiment of the present disclosure.

FIG. 32 shows a similar scenario to FIG. 31 except a HARQ-ACK codebook generation and a counter-DAI/a total-DAI of an activation DCI. The base station may indicate a number of HARQ-ACK bits corresponding to one or more SPS PDSCHs activated based on the activation DCI via the counter-DAI (C-DAI) and/or the total-DAI (T-DAI).

The one or more SPS PDSCHs may comprise an activated SPS PDSCH by the activation DCI. The one or more SPS PDSCHs may also comprise one or more second SPS PDSCH receptions determined based on a SPS configuration. For example, the one or more second SPS PDSCH receptions may comprise periodic resources based on a periodicity of the SPS configuration (e.g., a second SPS PDSCH reception (#2), a third SPS PDSCH reception (#3)), where PUCCH resource(s) of the one or more second SPS

PDSCH receptions are same as a PUCCH resource of the activated SPS PDSCH. The activated SPS PDSCH may refer a first SPS PDSCH scheduled by the activation DCI.

For example, the one or more second SPS PDSCH receptions may comprise consecutive resources (e.g., in consecutive sub-slots based on sps-nofsub-slots or in slots based on sps-nofslots) based on resources of the activated SPS PDSCH. A PUCCH resource of the one or more second SPS PDSCH receptions and the activated SPS PDSCH may be determined based on a last SPS PDSCH reception of the one or more second SPS PDSCH receptions. A PUCCH resource of the one or more second SPS PDSCH receptions and the activated SPS PDSCH may be determined based on the activated SPS PDSCH. A PUCCH resource may be determined for each of the one or more SPS PDSCH receptions.

A PUCCH resource of a SPS PDSCH or a PDSCH may be determined based on a PDSCH-to-HARQ\_feedback timing indicated by the activation DCI or a RRC signaling, where the PUCCH resource may occur after PDSCH-to-HARQ\_feedback timing since a reception timing of the SPS PDSCH or the PDSCH or resources of the SPS PDSCH reception.

The activation DCI may comprise the counter-DAI (refer to FIG. 26) that may count/represent an accumulative number of scheduled PDSCHs (e.g., comprising one or more SPS PDSCHs) or a number of HARQ-ACK bits up to a current PDCCH monitoring occasion of a serving cell. The current PDCCH monitoring occasion may refer a search space monitoring occasion where the wireless device monitors the activation DCI. The serving cell may refer a cell configured with the SPS configuration.

The activation DCI may comprise the total DAI. The total DAI may count/represent (refer to FIG. 26) a total number of scheduled PDSCHs or a number of HARQ-ACK bits up to the current PDCCH monitoring occasion of any serving cell. The total-DAI may count a number of HARQ-ACK bits or a number of scheduled PDSCHs of the current PDCCH monitoring occasion for the serving cell. The counter-DAI may not count the number of HARQ-ACK bits or the number of scheduled PDSCHs of the current PDCCH monitoring occasion for the serving cell. The number of HARQ-ACK bits or the number of scheduled PDSCHs may indicate how many SPS PDSCH receptions have been scheduled via the current PDCCH monitoring occasion of the cell.

For example, the base station may schedule K SPS PDSCH receptions based on the activation DCI. For the SPS configuration, the base station and the wireless device determine K based on one or more SPS PDSCH receptions corresponding to a same PUCCH resource to the activated SPS PDSCH.

FIG. 32 shows K is 3.

The C-DAI may determine a starting bit index of a HARQ-ACK codebook via the PUCCH resource. The starting bit index may be used for K SPS PDSCH receptions based on the activation DCI. The T-DAI may determine an ending bit index of the HARQ-ACK codebook for the K SPS PDSCH receptions.

In an example, the wireless device may determine a number of HARQ-ACK bits corresponding to the activation DCI based on a next DCI. When the wireless device is configured with a second PDCCH monitoring occasion via a second cell, where the second PDCCH monitoring occasion overlaps with the current PDCCH monitoring occasion of the cell, a second DCI via the second PDCCH monitoring occasion may comprise a second C-DAI and a second T-DAI.

The second C-DAI may indicate K as an accumulative number up to the second PDCCH monitoring occasion (but not including the second PDCCH monitoring occasion). The second T-DAI may indicate K+M and the T-DAI of the activation DCI may indicate K+M. For example, M is a number of PDSCH scheduled via the second DCI. The T-DAI of the activation DCI may be equal to the second T-DAI of the second DCI as the PDCCH monitoring occasion and the second PDCCH monitoring occasion overlap (or starting symbol of both monitoring occasions overlap).

Based on the C-DAI/T-DAI, the wireless device may determine a number of HARQ-ACK bits for the activation DCI. The wireless device may determine three HARQ-ACK bits for the three SPS PDSCHs. The wireless device may place a first HARQ-ACK bit for the activated SPS PDSCH (#1) first, a second HARQ-ACK bit for the second SPS PDSCH (#2) second, and a third HARQ-ACK bit for the third SPS PDSCH (#3) last. The wireless device may generate the number of HARQ-ACK bits for the three SPS PDSCHs. The wireless device may determine first HARQ-ACK sub-codebook for the HARQ-ACK bits. For example, the first HARQ-ACK sub-codebook may be used for one or more HARQ-ACK bits for transport blocks via PDSCHs based on non-CBG transmission (e.g., TB-based transmission). The wireless device may generate a HARQ-ACK codebook comprising the first HARQ-ACK sub-codebook. The wireless device may transmit the HARQ-ACK codebook comprising the HARQ-ACK bits via the PUCCH resource. In an example, the wireless device may determine second HARQ-ACK sub-codebook for the HARQ-ACK bits. The second HARQ-ACK sub-codebook may be used for a multi-PDSCH scheduling. The wireless device may determine the HARQ-ACK codebook comprising the second HARQ-ACK sub-codebook.

One or more examples shown in FIG. 24-25 in generating HARQ-ACK bits(bitmap may be used for generating/determining HARQ-ACK bits of one or more SPS PDSCH receptions.

In an example, a C-DAI may represent an accumulative number of scheduled PDSCHs or a number of HARQ-ACK bits, other than a current DCI, up to a current PDCCH monitoring occasion of a serving cell. The C-DAI may not count a number of scheduled PDSCHs/a number of HARQ-ACK bits by the current DCI via the current PDCCH monitoring occasion of the serving cell. The current DCI may refer a DCI scheduled via the current PDCCH monitoring occasion of the serving cell. C-DAI of the activation DCI based on the example may be 0.

In an example, a T-DAI may represent an accumulative/total number of scheduled PDSCHs or a number of HARQ-ACK bits, with one or more current DCIs, up to a current PDCCH monitoring occasion across one or more serving cells. The C-DAI may count a number of scheduled PDSCHs/a number of HARQ-ACK bits by the one or more current DCIs via the current PDCCH monitoring occasions of the one or more serving cells. The one or more current DCIs may refer one or more DCIs scheduled via the one or more current PDCCH monitoring occasion across the one or more serving cells. T-DAI of the activation DCI based on the example may be 2.

In an example, a C-DAI may represent an accumulative number of scheduled PDSCHs or a number of HARQ-ACK bits, with a current DCI, up to a current PDCCH monitoring occasion of a serving cell. The C-DAI may count a number of scheduled PDSCHs/a number of HARQ-ACK bits by a

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DCI via the current PDCCH monitoring occasion of the serving cell. C-DAI of the activation DCI based on the example may be 2.

In an example, a T-DAI may represent an accumulative/total number of scheduled PDSCHs or a number of HARQ-ACK bits, other than one or more current DCIs, up to a current PDCCH monitoring occasion across one or more serving cells. The C-DAI may not count a number of scheduled PDSCHs/a number of HARQ-ACK bits by the one or more current DCIs via the current PDCCH monitoring occasions of the one or more serving cells. The one or more current DCIs may refer one or more DCIs scheduled via the one or more current PDCCH monitoring occasion across the one or more serving cells. T-DAI of the activation DCI based on the example may be 0.

A combination of examples of a C-DAI and a T-DAI may be considered.

Example embodiments may reduce ambiguity in determining a HARQ-ACK codebook size. The wireless device may determine a number of HARQ-ACK bits based on C-DAI/T-DAI of one or more DCIs mapping to the PUCCH resource.

In an example, a semi-persistent CSI feedback may be configured via RRC signaling. A DCI may activate the semi-persistent CSI feedback (e.g., SP-CSI report) via PUSCHs or PUCCHs. Example embodiments may be applicable to determine a single PUSCH or a single PUCCH for each period/interval of the SP-CSI feedback. Example embodiments may be applicable to determine multiple PUSCHs or multiple PUCCHs in each period/interval of the SP-CSI feedback. When multiple PUSCHs or PUCCHs are determined for each interval/period, a UCI of a CSI feedback may be repeated over the multiple PUSCHs or the multiple PUCCHs. Alternatively, multiple CSI RS configurations may be configured via RRC signaling, where each of the multiple CSI RS configurations may correspond to each of the multiple PUSCHs or multiple PUCCHs.

FIG. 33 illustrates a flow diagram of an example embodiment as per an aspect of an embodiment of the present disclosure. A wireless device may receive configuration parameters indicating a SPS configuration for a cell. The SPS configuration may comprise a periodicity to determine periodic resources based on the SPS configuration. The wireless device may receive a DCI indicating an activation of the SPS configuration. The DCI may be referred as an activation DCI. The DCI may indicate a time domain resource for a SPS PDSCH. The SPS PDSCH may be referred as an activated SPS PDSCH reception or an activated SPS PDSCH. The SPS PDSCH may be first SPS PDSCH reception/occasion activated for the SPS configuration, based on the DCI. The time resource may indicate a time domain resource for the SPS PDSCH. The DCI may indicate an offset to determine a PUCCH resource. The wireless device may transmit a HARQ-ACK feedback for the SPS PDSCH via the PUCCH resource. The DCI may indicate/comprise a total DAI value/field. The total DAI may be used to determine a number of HARQ-ACK bits corresponding to the DCI.

The wireless device may determine a plurality of SPS PDSCHs based on the periodicity and resources of the SPS PDSCH. The plurality of SPS PDSCHs may comprise the SPS PDSCH. The plurality of SPS PDSCHs may comprise one or more second SPS PDSCH receptions/SPS PDSCHs. The one or more second SPS PDSCH receptions may occur a multiple of the periodicity since the SPS PDSCH. The one or more second SPS PDSCH receptions may be periodic resources determined based on the SPS configuration.

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The wireless device may determine one or more second PUCCH resources for the one or more second SPS PDSCH receptions. Each of the one or more second PUCCH resources may correspond to each of the one or more second SPS PDSCH receptions. Each of the one or more second PUCCH resources may be same as the PUCCH resource.

Feedback timing of the plurality of SPS PDSCHs may correspond to the PUCCH resource.

The wireless device may generate one or more HARQ 10 feedback bits of the plurality of SPS PDSCHs based on the total DAI. The wireless device may determine an order of a HARQ feedback bit for each of the plurality of SPS PDSCHs based on a reception timing or a time domain resource. The wireless device may generate a HARQ-ACK 15 codebook and/or a HARQ-ACK sub-codebook based on the one or more HARQ-ACK bits. The wireless device may transmit the HARQ-ACK codebook and/or the HARQ-ACK sub-codebook via the PUCCH resource.

In an example, a wireless device may receive configuration 20 parameters via RRC signalling. The configuration parameters may indicate one or more physical uplink control channel (PUCCH) resources and a periodicity of a semi-persistent scheduling (SPS) configuration. The wireless device may receive a DCI. The DCI may indicate to activate 25 the SPS configuration. The DCI may indicate resources for a SPS PDSCH reception. The DCI may indicate an offset to a PUCCH resource. The DCI may indicate a total downlink assignment index (T-DAI). The wireless device may activate the SPS configuration based on the DCI. The wireless device 30 may determine a plurality of SPS PDSCH receptions based on the SPS configuration. The plurality of SPS PDSCH receptions may comprise the SPS PDSCH reception. Feedback resource of the plurality of SPS PDSCH receptions may be the PUCCH resource. The wireless device may generate one or more hybrid automatic repeat request 35 (HARQ) feedback bits corresponding to the plurality of SPS PDSCH receptions. The wireless device may determine a number of the one or more HARQ feedback bits based on the total DAI. The wireless device may transmit the one or 40 more HARQ feedback bits via the PUCCH resource.

In an example embodiment, the wireless device may determine the PUCCH resource based on the offset and the resources for the SPS PDSCH reception. For example, the PUCCH resource may occur after the offset from the 45 resources.

In an example embodiment, the one or more PUCCH resources may be configured for a first cell operating a first subcarrier spacing.

In an example embodiment, the SPS configuration may be 50 for a second cell operating with a second subcarrier spacing that is larger than the first subcarrier spacing.

In an example embodiment, the periodicity of the SPS configuration may be smaller than a slot duration of the first cell.

In an example embodiment, the periodicity may be P slots 55 based on the second subcarrier spacing.

In an example embodiment, the plurality of SPS PDSCH receptions may comprise one or more second SPS PDSCH receptions that occur one or more times of the periodicity 60 since the SPS PDSCH reception.

In an example embodiment, the wireless device may determine a second PUCCH resource of a second SPS PDSCH reception of the one or more second SPS PDSCH receptions based on the offset and second resources of the 65 second SPS PDSCH reception.

In an example embodiment, the second PUCCH resource may be same as the PUCCH resource.

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In an example embodiment, the feedback resource of the plurality of SPS PDSCH receptions may be the PUCCH resource in response to the second PUCCH resource being same as the PUCCH resource.

In an example embodiment, the wireless device may determine the PUCCH resource based on a first slot, of the first cell, overlapping with a second slot, of the second cell, comprising the resources of the SPS PDSCH reception.

In an example embodiment, the PUCCH resource may occur after the offset from the first slot.

In an example embodiment, the DCI may comprise a total DAI field indicating the total DAI.

The method of claim 13, wherein the total DAI counts a number of the plurality of SPS PDSCH receptions.

In an example embodiment, the DCI may indicate a counter DAI.

In an example embodiment, the counter DAI may not count a number of plurality of SPS PDSCH receptions.

In an example embodiment, the wireless device may determine the number of HARQ feedback bits based on the total DAI, wherein the number of HARQ feedback bits is the total DAI.

In an example embodiment, the number of HARQ feedback bits may be determined by the total DAI subtracted by a second total DAI of a previous DCI.

In an example embodiment, the previous DCI may be transmitted immediately before the DCI by the base station, where a HARQ feedback resource for the previous DCI corresponds to the PUCCH resource.

In an example embodiment, the number of HARQ feedback bits may be determined based on the total DCI that is subtracted from a third DAI of a next DCI.

In an example embodiment, the next DCI may be transmitted immediately after the DCI by the base station, where a HARQ feedback resource for the next DCI corresponds to the PUCCH resource.

In an example, a base station may transmit configuration parameters to a wireless device. The configuration parameters may indicate one or more physical uplink control channel (PUCCH) resources and a periodicity of a semi-persistent scheduling (SPS) configuration. The base station may determine information for an activation DCI of the SPS configuration. For example, the information may comprise resources for a SPS physical downlink shared channel (PDSCH) reception, an offset to a PUCCH resource, and a total downlink assignment index (DAI). The base station may determine the total DAI based on a plurality of SPS PDSCHs comprising the SPS PDSCH. For example, a feedback resource of the plurality of SPS PDSCHs may correspond to /be the PUCCH resource. The base station may transmit the activation DCI to the wireless device. The base station may receive one or more hybrid automat repeat request (HARQ) feedback bits corresponding to the plurality of SPS PDSCH receptions based on the total DAI.

In an example embodiment, the base station may determine the PUCCH resource based on the offset and the resources for the SPS PDSCH reception. For example, the PUCCH resource may occur after the offset from the resources.

In an example embodiment, the one or more PUCCH resources may be configured for a first cell operating a first subcarrier spacing.

In an example embodiment, the SPS configuration may be for a second cell operating with a second subcarrier spacing that is larger than the first subcarrier spacing.

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In an example embodiment, the periodicity of the SPS configuration may be smaller than a slot duration of the first cell.

In an example embodiment, the periodicity may be P slots based on the second subcarrier spacing.

In an example embodiment, the plurality of SPS PDSCH receptions may comprise one or more second SPS PDSCH receptions that occur one or more times of the periodicity since the SPS PDSCH reception.

10 In an example embodiment, the base station may determine a second PUCCH resource of a second SPS PDSCH reception of the one or more second SPS PDSCH receptions based on the offset and second resources of the second SPS PDSCH reception.

15 In an example embodiment, the second PUCCH resource may be same as the PUCCH resource.

In an example embodiment, the feedback resource of the plurality of SPS PDSCH receptions may be the PUCCH resource in response to the second PUCCH resource being same as the PUCCH resource.

20 In an example embodiment, the base station may determine the PUCCH resource based on a first slot, of the first cell, overlapping with a second slot, of the second cell, comprising the resources of the SPS PDSCH reception.

25 In an example embodiment, the PUCCH resource may occur after the offset from the first slot.

In an example embodiment, the DCI may comprise a total DAI field indicating the total DAI.

30 In an example embodiment, wherein the total DAI counts a number of the plurality of SPS PDSCH receptions.

In an example embodiment, the DCI may indicate a counter DAI.

In an example embodiment, the counter DAI may not count a number of plurality of SPS PDSCH receptions.

35 In an example embodiment, the base station may determine the number of HARQ feedback bits based on the total DAI, wherein the number of HARQ feedback bits is the total DAI.

In an example embodiment, the number of HARQ feedback bits may be determined by the total DAI subtracted by a second total DAI of a previous DCI.

40 In an example embodiment, the previous DCI may be scheduled immediately before the DCI, where a HARQ feedback resource for the previous DCI corresponds to the PUCCH resource.

45 In an example embodiment, the number of HARQ feedback bits may be determined based on the total DCI that is subtracted from a third DAI of a next DCI.

In an example embodiment, the next DCI may be scheduled immediately after the DCI, where a HARQ feedback resource for the next DCI corresponds to the PUCCH resource.

50 In an example, a wireless device may receive configuration parameters for a cell. The configuration parameters may comprise/indicate a multi-physical downlink shared channel (PDSCH) scheduling. For example, a single downlink control information (DCI) may schedule resources for one or more transport blocks via one or more PDSCHs. The configuration parameters may comprise/indicate a semi-persistent scheduling (SPS) configuration with a periodicity. The wireless device may receive a DCI based on the multi-PDSCH scheduling. The DCI may indicate activating the SPS configuration. The DCI may indicate a plurality of time domain resource allocations across a plurality of slots. The

55 60 65 configuration parameters may comprise/indicate a semi-persistent scheduling (SPS) configuration with a periodicity. The wireless device may receive a DCI based on the multi-PDSCH scheduling. The DCI may indicate activating the SPS configuration. The DCI may indicate a plurality of time domain resource allocations across a plurality of slots. The DCI may indicate an offset to a physical uplink control channel (PUCCH) resource. The wireless device may determine periodic resources based on last time domain resource,

of a last slot of the plurality of slots, of the plurality of time domain resource allocations. The wireless device may determine a PUCCH resource based on the offset and the last time domain resource. The wireless device may receive data via one of the periodic resources. The wireless device may transmit the hybrid-automatic repeat request (HARQ) feedback via the PUCCH resource.

In an example, a wireless device may receive configuration parameters for a cell. The configuration parameters may indicate a multi-physical downlink shared channel (PDSCH) scheduling. For example, with the multi-PDSCH scheduling, a single downlink control information (DCI) may schedule resources for one or more transport blocks via one or more PDSCHs. The configuration parameters may indicate a semi-persistent scheduling (SPS) configuration with a periodicity. The wireless device may receive a DCI based on the multi-PDSCH scheduling. The DCI may indicate activating the SPS configuration. The DCI may indicate one or more time domain resources for one or more SPS PDSCHs. For example, each, of the one or more time domain resources may correspond to each of the one or more SPS PDSCHs. The wireless device may determine a hybrid automat repeat request (HARQ) process identifier based on first time domain resource of the one or more time domain resources for first SPS PDSCH of the one or more SPS PDSCHs. The wireless device may determine one or more HARQ process identifiers for the one or more SPS PDSCHs, other than the first SPS PDCH, based on the HARQ process identifier of the first SPS PDSCH. The wireless device may receive one or more transport blocks via the one or more SPS PDSCHs based on the one or more HARQ process identifiers and the HARQ process identifier. The wireless device may transmit one or more feedback corresponding to the one or more transport blocks via a feedback resource.

FIG. 34 illustrates an example of embodiment for a HARQ process ID for a multi-PDSCH/multi-PUSCH scheduling as per an aspect of an embodiment of the present disclosure.

For example, a DCI, of a multi-PDSCH scheduling, may schedule a plurality of PDSCHs over a plurality of slots. For example, the DCI may indicate a HARQ process ID=Q. The DCI may indicate a set of NDI fields/bits where each field/bit of the set of NDI fields/bits corresponds to a PDSCH of the plurality of PDSCHs or a slot of the plurality of slots. The DCI may indicate a set of RV fields/bits where each field/bits of the set of RV fields/bits corresponds to the PDSCH or the slot. For example, 2<sup>nd</sup> bit of a NDI bitmap or a set of NDI fields/bits indicate a NDI value for a second PDSCH (e.g., PDSCH #2) or a second slot (e.g., slot n+p+1). For example, 2<sup>nd</sup> two bits of a RV bitmap or a set of RV fields/bits may correspond to the second PDSCH or the second slot (e.g., NDI=0, RV=3).

For example, 3<sup>rd</sup> NDI bit of the NDI bitmap and 3<sup>rd</sup> two bits of RV bits of the RV bitmap may correspond to a third PDSCH (PDSCH #3) or a third slot (slot n+p+2). The k-th NDI bit of the NDI bitmap and k-th two bits of the RV bits of the RV bitmap may correspond to a K-th PDSCH (PDSCH #K) or k-th slot (slot n+p+K).

The DCI may indicate a first slot (slot n+p) for a first or an earliest PDSCH (e.g., PDSCH #1). The wireless device may map each PDSCH of the plurality of PDSCHs across one or more slots scheduled via a time domain resource allocation field by the DCI. For example, the time domain resource allocation field may comprise K SLIV values where each of the K SLIV values corresponds to each slot between [slot n+p, . . . , slot n+p+K]. For example, the K SLIV values may correspond to each downlink slot or each

valid slot between slot [n+p, . . . , slot M] (e.g., M>=n+p+K). The wireless device may determine a slot is a valid slot or a downlink slot based on slot formation indication via RRC and/or DCI signaling. For example, the RRC signaling may comprise TDD-UL-DL-ConfigCommon indicating semi-static downlink and/or uplink resources within one or more periodicities. The RRC signaling may comprise TDD-UL-DL-Config (e.g., a UE-specific signaling) indicating semi-static downlink and/or uplink resources for flexible resources indicated by the TDD-DL-UL-ConfigCommon.

The wireless device may determine a slot is a valid slot in response to symbol(s) indicated by a SLIV corresponding to the slot are configured with downlink resource and/or flexible resources by the RRC signaling. The wireless device may determine the slot is valid slot in response to the symbol(s) are indicated with downlink by RRC signaling and/or SFI DCI signaling.

In FIG. 34, the wireless device may determine slot n+p+3 are uplink slot. The wireless device may skip the slot n+p+3 from resource allocation by the DCI. The wireless device may determine a fourth PDSCH (PDSCH #4) in a slot n+p+4 by skipping the uplink slot or invalid slot.

For example, 4<sup>th</sup> NDI bit of the NDI bitmap and 4<sup>th</sup> two RV bits of the RV bitmap may correspond to a fourth PDSCH (PDSCH #4) in the slot n+p+4. The wireless device may skip the slot n+p+3 as the slot is an uplink slot or invalid slot.

The wireless device may determine a NDI bit is set to a first predetermined value and a RV bits are set to a second predetermined value for a PDSCH. In response to the determining, the wireless device may determine that the PDSCH is skipped.

For example, in FIG. 34, the wireless device may determine 2<sup>nd</sup> NDI bit being set to the first predetermined value (e.g., 0, or toggled or non-toggled) and 2<sup>nd</sup> two RV bits being set to the second predetermined value (e.g., 3, 2 or 1). The wireless device may determine that the second PDSCH or the second slot is skipped.

The wireless device may increment a HARQ process ID of each PDSCH by 1 in each slot allocated by the time domain resource allocation field of the DCI. The wireless device may determine a HARQ process ID of the first PDSCH (PDSCH #1) or the first slot as Q based on the DCI.

The wireless device may determine a HARQ process ID of the second PDSCH (PDSCH #2) or the second slot (slot n+p+1) as Q+1 even if the second PDSCH has been skipped. The wireless device may determine a HARQ process ID of the second slot as Q+1.

The wireless device may determine a HARQ process ID of the third PDSCH (PDSCH #3) or the third slot (slot n+p+2) as Q+2. The wireless device may skip incrementing the HARQ process ID for an invalid slot or uplink slot (e.g., skip slot n+p+3). The wireless device may determine a HARQ process ID of the fourth PDSCH (PDSCH #4) or the fifth slot (slot n+p+4) as Q+3 based on the fifth slot being fourth slot since the first slot based on the time domain resource allocation field of the DCI.

The wireless device may increment the HARQ process ID per each valid slot or for each allocated slot by the time domain allocation table by the DCI.

In an example, the wireless device may determine a slot is skipped or a PDSCH is skipped based on a SLIV value corresponding to the slot or the PDSCH. For example, if the SLIV value may indicate 0 duration or a reserved value, the wireless device may determine that the slot is skipped or the PDSCH is skipped.

In an example, a wireless device may have/support one or more capabilities (e.g., UE radio access capability parameters, radio access capability parameters, UE capabilities, wireless device capabilities). The wireless device may support a capability in response to the wireless device supporting a functionality indicated by the capability. The wireless device may have a capability where the base station configures a related functionality to the wireless device. For example, a capability of one or more capabilities may indicate whether the wireless device supports a carrier aggregation. Another capability may indicate a number of blind decodings and/or a number of non-overlapped CCEs in a slot. Another capability may indicate a number of antennas or a number of layers that the wireless device supports for a band and/or band combination. A capability may correspond to a functionality. One or more capabilities may correspond to a functionality.

The wireless device may indicate the one or more capabilities to a base station. The wireless device may support one or more second capabilities that are mandated by the wireless device to support. The wireless device may not indicate the one or more second capabilities. The base station may, based on the one or more capabilities and the one or more second capabilities, configure one or more configuration parameters (e.g., to support one or more functionalities) to the wireless device. The wireless device may support different functionalities between FDD and TDD, and/or between frequency range 1 (FR1) and frequency range 2 (FR2).

In an example, a wireless device may support one or more common search space (CSS) sets or one or more CSSs. For example, a Type0-PDCCH CSS set may be configured by pdccch-ConfigSIB1 in MIB or by searchSpaceSIB1 in PDCCH-ConfigCommon or by searchSpaceZero in PDCCH-ConfigCommon. The wireless device may monitor a DCI format with CRC scrambled by a SI-RNTI, via the Type0-PDCCH CSS (set) on a primary cell of the master cell group (MCG). For example, a Type0A-PDCCH CSS set may be configured by searchSpaceOtherSystemInformation in PDCCH-ConfigCommon. The wireless device may monitor a DCI format, via the Type0A-PDCCH CSS (set), with CRC scrambled by a SI-RNTI on the primary cell of the MCG. For example, a Type1-PDCCH CSS set may be configured by ra-SearchSpace in PDCCH-ConfigCommon. The wireless device may monitor a DCI format with CRC scrambled by a RA-RNTI, a MsgB-RNTI, or a TC-RNTI on the primary cell.

For example, a Type2-PDCCH CSS set may be configured by pagingSearchSpace in PDCCH-ConfigCommon. The wireless device may monitor a DCI format with CRC scrambled by a P-RNTI on the primary cell of the MCG. For example, a Type3-PDCCH CSS set may be configured by SearchSpace in PDCCH-Config with searchSpaceType=common. The wireless device may monitor DCI formats with CRC scrambled by INT-RNTI, SFI-RNTI, TPC-PUSCH-RNTI, TPC-PUCCH-RNTI, TPC-SRS-RNTI, or CI-RNTI and, only for the primary cell, C-RNTI, MCS-C-RNTI, CS-RNTI(s), or PS-RNTI. For example, a USS set may be configured by SearchSpace in PDCCH-Config with searchSpaceType=ue-Specific. The wireless device may monitor DCI formats with CRC scrambled by C-RNTI, MCS-C-RNTI, SP-CSI-RNTI, CS-RNTI(s), SL-RNTI, SL-CS-RNTI, or SL Semi-Persistent Scheduling V-RNTI.

In an example, a wireless device may support one or more basic functionalities for a downlink control channel and procedure. For example, a capability (e.g., radio access

capability) of the wireless device supporting the downlink control channel and the procedure may be referred as “Basic DL control channel”. The one or more basic functionalities for the downlink control channel and procedure may comprise the followings. First, the wireless device may support one configured coresset for a BWP for a cell where the one configured coresset may be different from a coresset with index 0 (e.g., coresset #0). The wireless device may support at least two coressets (e.g., a coresset with index being different from zero (e.g., non coresset #0) and a coresset #0). The wireless device may support a resource allocation for a coresset based on a bitmap, where each bit of the bitmap corresponds to contiguous P PRBs (e.g., P=6) in frequency domain. The resource allocation may comprise a time domain resource allocation of a duration of Q1 to Q3 symbols (e.g., Q1=1, Q3=3) for a first frequency range (e.g., below 6 GHz or below 7 GHz).

The wireless device may support Type1-PDCCH CSS set (e.g., a CSS where the wireless device monitors DCIs for receiving random access responses), where Type1-PDCCH CSS set may be configured via SIB message(s) or MIB message(s). For Type1-PDCCH CSS set configured based on non-wireless device specific RRC parameters, Type0-PDCCH CSS set (e.g., a CSS where the wireless device monitors DCIs for receiving SIB1 messages), Type0A-PDCCH CSS set (e.g., a CSS where the wireless device monitors DCIs for receiving SIB messages other than SIB1), and/or Type2-PDCCH CSS set (e.g., a CSS where the wireless device monitors DCIs for receiving paging messages/short messages), the wireless device may support up to Q3 symbols for a coresset (e.g., Q3=3) in a second frequency range (e.g., FR2).

For a Type1-PDCCH CSS set configured via a wireless device specific RRC signaling and/or for a type3-PDCCH CSS set (e.g., a CSS where the wireless device monitors group-common DCIs) and/or for one or more USS, the wireless device may support up to Q2 symbols for a coresset (e.g., Q2=2) for the second frequency range.

The wireless device may support a bundle size, of resource element groups (REGs) for a control channel elements (CCEs) of a coresset, of 2 or 3 RBs or 6 RBs. The wireless device may support interleaved or non-interleaved CCE-to-REG mapping. The wireless device may support precoder granularity of a REG bundle size. The wireless device may support a determination of a DM-RS scrambling sequence. The wireless device may support one or more TCI states for a coresset. The wireless device may support at least one CSS and at least one USS configurations for a unicast PDCCH transmission for a BWP of a cell. The wireless device may support aggregation levels, of 1, 2, 4, 8 and 16, for a PDCCH. The wireless device may support up to K (e.g., K=3) search space sets for a BWP of a secondary cell. The wireless device may support that a type1-PDCCH CSS set configured via a wireless device specific RRC signaling, a type3-PDCCH CSS set, and/or one or more USSs scheduled via first Q1-Q3 symbols (e.g., Q1=1 and Q3=3) of a slot (e.g., OFDM symbol 0, 1, and 2).

For Type1-PDCCH CSS set without a wireless device specific RRC signaling and for a Type0-PDCCH CSS/Type0A-PDCCH CSS/Type2-PDCCH CSS, a monitoring occasion may be in any symbol(s) of a slot. A Type1-PDCCH CSS without a wireless device specific RRC signaling and for a Type0-PDCCH CSS/Type0A-PDCCH CSS/Type2-PDCCH CSS within a single span may be confined within Q3 (e.g., Q3=3) consecutive symbols of a slot. A span

may comprise one or more consecutive symbols where one or more monitoring occasions of one or more search spaces may be present.

The wireless device may support monitoring DCIs based on one or more DCI formats. The one or more DCI formats may comprise a DCI format 0\_0, a DCI format 1\_0, a DCI format 0\_1 and a DCI format 1\_1. The wireless device may support a number of PDCCH blind decodings per a slot based on a subcarrier spacing of an active BWP of a cell. For example, the wireless device may support M1 (e.g., 44) for a 15 kHz SCS active BWP of the cell.

For example, the wireless device may support M2 (e.g., 36) for a 30 kHz SCS active BWP of the cell. The wireless device may support M3 (e.g., M3=22) for a 60 kHz SCS active BWP of the cell. The wireless device may support M4 (e.g., M4=20) for a 120 kHz SCS active BWP of the cell.

In an example, a wireless device may monitor one or more monitoring occasions of one or more search spaces in a span. The one or more search spaces may be associated with one or more coresets of an active BWP of a cell. The span may be determined as one or more consecutive (OFDM) symbols in a slot, where the one or more monitoring occasions are present over the span. Each PDCCH monitoring occasion (e.g., determined based on a search space set configuration) may be within one span. The wireless device may have a capability indicating a combination (X, Y). The wireless device may support a PDCCH monitoring occasions in any symbol of a slot with a minimum time gap/separation (e.g., a minimum gap, a minimum separation, a gap, a space, an offset, a minimum offset, a minimum space, a separation) between first symbols of two consecutive/adjacent spans, including across slots, may be X. A span may start at a first symbol of a slot, where a first PDCCH monitoring occasion may start. The span may end at a second symbol of the slot where a second PDCCH monitoring occasion may end. The first PDCCH monitoring occasion may be same or different from the second PDCCH monitoring occasion. A span may be up to Y symbols. For example, a maximum number of symbols in a span may be less than or equal to Y.

The wireless device may support one or more combinations (X, Y) for a SCS for an active BWP of a cell.

In an example, a wireless device may support one or more cells in a third frequency region (e.g., FR3), where a frequency of the third frequency region may be between [52.6, 71] GHz. The third frequency region may be between  $[f1] \geq 52.6$  GHz and  $f2 \leq 71$  GHz. The wireless device may support one or more subcarrier spacing for the one or more cells. For example, the one or more SCS may comprise at least one of {120 kHz, 240 kHz, 480 kHz, 960 kHz}. When an active BWP of a cell of the one or more cells operates based on 480 kHz or 960 kHz, a duration of a slot may be smaller than 32 us or 16 us.

In an example, the wireless device may support one or more blind decodings based on a single-slot span monitoring occasion. For example, the wireless device may have a span in each slot of the active BWP of the cell. The wireless device may support M number of blind decodings and P number of non-overlapped CCEs based on a single-slot span monitoring occasion. For example, M may be 4 for 480 kHz and M may be 2 for 960 kHz.

In an example, a wireless device may support a capability of a multi-slot PDCCH monitoring. The wireless device may support up to M blind decodings within a multi-slot span and up to P non-overlapped CCEs within the multi-slot span. A multi-slot span may comprise or span over a plurality of slots of an active BWP of a scheduling cell. For example, the wireless device may support the capability of the multi-slot

PDCCH monitoring in response to a SCS of an active BWP of the scheduling cell is one of {480 kHz, 960 kHz, 240 kHz}. The wireless device may transmit a capability of the capability for each SCS of {240 kHz, 480 kHz, 960 kHz} and/or a band/band combination.

In an example, the capability of the multi-slot PDCCH monitoring may be determined based on a fixed pattern of N slots. For example, the wireless device may determine N slots based on a predetermined pattern (e.g., a span is between slots with indices between  $[n+0, n+N-1]$  wherein  $(n \% N)=0$ ). For example, the wireless device may determine the N slots based on a pattern configured by an RRC/SIB/MIB message. For example, the wireless device may determine a starting slot with an index P where the wireless device may monitor/receive a cell-defining SSB. The wireless device may determine N that is a dividend of 64 or 32 (e.g., N=2, 4, 8, 16). The wireless device may determine an ending slot of N multi-slot span that is  $P+N-1$ . A span may be between [slot P, slot  $P+N-1$ ]. The wireless device may determine a starting slot with an index P, where the wireless device may monitor/receive a type0-PDCCH CSS (or a type2-PDCCH CSS, or a type0A-PDCCH CSS).

In an example, a wireless device may support a capability (e.g., pdcce-Monitoring-R16 (X, Y)). The capability may comprise a combination of (X, Y) for a subcarrier spacing. For example, X may determine consecutive OFDM symbols of a span. The span may comprise one or more monitoring occasions. Y may determine a minimum time gap/separation between two consecutive/adjacent spans. For example, X may determine consecutive slots of a span. The span may comprise one or more monitoring occasions. Y may determine a minimum time gap/separation between first slot of a first span and first slot of a second span, where the first span and the second span are adjacent or consecutive spans. For example, Y may be determined as a minimum gap/separation between two monitoring occasions based on a search space configuration, where the two monitoring occasions are adjacent or consecutive. For example, Y may be determined as a minimum periodicity that a search space for an active BWP of a cell may be configured with.

FIG. 35A illustrates an example of a multi-slot span as per an aspect of an embodiment of the present disclosure. For example, a span may be determined based on one or more consecutive symbols of a slot. A size/duration of the span may be up to Y symbols. Y may be greater than 3 symbols. FIG. 35A illustrates that a first span spans five OFDM symbols (e.g., Y=5). A second span may span three OFDM symbols (e.g., <=Y). In an example, a span may be determined as a slot where the wireless device may be configured with one or more monitoring occasions in the slot. The one or more monitoring occasions may occur consecutively or non-consecutively in time over the slot. For example, a first monitoring occasion based on a second search space (SS2) may occur symbols [9-11] in a slot n and a second monitoring occasion based on a first search space (SS1) may occur in symbols [4-5] in the slot n. The first monitoring occasion and the second monitoring occasion may not be contiguous. The span may comprise one or more contiguous or non-contiguous monitoring occasion in a slot.

A minimum time gap/separation between two spans may be determined based on first symbol of first slot of a first span and first symbol of first slot of a second span. The first span and the second span may be adjacent or consecutive spans. First symbol of first slot may be symbol 0 (or 1) of first slot of the first span. First symbol of first slot may be symbol 0 (or 1) of first slot of the second span. First symbol may or may not comprise a monitoring occasion. First slot

of the first span may comprise a monitoring occasion. First slot of the second span may comprise a monitoring occasion.

FIG. 35B illustrates an example of a multi-slot span as per an aspect of an embodiment of the present disclosure. In an example, a span may be determined based on one or more consecutive slots. A size/duration of the span may be up to Y slots. Y may be smaller than or equal to K slots (e.g., K=2, 4). A span may start a slot with index n such that  $n \% K = 0$  or  $n \% (K * X) = 0$ . X may be determined as a minimum time gap/separation between two consecutive/adjacent spans. The X may be measured between first slot of a first span of the two spans and a second slot of a second span of the two spans. In FIG. 35B, a span may span two slots (e.g., slot n and slot n+1) with Y=2 slots and a minimum gap X may be X slots. In each span, a number of consecutive slots with one or more monitoring occasions may be smaller than or equal to Y.

In an example, a wireless device may support a multi-slot PDCCH monitoring capability based on a sliding window of N slots. For example, the wireless device may support M blind decodings and/or P non-overlapped CCEs within any sliding window of size N slots. The base station may configure one or more search spaces, wherein one or more monitoring occasions based on the one or more search spaces are within M blind decodings and P non-overlapped CCEs within a sliding window of N slots. The wireless device may determine a sliding window of N slots based on a current slot n and N sliding window size (e.g., [slot n, slot n+N-1]). The wireless device may support in every sliding window, up to M blind decodings and/or P non-overlapped CCEs. For example, the wireless device may support M and/or P between [slot n, slot n+N-1], [slot n+1, slot n+N] . . . , slot [n+k, slot n+k+N-1], . . . and/or the like.

The wireless device may determine a sliding window or update the sliding window in every slot (e.g., the wireless device may support M and/or P between [slot n, slot n+N-1], [slot n+1, slot n+N] . . . , slot [n+k, slot n+k+N-1], . . . and/or the like.). The wireless device may determine or update the sliding window in every P slots (e.g., the wireless device may support M and/or P between [slot n, slot n+N-1], [slot n+P, slot n+P+N-1] . . . , slot [n+k\*P, slot n+k\*P+N-1], and/or the like). For example, P may be 2 or 4 or N.

The wireless device may report one or more capabilities of one or more multi-slot PDCCH monitoring for a cell. The base station may transmit one or more RRC messages indicating one multi-slot PDCCH monitoring of the one or more capabilities of the one or more multi-slot PDCCH. The one or more RRC messages may indicate/comprise configuration parameters. The configuration parameters may comprise/indicate one or more search spaces for the cell. The wireless device may determine one of the one or more capabilities, for the cell, based on the configuration parameters.

For example, the first SCS is 960 kHz. The wireless device may determine a number of blind decoding for a combination of (X, Y) for a SCS of an active BWP of a cell.

In an example, a value of a total DAI may denote/represent a total number of {serving, PDCCH monitoring occasion}-pair(s) up to a current PDCCH monitoring occasion across one or more serving cells. FIG. 36 illustrates an example of a counter-DAI (C-DAI or DAI) and/or a total DAI (T-DAI) when a wireless device is configured with a single serving cell. For example, the wireless device may determine a first monitoring occasion (a left box), a second monitoring occasion (a middle box) and a third monitoring occasion (a right box) in FIG. 36. The wireless device may be scheduled/received DCI(s) based on one or more DCI

formats via monitoring occasions (e.g., the first monitoring occasion, the second monitoring occasion, the third monitoring occasion). For example, the wireless device may receive a first DCI (DCI 1) via the first monitoring occasion where the first DCI indicates a DAI=0 and/or a T-DAI=0. The base station may set the DAI=0 and/or the T-DAI=0.

The wireless device may receive a third DCI (DCI 3) via the third monitoring occasion where the third DCI indicates a DAI=2 and/or a T-DAI=2. The first DCI and the third DCI 10 may indicate a same PUCCH resource for HARQ feedback. The wireless device may generate a first HARQ feedback bit for a PDSCH or a SPS PDSCH release scheduled by the first DCI. The wireless device may generate a third HARQ feedback bit for a second PDSCH or a second SPS PDSCH release 15 by the third DCI. The wireless device may not receive successfully a second DCI via the second monitoring occasion. The wireless device may determine a missed (e.g., failed to be received, failed in decoding, not received, failed) DCI (e.g., the second DCI) based on a DAI value of the third DCI.

The wireless device may generate NACK (e.g., negative ACK) for a third PDSCH or a third SPS PDSCH release. For example, the third PDSCH or the third SPS PDSCH release 20 may have been scheduled via the second DCI. The wireless device may not receive the third PDSCH or the third SPS PDSCH release as the second DCI has not been received successfully.

The wireless device may be scheduled with a SPS PDSCH reception between the second DCI and the third DCI. The wireless device may have received an activation DCI for a SPS PDSCH configuration. The wireless device 30 may determine the SPS PDSCH reception or an occasion of the SPS PDSCH reception based on the activation DCI and the SPS PDSCH configuration.

The wireless device may generate 3 bits HARQ feedback bits, a first bit corresponding to the first DCI, a second bit for the second DCI and a third bit for the third DCI. The wireless device may generate one or more HARQ-ACK bits corresponding to one or more PDCCH monitoring occasions, where the one or more PDCCH monitoring occasions 40 may schedule one or more PDSCHs corresponding to a PUCCH resource.

The wireless device may determine a number of HARQ feedback/HARQ-ACK codebook based on a T-DAI or 45 C-DAI of a most recent DCI for the PUCCH (or a PUCCH resource). The wireless device may transmit the HARQ feedback bits via the PUCCH or the PUCCH resource.

The wireless device may determine a first HARQ-ACK bit for a PDSCH scheduled by the first DCI or the first DCI 50 (e.g., DCI1) in a HARQ-ACK codebook. The wireless device may determine a NACK for a second HARQ-ACK bit as the wireless device misses the second DCI. The wireless device may determine a third HARQ-ACK bit (e.g., DAI=2) for the third DCI.

The wireless device may determine whether a SPS PDSCH reception based on a SPS configuration is mapped to the PUCCH resource. When a single SPS PDSCH reception across cells is mapped to the PUCCH resource, the wireless device may generate a HARQ-ACK bit corresponding 60 to the SPS PDSCH reception. The wireless device may append the HARQ-ACK bit after one or more HARQ-ACK bits based on the one or more PDCCH monitoring occasions.

In FIG. 36, the wireless device may append a HARQ-ACK bit for the SPS PDSCH after three bits of HARQ-ACK 65 bits for the first/second/third DCIs. The wireless device may transmit the appended HARQ-ACK bits via the PUCCH resource.

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FIG. 37 illustrates an example of HARQ feedback/code-book determination when a wireless device is configured with a plurality of serving cells. For example, the wireless device may be configured with a first cell (Cell 0) and a second cell (Cell 1). For example, the wireless device may receive a first DCI via the first cell (DCI 1) that may indicate a DAI=0 and a T-DAI=1. The base station may determine a C-DAI (or DAI) and/or T-DAI for a DCI.

The T-DAI may accumulate a number of PDCCH monitoring occasions and/or a number of DCIs, across all serving cells, up to a current PDCCH monitoring occasion. A first monitoring occasion of the first cell may overlap and may have a same starting time to a first monitoring occasion of the second cell. A base station may set the T-DAI of the first DCI being two. The base station may set a T-DAI of a second DCI (DCI 2) via the second cell.

A DAI value of the second DCI may be set to 1 (e.g., counter DAI). For example, the base station may set the DAI value of the second DCI to 1. The wireless device may not receive successfully a third DCI (DCI3) that may indicate a T-DAI=2 and DAI=2. The wireless device may receive a fourth DCI (DCI4) with a T-DAI=3 and DAI=3.

The wireless device may receive a fifth DCI (DCI5) with a T-DAI=4 and DAI=4.

A value of a T-DAI may be wrapped around (e.g., modulo operation, such as a modulo n, which may be expressed as a mode n or a % n) when it reaches a maximum value (e.g., n) or a threshold (e.g., a maximum value=4 based on 2 bits of T-DAI field, a maximum value=2^K or 2^K-1 where K is a number of bits used for a T-DAI field in a DCI format). The wireless device may determine HARQ-ACK bits as follows. For example, actual value of T-DAI and C-DAI vale may be 0 for the fifth DCI based on the wrapping up mechanism (e.g., 4 mod 4=0, 4% 4=0 when n is 4, an actual value may be determined based on modulo n, where n is 2^K with K bits used for a DAI field).

For example, for each PDCCH monitoring occasion (e.g., a first PDCCH monitoring occasion is a first time when the wireless device may monitor a first monitoring occasion via the first cell and a first monitoring occasion via the second cell), the wireless device may determine a number of HARQ-ACK feedback bits for each serving cell based on a cell index (e.g., determine the first cell and then determine the second cell when an index of the first cell is lower than an index of the second cell).

For example, a PDCCH monitoring occasion may indicate a starting time in a slot where a wireless device may start monitoring one or more PDCCH candidates via a monitoring occasion of a serving cell. For example, a PDCCH monitoring occasion may indicate a monitoring occasion determined/configured based on a search space configuration.

For example, the wireless device may determine a number of HARQ-ACK bits for a serving cell based on a DAI field of the each PDCCH monitoring occasion. For example, the wireless device may determine a bit index among HARQ-ACK bits to put ACK or NACK for a transport block or a SPS PDSCH release scheduled by a DCI for the serving cell, where the wireless device may receive the DCI via the each PDCCH monitoring occasion.

The wireless device may determine a first HARQ-ACK bit for a transport block of the first cell at the first PDCCH monitoring occasion. The wireless device may determine a second HARQ-ACK bit for a transport block of the second cell at the first PDCCH monitoring occasion. The wireless device may move to a next PDCCH monitoring occasion

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which occurs after the first monitoring occasion but occur before other monitoring occasions.

In FIG. 37, the wireless device may determine a second monitoring occasion via the first cell as the wireless device 5 may not detect any DCI via a second monitoring occasion via the second cell. The wireless device may determine a third HARQ ACK bit corresponding to a PDSCH or a SPS PDSCH release scheduled via the fourth DCI (DCI 4). The wireless device may move to a next PDCCH monitoring 10 occasion, where the wireless device receives a DCI with a DAI value. For example, the wireless device may determine a third monitoring occasion via the second cell as the next PDCCH monitoring occasion. The wireless device may determine a fourth HARQ ACK bit corresponding to a PDSCH or a SPS PDSCH scheduled by the fifth DCI (DCI5).

The wireless device may determine a total DAI value for a PUCCH resource, based on a last DCI received for the 20 PUCCH resource. For example, the fifth DCI may be a last DCI that the wireless device receives for the PUCCH resource in FIG. 37. The fifth DCI indicates a T-DAI=4 that may indicate five DCIs have been scheduled up to the current PDCCH monitoring occasion.

The wireless device may determine a number of HARQ-ACK bits based on the T-DAI of the last DCI.

The wireless device may determine an order (e.g., a bit order) of each DCI or a PDSCH scheduled by each DCI based on a C-DAI value of the each DCI. For example, a bit 30 order of the fourth DCI (DCI 4) is 3, the wireless device may place a HARQ-ACK bit for the fourth DCI in a bit with index 3 as shown in FIG. 37.

The wireless device may determine NACK for a missed DCI between the second DCI and the fourth DCI. The 35 wireless device may generate aggregated HARQ-ACK feedback by ascending order of a start time of a PDCCH monitoring occasion (e.g., the first DCI, the second DCI→ (the third DCI→ ) the fourth DCI→ the fifth DCI) and for each PDCCH monitoring occasion based on a cell index 40 (e.g., the first cell→ the second cell in the first monitoring occasion).

The wireless device may determine whether a SPS PDSCH reception based on a SPS configuration is mapped to the PUCCH resource. When a single SPS PDSCH reception 45 across cells is mapped to the PUCCH resource, the wireless device may generate a HARQ-ACK bit corresponding to the SPS PDSCH reception. The wireless device may append the HARQ-ACK bit after the aggregated HARQ-ACK feedback based on one or more PDCCH monitoring occasions.

In FIG. 37, the wireless device may append a HARQ-ACK bit for the SPS PDSCH after five bits of HARQ-ACK bits. The wireless device may transmit the appended HARQ-ACK bits via the PUCCH resource.

The wireless device may determine a bit order of HARQ-ACK feedback for one or more DCIs/PDSCHs based on C-DAI/T-DAI values of the one or more DCIs.

If the wireless device may be configured with a plurality of coresets pool indexes for a serving cell, the wireless device 60 may further order based on a coresets pool index (e.g., a first coressets pool→ a second coressets pool). When a wireless device may be configured with a plurality of transport blocks for any serving cell, the wireless device may determine two ACK and/or NACK bits for each PDCCH monitoring occasion of a serving cell. The wireless device may transmit 5 bits of HARQ ACK feedback corresponding to an order of DCI1, DCI2, DCI3, DCI4 and DCI5.

In an example, a wireless device may transmit a HARQ-ACK information (e.g., a HARQ-ACK codebook, one or more HARQ-ACK codebooks, and/or the like) in a PUCCH resource in a slot n. The wireless device may determine a bitmap of ACK-NACK information. The bitmap of ACK-NACK information may comprise a HARQ-ACK codebook, where the HARQ-ACK codebook may comprise one or more HARQ-ACK sub-codebooks. For example. The bitmap of ACK-NACK information may comprise one or more HARQ-ACK codebooks.

For example, the wireless device may generate a first bitmap for a first HARQ-ACK sub-codebook. The wireless device may generate a second bitmap for a second HARQ-ACK sub-codebook. For example, the wireless device may generate the first bitmap for a first HARQ-ACK codebook. The wireless device may generate the second bitmap for a second HARQ-ACK codebook. A PUCCH may comprise a HARQ-ACK codebook comprising one or more HARQ-ACK sub-codebooks. A PUCCH may comprise one or more HARQ-ACK codebooks.

For example, a wireless device may perform encoding based on a HARQ-ACK codebook. When a HARQ-ACK codebook comprises a plurality of HARQ-ACK sub-codebooks, the wireless device may append the plurality of HARQ-ACK sub-codebooks before performing encoding.

Example embodiments may generate a plurality of HARQ-ACK sub-codebooks for a HARQ-ACK codebook. Example embodiments may generate a plurality of HARQ-ACK codebooks, where each HARQ-ACK codebook, of the plurality of HARQ-ACK codebooks, may correspond to a HARQ-ACK sub-codebook of the examples.

In an example, a wireless device may generate a HARQ-ACK codebook comprising one or more HARQ-ACK sub-codebooks. The wireless device may encode the HARQ-ACK codebook and may transmit the encoded bits via a PUCCH resource.

For example, a first HARQ-ACK sub-codebook (e.g., a codebook, a sub-codebook, a first HARQ-ACK codebook) may correspond to one or more downlink channels (e.g., PDSCH), where each downlink channel carries one or more transport blocks. A second HARQ-ACK sub-codebook may correspond to one or more second downlink channels (e.g., PDSCH), where each second downlink channel carries one or more code block groups (CBGs).

For the first HARQ-ACK sub-codebook, the wireless device may generate P1 bits of ACK-NACK bits for a downlink channel of the one or more downlink channels. For example, P1 may be 1 in response to a number of transport block for a slot (e.g., maxNrofCodeWordsScheduled-ByDCI=1) being one. For example, P1 may be 2 in response to a number of transport block for a slot (e.g., maxNrofCodeWordsScheduledByDCI=2) being two. For example, the wireless device may generate P1 bits of ACK-NACK bit(s) for each DAI value based on counter DAI and/or T-DAI for the first HARQ-ACK sub-codebook.

For the second HARQ-ACK sub-codebook, the wireless device may generate P2 bits of ACK-NACK bits for a downlink channel of the one or more second downlink channels. For example, P2 may be M in response to a number of transport block for a slot (e.g., maxNrofCodeWordsScheduledByDCI=1) being one and a number of maximum CBGs configured to a serving cell being M. For example, P2 may be 2\*M in response to a number of transport block for a slot (e.g., maxNrofCodeWordsScheduledByDCI=2) being two and a number of maximum CBGs configured to a serving cell being M. For example, the wireless device may generate P2 bits of ACK-NACK bit(s)

for each DAI value based on counter DAI and/or T-DAI for the second HARQ-ACK sub-codebook.

In an example, the wireless device may determine a first C-DAI/T-DAI for the first HARQ-ACK sub-codebook. The wireless device may determine a second C-DAI/T-DAI for the second HARQ-ACK sub-codebook.

In an example, a wireless device may be configured with a first cell and a second cell. The first cell and the second cell may be activated. A base station may transmit one or more

- 10 RRC messages indicating configuration parameters. The configuration parameters may indicate/comprise a number of CBGs for the second cell. The wireless device may determine a DCI format, for the second cell, comprising a CBG transmission information (CBGTI). The CBGTI may be a bitmap, where each bit may correspond to each CBG of one or more CBGs, where a number of the one or more CBGs may be limited by the number of CBGs configured for the second cell. The base station may not configure a CBG transmission for the first cell. The base station may transmit
- 15 a second DCI format, for the first cell, based on a transport block transmission.

The wireless device may not be configured with a third DCI format, for the second cell, where the third DCI format may schedule resources of the second cell based on a transport block transmission.

- 25 The wireless device may receive a first DCI indicating downlink resources, of a first downlink channel, of the first cell with a PUCCH resource. The wireless device may receive a second DCI indicating second downlink resources, of a second downlink channel, of the second cell with the PUCCH resource. The wireless device may determine a first HARQ-ACK sub-codebook comprising ACK-NACK bit(s) corresponding to the first downlink channel. The wireless device may determine a second HARQ-ACK sub-codebook comprising ACK-NACK bit(s) corresponding to the second downlink channel. The wireless device may append the second HARQ-ACK sub-codebook to the first HARQ-ACK sub-codebook. The wireless device may transmit the appended bits via the PUCCH resource.

- 30 40 In an example, the wireless device may generate a HARQ-ACK bit for a semi-persistent scheduling (SPS) PDSCH reception based on a SPS PDSCH configuration. The wireless device may append the HARQ-ACK bit to the first HARQ-ACK sub-codebook, before appending the second HARQ-ACK sub-codebook to the first HARQ-ACK sub-codebook. The wireless device may place the HARQ-ACK bit of the SPS PDSCH reception via the first HARQ-ACK sub-codebook.

- 50 55 When semipersistent scheduling is activated, a wireless device may periodically receive downlink data transmissions (e.g., SPS PDSCH transmissions, via SPS PDSCH receptions, via SPS PDSCH occasions). The periodicity of receiving the downlink data transmissions may RRC-configured (e.g., based on one or more periodicity parameters received through RRC signaling). First resource of periodic resources may be scheduled via a downlink control channel. The wireless device may activate the first resource and a semi-persistent scheduling based on the downlink control channel. The wireless device may receive downlink data transmission via periodic resources other than first resource without receiving downlink control channel(s).

- 60 65 In an example, a wireless device may be configured with one or more serving cells. The wireless device may receive one or more RRC messages indicating configuration parameters. The configuration parameters may indicate/comprise one or more SPS PDSCH configurations (e.g., SPS PDSCH configs, SPS configs, SPS configurations) for a cell of the

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one or more serving cells. The wireless device may receive a DCI activating a single SPS PDSCH configuration of the one or more SPS PDSCH configurations. The DCI may comprise/indicate a slot offset/scheduling offset ( $k_0$ ) for receiving a first SPS PDSCH. The wireless device may determine the first SPS PDSCH reception based on the DCI and the slot offset ( $k_0$ ). For example, a slot  $n$  of the first SPS PDSCH is after  $k_0$  slots from the DCI (e.g., a first slot of the DCI).

The wireless device may determine one or more SPS PDSCH receptions where each of the one or more SPS PDSCH receptions may occur at a slot  $n+i*P$ , where  $i$  is 1, 2, ..., and  $P$  is a periodicity of the SPS configuration. An SPS PDSCH reception may be a resource (e.g., time-domain, frequency-domain, and/or spatial-domain) in the PDSCH or an SPS PDSCH during which the base station may, or may not, transmit a transport block to the wireless device. The SPS PDSCH reception may refer to resources of a SPS transmission by the base station.

The wireless device may determine a PUCCH resource of the first SPS PDSCH based on a PDSCH-to-HARQ\_feedback timing (e.g.,  $k_1$ ) indicated by the DCI. The wireless device may transmit a HARQ-ACK feedback for the first SPS PDSCH via the PUCCH resource. The wireless device may determine one or more PUCCH resources of the one or more SPS PDSCH receptions where each PUCCH resource of the one or more PUCCH resources may occur in a slot  $n+i*P+k_1$ . A same timing/scheduling offset/gap between a SPS PDSCH reception and a PUCCH resource may be repeated for each periodicity. The wireless device may transmit a HARQ-ACK feedback of each SPS PDSCH via each PUCCH resource of the one or more PUCCH resources.

The wireless device may determine a PUCCH resource in a slot  $n$ . The wireless device may determine a number of SPS PDSCH configuration(s), where a HARQ-ACK feedback corresponding to a SPS PDSCH, of one or more SPS PDSCH configurations, is scheduled via the PUCCH resource. For example, the wireless device may determine the one or more SPS configurations based on periodicity(s) and/or PDSCH-to-HARQ\_feedback timing values and/or a repetition of each SPS PDSCH.

The wireless device may determine HARQ-ACK feedbacks of a plurality of SPS PDSCH configurations may be mapped/correspond to a PUCCH resource (e.g., a same PUCCH resource). The wireless device may determine a plurality of HARQ-ACK bits for the plurality of SPS PDSCH configurations based on a procedure in FIG. 38-FIG. 39.

FIG. 38 illustrates an example of a HARQ-ACK codebook determination of SPS configurations as per an aspect of an embodiment of the present disclosure.

A wireless device may determine one or more HARQ-ACK bits based on an order of a serving cell index, a SPS configuration index, and a slot index of a DL slot of a SPS PDSCH reception. For example, the wireless device may determine one or more first HARQ-ACK bits for a first serving cell with a lowest index among one or more serving cells configured with a SPS configuration. The one or more first HARQ-ACK bits may be ordered based on a SPS configuration index if the first serving cell is configured with a plurality of SPS configurations.

Then the wireless device may determine/generate one or more second HARQ-ACK bits for a second serving cell with a next lowest index among the one or more serving cells. The wireless device may append the one or more second HARQ-ACK bits to the one or more first HARQ-ACK bits.

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The wireless device may iterate the process for the one or more serving cells based on an order of cell indexes.

In FIG. 38, a wireless device is configured with a first cell (Cell 0) and a second cell (Cell 1). For the first cell, the wireless device may be configured with a first SPS configuration (SPS Config 1) and a second SPS configuration (SPS Config 2). For the second cell, the wireless device may be configured with a third SPS configuration (SPS Config 3) and a fourth SPS configuration (SPS Config 4).

10 A first SPS PDSCH reception (#1), of the second SPS configuration, may occur before than a second SPS PDSCH reception (#2), of the first SPS configuration, via the first cell.

15 A third SPS PDSCH reception (#3), of the third SPS configuration, may occur before than a fourth SPS PDSCH reception (#4), of the fourth SPS configuration, via the second cell.

20 A first cell index of the first cell may be smaller than a second cell index of the second cell.

25 A first index of the first SPS configuration is smaller than a second index of the second SPS configuration.

30 A third index of the third SPS configuration is smaller than a fourth index of the fourth SPS configuration.

The wireless device may determine one or more HARQ-ACK bits of the first cell first based on the first cell index being smaller than the second cell index.

35 The wireless device may determine/order a first HARQ-ACK bit of the second SPS PDSCH reception (#2) before a second HARQ-ACK of the first SPS PDSCH reception (#1) based on the first index being smaller than the second index.

In an example, the wireless device may determine an order of the one or more HARQ-ACK bits based on a slot index of a corresponding SPS PDSCH reception (e.g., the second HARQ-ACK bit comes first/before than the first 35 HARQ-ACK bit in FIG. 38). The wireless device may determine the one or more HARQ-ACK bits across a plurality of SPS configurations based on an order of slot index(es).

40 For the second cell, the wireless device may determine/order a third HARQ-ACK bit of the third SPS PDSCH reception and a fourth HARQ-ACK bit of the fourth SPS PDSCH reception based on the third index being smaller than the fourth index (or based on a timing the third SPS PDSCH reception and the fourth SPS PDSCH reception).

45 The wireless device may determine four bits of HARQ-ACK bits in an order of the second SPS PDSCH reception, the first SPS PDSCH reception, the third SPS PDSCH reception and the fourth SPS PDSCH reception.

The wireless device may transmit the fourth bits of the 50 HARQ-ACK bits via a PUCCH resource.

FIG. 39 illustrates a pseudo code of a HARQ-ACK codebook determination of SPS configurations as per an aspect of an embodiment of the present disclosure.

For example, a wireless device may determine a number 55 ( $N^{DL\_cells}$ ) of serving cells configured to the wireless device. The number of serving cells may count one or more serving cells configured with one or more SPS configurations. The number of serving cells may count one or more serving cells regardless of a SPS configuration.

60 The wireless device may determine a number ( $N^{SPS\_c}$ ) of SPS configurations for a serving cell (c) of the one or more serving cells.

65 The wireless device may determine one or more downlink slots (e.g., DL slots) on the serving cell (c) where a HARQ-ACK bit of a PDSCH in a DL slot of the one or more downlink slots corresponds to (or is multiplexed with) the PUCCH resource. For example, the one or more DL slots

may be determined based on one or more k1 values configured to the wireless device. For example, k1 values may be configured via RRC signaling. The k1 values may comprise an offset between a first slot of the PDSCH to a second slot of the PUCCH resource. The k1 values may comprise an offset between a last OFDM symbol of the PDSCH to a first OFDM symbol of the PUCCH resource.

For example, the wireless device may determine a slot n for the PUCCH resource. The wireless device may be configured with k1 values of {1, 2, 8}. The wireless device may determine DL slots comprising {slot n-1, slot n-2, slot n-8}. For example, the wireless device may determine DL slots where each DL slot of the DL slots is determined based on a slot index of a PUCCH resource and a k1 value of one or more configured k1 values.

For a single serving cell, the wireless device may order one or more HARQ-ACK bits based on an index of a SPS configuration. For example, when a first SPS configuration with a first index and a second SPS configuration with a second index are configured to the single serving cell, the wireless device may determine the first SPS configuration first in response to the first index being smaller than the second index.

The wireless device may generate one or more third HARQ-ACK bits for the first SPS configuration. The wireless device may generate one or more fourth HARQ-ACK bits for the second SPS configuration.

The wireless device may append(concatenate the one or more fourth HARQ-ACK bits to the one or more third HARQ-ACK bits.

The wireless device may determine an order of the one or more third HARQ-ACK bits or the one or more fourth HARQ-ACK bits based on slot index(es) of one or more DL slots.

For example, for the first SPS configuration, a first DL slot with a first slot index and a second DL slot with a second slot index may transmit or be scheduled with SPS PDSCH receptions, the wireless device may determine a first HARQ-ACK bit for the first DL slot first/before a second HARQ-ACK bit for the second DL slot in response to the first slot index being smaller than the second slot index (or the first DL slot is earlier/before than the second DL slot).

The wireless device may append the second HARQ-ACK bit to the first HARQ-ACK bit.

The wireless device may append/aggregate(concatenate one or more first HARQ-ACK bits of a SPS configuration, based on DL slot(s), firstly.

The wireless device may append/aggregate(concatenate one or more second HARQ-ACK bits of a serving cell, based on an order of SPS configuration index(es), secondly.

The wireless device may append/aggregate(concatenate one or more third HARQ-ACK bits across one or more serving cells, based on an order of serving cell index(es), thirdly.

The wireless device may determine a number of HARQ-ACK bits of the one or more third HARQ-ACK bits.

In existing technologies, a wireless device may generate a HARQ-ACK bit for one or more SPS PDSCH receptions occurring between an interval or a time duration. The wireless device may receive one transport block via one or more SPS PDSCH receptions. The interval or the time duration may be determined based on a SPS configuration. The interval or the time duration may be determined based on a periodicity of the SPS configuration.

Implementation of existing technologies may enable one or more HARQ-ACK bits of a cell, where the cell is configured with one or more SPS configurations.

In recent technologies, a multi-PDSCH DCI is introduced. A single DCI may schedule resources for one or more PDSCHs, where each PDSCH may carry/comprise a transport block. A single multi-PDSCH DCI may schedule resources for one or more transport blocks.

Based on existing technologies, a multi-PDSCH DCI may activate, based on a SPS configuration, a single SPS PDSCH reception or one or more SPS PDSCH receptions in each periodicity. The one or more SPS PDSCH receptions may be used with a repetition of a transport block. The wireless device may determine a HARQ-ACK bit for the single SPS PDSCH repetition or the one or more SPS PDSCH receptions.

When the multi-PDSCH DCI may activate multiple SPS PDSCH receptions for multiple transport blocks in each interval/periodicity, implementation of existing technologies may be inefficient. For example, the wireless device may generate a single HARQ-ACK bit for the multiple transport blocks by aggregating HARQ-ACK feedback of the multiple transport blocks. The wireless device may transmit ACK when the multiple transport blocks are successfully received. The wireless device may transmit NACK when any of the multiple transport blocks is failed. For example, when the base station may not schedule a transport block of the multiple transport blocks, or when the wireless device may fail to receive a transport block of the multiple transport block, the wireless device may transmit a NACK to the base station.

In response to the NACK, the base station may need to retransmit all of the multiple transport blocks as the base station may not be able to determine which particular transport block(s) has been successfully received or failed. This may increase retransmission overhead since the base station may need to retransmit all of the multiple transport blocks even though, e.g., the wireless device did not fail to receive all of the transport blocks. For analogous reasons, this may decrease efficiency of a SPS configuration.

In an example, a wireless device may determine a HARQ-ACK bit corresponding to a SPS PDSCH that schedules/comprise/carries a transport block. The wireless device may determine a first HARQ-ACK bit for a first transport block and a second HARQ-ACK bit for a second transport block. In an example, the transport block may be transmitted via a first SPS PDSCH reception. The second transport block may be transmitted via a second SPS PDSCH reception. The first SPS PDSCH reception and the second SPS PDSCH reception may occur within an interval of a SPS configuration. The first SPS PDSCH reception and the second SPS PDSCH reception may be determined based on the SPS configuration. The first SPS PDSCH reception and the second SPS PDSCH reception may be activated based on a multi-PDSCH DCI.

For example, the wireless device may determine one or more HARQ-ACK bits for a SPS configuration. The wireless device may determine an order of the one or more HARQ-ACK bits based on a slot index or a received timing of one or more PDSCHs corresponding to the one or more HARQ-ACK bits.

The wireless device may append or concatenate the one or more HARQ-ACK bits to a first HARQ-ACK sub-codebook (e.g., for a TB-based transmissions) or to a second HARQ-ACK sub-codebook (e.g., for a CBG-based transmissions) or a third HARQ-ACK sub-codebook (e.g., for a multi-PDSCH DCI based transmissions).

The wireless device may determine the one or more HARQ-ACK bits based on a DL slot (e.g., determined by a PUCCH resource and a k1 offset) and a number of sched-

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utable/scheduled PDSCHs by a multi-PDSCH DCI. For example, when a multi-PDSCH DCI may be able to schedule M PDSCHs or M slots, the wireless device may determine a set of slots {slot n-k1-(M-1), n-k1-(M-2), ..., slot n-k1} for the one or more HARQ-ACK bits based on the slot n-k1 where a PUCCH is scheduled in a slot n and a PDSCH-to-HARQ\_feedback timing value (e.g., k1) is k1. The wireless device may determine a union of set of slots for each value of k1 among one or more PDSCH-to-HARQ\_feedback timing values configured to the wireless device for a serving cell.

The wireless device may determine the union of set of slots as DL slots.

The union of the set of slots may combine each set of slots based on each value of k1 among the one or more PDSCH-to-HARQ\_feedback timing values without repetition (e.g., without repeating the same slot twice). For example, the wireless device may determine a first DL slot and a second DL slot (e.g., a first set of slots) based on a first k1 value of the one or more PDSCH-t-HARQ\_feedback timing values. The wireless device may determine the second SL slot and a third slot (e.g., a second set of slots) based on a second k1 value of the one or more PDSCH-t-HARQ\_feedback timing values. The wireless device may determine the union of the first set of slots of the first k1 value and the second set of slots of the second k1 value as the first slot, the second slot and the third slot by counting each slot once.

The wireless device may determine the set of slots based on a number of scheduled PDSCHs/slots based on an activation DCI of the SPS configuration.

The wireless device may determine the one or more HARQ-ACK bits and may transmit the one or more HARQ-ACK bits via the PUCCH resource.

The base station may be able to determine which particular transport block/PDSCH has been successfully received and which particular transport block/PDSCH has been failed based on the one or more HARQ-ACK bits. Example embodiments may reduce unnecessary retransmissions. Example embodiments may allow an activation of a SPS configuration to enable multiple transport block transmissions in each periodicity. This may increase scheduling flexibility and performance.

The frequency domain resource may be applied, based on one or more frequency hopping patterns, via the one or more PDSCHs or the one or more time domain resources. For example, first PDSCH of the one or more PDSCHs may be mapped via the frequency domain resource. Second (e.g., next) PDSCH of the one or more PDSCHs may be mapped a second frequency domain resource. The second frequency domain resource may be determined based on the frequency domain resource and a hopping offset based on the one or more frequency hopping patterns.

The configuration parameters may indicate the one or more frequency hopping patterns for the SPS PDSCH configuration. The one or more frequency hopping patterns may comprise one or more of {an intra-slot hopping, an inter-slot hopping, an inter-repetition hopping}. For example, the intra-slot hopping, the wireless device may switch a frequency location in a slot where hopping occurs in half of a time duration of a PDSCH. The intra-slot hopping, the wireless device may switch a frequency location in different slots (e.g., first slot and a next slot). The hopping may occur in every slot boundary between two consecutive PDSCHs in consecutive valid slots (or valid transmissions). The inter-repetition may occur between two repetitions. The inter-

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repetition may occur in each PDSCH. In each PDSCH, the wireless device may switch a frequency location based on a hopping offset.

The wireless device may determine a number (Si) of PDSCHs scheduled in an i-th interval/period of the SPS configuration based on the DCI (e.g., an activation DCI) and the periodicity of the SPS configuration.

For example, the wireless device may determine N1 for one or more first SPS PDSCHs based on the one or more PDSCHs/slots scheduled by the activation DCI. The wireless device may determine N2 for one or more second SPS PDSCHs based on one or more second time domain resources (e.g., slots, SLIV values). The wireless device may determine the one or more second time domain resources based on the activation DCI and the periodicity. For example, the activation DCI may indicate one or more first time domain resources for the one or more first SPS PDSCHs. The wireless device may determine the one or more second time domain resources, where each of the one or more second time domain resources occur after the periodicity of each of the one or more first time domain resources.

For example, when the one or more first time domain resources indicates {[slot n, symbol 1-10], [slot n+1, symbol 1-4], [slot n+1, symbol 6-14]} for three SPS PDSCHs and the periodicity is 10 slots, the wireless device may determine the one or more second time domain resources of {[slot n+10, symbol 1-10], [slot n+11, symbol 1-4], [slot n+11, symbol 6-14]} based on each resource of the one or more first time domain resources and the periodicity.

Based on a mapping type and/or a configuration, a slot may be scheduled with at most a PDSCH or a slot may be scheduled with one or more PDSCHs. The example may indicate slot n+1 is scheduled with two PDSCHs.

Example embodiments in the specification may be applied for each slot. For example, a slot may be mapped to at most one PDSCH. Example embodiments in the specification may be applied for each PDSCH or each time domain resource. For example, a slot may be mapped to one or more PDSCHs. Each time domain resource (e.g., SLIV) may indicate a starting symbol and a length for a PDSCH. Each time domain resource (e.g., SLIV) may indicate a starting symbol, a length for a PDSCH and a repetition.

In an example, the wireless device may determine Ni of the i-th interval/period based on one or more following examples.

For example, Ni may be determined based on a maximum number of PDSCHs scheduled by a DCI based on a multi-PDSCH DCI format. The maximum number of PDSCHs may be configured, via RRC, MAC-CE, and/or DCI signaling, for a cell indicated with a multi-PDSCH scheduling. The wireless device may determine the maximum number of PDSCHs based on a TDRA table of the cell (e.g., a TDRA table of an active BWP of the cell).

The TDRA table of the cell may comprise one or more time domain resource allocation entries, where one entry of the one or more time domain resource allocation entries may be indicated by a downlink control information. An entry of the one or more time domain resource allocation entries may indicate time domain resources for one or more PDSCHs.

The maximum number of PDSCHs may be a maximum number of SLIV values of a TDRA entry of the TDRA table or a maximum number of slots of a second TDRA entry of the TDRA table. The wireless device may determine the maximum number of PDSCHs based on all entries in the TDRA table indicated for the multi-PDSCH scheduling.

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The maximum number of PDSCHs may be configured for the SPS configuration. For each SPS configuration of a cell may be configured/indicated with a maximum number of PDSCHs.

The maximum number of PDSCHs may be used to determine  $N_i$  of the  $i$ -th interval/period. The  $N_i$  may be equal to the maximum number of PDSCHs.

For example,  $N_i$  may be determined based on a number of PDSCHs (e.g., SPS PDSCHs) scheduled by an activation DCI of the SPS configuration. For example, the activation DCI may indicate  $M$  number of time domain resources, where each of the time domain resources corresponds to a PDSCH. The wireless device may determine the activation DCI indicates  $M$  number of PDSCHs. For example, the wireless device may determine a PDSCH of the  $M$  PDSCHs may be skipped (or invalid) based on a corresponding time domain resource, of the  $M$  time domain resources, overlapping (partially or fully) with uplink resources. For example, the wireless device may count  $M$  for the number of PDSCHs regardless of whether each PDSCH is skipped or not. The wireless device may determine  $M$  PDSCHs based on scheduled time domain resources. For example, the  $M$  time domain resources may indicate  $M$  slots. For example, the  $M$  time domain resources may indicate  $M$  SLIV values. For example, the  $M$  time domain resources may indicate  $M$  sub-slots. For example, a slot may comprise  $Q$  sub-slots (e.g.,  $Q=2, 4, 6, 7$ ). For example, when a slot comprises two sub-slots, each sub-slot may comprise  $X/2$  symbols (e.g.,  $X=14$  with normal CP,  $X=12$  with extended CP). For example, when a slot comprises four sub-slots, each subslot may comprise 3 or 4 symbols with normal CP and 3 symbols with extended CP. With extended CP,  $Q$  may be 6 instead of 7. With  $Q=6$  and extended CP, each sub-slot may comprise two symbols. With  $Q=7$  and normal CP, each sub-slot may comprise two symbols.

The  $N_i$  may be equal to the number of PDSCHs scheduled by the activation DCI of the SPS configuration.

The  $N_i$  may be same in each interval/periodicity. The  $N_i$  may be determined based on the activation DCI.

In an example, the wireless device may determine the number of PDSCHs based on valid PDSCH(s) scheduled by the activation DCI. For example, the activation DCI may indicate  $M$  time domain resources, where each of the  $M$  time domain resources may correspond to a PDSCH. The wireless device may determine a PDSCH is valid when corresponding time domain resource overlaps with downlink and/or flexible symbols/resources (e.g., does not overlap with uplink resources). The wireless device may determine a PDSCH is invalid when corresponding time domain resource overlaps with uplink symbols/resources. The wireless device may determine the number of valid PDSCHs that may be smaller than or equal to  $M$ . The wireless device may determine the number of valid PDSCHs in a first interval/period as  $S_1$ . The wireless device may determine  $N_i$  is same to  $S_1$ . The wireless device may assume that a same number of valid PDSCHs are scheduled in each interval/period. The base station may schedule time domain resources in a way that time domain resources in each interval/period may have same slot formation information and thus may lead same number of valid PDSCHs.

In an example, the wireless device may determine a number of valid PDSCHs in each interval/period (e.g.,  $N_i$  of  $i$ -th interval/period) may be equal to or smaller than  $N_1$  (the number of valid PDSCH in the first interval/period). When a number of valid PDSCHs in an interval/period is larger than  $S_1$ , the wireless device may ignore one or more valid PDSCHs (e.g., assume the one or more valid PDSCHs are

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skipped) until a number of PDSCHs becoming equal to  $S_1$ . The wireless device may assume that the base station may not schedule any data via the one or more PDSCHs (skipped/ignored).

5 Each  $N_i$  may be same to the  $S_1$ . The  $N_1$  may equal to the number of valid (SPS) PDSCHs in the first interval/period. The number of valid (SPS) PDSCHs may be determined based on one or more first time domain resources indicated by the activation DCI and slot formation information of one or more slots overlapping with the one or more first time domain resources.

For example,  $N_i$  may be determined based on a number of time domain resources (e.g., slots, SLIV values) scheduled/indicated by an activation DCI of the SPS configuration. For example, a time domain resource may indicate resources for a PDSCH. The time domain resource may indicate a slot. The time domain resource may indicate a sub-slot. The time domain resource may be determined based on a SLIV value of a TDRA entry of a TDRA table. The TDRA table may be configured for a multi-PDSCH scheduling of a cell. The TDRA table may be configured for an active BWP of the cell for the multi-PDSCH scheduling. The activation DCI may indicate the TDRA entry (e.g., comprise an index to the TDRA entry of the TDRA table). The TDRA entry may comprise one or more SLIV values, where each SLIV value may correspond to a PDSCH. The TDRA entry may comprise one or more sub-slots, where each sub-slot may correspond to a PDSCH. Each SLIV value may correspond to a sub-slot. The TDRA entry may comprise one or more of {an offset, a starting symbol, a length}. For example, the offset may be a slot offset or a sub-slot offset. For example, the starting symbol may indicate a first symbol in a slot or in a sub-slot. The wireless device may determine the slot or the sub-slot based on the slot offset or the sub-slot offset. The length may indicate a time duration. The wireless device may determine the slot or the sub-slot based on a first slot or a first sub-slot where the wireless device receives the activation DCI and the slot offset or the sub-slot offset.

40 The wireless device may determine one or more time domain resources indicated by the activation DCI. The wireless device may determine  $N_1$  is equal to the number of the one or more time domain resources. The wireless device may determine  $N_i$  is equal to the  $S_1$ .

45 For example,  $N_i$  may be determined based on a number of valid time domain resources in  $i$ -th period/interval. The wireless device may determine one or more first time domain resources based on the activation DCI. The one or more first time domain resources may be determined based on a TDRA entry indicated by the activation DCI. The wireless device may determine a time domain resource of the one or more first time domain resources is valid in response to all resources of the time domain resource overlapping (e.g., fully overlapping) with downlink and/or flexible symbols/resources. The time domain resource may fully overlap with downlink symbols. The time domain resource may fully overlap with flexible symbols. The time domain resource may fully overlap with a combination of downlink and flexible symbols.

50 The wireless device may determine a time domain resource of the one or more first time domain resources is invalid in response to any resources of the time domain resource overlapping (e.g., partially or fully overlapping) with uplink symbol(s)/resources.

55 The wireless device may determine valid time domain resource, for the first interval/period, based on the TDRA entry indicated by the activation DCI and slot formation

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information of one or more slots overlapping with the one or more first time domain resources.

The wireless device may determine one or more i-th time domain resources based on the TDRA entry and the periodicity of the SPS configuration. For example, the wireless device may determine each of the one or more i-th time domain resources occurs after each of the one or more first time domain resources by  $P^*(i-1)$  where P is the periodicity. The wireless device may determine valid time domain resource(s) of the one or more i-th time domain resources based on slot formation information of one or more i-th slots overlapping with the one or more i-th time domain resources.

For example, the wireless device may determine slot  $n+m+P$  and slot  $n+m+P+1$  are valid time domain resources in 2<sup>nd</sup> interval/period (see, e.g., FIG. 29).

For each interval/period, the wireless device may determine one or more i-th time domain resources based on a TDRA entry indicated by an activation DCI and a periodicity of a SPS configuration. The wireless device may determine one or more i-th valid time domain resources based on the one or more i-th time domain resources and slot formation information of one or more i-th slots overlapping with the one or more i-th time domain resources.

The wireless device may determine  $N_i$  is a number of the one or more i-th valid time domain resources. Each time domain resource may be mapped to a PDSCH. For example,  $N_i$  may be determined based on a number of valid PDSCHs determined in each i-th period/interval. For example, the number of valid PDSCHs may be same as a number of valid time domain resources in each period/interval.

For example,  $N_i$  may be determined based on a number of schedulable transport blocks in each i-th period/interval. When a number of valid PDSCHs may be M and each PDSCH may carry/comprise a transport block, the number of scheduled transport blocks may be same as the number of valid PDSCHs.

For example, when a repetition is used, where R PDSCHs may carry a transport block, a number of schedulable transport blocks may be determined as floor (or ceil) [M/R].

For example, when a PDSCH may carry one or more transport blocks, a number of schedulable transport blocks may be determined as  $M^*K$ , where K is a maximum number of transport blocks (or codewords) schedulable in a PDSCH.

The wireless device may determine a number of valid time domain resources in each interval/period. The wireless device may determine a number of schedulable transport blocks by a PDSCH (e.g., 1/R or K). The wireless device may determine a number of schedulable transport blocks by the number of valid time domain resources (or valid PDSCHs) (e.g., [M/R], [M\*K]). The wireless device may determine  $N_i$  is equal to the number of schedulable blocks in i-th interval/period.

In an example, the wireless device may determine one or more i-th SPS PDSCHs in i-th interval/period. For example, the wireless device may determine  $N_i$  PDSCHs in i-th interval/period. The wireless device may determine a first PUCCH resource for the one or more i-th SPS PDSCHs based on last SPS PDSCH of the one or more i-th SPS PDSCHs and an offset to the first PUCCH resource. For example, the offset may be indicated by an activation DCI with a PDSCH-to-HARQ\_feedback timing indicator (e.g., k1). The wireless device may determine a PUCCH resource (or feedback timing) of the one or more i-th SPS PDSCHs as the first PUCCH resource based on the last SPS PDSCH. For example, a same PUCCH resource may be used for the

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one or more i-th SPS PDSCHs. The same PUCCH resource may be determined based on the last SPS PDSCH and the k1 offset.

The wireless device may determine one or more intervals/periods, where a same PUCCH resource may be determined. For example, a subcarrier spacing of the PUCCH may be small and a subcarrier spacing of the SPS configuration may be large. One or more intervals/periods of the SPS configuration may be mapped to a single PUCCH resource.

10 In an example, the wireless device may determine one or more SPS PDSCH receptions where timing of HARQ-ACK feedback for the one or more SPS PDSCH receptions is the first PUCCH resource. For example, the one or more SPS PDSCH receptions may comprise the one or more i-th SPS PDSCHs. For example, the one or more SPS PDSCH receptions may comprise one or more i-1-th SPS PDSCHs and/or one or more i+1-th SPS PDSCHs. For example, the one or more SPS PDSCH receptions may comprise one or more SPS PDSCHs of one or more interval/period of the SPS configuration mapping to the first PUCCH resource.

The one or more SPS PDSCH reception may comprise one or more SPS PDSCHs of the SPS configuration.

The wireless device may determine a HARQ-ACK bit for 25 each of the one or more SPS PDSCH reception.

For example, when the one or more SPS PDSCH reception are the one or more i-th SPS PDSCHs (e.g.,  $N_i$  SPS PDSCH(s)), the wireless device may determine  $N_i$  HARQ-ACK bits. Each HARQ-ACK bit may correspond to each 30 SPS PDSCH of the  $N_i$  SPS PDSCH(s).

The wireless device may determine acknowledgement (ACK) or negative acknowledgement (NACK) for a SPS PDSCH where the SPS PDSCH is a valid PDSCH (e.g., not skipped or not ignored). The wireless device may determine 35 NACK for a second SPS PDSCH where the second SPS PDSCH is an invalid PDSCH (e.g., skipped or overlapping with uplink symbols/resources).

When a number of HARQ-ACK bits, of the SPS configuration, mapping to a PUCCH resource is larger than a 40 predetermined value (e.g., 1 or 2), the wireless device may determine a HARQ-ACK codebook for the SPS configuration based on examples shown in FIG. 38-39 and example embodiments of the specification.

When the number of HARQ-ACK bits is equal to or 45 smaller than the predetermined value, the wireless device may generate a predetermined value of HARQ-ACK bits, for the SPS configuration, for the PUCCH resource. The wireless device may append the HARQ-ACK bits to a HARQ-ACK sub-codebook. For example, the HARQ-ACK sub-codebook may be first HARQ-ACK sub-codebook for TB based transmission. For example, the predetermined value of HARQ-ACK bits, for the SPS configuration, for the PUCCH resource may be 1 or 2 bits.

In an example, a wireless device may determine a predetermined number (e.g., M) of HARQ-ACK bits for one or more SPS PDSCH receptions corresponding to a PUCCH resource. For example, M may be configured by a base station. For example, M may be determined based on  $N_1$  (e.g.,  $M=S_1$ ). For example, M may be determined based on 55 a maximum number of PDSCHs schedulable by a DCI of a multi-PDSCH scheduling.

When a number of one or more SPS PDSCH receptions is smaller than or equal to M, the wireless device may generate HARQ-ACK bit(s) for the one or more SPS PDSCH receptions and may generate NACK bit(s) for remaining bits (e.g., M-S). For example, S may represent a 60 number of the one or more SPS PDSCH receptions.

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When the number S is larger than M, the wireless device may truncate remaining bits (e.g., S-M bits). The wireless device may suppress any invalid PDSCH of the one or more SPS PDSCH receptions before truncating remaining bits. The wireless device may perform HARQ-ACK aggregation of S bits to produce/generate M bits (e.g., AND/OR operation for each two bits).

In an example, a wireless device may receive at most a PDSCH in a slot. The PDSCH may be scheduled by a DCI. The PDSCH may be scheduled by a SPS configuration activated by a DCI. The wireless device may generate one or two HARQ-ACK bits corresponding to the slot. The wireless device may generate one HARQ-ACK bit when a TB-based transmission is configured and a maxNrofCodeWordsScheduledByDCI is configured as 1. The wireless device may generate two HARQ-ACK bits when a TB-based transmission is configured and a maxNrofCodeWordsScheduledByDCI is configured as 2.

The wireless device may determine one or more downlink slots. The wireless device may generate one or two HARQ-ACK bits for a downlink slot when the downlink slot schedules a PDSCH (e.g., based on a DCI or based on a SPS configuration).

For a case, where a SPS configuration may be activated based on a multi-PDSCH DCI format, the wireless device may determine one or more HARQ-ACK bits based on one or more downlink slots. The wireless device may determine the one or more downlink slots for a PUCCH resource based on one or more PDSCH-to-HARQ\_feedback timing offset values (e.g., k1 values).

FIG. 40 illustrates an example embodiment of DL slot determination as per an aspect of an embodiment of the present disclosure.

For example, the wireless device may determine a PUCCH resource in slot S4 (e.g., a slot with index 4). The wireless device may be configured with one or more k1 values comprising T0 (e.g., 1), T1 (e.g., 3), and T2 (e.g., 4). A DCI may indicate an index of the one or more k1 values via a PDSCH-to-HARQ\_feedback timing indicator field (PDSCH-to-HARQ in FIG. 18). For example, the DCI may indicate T0, where the PUCCH resource may occur 1 slot after a slot of PDSCH scheduled by the DCI. The one or more k1 values may indicate one or more PDSCH-to-HARQ\_feedback timing values.

For example, an activation DCI may indicate T0 of the one or more k1 values. The activation DCI may schedule four SPS PDSCHs via slot S0, S1, S2 and S3. The wireless device may determine the PUCCH resource based on last SPS PDSCH of the four SPS PDSCHs. The wireless device may determine S4 as the PUCCH resource based on T0 (e.g., 1) offset between the last SPS PDSCH and the PUCCH resource.

The wireless device may determine one or more HARQ-ACK bits based on one or more DL slots for the PUCCH resource at the slot S4.

The wireless device may determine the one or more DL slots where the one or more DL slots may comprise a slot with an offset of a k1 value of the one or more k1 values. For example, T1 indicates three slots. A slot with an offset of three slots from S4 may be determined as a DL slot. For example, a slot S1 may be determined as a DL slot. Similarly, for T2 (e.g., 4) value, a slot S0 (offset of 4 slots from the PUCCH resource) may be determined as a DL slot. The one or more DL slots may comprise the slot S0 and the slot S1 and the slot S3 based on T0, T1 and T2 values.

The wireless device may not determine any HARQ-ACK bit for non-DL slot. For example, the wireless device may

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not determine any HARQ-ACK bit for a slot S2 as there is no k1 value indicating the slot S2 based on the PUCCH resource.

Based on example embodiments, the wireless device may drop one or more HARQ-ACK bits corresponding to a slot S2 as the slot S2 is not determined as a DL slot.

For example, the four SPS PDSCHs activated by the activation DCI may be scheduled via [S0, S3]. The wireless device may generate a first HARQ-ACK bit for a first SPS PDSCH in a slot S0. The wireless device may generate a second HARQ-ACK bit for a second SPS PDSCH in a slot S1. The wireless device may skip generating a HARQ-ACK bit for a third SPS PDSCH in the slot S2 as the slot S2 is not a DL slot. The wireless device may generate a HARQ-ACK bit for a fourth SPS PDSCH in the slot S3.

The wireless device may generate three HARQ-ACK bits for SPS PDSCH receptions for the PUCCH resource. The wireless device may transmit three HARQ-ACK bits via the PCCH resource in the slot S4.

20 In an example, a wireless device may determine one or more DL slots, for a PUCCH resource, based on one or more k1 values and a maximum number of slots/PDSCHs schedulable by an activation DCI, based on a multi-PDSCH scheduling, for a SPS configuration.

25 In an example, a wireless device may determine one or more DL slots, for a PUCCH resource, based on one or more k1 values and a number of slots/PDSCHs schedulable by an activation DCI, based on a multi-PDSCH scheduling, for a SPS configuration. For example, the number of slots/PDSCHs scheduled by an activation DCI may be determined based on a maximum number of PDSCHs or a maximum number of time domain resources by a DCI, based on a multi-PDSCH scheduling, scheduling resources for a cell. The cell may be configured with the multi-PDSCH scheduling. The SPS configuration may be configured for the cell.

30 In an example, the wireless device may be configured with a first value for a maximum number of PDSCHs (or time domain resources) for a multi-PDSCH scheduling for the cell. The wireless device may be configured with a second value for a maximum number of PDSCHs of a SPS PDSCH configuration for the cell. The second value may be determined based on the first value when the second value is not configured. The second value may be configured independently or jointly with the first value. The first value 35 may be used for a DCI scheduling resources of the cell dynamically (e.g., non-SPS configuration). The second value may be used for a second DCI activating one or more SPS configuration of the cell.

The wireless device may determine one or more DL slots 40 based on a k1 value and a maximum number of PDSCHs. The wireless device may determine a union of the one or more DL slots for each k1 value of one or more k1 values. The wireless device may determine one or more combined DL slots that are union of the one or more DL slots for all 45 k1 values configured for an active BWP of the cell.

FIG. 41 illustrates an example embodiment of DL slot determination as per an aspect of an embodiment of the present disclosure. FIG. 41 shows a similar scenario to FIG. 40, where three k1 values (T0, T1 and T2) are configured and a PUCCH resource occurs in a slot S4.

Four SPS PDSCHs may be scheduled based on an activation DCI and a SPS configuration. The wireless device may determine one or more first DL slots based on a first k1 value (e.g., T0) and a maximum number of PDSCHs (e.g., 65 maximum number of schedulable PDSCHs by a DCI based on a multi-PDSCH scheduling). In the example, the maximum number of PDSCHs schedulable by a DCI is consid-

ered as 4. The wireless device may determine a slot S3 as a first DL slot based on the slot S4 and T0 offset (e.g., T0=1).

The wireless device may determine one or more DL slots based on the first DL slot and the maximum number of PDSCHs. For example, the wireless device may determine one or more slots occurring before the first DL slot up to the maximum number of PDSCHs as the one or more DL slots (e.g., slot S3-1, slot S3-2, . . . slot S3-M-1, where M is the maximum number of schedulable PDSCHs). The wireless device may determine slot S0 (S3-3), S1 (S3-2), S1 (S3-1) as DL slots in addition to the slot S3.

Similarly, for T1 value (e.g., T1=3), the wireless device may determine a second DL slot based on the T1 value. The second DL slot is a slot S1. The wireless device may determine one or more additional DL slots based on the second DL slot and the maximum number of schedulable PDSCHs. The wireless device may determine a slot S6 (a slot occurring M-1 slots before the second slot), a slot S7 (a slot occurring M-2 slots before the second slot), and a slot S0 as additional DL slots. The slot S6, S7, S0 and S1 may be determined for DL slots based on the T1 value.

For T2 value (e.g., T2=4), the wireless device may determine a slot S5, a slot S6, a slot S7 and a slot S0 as DL slots.

The wireless device may combine one or more DL slots of each k1 value. The wireless device may determine slot S5 to slot S3 as DL slots based on the combining.

The wireless device may determine one or more HARQ-ACK bits for each SPS PDSCH of the four SPS PDSCHs, wherein the each SPS PDSCH overlaps with a DL slot of the one or more DL slots. For example, in FIG. 41, the wireless device may determine a HARQ-ACK bit for each SPS PDSCH as the each SPS PDSCH overlaps with a DL slot. The wireless device may determine a HARQ-ACK bit for a SPS PDSCH in response to the SPS PDSCH comprising a transport block. The wireless device may determine two HARQ-ACK bits for a SPS PDSCH in response to the SPS PDSCH comprising two transport blocks (e.g., without multiplexing HARQ-ACK bits). The wireless device may determine one HARQ-ACK bit for one or more SPS PDSCHs in response to the one or more SPS PDSCHs comprising a transport block (e.g., based on a repetition).

The wireless device may generate a HARQ-ACK codebook comprising HARQ-ACK bits of the four SPS PDSCHs. The wireless device may transmit the HARQ-ACK codebook via the PUCCH resource.

In an example, the maximum number of schedulable PDSCHs may be determined as a largest value among one or more maximum number of schedulable PDSCHs of one or more SPS configurations of a cell.

In an example, a wireless device may determine one or more DL slots, for a PUCCH resource, based on one or more k1 values and Ni (e.g., a number of SPS PDSCHs) of i-th interval/period based on a SPS configuration.

The wireless device may determine/combine each of one or more DL slots of a SPS configuration of a cell. For example, when the cell is configured with a plurality of SPS configurations, where a plurality of SPS PDSCHs based on the plurality of SPS configurations may correspond to a PUCCH resource. The wireless device may determine one or more combined DL slots that comprise a set of DL slots determined for a SPS configuration of the cell.

For example, based on FIG. 41, the wireless device may determine DL slots based on the T0 value and a number of scheduled SPS PDSCHs in an interval/period. For example, when two SPS PDSCHs are scheduled in an interval/period, the wireless device may determine a slot S2 and a slot S3 as

DL slots based on the T0. The wireless device may determine a slot S0 and a slot S1 as DL slots based on the T1. The wireless device may determine a slot S7 and a slot S0 as DL slots based on the T2. The wireless device may determine slot S7-S3 as DL slots based on a combination of all DL slots of all offset (k1) values.

In an example, a wireless device may determine one or more DL slots of a SPS configuration, for a PUCCH resource, based on a k1 value and Ni (e.g., a number of SPS PDSCHs) of i-th interval/period based on the SPS configuration. The k1 value may be indicated by an activation DCI of the SPS configuration. The wireless device may use the one or more DL slots to determine one or more HARQ-ACK bits for the SPS configuration via the PUCCH resource.

The wireless device may determine one or more second DL slots of a second SPS configuration for the PUCCH resource, based on a second k1 value and a second Nj (e.g., a number of SPS PDSCHs) of j-th interval/period based on the second SPS configuration. For example, the wireless device may determine one or more second HARQ-ACK bits of the second SPS configuration based on the one or more second DL slots.

In an example, the wireless device may combine the one or more first DL slots and the one or more second DL slots as one or more combined DL slots. The wireless device may determine one or more HARQ-ACK bits of one or more SPS PDSCHs based on the one or more combined DL slots.

FIG. 42 illustrates an example embodiment of DL slot determination as per an aspect of an embodiment of the present disclosure. For example, a wireless device may be configured with a first SPS configuration (SPS 1) for a first cell. The wireless device may be configured with a second SPS configuration (SPS 2) for a second cell. The first cell may be same as the second cell. The first cell may be different from the second cell. The wireless device may determine four SPS PDSCH receptions based on the first SPS configuration, wherein feedback timing of the four SPS PDSCH receptions is a PUCCH resource in a slot S4.

The wireless device may determine two SPS PDSCH receptions based on the second SPS configuration, wherein feedback timing of the two SPS PDSCH receptions is the PUCCH resource in the slot S4.

The wireless device may determine one or more first DL slots for the first SPS configuration based on a first k1 value and a Ni (a number of SPS PDSCHs in i-th interval/period) of the first SPS configuration. For example, FIG. 42 shows a number of SPS PDSCHs, Ni, is 4 and a value of k1 is T0 (e.g., 1). The wireless device may determine a slot S0, a slot S1, a slot S2 and a slot S3 as DL slots for the first SPS configuration. For example, k1 value may refer a PDSCH-to-HARQ\_feedback timing/offset (e.g., a gap between PDSCH to PUCCH resource). For example, Ni value may refer a number of SPS PDSCHs in an i-th interval/period of the SPS configuration.

The wireless device may determine one or more second DL slots for the second SPS configuration based on a second k1 value and a Nj (a number of SPS PDSCHs in j-th interval/period) of the second SPS configuration. For example, Nj is 2 in FIG. 42. A value of second k1 value is T2 (e.g., 4). The wireless device may determine a slot S7 and a slot S0 as DL slots.

The wireless device may determine one or more HARQ-ACK bits, of a PDSCH of one or more first SPS PDSCHs of the first SPS configuration, based on the one or more first DL slots. The one or more first SPS PDSCHs may comprise four SPS PDSCHs in FIG. 42. The wireless device may determine four HARQ-ACK bits for four SPS PDSCHs.

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The wireless device may determine one or more second HARQ-ACK bits, of a PDSCH of one or more second SPS PDSCHs of the second SPS configuration, based on the one or more second DL slots. For example, FIG. 42 shows that the one or more second SPS PDSCHs comprise two SPS PDSCHs. The wireless device may determine two HARQ-ACK bits for two SPS PDSCHs.

The wireless device may concatenate the four HARQ-ACK bits and the two HARQ-ACK bits based on an order (e.g., based on a cell index and/or a SPS index). The wireless device may transmit concatenated HARQ-ACK bits via the PUCCH resource.

The wireless device may determine the one or more DL slots for each SPS configuration of a cell. The wireless device may determine the one or more DL slots for each cell regardless of a number of SPS configurations for the each cell.

The wireless device may determine the one or more DL slots for a scheduled cell.

In an example, a wireless device may determine one or more DL slots based on example embodiments shown in FIG. 40 (e.g., based on one or more k1 values). The wireless device may be configured with a SPS configuration for a cell. The wireless device may receive a DCI activating the SPS configuration. The DCI may be based on a multi-PDSCH scheduling. The DCI may be based on a multi-PDSCH DCI format. The multi-PDSCH DCI format may comprise/indicate a plurality of NDI bits, where each bit of the plurality of NDI bits corresponds to a PDSCH or a transport block.

The DCI may schedule one or more time domain resources, where each time domain resource (e.g., a slot, a SLIV, a set of {slot offset, SLIV}) corresponds to a SPS PDSCH of first SPS PDSCH reception(s). The DCI may schedule the first SPS PDSCH receptions(s) (one or more first SPS PDSCHs).

For example, the DCI may indicate a k1 offset (PDSCH-to-HARQ). The wireless device may determine a PUCCH resource for the first SPS PDSCH reception(s) based on last SPS PDCH of the first SPS PDSCH receptions and the k1 offset.

The wireless device may determine one or more i-th SPS PDSCHs (i-th SPS PDSCH receptions) based on the one or more time domain resources and a periodicity of the SPS configuration. The wireless device may determine one or more i-th time domain resources, where each of the one or more i-th time domain resources occur  $(i-1)*P$  slots/units after each of the one or more time domain resources.

The wireless device may determine one or more i-th SPS PDSCHs based on the one or more i-th time domain resources and slot formation information of one or more slots overlapping with the one or more i-th time domain resources.

The wireless device may determine a second SPS PDSCH of the one or more i-th SPS PDSCHs, wherein the second SPS PDSCH is latest SPS PDSCH of the one or more i-th SPS PDSCHs. The wireless device may determine a second PUCCH resource for the one or more i-th SPS PDSCHs based on the second SPS PDSCH and the k1 offset.

For example, a slot of the second PCCH may occur after the k1 offset of a first slot of the second SPS PDSCH.

The wireless device may determine one or more DL slots based on one or more k1 offset values configured for an active BWP of a cell. The cell may be configured with the SPS configuration. The cell may be configured with a multi-PDSCH scheduling.

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For each of DL slot of the one or more DL slots, the wireless device may determine whether a last SPS PDSCH, of one or more i-th SPS PDSCHs, is scheduled.

The wireless device may determine one or more HARQ-ACK bits for the one or more i-th SPS PDSCHs in response to the last SPS PDSCH of the one or more i-th SPS PDSCHs overlapping with a DL slot. Each of the one or more HARQ-ACK bits may correspond to each SPS PDSCH of the one or more i-th SPS PDSCHs.

10 For example, for the last SPS PDSCH in a slot/unit X, the wireless device may determine a second slot/unit X-M, where M is a maximum number of schedulable PDSCHs based on a multi-PDSCH scheduling.

For each slot/unit between [the second slot/unit X-M, X], 15 the wireless device may determine a HARQ-ACK bit in response to a SPS PDSCH is scheduled in each slot/unit. Otherwise, the wireless device may skip the each slot/unit.

For example, for the last SPS PDSCH in a slot/unit X, the wireless device may determine a second slot/unit X-Ni, 20 where Ni is a number of scheduled PDSCHs in i-th interval/period of the SPS configuration.

For each slot/unit between [the second slot/unit X-Ni, X], the wireless device may determine a HARQ-ACK bit in 25 response to a SPS PDSCH is scheduled in each slot/unit. Otherwise, the wireless device may skip the each slot/unit.

The wireless device may generate one or more HARQ-ACK bits based on ascending or descending order of slot/unit index. Based on ascending order, a first HARQ-ACK bit (e.g., an earliest HARQ-ACK bit) may correspond to a 30 PDSCH in the second slot/unit (e.g., first slot/unit of the one or more i-th time resources or the one or more i-th SPS PDSCHs). Based on descending order, a first HARQ-ACK bit (e.g., the earliest HARQ-ACK bit) may correspond to the last SPS PDSCH of the one or more i-th SPS PDSCHs.

35 In an example, the wireless device may determine a last SPS PDSCH reception or a last SPS PDSCH based on one or more i-th time domain resources. For example, the wireless device may determine the one or more i-th time domain resources based on the one or more first time domain 40 resources (indicated by the DCI) and the periodicity of the SPS configuration. The wireless device may determine each of the one or more i-th time domain resources corresponds to each SPS PDSCH of the one or more i-th SPS PDSCHs. The wireless device may determine a SPS PDSCH of the one or more i-th SPS PDSCHs is skipped in response to a corresponding time resource of the SPS PDSCH overlapping with uplink symbol(s)/resources.

The wireless device may determine the last SPS PDSCH (e.g., latest SPS PDSCH) of the one or more i-th SPS PDSCH is skipped. The wireless device may determine the last SPS PDSCH among one or more SPS PDSCHs that are not skipped. The wireless device may determine the last SPS PDSCH among one or more SPS PDSCHs regardless of skipped or not.

55 For a HARQ-ACK determination, the wireless device may determine the last SPS PDSCH of the one or more i-th SPS PDSCH based on the one or more i-th time domain resources regardless of whether the last SPS PDSCH has been skipped/ignored/dropped or not.

60 FIG. 43 illustrates an example embodiment of generating HARQ-ACK bits for a SPS configuration as per an aspect of an embodiment of the present disclosure.

For example, the wireless device is configured with a SPS configuration. The wireless device may be configured/indicated with a maximum number (M) of PDSCHs scheduled by a DCI based on a multi-PDSCH scheduling. The M may be set to 5 in the example. The wireless device may

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determine a PUCCH resource in a slot S4. The wireless device may be configured with k1 values (T0, T1, and T2) as in FIG. 40.

The wireless device may determine DL slots based on k1 values and the slot S4. The wireless device may determine slot S3, S1 and S0 as DL slots for the S4 PUCCH resource.

For each DL slot of the DL slots, the wireless device may determine whether there is a last SPS PDSCH of one or more i-th SPS PDSCHs. The one or more i-th SPS PDSCHs may comprise a SPS PDSCH occurring in i-th interval/period of the SPS configuration. For example, based on an activation DCI of the SPS configuration, the wireless device may determine one or more i-th time domain resources based on the activation DCI and a periodicity of the SPS configuration.

For example, the wireless device may determine four time domain resources (#0, #1, #2 and #3 in FIG. 43). The wireless device may determine one or more valid SPS PDSCHs based on the one or more i-th time domain resources and slot formation information. For example, the wireless device may determine a SPS PDSCH #3 (e.g., first SPS PDSCH, earliest SPS PDSCH), a SPS PDSCH #1 and a SPS PDSCH #0 (e.g., last SPS PDSCH, latest SPS PDSCH) as valid SPS PDSCHs.

For example, the wireless device may determine the SPS PDSCH #0 as the last SPS PDSCH of the one or more i-th SPS PDSCHs. The wireless device may determine one or more HARQ-ACK bits based on the last SPS PDSCH and a maximum number of schedulable PDSCHs (or Ni).

For example, the wireless device may determine a HARQ-ACK bit for a valid SPS PDSCH between a first time (e.g., a first slot/time domain resource) and a second time (e.g., a second slot/time domain resource). For example, the second slot/time domain resource may be a time domain resource for the last SPS PDSCH. The first slot/time domain resource may be a time domain resource determined based on the first slot/time domain resource and the maximum number of PDSCHs or the Ni. For example, FIG. 43 illustrates a SPS PDSCH #4 (or a time domain resource #4) may be the first slot/time domain resource.

The wireless device may determine a first HARQ-ACK bit for the SPS PDSCH #3. The wireless device may determine a second HARQ-ACK bit for the SPS PDSCH #1. The wireless device may determine a third HARQ-ACK bit for the last SPS PDSCH regardless of whether the last SPS PDSCH is valid or not.

The wireless device may determine HARQ-ACK bits based on a received/scheduled timing (e.g., earlier SPS PDSCH is placed earlier) or a slot index. For example, the SPS PDSCH #3 (the first SPS PDSCH) may be placed first. The SPS PDSCH #1 (a next SPS PDSCH) may be placed next. The SPS PDSCH #0 (the last SPS PDSCH) may be placed in last. The order may be reverse (e.g., the last SPS PDSCH first and the first SPS PDSCH last).

The wireless device may not transmit/generate a HARQ-ACK bit for the last SPS PDSCH when the last SPS PDSCH is not valid. The wireless device may not transmit a HARQ-ACK bit #0 in FIG. 34.

A number of HARQ-ACK bits of i-th interval/period of the SPS configuration may be equal to Ni. The Ni may be determined based on one or more example embodiments in the specification.

In an example, a number (M) of HARQ-ACK bits for a SPS configuration may be configured by RRC/MAC-CE/DCI signaling.

For example, the M may be smaller than a number (N) of SPS PDSCH receptions mapping to a PUCCH resource. The

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wireless device may need to aggregate HARQ-ACK bits for one or more SPS PDSCHs, when N is larger than M. The N may be a number of transport blocks scheduled via the one or more SPS PDSCHs. The N may be a number of time domain resources for the one or more SPS PDSCHs. The N may be a number HARQ-ACK bits for the one or more SPS PDSCHs before aggregation.

FIG. 44 illustrates an example of a HARQ-ACK aggregation as per an aspect of an embodiment of the present disclosure.

The base station may schedule a multi-PDSCH DCI (e.g., an activation DCI) in a slot n via a first cell (e.g., cell 0). The multi-PDSCH DCI may activate a SPS configuration. The multi-PDSCH DCI may schedule N first SPS PDSCHs (e.g., PDSCH #1, . . . , PDSCH #K) via a TDRA entry of a TDRA table. For example, the TDRA entry may indicate K time domain resources, where each time domain resource of the K time domain resources may map to at most one PDSCH of the N PDSCHs. For example, N may be smaller than or equal to K. For example, the wireless device may exclude one or more skipped SPS PDSCHs (e.g., invalid SPS PDSCHs). For example, the wireless device may determine a SPS PDSCH is skipped that is scheduled via the slot n+p+1. The wireless device may not count the SPS PDSCH for the N SPS PDSCHs.

For example, N may be larger than M.

When N is larger than M, the wireless device may aggregate HARQ-ACK bits for N SPS PDSCHs based on one or more following rules. For example, the wireless device may sequentially map from first bit of M-bits to last bit of M-bits to first valid SPS PDSCH (e.g., non-skipped SPS PDSCH, an earliest non-skipped SPS PDSCH) to M-th valid SPS PDSCH. The wireless device may drop HARQ-ACK bit(s) for remaining valid SPS PDSCHs.

For example, the wireless device may determine S=ceil(N/M). The wireless device may determine a HARQ-ACK bits for each S SPS PDSCHs sequentially. For example, HARQ-ACK bits for 1<sup>st</sup> SPS PDSCH, . . . , S-th SPS PDSCH are aggregated to a single HARQ-ACK bit (e.g., first bit). The wireless device may determine the single HARQ-ACK bit based on “AND” operation or based on “OR” operation. For example, when “AND” operation is used, ACK is reported when all SPS PDSCHs are received correctly/successfully. For example, when “OR” operation is used, ACK is reported when any SPS PDSCH is received correctly/successfully. The wireless device may determine second HARQ-ACK bit for S+1-th PDSCH to 2\*S-th PDSCH. The wireless device may determine I-th HARQ-ACK bit for S\*(I-1)-th PDSCH to S\*I-th PDSCH.

For example, the wireless device may determine M-1 HARQ-ACK bits, where each HARQ-ACK bit corresponds to first valid SPS PDSCH to M-1-th valid SPS PDSCH. The wireless device may aggregate and generate a single HARQ-

55 Ack bits for remaining SPS PDSCHs (e.g., M-th valid SPS PDSCH to N-th valid SPS PDSCH). FIG. 42 illustrates the example. Each valid PDSCH may map to each bit of M-bits until M-1-th valid SPS PDSCH (shown between PDSCH #4 to PDSCH #K). The wireless device may aggregate M-th valid SPS PDSCH to N-th valid SPS PDSCH (e.g., PDSCH #K) to a single bit mapping to the last bit of the M-bits. The wireless device may transmit the M-bits via the second HARQ-ACK sub-codebook.

For example, M may be predetermined as 1 for a SPS configuration.

For example, M may be configured for a SPS configura-

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For example, M may be set to a maximum number of PDSCHs schedulable by a DCI across one or more serving cells. For each serving cell,  $M_c$  may be determined where  $M_c$  may represent a number of maximum PDSCHs schedulable by a single DCI for the each serving cell. M may be determined as a largest value of one or more  $M_c$  values.

In an example, a wireless device may be configured with a plurality of SPS configurations for a cell. For a PUCCH resource, the wireless device may determine a plurality of HARQ-ACK bits of the plurality of SPS configurations. For example, the plurality of SPS configurations may comprise a first SPS configuration and a second SPS configuration.

For example, the first SPS configuration may be activated by a first DCI based on a fallback DCI format or a single-PDSCH DCI format. The wireless device may determine a single SPS PDSCH reception in each interval/period of the first SPS configuration.

For example, the second SPS configuration may be activated by a second DCI based on a multi-PDSCH DCI format. The wireless device may determine one or more SPS PDSCH receptions in each interval/period of the second SPS configuration.

The wireless device may determine a first HARQ-ACK bit for the first SPS configuration.

The wireless device may determine one or more second HARQ-ACK bits for the one or more first SPS PDSCH receptions of the second SPS configuration.

In an example, the wireless device may append the one or more second HARQ-ACK bits to the first HARQ-ACK bit. The wireless device may prioritize a SPS configuration (or place HARQ-ACK bit earlier) activated based on a fallback DCI format or a single-PDSCH DCI format.

In an example, the wireless device may place the one or more second HARQ-ACK bits before the first HARQ-ACK bit in response to a first index of the first SPS configuration being smaller than a second index of the second SPS configuration.

In an example, the wireless device may append the first HARQ-ACK bit to a first HARQ-ACK sub-codebook (e.g., for a TB-based single-PDSCH transmission). The wireless device may append the one or more second HARQ-ACK bits to a third (or second) HARQ-ACK sub-codebook that is used for a multi-PDSCH scheduling.

In an example, the wireless device may be configured with a third SPS configuration for the cell.

For example, the third SPS configuration may be activated by a third DCI based on a multi-PDSCH DCI format. The wireless device may determine one or more second SPS PDSCH receptions in each interval/period of the third SPS configuration.

The wireless device may determine one or more third HARQ-ACK bits for the one or more second SPS PDSCH receptions of the third SPS configuration.

In an example, the wireless device may place the one or more second HARQ-ACK bits before the one or more third HARQ-ACK bit in response to the first index of the first SPS configuration being smaller than a third index of the second SPS configuration.

In an example, the wireless device may determine an order of HARQ-ACK bits of a plurality of SPS configurations based on a slot index. When a plurality of SPS PDSCH receptions may be scheduled in a slot, the wireless device may order the plurality of SPS PDSCH receptions in an order of index(es) of corresponding SPS configurations. A SPS PDSCH reception with lower slot index (or earlier slot) may be placed before a second SPS PDSCH reception with higher slot index (or later slot). A SPS PDSCH reception

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with higher slot index (or later slot) may be placed before a second SPS PDSCH reception with lower slot index (or earlier slot). A SPS PDSCH reception with lower SPS configuration index may be placed earlier than a second SPS PDSCH reception with higher SPS configuration index.

The wireless device may generate a SPS HARQ-ACK sub-codebook for one or more SPS configurations of one or more serving cells. For example, the one or more SPS configurations may comprise a SPS configuration activated by a DCI based on a multi-PDSCH DCI scheduling. The one or more SPS configurations may not comprise a second SPS configuration activated by a DCI based on a single-PDSCH DCI scheduling/format. For example, the one or more SPS configurations may comprise a SPS configuration of a serving cell regardless of a single-PDSCH DCI format or a multi-PDSCH DCI format is used for an activation of the SPS configuration.

In an example, the one or more serving cells may comprise a serving cell configured with a multi-PDSCH scheduling. The one or more serving cells may not comprise a second serving cell not configured with a multi-PDSCH scheduling. A numerology of the one or more serving cells may not comprise 480 kHz nor 960 kHz.

In another example, the one or more serving cells may comprise a serving cell regardless of configuration of a multi-PDSCH scheduling.

The wireless device may determine one or more HARQ-ACK bits for one or more SPS PDSCH receptions of the one or more SPS configurations. Feedback timing of the one or more SPS PDSCH receptions may determine a PUCCH resource for the one or more SPS PDSCH receptions. The wireless device may determine an order of the one or more HARQ-ACK bits based on cell index(es) of the one or more serving cells and/or indexes of the one or more SPS configurations and/or slot/unit index(es) of the one or more SPS PDSCH receptions. For example, the wireless device may place one or more first SPS configurations with a lower cell indexed cell before one or more second SPS configurations with a higher cell indexed cell. For example, the wireless device may place one or more first SPS PDSCHs with a lower index of a first SPS configuration before one or more second SPS PDSCHs with a higher index of a second SPS configuration.

For example, the wireless device may place a first HARQ-ACK bit for a first SPS PDSCH before a second SPS PDSCH where the first SPS PDSCH occurs before a second SPS PDSCH.

The wireless device may determine a first SPS HARQ-ACK sub-codebook for one or more first SPS configurations of one or more first serving cells. The one or more first SPS configurations may be activated based on a single-PDSCH DCI format or a fallback DCI format. The one or more first serving cells may not be configured with a multi-PDSCH scheduling.

A numerology of the one or more first serving cells may not comprise 480 kHz nor 960 kHz.

The one or more second SPS configurations may be activated based on a multi-PDSCH DCI format. The one or more second serving cells may be configured with a multi-PDSCH scheduling.

A numerology of the one or more second serving cells may comprise 480 kHz nor 960 kHz.

In an example, the wireless device may determine the first SPS HARQ-ACK sub-codebook for one or more SPS configurations of any serving cell.

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In an example, the wireless device may determine the second SPS HARQ-ACK sub-codebook for one or more SPS configurations of any serving cell.

The wireless device may generate the first SPS HARQ-ACK sub-codebook and/or the second SPS HARQ-ACK sub-codebook based on one or more example orders in the specification.

The wireless device may append the first SPS HARQ-ACK sub-codebook to the first HARQ-ACK sub-codebook. The wireless device may generate the first HARQ-ACK sub-codebook for one or more PDSCHs scheduled based on a TB-based scheduling (e.g., non-CBG) and a single-PDSCH DCI scheduling.

The wireless device may append the first SPS HARQ-ACK sub-codebook to the second HARQ-ACK sub-codebook. The wireless device may generate the second HARQ-ACK sub-codebook for one or more PDSCHs scheduled based on a CBG-based scheduling and a single-PDSCH DCI scheduling. The wireless device may generate the second HARQ-ACK sub-codebook for one or more PDSCHs scheduled based on a TB-based scheduling (e.g., non-CBG) and a multi-PDSCH DCI scheduling. The wireless device may append the first SPS HARQ-ACK sub-codebook to the second HARQ-ACK sub-codebook in response to any serving cell being configured with a CBG transmission.

The wireless device may append the first SPS HARQ-ACK sub-codebook to the third HARQ-ACK sub-codebook. The wireless device may generate the third HARQ-ACK sub-codebook for one or more PDSCHs scheduled based on a multi-PDSCH DCI scheduling.

The wireless device may append the second SPS HARQ-ACK sub-codebook to the first HARQ-ACK sub-codebook.

The wireless device may append the second SPS HARQ-ACK sub-codebook to the second HARQ-ACK sub-codebook. The wireless device may append the second SPS HARQ-ACK sub-codebook to the second HARQ-ACK sub-codebook in response to any serving cell being configured with a CBG transmission.

The wireless device may append the second SPS HARQ-ACK sub-codebook to the third HARQ-ACK sub-codebook.

The wireless device may generate a separate HARQ-ACK codebook (e.g., independent from PDSCH(s) scheduled dynamically) comprising at least one of the first SPS HARQ-ACK sub-codebook and the second SPS HARQ-ACK sub-codebook.

The wireless device may determine one or more HARQ-ACK bits for the SPS configuration based on example embodiments in the specification when the wireless device is configured with a dynamic HARQ-ACK codebook determination (e.g., Type-2 HARQ-ACK codebook determination).

A wireless device may determine first HARQ-ACK information bits in response to more than one SPS PDSCH receptions of one or more first SPS configurations that the wireless device is configured to receive. The first HARQ-ACK information bits may be ordered based on the example pseudo code in FIG. 39. The wireless device may determine second HARQ-ACK information bits in response to more than one SPS PDSCH receptions of one or more second SPS configurations that the wireless device is configured to receive. The second HARQ-ACK information bits may be ordered based on the example pseudo code shown in FIG. 39 or FIG. 45.

For example, when the wireless device is configured to receive SPS PDSCH and the wireless device multiplexes HARQ-ACK information for one activated SPS PDSCH reception in the PUCCH in slot n, the wireless device may

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generate one HARQ-ACK information bit associated with the SPS PDSCH reception and appends it to the  $O^{ACK}$  HARQ-ACK information bits (e.g., a HARQ-ACK codebook of dynamic scheduling based PDSCH(s)).

If a wireless device is configured to receive SPS PDSCH and the wireless device multiplexes HARQ-ACK information for one or more SPS PDSCH receptions of one activated SPS PDSCH configuration in the PUCCH in slot n, the wireless device generates one HARQ-ACK information bit associated with the SPS PDSCH reception and appends it to the  $O^{ACK}$  HARQ-ACK information bits.

If a wireless device is configured to receive SPS PDSCH and the wireless device multiplexes HARQ-ACK information for multiple SPS PDSCH receptions of one or more activated SPS PDSCH configurations in the PUCCH in slot n, the UE generates the HARQ-ACK information as described in FIG. 39 or FIG. 45 and appends it to the  $O^{ACK}$  HARQ-ACK information bits.

In an example, a location in the Type-1 HARQ-ACK codebook for HARQ-ACK information corresponding to a single SPS PDSCH release is same as for a corresponding SPS PDSCH reception. A location in the Type-1 HARQ-ACK codebook for HARQ-ACK information corresponding to multiple SPS PDSCH releases by a single DCI format may be same as for a corresponding SPS PDSCH reception with the lowest SPS configuration index among the multiple SPS PDSCH releases.

The corresponding SPS PDSCH reception may be a last SPS PDSCH of one or more SPS PDSCHs that are configured to receive based on the SPS configuration with the lowest SPS configuration index, excluding SPS PDSCH(s)s that are not required to be received in any slot among overlapping the one or more SPS PDSCHs or based on a wireless device capability for a number of PDSCH receptions in a slot, or due to overlapping with a set of symbols indicated as uplink by tdd-UL-DL-ConfigurationCommon or by tdd-UL-DL-ConfigurationDedicated.

The corresponding SPS PDSCH reception may be a last SPS PDSCH of one or more SPS PDSCHs that are configured to receive, based on the SPS configuration with the lowest SPS configuration index.

A location in the Type-1 HARQ-ACK codebook for HARQ-ACK information corresponding to a single SPS PDSCH release may be same as for a corresponding SPS PDSCH reception. A location in the Type-1 HARQ-ACK codebook for HARQ-ACK information corresponding to multiple SPS PDSCH releases by a single-PDSCH DCI format may be same as for a corresponding SPS PDSCH reception with the lowest SPS configuration index among the multiple SPS PDSCH releases. A location in the Type-1 HARQ-ACK codebook for HARQ-ACK information corresponding to multiple SPS PDSCH releases by a multi-PDSCH DCI format may be same as for the PDCCH monitoring occasion of the SPS PDSCH release.

If the wireless device reports HARQ-ACK information for the PDSCH reception in a slot other than slot  $n+k_0+k, \dots, n+km+k$  where  $k_0, \dots, km$  maps/corresponds to a slot of a multi-PDSCH DCI scheduling resources.

If the wireless device reports HARQ-ACK information for the one or more PDSCH receptions, of a DCI format or a SPS PDSCH reception, in a slot other than slot  $n+k$ , where the slot n is determined based on a last PDSCH of the one or more PDSCH receptions, the wireless device may set a value for each corresponding HARQ-ACK information bit to NACK.

FIG. 45 illustrates an example pseudo code as per an aspect of an embodiment of the present disclosure.

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For example, a wireless device may determine one or more serving cells configured with a SPS configuration. The one or more serving cells may be configured with a multi-PDSCH scheduling. The one or more serving cells may comprise a serving cell configured to the wireless device. The wireless device may determine one or more SPS configurations configured for the one or more serving cells.

The wireless device may order the one or more serving cells based on cell index(es) of the one or more serving cells. For example, the wireless device may order the one or more serving cells in ascending order based on the cell index(es).

For each serving cell ( $C_i$ ) of the one or more serving cells, the wireless device may determine one or more SPS configurations for the each serving cell. The wireless device may order the one or more SPS configurations based on ascending order of index(es) of the one or more SPS configurations.

For a SPS configuration, based on the ascending order, the wireless device may determine one or more HARQ-ACK bits.

For the SPS configuration, for each DL slot starting from a lowest slot indexed DL slot to a highest slot indexed DL slot, the wireless device may determine whether a last SPS PDSCH is scheduled via each DL slot.

For example, the last SPS PDSCH may refer a latest (or last) SPS PDSCH, of one or more SPS PDSCHs or one or more SPS PDSCH receptions, in  $i$ -th interval/period of the SPS configuration.

When the last SPS PDSCH is scheduled (e.g., resource is determined regardless of whether the last SPS PDSCH is valid or invalid), the wireless device may determine the one or more SPS PDSCHs of the  $i$ -th interval/period.

The wireless device may determine a number of the one or more SPS PDSCHs.

The wireless device may determine a number of valid SPS PDSCH(s) of the one or more SPS PDSCHs.

The wireless device may determine a number ( $O$ ) of HARQ-ACK bits equal to the number of the valid SPS PDSCH(s) or the one or more SPS PDSCHs.

The wireless device may generate  $O$  number of HARQ-ACK bits based on ascending order of receiving time/slot index of each PDSCH.

The wireless device may increment  $j$  (a total number of HARQ-ACK bits) by  $O$ .

The wireless device may move to a next DL slot.

The wireless device may complete the SPS configuration.

The wireless device may move a next SPS configuration and repeat the process.

The wireless device may complete the serving cell.

The wireless device may move to a next serving cell and repeat the process.

FIG. 46 shows an example embodiment of a HARQ-ACK sub-codebook as per an aspect of an embodiment of the present disclosure.

The wireless device may be configured with a first cell (cell 0), a second cell (cell 1) and a third cell (cell 2). The wireless device may be configured with a SPS configuration via the first cell. The wireless device may be configured with a multi-PDSCH scheduling for the first cell and the second cell. The wireless device may be configured with a CBG transmission for the third cell.

The wireless device may receive a first DCI (M-DCI) scheduling resources for  $Q$  PDSCHs. The first DCI may indicate a counter-DAI=0 and a total-DAI=Q-1. The wireless device may receive a second DCI (M CBG) scheduling  $M$  CBGs via a PDSCH. The second DCI may indicate a counter-DAI=0 and a total-DAI=0.

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The wireless device may determine  $M$  HARQ-ACK bits for a second HARQ-ACK sub-codebook based on the second DCI.

5 The wireless device may determine  $Q$  HARQ-ACK bits for a third HARQ-ACK sub-codebook based on the first DCI.

The wireless device may determine  $P$  HARQ-ACK bits for the SPS configuration, where  $P$  SPS PDSCHs are scheduled based on an activation DCI and the SPS configuration 10 mapping to a PUCCH resource.

The wireless device may append the  $P$  HARQ-ACK bits to the third HARQ-ACK sub-codebook. The wireless device may append the third HARQ-ACK sub-codebook to the second HARQ-ACK sub-codebook.

15 The wireless device may transmit the appended second HARQ-ACK sub-codebook via the PUCCH resource.

FIG. 47 illustrates an example of HARQ-ACK bits of a SPS configuration as per an aspect of an embodiment of the present disclosure.

20 For example, a wireless device may be configured with a TDRA table comprising three TDRA entries. The wireless device may be configured with a SPS configuration. The wireless device may receive a DCI activating the SPS configuration. The DCI may indicate a TDRA entry with index 1. The wireless device may determine three PDSCHs are scheduled in each interval/period based on three time domain resources being indicated in the TDRA entry.

The wireless device may determine a first PDSCH (PDSCH #1) mapping in a slot  $n$ . The wireless device may determine a second PDSCH (PDSCH #2) mapping in a slot  $n+1$ . The wireless device may map a third PDSCH (PDSCH #3) mapping in a slot  $n+3$ .

25 The wireless device may map a fourth PDSCH (PDSCH #4), a fifth PDSCH (PDSCH #5) and a sixth PDSCH (PDSCH #6) in a second interval/period.

The wireless device may determine slot  $n+1$ , slot  $n+p+2$  and slot  $n+p+3$  as uplink slots. The wireless device may determine the second PDSCH, the sixth PDSCH are invalid as resources overlap with the uplink slots.

30 40 The wireless device may determine one or more HARQ-ACK bits for the first interval/period. The wireless device may determine three HARQ-ACK bits for three scheduled PDSCHs.

The wireless device may determine two HARQ-ACK bits for two valid PDSCHs.

45 The wireless device may determine one or more second HARQ-ACK bits for the second interval/period. The wireless device may determine three bits for three scheduled PDSCHs in the second interval/period. The wireless device may determine two bits for two valid PDSCHs.

The wireless device may determine one or more second PDSCHs in the second interval/period based on the TDRA entry and a periodicity of the SPS configuration (e.g., occurring periodically).

50 55 FIG. 48 illustrates a flow diagram as per an aspect of an embodiment of the present disclosure.

The wireless device may be configured with a SPS configuration for a cell. The cell may be configured with a multi-PDSCH scheduling. The wireless device may receive an activation DCI for the SPS configuration. The activation DCI may indicate resources/slots for one or more PDSCHs. The activation DCI may indicate a timing offset for a PUCCH resource for a HARQ-ACK feedback.

60 65 The wireless device may determine a last SPS PDSCH of one or more SPS PDSCHs. The one or more SPS PDSCHs may comprise one or more SPS PDSCHs in each interval/period of the SPS configuration.

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The wireless device may determine the PUCCH resource based on the last SPS PDSCH.

The wireless device may determine the one or more SPS PDSCHs based on the last SPS PDSCH and the activation DCI. For example, the activation DCI may indicate a time domain resource entry that may indicate one or more time domain resources.

The wireless device may determine one or more HARQ-ACK bits corresponding to the one or more SPS PDSCHs. The wireless device may append the one or more HARQ-ACK bits to a HARQ-ACK sub-codebook. The wireless device may transmit the HARQ-ACK sub-codebook via the PUCCH resource.

In an example, a wireless device may determine a plurality of PUCCH resources for one or more PDSCHs scheduled/activated by a DCI based on a multi-PDSCH scheduling/format. For example, one or more first PDSCHs of the one or more PDSCHs may correspond to a first PUCCH resource of the plurality of PUCCH resources. One or more second PDSCHs of the one or more PDSCHs may correspond to a second PUCCH resource.

For example, the one or more first PDSCHs may comprise first (e.g., earliest) PDSCH of the one or more PDSCHs. When a number of the one or more PDSCHs is N, the wireless device may determine ceil (N/2) number of PDSCH(s), of the one or more PDSCHs, for the one or more first PDSCHs. The wireless device may determine remaining PDSCH(s), of the one or more PDSCHs, for the one or more second PDSCHs.

The wireless device may determine one or more i-th SPS PDSCHs for a SPS configuration. The one or more i-th SPS PDSCHs may be determined based on a periodicity of the SPS configuration and one or more time domain resources indicated by an activation DCI. The wireless device may determine a plurality of PUCCH resources for the one or more i-th SPS PDSCHs. For example, the plurality of PUCCH resources may comprise a first PUCCH resource for one or more first SPS PDSCHs and a second PUCCH resource for one or more second SPS PDSCHs. The one or more i-th SPS PDSCHs may be divided to the one or more first SPS PDSCHs and the one or more second SPS PDSCHs based on a rule.

The wireless device may apply example embodiments in the specification for the one or more first PDSCHs via the first PUCCH resource. The wireless device may apply example embodiments in the specification for the one or more second PDSCHs via the second PUCCH resource independently.

In an example, a wireless device may receive configuration parameters for a cell via RRC signalling. The configuration parameters may indicate a multi-physical downlink shared channel (PDSCH) scheduling. A single downlink control information (DCI) may schedule resources for one or more transport blocks via one or more PDSCHs. The configuration parameters may indicate a semi-persistent scheduling (SPS) configuration with a periodicity. The wireless device may receive a DCI, based on the multi-PDSCH scheduling, indicating activating the SPS configuration; one or more first time domain resources for one or more first SPS PDSCHs, wherein each, of the one or more time domain resources, corresponds to each of the one or more SPS PDSCHs; a downlink assignment index (DAI); and an offset to a hybrid-automatic repeat request (HARQ) feedback resource.

The wireless device may determine one or more second time domain resources, for one or more second SPS PDSCHs, based on the one or more first time domain

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resources and the periodicity. The wireless device may determine a second HARQ feedback resource based on the one or more second SPS PDSCHs and the offset. The wireless device may determine one or more downlink slots, for the second HARQ feedback resource, based on the one or more second time domain resources. The wireless device may generate one or more HARQ bits based on the one or more downlink slots and the one or more second SPS PDSCHs. The wireless device may transmit the one or more HARQ bits via the second HARQ feedback resource.

In an embodiment, the wireless device may generate a HARQ-ACK codebook comprising one or more HARQ-ACK bits for one or more downlink physical downlink channels (PDSCHs) scheduled by one or more DCIs comprising one or more DAI values.

In an embodiment, the wireless device may append the one or more HARQ bits to the HARQ-ACK codebook.

In an embodiment, the transmitting the one or more HARQ bits may be to transmit the HARQ-ACK codebook comprising the one or more HARQ bits.

In an embodiment, the DAI may be a counter DAI.

In an embodiment, the counter DAI may indicate a number of PDSCHs scheduled, by one or more DCIs, up to a current downlink monitoring occasion of the cell for the HARQ feedback resource.

In an embodiment, the counter DAI may not indicate a number of SPS PDSCHs other than one or more first SPS PDSCHs.

In an embodiment, the configuration parameters may further indicate a dynamic HARQ-ACK codebook determination mechanism. The wireless may determine a HARQ-ACK codebook based on one or more counter DAI values.

In an embodiment, the single DCI comprises a time domain resource allocation field indicating an index to a time domain resource allocation entry of a time domain resource allocation table.

In an embodiment, the time domain resource allocation entry may comprise one or more time domain resources of one or more slots.

In an embodiment, a time domain resource of the one or more time domain resources may correspond to a PDSCH of the one or more first SPS PDSCHs.

In an embodiment, the time domain resource may indicate a starting symbol index and a length of the time domain resource.

In an embodiment, the time domain resource may further indicate a slot offset.

In an embodiment, the wireless device may determine the DCI activating the SPS configuration in response to a first field of the DCI being set to a first predetermined value and a second field of the DCI being set to a second predetermined value.

In an embodiment, the first field may be a HARQ process identifier and the first predetermined value may be zero.

In an embodiment, the second field may be a redundancy version and the second predetermined value may be zero.

In an embodiment, the offset may indicate a gap between last PDSCH of the one or more first SPS PDSCHs and the HARQ feedback resource. In an embodiment, the determining the second HARQ feedback resource may be based on last PDSCH of the one or more second SPS PDSCHs and the offset.

In an embodiment, a slot of the second HARQ feedback may be after the offset from a first slot of the last PDSCH.

In an embodiment, the last PDSCH may be a scheduled SPS PDSCH based on the one or more second time domain resources.

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In an embodiment, each of the one or more second time domain resources may occur after the periodicity since each of the one or more first time domain resources.

In an embodiment, the each of the one or more second time domain resources may correspond to each of the one or more second SPS PDSCHs.

In an embodiment, the wireless device may drop a SPS PDSCH, of the one or more second SPS PDSCHs, in response to resource of the SPS PDSCH overlapping with uplink resources.

In an embodiment, the wireless device may determine uplink resources based on slot formation information configured by RRC signalling.

In an embodiment, the wireless device may not generate a HARQ bit for the SPS PDSCH being dropped.

In an embodiment, the wireless device may generate a HARQ bit for a second SPS PDSCH of the one or more second SPS PDSCHs. Resources of the second SPS PDSCH overlaps with non-uplink resources, based on the slot formation information.

In an embodiment, the configuration parameters may further indicate one or more offset values for HARQ feedback. The one or more offset values may comprise a value of the offset.

In an embodiment, the determining the one or more downlink slots may be further based on the one or more offset values.

In an embodiment, the one or more downlink slots may comprise a first slot occurring a first offset value, of the one or more offset values, before a second slot of the second HARQ feedback resource.

In an embodiment, the one or more downlink slots may comprise the first slot for each value of the one or more offset values.

In an embodiment, the one or more downlink slots may comprise a third slot occurring within a duration from the first slot.

In an embodiment, the wireless device may determine the duration based on a number of schedulable PDSCHs by the single DCI.

In an embodiment, the configuration parameters may indicate the number of schedulable PDSCHs.

In an embodiment, the wireless device may determine the duration based on a number of the one or more first SPS PDSCHs.

In an embodiment, the wireless device may determine the duration based on a number of the one or more first time domain resources.

In an embodiment, the wireless device may generate the one or more HARQ bits comprise generating each HARQ bit, of the one or more HARQ bits, for one or more second downlink slots of the one or more downlink slots. A SPS PDSCH, of the one or more second SPS PDSCHs is scheduled, without dropping, via the one or more second downlink slots.

In an embodiment, the wireless device may determine first bit of the one or more HARQ bits maps to earliest SPS PDSCH, scheduled without dropping, of the one or more second SPS PDSCHs.

In an embodiment, the wireless device may determine last bit of the one or more HARQ bits maps to latest SPS PDSCH, scheduled without dropping, of the one or more second SPS PDSCHs.

In an embodiment, the generating the one or more HARQ bits may comprise generating a HARQ bit for one or more second downlink slots of the one or more downlink slots.

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For example, last SPS PDSCH, of the one or more second SPS PDSCHs may be scheduled via the one or more second downlink slots.

In an embodiment, the wireless device may generate one or more second HARQ bits for one or more third SPS PDSCHs of the one or more second SPS PDSCHs. The one or more third SPS PDSCHs may comprise a SPS PDSCH scheduled without being dropped and the one or more third SPS PDSCHs do not comprise the last SPS PDSCH.

10 In an embodiment, the one or more HARQ bits may be the one or more second HARQ bits in response to the last SPS PDSCH being dropped. one or more HARQ bits may be determined based on concatenating the one or more second HARQ bits and the HARQ bit in response to the last SPS PDSCH being scheduled without being dropped

In an embodiment, first bit of the one or more second HARQ bits may correspond to earliest SPS PDSCH of the one or more third SPS PDSCHs.

15 In an embodiment, last bit of the one or more second HARQ bits may correspond to latest SPS PDSCH of the one or more third SPS PDSCHs.

In an example, a wireless device may receive a DCI indicating activating a semi-persistent scheduling (SPS) configuration with a periodicity. The DCI may further indicate first resources for one or more first SPS PDSCHs. The DCI may further indicate a downlink assignment index (DAI). The DCI may further indicate an offset to a hybrid-automatic repeat request (HARQ) feedback resource.

The wireless device may determine second resources for 30 one or more second SPS PDSCHs, based on the first resources and the periodicity. The wireless device may determine a second HARQ feedback resource based on last SPS PDSCH, of the one or more second PDSCHs, and the offset. The wireless device may determine one or more 35 downlink slots, for the second HARQ feedback resource, based on the second resources. The wireless device may generate one or more HARQ bits based on the one or more downlink slots and the one or more second SPS PDSCHs. The wireless device may transmit the one or more HARQ bits via the second HARQ feedback resource.

In an example, a wireless device may receive a DCI indicating activating a semi-persistent scheduling (SPS) configuration with a periodicity. The DCI may indicate first resources for one or more first SPS PDSCHs, a downlink 45 assignment index (DAI); and an offset to a hybrid-automatic repeat request (HARQ) feedback resource.

The wireless device may determine second resources for one or more second SPS PDSCHs, based on the first resources and the periodicity. The wireless device may 50 determine a second HARQ feedback resource based on last SPS PDSCH, of the one or more second PDSCHs, and the offset. The wireless device may determine a downlink, for the second HARQ feedback resource, based on the offset and the last SPS PDSCH. The wireless device may generate 55 one or more HARQ bits based on the downlink slot and the one or more second SPS PDSCHs. The wireless device may transmit the one or more HARQ bits via the second HARQ feedback resource.

In an embodiment, the wireless device may generate a 60 HARQ bit for the downlink slot of the last SPS PDSCH.

In an embodiment, the wireless device may generate one or more second HARQ bits for one or more third SPS PDSCHs of the one or more second SPS PDSCHs. For example, the one or more third SPS PDSCHs may comprise a SPS PDSCH scheduled without being dropped and the one or more third SPS PDSCHs do not comprise the last SPS PDSCH.

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In an embodiment, the one or more HARQ bits may be the one or more second HARQ bits in response to the last SPS PDSCH being dropped.

In an embodiment, the one or more HARQ bits may be based on concatenating the one or more second HARQ bits and the HARQ bit in response to the last SPS PDSCH being scheduled without being dropped.

In an embodiment, first bit of the one or more second HARQ bits corresponds to earliest SPS PDSCH of the one or more third SPS PDSCHs.

In an embodiment, last bit of the one or more second HARQ bits corresponds to latest SPS PDSCH of the one or more third SPS PDSCHs.

In an example, a wireless device may receive a first DCI indicating activating a first semi-persistent scheduling (SPS) configuration with a first periodicity. The first DCI may further indicate first resources for one or more first SPS PDSCHs; and a first offset to a hybrid-automatic repeat request (HARQ) feedback resource. The wireless device may receive a second DCI indicating activating a second SPS configuration with a second periodicity. The second DCI may further indicate second resources for a second SPS PDSCH; and a second offset to a second HARQ feedback resource.

The wireless device may determine third resources for one or more third SPS PDSCHs, based on the first resources and the first periodicity. The wireless device may determine fourth resources for a fourth SPS PDSCH based on the second resources and the second periodicity. The wireless device may determine a third HARQ feedback resource based on last SPS PDSCH, of the one or more second PDSCHs, and the first offset; and fourth SPS PDSCH and the second offset.

The wireless device may generate a first HARQ sub-codebook for the one or more third SPS PDSCHs. The wireless device may generate second HARQ sub-codebook for the fourth SPS PDSCH. The wireless device may append the first HARQ sub-codebook to the second HARQ sub-codebook. The wireless device may transmit the appended second HARQ sub-codebook via the third HARQ feedback resource.

In an embodiment, the wireless device may determine a HARQ codebook comprising the first HARQ sub-codebook and the second HARQ sub-codebook. The wireless device may place the second HARQ sub-codebook before the first HARQ sub-codebook in the HARQ codebook.

In an embodiment, the second HARQ sub-codebook may be for one or more DCIs scheduling a PDSCH. For example, a DCI of the one or more DCIs may comprise a first counter downlink assignment index (DAI) based on a first DAI procedure. The second HARQ sub-codebook may be determined based on the first DAI procedure.

In an embodiment, the first HARQ sub-codebook may be for one or more second DCIs scheduling one or more PDSCHs by a single DCI. For example, a DCI of the one or more second DCIs may comprise a second DAI based on a second DAI procedure. The first HARQ sub-codebook may be determined based on the second DAI procedure.

What is claimed is:

1. A method comprising:  
transmitting, by a base station to a wireless device, configuration parameters for semi-persistent scheduling (SPS) indicating periodic downlink resources for SPS physical downlink shared channel (PDSCH) transmissions on a first cell with a first subcarrier spacing; transmitting, to the wireless device, a downlink control information (DCI) indicating:

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an activation of the periodic downlink resources; a physical uplink control channel (PUCCH) resource, of a second cell with a second subcarrier spacing, for receiving feedback information corresponding to a plurality of SPS PDSCH transmissions via the periodic downlink resources, wherein the second subcarrier spacing is larger than the first subcarrier spacing; and a total downlink assignment index (DAI) incremented based on a number of the plurality of SPS PDSCH transmissions corresponding to the PUCCH resource; and receiving, from the wireless device via the PUCCH resource, feedback information bits for the plurality of SPS PDSCH transmissions based on the total DAI.

2. The method of claim 1, wherein two or more of the periodic downlink resources are used for the plurality of SPS PDSCH transmissions.

3. The method of claim 1, wherein:  
the feedback information bits are for the SPS PDSCH transmissions in downlink slots, of the first cell, that overlap with a first uplink slot of the second cell; the PUCCH resource is in a second uplink slot, of the second cell, that is a number of slots after the first uplink slot; and the number of slots is a slot offset indicated by the DCI.

4. The method of claim 3, wherein the feedback information bits do not correspond to the SPS PDSCH transmissions, in the downlink slots of the first cell, that occur after the first uplink slot of the second cell.

5. The method of claim 1, wherein the feedback information bits comprise at least one feedback information bit for an earliest SPS PDSCH transmission among the SPS PDSCH transmissions in downlink slots, of the first cell, that overlap with a first uplink slot of the second cell.

6. The method of claim 5, wherein the feedback information bits do not correspond to remaining SPS transmissions, other than the earliest SPS PDSCH transmission, that overlap with the first uplink slot.

7. The method of claim 1, further comprising:  
transmitting an earliest SPS PDSCH transmission, of the SPS PDSCH transmissions, in a downlink slot of the second cell; and transmitting one or more remaining SPS transmissions, of the SPS PDSCH transmissions other than the earliest SPS PDSCH transmission, in one or more downlink slots of the second cell based on a periodicity, for the SPS, indicated by the configuration parameters.

8. The method of claim 1, wherein the DCI comprises a counter DAI that is not incremented based on the number of SPS PDSCH transmissions.

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, configuration parameters for semi-persistent scheduling (SPS) indicating periodic downlink resources for SPS physical downlink shared channel (PDSCH) transmissions on a first cell with a first subcarrier spacing;  
transmit, to the wireless device, a downlink control information (DCI) indicating:  
an activation of the periodic downlink resources; a physical uplink control channel (PUCCH) resource, of a second cell with a second subcarrier spacing, for receiving feedback information corresponding to a plurality of SPS PDSCH trans-

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- missions via the periodic downlink resources, wherein the second subcarrier spacing is larger than the first subcarrier spacing; and
- a total downlink assignment index (DAI) incremented based on a number of the plurality of SPS PDSCH transmissions corresponding to the PUCCH resource; and
- receive, from the wireless device via the PUCCH resource, feedback information bits for the plurality of SPS PDSCH transmissions based on the total DAI.
- 10.** The base station of claim 9, wherein two or more of the periodic downlink resources are used for the plurality of SPS PDSCH transmissions.
- 11.** The base station of claim 9, wherein:
- the feedback information bits are for the SPS PDSCH transmissions in downlink slots, of the first cell, that overlap with a first uplink slot of the second cell;
  - the PUCCH resource is in a second uplink slot, of the second cell, that is a number of slots after the first uplink slot;
  - the number of slots is a slot offset indicated by the DCI; and
  - the feedback information bits do not correspond to the SPS PDSCH transmissions, in the downlink slots of the first cell, that occur after the first uplink slot of the second cell.
- 12.** The base station of claim 9, wherein the feedback information bits comprise at least one feedback information bit for an earliest SPS PDSCH transmission among the SPS PDSCH transmissions in downlink slots, of the first cell, that overlap with a first uplink slot of the second cell.
- 13.** The base station of claim 12, wherein the feedback information bits do not correspond to remaining SPS transmissions, other than the earliest SPS PDSCH transmission, that overlap with the first uplink slot.
- 14.** The base station of claim 9, wherein the instructions further cause the base station to:
- transmit an earliest SPS PDSCH transmission, of the SPS PDSCH transmissions, in a downlink slot of the first cell; and
  - transmit one or more remaining SPS transmissions, of the SPS PDSCH transmissions other than the earliest SPS PDSCH transmission, in one or more downlink slots of the second cell based on a periodicity, for the SPS, indicated by the configuration parameters.

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- 15.** The base station of claim 9, wherein the DCI comprises a counter DAI that is not incremented based on the number of SPS PDSCH transmissions.
- 16.** A method comprising:
- receiving, by a wireless device, configuration parameters for semi-persistent scheduling (SPS) indicating periodic downlink resources for SPS physical downlink shared channel (PDSCH) transmissions on a first cell with a first subcarrier spacing;
  - receiving a downlink control information (DCI) indicating:
    - an activation of the periodic downlink resources;
    - a physical uplink control channel (PUCCH) resource, of a second cell with a second subcarrier spacing, for receiving feedback information corresponding to a plurality of SPS PDSCH transmissions via the periodic downlink resources, wherein the second subcarrier spacing is larger than the first subcarrier spacing; and
    - a total downlink assignment index (DAI) corresponding to the PUCCH resource; and  - transmitting, via the PUCCH resource, feedback information bits for the plurality of SPS PDSCH transmissions based on the total DAI.
- 17.** The method of claim 16, wherein two or more of the periodic downlink resources are used for the plurality of SPS PDSCH transmissions.
- 18.** The method of claim 16, wherein:
- the feedback information bits are for the SPS PDSCH transmissions in downlink slots, of the first cell, that overlap with a first uplink slot of the second cell;
  - the PUCCH resource is in a second uplink slot, of the second cell, that is a number of slots after the first uplink slot; and
  - the number of slots is a slot offset indicated by the DCI.
- 19.** The method of claim 18, wherein the feedback information bits do not correspond to the SPS PDSCH transmissions, in the downlink slots of the first cell, that occur after the first uplink slot of the second cell.
- 20.** The method of claim 16, wherein the feedback information bits comprise at least one feedback information bit for an earliest SPS PDSCH transmission among the SPS PDSCH transmissions in downlink slots, of the first cell, that overlap with a first uplink slot of the second cell.

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