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(54) DISCONTINUOUS RECEPTION FOR EXTENDED REALITY

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

(72) Inventors: **Hsin-Hsi Tsai**, Reston, VA (US); **Hyoungsuk Jeon**, Centreville, VA (US); **Esmael Hejazi Dinan**, McLean, VA (US); **Hua Zhou**, Vienna, VA (US); **SungDuck Chun**, Fairfax, VA (US); **Ali Cagatay Cirik**, Chantilly, VA (US); **Taehun Kim**, Fairfax, VA (US); **Bing Hui**, Nanjing (CN); **Mohammad Ghadir Khoshkholgh Dashtaki**, Reston, VA (US); **Kyungmin Park**, Vienna, VA (US); **Gautham Prasad**, Herndon, VA (US)

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

(21) Appl. No.: **19/197,474**

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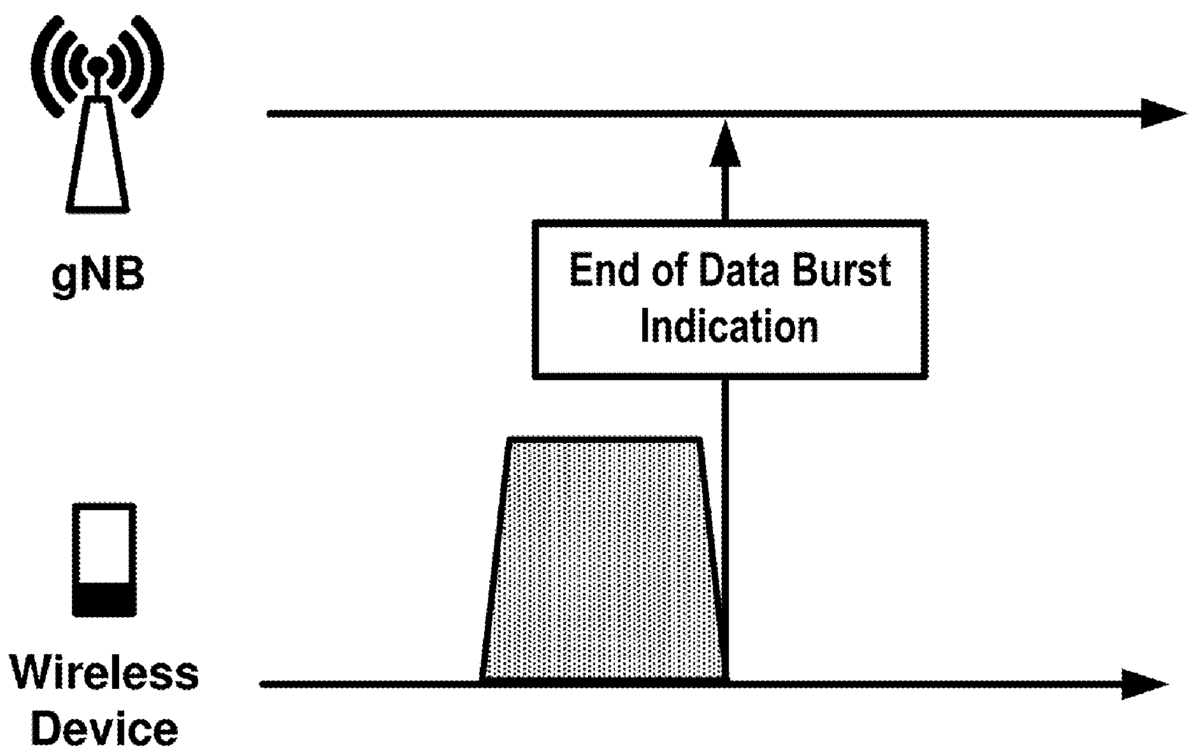
H04W 72/21 (2023.01)

(52) **U.S. Cl.**
CPC *H04W 76/28* (2018.02); *H04W 72/21* (2023.01)

(57) **ABSTRACT**

A wireless device receives a discontinuous reception (DRX) configuration. The wireless device starts, based on the DRX configuration, a first DRX timer in response to a new transmission associated with one or more data packets. The wireless device receives downlink control information (DCI) indicating an end of the one or more data packets. The wireless device transmits feedback information of the DCI. The wireless device stops, based on transmitting the feedback information, the first DRX timer.



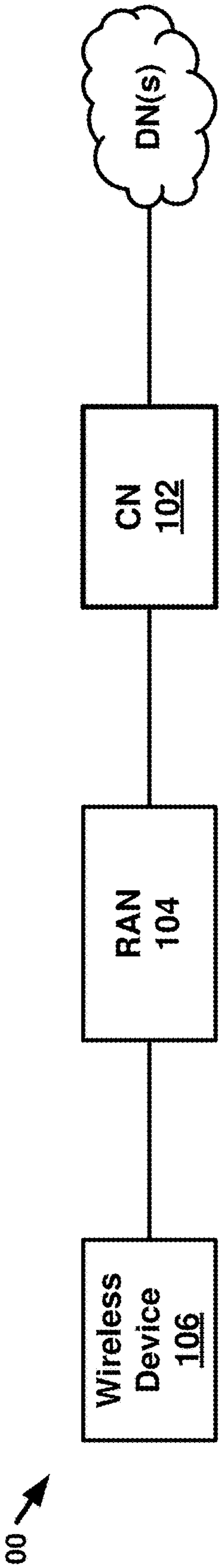

100
Wireless Device 106
RAN 104
CN 102
DN(s)

FIG. 1A

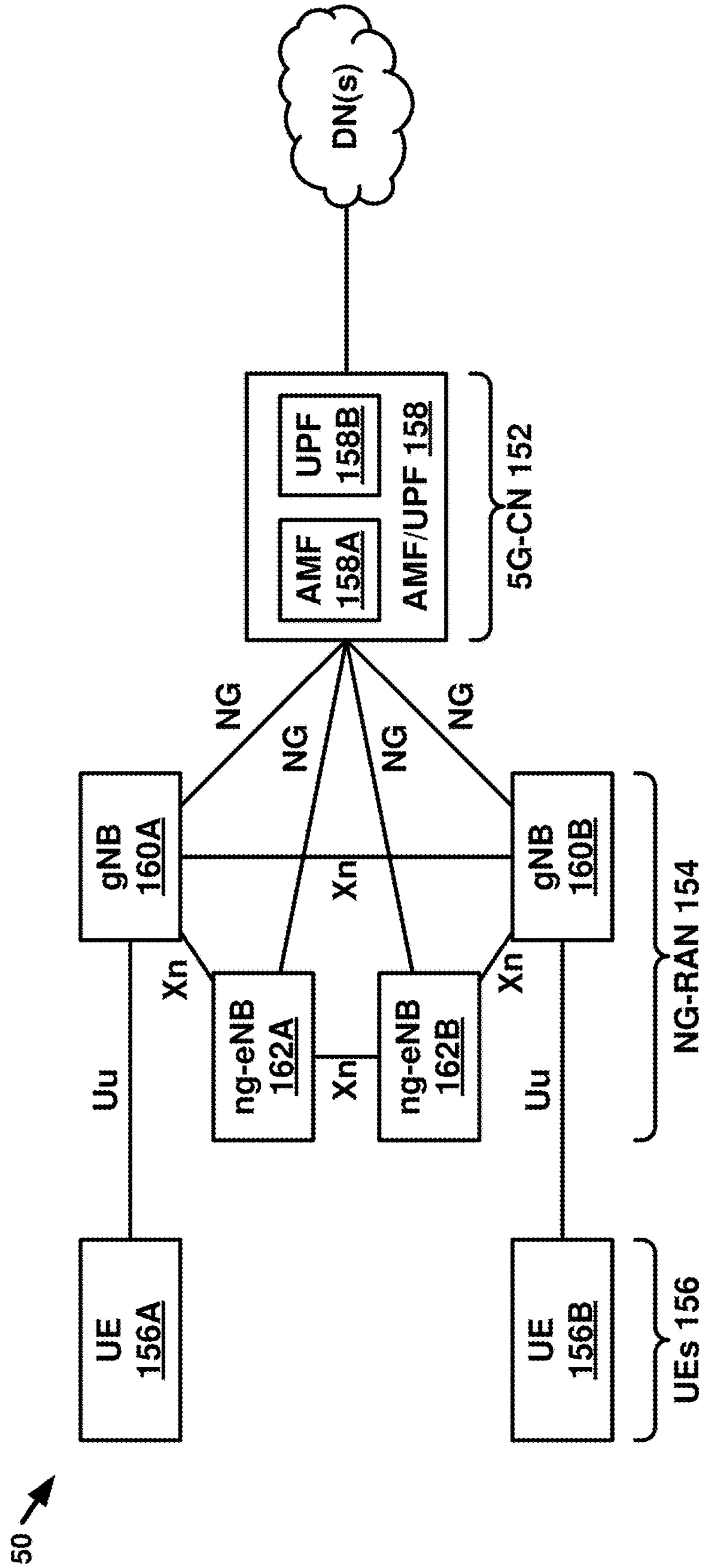

150
UE 156A
UE 156B
UEs 156
Uu
Uu
gNB 160A
gNB 160B
ng-eNB 162A
ng-eNB 162B
Xn
Xn
Xn
Xn
NG
NG
NG
NG
NG-RAN 154
AMF 158A
UPF 158B
AMF/UPF 158
5G-CN 152
DN(s)

FIG. 1B

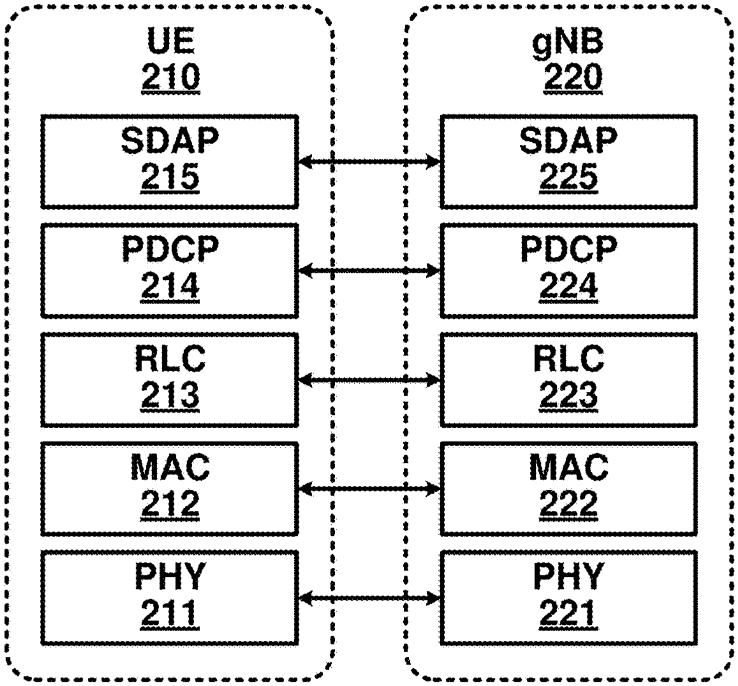

UE
210
SDAP
215
PDCP
214
RLC
213
MAC
212
PHY
211
gNB
220
SDAP
225
PDCP
224
RLC
223
MAC
222
PHY
221

FIG. 2A

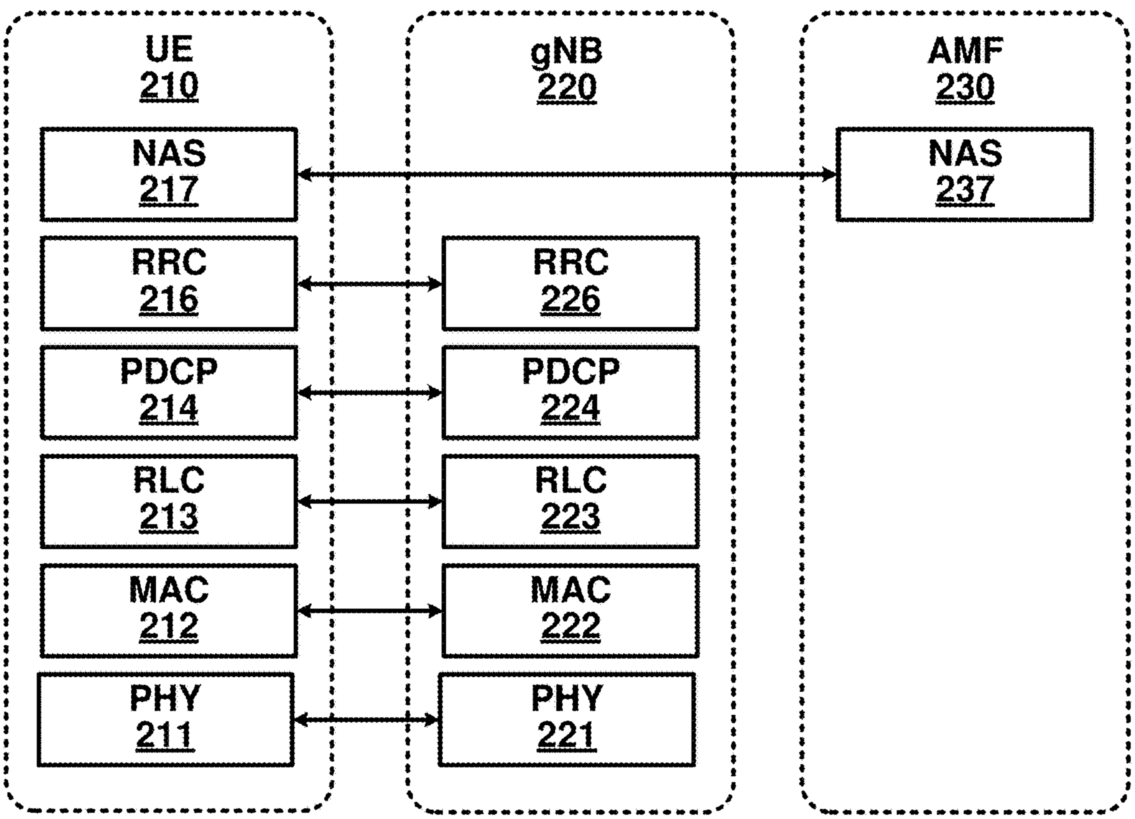

UE
210
NAS
217
RRC
216
PDCP
214
RLC
213
MAC
212
PHY
211
gNB
220
RRC
226
PDCP
224
RLC
223
MAC
222
PHY
221
AMF
230
NAS
237

FIG. 2B

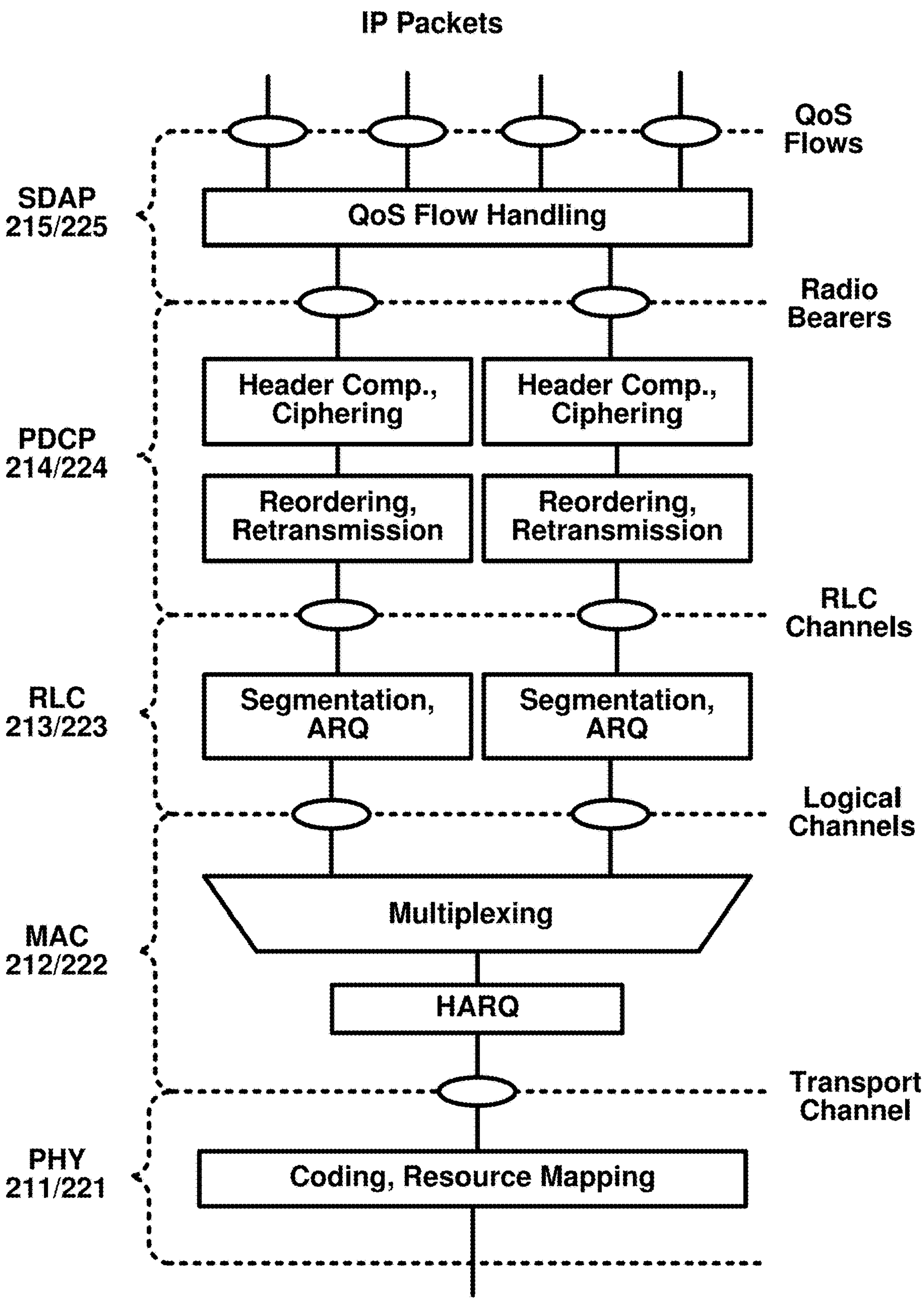
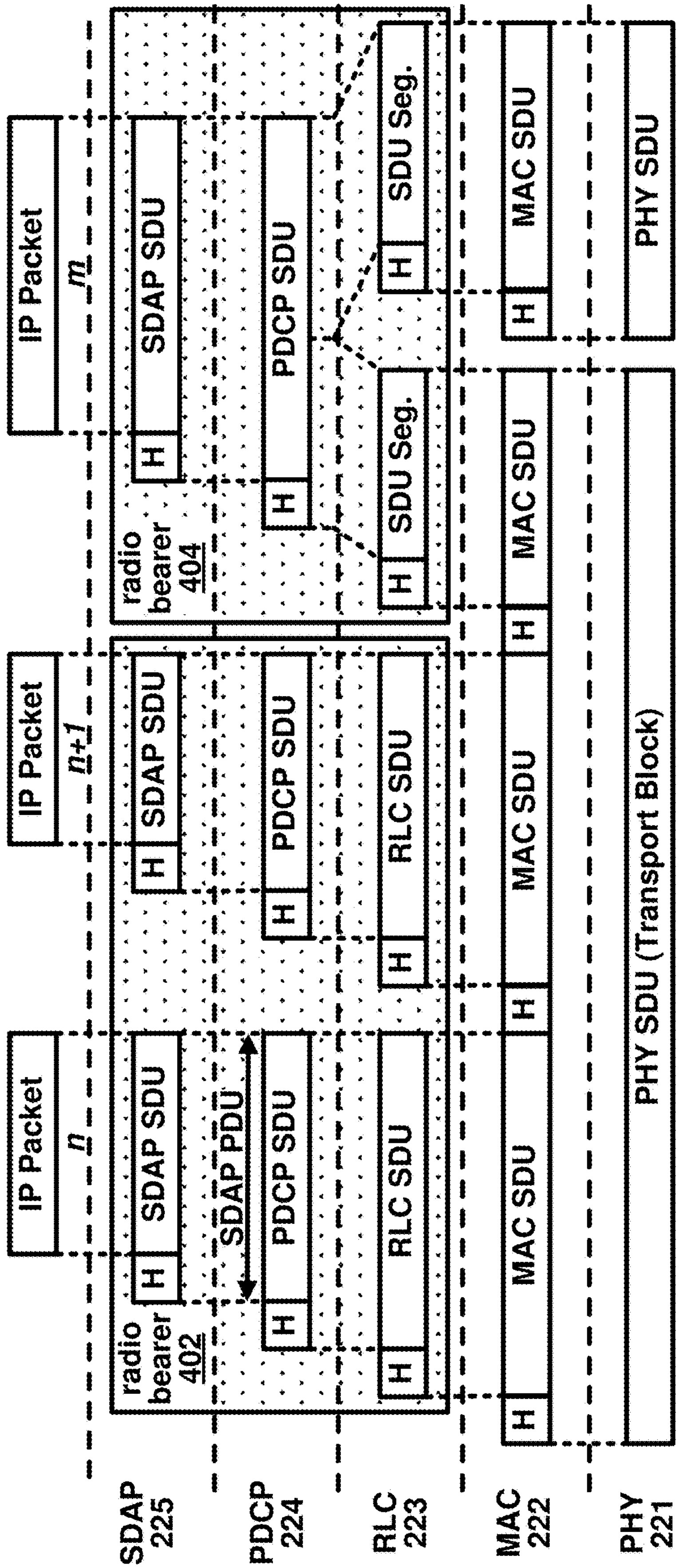
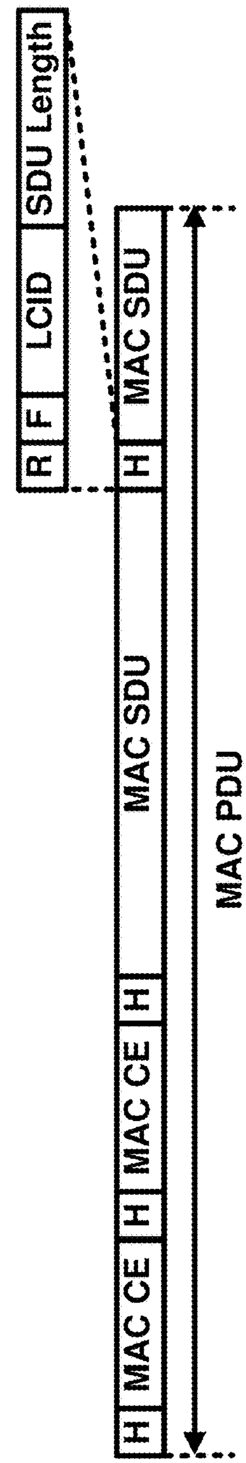

IP Packets
QoS Flows
SDAP 215/225
QoS Flow Handling
Radio Bearers
PDCP 214/224
Header Comp., Ciphering
Header Comp., Ciphering
Reordering, Retransmission
Reordering, Retransmission
RLC Channels
RLC 213/223
Segmentation, ARQ
Segmentation, ARQ
Logical Channels
MAC 212/222
Multiplexing
HARQ
Transport Channel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

FIG. 3



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

FIG. 4A



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

FIG. 4B

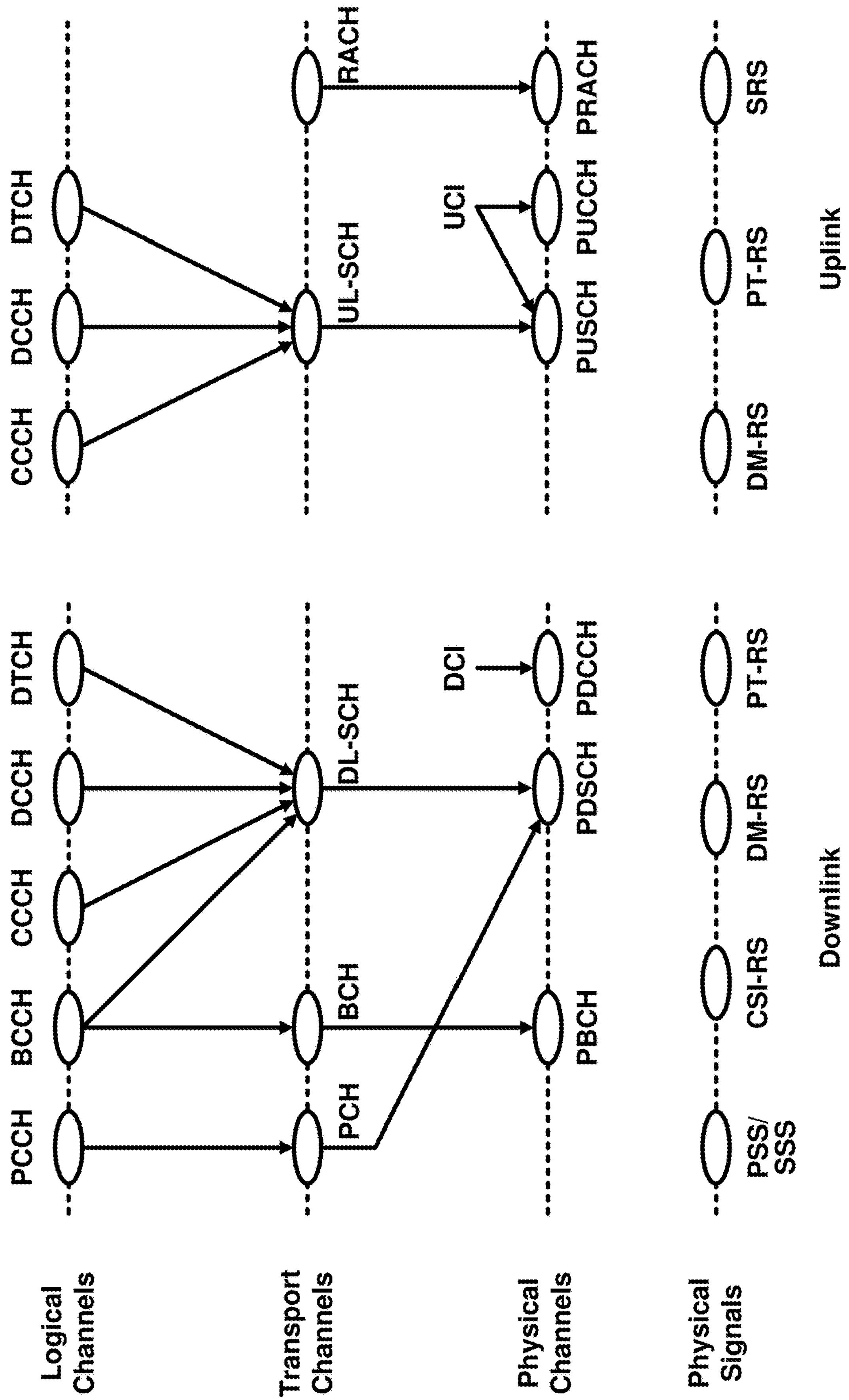

Logical Channels
Transport Channels
Physical Channels
Physical Signals
PCCH
BCCH
CCCH
DCCH
DTCH
PCH
BCH
DL-SCH
DCI
PBCH
PDSCH
PDCCH
PSS/SSS
CSI-RS
DM-RS
PT-RS
Downlink
CCCH
DCCH
DTCH
UL-SCH
RACH
UCI
PUSCH
PUCCH
PRACH
DM-RS
PT-RS
SRS
Uplink

FIG. 5A

FIG. 5B

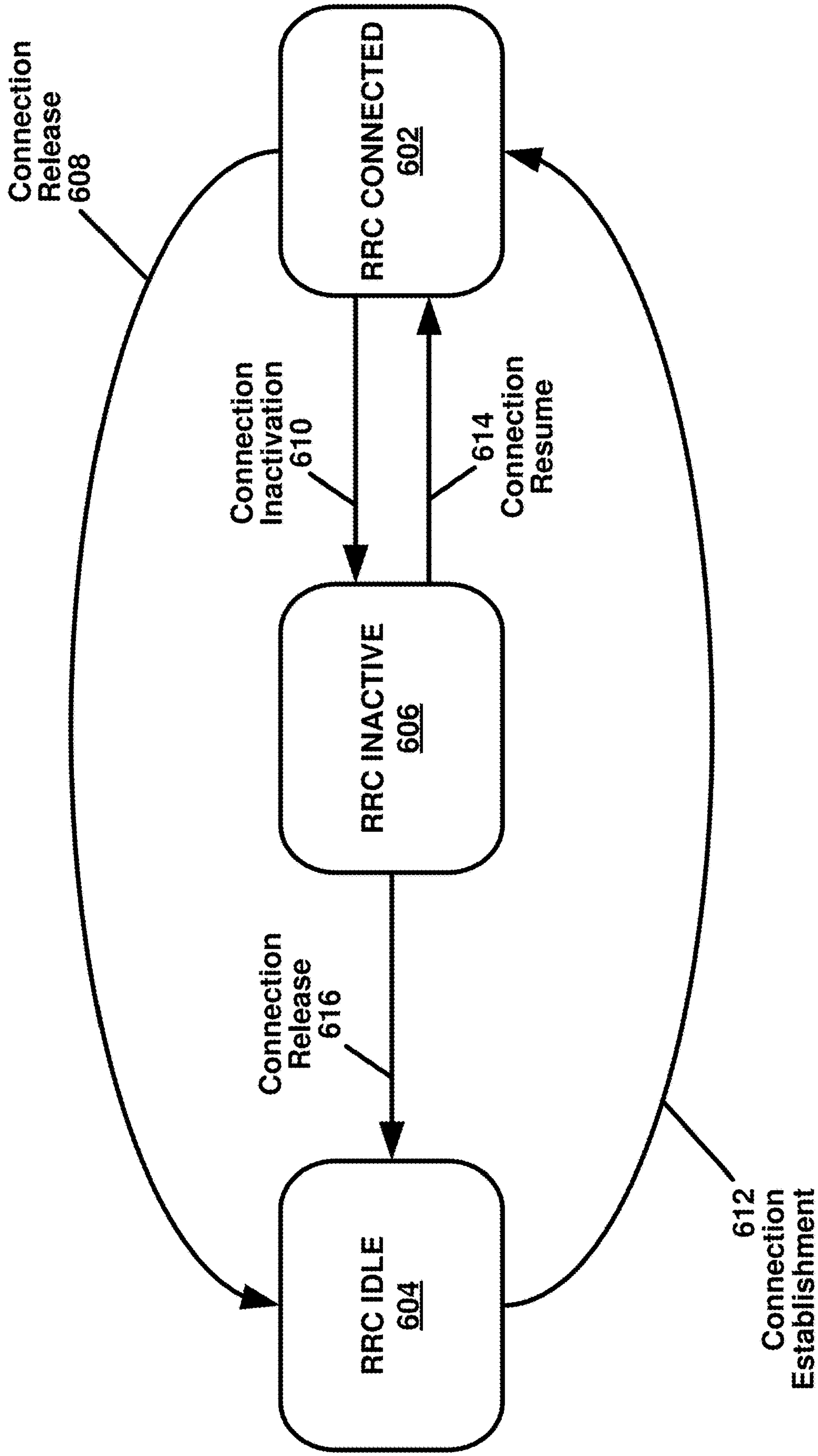

RRC CONNECTED
602
RRC INACTIVE
606
RRC IDLE
604
Connection
Release
608
Connection
Inactivation
610
614
Connection
Resume
Connection
Release
616
612
Connection
Establishment

FIG. 6

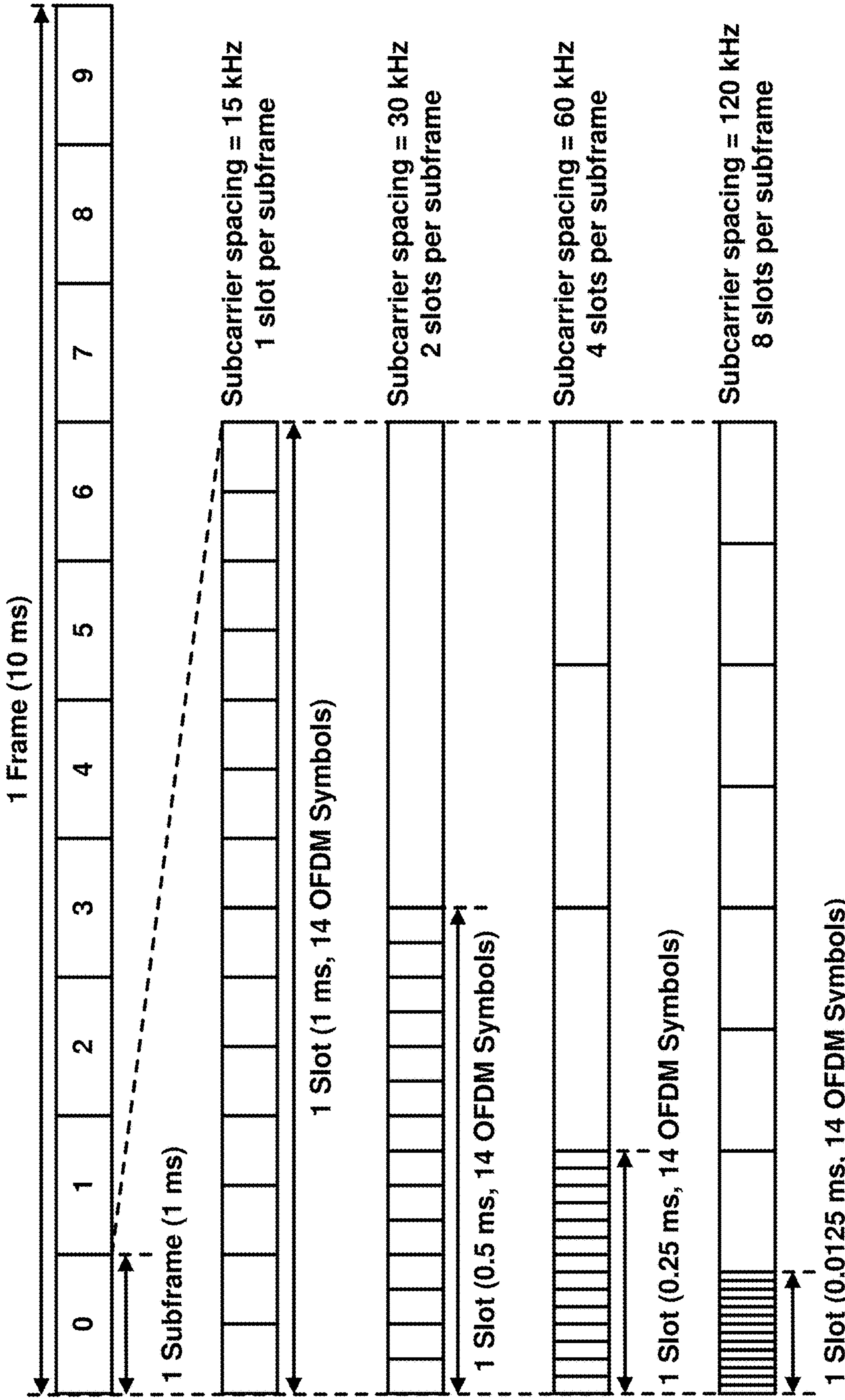

1 Frame (10 ms)
0
1
2
3
4
5
6
7
8
9
1 Subframe (1 ms)
Subcarrier spacing = 15 kHz
1 slot per subframe
1 Slot (1 ms, 14 OFDM Symbols)
Subcarrier spacing = 30 kHz
2 slots per subframe
1 Slot (0.5 ms, 14 OFDM Symbols)
Subcarrier spacing = 60 kHz
4 slots per subframe
1 Slot (0.25 ms, 14 OFDM Symbols)
Subcarrier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

FIG. 7

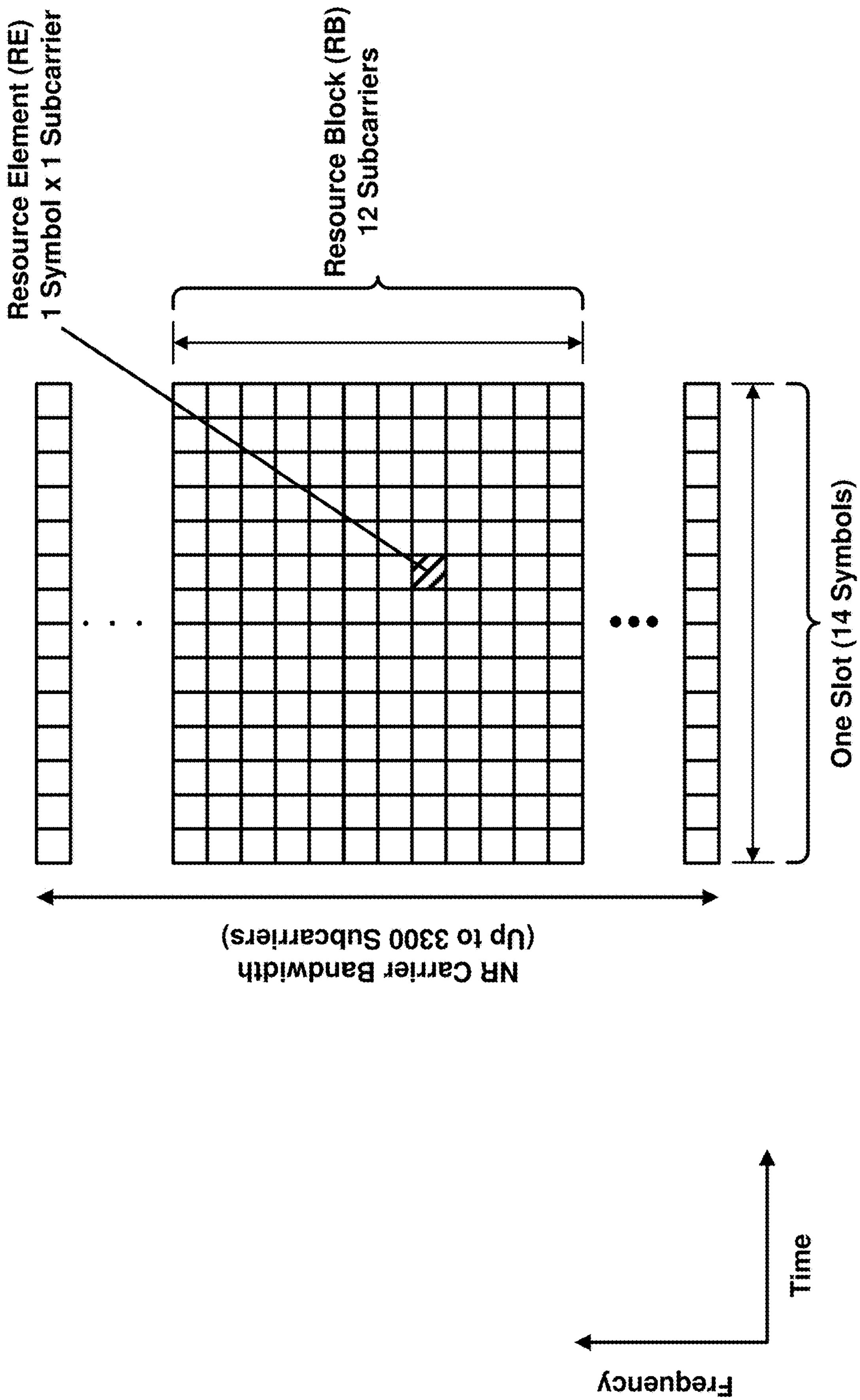

Resource Element (RE)
1 Symbol x 1 Subcarrier
Resource Block (RB)
12 Subcarriers
NR Carrier Bandwidth
(Up to 3300 Subcarriers)
One Slot (14 Symbols)
Time
Frequency

FIG. 8

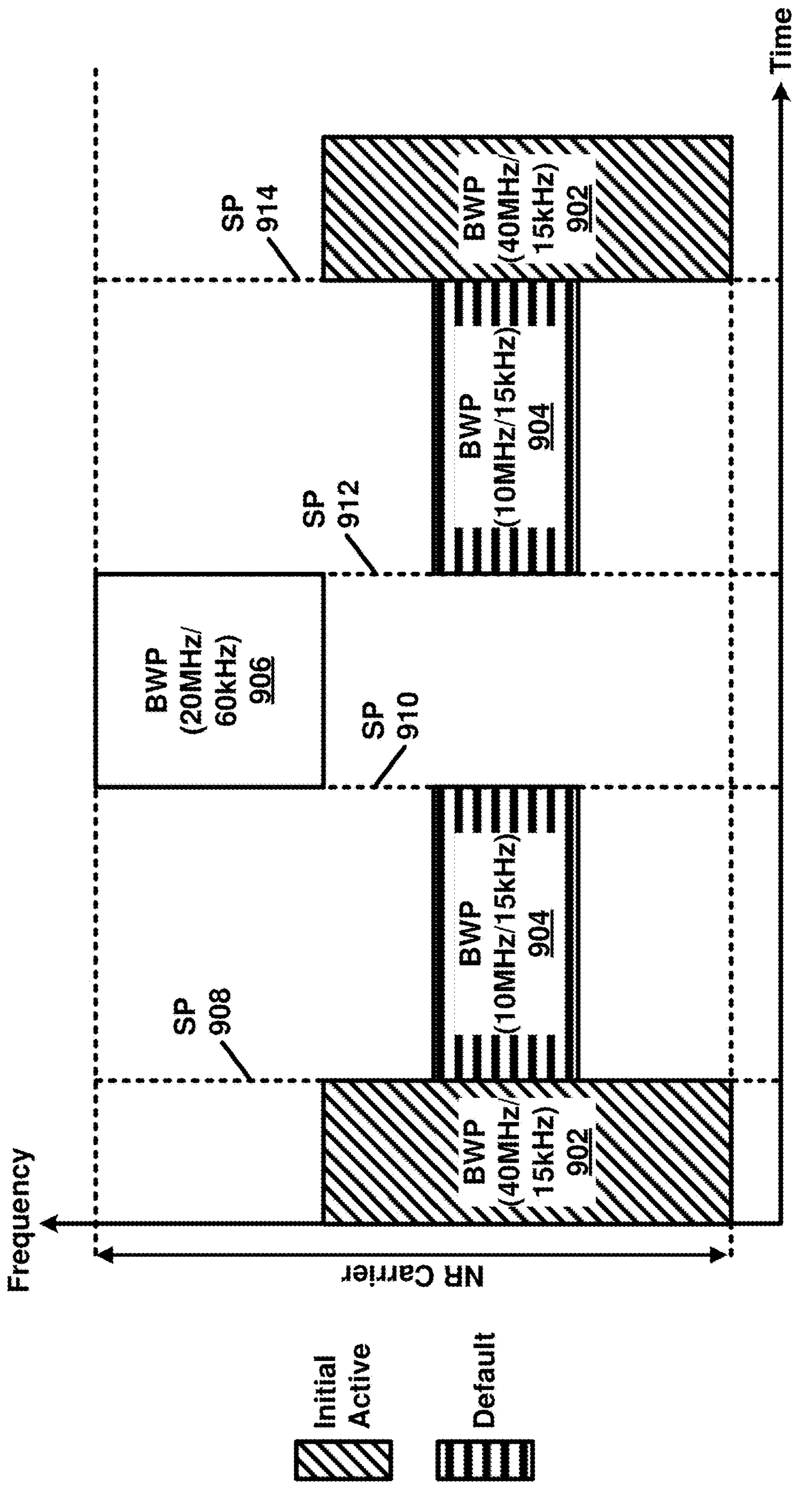

Time
Frequency
NR Carrier
SP 908
SP 910
SP 912
SP 914
BWP (40MHz/15kHz) 902
BWP (10MHz/15kHz) 904
BWP (20MHz/60kHz) 906
BWP (10MHz/15kHz) 904
BWP (40MHz/15kHz) 902
Initial Active
Default

FIG. 9

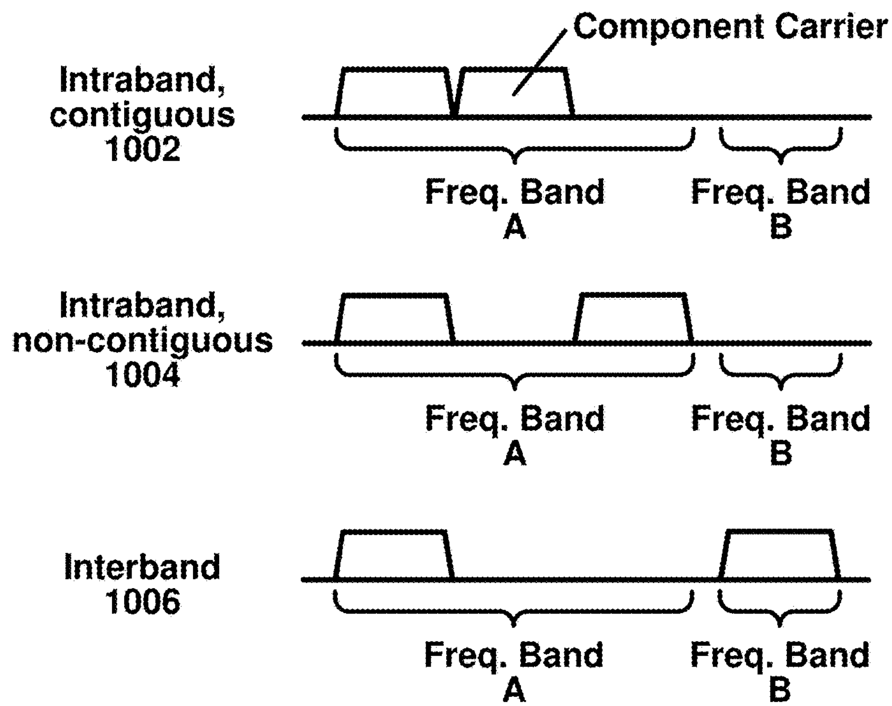


FIG. 10A

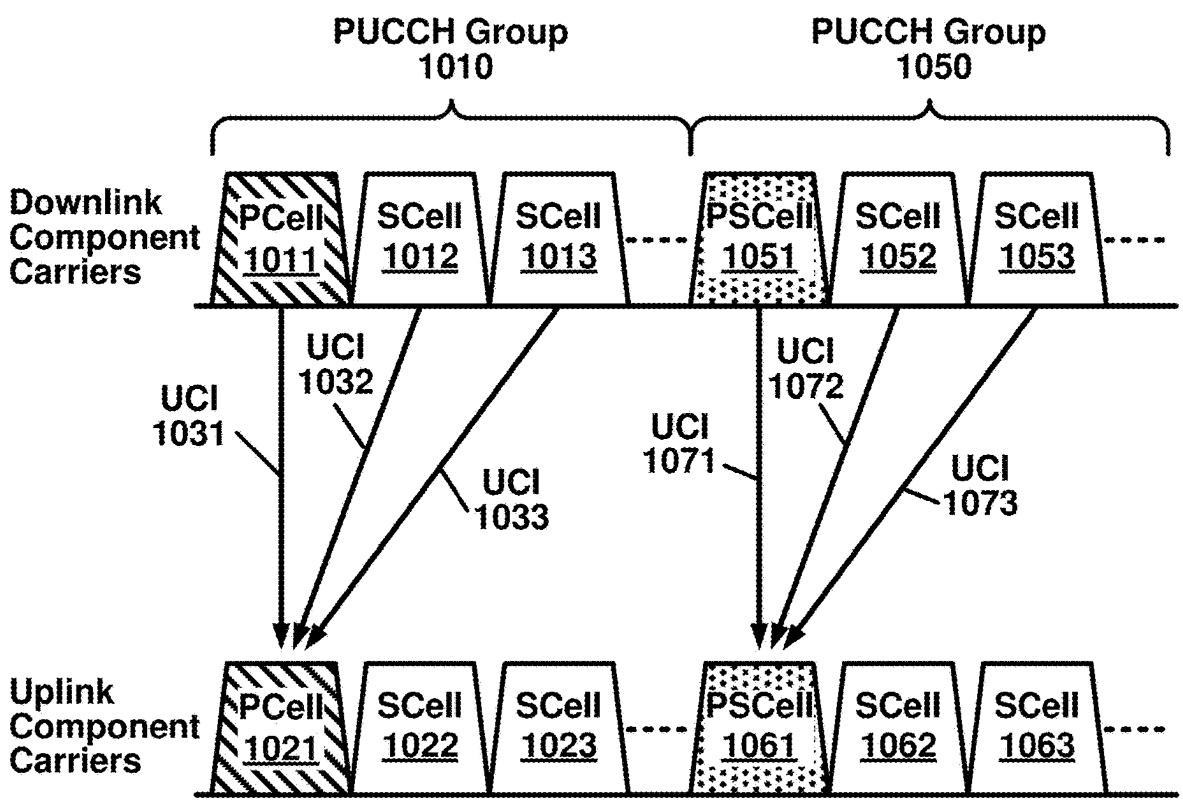


FIG. 10B

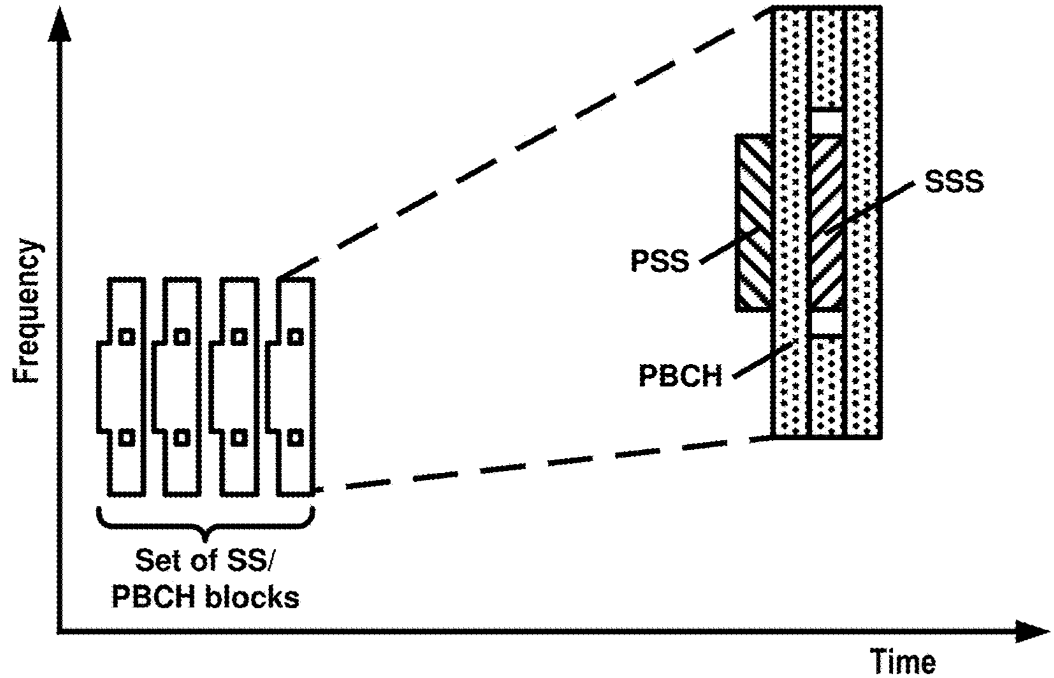


FIG. 11A

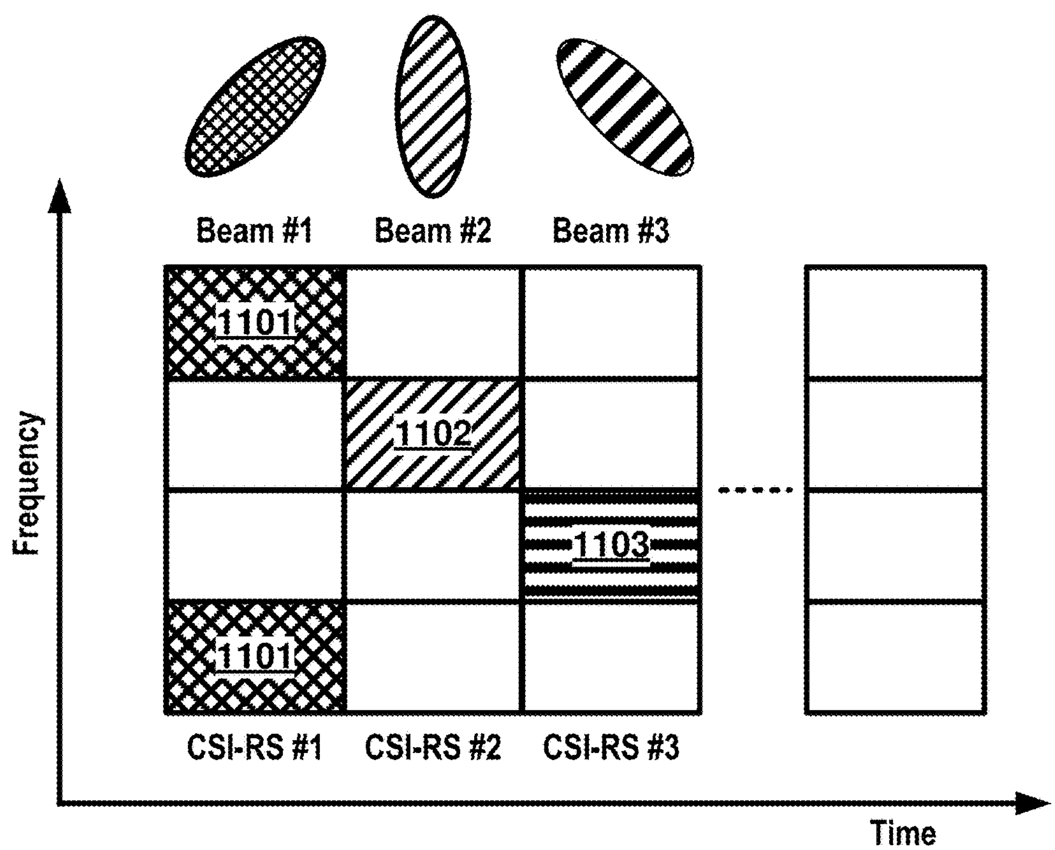


FIG. 11B

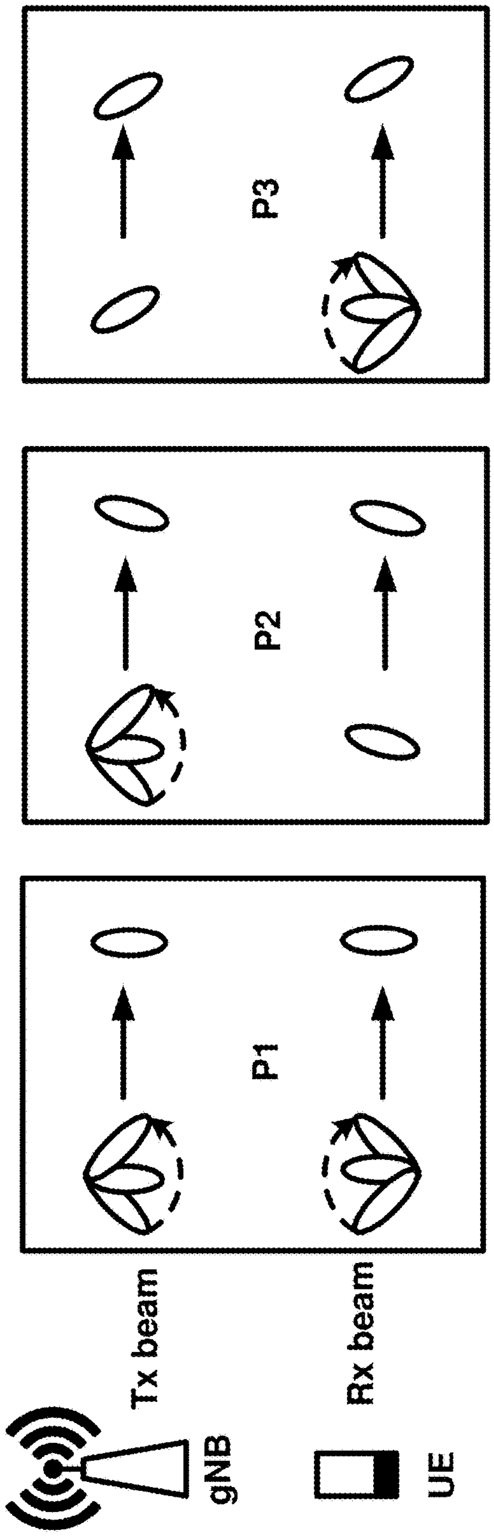


FIG. 12A

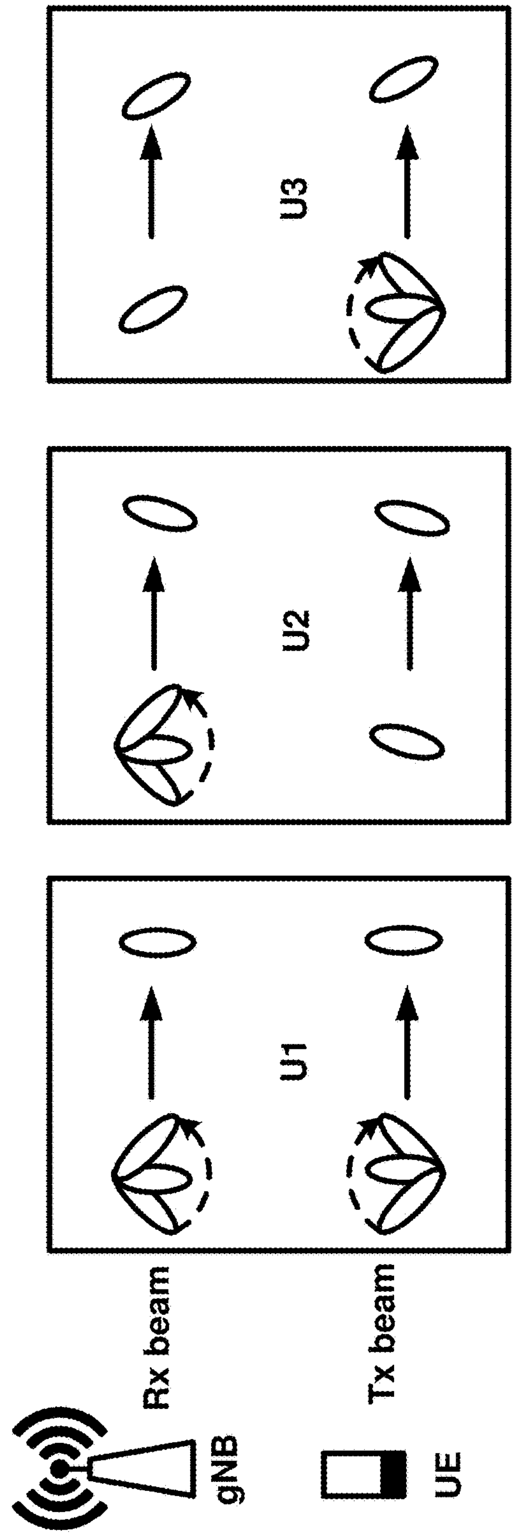


FIG. 12B

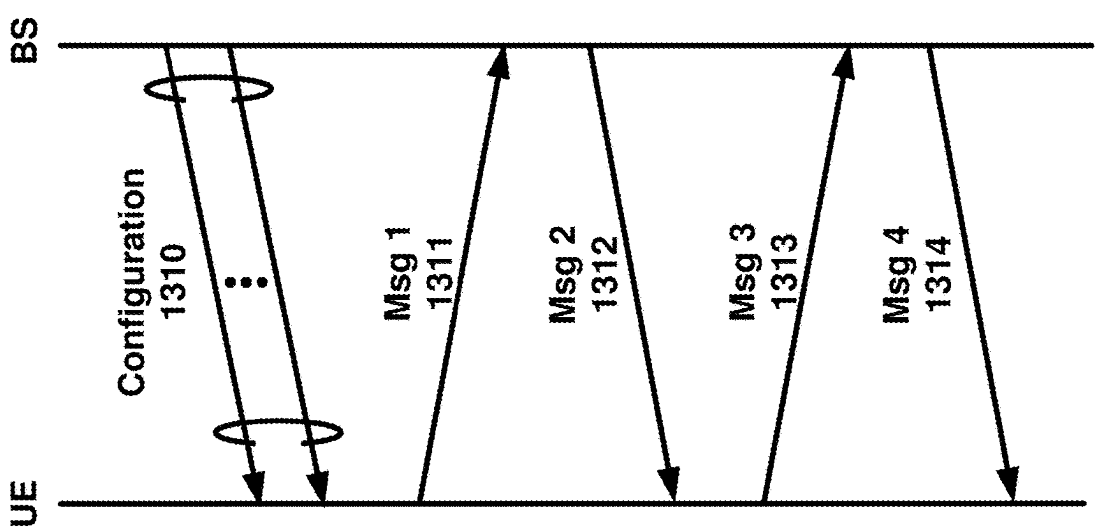


FIG. 13A

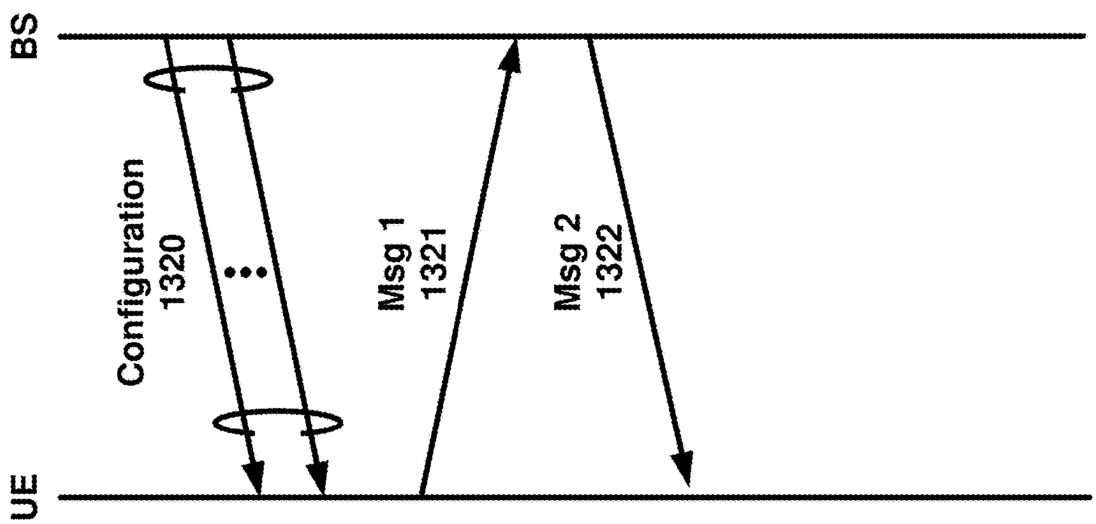


FIG. 13B

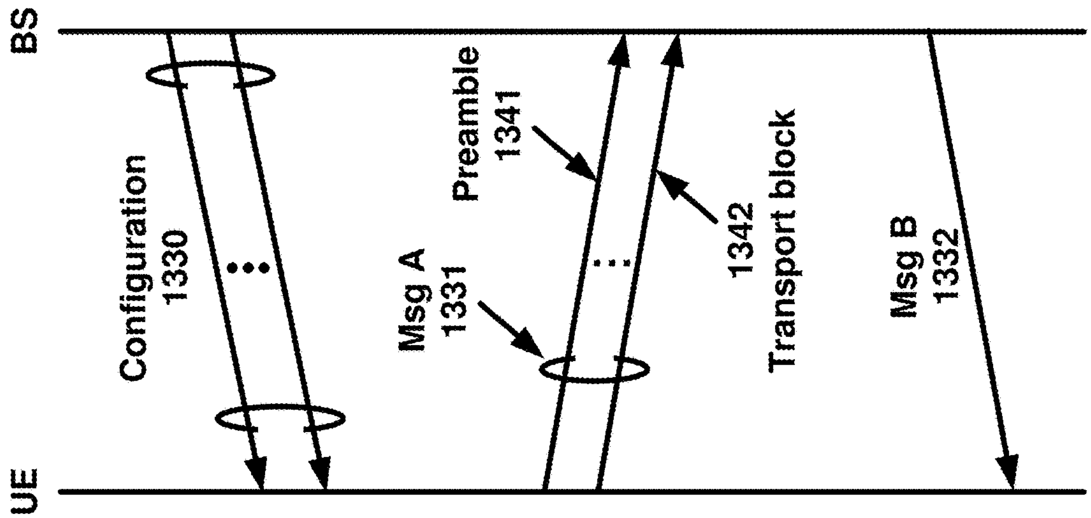


FIG. 13C

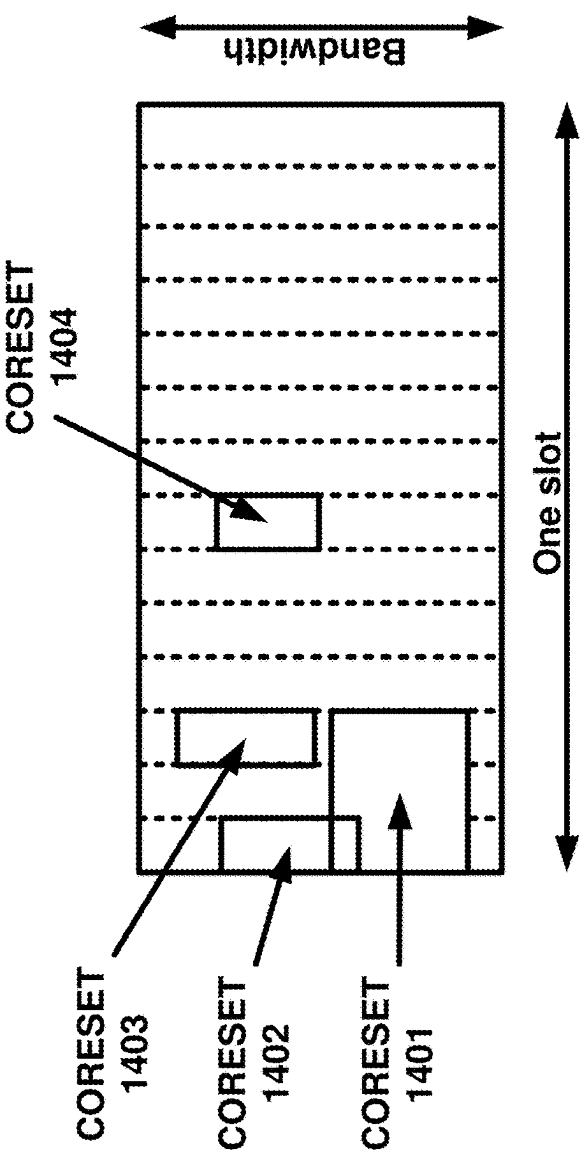


FIG. 14A

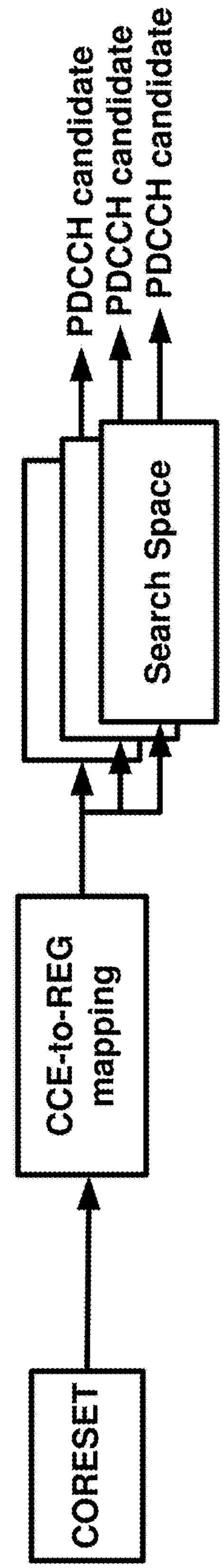


FIG. 14B

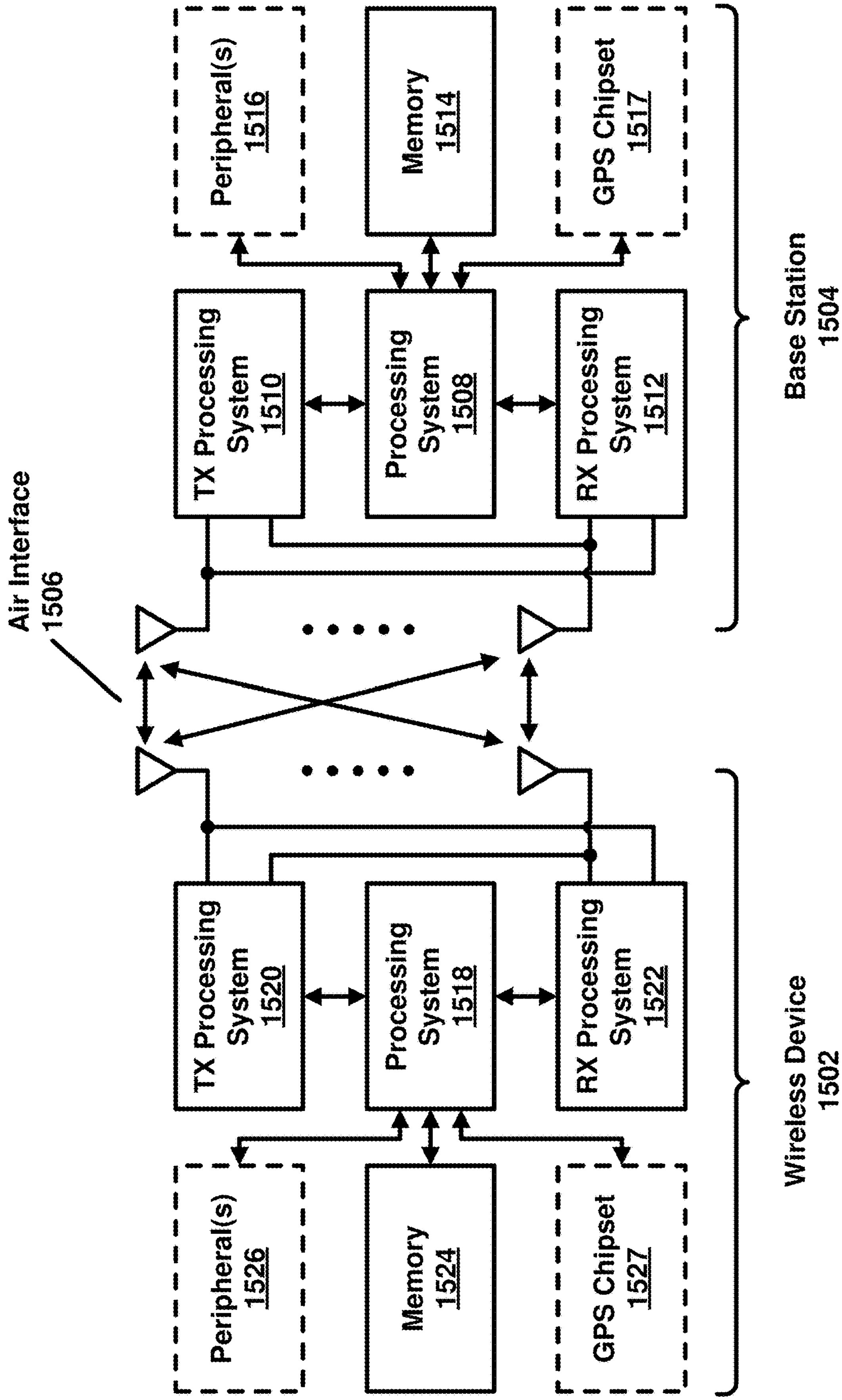

Peripheral(s) 1516
Memory 1514
GPS Chipset 1517
TX Processing System 1510
Processing System 1508
RX Processing System 1512
Base Station 1504
Air Interface 1506
TX Processing System 1520
Processing System 1518
RX Processing System 1522
Wireless Device 1502
Peripheral(s) 1526
Memory 1524
GPS Chipset 1527

FIG. 15

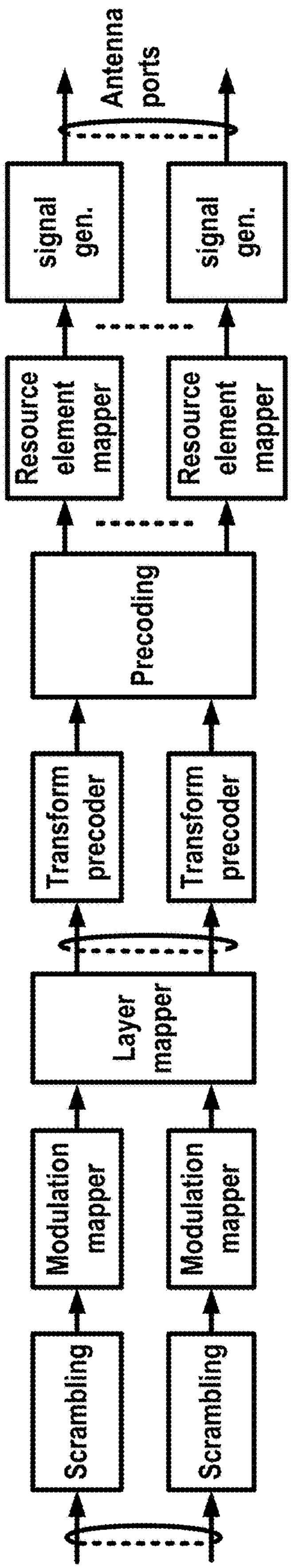


FIG. 16A

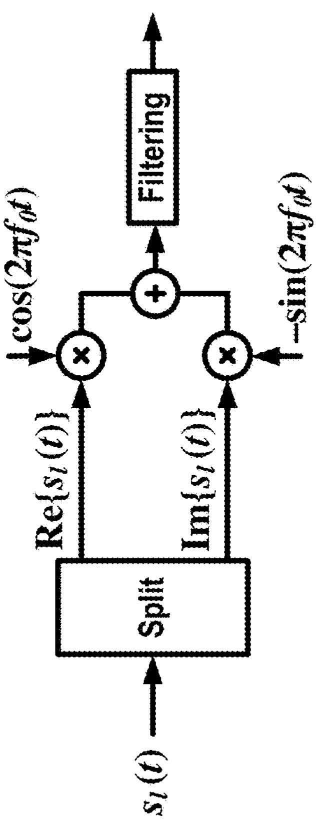


FIG. 16B

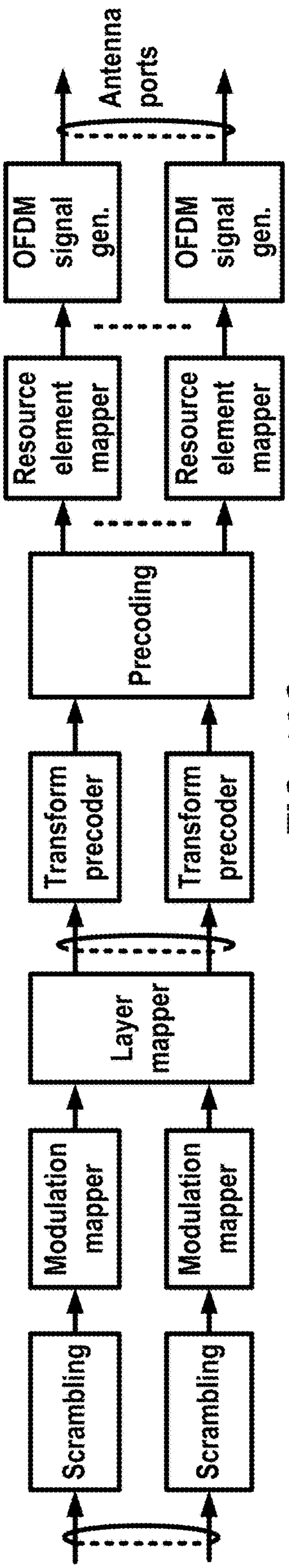


FIG. 16C

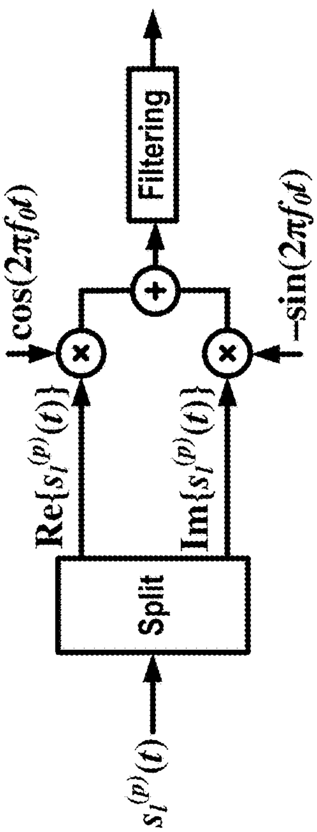


FIG. 16D

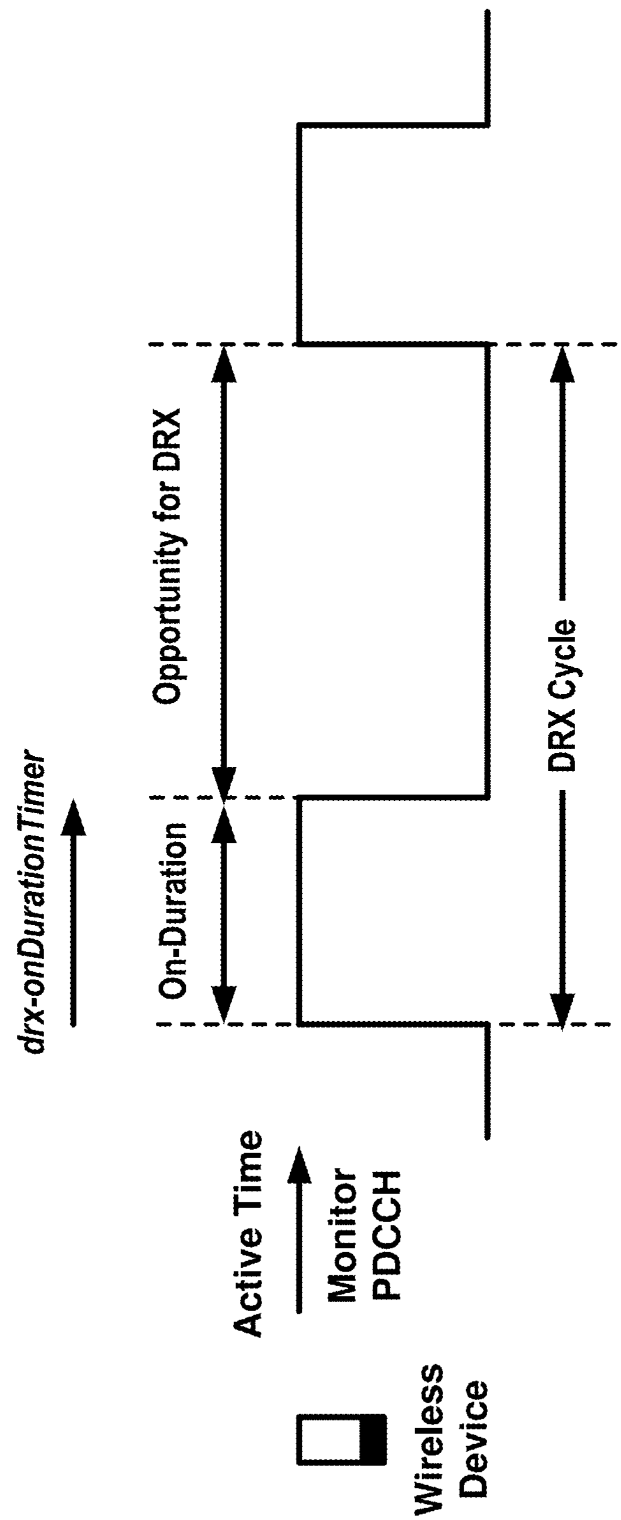

drx-onDurationTimer
Opportunity for DRX
On-Duration
DRX Cycle
Active Time
Monitor PDCCH
Wireless Device

FIG. 17

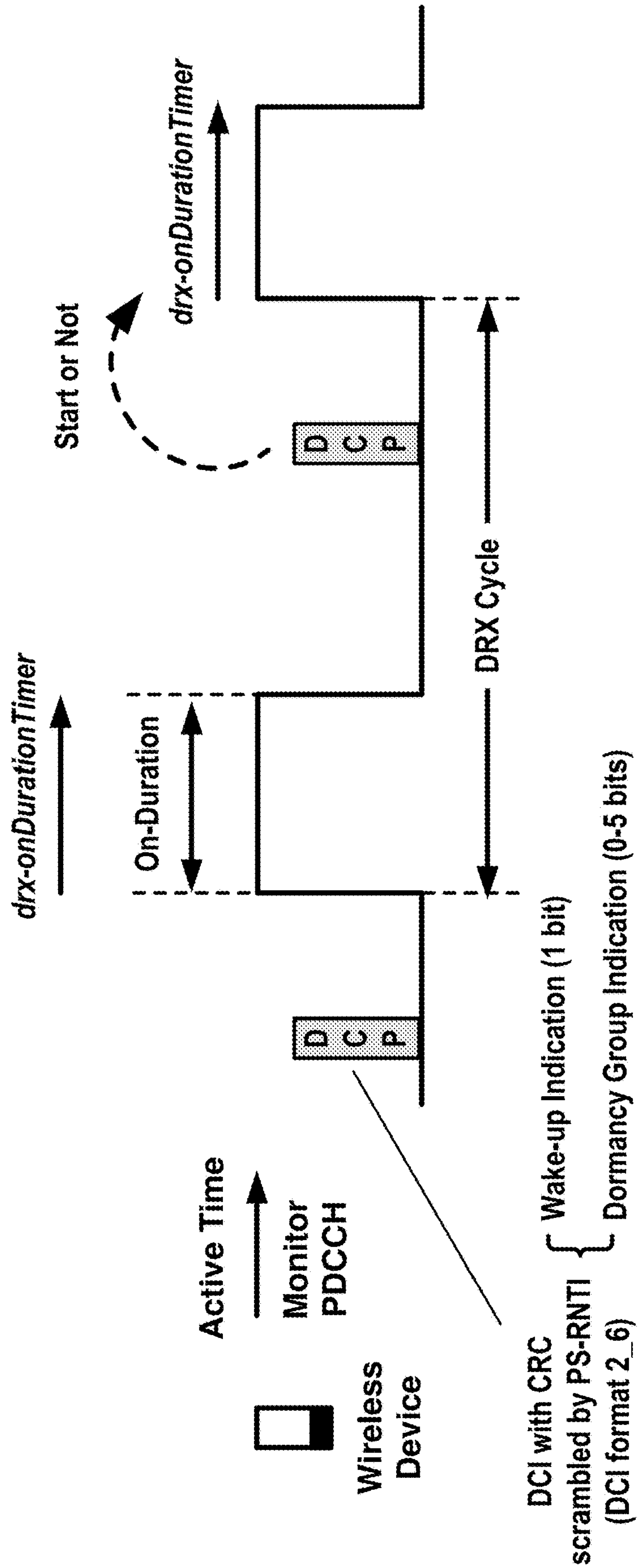

Wireless Device
Active Time
Monitor PDCCH
DCI with CRC scrambled by PS-RNTI (DCI format 2_6)
Wake-up Indication (1 bit)
Dormancy Group Indication (0-5 bits)
DCP
drx-onDurationTimer
On-Duration
DRX Cycle
DCP
Start or Not
drx-onDurationTimer

FIG. 18

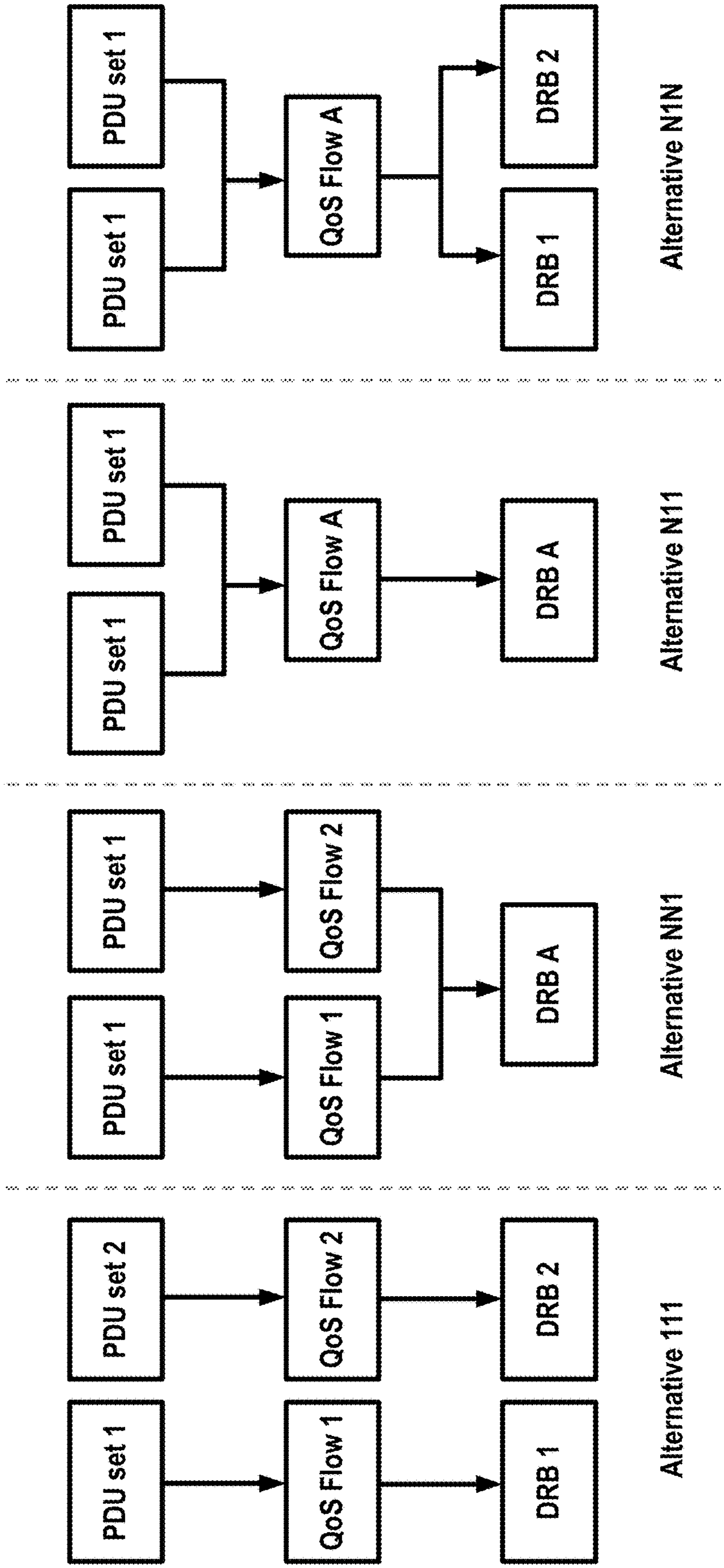

PDU set 1
PDU set 2
QoS Flow 1
QoS Flow 2
DRB 1
DRB 2
Alternative 111
PDU set 1
PDU set 1
QoS Flow 1
QoS Flow 2
DRB A
Alternative NN1
PDU set 1
PDU set 1
QoS Flow A
DRB A
Alternative N11
PDU set 1
PDU set 1
QoS Flow A
DRB 1
DRB 2
Alternative N1N

FIG. 19

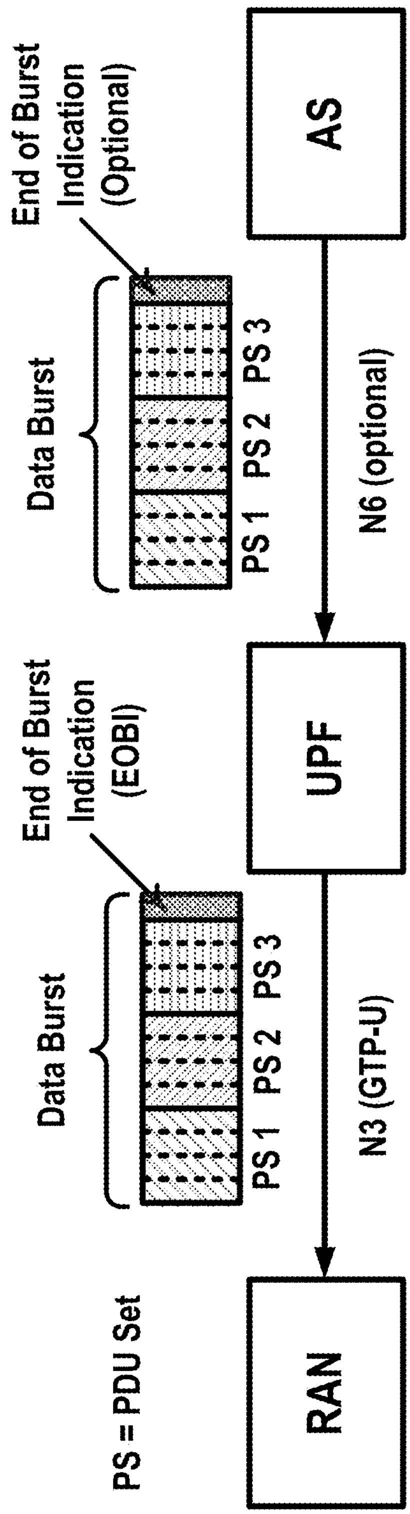

AS
End of Burst
Indication
(Optional)
Data Burst
PS 1
PS 2
PS 3
N6 (optional)
UPF
End of Burst
Indication
(EOBI)
Data Burst
PS 1
PS 2
PS 3
N3 (GTP-U)
RAN
PS = PDU Set

FIG. 20

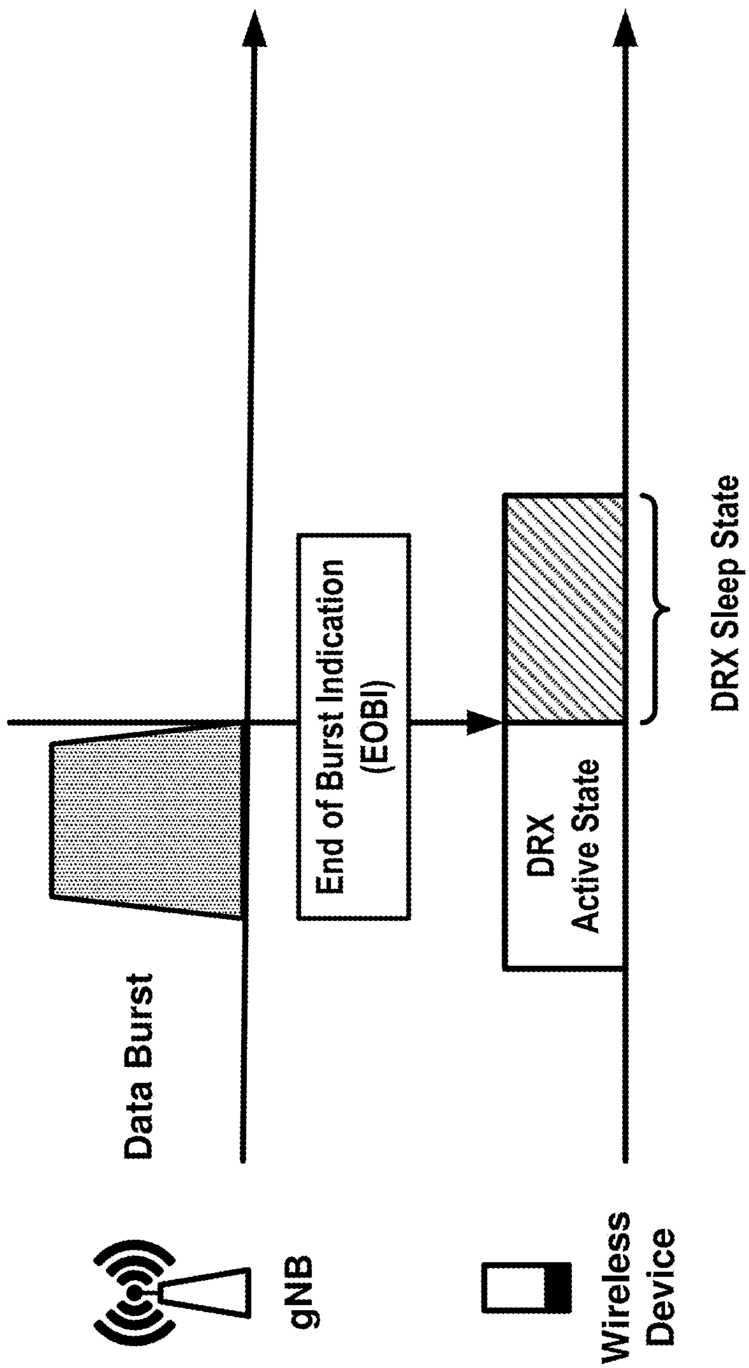

gNB
Data Burst
End of Burst Indication (EOBI)
Wireless Device
DRX Active State
DRX Sleep State

FIG. 21

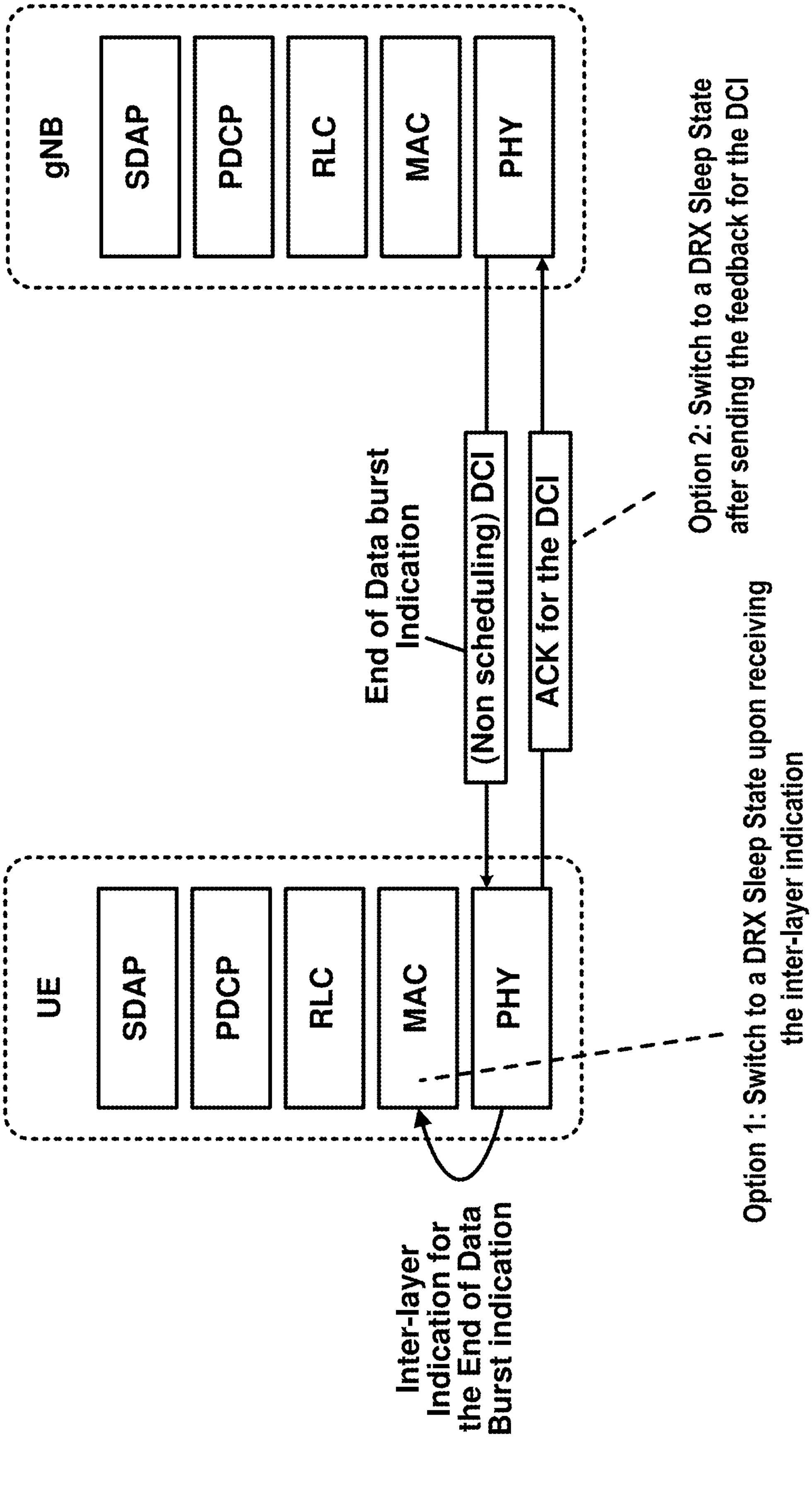
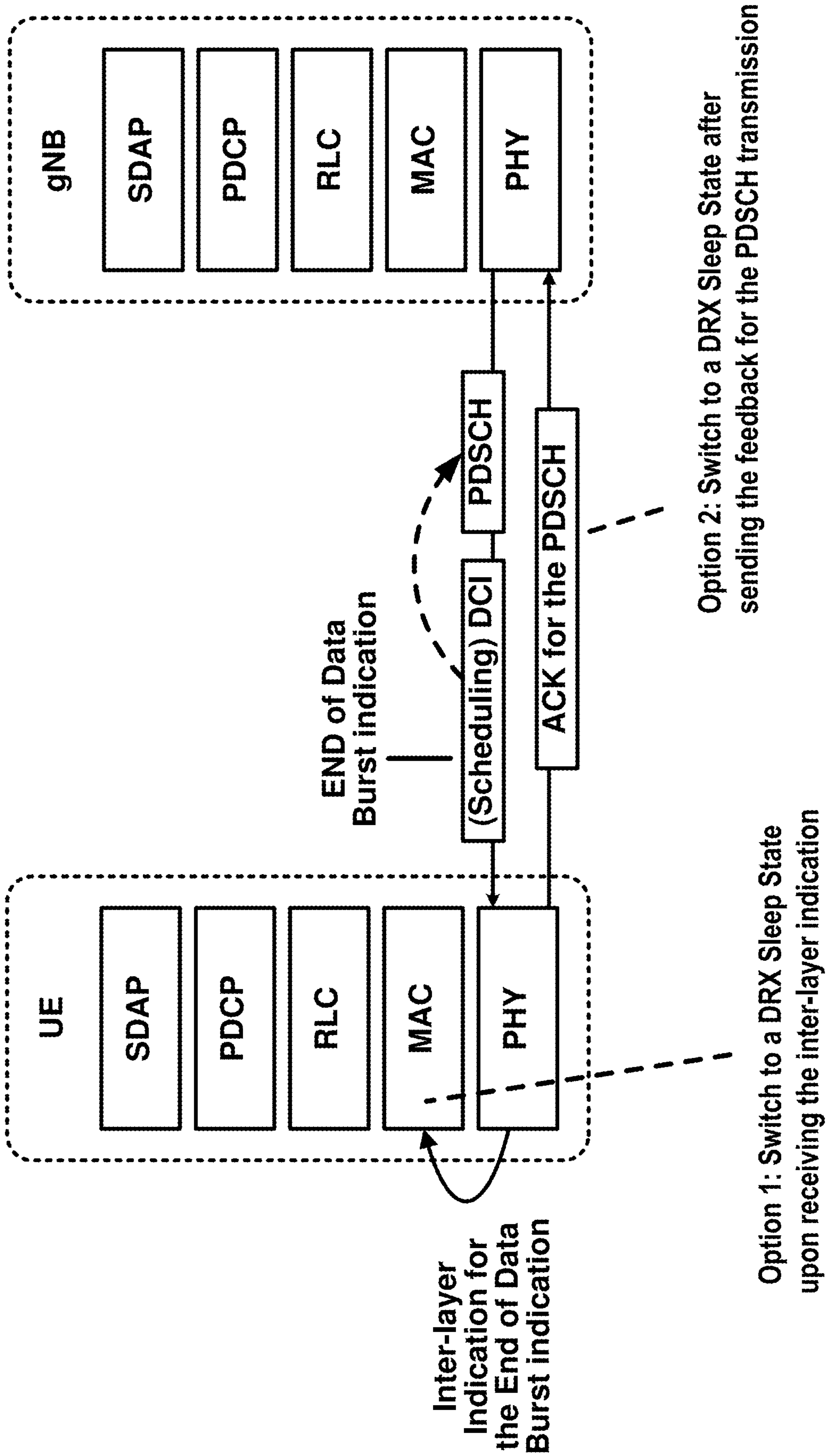

UE
SDAP
PDCP
RLC
MAC
PHY
gNB
SDAP
PDCP
RLC
MAC
PHY
End of Data burst Indication
(Non scheduling) DCI
ACK for the DCI
Inter-layer Indication for the End of Data Burst indication
Option 1: Switch to a DRX Sleep State upon receiving the inter-layer indication
Option 2: Switch to a DRX Sleep State after sending the feedback for the DCI

FIG. 22



gNB
SDAP
PDCP
RLC
MAC
PHY
UE
SDAP
PDCP
RLC
MAC
PHY
END of Data Burst indication
(Scheduling) DCI
PDSCH
ACK for the PDSCH
Option 2: Switch to a DRX Sleep State after sending the feedback for the PDSCH transmission
Inter-layer Indication for the End of Data Burst indication
Option 1: Switch to a DRX Sleep State upon receiving the inter-layer indication

FIG. 23

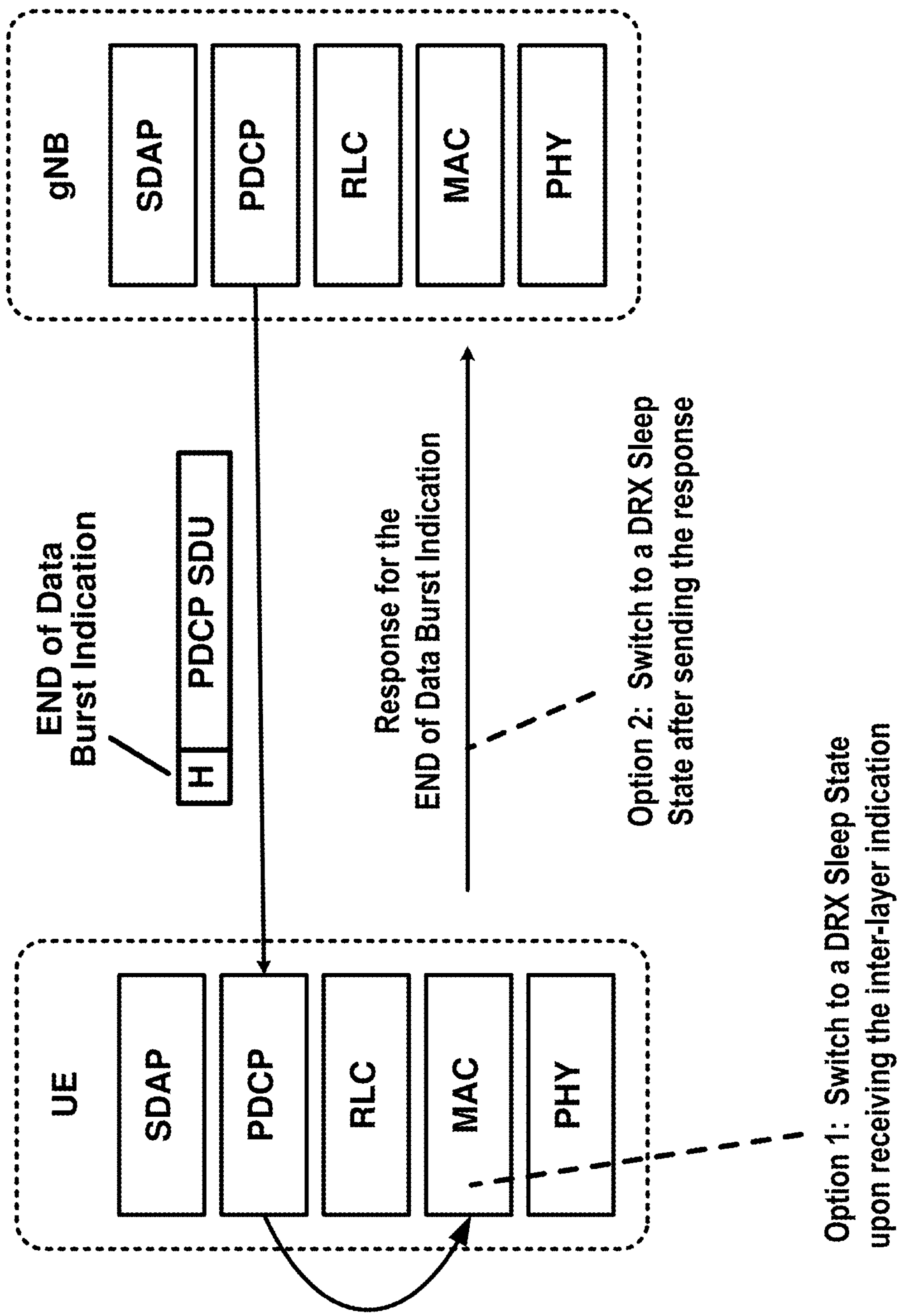

gNB
SDAP
PDCP
RLC
MAC
PHY
END of Data
Burst Indication
H
PDCP SDU
Response for the
END of Data Burst Indication
Option 2: Switch to a DRX Sleep
State after sending the response
UE
SDAP
PDCP
RLC
MAC
PHY
Option 1: Switch to a DRX Sleep State
upon receiving the inter-layer indication

FIG. 24

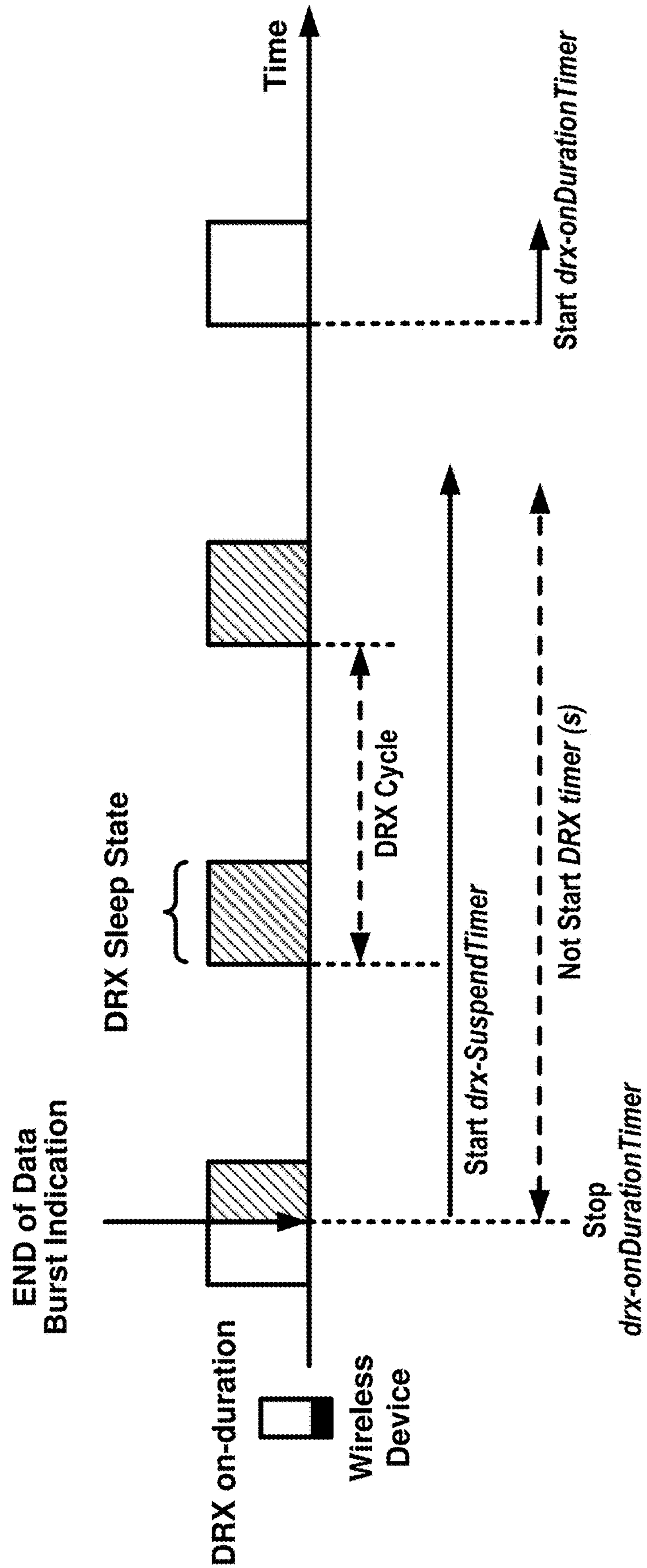

Time
Start drx-onDurationTimer
DRX Sleep State
DRX Cycle
Start drx-SuspendTimer
Not Start DRX timer (s)
END of Data Burst Indication
Stop drx-onDurationTimer
DRX on-duration
Wireless Device

FIG. 25

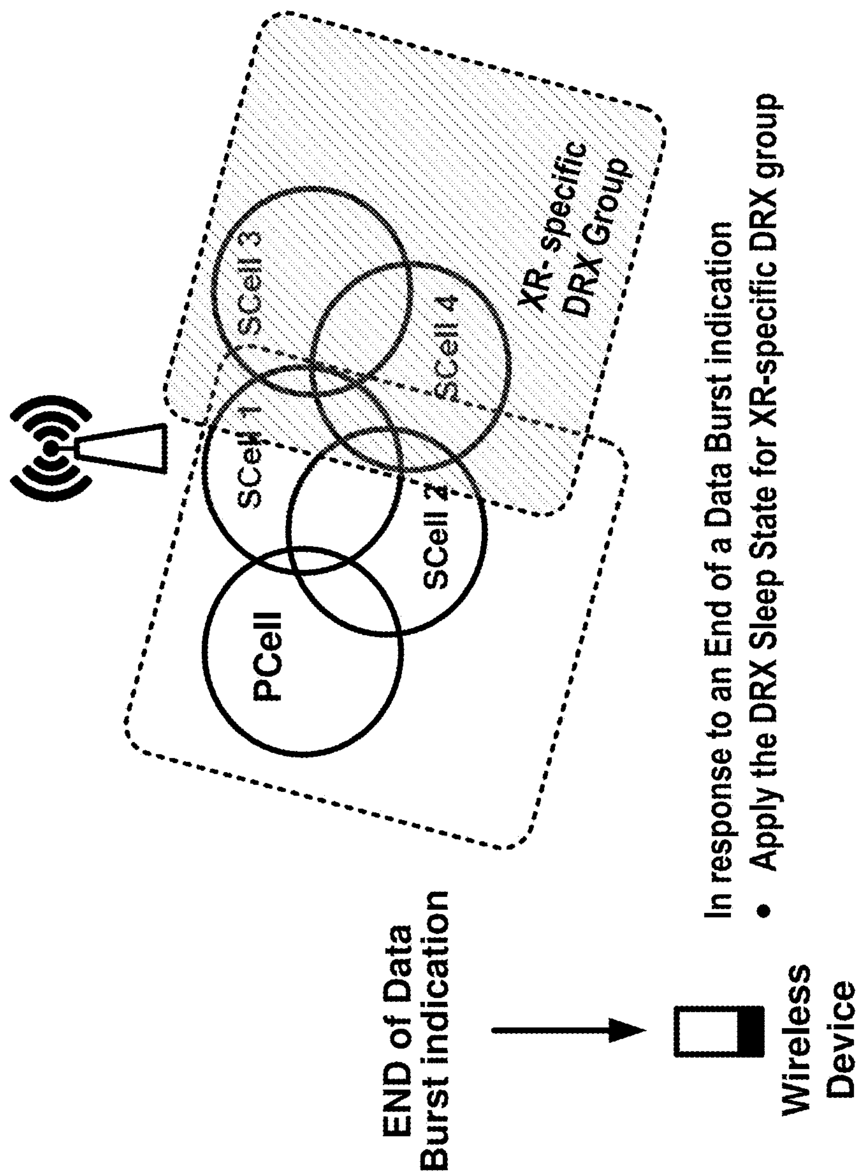

XR- specific
DRX Group
SCell 3
SCell 4
SCell 1
SCell 2
PCell
In response to an End of a Data Burst indication
• Apply the DRX Sleep State for XR-specific DRX group
END of Data
Burst indication
Wireless
Device

FIG. 26

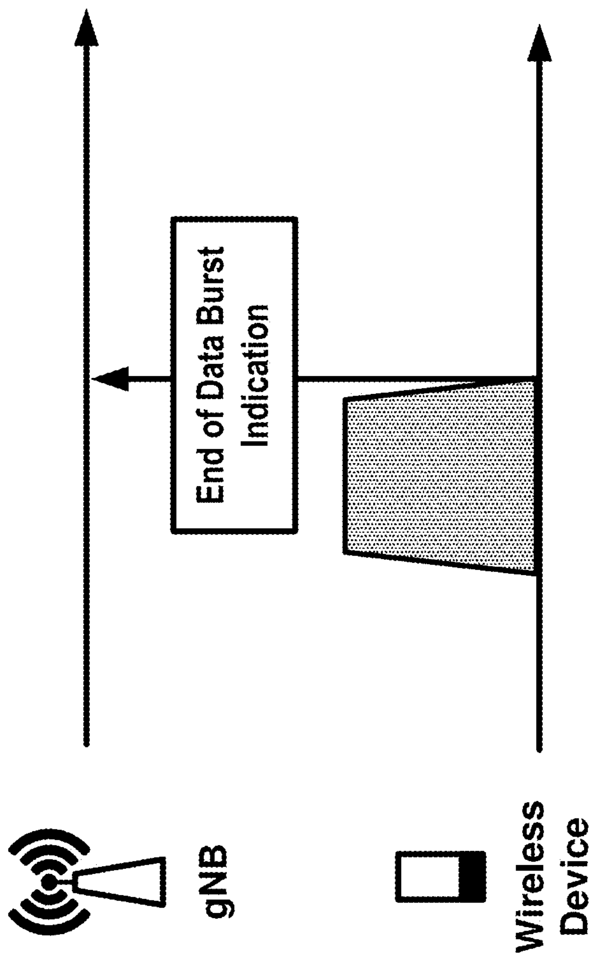


FIG. 27

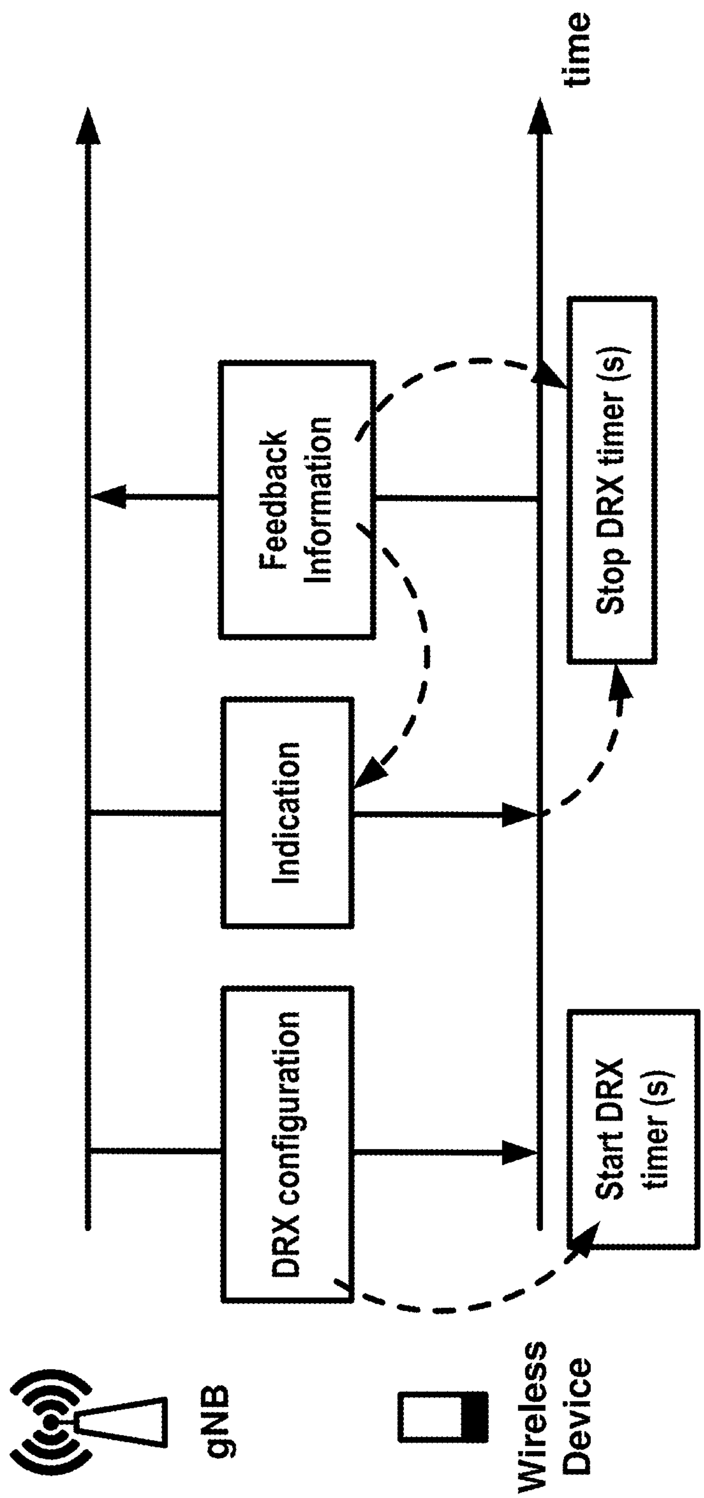

gNB
Wireless Device
time
DRX configuration
Indication
Feedback Information
Start DRX timer (s)
Stop DRX timer (s)

FIG. 28

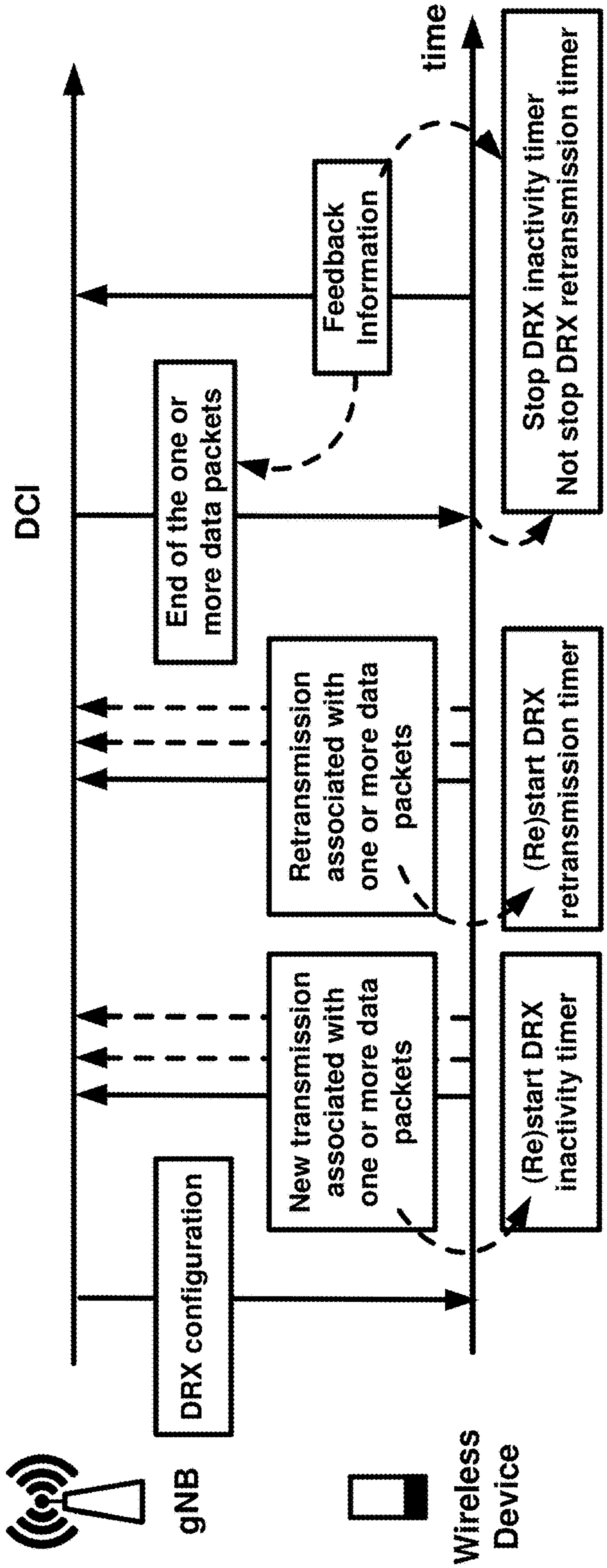

gNB
Wireless Device
DRX configuration
New transmission associated with one or more data packets
(Re)start DRX inactivity timer
Retransmission associated with one or more data packets
(Re)start DRX retransmission timer
DCI
End of the one or more data packets
Feedback Information
Stop DRX inactivity timer
Not stop DRX retransmission timer
time

FIG. 29

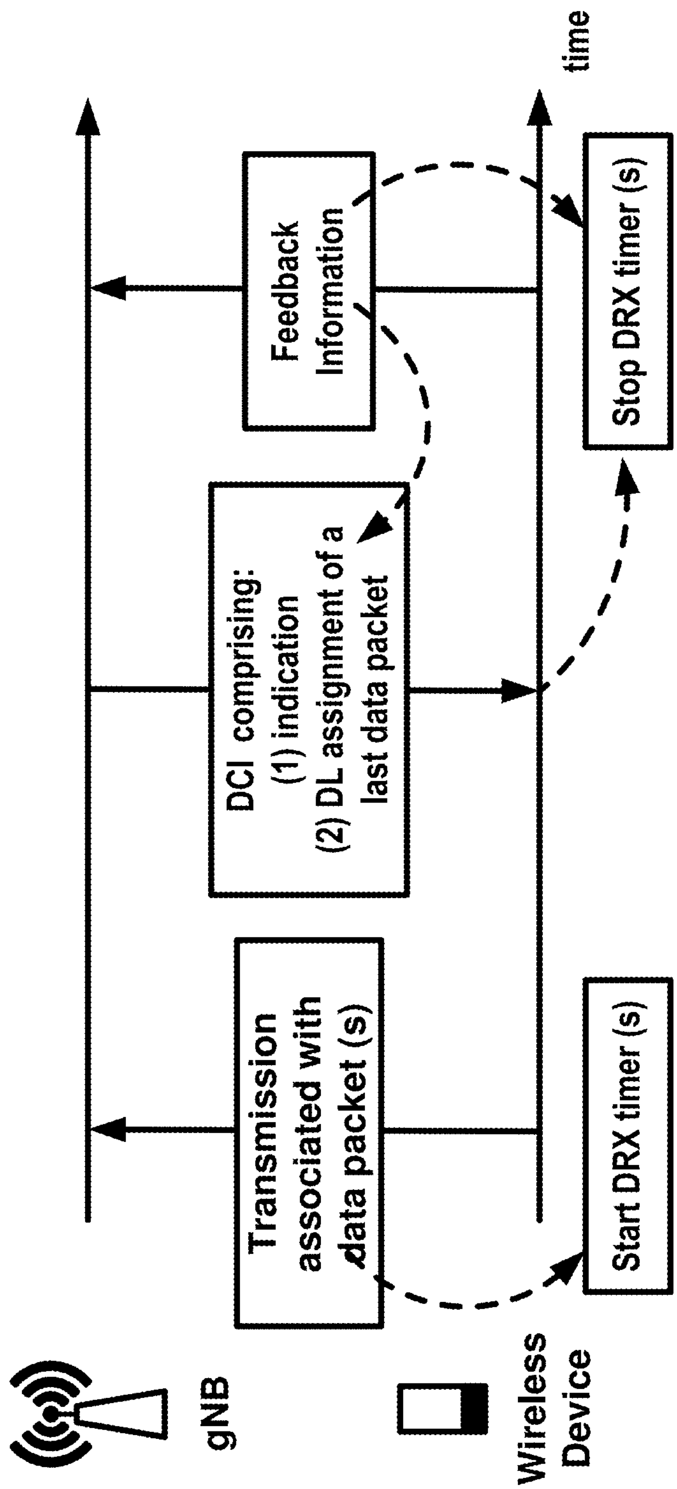

gNB
Wireless Device
time
Transmission associated with data packet (s)
Start DRX timer (s)
DCI comprising:
(1) indication
(2) DL assignment of a last data packet
Feedback Information
Stop DRX timer (s)

FIG. 30

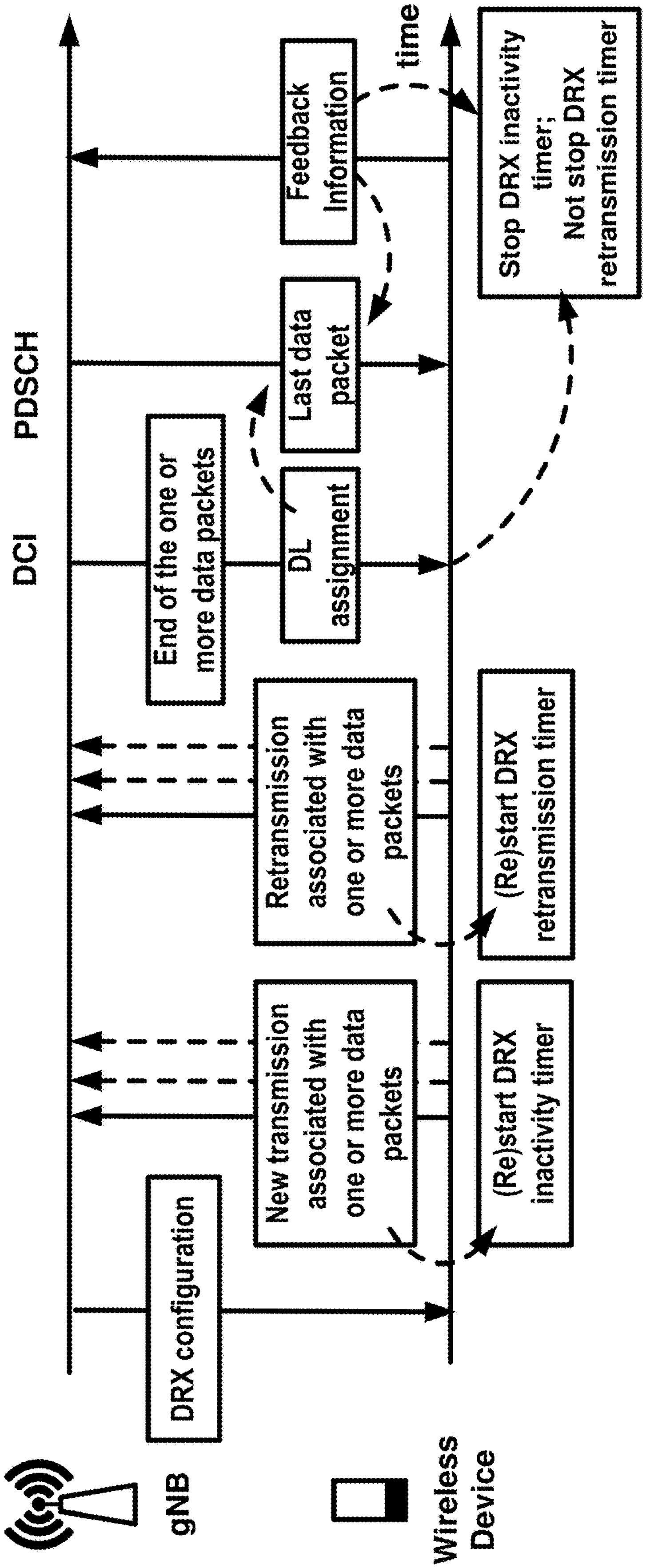

gNB
Wireless Device
DCI
PDSCH
time
DRX configuration
New transmission associated with one or more data packets
(Re)start DRX inactivity timer
Retransmission associated with one or more data packets
(Re)start DRX retransmission timer
End of the one or more data packets
DL assignment
Last data packet
Feedback Information
Stop DRX inactivity timer; Not stop DRX retransmission timer

FIG. 31

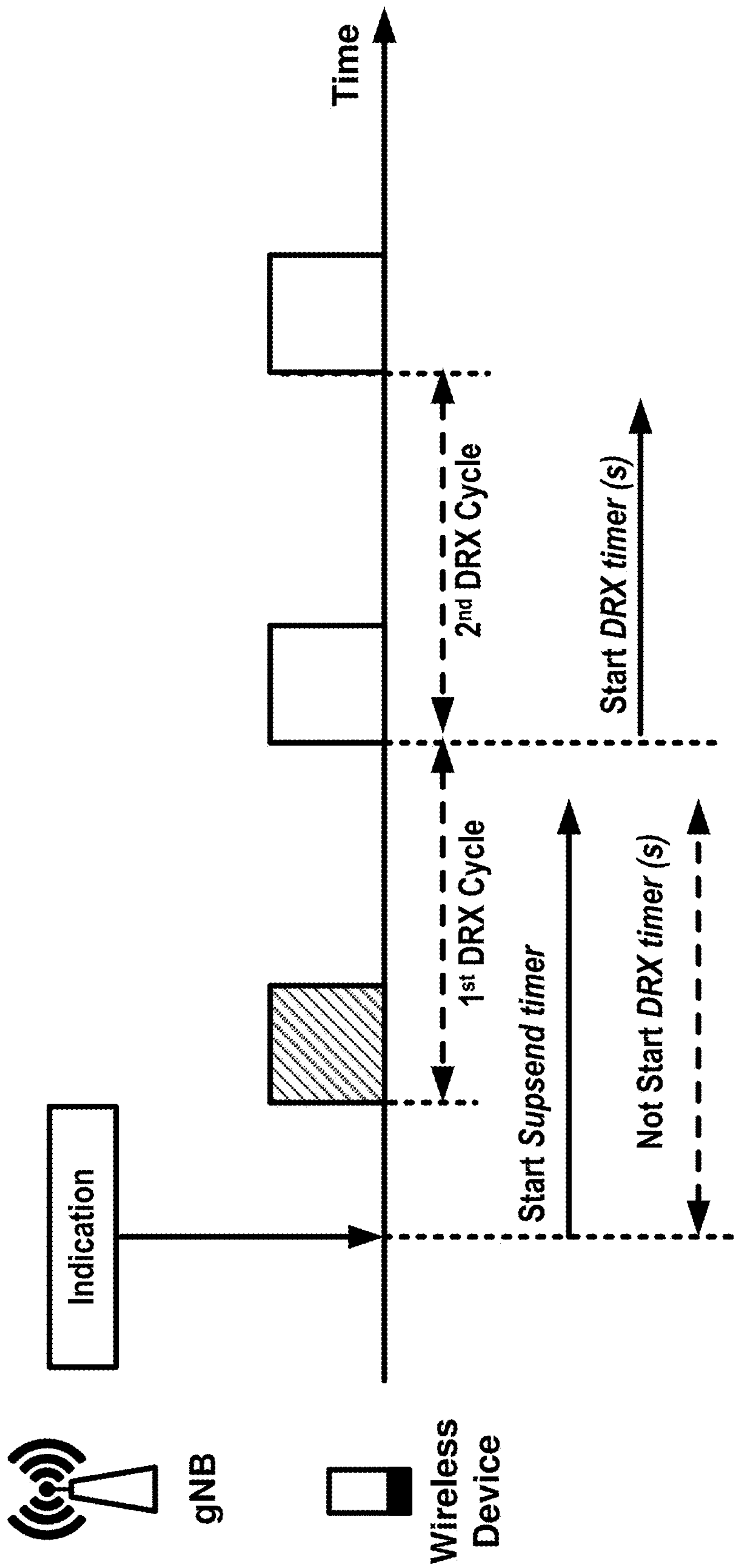

Time
2nd DRX Cycle
Start DRX timer (s)
1st DRX Cycle
Start Supsend timer
Not Start DRX timer (s)
Indication
gNB
Wireless Device

FIG. 32

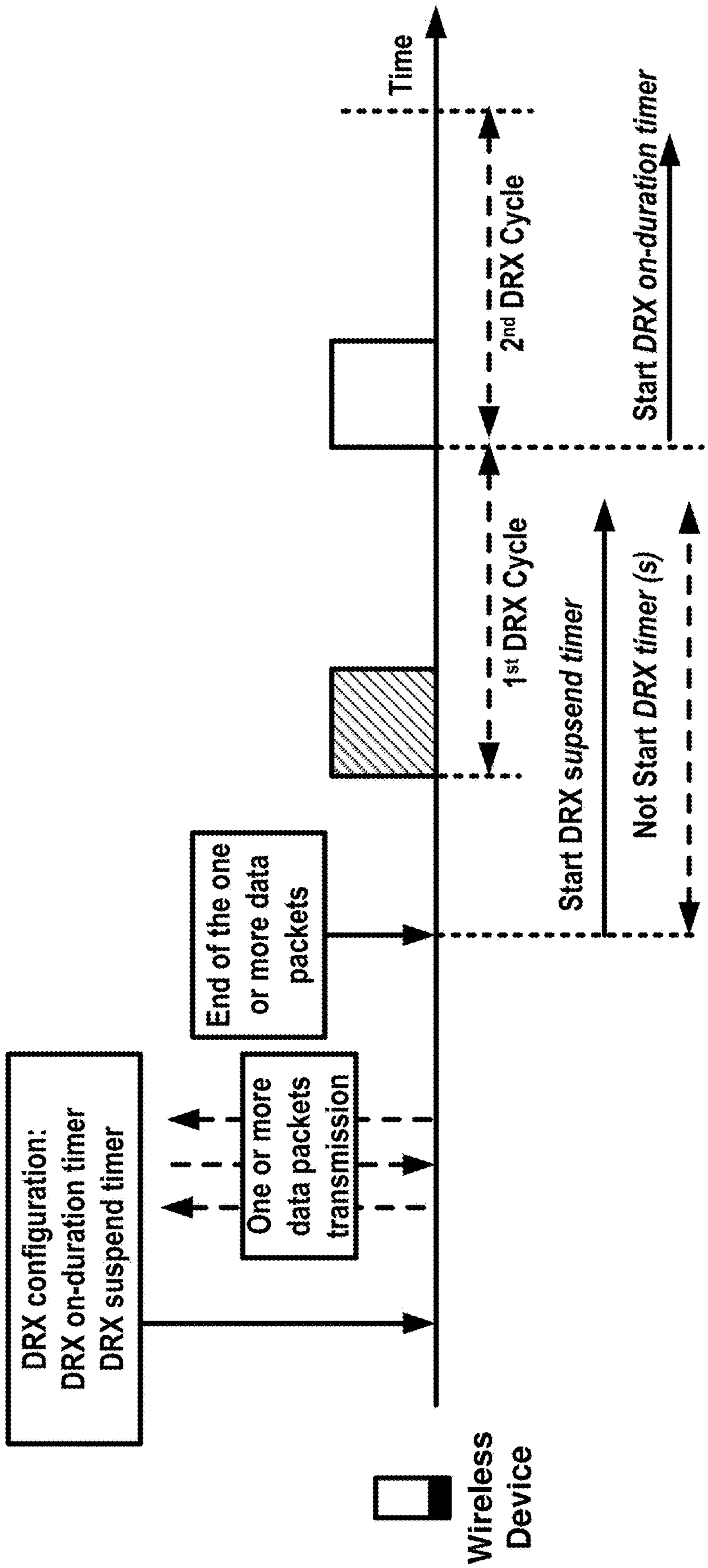

Time
2nd DRX Cycle
Start DRX on-duration timer
1st DRX Cycle
Start DRX supsend timer
Not Start DRX timer (s)
End of the one or more data packets
One or more data packets transmission
DRX configuration:
DRX on-duration timer
DRX suspend timer
Wireless Device

FIG. 33

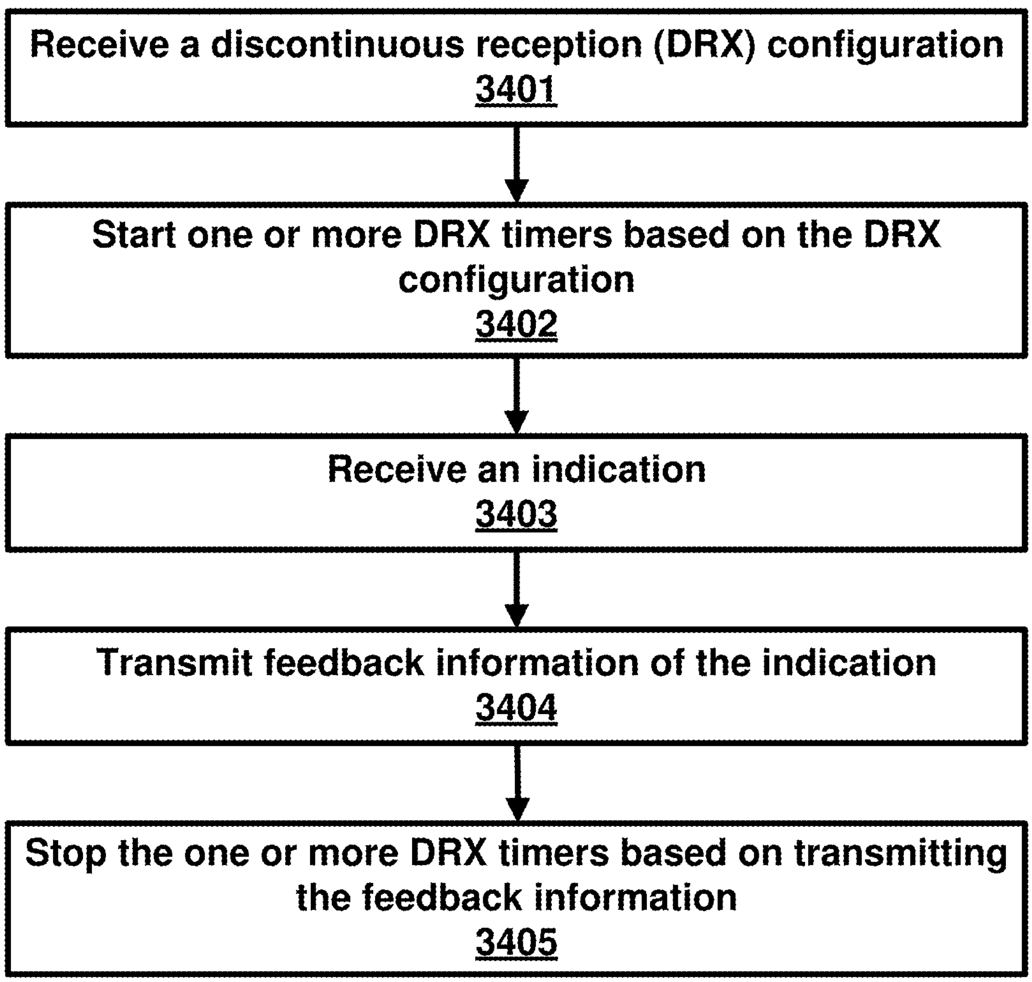

Receive a discontinuous reception (DRX) configuration
3401
Start one or more DRX timers based on the DRX configuration
3402
Receive an indication
3403
Transmit feedback information of the indication
3404
Stop the one or more DRX timers based on transmitting the feedback information
3405

FIG. 34

DISCONTINUOUS RECEPTION FOR EXTENDED REALITY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of International Application No. PCT/US2023/036618, filed Nov. 1, 2023, which claims the benefit of U.S. Provisional Application No. 63/421,826, filed Nov. 2, 2022, all of which are hereby incorporated by reference in their entireties.

BRIEF DESCRIPTION OF THE DRAWINGS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[0023] FIG. **17** illustrates an example of a DRX mechanism.

[0024] FIG. **18** illustrates an example of DCP operation.

[0025] FIG. **19** illustrates an example of alternatives for PDU Set/QoS Flow/DRB mapping.

[0026] FIG. **20** illustrates an example of End of Burst Indication from AS to UPF to RAN.

[0027] FIG. **21** illustrates an example of End of Burst Indication from RAN to UE.

[0028] FIG. **22** illustrates an example implementation based on End of Burst Indication and non-scheduling DCI.

[0029] FIG. **23** illustrates an example implementation based on an End of Burst Indication and a scheduling DCI.

[0030] FIG. **24** illustrates an example implementation based on an End of Burst Indication and a header of a PDU.

[0031] FIG. **25** illustrates an example implementation of DRX timer(s) suspension based on a specific timer.

[0032] FIG. **26** illustrates an example implementation of DRX group(s) and/or Cell Group(s) for End of Burst Indication

[0033] FIG. **27** illustrates an example implementation based on an UL End of Burst Indication

[0034] FIG. **28** illustrates an example implementation of DRX operation based on indication and feedback information.

[0035] FIG. **29** illustrates an example implementation of DRX operation based on End of Burst Indication and feedback information.

[0036] FIG. **30** illustrates an example implementation of DRX operation based on scheduling DCI and feedback information.

[0037] FIG. **31** illustrates an example implementation of DRX operation based on scheduling DCI and feedback information for DL data.

[0038] FIG. **32** illustrates an example implementation of DRX operation based on a suspend timer.

[0039] FIG. **33** illustrates an example implementation of DRX operation based on a DRX suspend timer.

[0040] FIG. **34** illustrates an example implementation of DRX operation.

DETAILED DESCRIPTION

[0041] 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.

[0042] 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.

[0043] 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.

[0044] 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.

[0045] If A and B are sets and every element of A is an element of B, A is called a subset of B. In this specification, only non-empty sets and subsets are considered. For example, possible subsets of B={cell1, cell2} are: {cell1}, {cell2}, and {cell1, cell2}. The phrase "based on" (or equally "based at least on") is indicative that the phrase following the term "based on" is an example of one of a multitude of suitable possibilities that may, or may not, be employed to one or more of the various embodiments. The phrase "in response to" (or equally "in response at least to") is indicative that the phrase following the phrase "in response to" is an example of one of a multitude of suitable possibilities that may, or may not, be employed to one or more of the various embodiments. The phrase "depending on" (or equally "depending at least to") is indicative that the phrase following the phrase "depending on" is an example of one of a multitude of suitable possibilities that may, or may not, be employed to one or more of the various embodiments. The phrase "employing/using" (or equally "employing/using at least") is indicative that the phrase following the phrase "employing/using" is an example of one of a multitude of suitable possibilities that may, or may not, be employed to one or more of the various embodiments.

[0046] The term configured may relate to the capacity of a device whether the device is in an operational or non-operational state. Configured may refer to specific settings in a device that effect the operational characteristics of the device whether the device is in an operational or non-operational state. In other words, the hardware, software, firmware, registers, memory values, and/or the like may be "configured" within a device, whether the device is in an operational or nonoperational state, to provide the device with specific characteristics. Terms such as "a control message to cause in a device" may mean that a control message has parameters that may be used to configure specific characteristics or may be used to implement certain actions in the device, whether the device is in an operational or non-operational state.

[0047] 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.

[0048] 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.

[0049] 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.

[0050] FIG. **1**A illustrates an example of a mobile communication network **100** in which embodiments of the present disclosure may be implemented. The mobile communication network **100** may be, for example, a public land mobile network (PLMN) run by a network operator. As illustrated in FIG. **1**A, the mobile communication network **100** includes a core network (CN) **102**, a radio access network (RAN) **104**, and a wireless device **106**.

[0051] 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.

[0052] 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.

[0053] 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.

[0054] 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).

[0055] 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.

[0056] In addition to three-sector sites, other implementations of base stations are possible. For example, one or more of the base stations in the RAN **104** may be implemented as a sectored site with more or less than three sectors. One or more of the base stations in the RAN **104** may be implemented as an access point, as a baseband processing unit coupled to several remote radio heads (RRHs), and/or as a repeater or relay node used to extend the coverage area of a donor node. A baseband processing unit coupled to RRHs may be part of a centralized or cloud RAN architecture, where the baseband processing unit may be either centralized in a pool of baseband processing units or virtualized. A repeater node may amplify and rebroadcast a radio signal received from a donor node. A relay node may perform the same/similar functions as a repeater node but may decode the radio signal received from the donor node to remove noise before amplifying and rebroadcasting the radio signal.

[0057] 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.

[0058] The Third-Generation Partnership Project (3GPP) was formed in 1998 to provide global standardization of specifications for mobile communication networks similar to the mobile communication network **100** in FIG. **1**A. To date, 3GPP has produced specifications for three generations of mobile networks: a third generation (3G) network known as Universal Mobile Telecommunications System (UMTS), a fourth generation (4G) network known as Long-Term Evolution (LTE), and a fifth generation (5G) network known as 5G System (5GS). Embodiments of the present disclosure are described with reference to the RAN of a 3GPP 5G network, referred to as next-generation RAN (NG-RAN). Embodiments may be applicable to RANs of other mobile communication networks, such as the RAN **104** in FIG. **1**A, the RANs of earlier 3G and 4G networks, and those of future networks yet to be specified (e.g., a 3GPP 6G network). NG-RAN implements 5G radio access technology known as New Radio (NR) and may be provisioned to implement 4G radio access technology or other radio access technologies, including non-3GPP radio access technologies.

[0059] FIG. **1**B illustrates another example mobile communication network **150** in which embodiments of the present disclosure may be implemented. Mobile communication network **150** may be, for example, a PLMN run by a network operator. As illustrated in FIG. **1**B, mobile communication network **150** includes a 5G core network (5G-CN) **152**, an NG-RAN **154**, and UEs **156**A and **156**B (collectively UEs **156**). These components may be implemented and operate in the same or similar manner as corresponding components described with respect to FIG. **1**A.

[0060] 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).

[0061] As illustrated in FIG. **1**B, the 5G-CN **152** includes an Access and Mobility Management Function (AMF) **158**A and a User Plane Function (UPF) **158**B, which are shown as one component AMF/UPF **158** in FIG. **1**B for ease of illustration. The UPF **158**B may serve as a gateway between the NG-RAN **154** and the one or more DNs. The UPF **158**B may perform functions such as packet routing and forwarding, packet inspection and user plane policy rule enforcement, traffic usage reporting, uplink classification to support routing of traffic flows to the one or more DNs, quality of service (QoS) handling for the user plane (e.g., packet filtering, gating, uplink/downlink rate enforcement, and uplink traffic verification), downlink packet buffering, and downlink data notification triggering. The UPF **158**B may serve as an anchor point for intra-/inter-Radio Access Technology (RAT) mobility, an external protocol (or packet) data unit (PDU) session point of interconnect to the one or more DNs, and/or a branching point to support a multi-homed PDU session. The UEs **156** may be configured to receive services through a PDU session, which is a logical connection between a UE and a DN.

[0062] The AMF **158**A may perform functions such as Non-Access Stratum (NAS) signaling termination, NAS signaling security, Access Stratum (AS) security control, inter-CN node signaling for mobility between 3GPP access networks, idle mode UE reachability (e.g., control and execution of paging retransmission), registration area management, intra-system and inter-system mobility support, access authentication, access authorization including checking of roaming rights, mobility management control (subscription and policies), network slicing support, and/or session management function (SMF) selection. NAS may refer to the functionality operating between a CN and a UE, and AS may refer to the functionality operating between the UE and a RAN.

[0063] The 5G-CN **152** may include one or more additional network functions that are not shown in FIG. **1**B for the sake of clarity. For example, the 5G-CN **152** may include one or more of a Session Management Function (SMF), an NR Repository Function (NRF), a Policy Control Function (PCF), a Network Exposure Function (NEF), a Unified Data Management (UDM), an Application Function (AF), and/or an Authentication Server Function (AUSF).

[0064] The NG-RAN **154** may connect the 5G-CN **152** to the UEs **156** through radio communications over the air interface. The NG-RAN **154** may include one or more gNBs, illustrated as gNB **160**A and gNB **160**B (collectively gNBs **160**) and/or one or more ng-eNBs, illustrated as ng-eNB **162**A and ng-eNB **162**B (collectively ng-eNBs **162**). The gNBs **160** and ng-eNBs **162** may be more generically referred to as base stations. The gNBs **160** and ng-eNBs **162** may include one or more sets of antennas for communicating with the UEs **156** over an air interface. For example, one or more of the gNBs **160** and/or one or more of the ng-eNBs **162** may include three sets of antennas to respectively control three cells (or sectors). Together, the cells of the gNBs **160** and the ng-eNBs **162** may provide radio coverage to the UEs **156** over a wide geographic area to support UE mobility.

[0065] As shown in FIG. **1**B, the gNBs **160** and/or the ng-eNBs **162** may be connected to the 5G-CN **152** by means of an NG interface and to other base stations by an Xn interface. The NG and Xn interfaces may be established using direct physical connections and/or indirect connections over an underlying transport network, such as an internet protocol (IP) transport network. The gNBs **160** and/or the ng-eNBs **162** may be connected to the UEs **156** by means of a Uu interface. For example, as illustrated in FIG. **1**B, gNB **160**A may be connected to the UE **156**A by means of a Uu interface. The NG, Xn, and Uu interfaces are associated with a protocol stack. The protocol stacks associated with the interfaces may be used by the network elements in FIG. **1**B to exchange data and signaling messages and may include two planes: a user plane and a control plane. The user plane may handle data of interest to a user. The control plane may handle signaling messages of interest to the network elements.

[0066] The gNBs **160** and/or the ng-eNBs **162** may be connected to one or more AMF/UPF functions of the 5G-CN **152**, such as the AMF/UPF **158**, by means of one or more NG interfaces. For example, the gNB **160**A may be connected to the UPF **158**B of the AMF/UPF **158** by means of an NG-User plane (NG-U) interface. The NG-U interface may provide delivery (e.g., non-guaranteed delivery) of user plane PDUs between the gNB **160**A and the UPF **158**B. The gNB **160**A may be connected to the AMF **158**A by means of an NG-Control plane (NG-C) interface. The NG-C interface may provide, for example, NG interface management, UE context management, UE mobility management, transport of NAS messages, paging, PDU session management, and configuration transfer and/or warning message transmission.

[0067] The gNBs **160** may provide NR user plane and control plane protocol terminations towards the UEs **156** over the Uu interface. For example, the gNB **160**A may provide NR user plane and control plane protocol terminations toward the UE **156**A over a Uu interface associated with a first protocol stack. The ng-eNBs **162** may provide Evolved UMTS Terrestrial Radio Access (E-UTRA) user plane and control plane protocol terminations towards the UEs **156** over a Uu interface, where E-UTRA refers to the 3GPP 4G radio-access technology. For example, the ng-eNB **162**B may provide E-UTRA user plane and control plane protocol terminations towards the UE **156**B over a Uu interface associated with a second protocol stack.

[0068] The 5G-CN **152** was described as being configured to handle NR and 4G radio accesses. It will be appreciated by one of ordinary skill in the art that it may be possible for NR to connect to a 4G core network in a mode known as "non-standalone operation." In non-standalone operation, a 4G core network is used to provide (or at least support) control-plane functionality (e.g., initial access, mobility, and paging). Although only one AMF/UPF **158** is shown in FIG. **1**B, one gNB or ng-eNB may be connected to multiple AMF/UPF nodes to provide redundancy and/or to load share across the multiple AMF/UPF nodes.

[0069] As discussed, an interface (e.g., Uu, Xn, and NG interfaces) between the network elements in FIG. **1**B may be associated with a protocol stack that the network elements use to exchange data and signaling messages. A protocol stack may include two planes: a user plane and a control plane. The user plane may handle data of interest to a user, and the control plane may handle signaling messages of interest to the network elements.

[0070] FIG. **2**A and FIG. **2**B respectively illustrate examples of NR user plane and NR control plane protocol stacks for the Uu interface that lies between a UE **210** and a gNB **220**. The protocol stacks illustrated in FIG. **2**A and FIG. **2**B may be the same or similar to those used for the Uu interface between, for example, the UE **156**A and the gNB **160**A shown in FIG. **1**B.

[0071] FIG. **2**A illustrates a NR user plane protocol stack comprising five layers implemented in the UE **210** and the gNB **220**. At the bottom of the protocol stack, physical layers (PHYs) **211** and **221** may provide transport services to the higher layers of the protocol stack and may correspond to layer 1 of the Open Systems Interconnection (OSI) model. The next four protocols above PHYs **211** and **221** comprise media access control layers (MACs) **212** and **222**, radio link control layers (RLCs) **213** and **223**, packet data convergence protocol layers (PDCPs) **214** and **224**, and service data application protocol layers (SDAPs) **215** and **225**. Together, these four protocols may make up layer 2, or the data link layer, of the OSI model.

[0072] FIG. **3** illustrates an example of services provided between protocol layers of the NR user plane protocol stack. Starting from the top of FIG. **2**A and FIG. **3**, the SDAPs **215** and **225** may perform QoS flow handling. The UE **210** may receive services through a PDU session, which may be a logical connection between the UE **210** and a DN. The PDU session may have one or more QoS flows. A UPF of a CN (e.g., the UPF **158**B) may map IP packets to the one or more QoS flows of the PDU session based on QoS requirements (e.g., in terms of delay, data rate, and/or error rate). The SDAPs **215** and **225** may perform mapping/de-mapping between the one or more QoS flows and one or more data radio bearers. The mapping/de-mapping between the QoS flows and the data radio bearers may be determined by the SDAP **225** at the gNB **220**. The SDAP **215** at the UE **210** may be informed of the mapping between the QoS flows and the data radio bearers through reflective mapping or control signaling received from the gNB **220**. For reflective mapping, the SDAP **225** at the gNB **220** may mark the downlink packets with a QoS flow indicator (QFI), which may be observed by the SDAP **215** at the UE **210** to determine the mapping/de-mapping between the QoS flows and the data radio bearers.

[0073] 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.

[0074] Packet duplication may be useful for services that require high reliability.

[0075] 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.

[0076] The RLCs **213** and **223** may perform segmentation, retransmission through Automatic Repeat Request (ARQ), and removal of duplicate data units received from MACs **212** and **222**, respectively. The RLCs **213** and **223** may support three transmission modes: transparent mode (TM); unacknowledged mode (UM); and acknowledged mode (AM). Based on the transmission mode an RLC is operating, the RLC may perform one or more of the noted functions. The RLC configuration may be per logical channel with no dependency on numerologies and/or Transmission Time Interval (TTI) durations. As shown in FIG. **3**, the RLCs **213** and **223** may provide RLC channels as a service to PDCPs **214** and **224**, respectively.

[0077] 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**.

[0078] 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**.

[0079] FIG. **4**A illustrates an example downlink data flow through the NR user plane protocol stack. FIG. **4**A illustrates a downlink data flow of three IP packets (n, n+1, and m) through the NR user plane protocol stack to generate two TBs at the gNB **220**. An uplink data flow through the NR user plane protocol stack may be similar to the downlink data flow depicted in FIG. **4**A.

[0080] The downlink data flow of FIG. **4**A begins when SDAP **225** receives the three IP packets from one or more QoS flows and maps the three packets to radio bearers. In FIG. **4**A, the SDAP **225** maps IP packets n and n+1 to a first radio bearer **402** and maps IP packet m to a second radio bearer **404**. An SDAP header (labeled with an "H" in FIG. **4**A) is added to an IP packet. The data unit from/to a higher protocol layer is referred to as a service data unit (SDU) of the lower protocol layer and the data unit to/from a lower protocol layer is referred to as a protocol data unit (PDU) of the higher protocol layer. As shown in FIG. **4**A, the data unit from the SDAP **225** is an SDU of lower protocol layer PDCP **224** and is a PDU of the SDAP **225**.

[0081] The remaining protocol layers in FIG. **4**A may perform their associated functionality (e.g., with respect to FIG. **3**), add corresponding headers, and forward their respective outputs to the next lower layer. For example, the PDCP **224** may perform IP-header compression and ciphering and forward its output to the RLC **223**. The RLC **223** may optionally perform segmentation (e.g., as shown for IP packet m in FIG. **4**A) and forward its output to the MAC **222**. The MAC **222** may multiplex a number of RLC PDUs and may attach a MAC subheader to an RLC PDU to form a transport block. In NR, the MAC subheaders may be distributed across the MAC PDU, as illustrated in FIG. **4**A. In LTE, the MAC subheaders may be entirely located at the beginning of the MAC PDU. The NR MAC PDU structure may reduce processing time and associated latency because the MAC PDU subheaders may be computed before the full MAC PDU is assembled.

[0082] FIG. **4**B illustrates an example format of a MAC subheader in a MAC PDU. The MAC subheader includes: an SDU length field for indicating the length (e.g., in bytes) of the MAC SDU to which the MAC subheader corresponds; a logical channel identifier (LCID) field for identifying the logical channel from which the MAC SDU originated to aid in the demultiplexing process; a flag (F) for indicating the size of the SDU length field; and a reserved bit (R) field for future use.

[0083] FIG. **4**B further illustrates MAC control elements (CEs) inserted into the MAC PDU by a MAC, such as MAC **212** or MAC **222**. For example, FIG. **4**B illustrates two MAC CEs inserted into the MAC PDU. MAC CEs may be inserted at the beginning of a MAC PDU for downlink transmissions (as shown in FIG. **4**B) and at the end of a MAC PDU for uplink transmissions. MAC CEs may be used for in-band control signaling.

[0084] 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.

[0085] 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.

[0086] FIG. **5**A and FIG. **5**B 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:

- **[0087]** 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;
- **[0088]** 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;
- **[0089]** a common control channel (CCCH) for carrying control messages together with random access;
- **[0090]** a dedicated control channel (DCCH) for carrying control messages to/from a specific the UE to configure the UE; and
- **[0091]** a dedicated traffic channel (DTCH) for carrying user data to/from a specific the UE.

[0092] 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:

[0093] a paging channel (PCH) for carrying paging messages that originated from the PCCH;

[0094] a broadcast channel (BCH) for carrying the MIB from the BCCH;

[0095] a downlink shared channel (DL-SCH) for carrying downlink data and signaling messages, including the SIBs from the BCCH;

[0096] an uplink shared channel (UL-SCH) for carrying uplink data and signaling messages; and

[0097] a random access channel (RACH) for allowing a UE to contact the network without any prior scheduling.

[0098] 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:

[0099] a physical broadcast channel (PBCH) for carrying the MIB from the BCH;

[0100] 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;

[0101] 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;

[0102] 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;

[0103] 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

[0104] a physical random access channel (PRACH) for random access.

[0105] 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. **5**A and FIG. **5**B, 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.

[0106] FIG. **2**B illustrates an example NR control plane protocol stack. As shown in FIG. **2**B, the NR control plane protocol stack may use the same/similar first four protocol layers as the example NR user plane protocol stack. These four protocol layers include the PHYs **211** and **221**, the MACs **212** and **222**, the RLCs **213** and **223**, and the PDCPs **214** and **224**. Instead of having the SDAPs **215** and **225** at the top of the stack as in the NR user plane protocol stack, the NR control plane stack has radio resource controls (RRCs) **216** and **226** and NAS protocols **217** and **237** at the top of the NR control plane protocol stack.

[0107] The NAS protocols **217** and **237** may provide control plane functionality between the UE **210** and the AMF **230** (e.g., the AMF **158**A) or, more generally, between the UE **210** and the CN. The NAS protocols **217** and **237** may provide control plane functionality between the UE **210** and the AMF **230** via signaling messages, referred to as NAS messages. There is no direct path between the UE **210** and the AMF **230** through which the NAS messages can be transported. The NAS messages may be transported using the AS of the Uu and NG interfaces. NAS protocols **217** and **237** may provide control plane functionality such as authentication, security, connection setup, mobility management, and session management.

[0108] 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.

[0109] FIG. **6** is an example diagram showing RRC state transitions of a UE. The UE may be the same or similar to the wireless device **106** depicted in FIG. **1**A, the UE **210** depicted in FIG. **2**A and FIG. **2**B, or any other wireless device described in the present disclosure. As illustrated in FIG. **6**, a UE may be in at least one of three RRC states: RRC connected **602** (e.g., RRC_CONNECTED), RRC idle **604** (e.g., RRC_IDLE), and RRC inactive **606** (e.g., RRC_INACTIVE).

[0110] In RRC connected **602**, the UE has an established RRC context and may have at least one RRC connection with a base station. The base station may be similar to one of the one or more base stations included in the RAN **104** depicted in FIG. **1**A, one of the gNBs **160** or ng-eNBs **162** depicted in FIG. **1**B, the gNB **220** depicted in FIG. **2**A and FIG. **2**B, or any other base station described in the present disclosure. The base station with which the UE is connected may have the RRC context for the UE. The RRC context, referred to as the UE context, may comprise parameters for communication between the UE and the base station. These parameters may include, for example: one or more AS contexts; one or more radio link configuration parameters; bearer configuration information (e.g., relating to a data radio bearer, signaling radio bearer, logical channel, QoS flow, and/or PDU session); security information; and/or PHY, MAC, RLC, PDCP, and/or SDAP layer configuration information. While in RRC connected **602**, mobility of the UE may be managed by the RAN (e.g., the RAN **104** or the NG-RAN **154**). The UE may measure the signal levels (e.g., reference signal levels) from a serving cell and neighboring cells and report these measurements to the base station currently serving the UE. The UE's serving base station may request a handover to a cell of one of the neighboring base stations based on the reported measurements. The RRC state may transition from RRC connected **602** to RRC idle **604** through a connection release procedure **608** or to RRC inactive **606** through a connection inactivation procedure **610**.

[0111] 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.

[0112] 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**.

[0113] 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).

[0114] 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.

[0115] RAN areas may be used to track the UE at the RAN level. For a UE in RRC inactive **606** state, the UE may be assigned a RAN notification area. A RAN notification area may comprise one or more cell identities, a list of RAIs, or a list of TAIs. In an example, a base station may belong to one or more RAN notification areas. In an example, a cell may belong to one or more RAN notification areas. If the UE moves, through cell reselection, to a cell not included in the RAN notification area assigned to the UE, the UE may perform a notification area update with the RAN to update the UE's RAN notification area.

[0116] A base station storing an RRC context for a UE or a last serving base station of the UE may be referred to as an anchor base station. An anchor base station may maintain an RRC context for the UE at least during a period of time that the UE stays in a RAN notification area of the anchor base station and/or during a period of time that the UE stays in RRC inactive **606**.

[0117] A gNB, such as gNBs **160** in FIG. **1**B, may be split in two parts: a central unit (gNB-CU), and one or more distributed units (gNB-DU). A gNB-CU may be coupled to one or more gNB-DUs using an F1 interface. The gNB-CU may comprise the RRC, the PDCP, and the SDAP. A gNB-DU may comprise the RLC, the MAC, and the PHY.

[0118] In NR, the physical signals and physical channels (discussed with respect to FIG. **5**A and FIG. **5**B) may be mapped onto orthogonal frequency divisional multiplexing (OFDM) symbols. OFDM is a multicarrier communication scheme that transmits data over F orthogonal subcarriers (or tones). Before transmission, the data may be mapped to a series of complex symbols (e.g., M-quadrature amplitude modulation (M-QAM) or M-phase shift keying (M-PSK) symbols), referred to as source symbols, and divided into F parallel symbol streams. The F parallel symbol streams may be treated as though they are in the frequency domain and used as inputs to an Inverse Fast Fourier Transform (IFFT) block that transforms them into the time domain. The IFFT block may take in F source symbols at a time, one from each of the F parallel symbol streams, and use each source symbol to modulate the amplitude and phase of one of F sinusoidal basis functions that correspond to the F orthogonal subcarriers. The output of the IFFT block may be F time-domain samples that represent the summation of the F orthogonal subcarriers. The F time-domain samples may form a single OFDM symbol. After some processing (e.g., addition of a cyclic prefix) and up-conversion, an OFDM symbol provided by the IFFT block may be transmitted over the air interface on a carrier frequency. The F parallel symbol streams may be mixed using an FFT block before being processed by the IFFT block. This operation produces Discrete Fourier Transform (DFT)-precoded OFDM symbols and may be used by UEs in the uplink to reduce the peak to average power ratio (PAPR). Inverse processing may be performed on the OFDM symbol at a receiver using an FFT block to recover the data mapped to the source symbols.

[0119] FIG. **7** illustrates an example configuration of an NR frame into which OFDM symbols are grouped. An NR frame may be identified by a system frame number (SFN). The SFN may repeat with a period of 1024 frames. As illustrated, one NR frame may be 10 milliseconds (ms) in duration and may include 10 subframes that are 1 ms in duration. A subframe may be divided into slots that include, for example, 14 OFDM symbols per slot.

[0120] The duration of a slot may depend on the numerology used for the OFDM symbols of the slot. In NR, a flexible numerology is supported to accommodate different cell deployments (e.g., cells with carrier frequencies below 1 GHz up to cells with carrier frequencies in the mm-wave range). A numerology may be defined in terms of subcarrier spacing and cyclic prefix duration. For a numerology in NR, subcarrier spacings may be scaled up by powers of two from a baseline subcarrier spacing of 15 kHz, and cyclic prefix durations may be scaled down by powers of two from a baseline cyclic prefix duration of 4.7 μs. For example, NR defines numerologies with the following subcarrier spacing/cyclic prefix duration combinations: 15 kHz/4.7 μs; 30 kHz/2.3 μs; 60 kHz/1.2 μs; 120 kHz/0.59 μs; and 240 kHz/0.29 μs.

[0121] 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.

[0122] FIG. **8** illustrates an example configuration of a slot in the time and frequency domain for an NR carrier. The slot includes resource elements (REs) and resource blocks (RBs). An RE is the smallest physical resource in NR. An RE spans one OFDM symbol in the time domain by one subcarrier in the frequency domain as shown in FIG. **8**. An RB spans twelve consecutive REs in the frequency domain as shown in FIG. **8**. An NR carrier may be limited to a width of **275** RBs or 275×12=3300 subcarriers. Such a limitation, if used, may limit the NR carrier to 50, 100, 200, and 400 MHz for subcarrier spacings of 15, 30, 60, and 120 kHz, respectively, where the 400 MHz bandwidth may be set based on a 400 MHz per carrier bandwidth limit.

[0123] 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.

[0124] 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.

[0125] NR defines bandwidth parts (BWPs) to support UEs not capable of receiving the full carrier bandwidth and to support bandwidth adaptation. In an example, a BWP may be defined by a subset of contiguous RBs on a carrier. A UE may be configured (e.g., via RRC layer) with one or more downlink BWPs and one or more uplink BWPs per serving cell (e.g., up to four downlink BWPs and up to four uplink BWPs per serving cell). At a given time, one or more of the configured BWPs for a serving cell may be active. These one or more BWPs may be referred to as active BWPs of the serving cell. When a serving cell is configured with a secondary uplink carrier, the serving cell may have one or more first active BWPs in the uplink carrier and one or more second active BWPs in the secondary uplink carrier.

[0126] 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.

[0127] For a downlink BWP in a set of configured downlink BWPs on a primary cell (PCell), a base station may configure a UE with one or more control resource sets (CORESETs) for at least one search space. A search space is a set of locations in the time and frequency domains where the UE may find control information. The search space may be a UE-specific search space or a common search space (potentially usable by a plurality of UEs). For example, a base station may configure a UE with a common search space, on a PCell or on a primary secondary cell (PSCell), in an active downlink BWP.

[0128] 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).

[0129] 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.

[0130] 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.

[0131] 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.

[0132] 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).

[0133] 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.

[0134] 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.

[0135] 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.

[0136] 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.

[0137] FIG. **10**A illustrates the three CA configurations with two CCs. In the intraband, contiguous configuration **1002**, the two CCs are aggregated in the same frequency band (frequency band A) and are located directly adjacent to each other within the frequency band. In the intraband, non-contiguous configuration **1004**, the two CCs are aggregated in the same frequency band (frequency band A) and are separated in the frequency band by a gap. In the interband configuration **1006**, the two CCs are located in frequency bands (frequency band A and frequency band B).

[0138] 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.

[0139] When CA is used, one of the aggregated cells for a UE may be referred to as a primary cell (PCell). The PCell may be the serving cell that the UE initially connects to at RRC connection establishment, reestablishment, and/or handover. The PCell may provide the UE with NAS mobility information and the security input. UEs may have different PCells. In the downlink, the carrier corresponding to the PCell may be referred to as the downlink primary CC (DL PCC). In the uplink, the carrier corresponding to the PCell may be referred to as the uplink primary CC (UL PCC). The other aggregated cells for the UE may be referred to as secondary cells (SCells). In an example, the SCells may be configured after the PCell is configured for the UE. For example, an SCell may be configured through an RRC Connection Reconfiguration procedure. In the downlink, the carrier corresponding to an SCell may be referred to as a downlink secondary CC (DL SCC). In the uplink, the carrier corresponding to the SCell may be referred to as the uplink secondary CC (UL SCC).

[0140] Configured SCells for a UE may be activated and deactivated based on, for example, traffic and channel conditions. Deactivation of an SCell may mean that PDCCH and PDSCH reception on the SCell is stopped and PUSCH, SRS, and CQI transmissions on the SCell are stopped. Configured SCells may be activated and deactivated using a MAC CE with respect to FIG. **4**B. For example, a MAC CE may use a bitmap (e.g., one bit per SCell) to indicate which SCells (e.g., in a subset of configured SCells) for the UE are activated or deactivated. Configured SCells may be deactivated in response to an expiration of an SCell deactivation timer (e.g., one SCell deactivation timer per SCell).

[0141] 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.

[0142] FIG. **10**B illustrates an example of how aggregated cells may be configured into one or more PUCCH groups. A

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

[0143] 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.

[0144] 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.

[0145] In the downlink, a base station may transmit (e.g., unicast, multicast, and/or broadcast) one or more Reference Signals (RSs) to a UE (e.g., PSS, SSS, CSI-RS, DMRS, and/or PT-RS, as shown in FIG. **5**A). In the uplink, the UE may transmit one or more RSs to the base station (e.g., DMRS, PT-RS, and/or SRS, as shown in FIG. **5**B). The PSS and the SSS may be transmitted by the base station and used by the UE to synchronize the UE to the base station. The PSS and the SSS may be provided in a synchronization signal (SS)/physical broadcast channel (PBCH) block that includes the PSS, the SSS, and the PBCH. The base station may periodically transmit a burst of SS/PBCH blocks.

[0146] FIG. **11**A illustrates an example of an SS/PBCH block's structure and location. A burst of SS/PBCH blocks may include one or more SS/PBCH blocks (e.g., 4 SS/PBCH blocks, as shown in FIG. **11**A). Bursts may be transmitted periodically (e.g., every 2 frames or 20 ms). A burst may be restricted to a half-frame (e.g., a first half-frame having a duration of 5 ms). It will be understood that FIG. **11**A is an example, and that these parameters (number of SS/PBCH blocks per burst, periodicity of bursts, position of burst within the frame) may be configured based on, for example: a carrier frequency of a cell in which the SS/PBCH block is transmitted; a numerology or subcarrier spacing of the cell; a configuration by the network (e.g., using RRC signaling); or any other suitable factor. In an example, the UE may assume a subcarrier spacing for the SS/PBCH block based on the carrier frequency being monitored, unless the radio network configured the UE to assume a different subcarrier spacing.

[0147] The SS/PBCH block may span one or more OFDM symbols in the time domain (e.g., 4 OFDM symbols, as shown in the example of FIG. **11**A) and may span one or more subcarriers in the frequency domain (e.g., 240 contiguous subcarriers). The PSS, the SSS, and the PBCH may have a common center frequency. The PSS may be transmitted first and may span, for example, 1 OFDM symbol and 127 subcarriers. The SSS may be transmitted after the PSS (e.g., two symbols later) and may span 1 OFDM symbol and 127 subcarriers. The PBCH may be transmitted after the PSS (e.g., across the next 3 OFDM symbols) and may span 240 subcarriers.

[0148] 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.

[0149] 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.

[0150] 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.

[0151] 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.

[0152] 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.

[0153] 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.

[0154] 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.

[0155] 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.

[0156] 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.

[0157] 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.

[0158] 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.

[0159] 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).

[0160] 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.

[0161] 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.

[0162] 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.

[0163] 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.

[0164] 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.

[0165] 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.

[0166] 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.

[0167] 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.

[0168] 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.

[0169] 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.

[0170] 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.

[0171] FIG. **11**B illustrates an example of channel state information reference signals (CSI-RSs) that are mapped in the time and frequency domains. A square shown in FIG. **11**B may span a resource block (RB) within a bandwidth of a cell. A base station may transmit one or more RRC messages comprising CSI-RS resource configuration parameters indicating one or more CSI-RSs. One or more of the following parameters may be configured by higher layer signaling (e.g., RRC and/or MAC signaling) for a CSI-RS resource configuration: a CSI-RS resource configuration identity, a number of CSI-RS ports, a CSI-RS configuration (e.g., symbol and resource element (RE) locations in a subframe), a CSI-RS subframe configuration (e.g., subframe location, offset, and periodicity in a radio frame), a CSI-RS power parameter, a CSI-RS sequence parameter, a code division multiplexing (CDM) type parameter, a frequency density, a transmission comb, quasi co-location (QCL) parameters (e.g., QCL-scramblingidentity, crs-portscount, mbsfn-subframeconfiglist, csi-rs-configZPid, qcl-csi-rs-configNZPid), and/or other radio resource parameters.

[0172] The three beams illustrated in FIG. **11**B may be configured for a UE in a UE-specific configuration. Three beams are illustrated in FIG. **11**B (beam #1, beam #2, and beam #3), more or fewer beams may be configured. Beam #1 may be allocated with CSI-RS **1101** that may be transmitted in one or more subcarriers in an RB of a first symbol. Beam #2 may be allocated with CSI-RS **1102** that may be transmitted in one or more subcarriers in an RB of a second symbol. Beam #3 may be allocated with CSI-RS **1103** that may be transmitted in one or more subcarriers in an RB of a third symbol. By using frequency division multiplexing (FDM), a base station may use other subcarriers in a same RB (for example, those that are not used to transmit CSI-RS **1101**) to transmit another CSI-RS associated with a beam for another UE. By using time domain multiplexing (TDM), beams used for the UE may be configured such that beams for the UE use symbols from beams of other UEs.

[0173] CSI-RSs such as those illustrated in FIG. **11**B (e.g., CSI-RS **1101**, **1102**, **1103**) may be transmitted by the base station and used by the UE for one or more measurements. For example, the UE may measure a reference signal received power (RSRP) of configured CSI-RS resources. The base station may configure the UE with a reporting configuration and the UE may report the RSRP measurements to a network (for example, via one or more base stations) based on the reporting configuration. In an example, the base station may determine, based on the reported measurement results, one or more transmission configuration indication (TCI) states comprising a number of reference signals. In an example, the base station may indicate one or more TCI states to the UE (e.g., via RRC signaling, a MAC CE, and/or a DCI). The UE may receive a downlink transmission with a receive (Rx) beam determined based on the one or more TCI states. In an example, the UE may or may not have a capability of beam correspondence. If the UE has the capability of beam correspondence, the UE may determine a spatial domain filter of a transmit (Tx) beam based on a spatial domain filter of the corresponding Rx beam. If the UE does not have the capability of beam correspondence, the UE may perform an uplink beam selection procedure to determine the spatial domain filter of the Tx beam. The UE may perform the uplink beam selection procedure based on one or more sounding reference signal (SRS) resources configured to the UE by the base station. The base station may select and indicate uplink beams for the UE based on measurements of the one or more SRS resources transmitted by the UE.

[0174] 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).

[0175] FIG. **12**A illustrates examples of three downlink beam management procedures: P**1**, P**2**, and P**3**. Procedure P**1** may enable a UE measurement on transmit (Tx) beams of a transmission reception point (TRP) (or multiple TRPs), e.g., to support a selection of one or more base station Tx beams and/or UE Rx beams (shown as ovals in the top row and bottom row, respectively, of P**1**). Beamforming at a TRP may comprise a Tx beam sweep for a set of beams (shown, in the top rows of P**1** and P**2**, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). Beamforming at a UE may comprise an Rx beam sweep for a set of beams (shown, in the bottom rows of P**1** and P**3**, as ovals rotated in a clockwise direction indicated by the dashed arrow). Procedure P**2** may be used to enable a UE measurement on Tx beams of a TRP (shown, in the top row of P**2**, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). The UE and/or the base station may perform procedure P**2** using a smaller set of beams than is used in procedure P**1**, or using narrower beams than the beams used in procedure P**1**. This may be referred to as beam refinement. The UE may perform procedure P**3** for Rx beam determination by using the same Tx beam at the base station and sweeping an Rx beam at the UE.

[0176] FIG. **12**B illustrates examples of three uplink beam management procedures: U**1**, U**2**, and U**3**. Procedure U**1** may be used to enable a base station to perform a measurement on Tx beams of a UE, e.g., to support a selection of one or more UE Tx beams and/or base station Rx beams (shown as ovals in the top row and bottom row, respectively, of U**1**). Beamforming at the UE may include, e.g., a Tx beam sweep from a set of beams (shown in the bottom rows of U**1** and U**3** as ovals rotated in a clockwise direction indicated by the dashed arrow). Beamforming at the base station may include, e.g., an Rx beam sweep from a set of beams (shown, in the top rows of U**1** and U**2**, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). Procedure U**2** may be used to enable the base station to adjust its Rx beam when the UE uses a fixed Tx beam. The UE and/or the base station may perform procedure U**2** using a smaller set of beams than is used in procedure P**1**, or using narrower beams than the beams used in procedure P**1**. This may be referred to as beam refinement The UE may perform procedure U3 to adjust its Tx beam when the base station uses a fixed Rx beam.

[0177] 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).

[0178] 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.

[0179] 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.

[0180] FIG. **13**A illustrates a four-step contention-based random access procedure. Prior to initiation of the procedure, a base station may transmit a configuration message **1310** to the UE. The procedure illustrated in FIG. **13**A comprises transmission of four messages: a Msg 1 **1311**, a Msg 2 **1312**, a Msg 3 **1313**, and a Msg 4 **1314**. The Msg 1 **1311** may include and/or be referred to as a preamble (or a random access preamble). The Msg 2 **1312** may include and/or be referred to as a random access response (RAR).

[0181] 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-configGenera/); 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**.

[0182] 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-Config/ndex). 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.

[0183] 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 **31313**; 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).

[0184] 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-ThresholdCS1-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.

[0185] 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.

[0186] 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).

[0187] 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 Typel-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).

[0188] 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:

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

where s_id may be an index of a first OFDM symbol of the PRACH occasion (e.g., $0 \leq s\_id < 14$), t_id may be an index of a first slot of the PRACH occasion in a system frame (e.g., $0 \leq t\_id < 80$), f_id may be an index of the PRACH occasion in the frequency domain (e.g., $0 \leq f\_id < 8$), and ul_carrier_id may be a UL carrier used for a preamble transmission (e.g., 0 for an NUL carrier, and 1 for an SUL carrier).

[0189] The UE may transmit the Msg 3 **1313** in response to a successful reception of the Msg 2 **1312** (e.g., using resources identified in the Msg 2 **1312**). The Msg 3 **1313** may be used for contention resolution in, for example, the contention-based random access procedure illustrated in FIG. **13**A. In some scenarios, a plurality of UEs may transmit a same preamble to a base station and the base station may provide an RAR that corresponds to a UE. Collisions may occur if the plurality of UEs interpret the RAR as corresponding to themselves. Contention resolution (e.g., using the Msg 3 **1313** and the Msg 4 **1314**) may be used to increase the likelihood that the UE does not incorrectly use an identity of another the UE. To perform contention resolution, the UE may include a device identifier in the Msg 3 **1313** (e.g., a C-RNTI if assigned, a TC-RNTI included in the Msg 2 **1312**, and/or any other suitable identifier).

[0190] The Msg 4 **1314** may be received after or in response to the transmitting of the Msg **31313**. 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 **31313** (e.g., if the UE is in an RRC_IDLE state or not otherwise connected to the base station), Msg **41314** 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.

[0191] 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 **31313**) 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).

[0192] FIG. **13**B illustrates a two-step contention-free random access procedure. Similar to the four-step contention-based random access procedure illustrated in FIG. **13**A, a base station may, prior to initiation of the procedure, transmit a configuration message **1320** to the UE. The configuration message **1320** may be analogous in some respects to the configuration message **1310**. The procedure illustrated in FIG. **13**B comprises transmission of two messages: a Msg 1 **1321** and a Msg 2 **1322**. The Msg 1 **1321** and the Msg 2 **1322** may be analogous in some respects to the Msg 1 **1311** and a Msg 2 **1312** illustrated in FIG. **13**A, respectively. As will be understood from FIGS. **13**A and **13**B, the contention-free random access procedure may not include messages analogous to the Msg **31313** and/or the Msg 4 **1314**.

[0193] The contention-free random access procedure illustrated in FIG. **13**B may be initiated for a beam failure recovery, other SI request, SCell addition, and/or handover. For example, a base station may indicate or assign to the UE the preamble to be used for the Msg 1 **1321**. The UE may receive, from the base station via PDCCH and/or RRC, an indication of a preamble (e.g., ra-Preamble/ndex).

[0194] 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., recoverySearchSpaceld). The UE may monitor for a PDCCH transmission addressed to a Cell RNTI (C-RNTI) on the search space. In the contention-free random access procedure illustrated in FIG. **13**B, the UE may determine that a random access procedure successfully completes after or in response to transmission of Msg 1 **1321** and reception of a corresponding Msg 2 **1322**. The UE may determine that a random access procedure successfully completes, for example, if a PDCCH transmission is addressed to a C-RNTI. The UE may determine that a random access procedure successfully completes, for example, if the UE receives an RAR comprising a preamble identifier corresponding to a preamble transmitted by the UE and/or the RAR comprises a MAC sub-PDU with the preamble identifier. The UE may determine the response as an indication of an acknowledgement for an SI request.

[0195] FIG. **13**C illustrates another two-step random access procedure. Similar to the random access procedures illustrated in FIGS. **13**A and **13**B, a base station may, prior to initiation of the procedure, transmit a configuration message **1330** to the UE. The configuration message **1330** may be analogous in some respects to the configuration message **1310** and/or the configuration message **1320**. The procedure illustrated in FIG. **13**C comprises transmission of two messages: a Msg A **1331** and a Msg B **1332**.

[0196] Msg A **1331** may be transmitted in an uplink transmission by the UE. Msg A **1331** may comprise one or more transmissions of a preamble **1341** and/or one or more transmissions of a transport block **1342**. The transport block **1342** may comprise contents that are similar and/or equivalent to the contents of the Msg **31313** illustrated in FIG. **13**A. The transport block **1342** may comprise UCI (e.g., an SR, a HARQ ACK/NACK, and/or the like). The UE may receive the Msg B **1332** after or in response to transmitting the Msg A **1331**. The Msg B **1332** may comprise contents that are similar and/or equivalent to the contents of the Msg 2 **1312** (e.g., an RAR) illustrated in FIGS. **13**A and **13**B and/or the Msg 4 **1314** illustrated in FIG. **13**A.

[0197] The UE may initiate the two-step random access procedure in FIG. **13**C for licensed spectrum and/or unlicensed spectrum. The UE may determine, based on one or more factors, whether to initiate the two-step random access procedure. The one or more factors may be: a radio access technology in use (e.g., LTE, NR, and/or the like); whether the UE has valid TA or not; a cell size; the UE's RRC state; a type of spectrum (e.g., licensed vs. unlicensed); and/or any other suitable factors.

[0198] The UE may determine, based on two-step RACH parameters included in the configuration message **1330**, a radio resource and/or an uplink transmit power for the preamble **1341** and/or the transport block **1342** included in the Msg A **1331**. The RACH parameters may indicate a modulation and coding schemes (MCS), a time-frequency resource, and/or a power control for the preamble **1341** and/or the transport block **1342**. A time-frequency resource for transmission of the preamble **1341** (e.g., a PRACH) and a time-frequency resource for transmission of the transport block **1342** (e.g., a PUSCH) may be multiplexed using FDM, TDM, and/or CDM. The RACH parameters may enable the UE to determine a reception timing and a downlink channel for monitoring for and/or receiving Msg B **1332**.

[0199] 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)).

[0200] 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**).

[0201] 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.

[0202] 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.

[0203] 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).

[0204] DCIs may be used for different purposes. A purpose may be indicated by the type of RNTI used to scramble the CRC parity bits. For example, a DCI having CRC parity bits scrambled with a paging RNTI (P-RNTI) may indicate paging information and/or a system information change notification. The P-RNTI may be predefined as "FFFE" in hexadecimal. A DCI having CRC parity bits scrambled with a system information RNTI (SI-RNTI) may indicate a broadcast transmission of the system information. The SI-RNTI may be predefined as "FFFF" in hexadecimal. A DCI having CRC parity bits scrambled with a random access RNTI (RA-RNTI) may indicate a random access response (RAR). A DCI having CRC parity bits scrambled with a cell RNTI (C-RNTI) may indicate a dynamically scheduled unicast transmission and/or a triggering of PDCCH-ordered random access. A DCI having CRC parity bits scrambled with a temporary cell RNTI (TC-RNTI) may indicate a contention resolution (e.g., a Msg 3 analogous to the Msg 3 **1313** illustrated in FIG. **13**A). Other RNTIs configured to the UE by a base station may comprise a Configured Scheduling RNTI (CS-RNTI), a Transmit Power Control-PUCCH RNTI (TPC-PUCCH-RNTI), a Transmit Power Control-PUSCH RNTI (TPC-PUSCH-RNTI), a Transmit Power Control-SRS RNTI (TPC-SRS-RNTI), an Interruption RNTI (INT-RNTI), a Slot Format Indication RNTI (SFI-RNTI), a Semi-Persistent CSI RNTI (SP-CSI-RNTI), a Modulation and Coding Scheme Cell RNTI (MCS-C-RNTI), and/or the like.

[0205] 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 00 may be used for scheduling of PUSCH in a cell. DCI format 00 may be a fallback DCI format (e.g., with compact DCI payloads). DCI format 01 may be used for scheduling of PUSCH in a cell (e.g., with more DCI payloads than DCI format 0_0). DCI format 10 may be used for scheduling of PDSCH in a cell. DCI format 10 may be a fallback DCI format (e.g., with compact DCI payloads). DCI format 11 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 21 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.

[0206] 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).

[0207] FIG. **14**A illustrates an example of CORESET configurations for a bandwidth part. The base station may transmit a DCI via a PDCCH on one or more control resource sets (CORESETs). A CORESET may comprise a time-frequency resource in which the UE tries to decode a DCI using one or more search spaces. The base station may configure a CORESET in the time-frequency domain. In the example of FIG. **14**A, a first CORESET **1401** and a second CORESET **1402** occur at the first symbol in a slot. The first CORESET **1401** overlaps with the second CORESET **1402** in the frequency domain. A third CORESET **1403** occurs at a third symbol in the slot. A fourth CORESET **1404** occurs at the seventh symbol in the slot. CORESETs may have a different number of resource blocks in frequency domain.

[0208] FIG. **14**B illustrates an example of a CCE-to-REG mapping for DCI transmission on a CORESET and PDCCH processing. The CCE-to-REG mapping may be an interleaved mapping (e.g., for the purpose of providing frequency diversity) or a non-interleaved mapping (e.g., for the purposes of facilitating interference coordination and/or frequency-selective transmission of control channels). The base station may perform different or same CCE-to-REG mapping on different CORESETs. A CORESET may be associated with a CCE-to-REG mapping by RRC configuration. A CORESET may be configured with an antenna port quasi co-location (QCL) parameter. The antenna port QCL parameter may indicate QCL information of a demodulation reference signal (DMRS) for PDCCH reception in the CORESET.

[0209] 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).

[0210] As shown in FIG. **14**B, the UE may determine a time-frequency resource for a CORESET based on RRC messages. The UE may determine a CCE-to-REG mapping (e.g., interleaved or non-interleaved, and/or mapping parameters) for the CORESET based on configuration parameters of the CORESET. The UE may determine a number (e.g., at most 10) of search space sets configured on the CORESET based on the RRC messages. The UE may monitor a set of PDCCH candidates according to configuration parameters of a search space set. The UE may monitor a set of PDCCH candidates in one or more CORESETs for detecting one or more DCIs. Monitoring may comprise decoding one or more PDCCH candidates of the set of the PDCCH candidates according to the monitored DCI formats. Monitoring may comprise decoding a DCI content of one or more PDCCH candidates with possible (or configured) PDCCH locations, possible (or configured) PDCCH formats (e.g., number of CCEs, number of PDCCH candidates in common search spaces, and/or number of PDCCH candidates in the UE-specific search spaces) and possible (or configured) DCI formats. The decoding may be referred to as blind decoding. The UE may determine a DCI as valid for the UE, in response to CRC checking (e.g., scrambled bits for CRC parity bits of the DCI matching a RNTI value). The UE may process information contained in the DCI (e.g., a scheduling assignment, an uplink grant, power control, a slot format indication, a downlink preemption, and/or the like).

[0211] The UE may transmit uplink control signaling (e.g., uplink control information (UCI)) to a base station. The uplink control signaling may comprise hybrid automatic repeat request (HARQ) acknowledgements for received DL-SCH transport blocks. The UE may transmit the HARQ acknowledgements after receiving a DL-SCH transport block. Uplink control signaling may comprise channel state information (CSI) indicating channel quality of a physical downlink channel. The UE may transmit the CSI to the base station. The base station, based on the received CSI, may determine transmission format parameters (e.g., comprising multi-antenna and beamforming schemes) for a downlink transmission. Uplink control signaling may comprise scheduling requests (SR). The UE may transmit an SR indicating that uplink data is available for transmission to the base station. The UE may transmit a UCI (e.g., HARQ acknowledgements (HARQ-ACK), CSI report, SR, and the like) via a physical uplink control channel (PUCCH) or a physical uplink shared channel (PUSCH). The UE may transmit the uplink control signaling via a PUCCH using one of several PUCCH formats.

[0212] There may be five PUCCH formats and the UE may determine a PUCCH format based on a size of the UCI (e.g., a number of uplink symbols of UCI transmission and a number of UCI bits). PUCCH format 0 may have a length of one or two OFDM symbols and may include two or fewer bits. The UE may transmit UCI in a PUCCH resource using PUCCH format 0 if the transmission is over one or two symbols and the number of HARQ-ACK information bits with positive or negative SR (HARQ-ACK/SR bits) is one or two. PUCCH format 1 may occupy a number between four and fourteen OFDM symbols and may include two or fewer bits. The UE may use PUCCH format 1 if the transmission is four or more symbols and the number of HARQ-ACK/SR bits is one or two. PUCCH format 2 may occupy one or two OFDM symbols and may include more than two bits. The UE may use PUCCH format 2 if the transmission is over one or two symbols and the number of UCI bits is two or more. PUCCH format 3 may occupy a number between four and fourteen OFDM symbols and may include more than two bits. The UE may use PUCCH format 3 if the transmission is four or more symbols, the number of UCI bits is two or more and PUCCH resource does not include an orthogonal cover code. PUCCH format 4 may occupy a number between four and fourteen OFDM symbols and may include more than two bits. The UE may use PUCCH format 4 if the transmission is four or more symbols, the number of UCI bits is two or more and the PUCCH resource includes an orthogonal cover code.

[0213] 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".

[0214] 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 10 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.

[0215] FIG. **15** illustrates an example of a wireless device **1502** in communication with a base station **1504** in accordance with embodiments of the present disclosure. The wireless device **1502** and base station **1504** may be part of a mobile communication network, such as the mobile communication network **100** illustrated in FIG. **1**A, the mobile communication network **150** illustrated in FIG. **1**B, or any other communication network. Only one wireless device **1502** and one base station **1504** are illustrated in FIG. **15**, but it will be understood that a mobile communication network may include more than one UE and/or more than one base station, with the same or similar configuration as those shown in FIG. **15**.

[0216] 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.

[0217] In the downlink, data to be sent to the wireless device **1502** from the base station **1504** may be provided to the processing system **1508** of the base station **1504**. The data may be provided to the processing system **1508** by, for example, a core network. In the uplink, data to be sent to the base station **1504** from the wireless device **1502** may be provided to the processing system **1518** of the wireless device **1502**. The processing system **1508** and the processing system **1518** may implement layer 3 and layer 2 OSI functionality to process the data for transmission. Layer 2 may include an SDAP layer, a PDCP layer, an RLC layer, and a MAC layer, for example, with respect to FIG. **2**A, FIG. **2**B, FIG. **3**, and FIG. **4**A. Layer 3 may include an RRC layer as with respect to FIG. **2**B.

[0218] After being processed by processing system **1508**, the data to be sent to the wireless device **1502** may be provided to a transmission processing system **1510** of base station **1504**. Similarly, after being processed by the processing system **1518**, the data to be sent to base station **1504** may be provided to a transmission processing system **1520** of the wireless device **1502**. The transmission processing system **1510** and the transmission processing system **1520** may implement layer 1 OSI functionality. Layer 1 may include a PHY layer with respect to FIG. **2**A, FIG. **2**B, FIG. **3**, and FIG. **4**A. For transmit processing, the PHY layer may perform, for example, forward error correction coding of transport channels, interleaving, rate matching, mapping of transport channels to physical channels, modulation of physical channel, multiple-input multiple-output (MIMO) or multi-antenna processing, and/or the like.

[0219] At the base station **1504**, a reception processing system **1512** may receive the uplink transmission from the wireless device **1502**. At the wireless device **1502**, a reception processing system **1522** may receive the downlink transmission from base station **1504**. The reception processing system **1512** and the reception processing system **1522** may implement layer 1 OSI functionality. Layer 1 may include a PHY layer with respect to FIG. **2**A, FIG. **2**B, FIG. **3**, and FIG. **4**A. For receive processing, the PHY layer may perform, for example, error detection, forward error correction decoding, deinterleaving, demapping of transport channels to physical channels, demodulation of physical channels, MIMO or multi-antenna processing, and/or the like.

[0220] 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.

[0221] The processing system **1508** and the processing system **1518** maybe 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.

[0222] The processing system **1508** and/or the processing system **1518** may comprise one or more controllers and/or one or more processors. The one or more controllers and/or one or more processors may comprise, for example, a general-purpose processor, a digital signal processor (DSP), a microcontroller, an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) and/or other programmable logic device, discrete gate and/or transistor logic, discrete hardware components, an on-board unit, or any combination thereof. The processing system **1508** and/or the processing system **1518** may perform at least one of signal coding/processing, data processing, power control, input/output processing, and/or any other functionality that may enable the wireless device **1502** and the base station **1504** to operate in a wireless environment.

[0223] 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.

[0224] FIG. **16**A illustrates an example structure for uplink transmission. A baseband signal representing a physical uplink shared channel may perform one or more functions. The one or more functions may comprise at least one of: scrambling; modulation of scrambled bits to generate complex-valued symbols; mapping of the complex-valued modulation symbols onto one or several transmission layers; transform precoding to generate complex-valued symbols; precoding of the complex-valued symbols; mapping of precoded complex-valued symbols to resource elements; generation of complex-valued time-domain Single Carrier-Frequency Division Multiple Access (SC-FDMA) or CP-OFDM signal for an antenna port; and/or the like. In an example, when transform precoding is enabled, a SC-FDMA signal for uplink transmission may be generated. In an example, when transform precoding is not enabled, an CP-OFDM signal for uplink transmission may be generated by FIG. **16**A. These functions are illustrated as examples and it is anticipated that other mechanisms may be implemented in various embodiments.

[0225] FIG. **16**B illustrates an example structure for modulation and up-conversion of a baseband signal to a carrier frequency. The baseband signal may be a complex-valued SC-FDMA or CP-OFDM baseband signal for an antenna port and/or a complex-valued Physical Random Access Channel (PRACH) baseband signal. Filtering may be employed prior to transmission.

[0226] FIG. **16**C illustrates an example structure for downlink transmissions. A baseband signal representing a physical downlink channel may perform one or more functions. The one or more functions may comprise: scrambling of coded bits in a codeword to be transmitted on a physical channel; modulation of scrambled bits to generate complex-valued modulation symbols; mapping of the complex-valued modulation symbols onto one or several transmission layers; precoding of the complex-valued modulation symbols on a layer for transmission on the antenna ports; mapping of complex-valued modulation symbols for an antenna port to resource elements; generation of complex-valued time-domain OFDM signal for an antenna port; and/or the like. These functions are illustrated as examples and it is anticipated that other mechanisms may be implemented in various embodiments.

[0227] FIG. **16**D illustrates another example structure for modulation and up-conversion of a baseband signal to a carrier frequency. The baseband signal may be a complex-valued OFDM baseband signal for an antenna port. Filtering may be employed prior to transmission.

[0228] 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.

[0229] 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.

[0230] When the wireless device is in RRC_CONNECTED, the wireless device may be configured (via RRC configuration by Network (NW)) with a DRX functionality that may control the wireless device's PDCCH monitoring activity. If DRX is configured, for all the activated Serving Cells, the wireless device may monitor the PDCCH discontinuously followed by the configured DRX operation.

[0231] The DRX operation may be characterized by the followings:

- **[0232]** on-duration may be a duration controlled by drx-onDuration Timer that the wireless device waits for, after waking up, to receive PDCCHs. If the wireless device successfully decodes a PDCCH, the wireless device may stay awake and starts the inactivity-timer.
- **[0233]** DRX cycle may specify the periodic repetition of the on-duration followed by a possible period of inactivity (configured by drx-LongCycleStartOffset, drx-ShortCycle, and/or drx-ShortCycleTimer).
- **[0234]** DRX inactivity timer may be a duration controlled by drx-InactivityTimer that the wireless device requires to decode a PDCCH, from the last successful decoding of a PDCCH. Conversely, if no PDCCH is decoded successfully while the drx-InactivityTimer is running, failing which the wireless device can go back to sleep. The wireless device shall restart the inactivity timer following a single successful decoding of a PDCCH for a first transmission only (i.e. not for retransmissions).
- **[0235]** DRX retransmission timer may be a duration until a retransmission can be expected, which may be controlled by drx-RetransmissionTimerDL and drx-RetransmissionTimerUL.
- **[0236]** DRX Hybrid Automatic Repeat Request (HARQ) Round Trip Time (RTT) timer may be the minimum duration before a DL assignment for HARQ

retransmission (configured by drx-HARQ-RTT-TimerDL) or the minimum duration before a UL HARQ retransmission grant (configured by drx-HARQ-RTT-TimerUL).DRX slot offset may be the delay before starting the drx-onDurationTimer (configured by drx-SlotOffset)

[0237] Active Time (e.g., may be referred to as DRX Active Time) may be a total duration that the wireless device monitors PDCCH. This may comprise the "on-duration" of the DRX cycle, the time the wireless device is performing continuous reception while the DRX inactivity timer has not expired, and the time when the wireless device is performing continuous reception while waiting for a retransmission opportunity (based on the DRX retransmission timer).

[0238] When DRX is configured, the Active Time of the wireless device may comprise the time while:

[0239] drx-onDurationTimer or drx-InactivityTimer configured is running; and/or

[0240] drx-RetransmissionTimerDL or drx-RetransmissionTimerUL is running on any Serving Cell; and/or

[0241] ra-ContentionResolutionTimer or msgB-ResponseWindow is running; and/or

[0242] a Scheduling Request is sent on PUCCH and is pending; and/or

[0243] a PDCCH indicating a new transmission addressed to the C-RNTI of the MAC entity has not been received after successful reception of a Random Access Response for the Random Access Preamble not selected by the MAC entity among the contention-based Random Access Preamble.

[0244] In an example shown in FIG. **17**, for each DRX cycle, the wireless device may start a drx-onDurationTimer at the beginning of the DRX cycle. The start timing of drx-onDurationTimer at the beginning of the DRX cycle may follow by an offset (e.g., drx-SlotOffset). For example, the wireless device may start drx-onDurationTimer after drx-SlotOffset from the beginning of the subframe of the DRX cycle. While the drx-onDurationTimer is running, the wireless device is in Active Time and the wireless device may keep monitoring PDCCH.

[0245] In an example of FIG. **18**. The wireless device may wake up to monitor the PDCCH for an on-duration at each DRX cycle. However, from wireless device's activity and data transmission point of view, the wireless device does not always need to be scheduled for each on-duration. Sometimes, the wireless device wastes its power to monitor the PDCCH without receiving any scheduling. Since PDCCH monitoring is a quite heavy power consumption behavior for the wireless device, Rel-16 introduced a new physical layer signalling which could be used to further control the PDCCH monitoring behavior for the on-duration based on the configured DRX mechanism, which means the NW could send the new physical layer signalling to the wireless device to ask it to wake up within on-duration or not. The new physical layer signalling may be a DCP, which may also be referred to a power saving signal.

[0246] DCP may be indicated by DCI format 2_6, which may be used for notifying the power saving information outside DRX Active Time for one or more UEs. The DCI format 2_6 may comprise one or more indications. For example, one may be "Wake-up Indication" (1 bit), and one may be "Dormancy Group Indication" (0-5 bits). The "Wake-up Indication" may be used to control the PDCCH monitoring behavior for the on-duration of DRX.

[0247] Regarding DCP, the wireless device may be indicated by a "Wake-up indication", when configured accordingly, whether it is required to monitor or not the PDCCH during the next occurrence of the on-duration, e.g., start drx-onDurationTimer or not, by a DCP monitored on the active BWP.

[0248] The wireless device may not start the drx-onDurationTimer for the next long DRX cycle when a value of the Wake-up indication bit is '0', and the wireless device may start the drx-onDurationTimer for the next long DRX cycle when a value of the Wake-up indication bit is '1'.

[0249] If the wireless device detects a DCP on the active BWP, the 1 bit "Wake-up indication" may indicate whether the wireless device needs to monitor the PDCCH during the next occurrence of the on-duration or not. However, in some cases, the wireless device may fail to detect the DCP, e.g., the wireless device monitors the DCP but unsuccessfully receives it (e.g., due to bad channel quality). In this case, if the wireless device does not detect a DCP on the active BWP, the wireless device may not monitor the PDCCH during the next occurrence of the on-duration (by default), unless it is explicitly configured to do so (e.g., by configuration). That is, the NW could indicate the wireless device to wake up or not when DCP is not detected outside active time (by the IE ps-Wakeup).

[0250] In an example, if a wireless device is provided with search space sets to monitor PDCCH for detection of DCI format 2_6 in the active DL BWP of the PCell or of the SpCell and the wireless device does not detect DCI format 2_6:

[0251] if the wireless device is provided ps-Wakeup, the wireless device is indicated by ps-Wakeup whether the wireless device may not start or whether the wireless device shall start the drx-onDurationTimer for the next DRX cycle;

[0252] if the wireless device is not provided ps-Wakeup, the wireless device may not start Active Time indicated by drx-onDurationTimer for the next DRX cycle.

[0253] Since the wake-up indication of DCP may be used to control the wireless device behavior for drx-onDurationTimer, a wireless device may only be configured to monitor DCP when connected mode DRX (C-DRX) is configured, and at monitoring occasion(s) (e.g., PDCCH occasions) at a configured offset before the on-duration. The offset may be configured by the IE ps-Offset. Furthermore, more than one monitoring occasions for DCP may be configured before the on-duration, i.e., a number of search space sets, by dci-Format2-6, to monitor PDCCH for detection of DCI format 2_6 on the active DL BWP (of the PCell or of the SpCell).

[0254] In some cases, the monitoring occasion of DCP may collide with other procedures or channels in time domain. Due to the restriction of UE capability, the wireless device may not perform all the defined behaviors simultaneously. Thus, the priority between the DCP monitoring and other procedures or channels is specified. That is, the wireless device may not need to monitor DCP on occasions occurring during: Active Time (of DRX), Measurement gap, and/or BWP switching.

[0255] On the other hand, when DCP monitoring occasion collides with other procedures with higher priority in PDCCH monitoring, the DCP monitoring occasion is considered invalid. Then wireless device may follow legacy behavior (i.e., WIRELESS DEVICE behaviors without DCP mechanism).

[0256] In addition, if no DCP monitoring occasion (e.g., search space) is configured in the active BWP, wireless device may follow normal DRX operation. Note that The monitoring occasion for DCP may be configured per BWP. However, the DCP configuration (i.e., DCP-Config) may be configured per cell group (i.e., MCG/SCG). The DCP configuration comprises some parameters for the DCP functionality (e.g., PS-RNTI, offset for monitoring DCP, size of DCI 2_6, etc.)

[0257] One DCP is configured to control PDCCH monitoring during on-duration for one or more wireless devices independently (based on ps-PositionDCI to indicate the starting position of wakeup and dormancy group indication in DCI format 2_6 for the WIRELESS DEVICEs). wireless device may be also configured (by RRC and/or BS) whether to report periodic L1-RSRP (by the IE ps-TransmitPeriodicL1-RSRP) or periodic CSI/L1-SINR (by the IE ps-TransmitPeriodicCSI) when wireless device is not indicated to wake up (i.e., does not start DRX onduration timer) at the DRX on-duration.

[0258] A wireless device may be provided a group index for a respective Type3-PDCCH CSS set or USS set by searchSpaceGroupIdList for PDCCH monitoring on a serving cell. If the wireless device is not provided searchSpaceGroupIdList for a search space set, the following procedures may not be applicable for PDCCH monitoring according to the search space set.

[0259] If a wireless device is provided cellGroupsForSwitchList, indicating one or more groups of serving cells, the following procedures may apply to all serving cells within each group; otherwise, the following procedures may apply only to a serving cell for which the wireless device is provided searchSpaceGroupIdList.

[0260] When a wireless device is provided searchSpaceGroupIdList, the wireless device may resets PDCCH monitoring according to search space sets with group index 0, if provided by searchSpaceGroupIdList.

[0261] A wireless device may be provided by searchSpaceSwitchDelay a number of symbols P_switch for UE processing capability 1 and UE processing capability 2 and SCS configuration p. UE processing capability 1 for SCS configuration p may apply unless the wireless device indicates support for UE processing capability 2.

[0262] A wireless device may be provided, by searchSpaceSwitchTimer, a timer value for a serving cell that the wireless device is provided searchSpaceGroupIdList or, if provided, for a set of serving cells provided by cellGroupsForSwitchList. The wireless device may decrement the timer value by one after each slot based on a reference SCS configuration that is the smallest SCS configuration p among all configured DL BWPs in the serving cell, or in the set of serving cells. The wireless device may maintain the reference SCS configuration during the timer decrement procedure.

[0263] If a wireless device is provided by SearchSpaceSwitchTrigger a location of a search space set group switching flag field in a DCI format 2_0, for a serving cell where the wireless device has active DL BWP with SCS configuration p.

[0264] if the wireless device detects a DCI format 2_0 and a value of the search space set group switching flag field in the DCI format 2_0 is 0, the wireless device may start monitoring PDCCH according to search space sets with group index 0, and stops monitoring PDCCH according to search space sets with group index 1, for the serving cell

[0265] at the beginning of the first slot that is at least P_switch symbols after the last symbol of the PDCCH with the DCI format 2_0 when $\mu \in \{0,1,2,3\}$

[0266] at the beginning of the first slot, of a group of X_s slots, that is at least P_switch symbols after the last symbol of the PDCCH with the DCI format 2_0 when $\mu \in$ {5,6

[0267] if the wireless device detects a DCI format 2_0 and a value of the search space set group switching flag field in the DCI format 2_0 is 1, the wireless device may start monitoring PDCCH according to search space sets with group index 1, and stops monitoring PDCCH according to search space sets with group index 0, for the serving cell

[0268] at the beginning of the first slot that is at least P_switch symbols after the last symbol of the PDCCH with the DCI format 2_0, when $\mu \in \{0,1,2,3\}$

[0269] at the beginning of the first slot, of a group of X_s slots, that is at least P_switch symbols after the last symbol of the PDCCH with the DCI format 2_0 when $\mu \in \{5,6\}$ and the wireless device may set the timer value to the value provided by searchSpaceSwitchTimer

[0270] if the wireless device monitors PDCCH for a serving cell according to search space sets with group index 1, the wireless device may start monitoring PDCCH for the serving cell according to search space sets with group index 0, and stops monitoring PDCCH according to search space sets with group index 1, for the serving cell

[0271] at the beginning of the first slot that is at least P_switch symbols after a slot where the timer expires or after a last symbol of a remaining channel occupancy duration for the serving cell if indicated by DCI format 2_0 when $\mu \in \{0,1,2,3\}$

[0272] at the beginning of the first slot, of a group of X_s slots, that is at least P_switch symbols after a slot where the timer expires or after a last symbol of a remaining channel occupancy duration for the serving cell if indicated by DCI format 2_0 when $\mu \in \{5,6\}$

[0273] If a wireless device is not provided SearchSpaceSwitchTrigger for a serving cell, if the wireless device detects a DCI format by monitoring PDCCH according to a search space set with group index 0, the wireless device may start monitoring PDCCH according to search space sets with group index 1, and stops monitoring PDCCH according to search space sets with group index 0, for the serving cell

[0274] at the beginning of the first slot that is at least P_switch symbols after the last symbol of the PDCCH with the DCI format when $\mu \in \{0,1,2,3\}$,

[0275] at the beginning of the first slot, of a group of X_s slots, that is at least P_switch symbols after the last symbol of the PDCCH with the DCI format when $\mu \in \{5,6\}$. the wireless device may set the timer value to the value provided by searchSpaceSwitchTimer if the wireless device detects a DCI format by monitoring PDCCH in any search space set

[0276] if the wireless device monitors PDCCH for a serving cell according to search space sets with group index 1, the wireless device may start monitoring PDCCH for the serving cell according to search space sets with group index 0, and stops monitoring PDCCH according to search space sets with group index 1, for the serving cell

[0277] at the beginning of the first slot that is at least P_switch symbols after a slot where the timer expires or, if the wireless device is provided a search space set to monitor PDCCH for detecting a DCI format 2_0, after a last symbol of a remaining channel occupancy duration for the serving cell if indicated by DCI format 2_0 when $\mu\in\{0,1,2,3\}$

[0278] at the beginning of the first slot, of a group of X_s slots, that is at least P_switch symbols after a slot where the timer expires or, if the wireless device is provided a search space set to monitor PDCCH for detecting a DCI format 2_0, after a last symbol of a remaining channel occupancy duration for the serving cell if indicated by DCI format 2_0 when $\mu\in\{\mathbf{5},\mathbf{6}\}$

[0279] A wireless device may determine a slot and a symbol in the slot to start or stop PDCCH monitoring according to search space sets for a serving cell that the wireless device is provided searchSpaceGroupIdList or, if cellGroupsForSwitchList is provided, for a set of serving cells, based on the smallest SCS configuration p among all configured DL BWPs in the serving cell or in the set of serving cells and, if any, in the serving cell where the wireless device receives a PDCCH and detects a corresponding DCI format 2_0 triggering the start or stop of PDCCH monitoring according to search space sets.

[0280] A wireless device may be provided a set of durations by PDCCHSkippingDurationList for PDCCH monitoring on an active DL BWP of a serving cell and, if the WIRELESS DEVICE is not provided searchSpaceGroupIdList-r17 on the active DL BWP of the serving cell, a DCI format 01 and a DCI format 0_2 that schedule PUSCH transmission, and a DCI format 1_1 and a DCI format 1_2 that schedule PDSCH receptions can include a PDCCH monitoring adaptation field of 1 bit or of 2 bits.

[0281] If the field has 1 bit and for PDCCH monitoring by the wireless device according to Type3-PDCCH CSS sets or USS sets on the active DL BWP of the serving cell

[0282] a '0' value for the bit may indicate no skipping in PDCCH monitoring

[0283] a '1' value for the bit may indicate skipping PDCCH monitoring for a duration provided by the first value in the set of durations

[0284] If the field has 2 bits and for PDCCH monitoring by the wireless device according to Type3-PDCCH CSS sets or USS sets on the active DL BWP of the serving cell

[0285] a '00' value for the bits may indicate no skipping in PDCCH monitoring

[0286] a '01' value for the bits may indicate skipping PDCCH monitoring for a duration provided by the first value in the set of durations

[0287] a '10' value for the bits may indicate skipping PDCCH monitoring for a duration provided by the second value in the set of durations

[0288] a '11' value for the bits may indicate skipping PDCCH monitoring for a duration provided by the third value in the set of durations, if any; otherwise, if the set of durations includes two values, a use of the '11' value is reserved

[0289] A wireless device may be provided group indexes for a Type3-PDCCH CSS set or USS set by searchSpaceGroupIdList-r17 for PDCCH monitoring on an active DL BWP of a serving cell and, if the wireless device is not provided PDCCHSkippingDurationList for the active DL BWP of the serving cell, a DCI format 01 and a DCI format 0_2 that schedule PUSCH transmissions and a DCI format 1_1 and a DCI format 1_2 that schedule PDSCH receptions can include a PDCCH monitoring adaptation field of 1 bit or of 2 bits for the serving cell.

[0290] If the field has 1 bit and for PDCCH monitoring by the wireless device according to Type3-PDCCH CSS sets or USS sets on the active DL BWP of the serving cell

[0291] a '0' value for the bit may indicate start of PDCCH monitoring according to search space sets with group index 0 and stop of PDCCH monitoring according to search space sets with other group indexes, if any

[0292] a '1' value for the bit may indicate start of PDCCH monitoring according to search space sets with group index 1 and stop of PDCCH monitoring according to search space sets with other group indexes, if any, and the wireless device sets the timer value to the one provided by searchSpaceSwitchTimer-r17.

[0293] If the field has 2 bits and for PDCCH monitoring by the wireless device according to Type3-PDCCH CSS sets or USS sets on the active DL BWP of the serving cell

[0294] a '00' value for the bit may indicate start of PDCCH monitoring according to search space sets with group index 0 and stop of PDCCH monitoring according to search space sets with other group indexes, if any

[0295] a '01' value for the bit may indicate start of PDCCH monitoring according to search space sets with group index 1 and stop of PDCCH monitoring according to search space sets with other group indexes, if any, and the wireless device may set the timer value to the one provided by searchSpaceSwitchTimer-r17

[0296] a '10' value for the bit may indicate start of PDCCH monitoring according to search space sets with group index 2 and stop of PDCCH monitoring according to search space sets with other group indexes, if any, and the wireless may set the timer value to the one provided by searchSpaceSwitchTimer-r17

[0297] a '11' value is reserved

[0298] A wireless device may be provided a set of durations by DCCHSkippingDurationList and group indexes for a Type3-PDCCH CSS set or USS set by searchSpaceGroupIdList-r17 for PDCCH monitoring on an active DL BWP of a serving cell and, a DCI format 01 and a DCI format 0_2 that schedule PUSCH transmissions, and a DCI format 1_1 and a DCI format 1_2 that schedule PDSCH receptions can include a PDCCH monitoring adaptation field of 2 bits.

[0299] If the set of durations includes one value and for PDCCH monitoring by the wireless device according to Type3-PDCCH CSS sets or USS sets on the active DL BWP of the serving cell

[0300] a '00' value for the bits may indicate start of PDCCH monitoring according to search space sets with group index 0 and stop of PDCCH monitoring according to search space sets with group index 1, if any

[0301] a '01' value for the bits may indicate start of PDCCH monitoring according to search space sets with group index 1 and stop of PDCCH monitoring according to search space sets with group index 0, if any, and the wireless device may set the timer value to the one provided by searchSpaceSwitchTimer-r17

[0302] a '10' value for the bits may indicate skipping PDCCH monitoring for a duration provided by the value in the set of durations

[0303] a '11' value is reserved

[0304] If the set of durations includes two values and for PDCCH monitoring by the wireless device according to Type3-PDCCH CSS sets or USS sets on active DL BWP of the serving cell

[0305] a '00' value for the bits may indicate start of PDCCH monitoring according to search space sets with group index 0 and stop of PDCCH monitoring according to search space sets with group index 1, if any

[0306] a '01' value for the bits may indicate start of PDCCH monitoring according to search space sets with group index 1 and stop of PDCCH monitoring according to search space sets with group index 0, if any, and the wireless device may set the timer value to the one provided by searchSpaceSwitchTimer-r17

[0307] a '10' value for the bits may indicate skipping PDCCH monitoring for a duration provided by the first value in the set of durations

[0308] a '11' value for the bits may indicate skipping PDCCH monitoring for a duration provided by the second value in the set of durations

[0309] When the PDCCH monitoring adaptation field indicates to a wireless device to start PDCCH monitoring according to search space sets with a first group index and stop PDCCH monitoring according to search space sets with a second group index, the wireless device may apply the indication

[0310] at the beginning of a first slot that is at least P_switch symbols after the last symbol of the PDCCH reception providing the DCI format with the PDCCH monitoring adaptation field when $\mu \in \{0,1,2,3\}$,

[0311] at the beginning of a first slot, of a slot group of X_s slots, that is at least P_switch symbols after the last symbol of the PDCCH reception providing the DCI format with the PDCCH monitoring adaptation field when $\mu \in \{5,6\}$

[0312] When the PDCCH monitoring adaptation field indicates to a wireless device to skip PDCCH monitoring for a duration on the active DL BWP of a serving cell, the wireless device may start skipping of PDCCH monitoring at the beginning of a first slot that is after the last symbol of the PDCCH reception providing the DCI format with the PDCCH monitoring adaptation field. If the wireless device transmits a PUCCH providing a positive SR after the wireless device detects a DCI format providing the PDCCH monitoring adaptation field indicating to the wireless device to skip PDCCH monitoring for the duration on the active DL BWP of the serving cell, the wireless device may resumes PDCCH monitoring starting at the beginning of a first slot that is after a last symbol of the PUCCH transmission. During the time of ra-ResponseWindow or msgB-ResponseWindow or the duration where ra-ContentionResolutionTimer is running, the wireless device may not skip PDCCH monitoring on SpCell. If the DRX group of the serving cell is configured and enters outside Active Time, the wireless device may terminates PDCCH skipping for the serving cell.

[0313] If the wireless device may change to a new active DL BWP of the serving cell by the expiration of bwp-InactivityTimer in a PDCCH skipping duration, the wireless device may

[0314] resumes PDCCH monitoring according to the search space sets on the new active BWP of the serving cell, if the WIRELESS DEVICE is not provided searchSpaceGroupIdList-r17 on the new active DL BWP

[0315] otherwise, monitors PDCCH according to search space sets with group index 0 on the new active BWP of the serving cell.

[0316] If a wireless device is provided group indexes for a Type3-PDCCH CSS set or a USS set by searchSpaceGroupIdList-r17 and a timer value by searchSpaceSwitchTimer-r17 for PDCCH monitoring an active DL BWP of on a serving cell and the timer is running, the wireless device may

[0317] resets the timer after a slot of the active DL BWP of the serving cell if the WIRELESS DEVICE detects a DCI format in a PDCCH reception in the slot for with CRC scrambled by C-RNTI/CS-RNTI/MCS-C-RNTI

[0318] otherwise, decrements the timer value by one after a slot of the active DL BWP of the serving cell

[0319] When the timer expires in a first slot, the wireless device may monitor PDCCH on the serving cell according to search space sets with group index 0 starting in a second slot that

[0320] is not earlier than P_switch symbols after the first slot when $\mu \in \{0,1,2,3\}$,

[0321] is a first slot in a slot group of X_s slots that is not earlier than P_switch symbols after the first slot when $\mu \in \{5,6\}$,

[0322] is not earlier than a slot where a PDCCH skipping duration expires, if applicable

[0323] When a wireless device receives a first PDCCH in a first slot that provides a DCI format with a PDCCH monitoring adaptation field having a first value indicating skipping PDCCH monitoring, or indicating start of PDCCH monitoring according to a search space sets with a first group index and stop of PDCCH monitoring according to search space sets with a second group index, for an active DL BWP and

[0324] a second PDCCH that provides a DCI format with a PDCCH monitoring adaptation field having a second value indicating skipping PDCCH monitoring, or indicating start of PDCCH monitoring according to search space sets with a first group index and stop of PDCCH monitoring according to search space sets with a second group index different than the first group index, for the active DL BWP where the second PDCCH is receive in the first slot if the first value indicates skipping PDCCH monitoring and/or before a slot that is at least P_switch symbols after the first slot if the first value indicates start of PDCCH monitoring according to search space sets with a first group index, the wireless device may not expect the second value to be different than the first value.

[0325] A wireless device may not expect to receive in a second slot a PDCCH on an active DL BWP that provides a DCI format indicating skipping PDCCH monitoring, or start of PDCCH monitoring according to search space sets with group index 1 or 2 for the active DL BWP, if the second slot is not at least P_switch symbols after a first slot where the timer expires.

[0326] The wireless device may determine if the wireless device is configured with enhancedSkipUplinkTxDynamic with value true and the grant indicated to the HARQ entity was addressed to a C-RNTI, or if the MAC entity is configured with enhancedSkipUplinkTxConfigured with value true and the grant indicated to the HARQ entity is a configured uplink grant.

[0327] The wireless device may not generate a MAC PDU for the HARQ entity if there is no UCI to be multiplexed on this PUSCH transmission; and/or if there is no aperiodic CSI requested for this PUSCH transmission; and/or if the MAC PDU includes zero MAC SDUs; and/or if the MAC PDU includes only the periodic Buffer Status Report (BSR) and there is no data available for any LCG, or the MAC PDU includes only the padding BSR.

[0328] The wireless device may not generate a MAC PDU for the HARQ entity if the wireless device is configured with skipUplinkTxDynamic with value true and the grant indicated to the HARQ entity was addressed to a C-RNTI, or the grant indicated to the HARQ entity is a configured uplink grant: if there is no aperiodic CSI requested for this PUSCH transmission; and/or if the MAC PDU includes zero MAC SDUs; and/or if the MAC PDU includes only the periodic BSR and/or there is no data available for any LCG, or the MAC PDU includes only the padding BSR.

[0329] XR may be refer to all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables. XR may be an umbrella term for different types of realities:

[0330] Virtual reality (VR) may be a rendered version of a delivered visual and audio scene. The rendering may be designed to mimic the visual and audio sensory stimuli of the real world as naturally as possible to an observer or user as they move within the limits defined by the application. Virtual reality usually, but not necessarily, requires a user to wear a head mounted display (HMD), to completely replace the user's field of view with a simulated visual component, and to wear headphones, to provide the user with the accompanying audio. Some form of head and motion tracking of the user in VR is usually also necessary to allow the simulated visual and audio components to be updated in order to ensure that, from the user's perspective, items and sound sources remain consistent with the user's movements.

[0331] Augmented reality (AR) is when a user is provided with additional information or artificially generated items or content overlaid upon their current environment. Such additional information or content will usually be visual and/or audible and their observation of their current environment may be direct, with no intermediate sensing, processing and rendering, or indirect, where their perception of their environment is relayed via sensors and may be enhanced or processed.

[0332] Mixed reality (MR) may be an advanced form of AR where some virtual elements are inserted into the physical scene with the intent to provide the illusion that these elements are part of the real scene.

[0333] Other terms used in the context of XR are Immersion as the sense of being surrounded by the virtual environment as well as Presence providing the feeling of being physically and spatially located in the virtual environment. The sense of presence provides significant minimum performance requirements for different technologies such as tracking, latency, persistency, resolution and optics.

[0334] This application may use the acronym XR throughout to refer to equipment, applications and functions used for VR, AR and MR. Examples include, but are not limited to HMDs for VR, optical see-through glasses and camera see-through HMDs for AR and MR and mobile devices with positional tracking and camera. They may all offer some degree of spatial tracking and the spatial tracking results in an interaction to view some form of virtual content.

[0335] Many of the XR and Cloud Gaming use cases may be characterized by quasi-periodic traffic (with possible jitter) with high data rate in DL (i.e., video steam) combined with the frequent UL (i.e., pose/control update) and/or UL video stream. Both DL and UL traffic are also characterized by relatively strict packet delay budget (PDB). Hence, there is a need to study and potentially specify possible solutions to better support such challenging services, i.e., by better matching the non-integer periodicity of traffic, such as 60/90/120 frames per second to the NR signalling.

[0336] Many of the end user XR and CG devices are expected to be mobile and of small-scale, thus having limited battery power resources. Therefore, additional power enhancements may be needed to reduce the overall UE power consumption when running XR and CG services and thus extend the effective UE battery lifetime. From the Release 17 Study Item on "XR evaluations" it is identified that the current DRX configurations do not fit well for (i) the non-integer XR traffic periodicity, (ii) variable XR data rate and (iii) quasi-periodic XR periodicity, hence enhancements would be beneficial in this area.

[0337] The set of anticipated XR and CG services has a certain variety and characteristics of the data streams (i.e., video) may change "on-the-fly", while the services are running over NR. Therefore, additional information on the running services from higher layers may be beneficial to facilitate informed choices of radio parameters.

[0338] Table 1 shows the XR traffics characteristics.

TABLE 1

Traffic	Period (ms) (120 fps)	(90 fps)	(60 fps - baseline)	Jitter	Rate (Mb/s)	Packet size (kbytes)	Direction	PDB	Packet success rate
Video	8.33333	11.1111	16.66667	+/−4 ms	45	93.7 +/− 50%	DL & UL	10 ms (baseline DL), 30 ms UL	99%

TABLE 1-continued

Traffic	Period (ms) (120 fps)	(90 fps)	(60 fps - baseline)	Jitter	Rate (Mb/s)	Packet size (kbytes)	Direction	PDB	Packet success rate
Audio + data		10		0	1.12	1.4	DL & UL	30 ms	99%
Pose/ control		4		0	0.025	100 bytes	UL	10 ms	99%

[0339] XR content may be represented in different formats, e.g. panoramas or spheres depending on the capabilities of the capture systems. Since modern video coding standards are not designed to handle spherical content. projection is used for conversion of a spherical (or 360°) video into a two-dimensional rectangular video before the encoding stage. After projection, the obtained two-dimensional rectangular image can be partitioned into regions (e.g. front, right, left, back, top, bottom) that can be rearranged to generate "packed" frames to increase coding efficiency or viewport dependent stream arrangement.

[0340] The frame rate for XR video varies from 30 frames per second up to 90 or even 120 frames per second, with a typical minimum of 60 for VR. The latency of action of the angular or rotational vestibulo-ocular reflex is known to be of the order of 10 ms or in a range from 7-15 milliseconds and it seems reasonable that this should represent a performance goal for XR systems. This results in a motion-to-photon latency of less than 20 milliseconds, with 10 ms being given as a goal. Regarding the bit rates, between 10 and 200 Mbps can be expected for XR depending on frame rate, resolution and codec efficiency.

[0341] For Audio, we can distinguish channel-based and object-based representations:

- **[0342]** Channel-based representation using multiple microphones to capture sounds from different directions and post-processing techniques are well known in the industry, as they have been the standard for decades.
- **[0343]** Object-based representations represent a complex auditory scene as a collection of single audio elements, each comprising an audio waveform and a set of associated parameters or metadata. The metadata embody the artistic intent by specifying the transformation of each of the audio elements to playback by the final reproduction system. Sound objects generally use monophonic audio tracks that have been recorded or synthesized through a process of sound design. These sound elements can be further manipulated, so as to be positioned in a horizontal plane around the listener, or in full three-dimensional space using positional metadata.

[0344] Due to the relatively slower speed of sound compared to that of light, it is natural that users are more accustomed to, and therefore tolerant of, sound being relatively delayed with respect to the video component than sound being relatively in advance of the video component. Recent studies have led to recommendations of an accuracy of between 15 ms (audio delayed) and 5 ms (audio advanced) for the synchronization, with recommended absolute limits of 60 ms (audio delayed) and 40 ms (audio advanced) for broadcast video.

[0345] To maintain a reliable registration of the virtual world with the real world, as well as to ensure accurate tracking of the XR Viewer pose, XR applications require highly accurate, low-latency tracking of the device at about 1 kHz sampling frequency. The size of a XR Viewer Pose associated to time, typically results in packets of size in the range of 30-100 bytes, such that the generated data is around several hundred kbit/s if delivered over the network.

[0346] Pose information has to be delivered with ultra-high reliability, therefore, similar performance as Ultra-Reliable Low-Latency Communication (URLLC) may be expected i.e., packet loss rate should be lower than 10E-4 for uplink sensor data.

[0347] Data Burst: A set of multiple PDUs generated and sent by the application in a short period of time. A Data Burst may be composed by one or multiple PDU Sets. A Data Burst can be composed by one or more data packets.

[0348] PDU Set: A PDU Set is composed of one or more PDUs carrying the payload of one unit of information generated at the application level (e.g., a frame or video slice for XRM Services). In some implementations all PDUs in a PDU Set are needed by the application layer to use the corresponding unit of information. In other implementations, the application layer can still recover parts all or of the information unit, when some PDUs are missing. A PDU sets may be composed by one or more data packets.

[0349] The PDU-Set Delay Budget (PSDB) may define an upper bound for the time that a PDU-Set may be delayed between the UE and the N6 termination point at the UPF. PSDB applies to the DL PDU-Set received by the UPF over the N6 interface, and to the UL PDU-Set sent by the UE. For a certain 5QI the value of the PSDB is the same in UL and DL. In the case of 3GPP access, the PSDB may be used to support the configuration of scheduling and link layer functions (e.g., the setting of scheduling priority weights and HARQ target operating points). For GBR QoS Flows using the Delay-critical resource type, a PDU-Set delayed more than PSDB is counted as lost if the QoS Flow is not exceeding the GFBR. For GBR QoS Flows with GBR resource type not exceeding GFBR, of the PDU-Sets may commonly not experience a delay exceeding the 5QI's PSDB to a very high percentage.

[0350] The PDU-Set Error Rate (PSER) may define an upper bound for the rate of PDU-Sets (e.g. set of IP packets constituting a PDU-Set) that have been processed by the sender of a link layer protocol (e.g. RLC in RAN of a 3GPP access) but where all of the PDUs in the PDU-Set are not successfully delivered by the corresponding receiver to the upper layer (e.g. PDCP in RAN of a 3GPP access). Thus, the PSER may define an upper bound for a rate of non-congestion related packet losses. The purpose of the PSER is to allow for appropriate link layer protocol configurations (e.g., RLC and HARQ in RAN of a 3GPP access). For every 5Q1 the value of the PSER is the same in UL and DL. For GBR QoS Flows with Delay-critical GBR resource type, a

PDU-Set which is delayed more than PSDB is counted as lost, and included in the PSER unless the QoS Flow is exceeding the GFBR. Congestion related packet drops should be avoided by means of an application layer rate adaptation scheme.

[0351] In an example of FIG. **19**, depending on how the mapping of PDU sets onto QoS flows is done in the NAS and how QoS flows are mapped onto DRBs in the AS, we can distinguish the following alternatives:

[0352] 111: one-to-one mapping between types of PDU sets and QoS flows in the NAS and one-to-one mapping between QoS flows and DRBs in the AS.

[0353] NN1: one-to-one mapping between types of PDU sets and QoS flows in the NAS and possible multiplexing of QoS flows in one DRB in the AS.

[0354] N11: possible multiplexing of types of PDU sets in one QoS flow in the NAS and one-to-one mapping between QoS flows and DRBs in the AS.

[0355] N1N: possible multiplexing of types of PDU sets in one QoS flow in the NAS and demultiplexing of types of PDU sets from one QoS flow on multiple DRBs in the AS.

[0356] For XR traffic, A Packet Data Unit (PDU) Set may be composed of one or more PDUs carrying the payload of one unit of information generated at the application level (e.g., a frame or video). A data burst may be composed by one or multiple PDU sets. In an example embodiment of the present disclosure, a data burst comprising one or multiple PDU sets may be referred to as one or more data packets. For example, a wireless device may receive, from a NW, an end indication of the data burst or a data burst comprising one or multiple PDU sets. In an example embodiment of the present disclosure, the end indication of the data burst may be referred to as the end indication of the one or more data packets.

[0357] In an example of FIG. **20**, the User Plane Function (UPF) may provide an End of data Burst indication (EOBI) in the GPRS Tunneling Protocol User Plane (GTP-U) header of the last PDU (of the last PDU set) of a Data Burst to NG-RAN. Such indication may be used by the RAN to decide when to put the UE to sleep. The UPF may decide when to insert the EOBI based on implementation specific mechanisms to detect the end of the data burst, or based on explicit indications from the AS. The UPF may detects the EOBI and marks the EOBI over GTP—U based on information provided by the AS in the PDU (e.g. "End" in the RTP extended header when only one media unit (e.g. NAL Unit) within each data burst). When the NG-RAN receives the EOBI in the GTP-U header, it may understand that a specific PDU is the last PDU of a given Data Burst and it may put the UE to sleep

[0358] Referring to FIG. **21**, in existing technologies, a NW (e.g., gNB) may send an End of Burst Indication (EOBI) to the wireless device. When the wireless device receives the EOBI, the wireless device may switch from a DRX Active State (e.g., state in which the wireless device is in an DRX Active Time) to a DRX Sleep State (e.g., state in which the wireless device is outside an DRX Active Time, stops (e.g., does not run) DRX Timer(s) and/or skips PDCCH monitoring) to save power. However, there are some problems in accordance with the implementations. For example, how to indicate the EOBI from the NW to the wireless device? How to identify, by the wireless device, an indication is a EOBI and/or the indication is to switch the DRX Active State to the DRX Sleep state? What's the UE behaviors to perform the DRX Sleep State? When to start the DRX Sleep State? How long to keep in the DRX Sleep State? Perform the DRX Sleep State on which Cell(s)/DRX group(s)? Example aspects and implementations disclosed herein provide methods that may resolve at least the aforementioned problems.

[0359] In some implementations, the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) may be indicated by a RRC message, a SDAP signaling, a PDCP signaling, RLC signaling, a MAC CE, and/or a PHY signaling.

[0360] In some implementations, when/after the wireless device receives an indication, the wireless device may identify whether the indication is the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) based on a parameter, a field, a flab, a header, a SN of a data, a bit(s), a format, a scrambled RNTI, and/or a specific search space to receive the indication.

[0361] The RRC message may indicate the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) via a configuration/IE/parameter. The SDAP/PDCP/RLC may indicate the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) via a header, a control PDU, and/or a data PDU. The header, the control PDU, and/or the data PDU may comprise an end marker. The header, the control PDU, and/or the data PDU may comprise a sequence number (SN) to indicate it. The MAC CE may indicate the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) via zero, one, or more bits. The PHY signaling may indicate the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) via a DCI. The DCI may be a specific DCI format (e.g., DCI format 2_6). The DCI may be scrambled by a RNTI. The DCI may be a DCP. The DCI may be a scheduling DCI and/or a non-scheduling DCI.

[0362] In some implementations, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may stop/suspend DRX Active Time. In some examples, the wireless device may stop/suspend DRX Active Time no matter whether any DRX timer(s) is running, and/or no matter any events (e.g., Scheduling Request (SR), Random Access (RA)) trigger the DRX active time are pending.

[0363] The DRX Active Time may comprise the time while:

[0364] drx-onDurationTimer or drx-InactivityTimer configured for the DRX group is running; and/or

[0365] drx-RetransmissionTimerDL, drx-RetransmissionTimerUL is running; and/or

[0366] ra-ContentionResolutionTimer or msgB-ResponseWindow is running; and/or

[0367] a Scheduling Request is sent on PUCCH and is pending; and/or

[0368] a PDCCH indicating a new transmission addressed to the Cell-Radio Network Temporary Identifier (C-RNTI) of the MAC entity has not been received after successful reception of a Random Access Response for the Random Access Preamble not selected by the MAC entity among the contention-based Random Access Preamble.

[0369] In some implementations, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may stop one or more DRX timer(s).

[0370] The DRX timer(s) may comprise drx-onDurationTimer, drx-InactivityTimer, drx-RetransmissionTimerDL, drx-RetransmissionTimerUL, drx-HARQ-RTT-TimerDL, and/or drx-HARQ-RTT-TimerUL.

[0371] In some implementations, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may not stop one or more of a specific DRX timer(s) in some cases. For example, the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) may indicate which DRX timers can be stopped. For example, the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) may stop the DRX timer(s) for new transmission (e.g., drx-onDurationTimer, drx-InactivityTimer), but may not stop the specific DRX timers for retransmission (e.g., drx-RetransmissionTimerDL, drx-RetransmissionTimerUL, drx-HARQ-RTT-TimerDL, and/or drx-HARQ-RTT-TimerUL).

[0372] The specific DRX timer(s) may comprise drx-onDurationTimer, drx-InactivityTimer, drx-RetransmissionTimerDL, drx-RetransmissionTimerUL, drx-HARQ-RTT-TimerDL, and/or drx-HARQ-RTT-TimerUL.

[0373] In some implementations, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may perform PDCCH skipping. For example, the wireless device may not monitor PDCCH within a duration no matter whether it is DRX Active Time when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring).

[0374] In some implementations, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may perform SSSG switching to a specific SSSG. For example, the wireless device may monitor PDCCH on a set of search space configured by the specific SSSG when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring).

[0375] In some implementations, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may determine when to switch to the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring).

[0376] Upon receiving the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may switch to the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring).

[0377] In an example of FIG. **22**, after receiving the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may switch to the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) when a upper layer (e.g., MAC layer) of the wireless device receives an inter-layer indication from an upper layer (e.g., PHY layer) of the wireless device. For example, the inter-layer indication may indicates the MAC layer to stop the DRX timer(s). The MAC layer may switch to the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) after sending the feedback information for the indication (e.g., DCI).

[0378] In an example of FIG. **23**, after receiving the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may switch to the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) when a upper layer (e.g., MAC layer) of the wireless device receives an inter-layer indication from an upper layer (e.g., PHY layer) of the wireless device. For example, the inter-layer indication may indicate the MAC layer to stop the DRX timer(s). The EOBI and/or the indication to switch to a DRX Sleep State may further schedule a PDSCH transmission. The UE may switch to the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) after sending the feedback information for the PDSCH transmission.

[0379] In an example of FIG. **24**, after receiving the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may switch to the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) when a lower layer (e.g., MAC layer/PHY layer) of the wireless device receives an inter-layer indication from an upper layer (e.g., RRC/SDAP/PDCP/RLC/MAC layer) of the wireless device. For example, the inter-layer indication may indicate the MAC layer to stop the DRX timer(s) and/or indicate the PHY layer to skip PDCCH monitoring. The UE may switch to the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) after sending a response/feedback information for the PDSCH transmission.

[0380] After receiving the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may switch to the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) when/after the wireless device sends a response/indication/feedback information to the NW.

[0381] The feedback information may be a ACK and/or a NACK information. The ACK and/or the NACK information may be a feedback information for the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), The ACK and/or the NACK information may be a feedback information for a DCI. ACK and/or the NACK information may be a feedback information for a PDSCH scheduled by the DCI.

[0382] The response/indication/feedback information may be transmitted on a PUCCH and/or PUSCH.

[0383] The response/indication/feedback information may be a PDCP/RLC PDU, MAC CE and/or a UCI.

[0384] In some implementations, the wireless device may switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) for a duration/period. For example, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may switch to the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), and continue the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) until the duration/period ends.

[0385] The duration/period may be configured by the NW. For. Example, the duration/period may be configured by a value of an IE/parameter (of RRC configuration). The units of the value may be symbol, subframe, system frame, millisecond, and/or second.

[0386] The duration/period may be one or more DRX cycles. For example, the wireless device may switch to the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) at a first DRX cycle, and the wireless device may switch out of the DRX sleep state (e.g., start DRX Timer(s) and/or not skip PDCCH monitoring) at a second DRX cycle.

[0387] In some implementations, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may keep in the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) until receives another indication. For example, another indication may indicate the wireless device to switch out of the DRX sleep state (e.g., start DRX Timer(s) and/or not skip PDCCH monitoring).

[0388] In some implementations, a timer (e.g., DRX suspend timer) may be used to control whether the UE could start or restart a DRX timer(s) (e.g., DRX onduration and/or DRX inactivity timer). For example, while the timer (e.g., DRX suspend timer) is running the wireless device may not start or restart a DRX timer(s). The wireless device may start or restart a DRX timer(s) when the timer (e.g., DRX suspend timer) is not running.

[0389] In an example of FIG. **25**, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may start the timer (e.g., DRX suspend timer) and/or the wireless device may stop a DRX timer (e.g., DRX onduration timer). While the timer (e.g., DRX suspend timer) is running, the wireless device may not start a DRX timer (e.g., DRX onduration timer) for each DRX cycle (e.g., during the DRX cycle). While the timer (e.g., DRX suspend timer) is not running, the wireless device may (re-)start a DRX timer (e.g., DRX onduration timer) for each DRX cycle (e.g., during the DRX cycle).

[0390] In some implementations, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may determine to apply the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) for which DRX group(s).

[0391] In an example of FIG. **26**, the wireless device may be configured with a XR-specific group which comprises one or more cells (e.g., PCell and/or SCell (s)). When/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may apply the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring on a first cell(s) of the XR-specific DRX group, and may not apply the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring on a second cell(s) not in the XR-specific DRX group.

[0392] In some implementations, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may determine to apply the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) on which cell(s) and/or cell group (e.g., dormancy SCell group).

[0393] In an example, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may apply the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) on a SCell(s) but not on the PCell.

[0394] In an example, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may apply the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) on a SCell(s) of the dormancy SCell group 1 but not on the PCell and/or SCells which are not associated with the dormancy Scell group 1.

[0395] In an example, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may apply the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) on a cell which indicates the EOBI and/or the indication, but not other cells.

[0396] In some implementations of FIG. **27**, an "UL EOBI" may be indicated by the wireless device to the NW. The EOBI indicated by the wireless device may be used to indicate and end of data burst for UL traffic. The UL EOBI may be a request for switching to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring).

[0397] In some implementations, the UL EOBI may be indicated by a RRC message, a SDAP signaling, a PDCP signaling, RLC signaling, a MAC CE, and/or a PHY signaling.

[0398] The UL EOBI may be indicated by the RRC message via a UE assistance information. The UL EOBI may be indicated by the SDAP/PDCP/RLC via a header, a control PDU, and/or a data PDU. The header, the control PDU, and/or the data PDU may comprise an end marker. The header, the control PDU, and/or the data PDU may comprise a sequence number (SN) to indicate it. The UL EOBI may be indicated by the MAC CE via zero, one, or more bits. The UL EOBI may be indicated by a BSR MAC CE. The UL EOBI may be indicated by PHY signaling via a UCI.

[0399] In some implementations, the wireless device may trigger/transmit the "UL EOBI" when the wireless device detects there in an end of a data burst and/or end of one or more PDU set(s).

[0400] In some implementations, the wireless device may trigger/transmit the "UL EOBI" based on remaining time of a PDU/PDU set/data burst, based on PSDB and/or based on PSER. For example, when the wireless device detects that the remaining time of a PDU/PDU set/data burst is lower than a threshold (e.g., based on PSDB), the wireless device trigger/transmit the "UL EOBI".

[0401] The "UL EOBI" information may be indicated via a BSR MAC CE. For example, the "UL EOBI" information may be comprised in the field of the BSR MAC CE.

[0402] In some implementations, the wireless device may trigger a BSR (procedure) and/or SR for the UL EOBI. For example, when the wireless device detects the end of data burst (e.g., based an indication from upper layer, a header, a Sequence Number (SN) of a data, and/or a threshold), the wireless device may trigger a BSR and/or SR. More specifically, the wireless device may set the value of the buffer size field of the BSR to a specific value (e.g., zero).

[0403] The wireless device may set the value of the buffer size field associated with a Logical Channel Group (LCG) ID of the BSR to a specific value (e.g., zero). More specifically, the wireless device may trigger a specific BSR report (e.g., a BSR without LCG and/or buffer size).

[0404] In some implementations, the wireless device may trigger a BSR (procedure) and/or SR based on PSDB and/or remaining time information. For example, when the wireless device detects that the remaining time of a PDU/PDU set/data burst is lower than a threshold (e.g., based on PSDB), the wireless device may trigger a BSR (procedure) and/or SR.

[0405] The wireless device may detect the remaining time of a PDU/PDU set/data burst for one or more QoS flow/DRB/LCH(s)/LCG(s).

[0406] The threshold may be configured in BSR configuration, SR configuration, and/or LCH configuration.

[0407] In some implementations, the wireless device may switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) when/after triggering/transmitting the "UL EOBI".

[0408] In some implementations, the wireless device may switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) when/after skipping one or more UL grants (or UL transmission) (e.g., based on a counter).

[0409] In some implementations, the wireless device may switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) based on the "UL EOBI" for a duration/period. For example, when/after the wireless device triggers/transmits the UL EOBI, the wireless device may switch to the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), and continue the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) until the duration/period ends.

[0410] The duration/period may be configured by the NW. For. Example, the duration/period may be configured by a value of an IE/parameter (of RRC configuration). The units of the value may be symbol, subframe, system frame, millisecond, second, and/or DRX cycle. The duration/period may be one or more DRX cycles. For example, the wireless device may switch to the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) at a first DRX cycle, and the wireless device may switch out of the DRX sleep state (e.g., start DRX Timer(s) and/or not skip PDCCH monitoring) at a second DRX cycle.

[0411] In some implementations, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may keep in the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) until receives another indication. For example, another indication may indicate the wireless device to switch out of the DRX sleep state (e.g., start DRX Timer(s) and/or not skip PDCCH monitoring).

[0412] In some implementations, when/after the wireless device receives the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), the wireless device may keep in the DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring) until the wireless device triggers a BSR, SR, and/or RA procedure.

[0413] A wireless device may be configured with multiple DRX configurations. The multiple DRX configurations may comprised different DRX parameters (e.g., drx-onDurationTimer, drx-InactivityTimer, drx-HARQ-RTT-TimerDL, drx-HARQ-RTT-TimerUL, drx-RetransmissionTimerDL, drx-RetransmissionTimerUL, drx-LongCycleStartOffset, shortDRX, drx-ShortCycle, drx-ShortCycleTimer, drx-SlotOffset).

[0414] In some implementations, the wireless device may switch the DRX configuration from a first DRX configuration to a second DRX configuration.

[0415] In some implementations, the wireless device may determine whether to switch the DRX configuration from a first DRX configuration to a second DRX configuration based on an indication. For example, when/after the wireless device receives an indication, the wireless device may switch the DRX configuration from a first DRX configuration to a second DRX configuration.

[0416] In some implementations, the indication may be the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring). The indication may be UL EOBI.

[0417] The indication may be a DCI, MAC CE, and/or RRC configuration. The indication may be a DCP. The indication may indicate the value/configuration of time offset and/or start offset. The indication may indicate one or more index of the DRX configuration. For example, when the wireless device receives the indication indicating an index of the DRX configuration, the wireless device may switch to the DRX configuration based on the index. The indication may indicate information of a MAC entity/DRX group/DRX configuration/Cell Group (MCG/SCG)/cell/serving cell/BWP/set of cells. The indication may indicate the specific DRX cycle. The indication may be a UL grant and/or a DL assignment that schedules XR traffics. The indication may be a DCI received on a PDCCH/search space/CORESET configured for XR traffics. The indication may be a PDCCH/DCI addressed to a specific RNTI (e.g., XR-RNTI). The indication may be a PDCCH/DCI monitored/received on a specific search space/CORESET (e.g., for XR). The indication may be a PDCCH/DCI with a specific DCI format (e.g., for XR).

[0418] In some implementations, when/after the wireless device receives the indication, the wireless device may determine when to switch the DRX configuration from a first DRX configuration to a second DRX configuration.

[0419] In an example, upon receiving the indication to switch the DRX configuration, the wireless device may switch the DRX configuration from a first DRX configuration to a second DRX configuration.

[0420] In an example, after receiving the indication to switch the DRX configuration, the wireless device may switch the DRX configuration from a first DRX configuration to a second DRX configuration when a upper layer (e.g., MAC layer) of the wireless device receives an inter-layer indication from an upper layer (e.g., PHY layer) of the wireless device. In an example, the inter-layer indication may indicate the MAC layer to switch the DRX configuration from a first DRX configuration to a second DRX configuration after sending the feedback information for the indication (e.g., DCI).

[0421] In an example, after receiving the indication to switch the DRX configuration, the wireless device may switch the DRX configuration from a first DRX configuration to a second DRX configuration when a upper layer (e.g., MAC layer) of the wireless device receives an inter-layer indication from an upper layer (e.g., PHY layer) of the wireless device. For example, the inter-layer indication may indicate the MAC layer to switch the DRX configuration. The indication to switch the DRX configuration may further schedule a PDSCH transmission. The UE may switch the DRX configuration from a first DRX configuration to a second DRX configuration after sending the feedback information for the PDSCH transmission.

[0422] In an example, after receiving the indication to switch the DRX configuration, the wireless device may switch the DRX configuration from a first DRX configuration to a second DRX configuration when a lower layer (e.g., MAC layer/PHY layer) of the wireless device receives an inter-layer indication from an upper layer (e.g., RRC/SDAP/PDCP/RLC/MAC layer) of the wireless device. For example, the inter-layer indication may indicate the MAC layer to switch the DRX configuration from a first DRX configuration to a second DRX configuration. The UE may switch the DRX configuration from a first DRX configuration to a second DRX configuration after sending a response/feedback information for the PDSCH transmission.

[0423] In an example, after receiving the indication to switch the DRX configuration from a first DRX configuration to a second DRX configuration, the wireless device may switch the DRX configuration from a first DRX configuration to a second DRX configuration when/after the wireless device sends a response/indication/feedback information to the NW.

[0424] The feedback information may be a ACK and/or a NACK information. The ACK and/or the NACK information may be a feedback information for the EOBI and/or the indication to switch to a DRX Sleep State (e.g., stop DRX Timer(s) and/or skip PDCCH monitoring), The ACK and/or the NACK information may be a feedback information for a DCI. ACK and/or the NACK information may be a feedback information for a PDSCH scheduled by the DCI.

[0425] The response/indication/feedback information may be transmitted on a PUCCH and/or PUSCH. The response/indication/feedback information may be a PDCP/RLC PDU, MAC CE and/or a UCI.

[0426] In some implementations, the wireless device may switch the DRX configuration from a first DRX configuration to a second DRX configuration for a duration/period. For example, when/after the wireless device receives the indication to switch the DRX configuration, the wireless device may switch the DRX configuration from a first DRX configuration to a second DRX configuration and keep in the second DRX configuration until the duration/period ends.

[0427] The duration/period may be configured by the BS. For. Example, the duration/period may be configured by a value of an IE/parameter (of RRC configuration). The units of the value may be symbol, subframe, system frame, millisecond, and/or second. The duration/period may be one or more DRX cycles. For example, the wireless device may switch the DRX configuration from a first DRX configuration to a second DRX configuration at a first DRX cycle, and the wireless device may switch the DRX configuration from a first DRX configuration to a second DRX configuration at a second DRX cycle.

[0428] In some implementations, when/after the wireless device receives the indication to switch the DRX configuration from a first DRX configuration to a second DRX configuration, the wireless device may keep in second DRX configuration until receives another indication. For example, another indication may indicate the wireless device to switch the DRX configuration.

[0429] In some implementations, a timer (e.g., DRX suspend timer) may be used to control how long the wireless device should keep in a second DRX configuration (e.g., after switching the DRX configuration from a first DRX configuration to a second DRX configuration). For example, when/after the wireless device switches the DRX configuration from a first DRX configuration to a second DRX configuration, the wireless device may start a timer. While the timer is running, the wireless device may keep in the second DRX configuration. When the timer expires, the wireless device may switch the DRX configuration from the second DRX configuration to the first DRX configuration.

[0430] In an example embodiment (e.g., as shown in FIG. **28**), a wireless device may receive a DRX configuration. The wireless device may start one or more DRX timers based on the DRX configuration. The wireless device may receive an indication. The wireless device may transmit feedback information of the indication. The wireless device may stop the one or more DRX timers based on transmitting the feedback information.

[0431] In an example embodiment (e.g., as shown in FIG. **29**), a wireless device may receive a discontinuous reception (DRX) configuration. Based on the DRX configuration, the wireless device may start or restart a DRX inactivity timer in response to a new transmission associated with one or more data packets. Based on the DRX configuration, the wireless device may start or restart a DRX retransmission timer in response to retransmission associated with one or more data packets. The wireless device may receive downlink control information (DCI) indicating an end of the one or more data packets. The wireless device may transmit feedback information of the DCI. The wireless device may, based on transmitting the feedback information, stop the DRX inactivity timer and/or not stop the DRX retransmission timer.

[0432] According to an example embodiment, the indication indicates an end of data burst. According to an example embodiment, the indication indicates a stop of a DRX Active Time. According to an example embodiment, the indication indicates a stop of one or more DRX timers. According to an example embodiment, the indication indicates by a header of a PDCP PDU or a header of a RLC PDU. According to an example embodiment, the indication is indicated by a RRC message, a PDCP control PDU, ad RLC control PDU, a MAC CE, or a DCI.

[0433] According to an example embodiment, the one or more data packets is a data burst. According to an example embodiment, the one or more data packets is associated with a PDU set. According to an example embodiment, the one or more data packets are UL data or DL data. According to an example embodiment, the PDU is a SDAP PDU, a PDCP PDU, a RLC PDU, or a MAC PDU. According to an example embodiment, the SDU is a SDAP SDU, a PDCP SDU, a RLC SDU, a MAC SDU, or a PHY SDU.

[0434] According to an example embodiment, the DCI is received on PDCCH. According to an example embodiment, the DCI is a DCI scrambled by a PS-RNTI (DCP). According to an example embodiment, the DCI is monitored on a power saving search space.

[0435] According to an example embodiment, the DRX timer comprises one or more of drx-onDurationTimer, drx-InactivityTimer, drx-RetransmissionTimerDL, drx-RetransmissionTimerUL, drx-HARQ-RTT-TimerDL, and drx-HARQ-RTT-TimerUL.

[0436] According to an example embodiment, the feedback information is HARQ feedback information. According to an example embodiment, the feedback information is included in a STATUS PDU. According to an example embodiment, the feedback information is ACK or NACK. According to an example embodiment, the feedback information is transmitted on PUCCH or PUSCH.

[0437] In an example embodiment (e.g., as shown in FIG. **30**), the wireless device may start one or more DRX timers in response to one or more transmission associated with one or more data packets. The wireless device may receive downlink control information (DCI) comprising an indication and/or downlink assignment of a last data packet of the one or more data packets. The wireless device may transmit feedback information of the last data packet. The wireless device may stop the one or more DRX timers based on the indication and transmitting the feedback information.

[0438] In an example embodiment (e.g., as shown in FIG. **31**), a wireless device may receive a message comprising a DRX configuration. Based on the DRX configuration, the wireless device may start or restart a DRX inactivity timer in response to a new transmission associated with one or more data packets. Based on the DRX configuration, the wireless device may start or restart a DRX retransmission timer in response to a retransmission associated with the one or more data packets. The wireless device may receive downlink control information (DCI). The DCI may comprise an indication of an end of the one or more data packets and/or downlink assignment of a last data packet of the one or more data packets. The wireless device may receive, based on the downlink assignment, the last data packet. The wireless device may transmit feedback information of the last data packet. Based on the indication and transmitting the feedback information, the wireless device may stop the DRX inactivity timer and/or not stop the DRX retransmission timer.

[0439] According to an example embodiment, the last data packet may be transmitted via a physical downlink shared channel (PDSCH).

[0440] In an example embodiment (e.g., as shown in FIG. **32**), the wireless device may receive an indication. The wireless device may start a suspend timer based on the indication. The wireless device may not start a DRX timer, during a first DRX cycle, based on the suspend timer being running. The wireless device may start the DRX timer, during a second DRX cycle, based on the suspend timer being not running.

[0441] In an example embodiment (e.g., as shown in FIG. **33**), a wireless device may receive a discontinuous reception (DRX) configuration comprising parameters of a DRX on-duration timer and/or a DRX suspend timer. The wireless device may receive or transmit one or more data packets. The wireless device may receive an indication indicating an end of the one or more data packets. The wireless device may start the DRX suspend timer based on the indication. The wireless device may not start the DRX on-duration timer, during a first DRX cycle, based on the DRX suspend timer being running. The wireless device may start the DRX on-duration timer, during a second DRX cycle, based on the DRX suspend timer being not running.

[0442] According to an example embodiment, the suspend timer is configured by a DRX configuration.

[0443] According to an example embodiment, the DRX timer is started at the beginning of the DRX cycle. According to an example embodiment, the DRX timer being not running after the DRX timer is stopped. According to an example embodiment, the DRX timer being not running after the DRX timer is expiry.

[0444] According to an example embodiment, the DRX cycle is a short DRX cycle or a long DRX cycle.

[0445] In an example embodiment, a wireless device may receive, by an upper layer of the wireless device, a header of a PDU. The wireless device may indicate an instruction, by the upper layer of the wireless device to a MAC layer of the wireless device, to stop a DRX timer based on the header of the PDU. The wireless device may stop the DRX timer on a specific timing, by the MAC layer of the wireless device, in response to the instruction. For example, the specific timing may include one or more of: (1) when receiving the instruction; and/or (2) when transmitting a signaling.

[0446] According to an example embodiment, the header includes an end marker. According to an example embodiment, the header indicates an end of a data burst or an end of a PDU set.

[0447] According to an example embodiment, the upper layer is a PDCP layer, a RLC layer, or a SDAP layer.

[0448] According to an example embodiment, the signaling is a UCI or a MAC CE. According to an example embodiment, the signaling is transmitted on a PUCCH or a PUSCH.

[0449] In an example embodiment, a wireless device may receive a first DRX configuration and a second DRX configuration. The wireless device may activate the first DRX configuration and may deactivate the second DRX configuration. The wireless device may start or restart a DRX timer based on the first DRX configuration, The wireless device may detect, by a physical layer of wireless device, a Downlink Control Information (DCI). The wireless device may indicate an instruction, by the physical layer of the wireless device to a MAC layer of the wireless device, to switch the first DRX configuration to a second DRX configuration based on a field of the DCI. The wireless device may deactivate the first DRX configuration and may activate the second DRX configuration in response to the instruction. The wireless device may start or restart the DRX timer based on the second DRX configuration.

[0450] According to an example embodiment, the wireless device may start or restart the DRX timer for a first group of cells. The wireless device may not start or restart the DRX timer for a second group of cells.

[0451] In an example embodiment, a wireless device may detect, by a physical layer of wireless device, a Downlink Control Information (DCI). The wireless device may indicate an instruction, by the physical layer of the wireless device to a MAC layer of the wireless device, to stop a DRX timer based on a field of the DCI. The wireless device may stop the DRX timer on a specific timing, by the MAC layer of the wireless device, in response to the instruction. For example, the specific timing may include one or more of: (1) when receiving the instruction and/or (2) when transmitting a HARQ feedback information for the DCI.

[0452] According to an example embodiment, the instruction indicates to stop the DRX timer if the field indicates a first value. According to an example embodiment, the instruction indicates to not stop the DRX timer if the field indicates a second value.

[0453] According to an example embodiment, the specific timing further comprises a processing time. According to an example embodiment, the specific timing further comprises an application delay.

[0454] According to an example embodiment, the wireless device may start or restart the DRX timer on the specific timing if the field of the DCI indicates a specific value.

[0455] In an example embodiment, the wireless device may detect, by a physical layer of the wireless device, a Downlink Control Information (DCI). The wireless device may receive, by the physical layer of the wireless device, a PDSCH scheduled by the DCI. The wireless device may indicate an instruction, by the physical layer of the wireless device to a MAC layer of the wireless device, to stop a DRX timer based on a field of the DCI. The wireless device may stop the DRX timer on a specific timing, by the MAC layer of the wireless device, in response to the instruction. For example, the specific timing may includes one or more of: (1) when receiving the instruction and/or (2) when transmitting a HARQ feedback information for the PDSCH.

[0456] According to an example embodiment, the wireless device may stop a DRX on-duration timer, a DRX inactivity timer, and/or a DRX retransmission timer if the HARQ feedback information is the ACK.

[0457] According to an example embodiment, the wireless device may stop a DRX on-duration timer and/or a DRX inactivity timer, if the HARQ feedback information is the NACK.

[0458] In an example embodiment, a wireless device may receive an indication. The wireless device may stop a DRX timer in response to receiving the indication. The wireless device may start a specific timer in response to stopping the DRX timer. The wireless device may determine whether to start a DRX on-duration timer based on whether the specific timer is running. The wireless device may start a DRX on-duration timer if the specific timer is not running. The wireless device may not start a DRX on-duration timer if the specific timer is running.

[0459] According to an example embodiment, the wireless device may restart the specific timer, when the specific timer is running, in response to receiving the indication.

[0460] According to an example embodiment, the wireless device may stop the specific timer in response to receiving the indication and the indication indicating a specific value.

[0461] According to an example embodiment, the wireless device may stop the specific timer in response to receiving a second indication.

[0462] According to an example embodiment, the wireless device may stop the specific timer in a case that the wireless device triggers a scheduling request (SR).

[0463] According to an example embodiment, the wireless device may stop the specific timer in a case that the wireless device initiates a RA procedure.

[0464] FIG. **34** illustrates an example embodiment of DRX operation. At **3401**, a wireless device may receive a DRX configuration. At **3402**, the wireless device may start one or more DRX timers based on the DRX configuration. At **3403**, the wireless device may receive an indication. At **3404**, the wireless device may transmit feedback information of the indication. At **3405**, the wireless device may stop the one or more DRX timers based on transmitting the feedback information.

What is claimed is:

1. A wireless device comprising:
one or more processors; and
memory storing instructions that, when executed by the one or more processors, cause the wireless device to:
receive a discontinuous reception (DRX) configuration;
start, based on the DRX configuration, a first DRX timer in response to a new transmission associated with one or more data packets;
receive downlink control information (DCI) indicating an end of the one or more data packets;
transmit feedback information of the DCI; and
stop, based on transmitting the feedback information, the first DRX timer.

2. The wireless device of claim **1**, wherein the instructions further cause the wireless device to start, based on the DRX configuration, a second DRX timer in response to a retransmission associated with the one or more data packets.

3. The wireless device of claim **2**, wherein the instructions further cause the wireless device to not stop, based on transmitting the feedback information, the second DRX timer.

4. The wireless device of claim **2** wherein the second DRX timer is a DRX retransmission timer.

5. The wireless device of claim **1**, wherein the first DRX timer is a DRX inactivity timer.

6. The wireless device of claim **1**, wherein the DCI further indicates an end of a data burst comprising the one or more data packets.

7. The wireless device of claim **1**, wherein the DCI further indicates a stop of a DRX active time.

8. The wireless device of claim **1**, wherein the one or more data packets is associated with a protocol data unit (PDU) set or a data burst.

9. The wireless device of claim **1**, wherein the feedback information comprises hybrid automatic repeat request (HARQ) feedback information indicating an acknowledgement (ACK) or an negative ACK (NACK).

10. The wireless device of claim **1**, wherein the instructions further cause the wireless device to transmit the feedback information on:
a physical uplink control channel (PUCCH); or
a physical uplink shared channel (PUSCH).

11. A method comprising:
receiving, by a wireless device, a discontinuous reception (DRX) configuration;
starting, based on the DRX configuration, a first DRX timer in response to a new transmission associated with one or more data packets;
receiving downlink control information (DCI) indicating an end of the one or more data packets;
transmitting feedback information of the DCI; and
stopping, based on the transmitting the feedback information, the first DRX timer.

12. The method of claim **11**, further comprising starting, based on the DRX configuration, a second DRX timer in response to a retransmission associated with the one or more data packets.

13. The method of claim **12**, further comprising not stopping, based on the transmitting the feedback information, the second DRX timer.

14. The method of claim **12** wherein the second DRX timer is a DRX retransmission timer.

15. The method of claim **11**, wherein the first DRX timer is a DRX inactivity timer.

16. The method of claim **11**, wherein the DCI further indicates an end of a data burst comprising the one or more data packets.

17. The method of claim **11**, wherein the DCI further indicates a stop of a DRX active time.

18. The method of claim **11**, wherein the one or more data packets is associated with a protocol data unit (PDU) set or a data burst.

19. The method of claim **11**, wherein the feedback information comprises hybrid automatic repeat request (HARQ) feedback information indicating an acknowledgement (ACK) or an negative ACK (NACK).

20. A non-transitory computer-readable medium comprising instructions that, when executed by one or more processors of a wireless device, cause the wireless device to:

receive a discontinuous reception (DRX) configuration;

start, based on the DRX configuration, a first DRX timer in response to a new transmission associated with one or more data packets;

receive downlink control information (DCI) indicating an end of the one or more data packets;

transmit feedback information of the DCI; and

stop, based on transmitting the feedback information, the first DRX timer.

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