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(54) SIDELINK COMMUNICATIONS IN UNLICENSED BAND

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

(72) Inventors: **Huifa Lin**, Reston, VA (US); **Hyoungsuk Jeon**, Centreville, VA (US); **Esmael Hejazi Dinan**, McLean, VA (US); **Bing Hui**, Nanjing (CN); **Nazanin Rastegardoost**, McLean, VA (US); **Jongwoo Hong**, Vienna, VA (US); **Taehun Kim**, Fairfax, VA (US)

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

(21) Appl. No.: **19/096,283**

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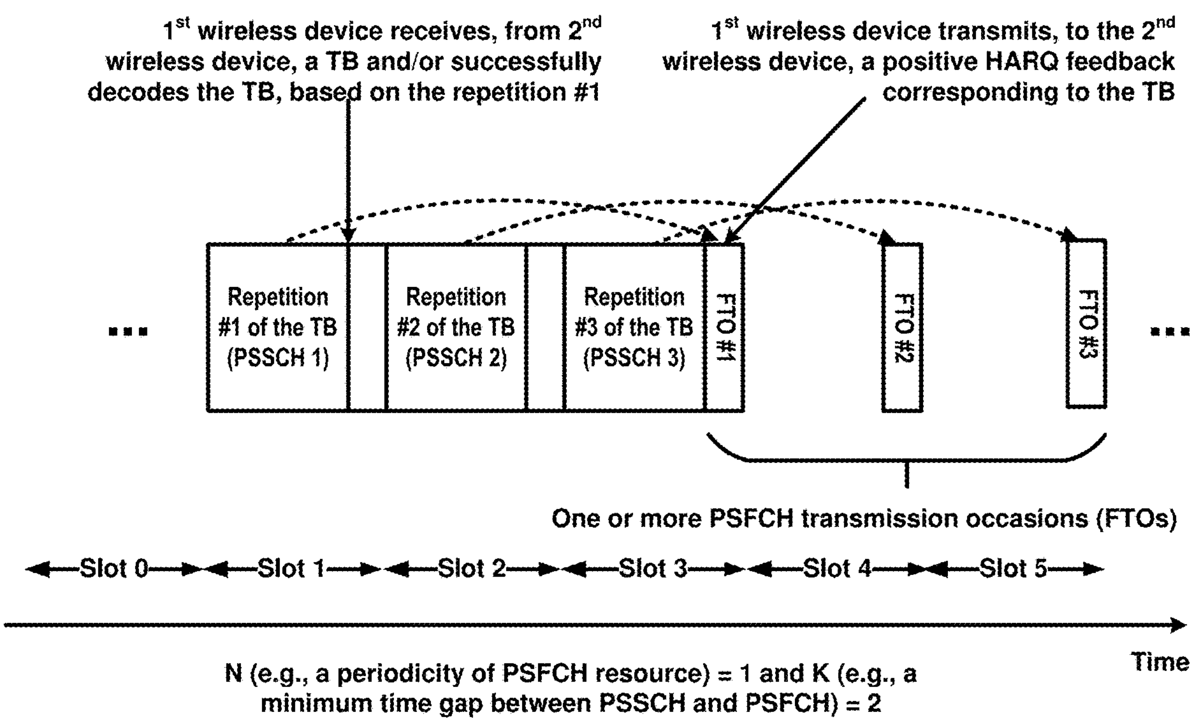
H04W 72/044 (2023.01)
H04W 74/0808 (2024.01)

(52) **U.S. Cl.**
CPC ***H04W 72/25*** (2023.01); ***H04W 72/044*** (2013.01); ***H04W 74/0808*** (2013.01)

(57) **ABSTRACT**

A first wireless device determines, for transmission of a physical sidelink feedback channel (PSFCH) for a transport block (TB), a plurality of PSFCH transmission occasions associated with the TB, based on: a number of slots between a slot comprising a PSFCH resource and a last slot of reception of the TB, and a periodicity of the slot comprising the PSFCH resource. The first wireless device performs, in response to not transmitting the PSFCH via one or more first PSFCH transmission occasions, a channel access procedure to transmit the PSFCH, via a second PSFCH transmission occasion among the plurality of PSFCH transmission occasions, wherein the second PSFCH transmission occasion occurs after the one or more first PSFCH transmission occasions. The first wireless device transmits, via the second PSFCH transmission occasion and based on performing the channel access procedure, the PSFCH.



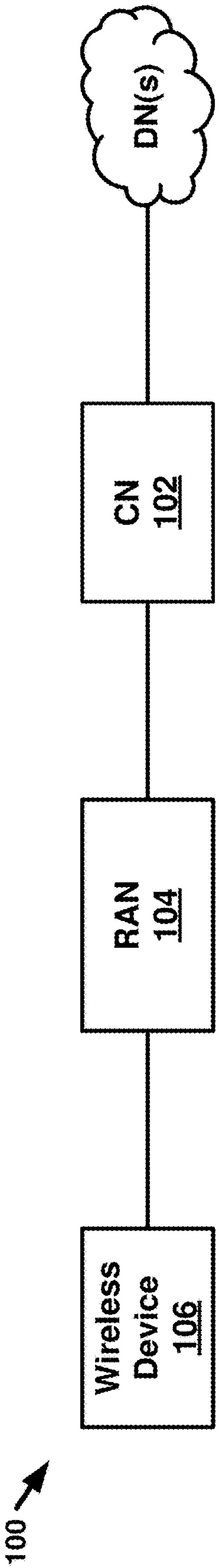

100
Wireless Device 106
RAN 104
CN 102
DN(s)

FIG. 1A

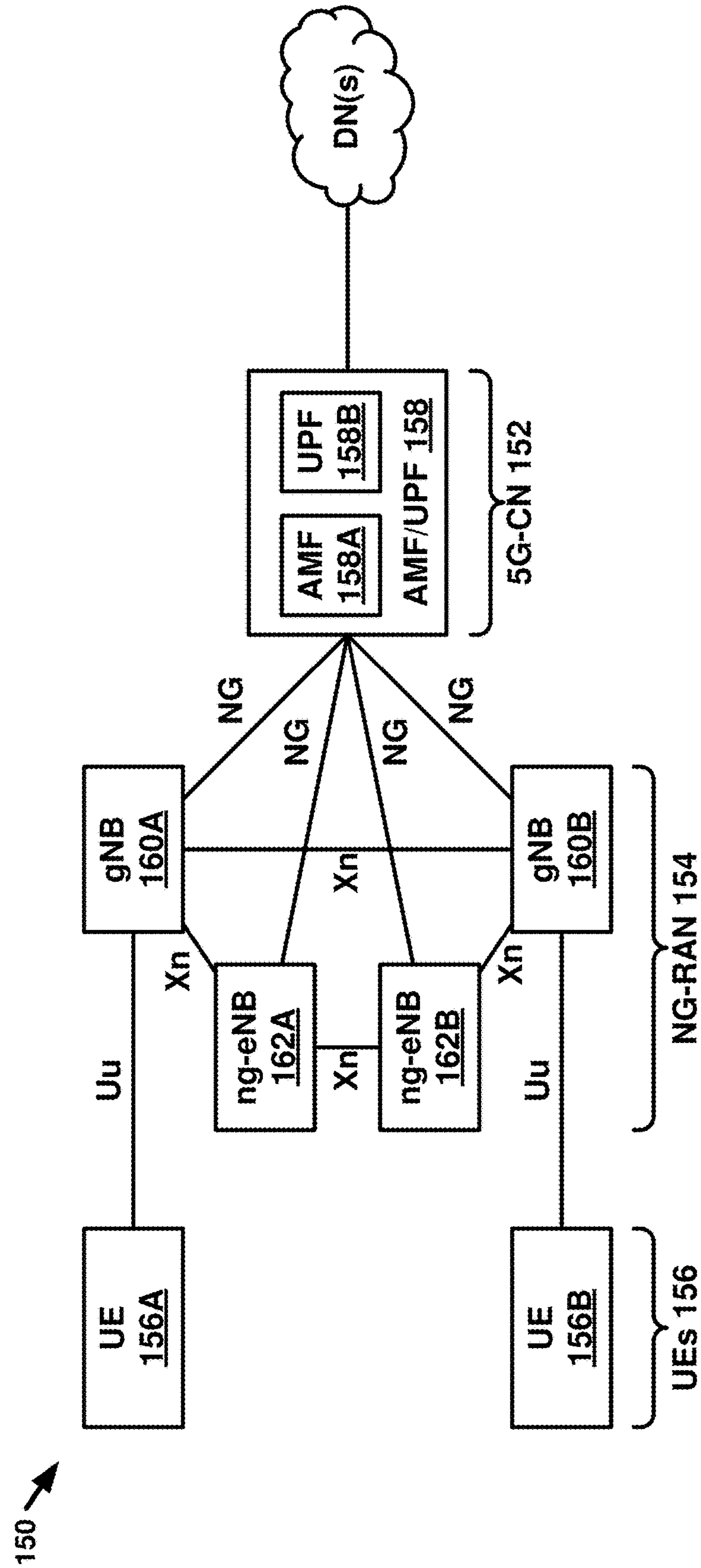

150
UE 156A
UE 156B
UEs 156
Uu
Uu
gNB 160A
gNB 160B
ng-eNB 162A
ng-eNB 162B
Xn
Xn
Xn
Xn
NG-RAN 154
NG
NG
NG
NG
AMF 158A
UPF 158B
AMF/UPF 158
5G-CN 152
DN(s)

FIG. 1B

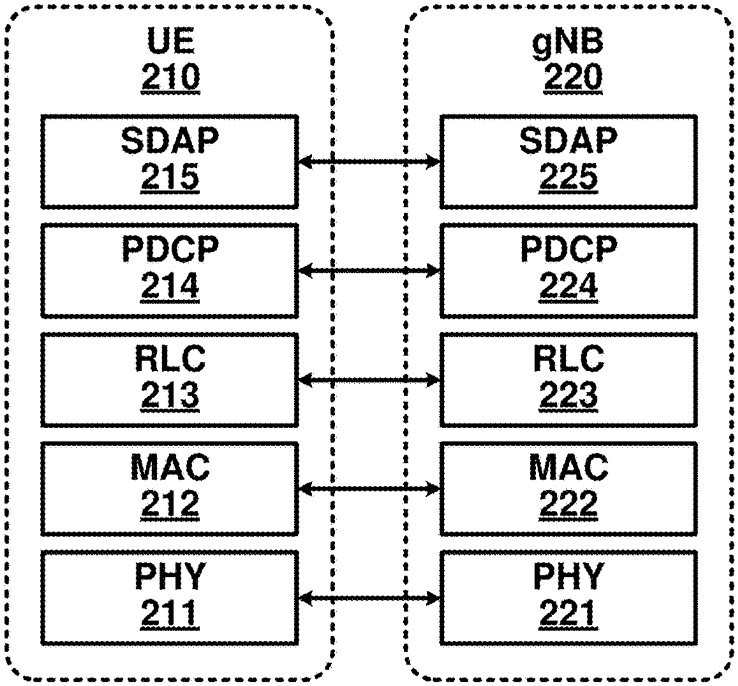

UE
210
SDAP
215
PDCP
214
RLC
213
MAC
212
PHY
211
gNB
220
SDAP
225
PDCP
224
RLC
223
MAC
222
PHY
221

FIG. 2A

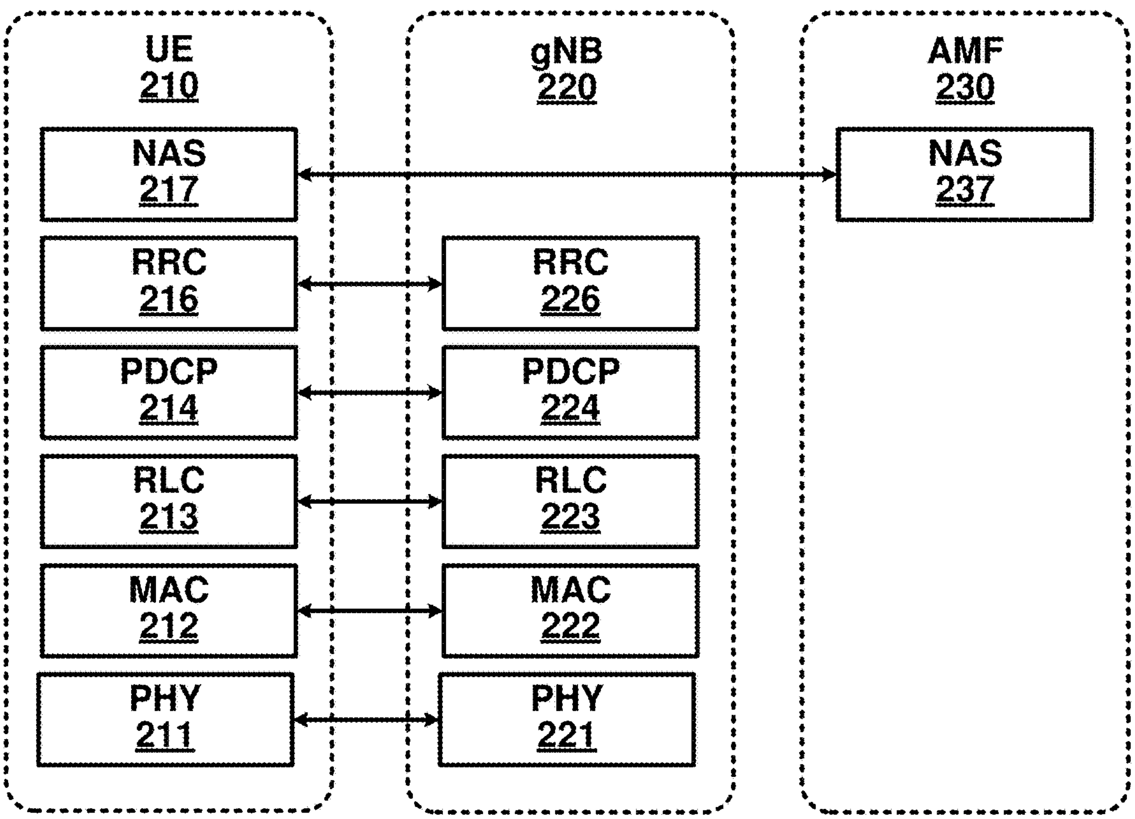
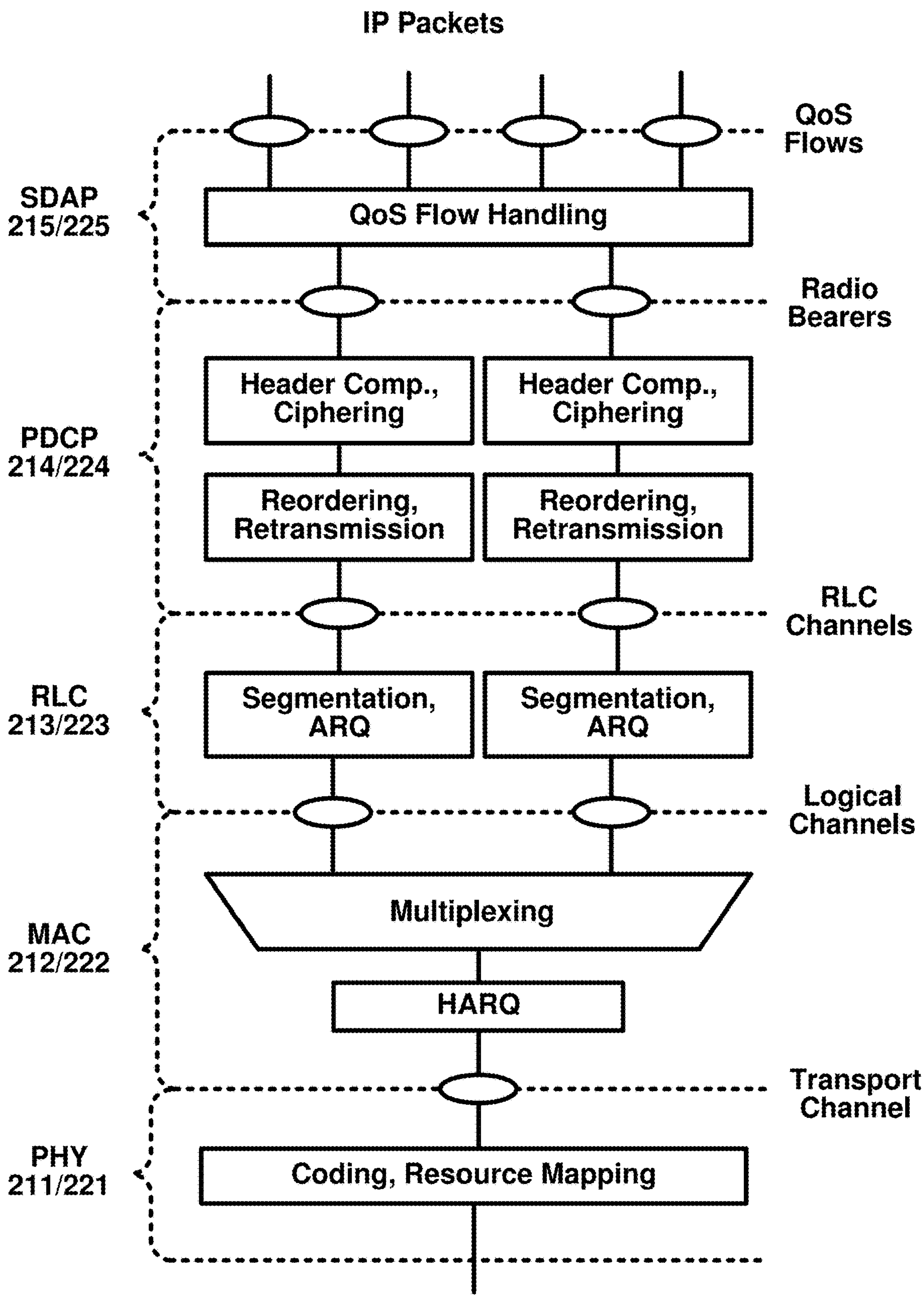

UE
210
NAS
217
RRC
216
PDCP
214
RLC
213
MAC
212
PHY
211
gNB
220
RRC
226
PDCP
224
RLC
223
MAC
222
PHY
221
AMF
230
NAS
237

FIG. 2B



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

FIG. 3

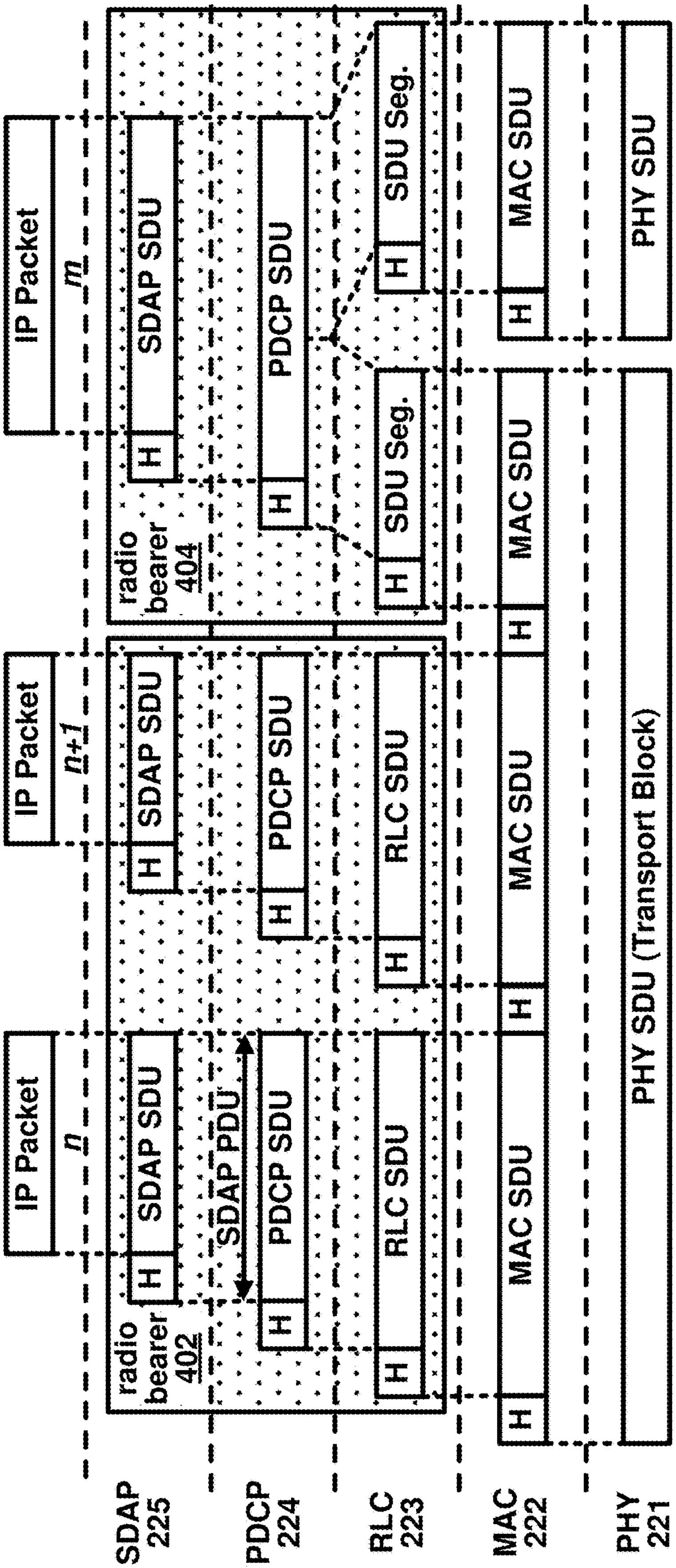

SDAP 225
PDCP 224
RLC 223
MAC 222
PHY 221
IP Packet n
IP Packet n+1
IP Packet m
radio bearer 402
radio bearer 404
H
SDAP SDU
SDAP PDU
PDCP SDU
RLC SDU
SDU Seg.
MAC SDU
PHY SDU (Transport Block)
PHY SDU

FIG. 4A

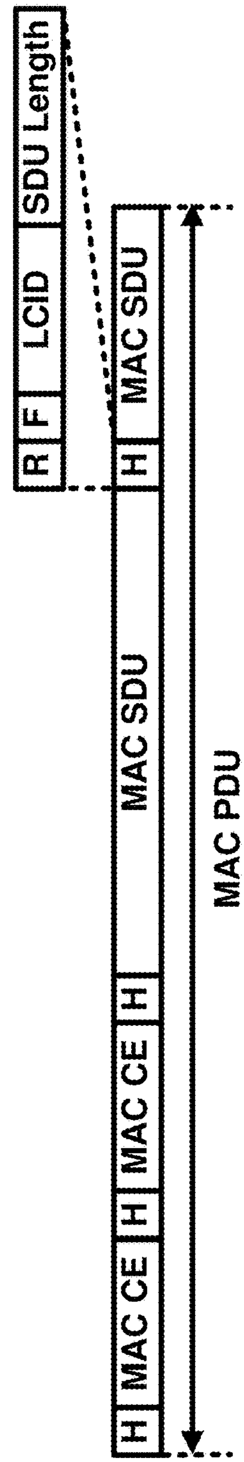

R
F
LCID
SDU Length
H
MAC CE
MAC SDU
MAC PDU

FIG. 4B

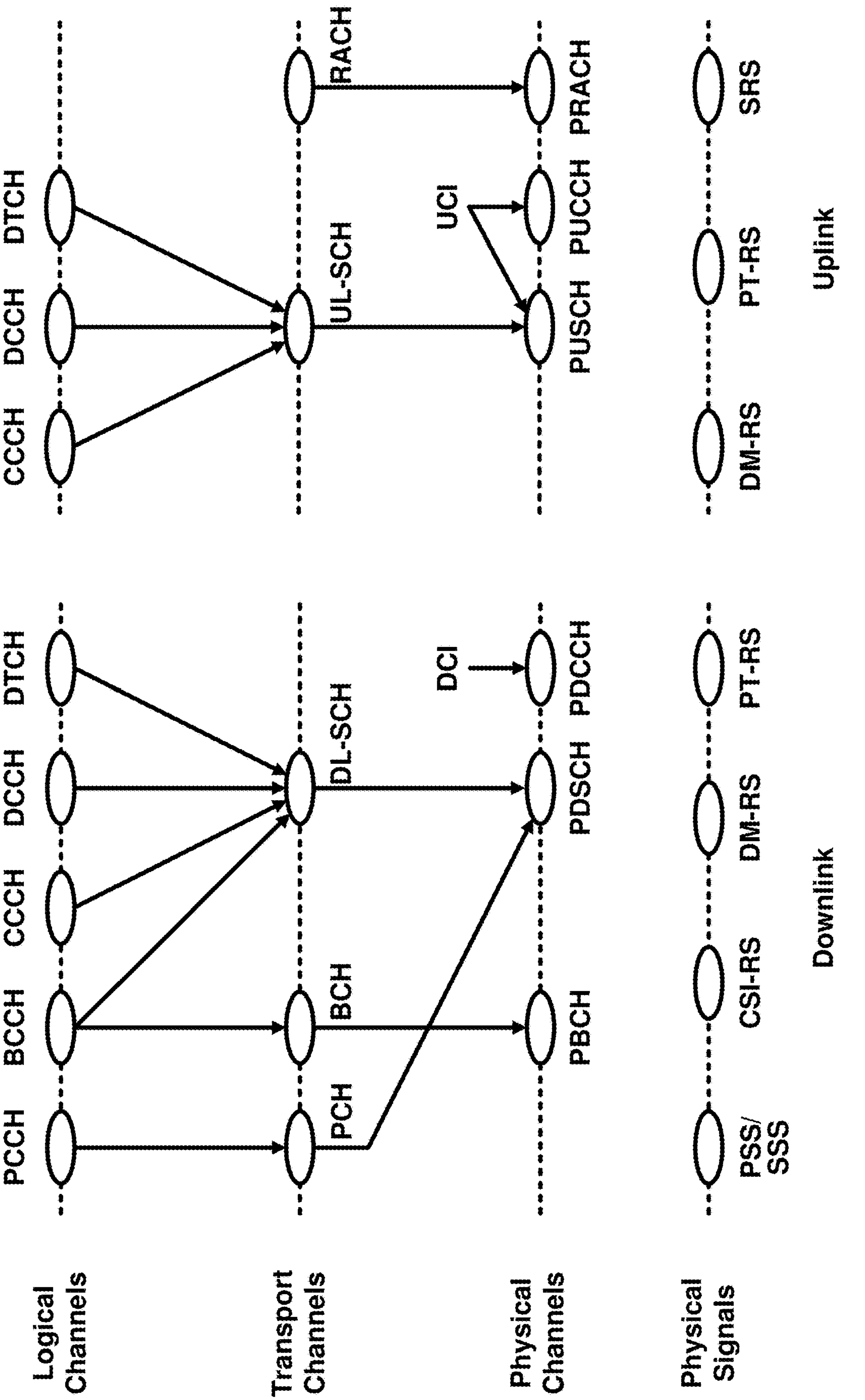

Logical Channels
Transport Channels
Physical Channels
Physical Signals
PCCH
BCCH
CCCH
DCCH
DTCH
PCH
BCH
DL-SCH
PBCH
PDSCH
PDCCH
DCI
PSS/ SSS
CSI-RS
DM-RS
PT-RS
Downlink
CCCH
DCCH
DTCH
UL-SCH
RACH
PUSCH
PUCCH
PRACH
UCI
DM-RS
PT-RS
SRS
Uplink

FIG. 5A

FIG. 5B

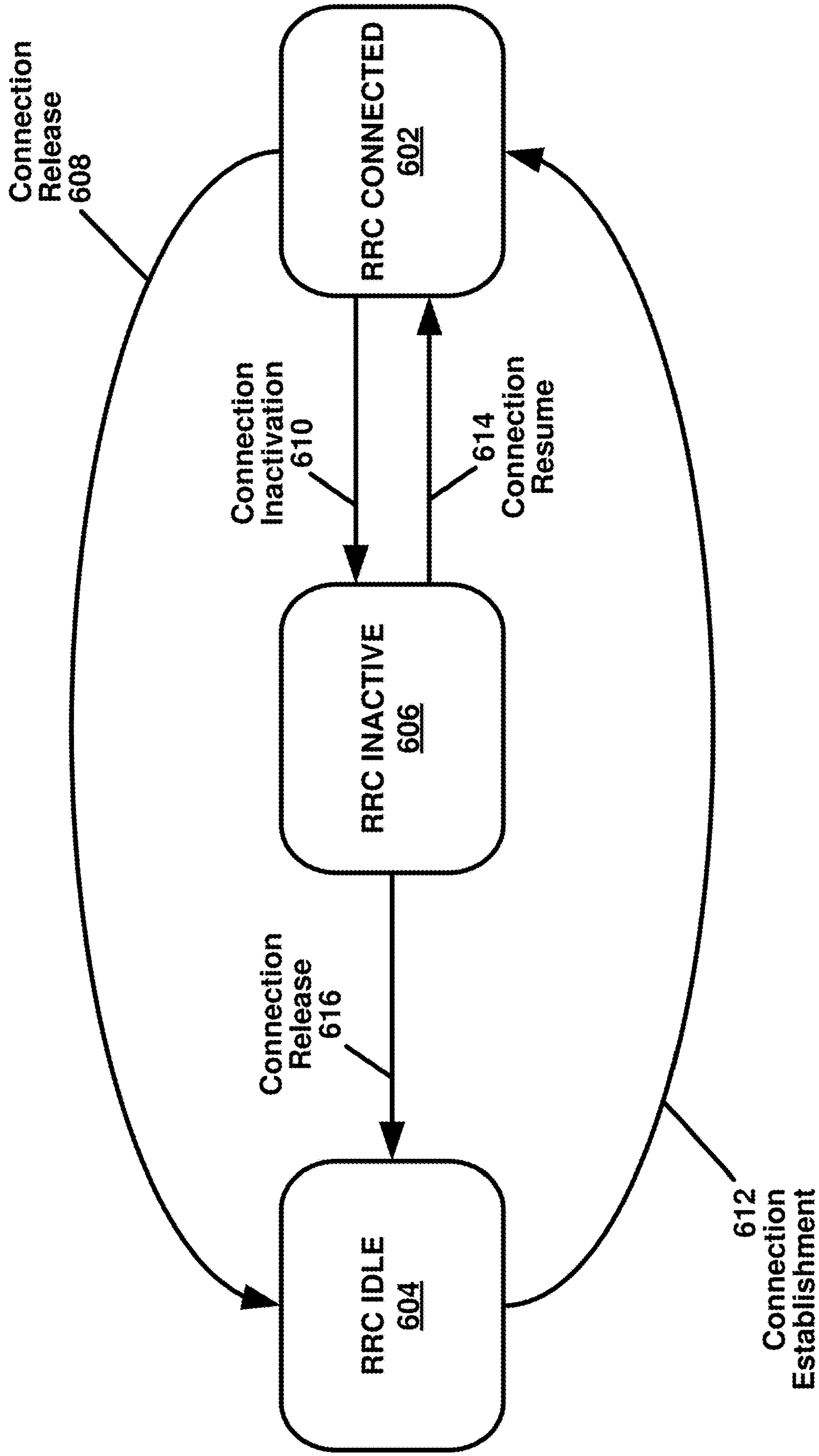

RRC CONNECTED
602
RRC INACTIVE
606
RRC IDLE
604
Connection Release 608
Connection Inactivation 610
612 Connection Establishment
614 Connection Resume
Connection Release 616

FIG. 6

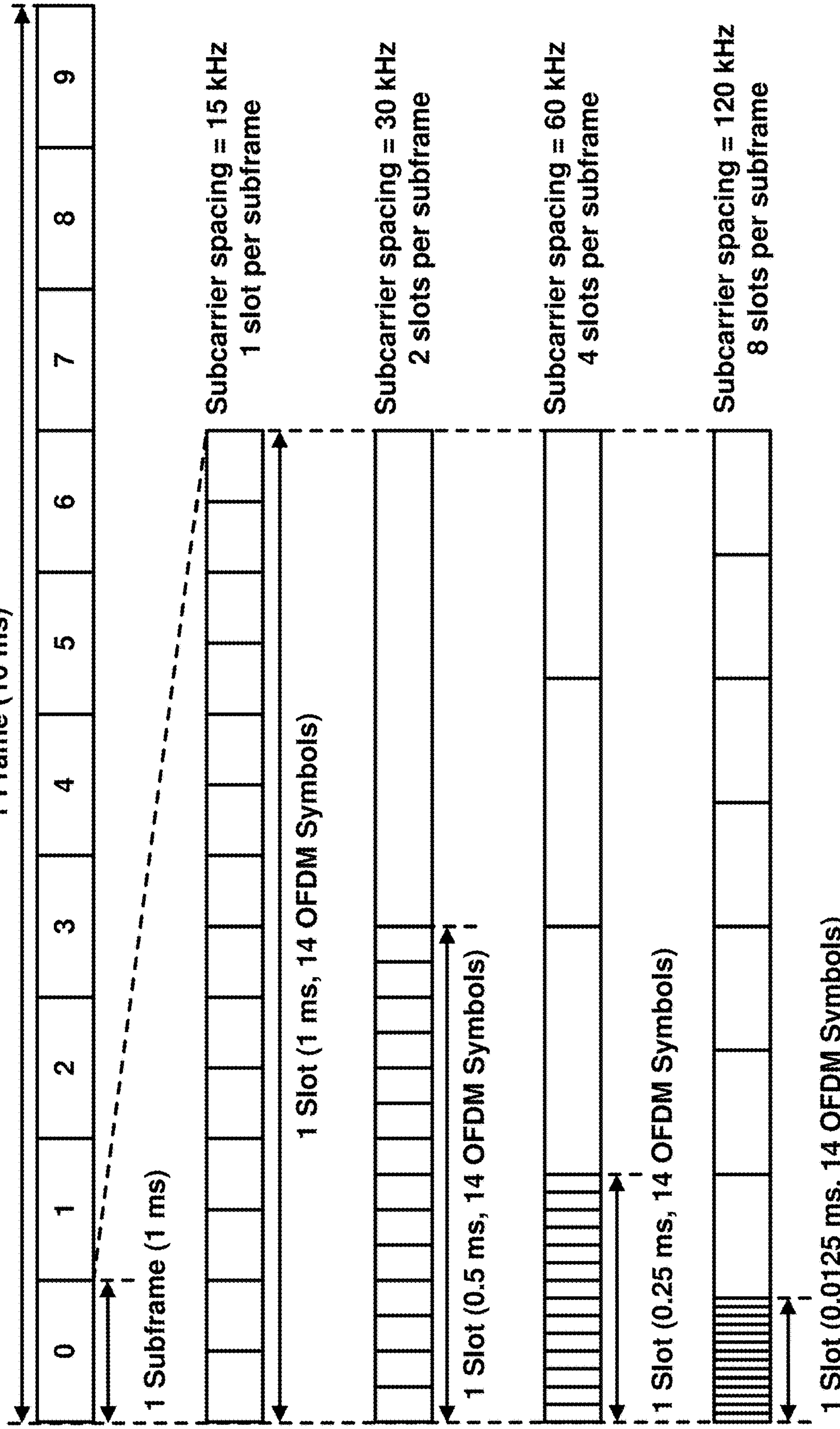

1 Frame (10 ms)
0
1
2
3
4
5
6
7
8
9
1 Subframe (1 ms)
Subcarrier spacing = 15 kHz
1 slot per subframe
1 Slot (1 ms, 14 OFDM Symbols)
Subcarrier spacing = 30 kHz
2 slots per subframe
1 Slot (0.5 ms, 14 OFDM Symbols)
Subcarrier spacing = 60 kHz
4 slots per subframe
1 Slot (0.25 ms, 14 OFDM Symbols)
Subcarrier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

FIG. 7

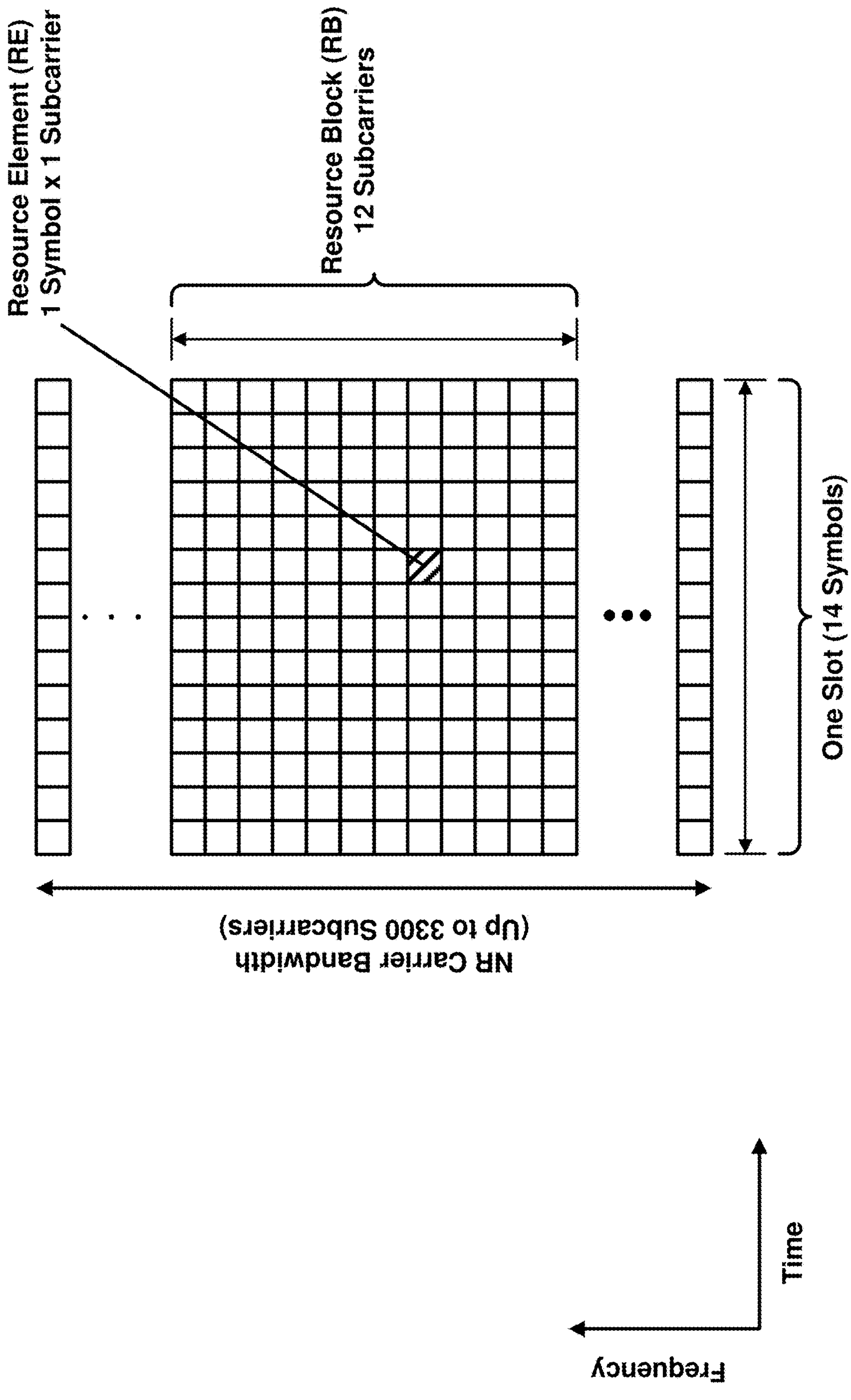

Resource Element (RE)
1 Symbol x 1 Subcarrier
Resource Block (RB)
12 Subcarriers
One Slot (14 Symbols)
NR Carrier Bandwidth
(Up to 3300 Subcarriers)
Time
Frequency

FIG. 8

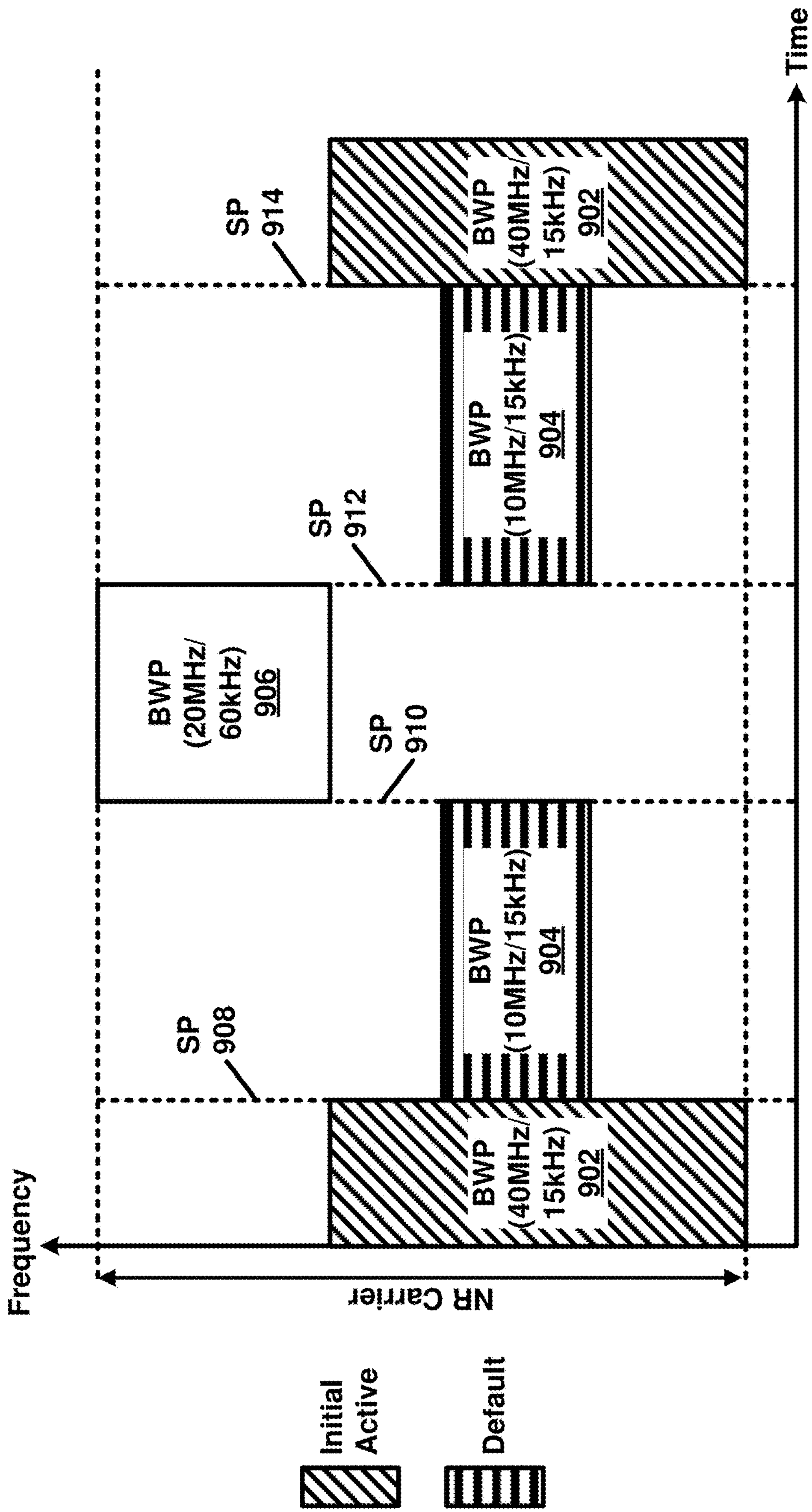

Time
Frequency
NR Carrier
BWP (40MHz/ 15kHz) 902
BWP (10MHz/15kHz) 904
BWP (20MHz/ 60kHz) 906
BWP (10MHz/15kHz) 904
BWP (40MHz/ 15kHz) 902
SP 908
SP 910
SP 912
SP 914
Initial Active
Default

FIG. 9

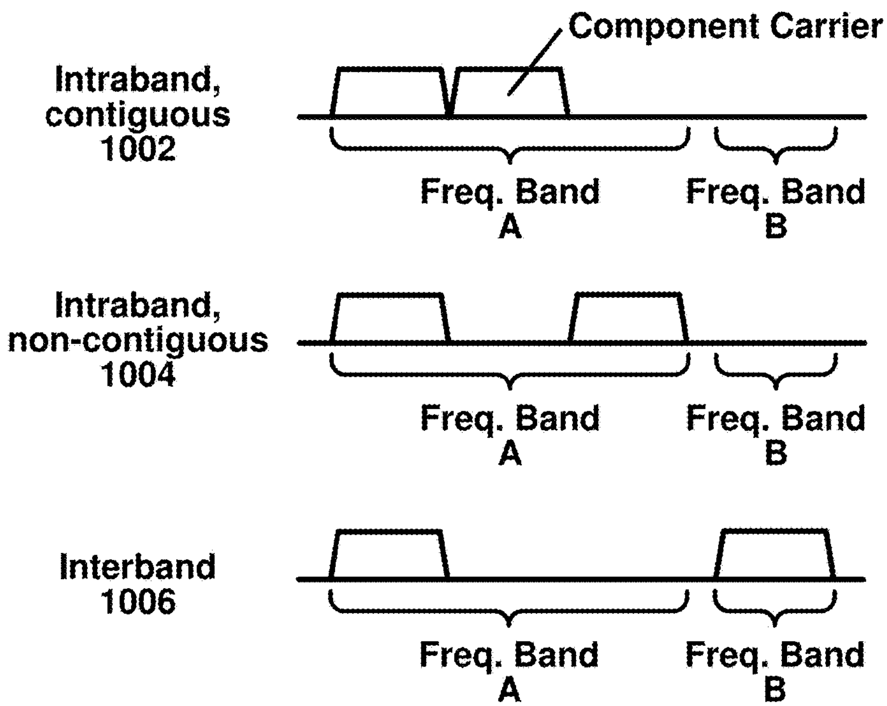


FIG. 10A

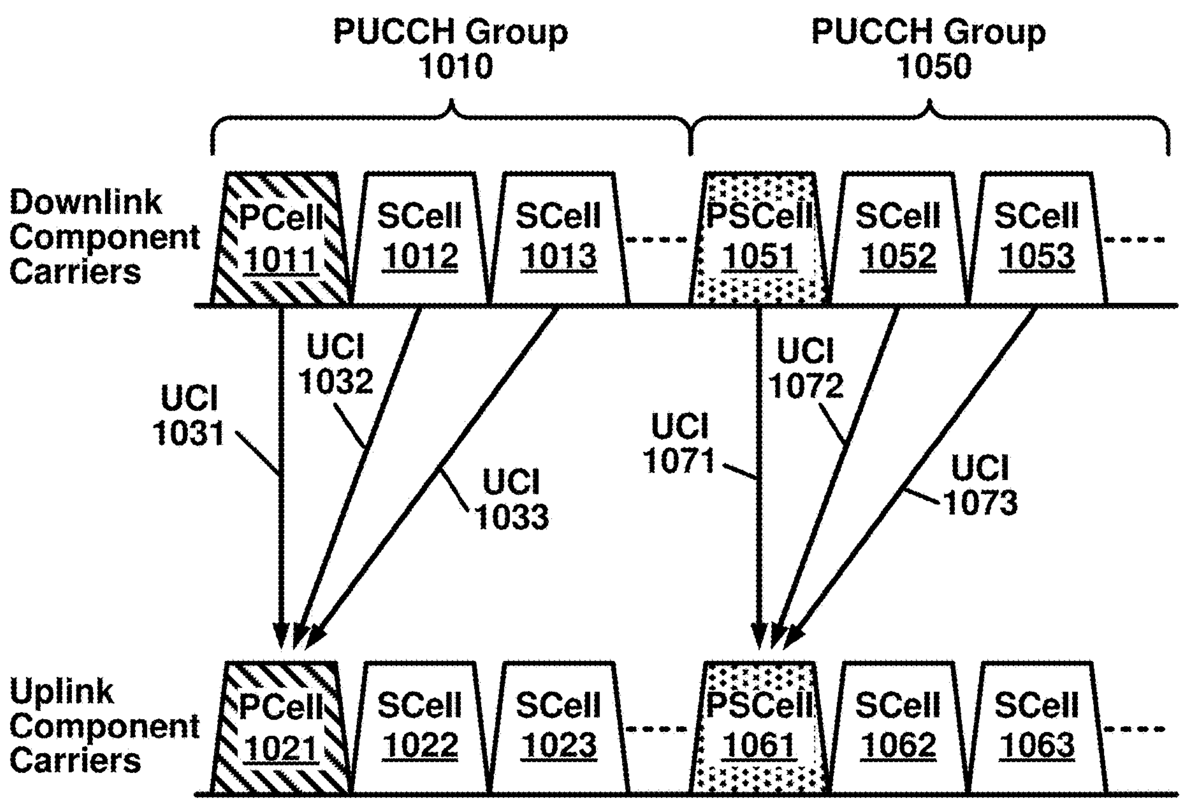


FIG. 10B

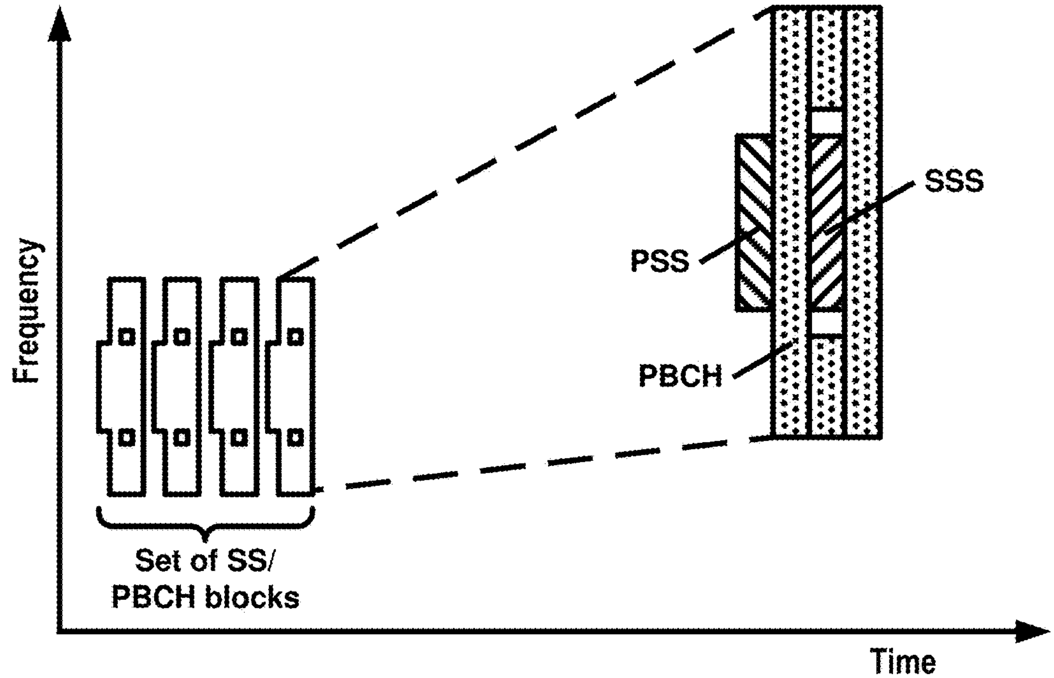


FIG. 11A

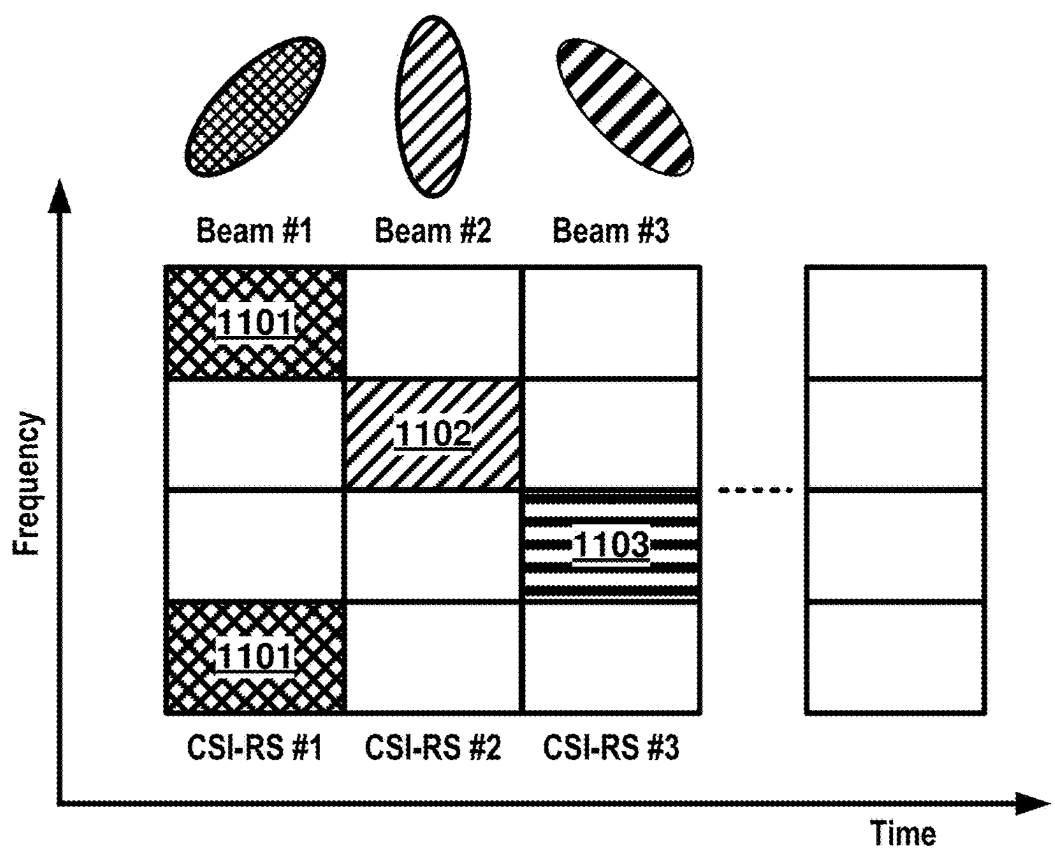


FIG. 11B

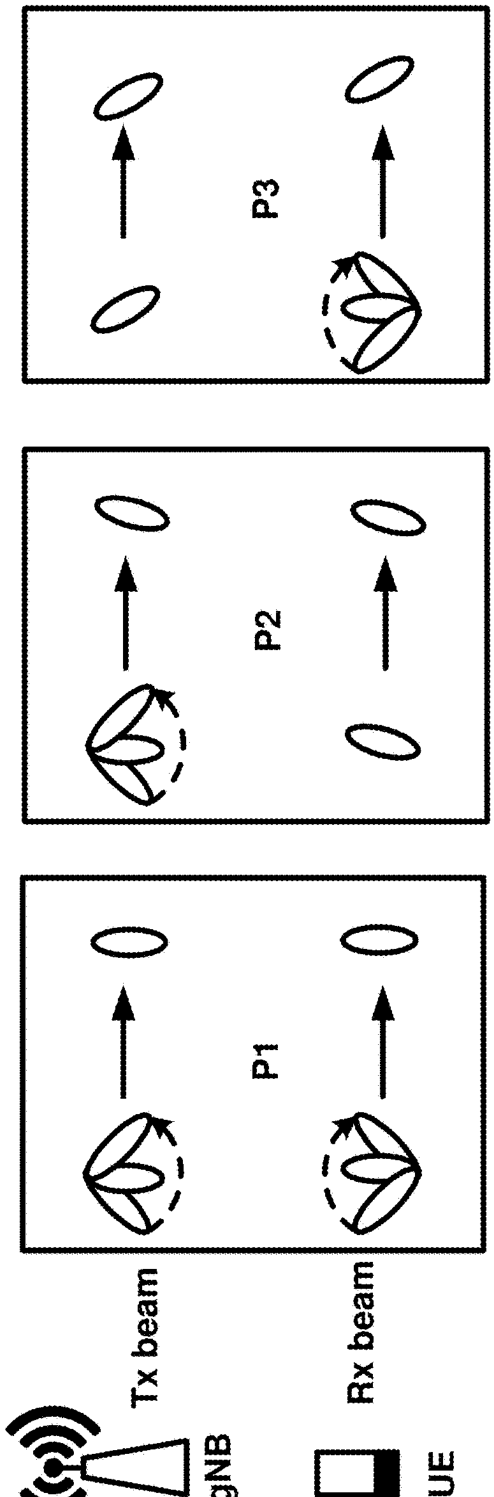


FIG. 12A

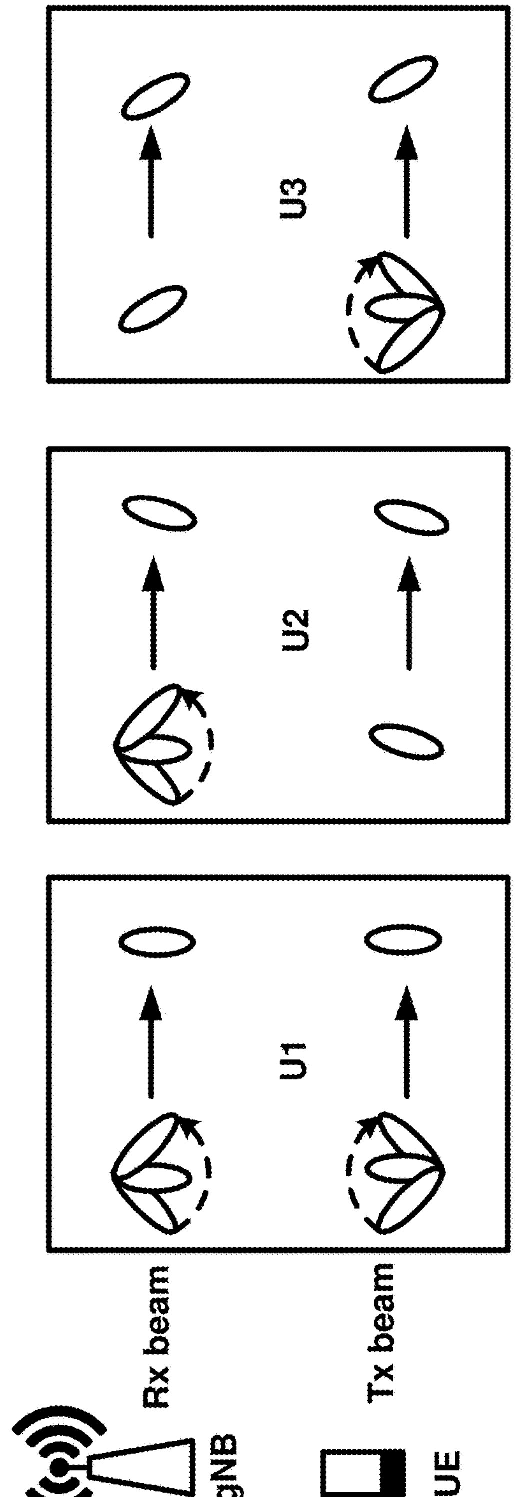


FIG. 12B

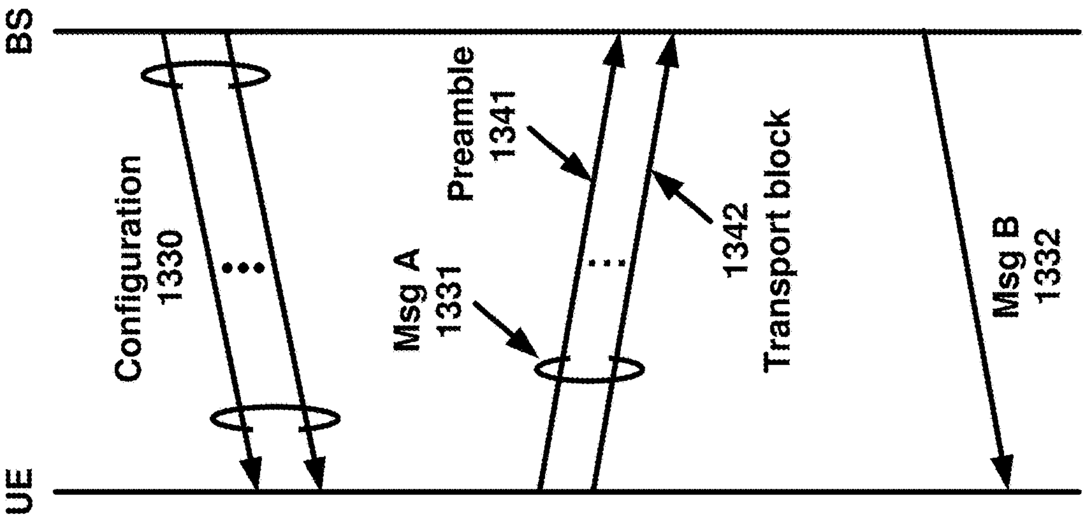


FIG. 13C

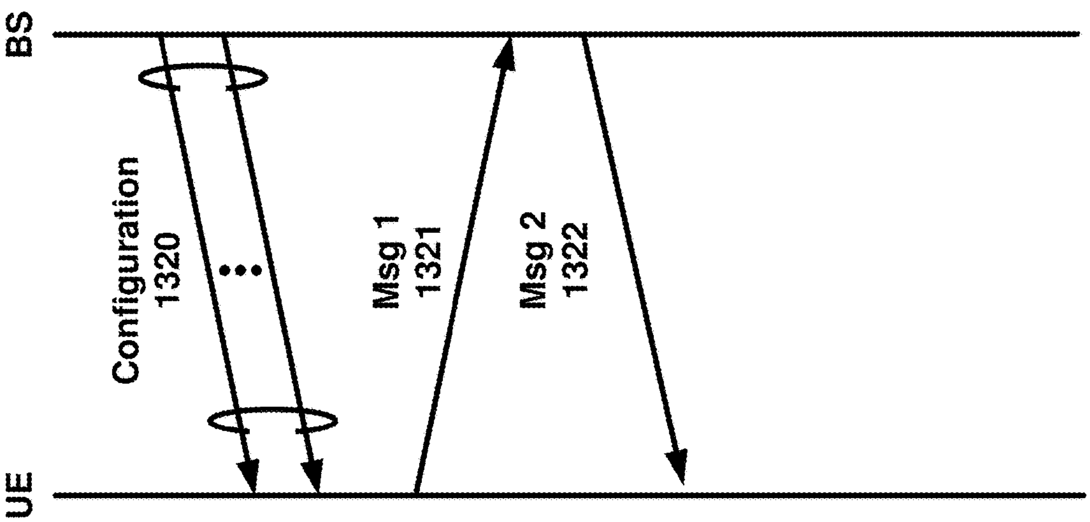


FIG. 13B

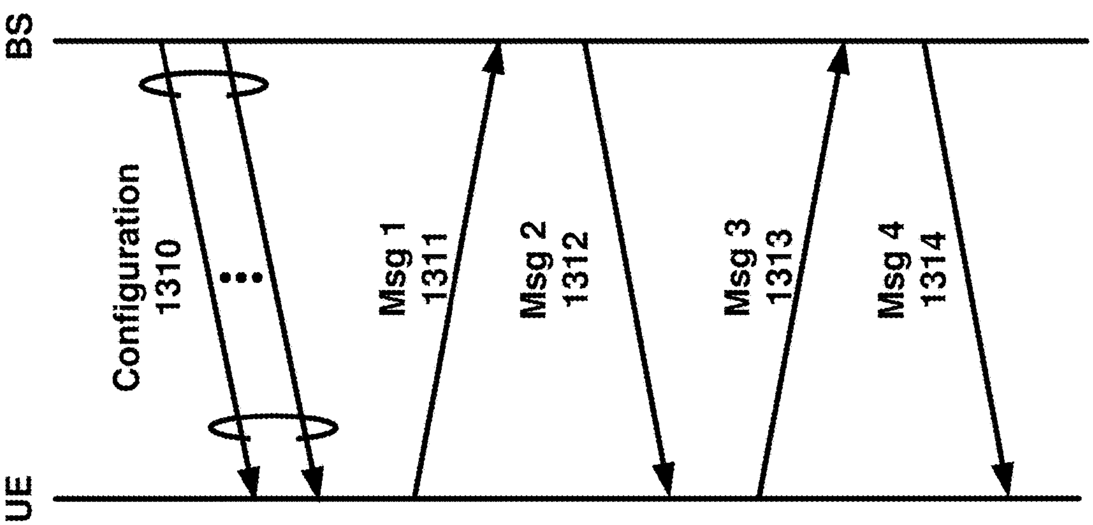


FIG. 13A

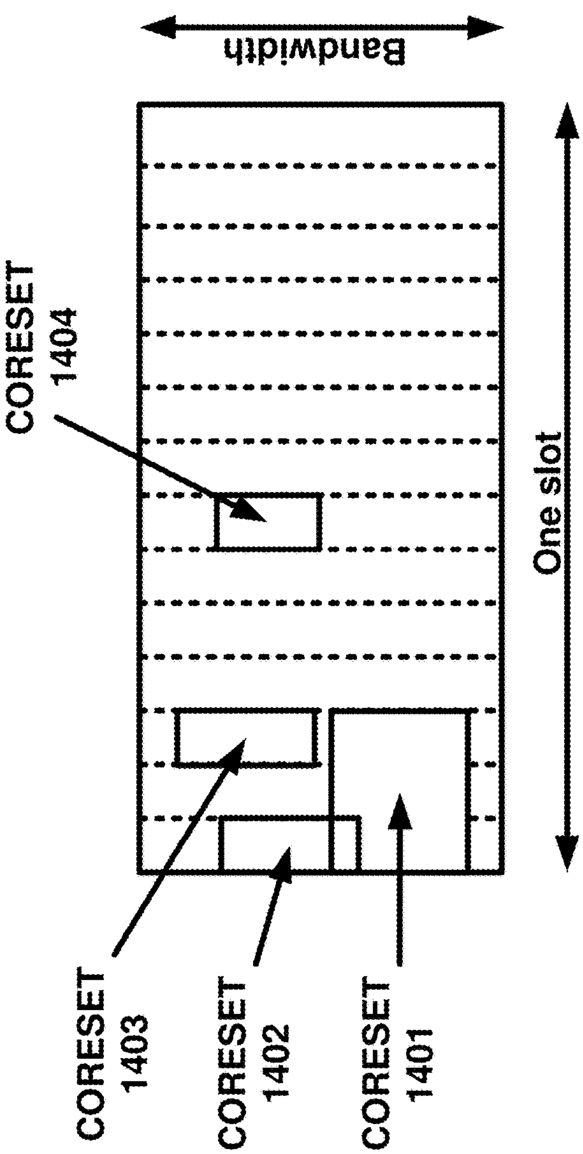


FIG. 14A

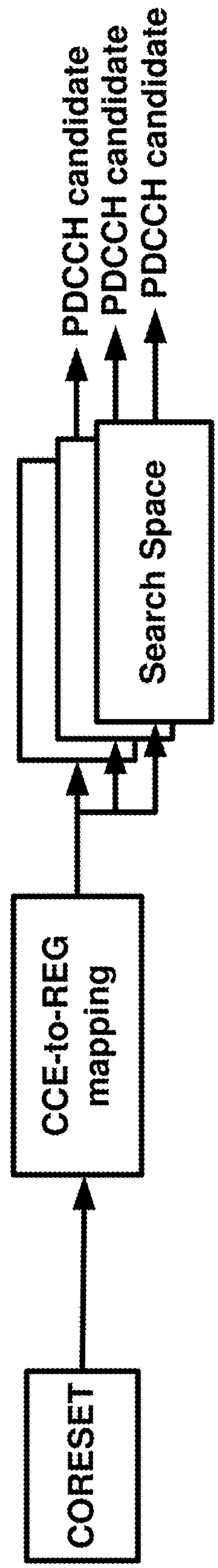


FIG. 14B

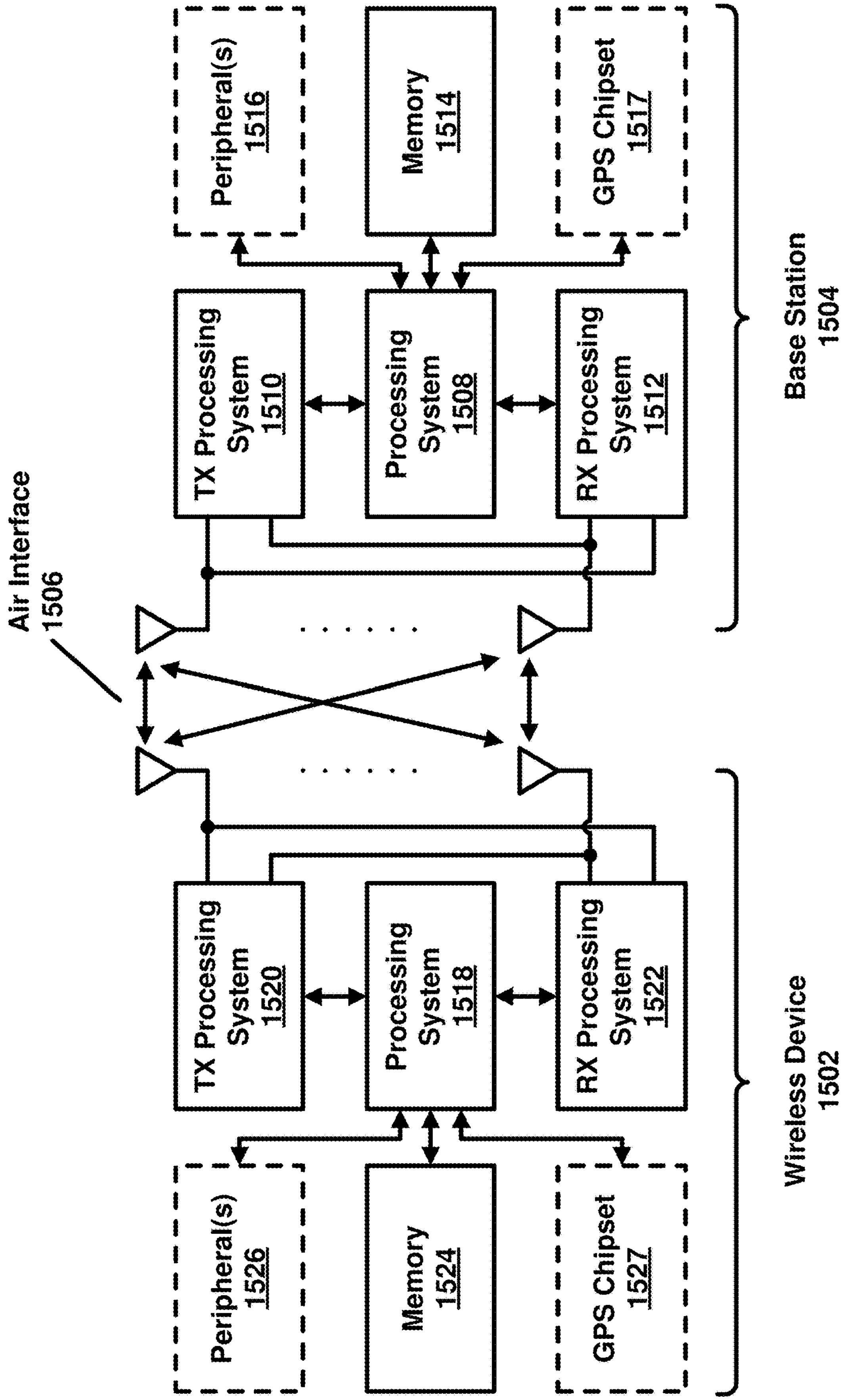

Peripheral(s) 1516
Memory 1514
GPS Chipset 1517
TX Processing System 1510
Processing System 1508
RX Processing System 1512
Base Station 1504
Air Interface 1506
TX Processing System 1520
Processing System 1518
RX Processing System 1522
Wireless Device 1502
Peripheral(s) 1526
Memory 1524
GPS Chipset 1527

FIG. 15

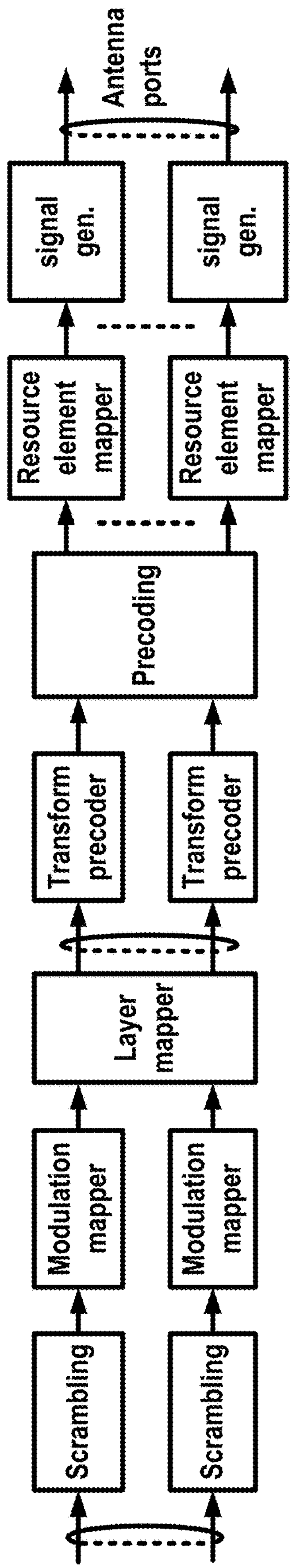


FIG. 16A

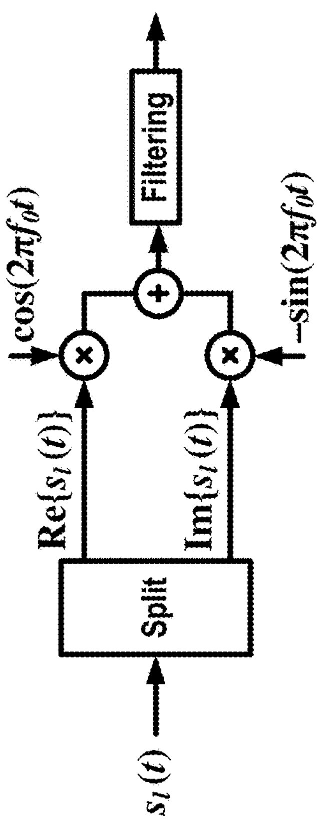


FIG. 16B

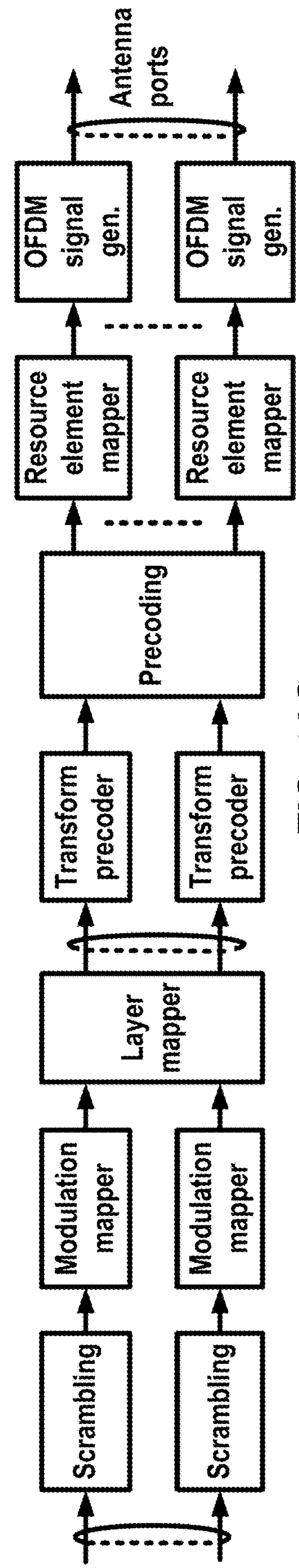


FIG. 16C

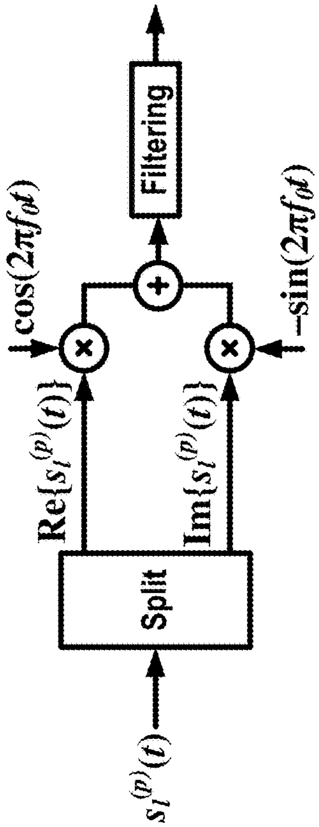
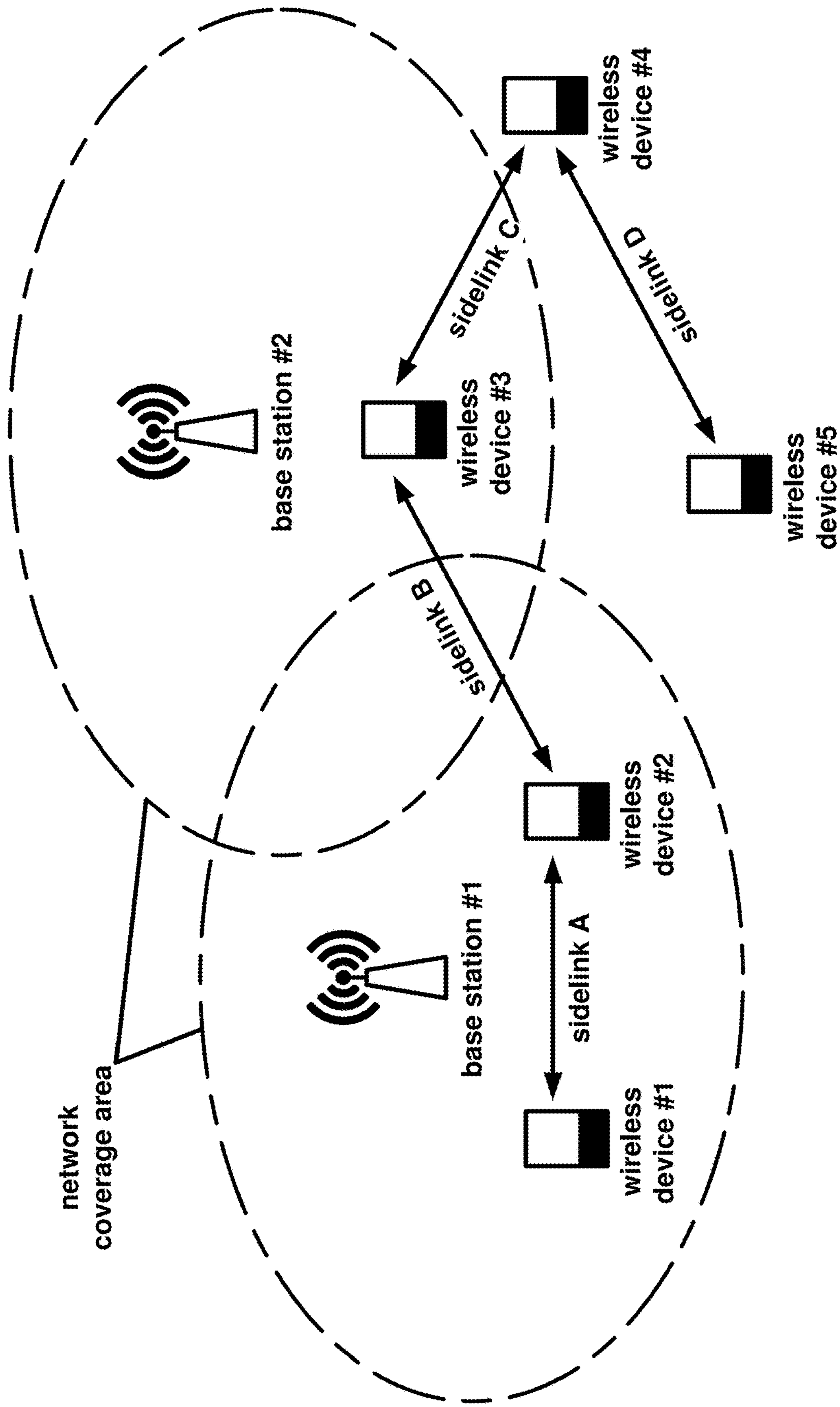


FIG. 16D



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

FIG. 17

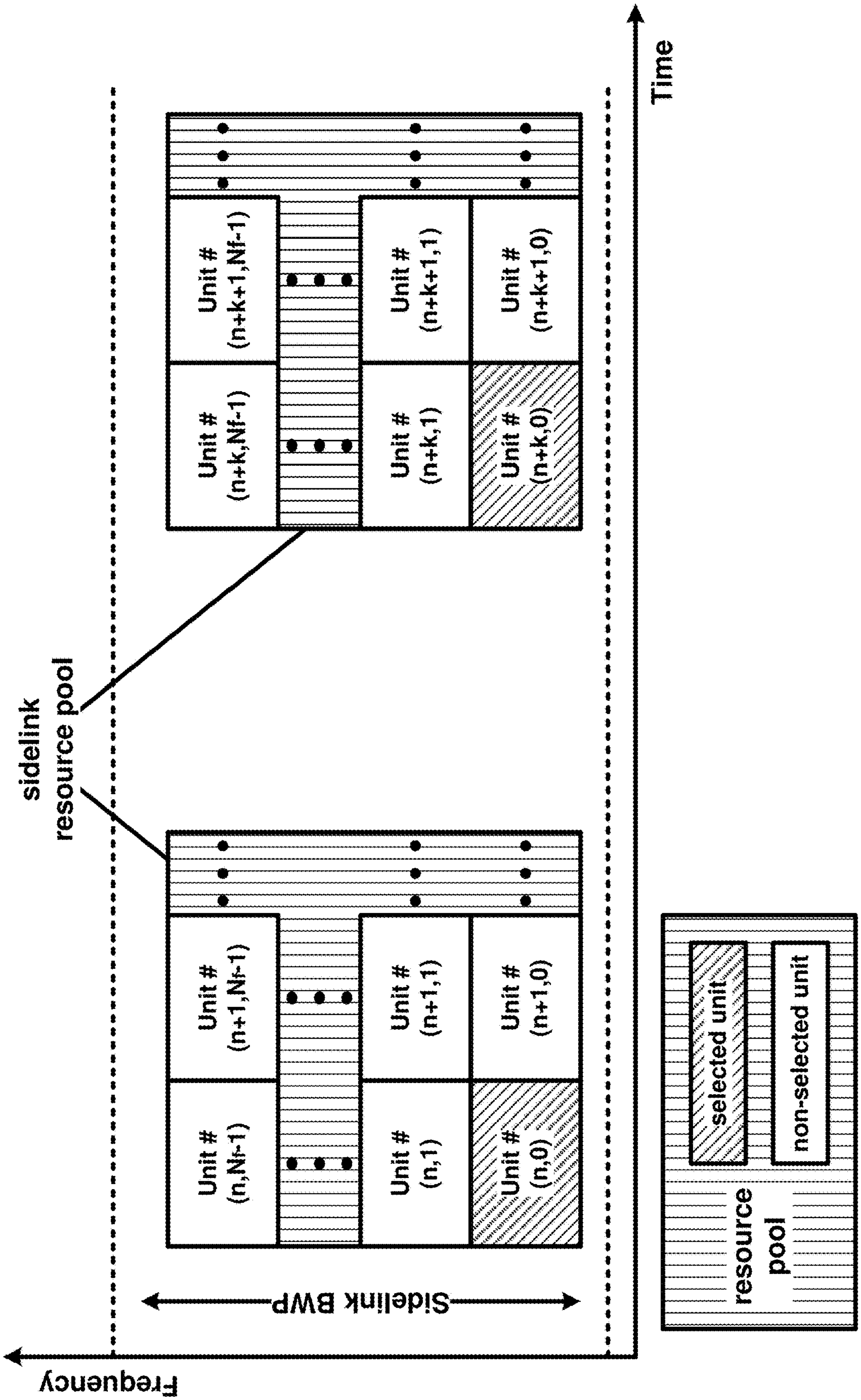

Time
Frequency
Sidelink BWP
sidelink resource pool
Unit # (n,Nf-1)
Unit # (n,1)
Unit # (n,0)
Unit # (n+1,Nf-1)
Unit # (n+1,1)
Unit # (n+1,0)
Unit # (n+k,Nf-1)
Unit # (n+k,1)
Unit # (n+k,0)
Unit # (n+k+1,Nf-1)
Unit # (n+k+1,1)
Unit # (n+k+1,0)
resource pool
selected unit
non-selected unit

FIG. 18

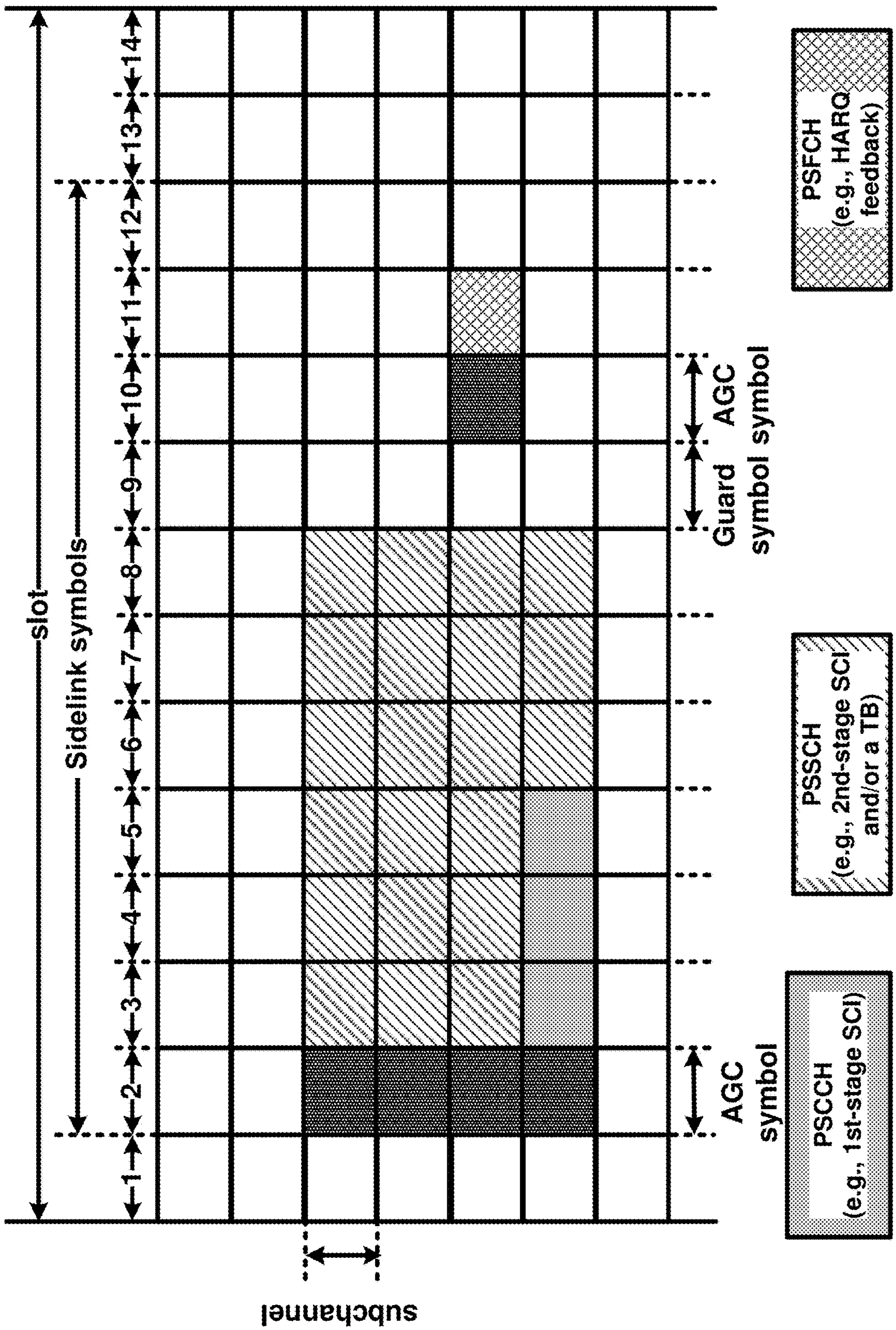

slot
Sidelink symbols
1
2
3
4
5
6
7
8
9
10
11
12
13
14
AGC symbol
Guard symbol
AGC symbol
subchannel
PSCCH (e.g., 1st-stage SCI)
PSSCH (e.g., 2nd-stage SCI and/or a TB)
PSFCH (e.g., HARQ feedback)

FIG. 19

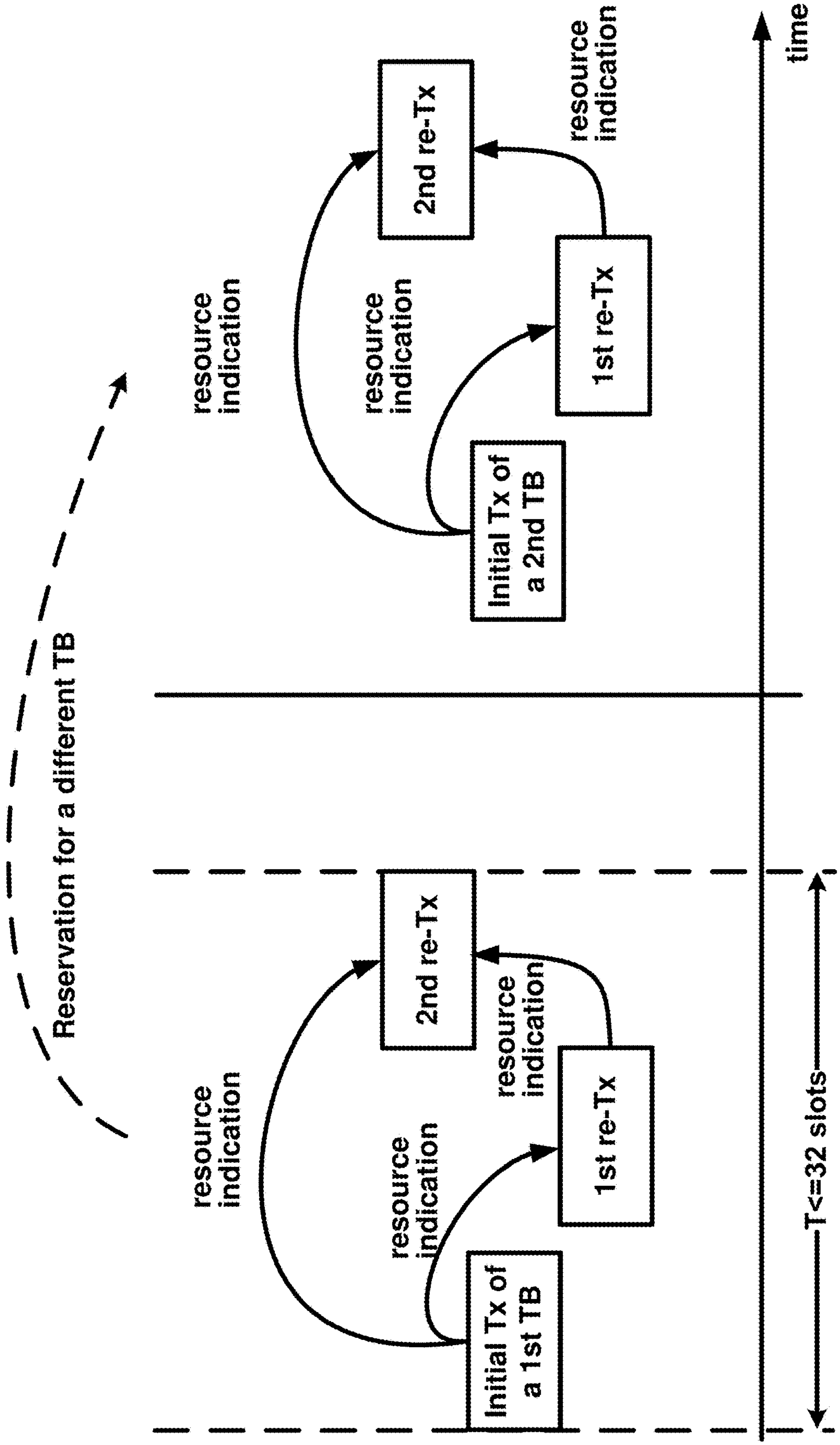

Reservation for a different TB
resource indication
resource indication
resource indication
Initial Tx of a 1st TB
1st re-Tx
2nd re-Tx
T<=32 slots
resource indication
resource indication
resource indication
Initial Tx of a 2nd TB
1st re-Tx
2nd re-Tx
time

FIG. 20

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

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

FIG. 21

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

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

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

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

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

FIG. 22

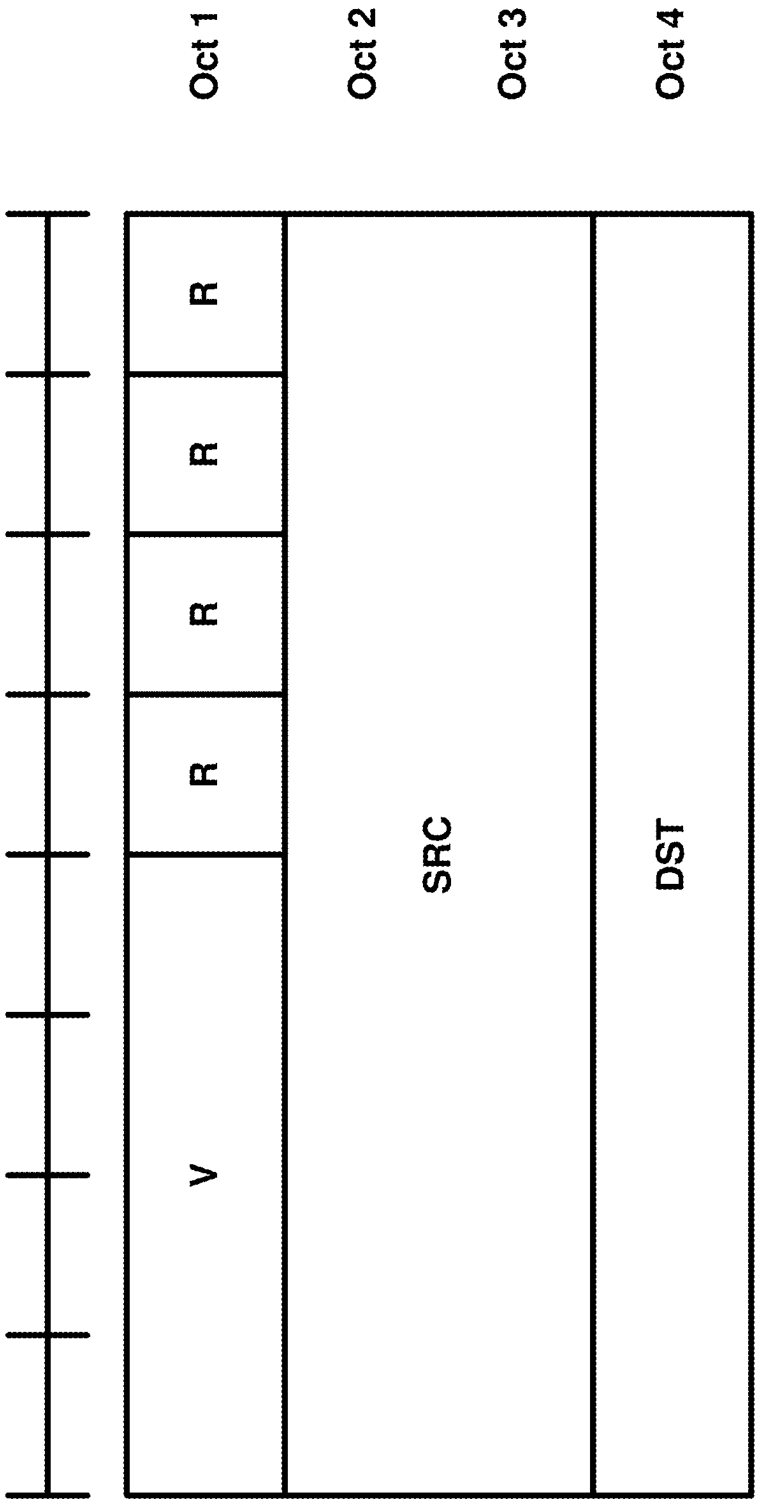


FIG. 23

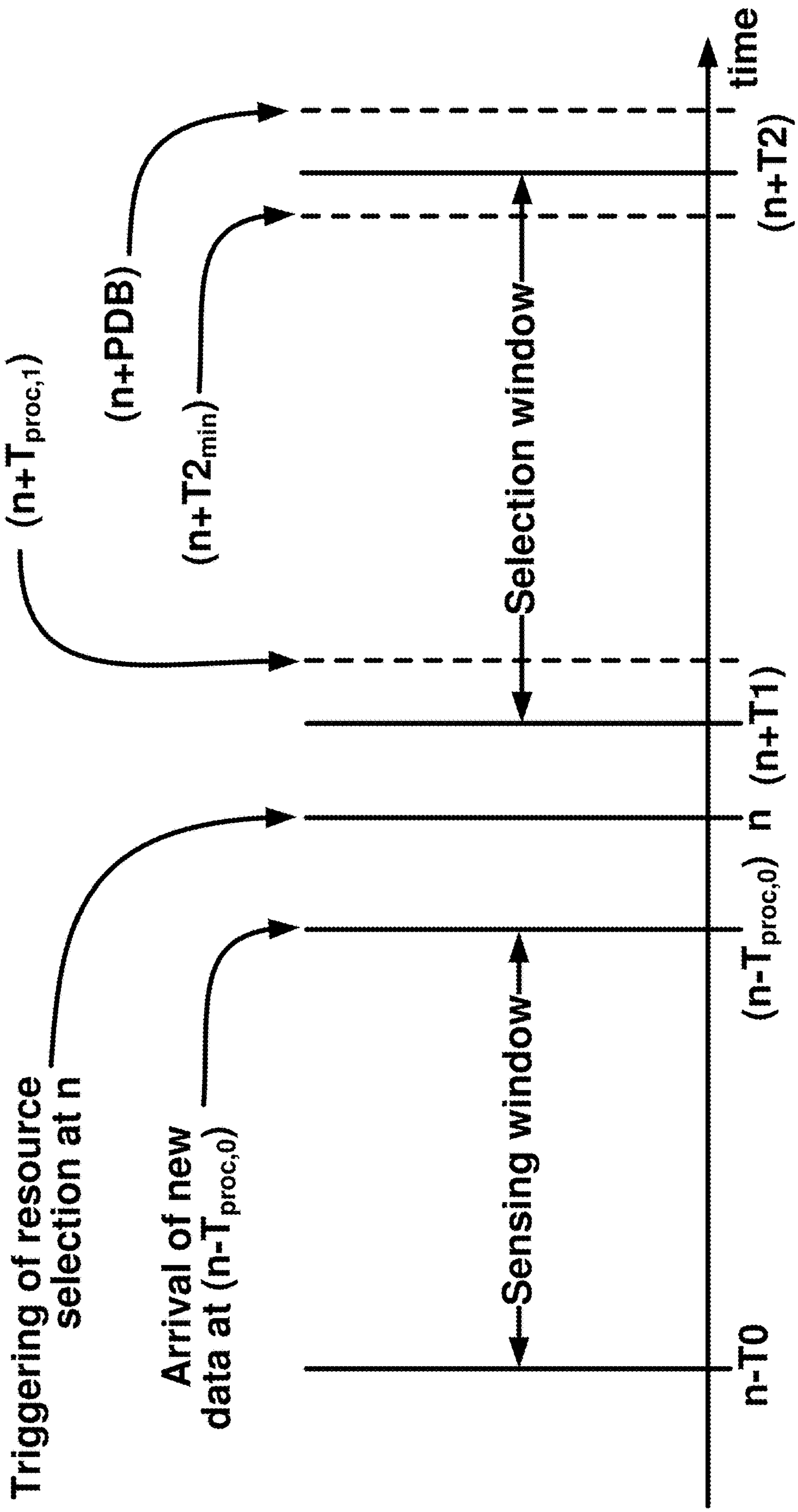

Triggering of resource selection at n
Arrival of new data at $(n-T_{proc,0})$
Sensing window
Selection window
$(n+T_{proc,1})$
(n+PDB)
$(n+T2_{min})$
n-T0
$(n-T_{proc,0})$
n
(n+T1)
(n+T2)
time

FIG. 24

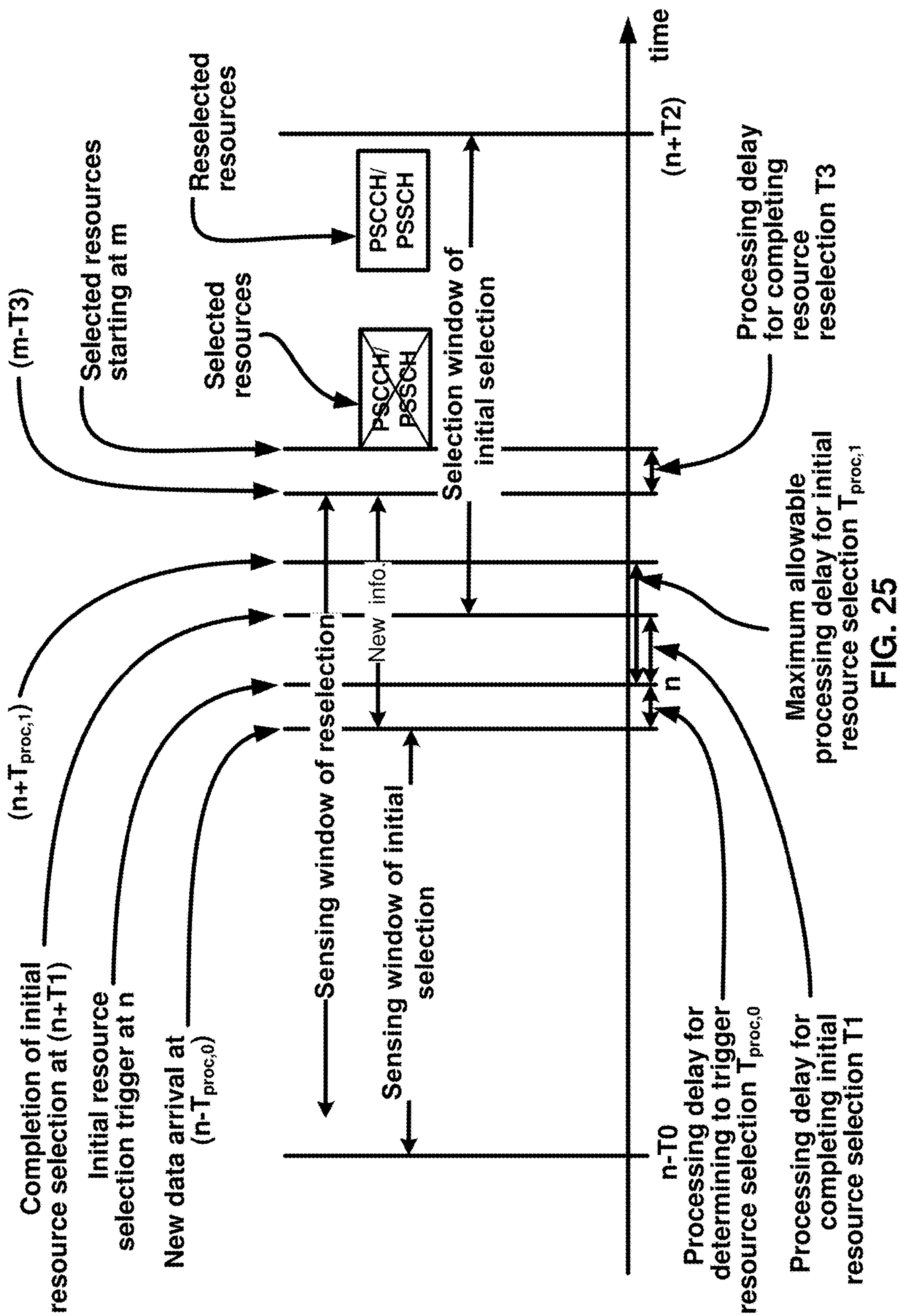

Completion of initial resource selection at (n+T1)
Initial resource selection trigger at n
New data arrival at $(n-T_{proc,0})$
$(n+T_{proc,1})$
(m-T3)
Selected resources starting at m
Selected resources
PSCCH/ PSSCH
Reselected resources
PSCCH/ PSSCH
Sensing window of reselection
New info.
Sensing window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

FIG. 25

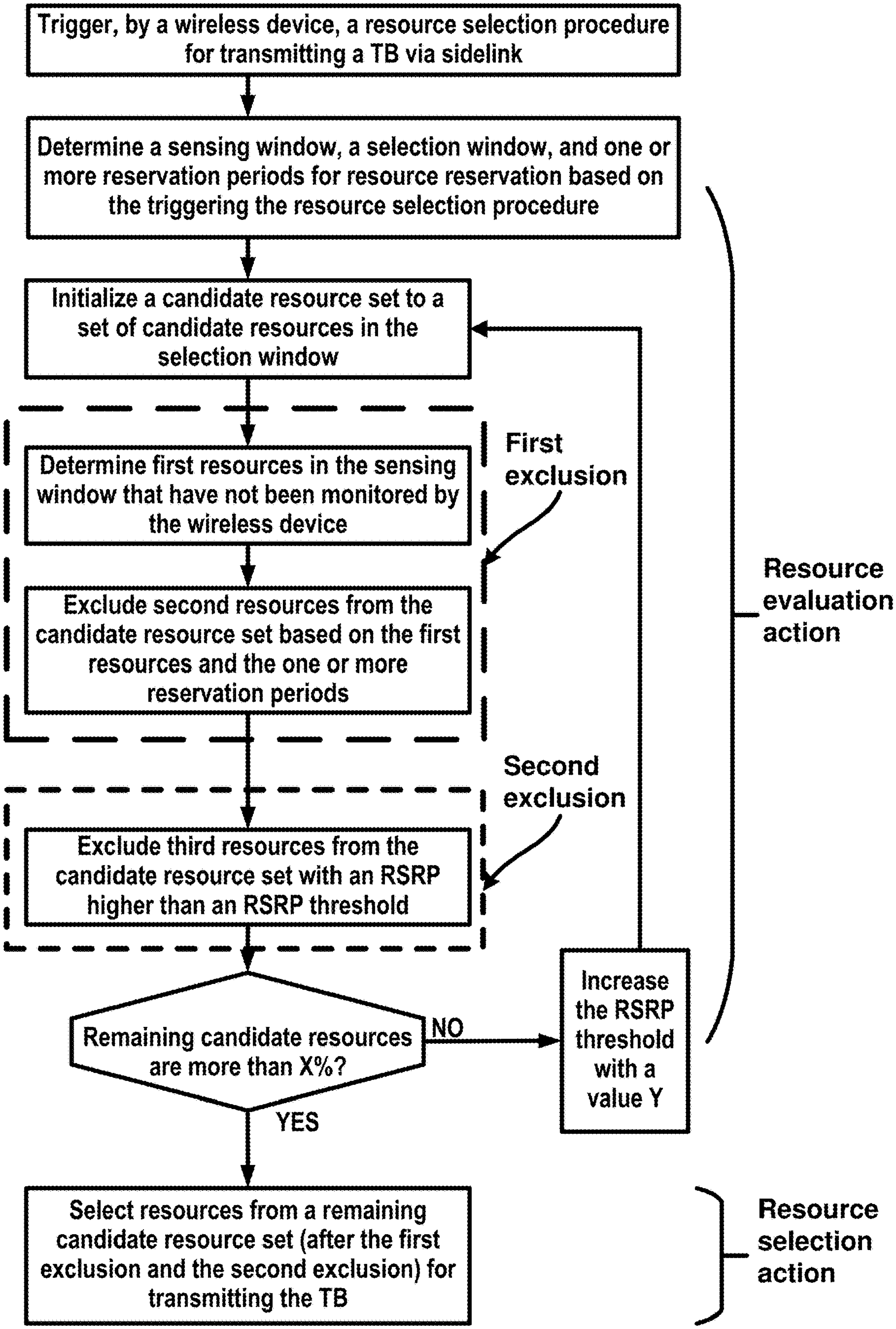

Trigger, by a wireless device, a resource selection procedure for transmitting a TB via sidelink
Determine a sensing window, a selection window, and one or more reservation periods for resource reservation based on the triggering the resource selection procedure
Initialize a candidate resource set to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

FIG. 26

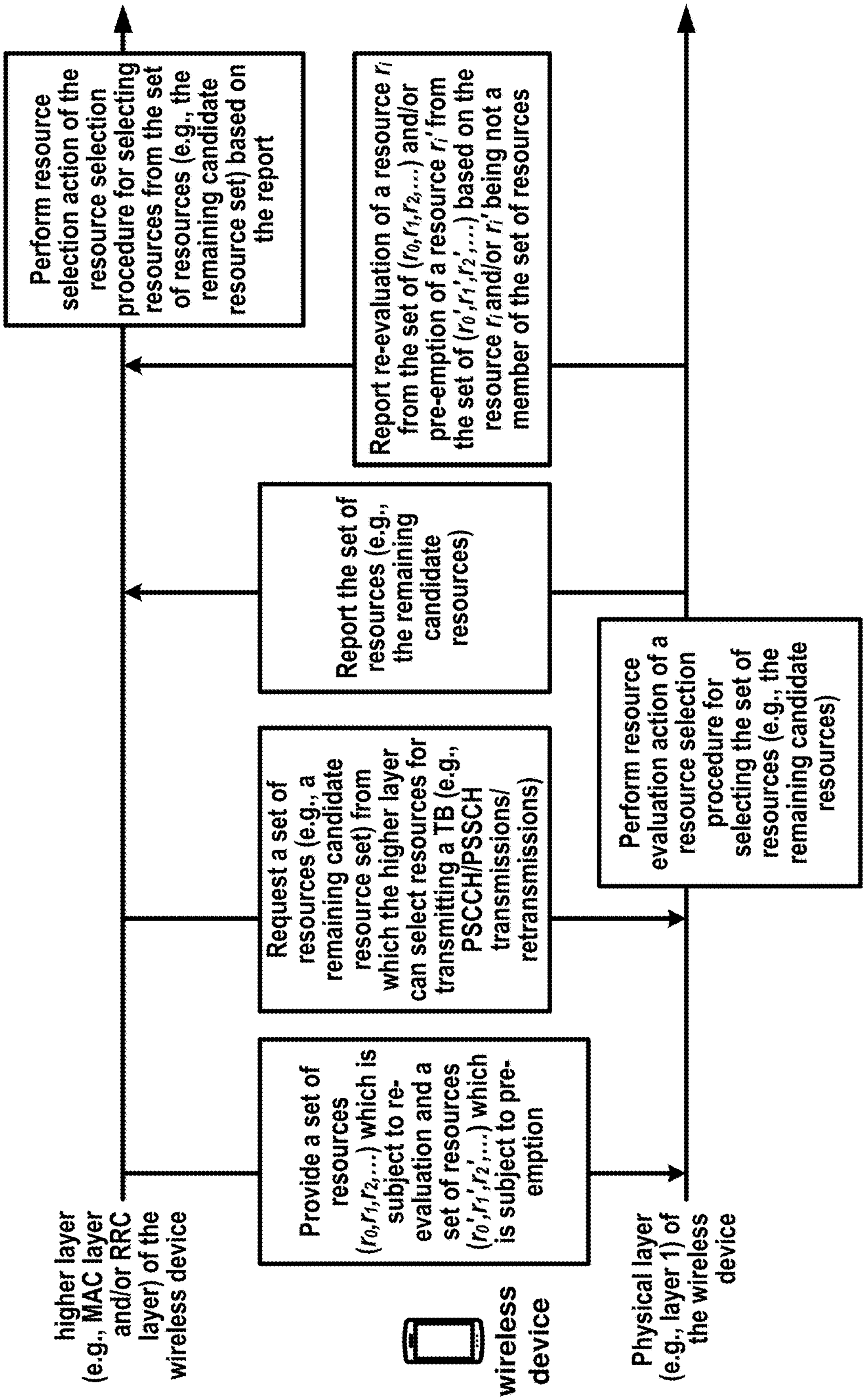
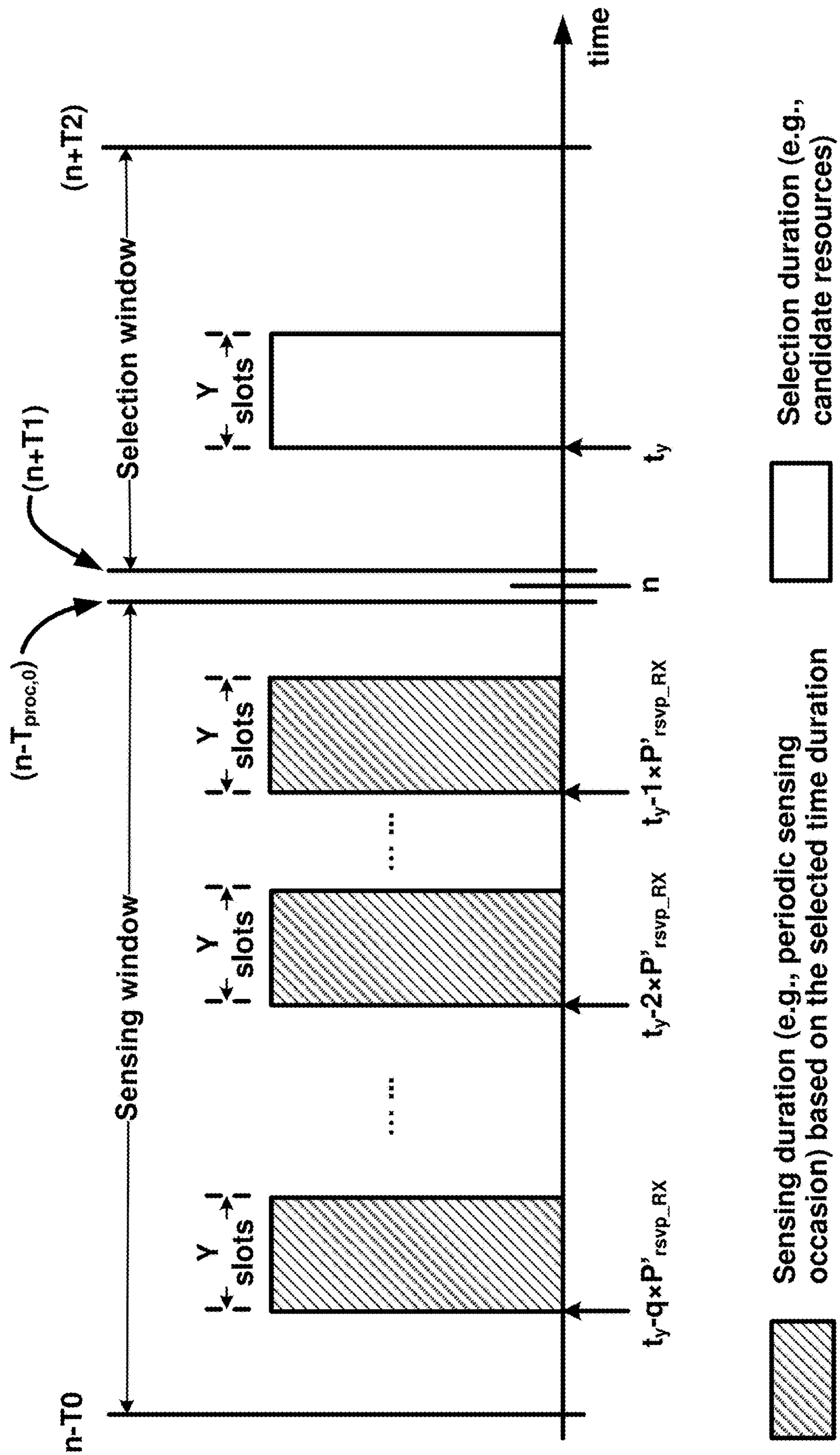

higher layer (e.g., MAC layer and/or RRC layer) of the wireless device
wireless device
Physical layer (e.g., layer 1) of the wireless device
Provide a set of resources (r_0,r_1,r_2,...) which is subject to re-evaluation and a set of resources (r_0',r_1',r_2',...) which is subject to pre-emption
Request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

FIG. 27



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

FIG. 28

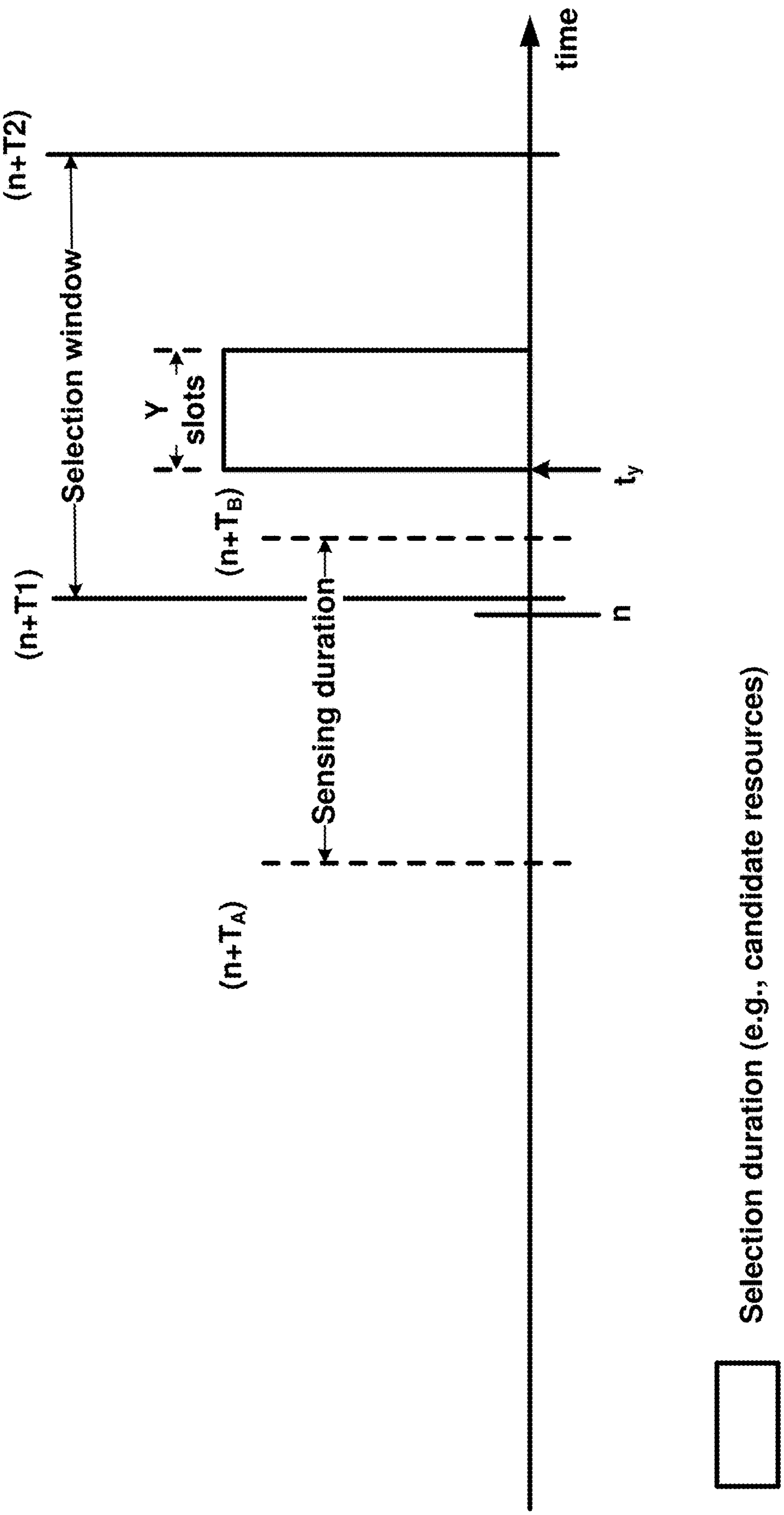

time
(n+T2)
Selection window
(n+T1)
Y
slots
t_y
$(n+T_B)$
n
Sensing duration
$(n+T_A)$
Selection duration (e.g., candidate resources)

FIG. 29

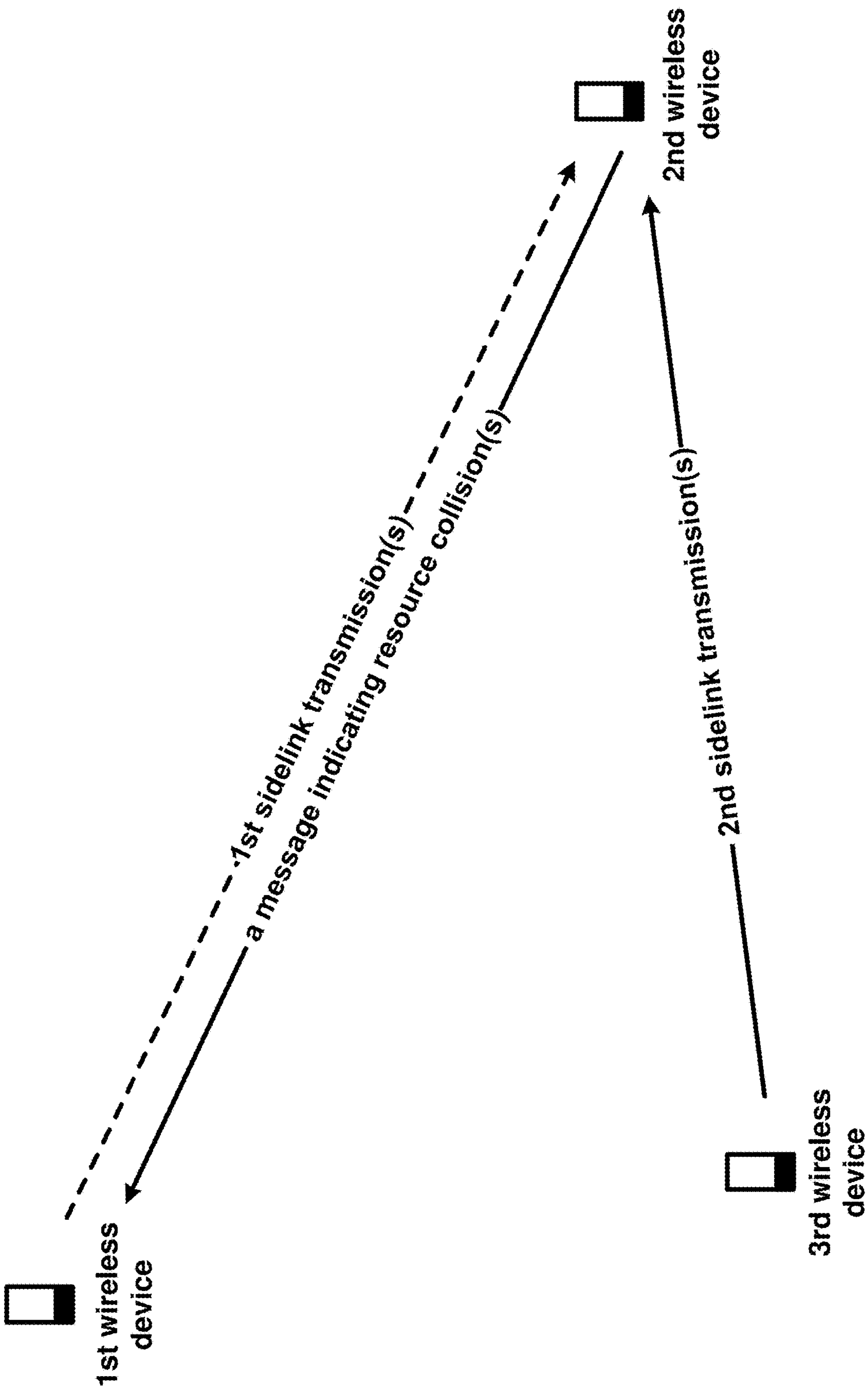

2nd wireless device
1st sidelink transmission(s)
a message indicating resource collision(s)
2nd sidelink transmission(s)
1st wireless device
3rd wireless device

FIG. 30

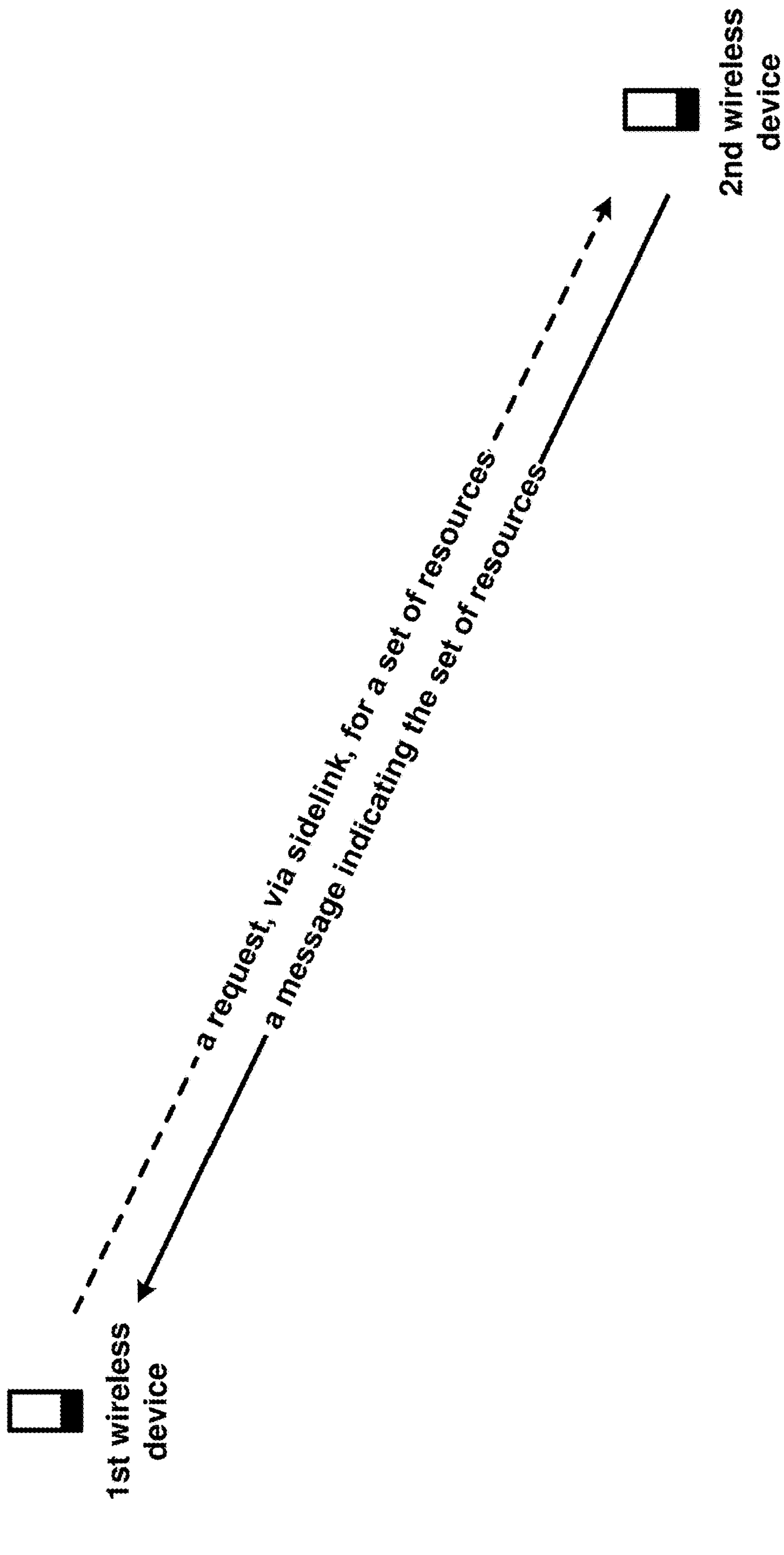

2nd wireless device
a request, via sidelink, for a set of resources
a message indicating the set of resources
1st wireless device

FIG. 31

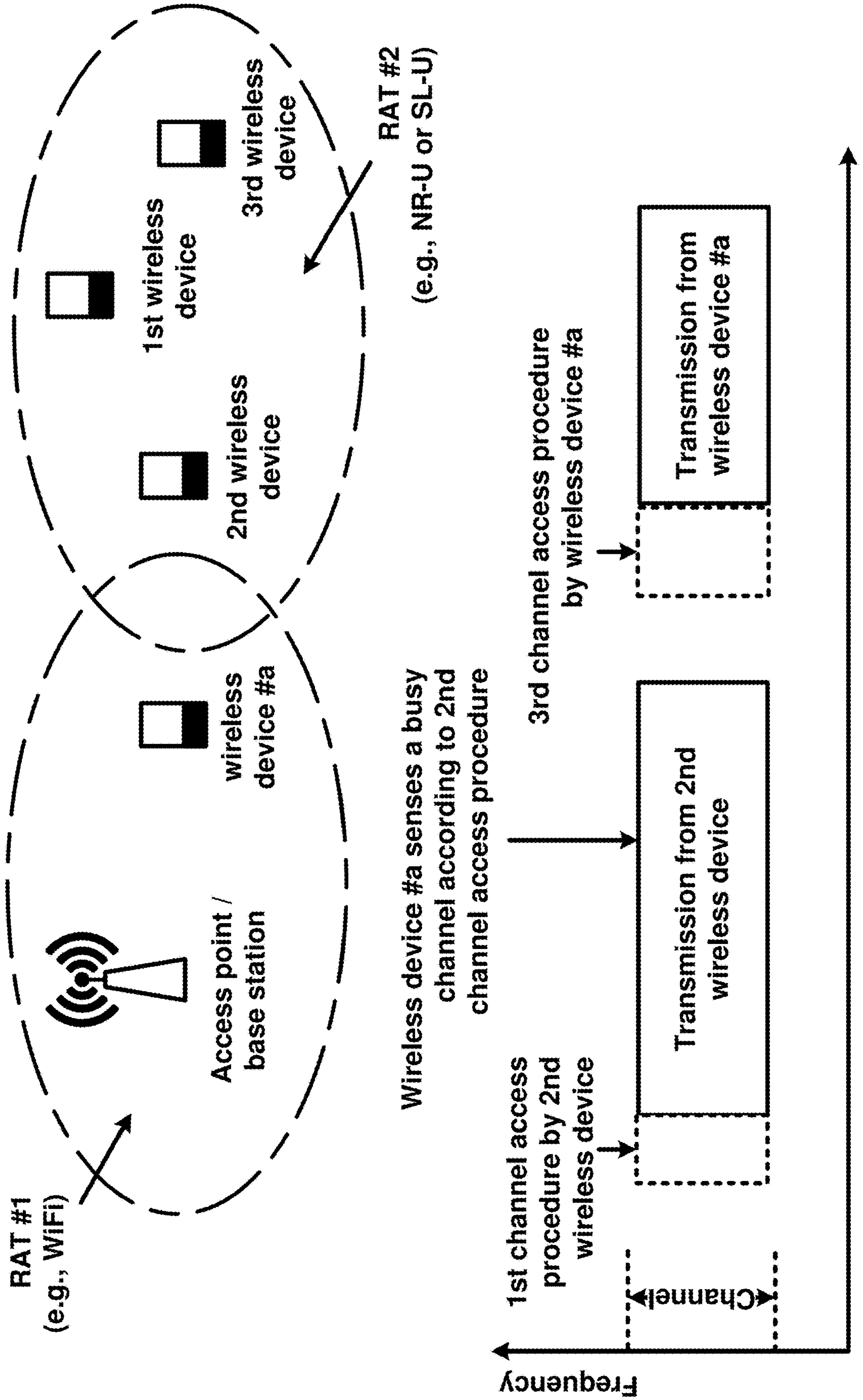

RAT #1
(e.g., WiFi)
Access point /
base station
wireless
device #a
2nd wireless
device
1st wireless
device
3rd wireless
device
RAT #2
(e.g., NR-U or SL-U)
Wireless device #a senses a busy
channel according to 2nd
channel access procedure
3rd channel access procedure
by wireless device #a
1st channel access
procedure by 2nd
wireless device
Transmission from 2nd
wireless device
Transmission from
wireless device #a
Channel
Frequency
Time

FIG. 32

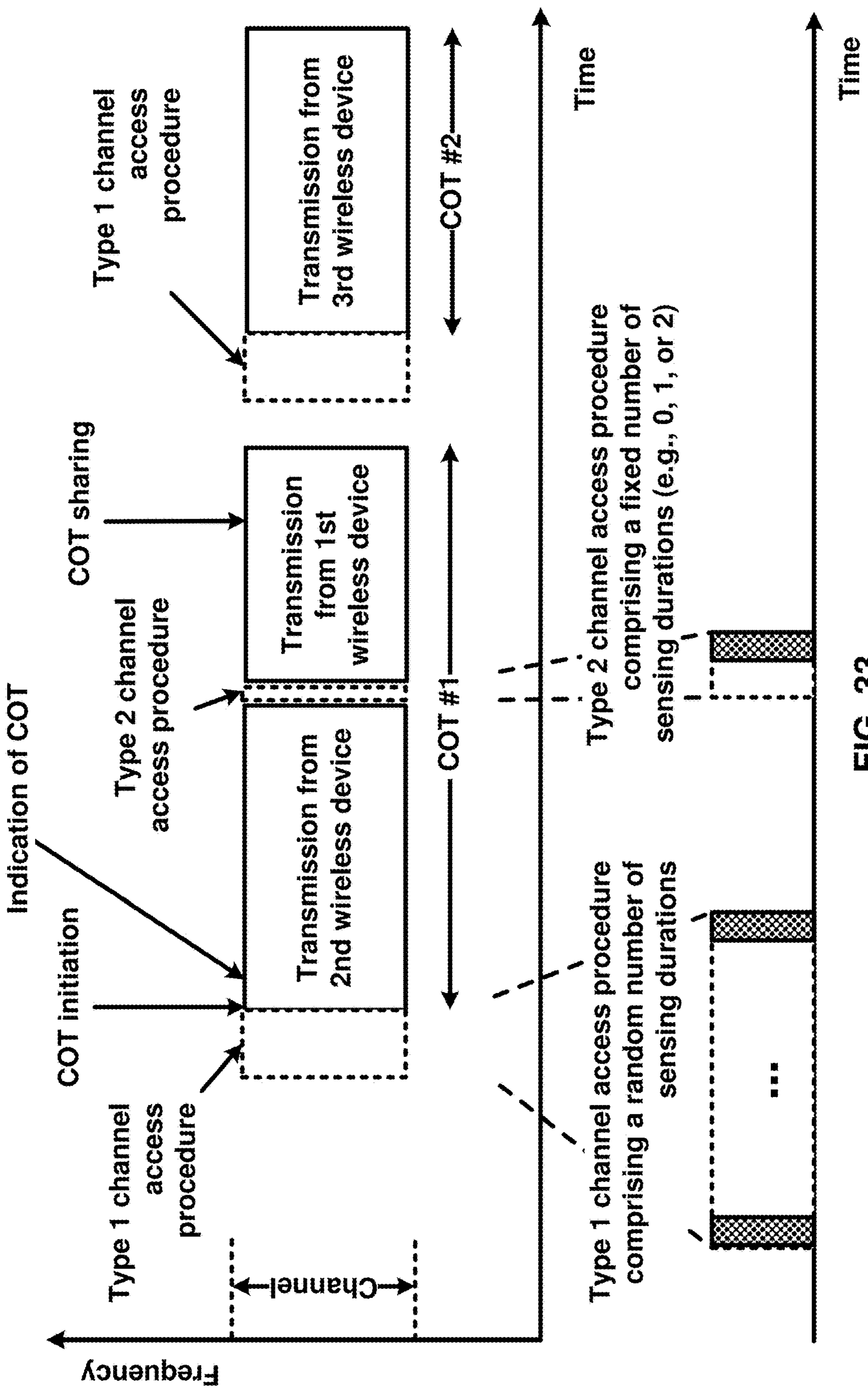

Frequency
Channel
Time
Time
Type 1 channel access procedure
COT initiation
Indication of COT
Type 2 channel access procedure
COT sharing
Type 1 channel access procedure
Transmission from 2nd wireless device
Transmission from 1st wireless device
Transmission from 3rd wireless device
COT #1
COT #2
Type 1 channel access procedure comprising a random number of sensing durations
...
Type 2 channel access procedure comprising a fixed number of sensing durations (e.g., 0, 1, or 2)

FIG. 33

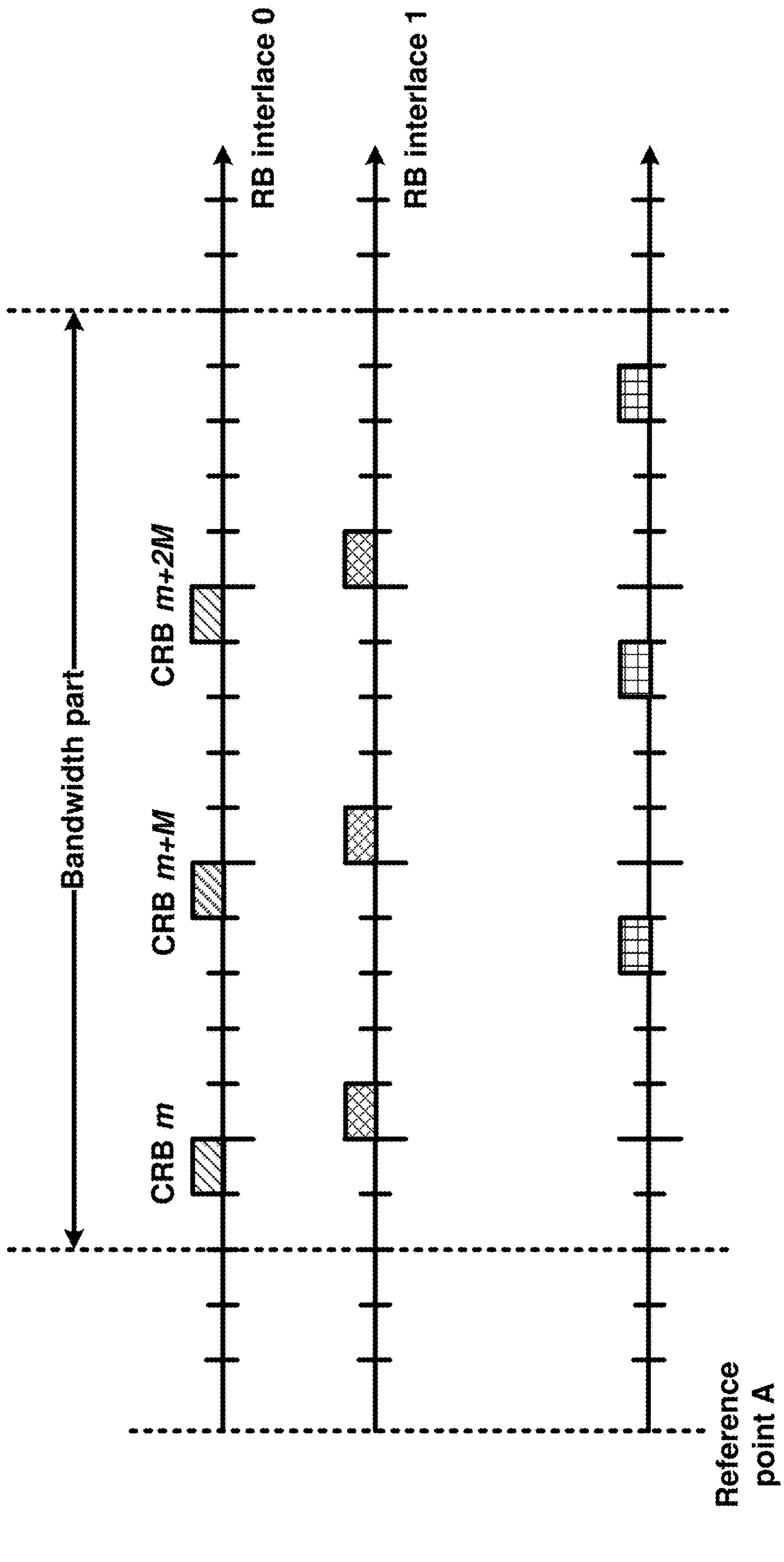

RB interlace 0
RB interlace 1
Bandwidth part
CRB m
CRB m+M
CRB m+2M
Reference point A

FIG. 34

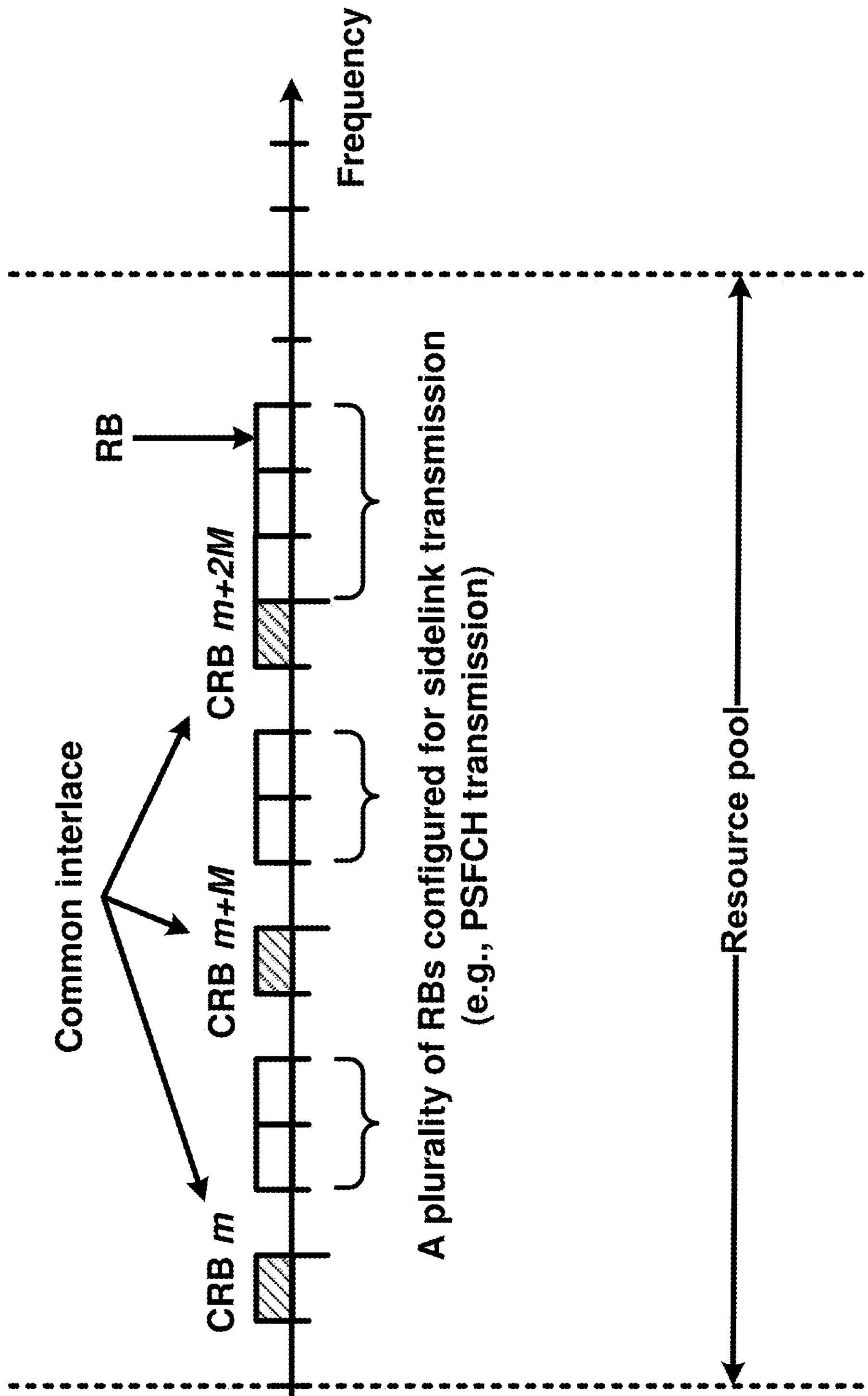

Frequency
RB
Common interlace
CRB m
CRB m+M
CRB m+2M
A plurality of RBs configured for sidelink transmission
(e.g., PSFCH transmission)
Resource pool

FIG. 35

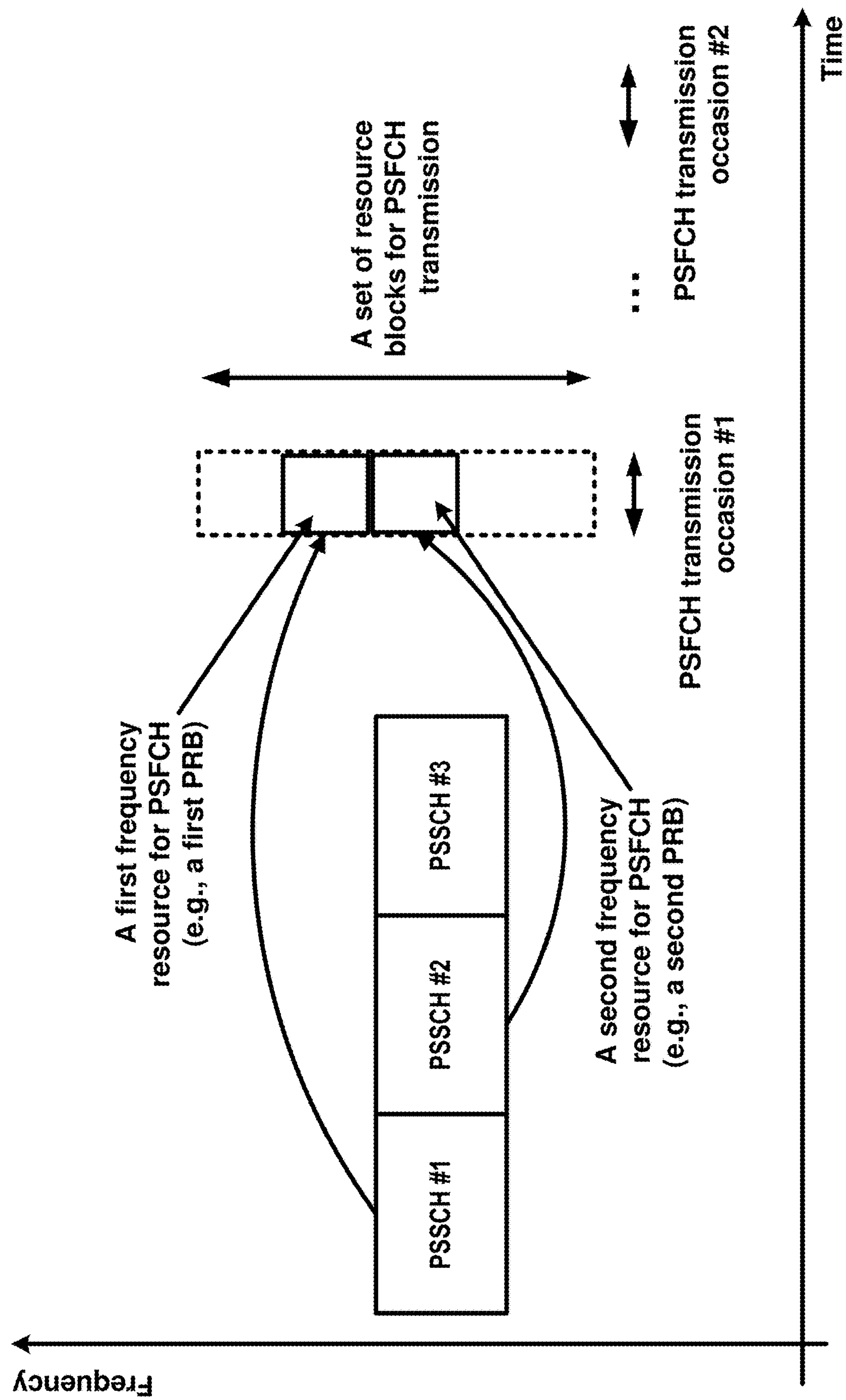

A first frequency resource for PSFCH (e.g., a first PRB)
A second frequency resource for PSFCH (e.g., a second PRB)
A set of resource blocks for PSFCH transmission
PSSCH #1
PSSCH #2
PSSCH #3
PSFCH transmission occasion #1
PSFCH transmission occasion #2
...
Frequency
Time

FIG. 36

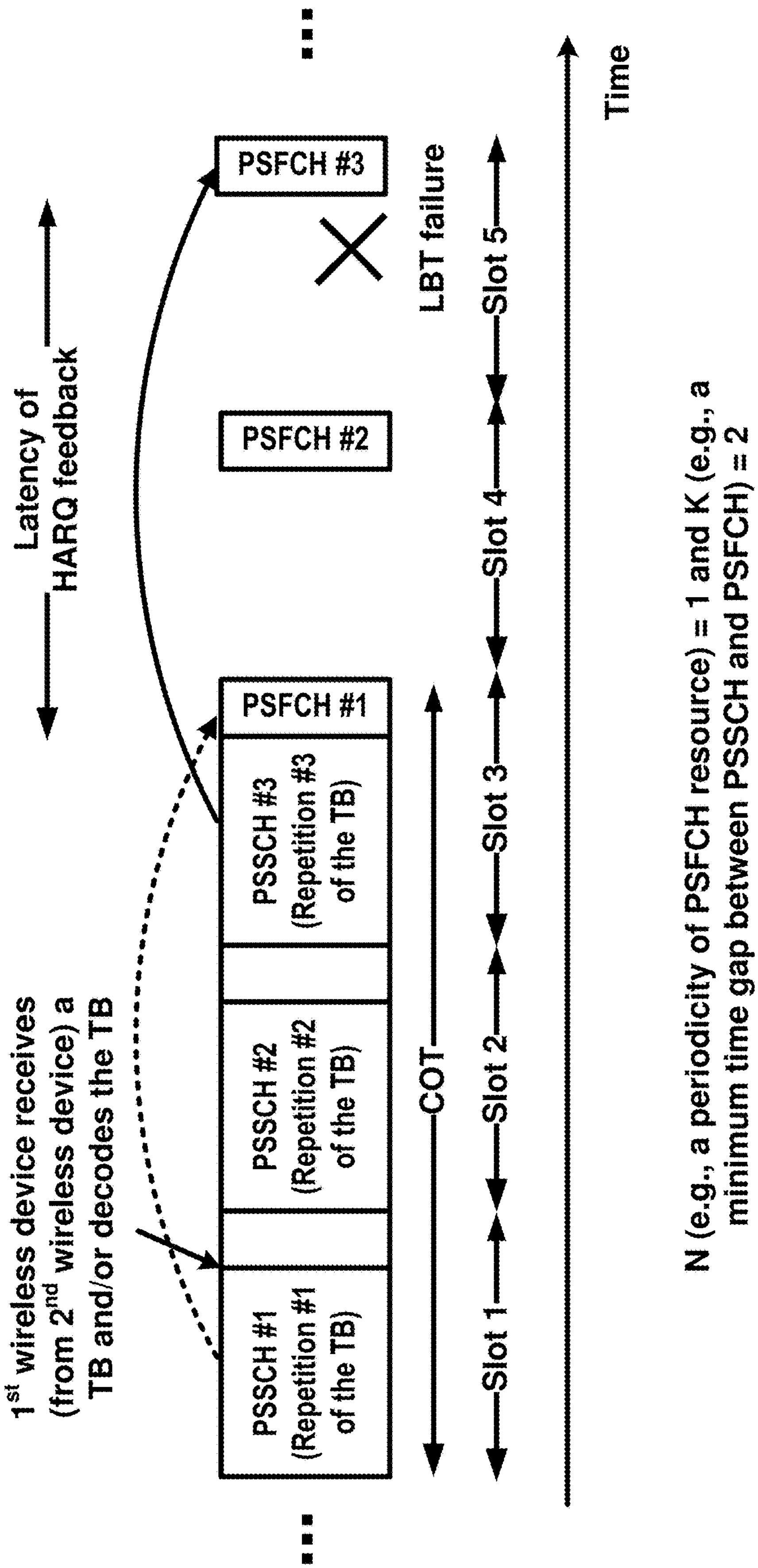
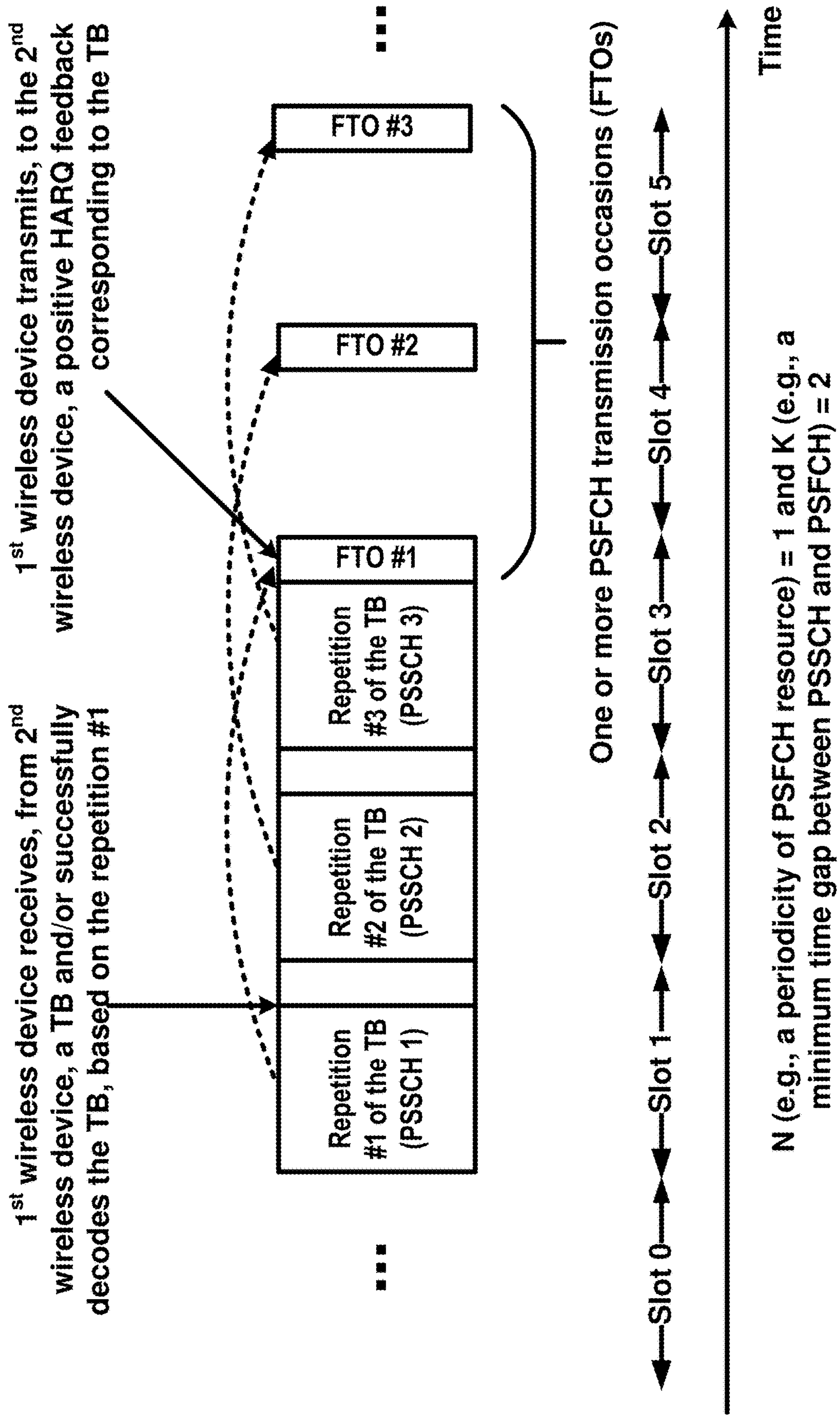

1st wireless device receives (from 2nd wireless device) a TB and/or decodes the TB
Latency of HARQ feedback
PSSCH #1 (Repetition #1 of the TB)
PSSCH #2 (Repetition #2 of the TB)
PSSCH #3 (Repetition #3 of the TB)
PSFCH #1
PSFCH #2
PSFCH #3
LBT failure
COT
Slot 1
Slot 2
Slot 3
Slot 4
Slot 5
Time
N (e.g., a periodicity of PSFCH resource) = 1 and K (e.g., a minimum time gap between PSSCH and PSFCH) = 2

FIG. 37



1st wireless device receives, from 2nd wireless device, a TB and/or successfully decodes the TB, based on the repetition #1
1st wireless device transmits, to the 2nd wireless device, a positive HARQ feedback corresponding to the TB
Repetition #1 of the TB (PSSCH 1)
Repetition #2 of the TB (PSSCH 2)
Repetition #3 of the TB (PSSCH 3)
FTO #1
FTO #2
FTO #3
One or more PSFCH transmission occasions (FTOs)
Slot 0
Slot 1
Slot 2
Slot 3
Slot 4
Slot 5
Time
N (e.g., a periodicity of PSFCH resource) = 1 and K (e.g., a minimum time gap between PSSCH and PSFCH) = 2

FIG. 38

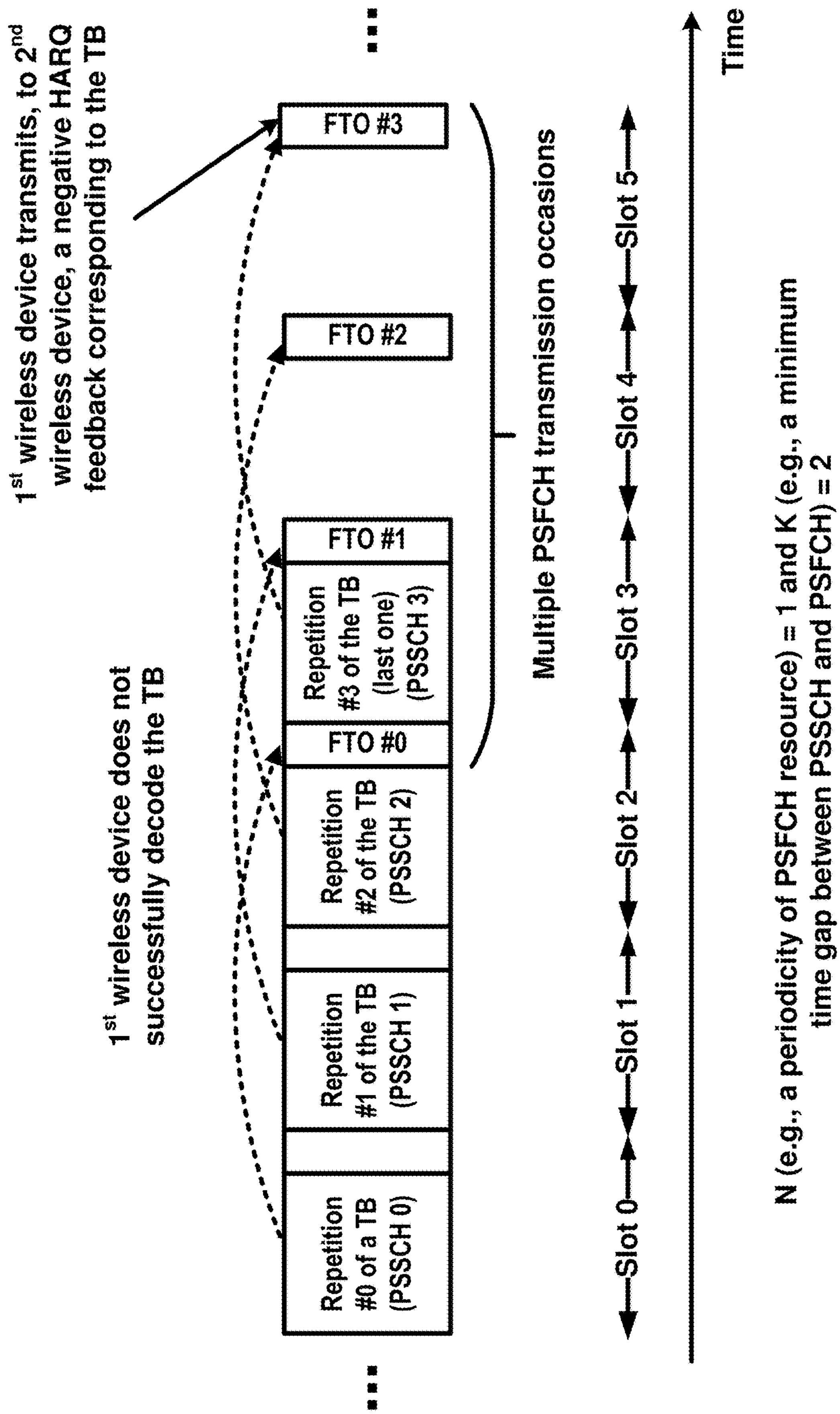

1st wireless device transmits, to 2nd wireless device, a negative HARQ feedback corresponding to the TB
1st wireless device does not successfully decode the TB
FTO #3
FTO #2
FTO #1
FTO #0
Repetition #0 of a TB (PSSCH 0)
Repetition #1 of the TB (PSSCH 1)
Repetition #2 of the TB (PSSCH 2)
Repetition #3 of the TB (last one) (PSSCH 3)
Multiple PSFCH transmission occasions
Slot 0
Slot 1
Slot 2
Slot 3
Slot 4
Slot 5
Time
N (e.g., a periodicity of PSFCH resource) = 1 and K (e.g., a minimum time gap between PSSCH and PSFCH) = 2

FIG. 39

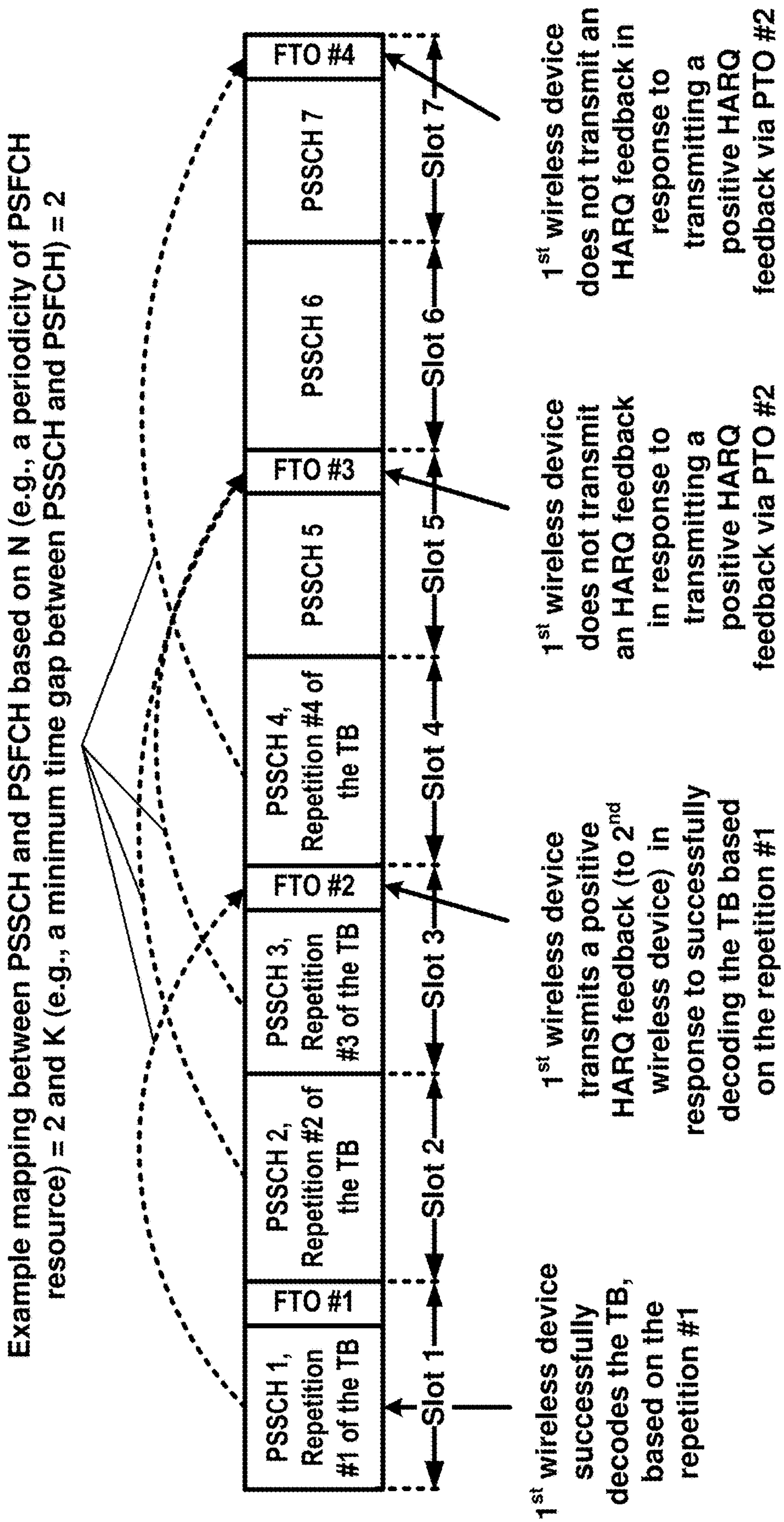

Example mapping between PSSCH and PSFCH based on N (e.g., a periodicity of PSFCH resource) = 2 and K (e.g., a minimum time gap between PSSCH and PSFCH) = 2
PSSCH 1, Repetition #1 of the TB
FTO #1
PSSCH 2, Repetition #2 of the TB
PSSCH 3, Repetition #3 of the TB
FTO #2
PSSCH 4, Repetition #4 of the TB
PSSCH 5
FTO #3
PSSCH 6
PSSCH 7
FTO #4
Slot 1
Slot 2
Slot 3
Slot 4
Slot 5
Slot 6
Slot 7
1st wireless device successfully decodes the TB, based on the repetition #1
1st wireless device transmits a positive HARQ feedback (to 2nd wireless device) in response to successfully decoding the TB based on the repetition #1
1st wireless device does not transmit an HARQ feedback in response to transmiting a positive HARQ feedback via PTO #2
1st wireless device does not transmit an HARQ feedback in response to transmiting a positive HARQ feedback via PTO #2

FIG. 40

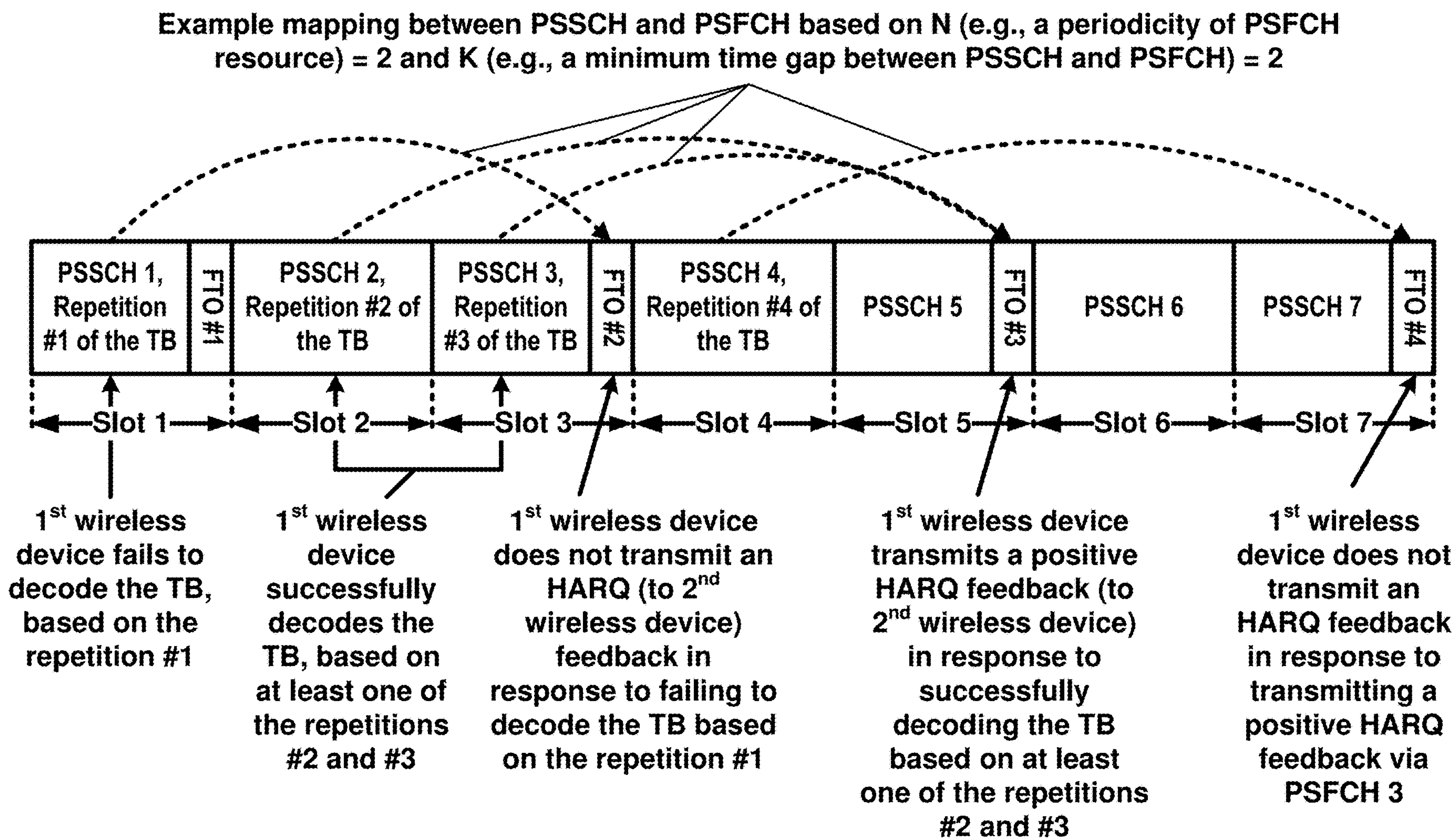

Example mapping between PSSCH and PSFCH based on N (e.g., a periodicity of PSFCH resource) = 2 and K (e.g., a minimum time gap between PSSCH and PSFCH) = 2
PSSCH 1, Repetition #1 of the TB
FTO #1
PSSCH 2, Repetition #2 of the TB
PSSCH 3, Repetition #3 of the TB
FTO #2
PSSCH 4, Repetition #4 of the TB
PSSCH 5
FTO #3
PSSCH 6
PSSCH 7
FTO #4
Slot 1
Slot 2
Slot 3
Slot 4
Slot 5
Slot 6
Slot 7
1st wireless device fails to decode the TB, based on the repetition #1
1st wireless device successfully decodes the TB, based on at least one of the repetitions #2 and #3
1st wireless device does not transmit an HARQ (to 2nd wireless device) feedback in response to failing to decode the TB based on the repetition #1
1st wireless device transmits a positive HARQ feedback (to 2nd wireless device) in response to successfully decoding the TB based on at least one of the repetitions #2 and #3
1st wireless device does not transmit an HARQ feedback in response to transmitting a positive HARQ feedback via PSFCH 3

FIG. 41

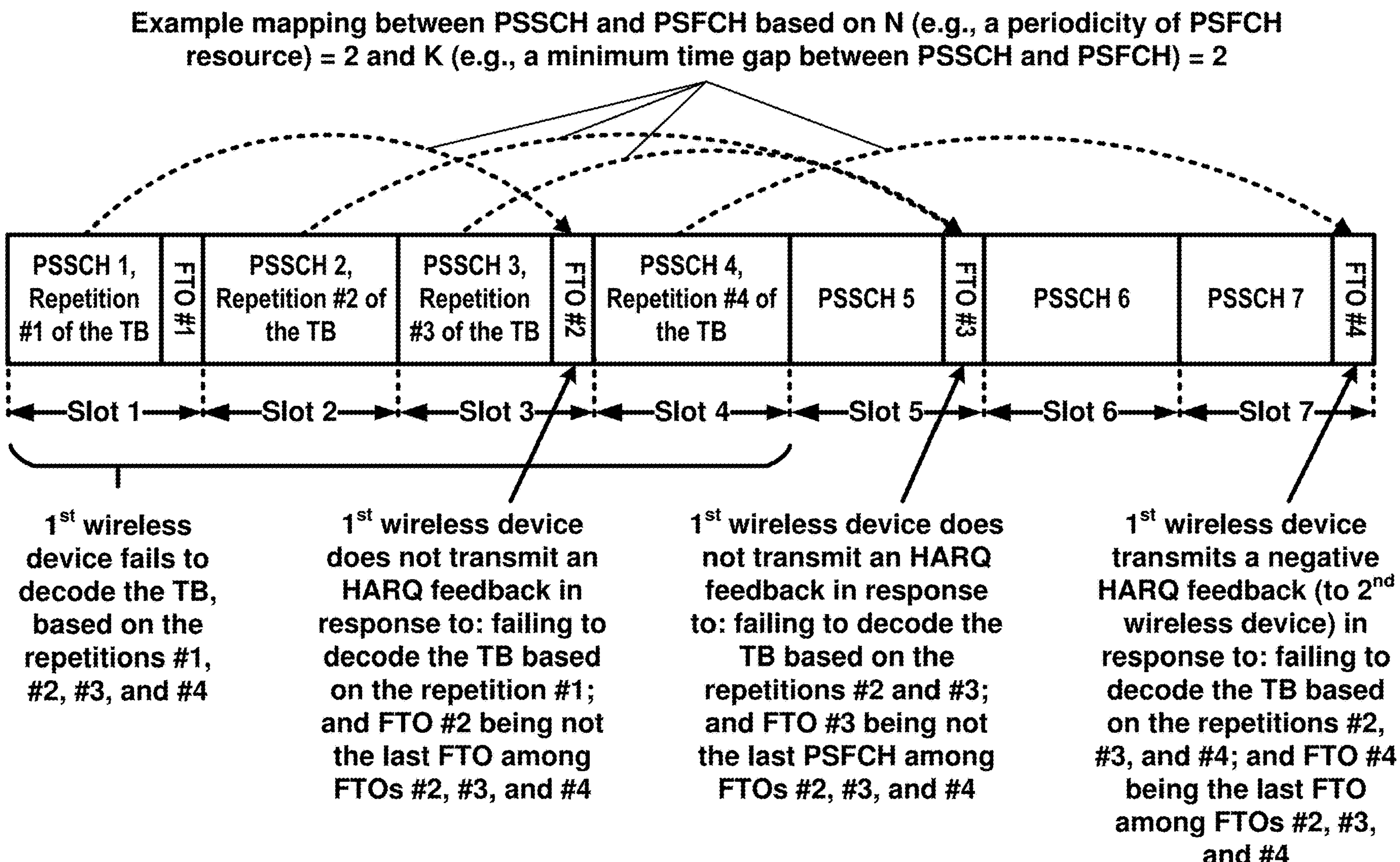

Example mapping between PSSCH and PSFCH based on N (e.g., a periodicity of PSFCH resource) = 2 and K (e.g., a minimum time gap between PSSCH and PSFCH) = 2
PSSCH 1, Repetition #1 of the TB
FTO #1
PSSCH 2, Repetition #2 of the TB
PSSCH 3, Repetition #3 of the TB
FTO #2
PSSCH 4, Repetition #4 of the TB
PSSCH 5
FTO #3
PSSCH 6
PSSCH 7
FTO #4
Slot 1
Slot 2
Slot 3
Slot 4
Slot 5
Slot 6
Slot 7
1st wireless device fails to decode the TB, based on the repetitions #1, #2, #3, and #4
1st wireless device does not transmit an HARQ feedback in response to: failing to decode the TB based on the repetition #1; and FTO #2 being not the last FTO among FTOs #2, #3, and #4
1st wireless device does not transmit an HARQ feedback in response to: failing to decode the TB based on the repetitions #2 and #3; and FTO #3 being not the last PSFCH among FTOs #2, #3, and #4
1st wireless device transmits a negative HARQ feedback (to 2nd wireless device) in response to: failing to decode the TB based on the repetitions #2, #3, and #4; and FTO #4 being the last FTO among FTOs #2, #3, and #4

FIG. 42

Receive, by a wireless device and via a first slot, a 1st repetition of multiple repetitions of a transport block (TB), wherein each of the multiple repetitions is associated with a respective physical sidelink feedback channel (PSFCH) transmission occasion of multiple PSFCH transmission occasions

4301

Select, among one or more first PSFCH transmission occasions of the multiple PSFCH transmission occasions, a first PSFCH transmission occasion for transmission of a positive hybrid automatic repeat-request (HARQ) feedback of the TB, wherein:

the first PSFCH transmission occasion is one of the one or more first PSFCH transmission occasions; and

the one or more first PSFCH transmission occasions occur after the first slot; and

transmitting the positive HARQ feedback via the first PSFCH transmission occasion

4302

FIG. 43

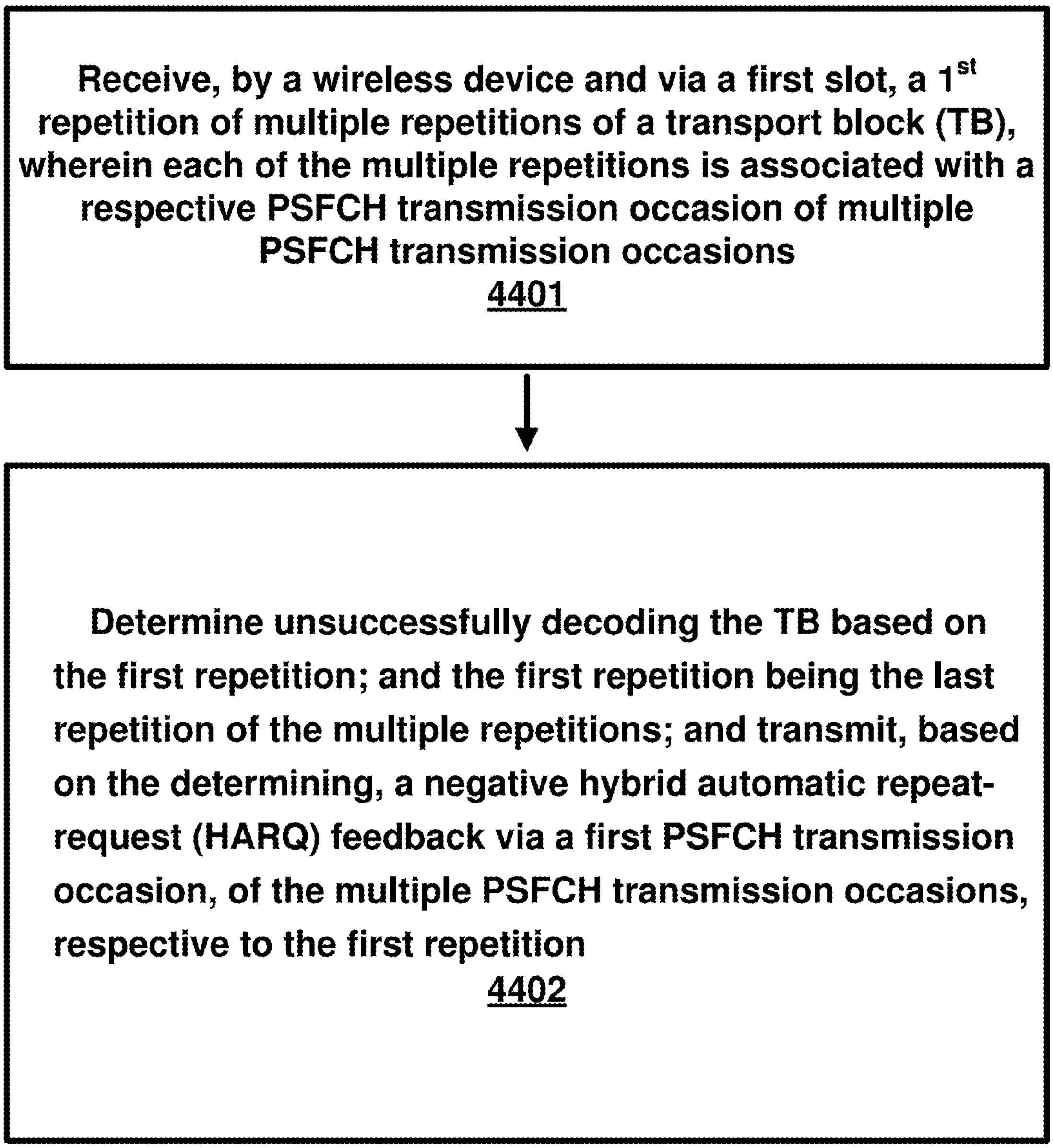

Receive, by a wireless device and via a first slot, a 1st repetition of multiple repetitions of a transport block (TB), wherein each of the multiple repetitions is associated with a respective PSFCH transmission occasion of multiple PSFCH transmission occasions
4401
Determine unsuccessfully decoding the TB based on the first repetition; and the first repetition being the last repetition of the multiple repetitions; and transmit, based on the determining, a negative hybrid automatic repeat-request (HARQ) feedback via a first PSFCH transmission occasion, of the multiple PSFCH transmission occasions, respective to the first repetition
4402

FIG. 44

SIDELINK COMMUNICATIONS IN UNLICENSED BAND

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of International Application No. PCT/US2023/034049, filed Sep. 28, 2023, which claims the benefit of U.S. Provisional Application No. 63/411,489, filed Sep. 29, 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 examples of device-to-device (D2D) communication as per an aspect of an example embodiment of the present disclosure.

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

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

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

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

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

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

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

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

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

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

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

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

[0036] FIG. **30** illustrates an example of a sidelink inter-UE coordination (e.g., an inter-UE coordination scheme 1) as per an aspect of an example embodiment of the present disclosure.

[0037] FIG. **31** illustrates an example of a sidelink inter-UE coordination (e.g., an inter-UE coordination scheme 2) as per an aspect of an example embodiment of the present disclosure.

[0038] FIG. **32** illustrates an example of unlicensed operation in an unlicensed/shared spectrum/band/carrier/cell as per an aspect of an example embodiment of the present disclosure.

[0039] FIG. **33** illustrates an example of COT sharing in an unlicensed/shared spectrum/band/carrier/cell as per an aspect of an example embodiment of the present disclosure.

[0040] FIG. **34** illustrates an example of a plurality of resource block (RB) interlaces comprising one or more RB interlaces

[0041] FIG. **35** illustrates an example of frequency resource configuration with a common interlace and resource blocks as per an aspect of an example embodiment of the present disclosure.

[0042] FIG. **36** illustrates an example of PSFCH transmission occasion and PSFCH resource as per an aspect of an example embodiment of the present disclosure.

[0043] FIG. **37** illustrates an example of transmission of HARQ feedback for MCST as per an aspect of an example embodiment of the present disclosure.

[0044] FIG. **38** illustrates an example of transmission of HARQ feedback for MOST as per an aspect of an example embodiment of the present disclosure.

[0045] FIG. **39** illustrates an example of transmission of HARQ feedback for MCST as per an aspect of an example embodiment of the present disclosure.

[0046] FIG. **40** illustrates an example of transmission of HARQ feedback for MCST as per an aspect of an example embodiment of the present disclosure.

[0047] FIG. **41** illustrates an example of transmission of HARQ feedback for MCST as per an aspect of an example embodiment of the present disclosure.

[0048] FIG. **42** illustrates an example of transmission of HARQ feedback for MCST as per an aspect of an example embodiment of the present disclosure.

[0049] FIG. **43** illustrates an example of flow diagram as per an aspect of an embodiment of the present disclosure.

[0050] FIG. **44** illustrates an example of flow diagram as per an aspect of an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0051] 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.

[0052] Embodiments may be configured to operate as desired. The disclosed mechanism may be performed when certain criteria are met, for example, in a wireless device, a base station, a radio environment, a network, a combination of the above, and/or the like. Example criteria may be based, at least in part, on for example, wireless device or network node configurations, traffic load, initial system set up, packet sizes, traffic characteristics, a combination of the above, and/or the like. When the one or more criteria are met, various example embodiments may be applied. Therefore, it may be possible to implement example embodiments that selectively implement disclosed protocols.

[0053] A base station may communicate with a mix of wireless devices. Wireless devices and/or base stations may support multiple technologies, and/or multiple releases of the same technology. Wireless devices may have some capability(ies) depending on wireless device category and/or capability (ies). When this disclosure refers to a base station communicating with a plurality of wireless devices, this disclosure may refer to a subset of the total wireless devices in a coverage area. This disclosure may refer to, for example, a plurality of wireless devices of a given LTE or 5G release with a given capability and in a given sector of the base station. The plurality of wireless devices in this disclosure may refer to a selected plurality of wireless devices, and/or a subset of total wireless devices in a coverage area which perform according to disclosed methods, and/or the like. There may be a plurality of base stations or a plurality of wireless devices in a coverage area that may not comply with the disclosed methods, for example, those wireless devices or base stations may perform based on older releases of LTE or 5G technology.

[0054] 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.

[0055] 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.

[0056] The term configured may relate to the capacity of a device whether the device is in an operational or non-operational state. Configured may refer to settings in a device that effect the operational characteristics of the device whether the device is in an operational or non-operational state. In other words, the hardware, software, firmware, registers, memory values, and/or the like may be "configured" within a device, whether the device is in an operational or nonoperational state, to provide the device with characteristics. Terms such as "a control message to cause in a device" may mean that a control message has parameters that may be used to configure characteristics or may be used to implement certain actions in the device, whether the device is in an operational or non-operational state.

[0057] 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.

[0058] 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.

[0059] 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.

[0060] 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**.

[0061] 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.

[0062] 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.

[0063] The term wireless device may be used throughout this disclosure to refer to and encompass any mobile device or fixed (non-mobile) device for which wireless communication is desired or usable. For example, a wireless device may be a telephone, smart phone, tablet, computer, laptop, sensor, meter, wearable device, Internet of Things (IoT) device, vehicle road side unit (RSU), relay node, automobile, and/or any combination thereof. The term wireless device encompasses other terminology, including user equipment (UE), user terminal (UT), access terminal (AT), mobile station, handset, wireless transmit and receive unit (WTRU), and/or wireless communication device.

[0064] 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).

[0065] 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.

[0066] 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.

[0067] 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.

[0068] 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.

[0069] 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.

[0070] 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).

[0071] 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.

[0072] 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.

[0073] 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).

[0074] 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.

[0075] 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.

[0076] 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.

[0077] 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.

[0078] 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.

[0079] 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.

[0080] 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.

[0081] 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.

[0082] 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 constraints (e.g., in terms of delay, data rate, and/or error rate). The SDAPs **215** and **225** may perform mapping/de-mapping between the one or more QoS flows and one or more data radio bearers. The mapping/de-mapping between the QoS flows and the data radio bearers may be determined by the SDAP **225** at the gNB **220**. The SDAP **215** at the UE **210** may be informed of the mapping between the QoS flows and the data radio bearers through reflective mapping or control signaling received from the gNB **220**. For reflective mapping, the SDAP **225** at the gNB **220** may mark the downlink packets with a QoS flow indicator (QFI), which may be observed by the SDAP **215** at the UE **210** to determine the mapping/de-mapping between the QoS flows and the data radio bearers.

[0083] The PDCPs **214** and **224** may perform header compression/decompression to reduce the amount of data to be transmitted over the air interface, ciphering/deciphering to prevent unauthorized decoding of data transmitted over the air interface, and integrity protection (to ensure control messages originate from intended sources. The PDCPs **214** and **224** may perform retransmissions of undelivered packets, in-sequence delivery and reordering of packets, and removal of packets received in duplicate due to, for example, an intra-gNB handover. The PDCPs **214** and **224** may perform packet duplication to improve the likelihood of the packet being received and, at the receiver, remove any duplicate packets. Packet duplication may be useful for services that use high reliability.

[0084] 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.

[0085] 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.

[0086] 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**.

[0087] 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**.

[0088] 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.

[0089] 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**.

[0090] 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.

[0091] 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.

[0092] FIG. **4**B further illustrates MAC control elements (CEs) inserted into the MAC PDU by a MAC, such as MAC **212** or MAC **222**. For example, FIG. **4**B illustrates two MAC CEs inserted into the MAC PDU. MAC CEs may be inserted at the beginning of a MAC PDU for downlink transmissions (as shown in FIG. **4**B) and at the end of a MAC PDU for uplink transmissions. MAC CEs may be used for in-band control signaling. Example MAC CEs include: scheduling-related MAC CEs, such as buffer status reports and power headroom reports; activation/deactivation MAC CEs, such as those for activation/deactivation of PDCP duplication detection, channel state information (CSI) reporting, sounding reference signal (SRS) transmission, and prior configured components; discontinuous reception (DRX) related MAC CEs; timing advance MAC CEs; and random access related MAC CEs. A MAC CE may be preceded by a MAC subheader with a similar format as described for MAC SDUs and may be identified with a reserved value in the LCID field that indicates the type of control information included in the MAC CE.

[0093] 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.

[0094] 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 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:

- **[0095]** 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;
- **[0096]** 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;
- **[0097]** a common control channel (CCCH) for carrying control messages together with random access;
- **[0098]** a dedicated control channel (DCCH) for carrying control messages to/from a UE to configure the UE; and
- **[0099]** a dedicated traffic channel (DTCH) for carrying user data to/from a UE.

[0100] 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:

- **[0101]** a paging channel (PCH) for carrying paging messages that originated from the PCCH;
- **[0102]** a broadcast channel (BCH) for carrying the MIB from the BCCH;
- **[0103]** a downlink shared channel (DL-SCH) for carrying downlink data and signaling messages, including the SIBs from the BCCH;
- **[0104]** an uplink shared channel (UL-SCH) for carrying uplink data and signaling messages; and
- **[0105]** a random access channel (RACH) for allowing a UE to contact the network without any prior scheduling.

[0106] 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:

- **[0107]** a physical broadcast channel (PBCH) for carrying the MIB from the BCH;
- **[0108]** 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;
- **[0109]** 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;
- **[0110]** 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;
- **[0111]** 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
- **[0112]** a physical random access channel (PRACH) for random access.

[0113] 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.

[0114] 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.

[0115] 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.

[0116] 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.

[0117] 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).

[0118] 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**.

[0119] 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.

[0120] 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**.

[0121] 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).

[0122] 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.

[0123] 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.

[0124] 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**.

[0125] 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.

[0126] 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.

[0127] 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.

[0128] 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.

[0129] A slot may have a fixed number of OFDM symbols (e.g., 14 OFDM symbols). A numerology with a higher subcarrier spacing has a shorter slot duration and, correspondingly, more slots per subframe. FIG. **7** illustrates this numerology-dependent slot duration and slots-per-subframe transmission structure (the numerology with a subcarrier spacing of 240 KHz is not shown in FIG. **7** for ease of illustration). A subframe in NR may be used as a numerology-independent time reference, while a slot may be used as the unit upon which uplink and downlink transmissions are scheduled. To support low latency, scheduling in NR may be decoupled from the slot duration and start at any OFDM symbol and last for as many symbols as provided for a transmission. These partial slot transmissions may be referred to as mini-slot or subslot transmissions.

[0130] 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.

[0131] 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.

[0132] 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.

[0133] 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.

[0134] 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.

[0135] 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.

[0136] 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).

[0137] 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.

[0138] 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.

[0139] 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.

[0140] 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).

[0141] 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.

[0142] 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.

[0143] 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.

[0144] 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.

[0145] 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).

[0146] 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.

[0147] 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).

[0148] 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).

[0149] 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.

[0150] 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.

[0151] 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.

[0152] 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.

[0153] 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.

[0154] 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.

[0155] 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.

[0156] 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

[0157] 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.

[0158] The PBCH may use a QPSK modulation and may use forward error correction (FEC). The FEC may use polar coding. One or more symbols spanned by the PBCH may carry one or more DMRSs for demodulation of the PBCH. The PBCH may include an indication of a current system frame number (SFN) of the cell and/or a SS/PBCH block timing index. These parameters may facilitate time synchronization of the UE to the base station. The PBCH may include a master information block (MIB) used to provide the UE with one or more parameters. The MIB may be used by the UE to locate remaining minimum system information (RMSI) associated with the cell. The RMSI may include a System Information Block Type 1 (SIB1). The SIB1 may contain information configured for the UE to access the cell. The UE may use one or more parameters of the MIB to monitor PDCCH, which may be used to schedule PDSCH. The PDSCH may include the SIB1. The SIB1 may be decoded using parameters provided in the MIB. The PBCH may indicate an absence of SIB1. Based on the PBCH indicating the absence of SIB1, the UE may be pointed to a frequency. The UE may search for an SS/PBCH block at the frequency to which the UE is pointed.

[0159] 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.

[0160] 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.

[0161] 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.

[0162] 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.

[0163] 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.

[0164] 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.

[0165] 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.

[0166] 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.

[0167] 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).

[0168] 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.

[0169] 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.

[0170] 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.

[0171] 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.

[0172] 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.

[0173] SRS may be transmitted by a UE to a base station for channel state estimation to support uplink channel dependent scheduling and/or link adaptation. SRS transmitted by the UE may allow a base station to estimate an uplink channel state at one or more frequencies. A scheduler at the base station may employ the estimated uplink channel state to assign one or more resource blocks for an uplink PUSCH transmission from the UE. The base station may semi-statically configure the UE with one or more SRS resource sets. For an SRS resource set, the base station may configure the UE with one or more SRS resources. An SRS resource set applicability may be configured by a higher layer (e.g., RRC) parameter. For example, when a higher layer parameter indicates beam management, an SRS resource in an SRS resource set of the one or more SRS resource sets (e.g., with the same/similar time domain behavior, periodic, aperiodic, and/or the like) may be transmitted at a time instant (e.g., simultaneously). The UE may transmit one or more SRS resources in SRS resource sets. An NR network may support aperiodic, periodic and/or semi-persistent SRS transmissions. The UE may transmit SRS resources based on one or more trigger types, wherein the one or more trigger types may comprise higher layer signaling (e.g., RRC) and/or one or more DCI formats. In an example, at least one DCI format may be employed for the UE to select at least one of one or more configured SRS resource sets. An SRS trigger type 0 may refer to an SRS triggered based on a higher layer signaling. An SRS trigger type 1 may refer to an SRS triggered based on one or more DCI formats. In an example, when PUSCH and SRS are transmitted in a same slot, the UE may be configured to transmit SRS after a transmission of a PUSCH and a corresponding uplink DMRS.

[0174] 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.

[0175] 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.

[0176] Channels that use beamforming may use beam management. Beam management may comprise beam measurement, beam selection, and beam indication. A beam may be associated with one or more reference signals. For example, a beam may be identified by one or more beamformed reference signals. The UE may perform downlink beam measurement based on downlink reference signals (e.g., a channel state information reference signal (CSI-RS) and generate a beam measurement report. The UE may perform the downlink beam measurement procedure after an RRC connection is set up with a base station.

[0177] 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.

[0178] 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.

[0179] 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.

[0180] 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).

[0181] FIG. **12**A illustrates examples of three downlink beam management procedures: P1, P2, and P3. Procedure P1 may enable a UE measurement on transmit (Tx) beams of a transmission reception point (TRP) (or multiple TRPs), e.g., to support a selection of one or more base station Tx beams and/or UE Rx beams (shown as ovals in the top row and bottom row, respectively, of P1). Beamforming at a TRP may comprise a Tx beam sweep for a set of beams (shown, in the top rows of P1 and P2, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). Beamforming at a UE may comprise an Rx beam sweep for a set of beams (shown, in the bottom rows of P1 and P3, as ovals rotated in a clockwise direction indicated by the dashed arrow). Procedure P2 may be used to enable a UE measurement on Tx beams of a TRP (shown, in the top row of P2, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). The UE and/or the base station may perform procedure P2 using a smaller set of beams than is used in procedure P1, or using narrower beams than the beams used in procedure P1. This may be referred to as beam refinement. The UE may perform procedure P3 for Rx beam determination by using the same Tx beam at the base station and sweeping an Rx beam at the UE.

[0182] FIG. **12**B illustrates examples of three uplink beam management procedures: U1, U2, and U3. Procedure U1 may be used to enable a base station to perform a measurement on Tx beams of a UE, e.g., to support a selection of one or more UE Tx beams and/or base station Rx beams (shown as ovals in the top row and bottom row, respectively, of U1). Beamforming at the UE may include, e.g., a Tx beam sweep from a set of beams (shown in the bottom rows of U1 and U3 as ovals rotated in a clockwise direction indicated by the dashed arrow). Beamforming at the base station may include, e.g., an Rx beam sweep from a set of beams (shown, in the top rows of U1 and U2, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). Procedure U2 may be used to enable the base station to adjust its Rx beam when the UE uses a fixed Tx beam. The UE and/or the base station may perform procedure U2 using a smaller set of beams than is used in procedure P1, or using narrower beams than the beams used in procedure P1. This may be referred to as beam refinement The UE may perform procedure U3 to adjust its Tx beam when the base station uses a fixed Rx beam.

[0183] 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).

[0184] 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.

[0185] 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.

[0186] 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).

[0187] The configuration message **1310** may be transmitted, for example, using one or more RRC messages. The one or more RRC messages may indicate one or more random access channel (RACH) parameters to the UE. The one or more RACH parameters may comprise at least one of following: general parameters for one or more random access procedures (e.g., RACH-configGeneral); cell-specific parameters (e.g., RACH-ConfigCommon); and/or dedicated parameters (e.g., RACH-configDedicated). The base station may broadcast or multicast the one or more RRC messages to one or more UEs. The one or more RRC messages may be UE-specific (e.g., dedicated RRC messages transmitted to a UE in an RRC_CONNECTED state and/or in an RRC_INACTIVE state). The UE may determine, based on the one or more RACH parameters, a time-frequency resource and/or an uplink transmit power for transmission of the Msg 1 **1311** and/or the Msg 3 **1313**. Based on the one or more RACH parameters, the UE may determine a reception timing and a downlink channel for receiving the Msg 2 **1312** and the Msg 4 **1314**.

[0188] The one or more RACH parameters provided in the configuration message **1310** may indicate one or more Physical RACH (PRACH) occasions available for transmission of the Msg 1 **1311**. The one or more PRACH occasions may be predefined. The one or more RACH parameters may indicate one or more available sets of one or more PRACH occasions (e.g., prach-ConfigIndex). The one or more RACH parameters may indicate an association between (a) one or more PRACH occasions and (b) one or more reference signals. The one or more RACH parameters may indicate an association between (a) one or more preambles and (b) one or more reference signals. The one or more reference signals may be SS/PBCH blocks and/or CSI-RSs. For example, the one or more RACH parameters may indicate a number of SS/PBCH blocks mapped to a PRACH occasion and/or a number of preambles mapped to a SS/PBCH blocks.

[0189] The one or more RACH parameters provided in the configuration message **1310** may be used to determine an uplink transmit power of Msg 1 **1311** and/or Msg 3 **1313**. For example, the one or more RACH parameters may indicate a reference power for a preamble transmission (e.g., a received target power and/or an initial power of the preamble transmission). There may be one or more power offsets indicated by the one or more RACH parameters. For example, the one or more RACH parameters may indicate: a power ramping step; a power offset between SSB and CSI-RS; a power offset between transmissions of the Msg 1 **1311** and the Msg 3 **1313**; and/or a power offset value between preamble groups. The one or more RACH parameters may indicate one or more thresholds based on which the UE may determine at least one reference signal (e.g., an SSB and/or CSI-RS) and/or an uplink carrier (e.g., a normal uplink (NUL) carrier and/or a supplemental uplink (SUL) carrier).

[0190] 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-Threshold-CSI-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.

[0191] 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.

[0192] 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).

[0193] The Msg 2 **1312** received by the UE may include an RAR. In some scenarios, the Msg 2 **1312** may include multiple RARs corresponding to multiple UEs. The Msg 2 **1312** may be received after or in response to the transmitting of the Msg 1 **1311**. The Msg 2 **1312** may be scheduled on the DL-SCH and indicated on a PDCCH using a random access RNTI (RA-RNTI). The Msg 2 **1312** may indicate that the Msg 1 **1311** was received by the base station. The Msg 2 **1312** may include a time-alignment command that may be used by the UE to adjust the UE's transmission timing, a scheduling grant for transmission of the Msg 3 **1313**, and/or a Temporary Cell RNTI (TC-RNTI). After transmitting a preamble, the UE may start a time window (e.g., ra-ResponseWindow) to monitor a PDCCH for the Msg 2 **1312**. The UE may determine when to start the time window based on a PRACH occasion that the UE uses to transmit the preamble. For example, the UE may start the time window one or more symbols after a last symbol of the preamble (e.g., at a first PDCCH occasion from an end of a preamble transmission). The one or more symbols may be determined based on a numerology. The PDCCH may be in a common search space (e.g., a Type1-PDCCH common search space) configured by an RRC message. The UE may identify the RAR based on a Radio Network Temporary Identifier (RNTI). RNTIs may be used depending on one or more events initiating the random access procedure. The UE may use random access RNTI (RA-RNTI). The RA-RNTI may be associated with PRACH occasions in which the UE transmits a preamble. For example, the UE may determine the RA-RNTI based on: an OFDM symbol index; a slot index; a frequency domain index; and/or a UL carrier indicator of the PRACH occasions. An example of RA-RNTI may be as follows:

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

where s_id may be an index of a first OFDM symbol of the PRACH occasion (e.g., $0 \le s\_id < 14$), t_id may be an index of a first slot of the PRACH occasion in a system frame (e.g., $0 \le t\_id < 80$), f_id may be an index of the PRACH occasion in the frequency domain (e.g., $0 \le f\_id < 8$), 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).

[0194] 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).

[0195] The Msg 4 **1314** may be received after or in response to the transmitting of the Msg 3 **1313**. If a C-RNTI was included in the Msg 3 **1313**, the base station will address the UE on the PDCCH using the C-RNTI. If the UE's unique C-RNTI is detected on the PDCCH, the random access procedure is determined to be successfully completed. If a TC-RNTI is included in the Msg 3 **1313** (e.g., if the UE is in an RRC_IDLE state or not otherwise connected to the base station), Msg 4 **1314** will be received using a DL-SCH associated with the TC-RNTI. If a MAC PDU is successfully decoded and a MAC PDU comprises the UE contention resolution identity MAC CE that matches or otherwise corresponds with the CCCH SDU sent (e.g., transmitted) in Msg 3 **1313**, the UE may determine that the contention resolution is successful and/or the UE may determine that the random access procedure is successfully completed.

[0196] The UE may be configured with a supplementary uplink (SUL) carrier and a normal uplink (NUL) carrier. An initial access (e.g., random access procedure) may be supported in an uplink carrier. For example, a base station may configure the UE with two separate RACH configurations: one for an SUL carrier and the other for an NUL carrier. For random access in a cell configured with an SUL carrier, the network may indicate which carrier to use (NUL or SUL). The UE may determine the SUL carrier, for example, if a measured quality of one or more reference signals is lower than a broadcast threshold. Uplink transmissions of the random access procedure (e.g., the Msg 1 **1311** and/or the Msg 3 **1313**) may remain on the selected carrier. The UE may switch an uplink carrier during the random access procedure (e.g., between the Msg 1 **1311** and the Msg 3 **1313**) in one or more cases. For example, the UE may determine and/or switch an uplink carrier for the Msg 1 **1311** and/or the Msg 3 **1313** based on a channel clear assessment (e.g., a listen-before-talk).

[0197] FIG. **13**B illustrates a two-step contention-free random access procedure. Similar to the four-step contention-based random access procedure illustrated in FIG. **13**A, a base station may, prior to initiation of the procedure, transmit a configuration message **1320** to the UE. The configuration message **1320** may be analogous in some respects to the configuration message **1310**. The procedure illustrated in FIG. **13**B comprises transmission of two messages: a Msg 1 **1321** and a Msg 2 **1322**. The Msg 1 **1321** and the Msg 2 **1322** may be analogous in some respects to the Msg 1 **1311** and a Msg 2 **1312** illustrated in FIG. **13**A, respectively. As will be understood from FIGS. **13**A and **13**B, the contention-free random access procedure may not include messages analogous to the Msg 3 **1313** and/or the Msg 4 **1314**.

[0198] The contention-free random access procedure illustrated in FIG. **13**B may be initiated for a beam failure recovery, other SI request, SCell addition, and/or handover. For example, a base station may indicate or assign to the UE the preamble to be used for the Msg 1 **1321**. The UE may receive, from the base station via PDCCH and/or RRC, an indication of a preamble (e.g., ra-PreambleIndex).

[0199] After transmitting a preamble, the UE may start a time window (e.g., ra-ResponseWindow) to monitor a PDCCH for the RAR. In the event of a beam failure recovery request, the base station may configure the UE with a separate time window and/or a separate PDCCH in a search space indicated by an RRC message (e.g., recoverySearchSpaceId). The UE may monitor for a PDCCH transmission addressed to a Cell RNTI (C-RNTI) on the search space. In the contention-free random access procedure illustrated in FIG. **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.

[0200] 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**.

[0201] Msg A **1331** may be transmitted in an uplink transmission by the UE. Msg A **1331** may comprise one or more transmissions of a preamble **1341** and/or one or more transmissions of a transport block **1342**. The transport block **1342** may comprise contents that are similar and/or equivalent to the contents of the Msg 3 **1313** illustrated in FIG. **13**A. The transport block **1342** may comprise UCI (e.g., an SR, a HARQ ACK/NACK, and/or the like). The UE may receive the Msg B **1332** after or in response to transmitting the Msg A **1331**. The Msg B **1332** may comprise contents that are similar and/or equivalent to the contents of the Msg

2 **1312** (e.g., an RAR) illustrated in FIGS. **13**A and **13**B and/or the Msg 4 **1314** illustrated in FIG. **13**A.

[0202] 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.

[0203] 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**.

[0204] The transport block **1342** may comprise data (e.g., delay-sensitive data), an identifier of the UE, security information, and/or device information (e.g., an International Mobile Subscriber Identity (IMSI). The base station may transmit the Msg B **1332** as a response to the Msg A **1331**. The Msg B **1332** may comprise at least one of following: a preamble identifier; a timing advance command; a power control command; an uplink grant (e.g., a radio resource assignment and/or an MCS); a UE identifier for contention resolution; and/or an RNTI (e.g., a C-RNTI or a TC-RNTI). The UE may determine that the two-step random access procedure is successfully completed if: a preamble identifier in the Msg B **1332** is matched to a preamble transmitted by the UE; and/or the identifier of the UE in Msg B **1332** is matched to the identifier of the UE in the Msg A **1331** (e.g., the transport block **1342**).

[0205] 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.

[0206] 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.

[0207] 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).

[0208] 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.

[0209] Depending on the purpose and/or content of a DCI, the base station may transmit the DCIs with one or more DCI formats. For example, DCI format 0_0 may be used for scheduling of PUSCH in a cell. DCI format 0_0 may be a fallback DCI format (e.g., with compact DCI payloads). DCI format 0_1 may be used for scheduling of PUSCH in a cell (e.g., with more DCI payloads than DCI format 0_0). DCI format 1_0 may be used for scheduling of PDSCH in a cell. DCI format 1_0 may be a fallback DCI format (e.g., with compact DCI payloads). DCI format 1_1 may be used for scheduling of PDSCH in a cell (e.g., with more DCI payloads than DCI format 1_0). DCI format 2_0 may be used for providing a slot format indication to a group of UEs. DCI format 2_1 may be used for notifying a group of UEs of a physical resource block and/or OFDM symbol where the UE may assume no transmission is intended to the UE. DCI format 2_2 may be used for transmission of a transmit power control (TPC) command for PUCCH or PUSCH. DCI format 2_3 may be used for transmission of a group of TPC commands for SRS transmissions by one or more UEs. DCI format(s) for new functions may be defined in future releases. DCI formats may have different DCI sizes, or may share the same DCI size.

[0210] 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).

[0211] 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.

[0212] 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.

[0213] 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).

[0214] 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).

[0215] 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.

[0216] 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.

[0217] 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".

[0218] After determining a PUCCH resource set from a plurality of PUCCH resource sets, the UE may determine a PUCCH resource from the PUCCH resource set for UCI (HARQ-ACK, CSI, and/or SR) transmission. The UE may determine the PUCCH resource based on a PUCCH resource indicator in a DCI (e.g., with a DCI format 1_0 or DCI for 1_1) received on a PDCCH. A three-bit PUCCH resource indicator in the DCI may indicate one of eight PUCCH resources in the PUCCH resource set. Based on the PUCCH resource indicator, the UE may transmit the UCI (HARQ-ACK, CSI and/or SR) using a PUCCH resource indicated by the PUCCH resource indicator in the DCI.

[0219] 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**.

[0220] 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.

[0221] 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.

[0222] 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.

[0223] 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.

[0224] 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.

[0225] The processing system **1508** and the processing system **1518** may be associated with a memory **1514** and a memory **1524**, respectively. Memory **1514** and memory **1524** (e.g., one or more non-transitory computer readable mediums) may store computer program instructions or code that may be executed by the processing system **1508** and/or the processing system **1518** to carry out one or more of the functionalities discussed in the present application. Although not shown in FIG. **15**, the transmission processing system **1510**, the transmission processing system **1520**, the reception processing system **1512**, and/or the reception processing system **1522** may be coupled to a memory (e.g., one or more non-transitory computer readable mediums) storing computer program instructions or code that may be executed to carry out one or more of their respective functionalities.

[0226] 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.

[0227] 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.

[0228] 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.

[0229] 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.

[0230] 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.

[0231] 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.

[0232] 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.

[0233] A timer may begin running once it is started and continue running until it is stopped or until it expires. A timer may be started if it is not running or restarted if it is running. A timer may be associated with a value (e.g., the timer may be started or restarted from a value or may be started from zero and expire once it reaches the value). The duration of a timer may not be updated until the timer is stopped or expires (e.g., due to BWP switching). A timer may be used to measure a time period/window for a process. When the specification refers to an implementation and procedure related to one or more timers, it will be understood that there are multiple ways to implement the one or more timers. For example, it will be understood that one or more of the multiple ways to implement a timer may be used to measure a time period/window for the procedure. For example, a random access response window timer may be used for measuring a window of time for receiving a random access response. In an example, instead of starting and expiry of a random access response window timer, the time difference between two time stamps may be used. When a timer is restarted, a process for measurement of time window may be restarted. Other example implementations may be provided to restart a measurement of a time window. FIG. **17** illustrates examples of device-to-device (D2D) communication, in which there is a direct communication between wireless devices. In an example, D2D communication may be performed via a sidelink (SL). The wireless devices may exchange sidelink communications via a sidelink interface (e.g., a PC5 interface). Sidelink differs from uplink (in which a wireless device communicates to a base station) and downlink (in which a base station communicates to a wireless device). A wireless device and a base station may exchange uplink and/or downlink communications via a user plane interface (e.g., a Uu interface).

[0234] As shown in the figure, wireless device #1 and wireless device #2 may be in a coverage area of base station #1. For example, both wireless device #1 and wireless device #2 may communicate with the base station #1 via a Uu interface. Wireless device #3 may be in a coverage area of base station #2. Base station #1 and base station #2 may share a network and may jointly provide a network coverage area. Wireless device #4 and wireless device #5 may be outside of the network coverage area.

[0235] In-coverage D2D communication may be performed when two wireless devices share a network coverage area. Wireless device #1 and wireless device #2 are both in the coverage area of base station #1. Accordingly, they may perform an in-coverage intra-cell D2D communication, labeled as sidelink A. Wireless device #2 and wireless device #3 are in the coverage areas of different base stations, but share the same network coverage area. Accordingly, they may perform an in-coverage inter-cell D2D communication, labeled as sidelink B. Partial-coverage D2D communications may be performed when one wireless device is within the network coverage area and the other wireless device is outside the network coverage area. Wireless device #3 and wireless device #4 may perform a partial-coverage D2D communication, labeled as sidelink C. Out-of-coverage D2D communications may be performed when both wireless devices are outside of the network coverage area. Wireless device #4 and wireless device #5 may perform an out-of-coverage D2D communication, labeled as sidelink D.

[0236] Sidelink communications may be configured using physical channels, for example, a physical sidelink broadcast channel (PSBCH), a physical sidelink feedback channel (PSFCH), a physical sidelink discovery channel (PSDCH), a physical sidelink control channel (PSCCH), and/or a physical sidelink shared channel (PSSCH). PSBCH may be used by a first wireless device to send broadcast information to a second wireless device. PSBCH may be similar in some respects to PBCH. The broadcast information may comprise, for example, a slot format indication, resource pool information, a sidelink system frame number, or any other suitable broadcast information. PSFCH may be used by a first wireless device to send feedback information to a second wireless device. The feedback information may comprise, for example, HARQ feedback information. PSDCH may be used by a first wireless device to send discovery information to a second wireless device. The discovery information may be used by a wireless device to signal its presence and/or the availability of services to other wireless devices in the area. PSCCH may be used by a first wireless device to send sidelink control information (SCI) to a second wireless device. PSCCH may be similar in some respects to PDCCH and/or PUCCH. The control information may comprise, for example, time/frequency resource allocation information (RB size, a number of retransmissions, etc.), demodulation related information (DMRS, MCS, RV, etc.), identifying information for a transmitting wireless device and/or a receiving wireless device, a process identifier (HARQ, etc.), or any other suitable control information. The PSCCH may be used to allocate, prioritize, and/or reserve sidelink resources for sidelink transmissions. PSSCH may be used by a first wireless device to send and/or relay data and/or network information to a second wireless device. PSSCH may be similar in some respects to PDSCH and/or PUSCH. Each of the sidelink channels may be associated with one or more demodulation reference signals. Sidelink operations may utilize sidelink synchronization signals to establish a timing of sidelink operations. Wireless devices configured for sidelink operations may send sidelink synchronization signals, for example, with the PSBCH. The sidelink synchronization signals may include primary sidelink synchronization signals (PSSS) and secondary sidelink synchronization signals (SSSS).

[0237] Sidelink resources may be configured to a wireless device in any suitable manner. A wireless device may be pre-configured for sidelink, for example, pre-configured with sidelink resource information. Additionally, or alternatively, a network may broadcast system information relating to a resource pool for sidelink. Additionally, or alternatively, a network may configure a particular wireless device with a dedicated sidelink configuration. The configuration may identify sidelink resources to be used for sidelink operation (e.g., configure a sidelink band combination).

[0238] The wireless device may operate in different modes, for example, an assisted mode (which may be referred to as mode **1**) or an autonomous mode (which may be referred to as mode **2**). Mode selection may be based on a coverage status of the wireless device, a radio resource control status of the wireless device, information and/or instructions from the network, and/or any other suitable factors. For example, if the wireless device is idle or inactive, or if the wireless device is outside of network coverage, the wireless device may select to operate in autonomous mode. For example, if the wireless device is in a connected mode (e.g., connected to a base station), the wireless device may select to operate (or be instructed by the base station to operate) in assisted mode. For example, the network (e.g., a base station) may instruct a connected wireless device to operate in a particular mode.

[0239] In an assisted mode, the wireless device may request scheduling from the network. For example, the wireless device may send a scheduling request to the network and the network may allocate sidelink resources to the wireless device. Assisted mode may be referred to as network-assisted mode, gNB-assisted mode, or base station-assisted mode. In an autonomous mode, the wireless device may select sidelink resources based on measurements within one or more resource pools (for example, pre-configure or network-assigned resource pools), sidelink resource selections made by other wireless devices, and/or sidelink resource usage of other wireless devices.

[0240] To select sidelink resources, a wireless device may observe a sensing window and a selection window. During the sensing window, the wireless device may observe SCI transmitted by other wireless devices using the sidelink resource pool. The SCIs may identify resources that may be used and/or reserved for sidelink transmissions. Based on the resources identified in the SCIs, the wireless device may select resources within the selection window (for example, resource that are different from the resources identified in the SCIs). The wireless device may transmit using the selected sidelink resources.

[0241] FIG. **18** illustrates an example of a resource pool for sidelink operations. A wireless device may operate using one or more sidelink cells. A sidelink cell may include one or more resource pools. Each resource pool may be configured to operate in accordance with a particular mode (for example, assisted or autonomous). The resource pool may be divided into resource units. In the frequency domain, each resource unit may comprise, for example, one or more resource blocks which may be referred to as a sub-channel. In the time domain, each resource unit may comprise, for example, one or more slots, one or more subframes, and/or one or more OFDM symbols. The resource pool may be continuous or non-continuous in the frequency domain and/or the time domain (for example, comprising contiguous resource units or non-contiguous resource units). The resource pool may be divided into repeating resource pool portions. The resource pool may be shared among one or more wireless devices. Each wireless device may attempt to transmit using different resource units, for example, to avoid collisions.

[0242] Sidelink resource pools may be arranged in any suitable manner. In the figure, the example resource pool is non-contiguous in the time domain and confined to a single sidelink BWP. In the example resource pool, frequency resources are divided into a Nf resource units per unit of time, numbered from zero to Nf−1. The example resource pool may comprise a plurality of portions (non-contiguous in this example) that repeat every k units of time. In the figure, time resources are numbered as n, n+1 . . . n+k, n+k+1 . . . , etc.

[0243] A wireless device may select for transmission one or more resource units from the resource pool. In the example resource pool, the wireless device selects resource unit (n,0) for sidelink transmission. The wireless device may further select periodic resource units in later portions of the resource pool, for example, resource unit (n+k,0), resource unit (n+2k,0), resource unit (n+3k,0), etc. The selection may be based on, for example, a determination that a transmission using resource unit (n,0) will not (or is not likely) to collide with a sidelink transmission of a wireless device that shares the sidelink resource pool. The determination may be based on, for example, behavior of other wireless devices that share the resource pool. For example, if no sidelink transmissions are detected in resource unit (n−k,0), then the wireless device may select resource unit (n,0), resource (n+k,0), etc. For example, if a sidelink transmission from another wireless device is detected in resource unit (n−k, 1), then the wireless device may avoid selection of resource unit (n,1), resource (n+k, 1), etc.

[0244] Different sidelink physical channels may use different resource pools. For example, PSCCH may use a first resource pool and PSSCH may use a second resource pool. Different resource priorities may be associated with different resource pools. For example, data associated with a first QoS, service, priority, and/or other characteristic may use a first resource pool and data associated with a second QoS, service, priority, and/or other characteristic may use a second resource pool. For example, a network (e.g., a base station) may configure a priority level for each resource pool, a service to be supported for each resource pool, etc. For example, a network (e.g., a base station) may configure a first resource pool for use by unicast UEs, a second resource pool for use by groupcast UEs, etc. For example, a network (e.g., a base station) may configure a first resource pool for transmission of sidelink data, a second resource pool for transmission of discovery messages, etc.

[0245] In an example of vehicle-to-everything (V2X) communications via a Uu interface and/or a PC5 interface, the V2X communications may be vehicle-to-vehicle (V2V) communications. A wireless device in the V2V communications may be a vehicle. In an example, the V2X communications may be vehicle-to-pedestrian (V2P) communications. A wireless device in the V2P communications may be a pedestrian equipped with a mobile phone/handset. In an example, the V2X communications may be vehicle-to-infrastructure (V2I) communications. The infrastructure in the V2I communications may be a base station/access point/node/roadside unit. A wireless device in the V2X communications may be a transmitting wireless device performing one or more sidelink transmissions to a receiving wireless device. The wireless device in the V2X communications may be a receiving wireless device receiving one or more sidelink transmissions from a transmitting wireless device.

[0246] FIG. **19** illustrates an example of sidelink symbols in a slot. In an example, a sidelink transmission may be transmitted in a slot in the time domain. In an example, a wireless device may have data to transmit via sidelink. The wireless device may segment the data into one or more transport blocks (TBs). The one or more TBs may comprise different pieces of the data. A TB of the one or more TBs may be a data packet of the data. The wireless device may transmit a TB of the one or more TBs (e.g., a data packet) via one or more sidelink transmissions (e.g., via PSCCH/PSSCH in one or more slots). In an example, a sidelink transmission (e.g., in a slot) may comprise SCI. The sidelink transmission may further comprise a TB. The SCI may comprise a 1^{st}-stage SCI and a 2^{nd}-stage SCI. A PSCCH of the sidelink transmission may comprise the 1^{st}-stage SCI for scheduling a PSSCH (e.g., the TB). The PSSCH of the sidelink transmission may comprise the 2^{nd}-stage SCI. The PSSCH of the sidelink transmission may further comprise the TB. In an example, sidelink symbols in a slot may or may not start from the first symbol of the slot. The sidelink symbols in the slot may or may not end at the last symbol of the slot. In an example of FIG. **19**, sidelink symbols in a slot start from the second symbol of the slot. The sidelink symbols in the slot end at the twelfth symbol of the slot. A first sidelink transmission may comprise a first automatic gain control (AGC) symbol (e.g., the second symbol in the slot), a PSCCH (e.g., in the third, fourth and the fifth symbols in a sub-channel in the slot), a PSSCH (e.g., from the third symbol to the eighth symbol in the slot), and/or a first guard symbol (e.g., the ninth symbol in the slot). A second sidelink transmission may comprise a second AGC symbol (e.g., the tenth symbol in the slot), a PSFCH (e.g., the eleventh symbol in the slot), and/or a second guard symbol for the second sidelink transmission (e.g., the twelfth symbol in the slot). In an example, one or more HARQ feedbacks (e.g., positive acknowledgement or ACK and/or negative acknowledgement or NACK) may be transmitted via the PSFCH. In an example, the PSCCH, the PSSCH, and the PSFCH may have different number of sub-channels (e.g., a different number of frequency resources) in the frequency domain.

[0247] In an example, a set of slots that may belong to a sidelink resource pool is denoted by (t_0^{SL}, t_1^{SL}, . . . $t_{T_{max}-1}^{SL}$) where

$$0 \le t_i^{SL} < 10240 \times 2^{\mu},\ 0 \le i < T_{max},$$

[0248] the slot index is relative to slot #0 of the radio frame corresponding to SFN 0 of the serving cell or DFN 0,

[0249] the set includes all the slots except the following slots (e.g., from a set of slots consecutively located in the radio frame),

[0250] N_{S_SSB} slots in which S-SS/PSBCH block (S-SSB) is configured,

[0251] N_{nonSL} slots in each of which at least one of Y-th, (Y+1)-th, . . . , (Y+X−1)-th OFDM symbols are not semi-statically configured as uplink as per the higher layer parameter tdd-UL-DL-ConfigurationCommon of the serving cell if provided or sl-TDD-Configuration if provided or sl-TDD-Config of the received PSBCH if provided, where Y and X are set by the higher layer parameters sl-StartSymbol and sl-LengthSymbols, respectively.

[0252] The reserved slots which are determined by the following steps.

[0253] 1) the remaining slots excluding N_{S_SSB} slots and N_{nonSL} slots from the set of all the slots are denoted by (l_0, l_1, . . . , $l_{(10240\times2^{\mu}-NS_{SSB}-N_{nonSL}-1)}$) arranged in increasing order of slot index.

[0254] a slot l_r ($0 \le r < 10240\times2^{\mu}-N_{S_{SSB}}-N_{nonSL}$) belongs to the reserved slots if

$$r = \left\lfloor \frac{m \cdot (10240 \times 2^{\mu} - N_{S_{SSB}} - N_{nonSL})}{N_{reserved}} \right\rfloor,$$

here m=0, 1, . . . , $N_{reserved}-1$ and $N_{reserved}=(10240\times2^{\mu}-N_{S_{SSB}}-N_{nonSL}) \bmod L_{bitmap}$ where L_{bitmap} denotes the length of bitmap configured by higher layers.

[0255] The slots in the set are arranged in increasing order of slot index.

[0256] In an example, a wireless device may determine the set of slots assigned to a sidelink resource pool as follows:

[0257] a bitmap (b_0, b_1, . . . , $b_{L_{bitmap}-1}$ associated with the resource pool is used where L_{bitmap} the length of the bitmap is configured by higher layers.

[0258] a slot t_k^{SL} ($0 \le k < 10240\times2^{\mu}-N_{S_{SSB}}-N_{nonSL}-N_{reserved}$) belongs to the set if $b_{k'}=1$ where k'=k mod L_{bitmap}.

[0259] The slots in the set are re-indexed such that the subscripts i of the remaining slots t'SL are successive {0, 1, ... $T'_{max}-1$} where T'_{max} is the number of the slots remaining in the set.

[0260] In an example, a slot of the set of slots assigned to a sidelink resource pool (e.g., after excluding the S-SSB slots, the non-sidelink slots, and the reserved slots, mapping according to the bitmap, and re-indexing the slot index) may be referred to as a logical slot. A slot of the set of slots consecutively located in the radio frame may be referred to as physical slot. For example, the set of slots consecutively located in the radio frame may comprise slot #0, slot #1, . . . , slot #10240×2^{μ}−1. The set of slots assigned to a sidelink resource pool may be mapped/associated to a subset of slots in the set of slots consecutively located in the radio frame. The set of slots assigned to a sidelink resource pool may be consecutively indexed. The set of slots assigned to a sidelink resource pool may be not consecutively located in the radio frame.

[0261] In an example, a wireless device may receive, from a second wireless device, an SCI (e.g., SCI format). The SCI may schedule to receive a PSSCH from the second wireless device and/or may schedule a transmission of a PSFCH, to the second wireless device, with HARQ-ACK information corresponding to the reception of the PSSCH. The wireless device may transmit HARQ-ACK information that comprises ACK or NACK on the reception of the PSSCH. For example, the wireless device may transmit a PSFCH indicating an ACK via a PSFCH transmission occasion resource if the reception and/or decoding of the PSCCH is successful. For example, the wireless device may transmit a NACK via a PSFCH transmission occasion resource if the reception and/or decoding of the PSCCH is not successful.

[0262] In an example, a wireless device may receive a message (e.g., RRC message and/or SIB) from a base station and/or a second wireless device. The message may comprise a configuration parameter, e.g., sl-PSFCH-Period, indicating a periodicity of a slot comprising a PSFCH transmission occasion resource. For example, the configuration parameter may indicate a number of slots in a sidelink resource pool for a period of PSFCH transmission occasion resources. If the number of slots is X (e.g., 1, 2, or 4), the PSFCH period may be X slots indicating that a slot comprising a PSFCH transmission occasion resource is configured in every X slots in the sidelink resource pool. If the number of slots is zero, no PSFCH transmission occasions resource is configured in the sidelink resource pool.

[0263] In an example, a wireless device may determine that a slot t'^{SL}_k ($0 \le k < T'_{max}$) comprising a PSFCH transmission occasion resource, e.g., if k mod $N_{PSSCH}^{PSFCH}=0$. For example, t'^{SL}_k is a slot, of a sidelink resource pool, comprising PSSCH, PSCCH, PSBCH, and/or PSFCH. For example, T'_{max} may be a number of slots that belong to the resource pool within a reference time duration (e.g., 10240 msec). For example, N_{PSSCH}^{PSFCH} may be a periodicity (e.g., sl-PSFCH-Period) of a slot comprising a PSFCH transmission occasion resource.

[0264] In an example, a wireless device may receive, via a PSCCH, a first-stage SCI (e.g., SCI format 1-A) that schedule a second stage SCI (e.g., SCI format 2-A, SCI format 2-B, and/or SCI format 2-C) and a PSCCH associated with the first-stage SCI and the second stage SCI. The wireless device may receive, via a PSSCH indicated by the first-stage SCI, the second stage SCI (e.g., SCI format 2-A, SCI format 2-B, and/or SCI format 2-C) and the PSCCH associated with the first-stage SCI and the second stage SCI. The wireless device may transmit the HARQ-ACK feedback via a PSFCH transmission occasion resource in a sidelink resource pool, e.g., if the wireless device receives the PSSCH in the sidelink resource pool and/or if the HARQ feedback enabled/disabled indicator field in the second-stage SCI indicates the HARQ feedback is enabled. The wireless device may transmit the PSFCH in a first slot that comprise PSFCH resources and is at least a number of slots, provided by sl-MinTimeGapPSFCH, of the resource pool after a last slot of the PSSCH reception.

[0265] In an example, a wireless device is provided by sl-PSFCH-RB-Set a set of $M_{PRB,\ set}^{PSFCH}$ PRBs in a resource pool for PSFCH transmission with HARQ-ACK information in a PRB of the resource pool. A wireless device can be provided by sl-PSFCH-Conflict-RB-Set a set of $M_{PRB,\ set}^{PSFCH}$ PRBs in a resource pool for PSFCH transmission with conflict information in a PRB of the resource pool. For a number of N_{subch} sub-channels for the resource pool, provided by sl-NumSubchannel, and a number of PSSCH slots associated with a PSFCH slot that is less than or equal to N_{PSSCH}^{PSFCH}, the wireless device allocates the $[(i+j\cdot N_{PSSCH}^{PSFCH})\cdot M_{subch,\ slot}^{PSFCH},\ (i+1+j\cdot N_{PSSCH}^{PSFCH})\cdot M_{subch,\ slot}^{PSFCH}-1$ PRBs from the $M_{PRB,\ set}^{PSFCH}$ PRBs to slot i among the PSSCH slots associated with the PSFCH slot and sub-channel j, where $M_{subch,\ slot}^{PSFCH}=M_{PRB,\ set}^{PSFCH}/(N_{subch}\cdot N_{PSSCH}^{PSFCH})$, $0\le i<N_{PSSCH}^{PSFCH}$, $0\le j<N_{subch}$, and the allocation starts in an ascending order of i and continues in an ascending order of j. The wireless device expects that $M_{PRB,\ set}^{PSFCH}$ is a multiple of $N_{subch}\cdot N_{PSSCH}^{PSFCH}$.

[0266] In an example, a wireless device that transmitted a PSSCH scheduled by a SCI format 2-A or a SCI format 2-B that indicates HARQ feedback enabled, may attempt to receive associated PSFCHs with HARQ-ACK information according to determined PSFCH resources. The wireless device may determine an ACK or a NACK value for HARQ-ACK information provided in each PSFCH resource. The wireless device does not determine both an ACK value and a NACK value at a same time for a PSFCH resource.

[0267] The 1^{st}-stage SCI may be a SCI format 1-A. The SCI format 1-A may comprise a plurality of fields used for scheduling of the first TB on the PSSCH and the 2^{nd}-stage SCI on the PSSCH. The following information may be transmitted by means of the SCI format 1-A.

- **[0268]** A priority of the sidelink transmission. For example, the priority may be a physical layer (e.g., layer 1) priority of the sidelink transmission. For example, the priority may be determined based on logical channel priorities of the sidelink transmission;
- **[0269]** Frequency resource assignment of the PSSCH;
- **[0270]** Time resource assignment of the PSSCH;
- **[0271]** Resource reservation period/interval for a second TB;
- **[0272]** Demodulation reference signal (DMRS) pattern;
- **[0273]** A format of the 2^{nd}-stage SCI;
- **[0274]** Beta_offset indicator,
- **[0275]** Number of DMRS port;
- **[0276]** Modulation and coding scheme of the PSSCH;
- **[0277]** Additional MCS table indicator;
- **[0278]** PSFCH overhead indication;
- **[0279]** Reserved bits.

[0280] The 2^{nd}-stage SCI may be a SCI format 2-A. The SCI format 2-A may be used for the decoding of the PSSCH, with HARQ operation when HARQ-ACK information includes ACK or NACK, or when there is no feedback of HARQ-ACK information. The SCI format 2-A may comprise a plurality of fields indicating the following information.

- **[0281]** HARQ process number;
- **[0282]** New data indicator,
- **[0283]** Redundancy version;
- **[0284]** Source ID of a transmitter (e.g., a transmitting wireless device) of the sidelink transmission;
- **[0285]** Destination ID of a receiver (e.g., a receiving wireless device) of the sidelink transmission;
- **[0286]** HARQ feedback enabled/disabled indicator,
- **[0287]** Cast type indicator indicating that the sidelink transmission is a broadcast, a groupcast and/or a unicast;
- **[0288]** CSI request.

[0289] The 2^{nd}-stage SCI may be a SCI format 2-B. The SCI format 2-B may be used for the decoding of the PSSCH, with HARQ operation when HARQ-ACK information includes only NACK, or when there is no feedback of HARQ-ACK information. The SCI format 2-B may comprise a plurality of fields indicating the following information.

- **[0290]** HARQ process number;
- **[0291]** New data indicator,
- **[0292]** Redundancy version;
- **[0293]** Source ID of a transmitter (e.g., a transmitting wireless device) of the sidelink transmission;
- **[0294]** Destination ID of a receiver (e.g., a receiving wireless device) of the sidelink transmission;
- **[0295]** HARQ feedback enabled/disabled indicator;
- **[0296]** Zone ID indicating a zone in which a transmitter (e.g., a transmitting wireless device) of the sidelink transmission is geographic located;
- **[0297]** Communication range requirement indicating a communication range of the sidelink transmission.

[0298] FIG. **20** illustrates an example of resource indication for a first TB (e.g., a first data packet) and resource reservation for a second TB (e.g., a second data packet). SCI of an initial transmission (e.g., a first transmission) and/or retransmission of the first TB may comprise one or more first parameters (e.g., Frequency resource assignment and Time resource assignment) indicating one or more first time and frequency (T/F) resources for transmission and/or retransmission of the first TB. The SCI may further comprise one or more second parameters (e.g., Resource reservation period) indicating a reservation period/interval of one or more second T/F resources for initial transmission and/or retransmission of the second TB.

[0299] In an example, in response to triggering a resource selection procedure, a wireless device may select one or more first T/F resources for initial transmission and/or retransmission of a first TB. As shown in FIG. **20**, the wireless device may select three resources for transmitting the first TB. The wireless device may transmit an initial transmission (initial Tx of a first TB in FIG. **20**) of the first TB via a first resource of the three resources. The wireless device may transmit a first retransmission (1st re-Tx in FIG. **20**) of the first TB via a second resource of the three resources. The wireless device may transmit a second retransmission (2^{nd} re-Tx in FIG. **20**) of the first TB via a third resource of the three resources. A time duration between a starting time of the initial transmission of the first TB and the second retransmission of the first TB may be smaller than or equal to 32 sidelink slots (e.g., T≤32 slots in FIG. **20**). A first SCI may associate with the initial transmission of the first TB. The first SCI may indicate a first T/F resource indication for the initial transmission of the first TB, the first retransmission of the first TB and the second retransmission of the first TB. The first SCI may further indicate a reservation period/interval of resource reservation for a second TB. A second SCI may associate with the first retransmission of the first TB. The second SCI may indicate a second T/F resource indication for the first retransmission of the first TB and the second retransmission of the first TB. The second SCI may further indicate the reservation period/interval of resource reservation for the second TB. A third SCI may associate with the second retransmission of the first TB. The third SCI may indicate a third T/F resource indication for the second retransmission of the first TB. The third SCI may further indicate the reservation period/interval of resource reservation for the second TB.

[0300] FIG. **21** and FIG. **22** illustrate examples of configuration information for sidelink communication. In an example, a base station may transmit one or more radio resource control (RRC) messages to a wireless device for delivering the configuration information for the sidelink communication. The configuration information may comprise a field of sl-UE-SelectedConfigRP. A parameter sl-ThresPSSCH-RSRP-List in the field may indicate a list of 64 thresholds. In an example, a wireless device may receive first sidelink control information (SCI) indicating a first priority. The wireless device may have second SCI to be transmitted. The second SCI may indicate a second priority. The wireless device may select a threshold from the list based on the first priority in the first SCI and the second priority in the second SCI. Referring to second exclusion in FIG. **26**, the wireless device may exclude resources from candidate resource set based on the threshold. A parameter sl-MaxNumPerReserve in the field may indicate a maximum number of reserved PSCCH/PSSCH resources indicated in an SCI. A parameter sl-MultiReserveResource in the field may indicate if it is allowed to reserve a sidelink resource for an initial transmission of a TB by an SCI associated with a different TB, based on sensing and resource selection procedure. A parameter sl-ResourceReservePeriodList may indicate a set of possible resource reservation periods/intervals (e.g., SL-ResourceReservedPeriod) allowed in a resource pool. Up to 16 values may be configured per resource pool. A parameter sl-RS-ForSensing may indicate whether DMRS of PSCCH or PSSCH is used for layer 1 (e.g., physical layer) RSRP measurement in sensing operation. A parameter sl-SensingWindow may indicate a start of a sensing window. A parameter sl-Selection WindowList may indicate an end of a selection window in resource selection procedure for a TB with respect to priority indicated in SCI. Value n1 may correspond to 1*2μ, value n5 corresponds to 5*2μ, and so on, where μ=0, 1, 2, 3 for subcarrier spacing (SCS) of 15, 30, 60, and 120 kHz respectively. A parameter SL-SelectionWindowConfig may indicate a mapping between a sidelink priority (e.g., sl-Priority) and the end of the selection window (e.g., sl-SelectionWindow).

[0301] The configuration information may comprise a parameter sl-PreemptionEnable indicating whether sidelink pre-emption is disabled or enabled in a resource pool. For example, a priority level p_preemption may be configured if the sidelink pre-emption is enabled. For example, if the sidelink pre-emption is enabled but the p_preemption is not configured, the sidelink pre-emption may be applicable to all priority levels.

[0302] The configuration information may comprise a parameter sl-TxPercentageList indicating a portion of candidate single-slot PSSCH resources over total resources. For example, value p20 may correspond to 20%, and so on. A parameter SL-TxPercentageConfig may indicate a mapping between a sidelink priority (e.g., sl-Priority) and the portion of candidate single-slot PSSCH resources over total resources (e.g., sl-TxPercentage).

[0303] FIG. **23** illustrates an example format of a MAC subheader for sidelink shared channel (SL-SCH). The MAC subheader for SL-SCH may comprise seven header fields V/R/R/R/R/SCR/DST. The MAC subheader is octet aligned. For example, the V field may be a MAC protocol data units (PDU) format version number field indicating which version of the SL-SCH subheader is used. For example, the SRC field may carry 16 bits of a Source Layer-2 identifier (ID) field set to a first identifier provided by upper layers. For example, the DST field may carry 8 bits of the Destination Layer-2 ID set to a second identifier provided by upper layers. In an example, if the V field is set to “1”, the second identifier may be a unicast identifier. In an example, if the V field is set to “2”, the second identifier may be a groupcast identifier. In an example, if the V field is set to “3”, the second identifier may be a broadcast identifier. For example, the R field may indicate reserved bit.

[0304] FIG. **24** illustrates an example of a resource selection procedure. A wireless device may perform the resource selection procedure to select resources for one or more sidelink transmissions. As shown in FIG. **24**, a sensing window of the resource selection procedure may start at time (n−T0) (e.g., parameter sl-SensingWindow). The sensing window may end at time ($n-T_{proc,0}$). New data of the one or more sidelink transmissions may arrive at the wireless device at time ($n-T_{proc,0}$). The time period $T_{proc,0}$ may be a processing delay of the wireless device to determine to trigger the resource selection procedure. The wireless device may determine to trigger the resource selection procedure at time n to select the resources for the new data arrived at time ($n-T_{proc,0}$). The wireless device may complete the resource selection procedure at time (n+T1). The wireless device may determine the parameter T1 based on a capability of the wireless device. The capability of the wireless device may be a processing delay of a processor of the wireless device. A selection window of the resource selection procedure may start at time (n+T1). The selection window may end at time (n+T2) indicating the ending of the selection window. The wireless device may determine the parameter T2 based on a parameter T2 min (e.g., sl-SelectionWindow). In an example, the wireless device may determine the parameter T2 subject to T2 min≤T2≤PDB, where the PDB (packet delay budget) may be the maximum allowable delay (e.g., a delay budget) for successfully transmitting the new data via the one or more sidelink transmissions. The wireless device may determine the parameter T2 min to a corresponding value for a priority of the one or more sidelink transmissions (e.g., based on a parameter SL-SelectionWindowConfig indicating a mapping between a sidelink priority sl-Priority and the end of the selection window sl-SelectionWindow).

In an example, the wireless device may set the parameter T2=PDB if the parameter T2 min>PDB.

[0305] FIG. **25** illustrates an example timing of a resource selection procedure. A wireless device may perform the resource selection procedure for selecting resources for one or more sidelink transmissions. Referring to FIG. **24**, a sensing window of initial selection may start at time (n−T0). The sensing window of initial selection may end at time ($n-T_{proc,0}$). New data of the one or more sidelink transmissions may arrive at the wireless device at the time ($n-T_{proc,0}$). The time period $T_{proc,0}$ may be a processing delay for the wireless device to determine to trigger the initial selection of the resources. The wireless device may determine to trigger the initial selection at time n for selecting the resources for the new data arrived at the time ($n-T_{proc,0}$). The wireless device may complete the resource selection procedure at time (n+T1). The time ($n+T_{proc,1}$) may be the maximum allowable processing latency for completing the resource selection procedure being triggered at the time n, where $0<T1\leq T_{proc,1}$. A selection window of initial selection may start at time (n+T1). The selection window of initial selection may end at time (n+T2). The parameter T**2** may be configured, preconfigured, or determined at the wireless device.

[0306] The wireless device may determine first resources (e.g., selected resources in FIG. **25**) for the one or more sidelink transmissions based on the completion of the resource selection procedure at the time (n+T1). The wireless device may select the first resources from candidate resources in the selection window of initial selection based on measurements in the sensing window for initial selection. The wireless device may determine a resource collision between the first resources and other resources reserved by another wireless device. The wireless device may determine to drop the first resources for avoiding interference. The wireless device may trigger a resource reselection procedure (e.g., a second resource selection procedure) at time (m−T3) and/or before time (m-T3). The time period T3 may be a processing delay for the wireless device to complete the resource reselection procedure (e.g., a second resource selection procedure). The wireless device may determine second resources (e.g., reselected resource in FIG. **25**) via the resource reselection procedure (e.g., a second resource selection procedure). The start time of the first resources may be time m (e.g., the first resources may be in slot m).

[0307] In an example, at least one of time parameters T0, $T_{proc,0}$, $T_{proc,1}$, T2, and PDB may be configured by a base station to the wireless device. In an example, the at least one of the time parameters T0, $T_{proc,0}$, $T_{proc,1}$, T2, and PDB may be preconfigured to the wireless device. The at least one of the time parameters T0, $T_{proc,0}$, $T_{proc,1}$, T2, and PDB may be stored in a memory of the wireless device. In an example, the memory may be a Subscriber Identity Module (SIM) card. In an example of FIG. **24** and FIG. **25**, the time n, m, TO, T1, $T_{proc,0}$, $T_{proc,1}$) T2, T2 min, T3, and PDB may be in terms of slots and/or slot index.

[0308] FIG. **26** illustrates an example flowchart of a resource selection procedure by a wireless device for transmitting a TB (e.g., a data packet) via sidelink.

[0309] FIG. **27** illustrates an example diagram of the resource selection procedure among layers of the wireless device.

[0310] Referring to FIG. **26** and FIG. **27**, the wireless device may transmit one or more sidelink transmissions (e.g., a first transmission of the TB and one or more retransmissions of the TB) for the transmitting of the TB. Referring to FIG. **19**, a sidelink transmission of the one or more sidelink transmission may comprise a PSCCH. The sidelink transmission may comprise a PSSCH. The sidelink transmission may comprise a PSFCH. The wireless device may trigger the resource selection procedure for the transmitting of the TB. The resource selection procedure may comprise two actions. The first action of the two actions may be a resource evaluation action. Physical layer (e.g., layer 1) of the wireless device may perform the first action. The physical layer may determine a subset of resources based on the first action and report the subset of resources to higher layer (e.g., RRC layer and/or MAC layer) of the wireless device. The second action of the two actions may be a resource selection action. The higher layer (e.g., RRC layer and/or MAC layer) of the wireless device may perform the second action based on the reported the subset of resources from the physical layer.

[0311] In an example, higher layer (e.g., RRC layer and/or MAC layer) of a wireless device may trigger a resource selection procedure for requesting the wireless device to determine a subset of resources. The higher layer may select resources from the subset of resources for PSSCH and/or PSCCH transmission. To trigger the resource selection procedure, e.g., in slot n, the higher layer may provide the following parameters for the PSSCH and/or PSCCH transmission:

- **[0312]** a resource pool, from which the wireless device may determine the subset of resources;
- **[0313]** layer 1 priority, $prio_{TX}$ (e.g., sl-Priority referring to FIG. **21** and FIG. **22**), of the PSSCH/PSCCH transmission;
- **[0314]** remaining packet delay budget (PDB) of the PSSCH and/or PSCCH transmission;
- **[0315]** a number of sub-channels, L_{subCH}, for the PSSCH and/or PSCCH transmission in a slot;
- **[0316]** a resource reservation period/interval, P_{rsvp_TX}, in units of millisecond (ms).

[0317] In an example, if the higher layer requests the wireless device to determine a subset of resources from which the higher layer will select the resources for the PSSCH and/or PSCCH transmission for re-evaluation and/or pre-emption, the higher layer may provide a set of resources (r_0, r_1, r_2, . . .) which may be subject to the re-evaluation and a set of resources (r'_0, r'_1, r'_2, . . .) which may be subject to the pre-emption.

[0318] In an example, a base station (e.g., network) may transmit a message comprising one or more parameters to the wireless device for performing the resource selection procedure. The message may be an RRC/SIB message, a MAC CE, and/or a DCI. In an example, a second wireless device may transmit a message comprising one or more parameters to the wireless device for performing the resource selection procedure. The message may be an RRC message, a MAC CE, and/or a SCI. The one or more parameters may indicate following information.

- **[0319]** sl-SelectionWindowList (e.g., sl-SelectionWindow referring to FIG. **21** and FIG. **22**): an internal parameter T2 min (e.g., T2 min referring to FIG. **24**) may be set to a corresponding value from the parameter sl-Selection WindowList for a given value of $prio_{TX}$ (e.g., based on SL-SelectionWindowConfig referring to FIG. **21** and FIG. **22**).

[0320] sl-ThresPSSCH-RSRP-List (e.g., sl-ThresPSSCH-RSRP-List referring to FIG. **21** and FIG. **22**): a parameter may indicate an RSRP threshold for each combination (p_i, p_j), where p_i is a value of a priority field in a received SCI format 1-A and p; is a priority of a sidelink transmission (e.g., the PSSCH/PSCCH transmission) of the wireless device; In an example of the resource selection procedure, an invocation of p_j may be p_j=$prio_{TX}$.

[0321] sl-RS-ForSensing (e.g., sl-RS-ForSensing referring to FIG. **21** and FIG. **22**): a parameter may indicate whether DMRS of a PSCCH or a PSSCH is used, by the wireless device, for layer 1 (e.g., physical layer) RSRP measurement in sensing operation.

[0322] sl-ResourceReservePeriodList (e.g., sl-ResourceReservePeriodList referring to FIG. **21** and FIG. **22**)

[0323] sl-SensingWindow (e.g., sl-SensingWindow referring to FIG. **21** and FIG. **22**): an internal parameter T_0 may be defined as a number of slots corresponding to t0_Sensing Window ms.

[0324] sl-TxPercentageList (e.g., based on SL-TxPercentageConfig referring to FIG. **21** and FIG. **22**): an internal parameter X (e.g., sl-TxPercentage referring to FIG. **21** and FIG. **22**) for a given $prio_{TX}$ (e.g., sl-Priority referring to FIG. **21** and FIG. **22**) may be defined as sl-xPercentage ($prio_{TX}$) converted from percentage to ratio.

[0325] sl-PreemptionEnable (e.g., p_preemption referring to FIG. **21** and FIG. **22**): an internal parameter $prio_{pre}$ may be set to a higher layer provided parameter sl-PreemptionEnable.

[0326] The resource reservation period/interval, P_{rsvp_TX}, if provided, may be converted from units of ms to units of logical slots, resulting in P'_{rsvp_TX}.

[0327] Notation: (t_0^{SL}, t_1^{SL}, t_2^{SL}, . . .) may denote a set of slots of a sidelink resource pool.

[0328] In the resource evaluation action (e.g., the first action in FIG. **26**), the wireless device may determine a sensing window (e.g., the sensing window shown in FIG. **24** and FIG. **25** based on sl-SensingWindow) based on the triggering the resource selection procedure. The wireless device may determine a selection window (e.g., the selection window shown in FIG. **24** and FIG. **25** based on sl-SelectionWindowList) based on the triggering the resource selection procedure. The wireless device may determine one or more reservation periods/intervals (e.g., parameter sl-ResourceReservePeriodList) for resource reservation. In an example, a candidate single-slot resource for transmission $R_{x,y}$ may be defined as a set of L_{subCH} contiguous sub-channels with sub-channel x+j in slot t_y^{SL} where j=0, . . . , $L_{subCH}-1$. The wireless device may assume that a set of L_{subCH} contiguous sub-channels in the resource pool within a time interval [$n+T_1$, $n+T_2$] correspond to one candidate single-slot resource (e.g., referring to FIG. **24** and FIG. **25**). A total number of candidate single-slot resources may be denoted by M_{total}. In an example, referring to FIG. **24** and FIG. **25**, the sensing window may be defined by a number of slots in a time duration of [n-To, n-$T_{proc,0}$). The wireless device may monitor a first subset of the slots, of a sidelink resource pool, within the sensing window. The wireless device may not monitor a second subset of the slots than the first subset of the slots due to half duplex. The wireless device may perform the following actions based on PSCCH decoded and RSRP measured in the first subset of the slots. In an example, an internal parameter Th(p_i, p_j) may be set to the corresponding value of RSRP threshold indicated by the i-th field in sl-ThresPSSCH-RSRP-List, where i=p_i+(p_j−1)*8.

[0329] Referring to FIG. **26** and FIG. **27**, in the resource evaluation action (e.g., the first action in FIG. **26**), the wireless device may initialize a candidate resource set (e.g., a set S_A) to be a set of candidate resources. In an example, the candidate resource set may be the union of candidate resources within the selection window. In an example, a candidate resource may be a candidate single-subframe resource. In an example, a candidate resource may be a candidate single-slot resource. In an example, the set S_A may be initialized to a set of all candidate single-slot resources.

[0330] The terminologies of "a set of candidate resource" and "a candidate resource set", and "S_A" may be used interchangeably.

[0331] Referring to FIG. **26** and FIG. **27**, in the resource evaluation action (e.g., the first action in FIG. **26**), the wireless device may perform a first exclusion for excluding second resources from the candidate resource set based on first resources and one or more reservation periods/intervals. In an example, the wireless device may not monitor the first resources within a sensing window. In an example, the one or more reservation periods/intervals may be configured/associated with a resource pool of the second resources. In an example, the wireless device may determine the second resources within a selection window which might be reserved by a transmission transmitted via the first resources based on the one or more reservation periods/intervals. In an example, the wireless device may exclude a candidate single-slot resource $R_{x,y}$ from the set S_A based on following conditions:

[0332] the wireless device has not monitored slot t_m^{SL} in the sensing window.

[0333] for any periodicity value allowed by the parameter sl-ResourceReservePeriodList and a hypothetical SCI format 1-A received in the slot t_m^{SL} with "Resource reservation period" field set to that periodicity value and indicating all sub-channels of the resource pool in this slot, condition c of a second exclusion would be met.

[0334] Referring to FIG. **26** and FIG. **27**, in the resource evaluation action (e.g., the first action in FIG. **26**), the wireless device may perform a second exclusion for excluding third resources from the candidate resource set. In an example, a SCI may indicate a resource reservation of the third resources. The SCI may further indicate a priority value (e.g., indicated by a higher layer parameter sl-Priority). The wireless device may exclude the third resources from the candidate resource set based on a reference signal received power (RSRP) of the third resources being higher than an RSRP threshold (e.g., indicated by a higher layer parameter sl-ThresPSSCH-RSRP-List). The RSRP threshold may be related to the priority value based on a mapping list of RSRP thresholds to priority values configured and/or pre-configured to the wireless device. In an example, a base station may transmit a message to the wireless device for configuring the mapping list. The message may be a radio resource control (RRC) message. In an example, the mapping list may be pre-configured to the wireless device. A memory of the wireless device may store the mapping list. In an example, a priority indicated by the priority value may be a layer 1 priority (e.g., physical layer priority). In an example, a bigger priority value may indicate a higher priority of a sidelink transmission. A smaller priority value may indicate a lower priority of the sidelink transmission. In another example, a bigger priority value may indicate a lower priority of a sidelink transmission. A smaller priority value may indicate a higher priority of the sidelink transmission. In an example, the wireless device may exclude a candidate single-slot resource $R_{x,y}$ from the set S_A based on following conditions:

[0335] a) the wireless device receives an SCI format 1-A in slot t_m^{SL}, and "Resource reservation period" field, if present, and "Priority" field in the received SCI format 1-A indicate the values P_{rsvp_RX} and $prio_{RX}$;

[0336] b) the RSRP measurement performed, for the received SCI format 1-A, is higher than $Th(prio_{RX}, prio_{TX})$;

[0337] c) the SCI format received in slot t_m^{SL} or the same SCI format which, if and only if the "Resource reservation period" field is present in the received SCI format 1-A, is assumed to be received in slot(s) $t_{m+q\times P'_{rsvp\_RX}}^{SL}$ determines the set of resource blocks and slots which overlaps with $R_{x,y+j\times P'_{rsvp\_TX}}$ for q=1, 2, . . . , Q and j=0, 1, . . . , $C_{resel}-1$. Here, P'_{rsvp_RX} is P_{rsvp_RX} converted to units of logical slots,

$$Q = \left\lceil \frac{T_{scal}}{P_{rsvp\_RX}} \right\rceil$$

if $P_{rsvp\_RX}<T_{scal}$ and $n'-m\le P'_{rsvp\_RX}$, where $t_{n'}^{SL}=n$ if slot n belongs to the set $(t_0^{SL}, t_1^{SL}, \ldots t_{T_{max}}^{SL})$, otherwise slot $t_{n'}^{SL}$ at is the first slot after slot n belonging to the set $(t_0^{SL}, t_1^{SL}, \ldots, t_{T_{max}}^{SL})$; otherwise Q=1. T_{scal} is set to selection window size T2 converted to units of ms.

[0338] Referring to FIG. **26** and FIG. **27**, in the resource evaluation action (e.g., the first action in FIG. **26**), the wireless device may determine whether remaining candidate resources in the candidate resource set are sufficient for selecting resources for the one or more sidelink transmissions of the TB based on a condition, after performing the first exclusion and the second exclusion. In an example, the condition may be the total amount of the remaining candidate resources in the candidate resource set being more than X percent (e.g., indicated by a higher layer parameter sl-TxPercentageList) of the candidate resources in the candidate resource set before performing the first exclusion and the second exclusion. If the condition is not met, the wireless device may increase the RSRP threshold used to exclude the third resources with a value Y and iteratively re-perform the initialization, first exclusion, and second exclusion until the condition being met. In an example, if the number of remaining candidate single-slot resources in the set S_A is smaller than $X\cdot M_{total}$, then $Th(p_i, p_j)$ may be increased by 3 dB and the procedure continues with re-performing of the initialization, first exclusion, and second exclusion until the condition being met. In an example, the wireless device may report the set S_A (e.g., the remaining candidate resources of the candidate resource set) to the higher layer of the wireless device. In an example, based on the wireless device determining that the number of remaining candidate single-slot resources in the set S_A are greater than or equal to $X\cdot M_{total}$, the wireless device may report the set S_A (e.g., the remaining candidate resources of the candidate resource set when the condition is met) to the higher layer of the wireless device.

[0339] Referring to FIG. **26** and FIG. **27**, in the resource selection action (e.g., the second action in FIG. **26**), the wireless device (e.g., the higher layer of the wireless device) may select fourth resources from the remaining candidate resources of the candidate resource set (e.g., the set S_A reported by the physical layer) for the one or more sidelink transmissions of the TB. In an example, the wireless device may randomly select the fourth resources from the remaining candidate resources of the candidate resource set.

[0340] Referring to FIG. **26** and FIG. **27**, in an example, if a resource r_i from the set $(r_0, r_1, r_2, \ldots)$ is not a member of S_A (e.g., the remaining candidate resources of the candidate resource set when the condition is met), the wireless device may report re-evaluation of the resource r_i to the higher layers.

[0341] Referring to FIG. **26** and FIG. **27**, in an example, if a resource r' from the set $(r''_0, r'_1, r'_2, \ldots)$ meets the conditions below, then the wireless device may report pre-emption of the resource r' to the higher layers.

[0342] r'_i is not a member of S, and

[0343] r'_i meets the conditions for the second exclusion, with $Th(prio_{RX}, prio_{TX})$ set to a final threshold for reaching $X\cdot M_{total}$, and

[0344] the associated priority $prio_{RX}$, satisfies one of the following conditions:

[0345] sl-PreemptionEnable is provided and is equal to 'enabled' and $prio_{TX}>prio_{RX}$

[0346] sl-PreemptionEnable is provided and is not equal to 'enabled', and $prio_{RX}<prio_{pre}$ and $prio_{TX}>prio_{RX}$

[0347] In an example, if the resource r_i is indicated for re-evaluation by the wireless device (e.g., the physical layer of the wireless device), the higher layer of the wireless device may remove the resource r_i from the set $(r_0, r_1, r_2, \ldots)$. In an example, if the resource r_i' is indicated for pre-emption by the wireless device (e.g., the physical layer of the wireless device), the higher layer of the wireless device may remove the resource r_i' from the set $(r'_0, r'_1, r'_2, \ldots)$. The higher layer of the wireless device may randomly select new time and frequency resources from the remaining candidate resources of the candidate resource set (e.g., the set S_A reported by the physical layer) for the removed resources r_i and/or r_i'. The higher layer of the wireless device may replace the removed resources r_i and/or r_i' by the new time and frequency resources. For example, the wireless device may remove the resources r_i and/or r_i' from the set $(r_0, r_1, r_2, \ldots)$ and/or the set $(r'_0, r'_1, r'_2, \ldots)$ and add the new time and frequency resources to the set $(r_0, r_1, r_2, \ldots)$ and/or the set $(r_0, r_1, r_2, \ldots)$ based on the removing of the resources r_i and/or r_i'.

[0348] In an example, the MAC layer may trigger a resource evaluation, revaluation, or preemption procedure. The PHY layer may report to the MAC layer with a set of candidate resources after performing the resource evaluation, revaluation, or preemption procedure at the PHY layer.

[0349] Sidelink pre-emption may happen between a first wireless device and a second wireless device. The first wireless device may select first resources for a first sidelink transmission. The first sidelink transmission may have a first priority. The second wireless device may select second resources for a second sidelink transmission. The second sidelink transmission may have a second priority. The first resources may partially and/or fully overlap with the second resources. The first wireless device may determine a resource collision between the first resources and the second resources based on the first resources and the second resources being partially and/or fully overlapped. The resource collision may imply fully and/or partially overlapping between the first resources and the second resources in time, frequency, code, power, and/or spatial domain. Referring to an example of FIG. **18**, the first resources may comprise one or more first sidelink resource units in a sidelink resource pool. The second resources may comprise one or more second sidelink resource units in the sidelink resource pool. A partial resource collision between the first resources and the second resources may indicate that the at least one sidelink resource unit of the one or more first sidelink resource units belongs to the one or more second sidelink resource units. A full resource collision between the first resources and the second resources may indicate that the one or more first sidelink resource units may be the same as or a subset of the one or more second sidelink resource units. In an example, a bigger priority value may indicate a lower priority of a sidelink transmission. A smaller priority value may indicate a higher priority of the sidelink transmission. In an example, the first wireless device may determine the sidelink pre-emption based on the resource collision and the second priority being higher than the first priority. That is, the first wireless device may determine the sidelink pre-emption based on the resource collision and a value of the second priority being smaller than a value of the first priority. In another example, the first wireless device may determine the sidelink pre-emption based on the resource collision, the value of the second priority being smaller than a priority threshold, and the value of the second priority being smaller than the value of the first priority.

[0350] Referring to FIG. **25**, a first wireless device may trigger a first resource selection procedure for selecting first resources (e.g., selected resources after resource selection with collision in FIG. **25**) for a first sidelink transmission. A second wireless device may transmit an SCI indicating resource reservation of the first resource for a second sidelink transmission. The first wireless device may determine a resource collision on the first resources between the first sidelink transmission and the second sidelink transmission. The first wireless device may trigger a resource re-evaluation (e.g., a resource evaluation action of a second resource selection procedure) at and/or before time (m−T3) based on the resource collision. The first wireless device may trigger a resource reselection (e.g., a resource selection action of the second resource selection procedure) for selecting second resources (e.g., reselected resources after resource reselection in FIG. **25**) based on the resource re-evaluation. The start time of the second resources may be time m.

[0351] FIG. **28** illustrates an example of a resource selection procedure (e.g., periodic partial sensing) by a wireless device for transmitting a TB (e.g., a data packet) via sidelink. Referring to FIG. **24**, a wireless device may perform the resource selection procedure (e.g., periodic partial sensing) for selecting resources for one or more sidelink transmissions in a sidelink resource pool. A sensing window of the resource selection procedure may start at time (n−T0). The sensing window may end at time ($n-T_{proc,0}$). The wireless device may determine to trigger the resource selection procedure at time n for selecting the resources for the new data arrived at the time ($n-T_{proc,0}$). The wireless device may complete the resource selection procedure at time (n+T1). A selection window of the resource selection procedure may start at time (n+T1). The selection window may end at time (n+T2).

[0352] Referring to FIG. **28**, the wireless device may select a selection duration comprising Y slots in the selection window as candidate slots for the resource selection procedure. The number of Y slots may be configured by a base station/RSU/second wireless device and/or pre-configured to the wireless device. In an example, the base station/RSU/second wireless device may send a message comprising a parameter/field, to the wireless device, for indicating the number of Y slots. The parameter/field may be a portion/percentage of resources in the selection window. The message may be an RRC/SIB, MAC CE, DCI and/or SCI. The selection duration may start from a time indicated by a slot t_y.

[0353] Referring to FIG. **28**, the base station/RSU/second wireless device may send a message to the wireless device configuring one or more reservation intervals/periods (e.g., sl-ThresPSSCH-RSRP-List referring to FIG. **21** and FIG. **22**) of the sidelink resource pool. Referring to FIG. **26** and FIG. **27**, the wireless device may determine one or more sensing durations (e.g., periodic sensing occasions) in the sensing window based on the time t_y, the Y slots, and/or reservation intervals/periods P'_{rsvp_RX} in SCI. The wireless device may receive the SCI in the one or more sensing durations. In an example, the configured/pre-configured one or more reservation intervals/periods (e.g., sl-ThresPSSCH-RSRP-List referring to FIG. **21** and FIG. **22**) of the sidelink resource pool may comprise the reservation intervals/periods P'_{rsvp_RX}. The one or more sensing durations in the sensing window may be $t_y - q \times P'_{rsvp\_RX}$, where q is a positive integer number. The wireless device may select resources from the selection duration based on sensing in the one or more sensing durations according to examples of FIG. **26** and FIG. **27**. The wireless device may perform resource re-evaluation and/or pre-emption based on the resource selection procedure of FIG. **28** (e.g., periodic partial sensing) according to examples of FIG. **26** and FIG. **27**.

[0354] FIG. **29** illustrates an example of a resource selection procedure (e.g., contiguous partial sensing) by a wireless device for transmitting a TB (e.g., a data packet) via sidelink. Referring to FIG. **20**, an initial sidelink transmission may comprise SCI indicating resource indication of one or more resources for re-transmission(s) of the sidelink transmission. The initial sidelink transmission and the re-transmission(s) of a TB may be in a time duration of 32 slots. Referring to FIG. **28**, a wireless device may select a selection duration comprising Y slots in the selection window as candidate slots for the resource selection procedure. The number of Y slots may be configured by a base station/RSU/second wireless device and/or pre-configured to the wireless device. In an example, the base station/RSU/second wireless device may send a message comprising a parameter/field, to the wireless device, for indicating the number of Y slots. The parameter/field may be a portion/percentage of resources in the selection window. The message may be an RRC/SIB, MAC CE, DCI and/or SCI. The selection duration may start from a time indicated by a slot t_y. The wireless device may determine a sensing duration of [n+TA, n+TB] based on the time n and/or the time t_y, the Y slots, and/or reservation indication (e.g., Time resource assignment of a PSSCH) for retransmissions of a TB in SCI. The wireless device may receive the SCI in the sensing duration (e.g., contiguous partial sensing duration). The wireless device may exclude one or more resources from the Y candidate slots based on the reservation indication in the SCI and/or a RSRP measurement based on SCI. The value of T_A and T_B may be a zero, positive and/or negative number. T_A may be larger than or equal to −32. T_B may be larger than or equal to T_A.

[0355] FIG. **30** illustrates an example of a sidelink inter-UE coordination (e.g., an inter-UE coordination scheme 1). A first wireless device and a second wireless device may perform an inter-UE coordination. The first wireless device may be a requesting wireless device of the inter-UE coordination between the first wireless device and the second wireless device. The first wireless device may be a transmitter of one or more sidelink transmissions. The second wireless device may be a coordinating wireless device of the inter-UE coordination. The second wireless device may or may not be an intended receiver of the one or more sidelink transmissions by the first wireless device.

[0356] Referring to FIG. **19**, a sidelink transmission may comprise a PSCCH, a PSSCH and/or a PSFCH. A SCI of the sidelink transmission may comprise a destination ID of the sidelink transmission. A wireless device may be an intended receiver of the sidelink transmission when the wireless device has a same ID as the destination ID in the SCI.

[0357] In an example, before transmitting the one or more sidelink transmissions, the first wireless device may request, from the second wireless device, coordination information (e.g., assistance information) for the one or more sidelink transmissions. The coordination information may comprise a first set of resources for transmitting the one or more sidelink transmissions. The first wireless device may send/transmit, to the second wireless device and via sidelink, a request message, for the requesting of the coordination information (e.g., the first set of resources), to trigger the inter-UE coordination. The second wireless device may trigger the inter-UE coordination based on the receiving of the request message from the first wireless device. In an example, the first wireless device may not transmit a request message to trigger the inter-UE coordination. The second wireless device may trigger the inter-UE coordination based on an event and/or condition.

[0358] In response to the triggering of the inter-UE coordination, the second wireless device may select the first set of resources for the inter-UE coordination. In an example, the second wireless device may trigger a first resource selection procedure for selecting the first set of resources. In an example, the second wireless device may not trigger a first resource selection procedure for selecting the first set of resources. The second wireless device may select the first set of resources based on resource reservation/allocation information at the second wireless device. For example, the second wireless device may select the first set of resources based on that the first set of resources are reserved for uplink transmissions of the intended receiver of the one or more sidelink transmissions. For example, the second wireless device may select the first set of resources based on that the intended receiver of the one or more sidelink transmissions would receive other sidelink transmissions via the first set of resources. In an example, the first set of resources may be a set of preferred resources by the first wireless device for the one or more sidelink transmissions. The first set of resources may be a set of preferred resources by an intended receiver of the one or more sidelink transmissions. In an example, the first set of resources may be a set of non-preferred resources by the first wireless device for the one or more sidelink transmissions. The first set of resources may be a set of non-preferred resources by the intended receiver of the one or more sidelink transmissions.

[0359] The second wireless device may transmit, to the first wireless device and via sidelink, a message (e.g., the coordination information) comprising/indicating the first set of resources. The message may comprise a RRC, MAC CE, and/or SCI. Referring to FIG. **19**, the SCI may comprise a first stage and a second stage. In an example, the first stage of the SCI may comprise/indicate the first set of resources. In an example, the second stage of the SCI may comprise/indicate the first set of resources.

[0360] In response to receiving the message, the first wireless device may select a second set of resources based on the first set of resources. In an example, the first wireless device may trigger a second resource selection procedure for the selecting of the second set of resources. In an example, the first wireless device may not trigger a second resource selection procedure for the selecting of the second set of resources. The first wireless device may select the second set of resources based on (e.g., from) the first set of resources. For example, the first wireless device may randomly select a resource, from the first set of resources, for the second set of resources. For example, the first wireless device may select a resource, from the first set of resources, for the second set of resources, if the resource is in a selection window of the second resource selection procedure. For example, the first wireless device may select a resource, from the first set of resources, for the second set of resources, if the resource is before a PDB (e.g., no later than the PDB) of the one or more sidelink transmissions.

[0361] The example of the inter-UE coordination in FIG. **30** may be an inter-UE coordination scheme 1. In the inter-UE coordination scheme 1, a coordinating wireless device may select a set of preferred resources and/or a set of non-preferred resources for a requesting wireless device. The coordinating wireless device may transmit/send/provide/indicate the set of preferred resources and/or the set of non-preferred resources (e.g., coordination information/assistance information) to the requesting wireless device. The requesting wireless device may transmit one or more sidelink transmissions based on the set of preferred resources and/or the set of non-preferred resources.

[0362] In an example, a preferred resource, for transmitting (e.g., by a requesting wireless device of an inter-UE coordination) and/or receiving (e.g., by a coordinating wireless device of the inter-UE coordination) a sidelink transmission, may be a resource with a RSRP (e.g., measured by the coordinating wireless device) being lower than a RSRP threshold. In an example, a preferred resource, for transmitting (e.g., by a requesting wireless device of an inter-UE coordination) and/or receiving (e.g., by a coordinating wireless device of the inter-UE coordination) a sidelink transmission, may be a resource with a priority value being greater than a priority threshold.

[0363] In an example, a non-preferred resource, for transmitting (e.g., by a requesting wireless device of an inter-UE coordination) and/or receiving (e.g., by a coordinating wireless device of the inter-UE coordination) a sidelink transmission, may be a resource with a RSRP (e.g., measured by the coordinating wireless device) being higher than a RSRP threshold (e.g., hidden node problem with high interference level). In an example, a non-preferred resource, for transmitting (e.g., by a requesting wireless device of an inter-UE coordination) and/or receiving (e.g., by a coordinating wireless device of the inter-UE coordination) a sidelink transmission, may be a resource with a priority value being smaller than the priority threshold (e.g., resource collision problem with another sidelink transmission/reception, which has a high priority). In an example, a non-preferred resource, for transmitting (e.g., by a requesting wireless device of an inter-UE coordination) and/or receiving (e.g., by a coordinating wireless device of the inter-UE coordination) a sidelink transmission, may be a resource being reserved for a second sidelink and/or uplink transmission by the coordinating wireless device and/or an intended receiver (e.g., half-duplex problem). The coordinating wireless device may or may not perform a resource selection procedure for selecting a set of non-preferred resources. The coordinating wireless device may select the set of non-preferred resources based on sensing results of the coordinating wireless device.

[0364] In an example, a larger priority value may indicate a lower priority. A smaller priority value may indicate a higher priority. For example, a first sidelink transmission may have a first priority value. A second sidelink transmission may have a second priority value. The first priority value may be greater than the second priority value, while a first priority of the first sidelink transmission indicated by the first priority value is lower than a second priority of the second sidelink transmission indicated by the second priority value.

[0365] FIG. **31** illustrates an example of a sidelink inter-UE coordination (e.g., an inter-UE coordination scheme 2). A first wireless device and a second wireless device may perform an inter-UE coordination. The first wireless device may be a requesting wireless device of the inter-UE coordination between the first wireless device and the second wireless device. The first wireless device may be a transmitter of one or more first sidelink transmissions. The second wireless device may be a coordinating wireless device of the inter-UE coordination. The second wireless device may or may not be an intended receiver of the one or more first sidelink transmissions by the first wireless device.

[0366] Referring to FIG. **19**, a sidelink transmission may comprise a PSCCH, a PSSCH and/or a PSFCH. A SCI of the sidelink transmission may comprise a destination ID of the sidelink transmission. A wireless device may be an intended receiver of the sidelink transmission when the wireless device has a same ID as the destination ID in the SCI.

[0367] In an example, the first wireless device may request, from the second wireless device, coordination information (e.g., assistance information) for the one or more sidelink transmissions. The first wireless device may send/transmit, to the second wireless device and via sidelink, a request message, for the requesting of the coordination information, to trigger the inter-UE coordination. The second wireless device may trigger the inter-UE coordination based on the receiving of the request message from the first wireless device. In an example, the first wireless device may not transmit a request message to trigger the inter-UE coordination. The second wireless device may trigger the inter-UE coordination based on an event and/or condition.

[0368] In an example, the second wireless device may receive a first SCI from the first wireless device. The first SCI may reserve one or more first resources for the one or more sidelink transmissions. In an example, the request message may comprise the first SCI. In an example, the one or more sidelink transmissions may comprise the first SCI. In an example, the second wireless device may receive, from a third wireless device, one or more second sidelink transmissions. The one or more second sidelink transmissions may comprise a second SCI. The second SCI may reserve one or more second resources for the one or more second sidelink transmissions. The second wireless device may or may not be an intended receiver of the one or more second sidelink transmissions.

[0369] In response to the triggering of the inter-UE coordination, the second wireless device may determine the coordination information for the inter-UE coordination. In an example, the second wireless device may determine the coordination information based on the first SCI. The second wireless device may determine the one or more first resources comprising resources on which the second wireless device would not receive the one or more first sidelink transmissions, e.g., when the second wireless device is an intended receiver of the one or more first sidelink transmissions. The second wireless device may transmit via sidelink and/or uplink via the resources on which the second wireless device would not receive the one or more first sidelink transmissions. The second wireless device may experience half-duplex when transmitting via the resources (e.g., transmit via sidelink). The coordination information may comprise/indicate the resources on which the second wireless device would not receive the one or more first sidelink transmissions, e.g., when the second wireless device is an intended receiver of the one or more first sidelink transmissions. In an example, the second wireless device may determine the coordination information based on the first SCI and/or the second SCI. In an example, the second wireless device may determine the one or more first resources fully/partially overlapping with the one or more second resources. The second wireless device may determine the coordination information indicating overlapped resources of the one or more first resources and the one or more second resources. The overlapped resources may be expected/potential overlapped resources (e.g., future resources) and/or detected overlapped resources (e.g., past resources). The coordination information may comprise/indicate the overlapped resources between the one or more first resources and the one or more second resources. Referring to FIG. **18**, fully overlapping between a first set of resources and a second set of resources may indicate that the first set of resources is the same as the second set of resources (e.g., the same as a subset of the second set of resources). Partially overlapping between a first set of resources and a second set of resources may indicate that the first set of resources and the second set of resources comprise overlapped (e.g., identical) one or more first sidelink resource units and/or non-overlapped (e.g., different) one or more second sidelink resource units. In an example, the second wireless device may transmit, to the first wireless device and via sidelink, a message (e.g., coordination information/assistance information) comprising/indicating the coordination information, e.g., comprising indication of one or more resources based on example embodiments described above. The message may comprise a RRC, MAC CE, SCI and/or a PSFCH (e.g., a PSFCH format 0). A PSFCH format 0 may be a pseudo-random (PN) sequence defined by a length −31 Gold sequence. An index of a PN sequence of a

PSFCH format 0 may indicate a resource collision on a resource, when the resource is associated with a PSFCH resource conveying the PSFCH format 0. Referring to FIG. **19**, the SCI may comprise a first stage and a second stage. In an example, the first stage of the SCI may comprise/indicate the coordination information. In an example, the second stage of the SCI may comprise/indicate the coordination information.

[0370] In response to receiving the coordination message, the first wireless device may select and/or update a set of resources for the one or more first sidelink transmissions based on the coordination information. In an example, the first wireless device may trigger a resource selection procedure for the selecting/updating of the set of resources. In an example, the first wireless device may not trigger a resource selection procedure for the selecting/updating of the set of resources. In an example, the first wireless device may determine whether to retransmit the one or more first sidelink transmissions based on the coordination information.

[0371] The example of the inter-UE coordination in FIG. **31** may be an inter-UE coordination scheme 2. In the inter-UE coordination scheme 2, a coordinating wireless device may determine coordination information based on expected/potential overlapped/collided resources (e.g., future resources) and/or detected overlapped/collided resources (e.g., past resources) between a first set of resources reserved by a requesting wireless device and a second set of resources reserved by a third wireless device.

[0372] In an example embodiment, Listen-before-talk (LBT) may be implemented for transmission in an unlicensed/shared cell. The unlicensed/shared cell may be referred to as a LAA cell and/or a NR-U cell. The unlicensed/shared cell may be operated as non-standalone with an anchor cell in a licensed band or standalone without an anchor cell in a licensed band. LBT may comprise a clear channel assessment (CCA). For example, in an LBT procedure, equipment may apply a CCA before using the unlicensed/shared cell or channel. The CCA may comprise an energy detection that determines the presence of other signals on a channel (e.g., channel is occupied) or absence of other signals on a channel (e.g., channel is clear). A regulation of a country may impact the LBT procedure. For example, European and Japanese regulations may mandate the usage of LBT in the unlicensed/shared bands, such as the 5 GHz unlicensed/shared band. Apart from regulatory constraints, carrier sensing via LBT may be one way for fairly sharing the unlicensed/shared spectrum among different devices and/or networks attempting to utilize the unlicensed/shared spectrum. In some cases, a wireless device may determine a location of a guard band based on a configuration of the wireless device, one or more message received from a base station, one or more messages received from another wireless device, a regulation of a country, or a geographic location of the wireless device, or any combination thereof.

[0373] NR communications/systems/networks in a shared spectrum may be denoted as NR Unlicensed (NR-U). Sidelink communications/systems/networks in a shared spectrum may be denoted as Sidelink Unlicensed (SL-U). In the example embodiment of present disclosure, the spectrum may be interchangeable with a band. In the example embodiment of present disclosure, the unlicensed spectrum (or band) may be interchangeable with a shared spectrum (or band). In the example embodiment of present disclosure, a cell and/or a carrier operation in the shared spectrum (or the unlicensed spectrum) may be referred to as an unlicensed cell and/or an unlicensed carrier, respectively.

[0374] In an example embodiment, discontinuous transmission on an unlicensed/shared band with limited maximum transmission duration may be enabled. Some of these functions may be supported by one or more signals to be transmitted from the beginning of a discontinuous downlink transmission in the unlicensed/shared band. Channel reservation may be enabled by the transmission of signals, by an NR-U node, after or in response to gaining channel access based on a successful LBT operation. Other nodes may receive the signals (e.g., transmitted for the channel reservation) with an energy level above a certain threshold that may sense the channel to be occupied. Functions that may be supported by one or more signals for operation in unlicensed/shared band with discontinuous downlink transmission may comprise one or more of the following: detection of the downlink transmission in unlicensed/shared band (including cell identification) by wireless devices; time and frequency synchronization of wireless devices.

[0375] In an example embodiment, downlink transmission and frame structure design for operation in an unlicensed/shared band may employ subframe, (mini-) slot, and/or symbol boundary alignment according to timing relationships across serving cells aggregated by carrier aggregation. This may not imply that base station transmissions start at the subframe, (mini-) slot, and/or symbol boundary. Unlicensed/shared cell operation (e.g., LAA and/or NR-U) may support transmitting PDSCH, for example, when not all OFDM symbols are available for transmission in a subframe according to LBT. Delivery of control information (e.g., control information used) for the PDSCH may also be supported.

[0376] An LBT procedure may be employed for fair and friendly coexistence of a 3GPP system (e.g., LTE and/or NR) with other operators and/or radio access technologies (RATs), e.g., WiFi, etc., operating in unlicensed/shared spectrum. For example, a node attempting to transmit on a carrier in unlicensed/shared spectrum may perform a CCA as a part of an LBT procedure to determine if the channel is free/idle for use. The LBT procedure may involve energy detection to determine if the channel is being used/occupied. For example, regulatory constraints in some regions, e.g., in Europe, specify an energy detection threshold such that if a node receives energy greater than the threshold, the node assumes that the channel is being used/occupied and not free/idle. While nodes may follow such regulatory constraints, a node may optionally use a lower threshold for energy detection than that specified by regulatory constraints. A radio access technology (e.g., WiFi, LTE and/or NR) may employ a mechanism to adaptively change the energy detection threshold. For example, NR-U may employ a mechanism to adaptively lower the energy detection threshold from an upper bound. An adaptation mechanism may not preclude static or semi-static setting of the threshold. In an example, Category 4 LBT (CAT4 LBT) mechanism or other type of LBT mechanisms may be implemented.

[0377] Various example LBT mechanisms may be implemented. In an example, for some signals, in some implementation scenarios, in some situations, and/or in some frequencies no LBT procedure may be performed by the transmitting entity. In an example, Category 1 (CAT1, e.g., no LBT) may be implemented in one or more cases. For example, a channel in unlicensed/shared band may be hold by a first device (e.g., a base station for DL transmission), and a second device (e.g., a wireless device) takes over the for a transmission without performing the CAT1 LBT. In an example, Category 2 (CAT2, e.g., LBT without random back-off and/or one-shot LBT) may be implemented. The duration of time determining that the channel is idle may be deterministic (e.g., by a regulation). A base station may transmit an uplink grant indicating a type of LBT (e.g., CAT2 LBT) to a wireless device. CAT1 LBT and CAT2 LBT may be employed for Channel occupancy time (COT) sharing. For example, a base station (a wireless device) may transmit an uplink grant (resp. uplink control information) comprising a type of LBT. For example, CAT1 LBT and/or CAT2 LBT in the uplink grant (or uplink control information) may indicate, to a receiving device (e.g., a base station, and/or a wireless device) to trigger COT sharing.

[0378] In an example, Category 3 (CAT3, e.g., LBT with random back-off with a contention window of fixed size) may be implemented. The LBT procedure may have the following procedure as one of its components. The transmitting entity may draw a random number N within a contention window. The size of the contention window may be specified by the minimum and maximum value of N. The size of the contention window may be fixed. The random number N may be employed in the LBT procedure to determine the duration of time that the channel is sensed to be idle before the transmitting entity transmits on the channel. In an example, Category 4 (CAT4, e.g., LBT with random back-off with a contention window of variable size) may be implemented. The transmitting entity may draw a random number N within a contention window. The size of contention window may be specified by the minimum and maximum value of N. The transmitting entity may vary the size of the contention window when drawing the random number N. The random number N may be used in the LBT procedure to determine the duration of time that the channel is sensed to be idle before the transmitting entity transmits on the channel.

[0379] In an example, a wireless device may employ uplink (UL) LBT. The UL LBT may be different from a downlink (DL) LBT (e.g., by using different LBT mechanisms or parameters) for example, since the NR-U UL may be based on scheduled access which affects a wireless device's channel contention opportunities. Other considerations motivating a different UL LBT comprise, but are not limited to, multiplexing of multiple wireless devices in a subframe (slot, and/or mini-slot).

[0380] In an example, DL transmission burst(s) may be a continuous (unicast, multicast, broadcast, and/or combination thereof) transmission by a base station (e.g., to one or more wireless devices) on a carrier component (CC). UL transmission burst(s) may be a continuous transmission from one or more wireless devices to a base station on a CC. In an example, DL transmission burst(s) and UL transmission burst(s) on a CC in an unlicensed/shared spectrum may be scheduled in a TDM manner over the same unlicensed/shared carrier. Switching between DL transmission burst(s) and UL transmission burst(s) may use an LBT (e.g., CAT1 LBT, CAT2 LBT, CAT3 LBT, and/or CAT4 LBT). For example, an instant in time may be part of a DL transmission burst or an UL transmission burst.

[0381] FIG. **32** illustrates an example of unlicensed operation with multiple RATs in an unlicensed/shared spectrum/band/carrier/cell as per an aspect of an example embodiment of the present disclosure.

[0382] In an example of FIG. **32**, a plurality of radio access technologies (RATs) may share a channel (e.g., a radio resource, LBT subband, an RB set) in an unlicensed/shared spectrum/band/carrier/cell. For example, the plurality of RATs may comprise a RAT #1 (e.g., WiFi) and a RAT #2 (e.g., NR-U or SL-U). The RAT #1 may comprise an access point/base station and a wireless device #a. The RAT #2 may comprise a first wireless device, a second wireless device, and third wireless device (e.g., the wireless devices as shown in FIG. **17**). In the unlicensed operation, a wireless device (e.g., a wireless device of the RAT #1 or the RAT #2) may perform a channel access procedure on a channel before transmission via the channel. The wireless device may be allowed to perform the transmission based on the wireless device sensing the channel is idle. In an example, the second wireless device of RAT #2 may attempt to obtain the channel to perform transmission to the first wireless device and/or the third wireless device.

[0383] In an example of FIG. **32**, the second wireless device may perform a first channel access procedure on the channel. The second wireless device may perform one or more transmissions based on the second wireless device sensing, according to the first channel access procedure, that the channel is idle. During the transmission from the second wireless device, the channel may be occupied by the second wireless device. The wireless device #a may attempt to obtain the channel by performing a second channel access procedure. The wireless device #a may drop/cancel/suspend/postpone its transmission based on the wireless device #a sensing that the channel is busy. The wireless device #a may attempt to obtain the channel by performing a third channel access procedure. The wireless device #a may perform transmission from the wireless device #a to the access point/base station based on the wireless device #a sensing, according to the third channel access procedure, that the channel is idle. With this unlicensed operation (or similar unlicensed operations), wireless devices in the plurality of RATs may share the channel in the unlicensed/shared spectrum/band/carrier/cell to perform transmissions from the wireless devices.

[0384] In an example, a base station and/or a wireless device may perform multiple types of channel access procedures (e.g., LBT procedures) for unlicensed/shared spectrum. The multiple types of channel access procedures may comprise at least one of: a Type 1 channel access procedure (also may be referred to as an LBT based Type 1 channel access procedure) and Type 2 channel access procedures (also may be referred to as LBT based Type 2 channel access procedures). The base station and/or the wireless device may perform the Type 1 channel access procedure (e.g., CAT4 LBT) for starting uplink or downlink data transmission at a beginning of a COT. The Type 1 channel access may comprise a random number of channel sensing slots/intervals/durations. The base station and/or the wireless device may perform the Type 2 channel access procedures for COT sharing and/or transmission of discovery bust. Based on a duration of a gap in a COT, the Type 2 channel access procedures may comprise a type 2A, a type 2B, and/or a type 2C channel access procedure. In an example, the Type 2A channel access procedure (e.g., CAT2 LBT) may be used when a COT gap is 25 us or more, and/or for transmission of discovery burst. The 2A channel access procedure may comprise a single channel sensing interval of 25 μs. In an example, the type 2B channel access procedure may be used when a COT gap is 16 μs. The type 2B channel access procedure may comprise a single channel sensing interval of 16 μs. In an example, the type 2C channel access procedure (e.g., CAT1 LBT) may be used when a COT gap is 16 us or less. The type 2C channel access procedure may be without any channel sensing.

[0385] In an example, a LBT failure of a LBT procedure for one or more resources may indicate a channel access failure of the one or more resources. In an example, a LBT failure of a LBT procedure for one or more resources may indicate that the one or more resources are not idle (e.g., occupied) during one or more sensing slot durations before a transmission via the one or more resources (e.g., immediately before the transmission via the one or more resources). In an example, a LBT success of a LBT procedure for one or more resources may indicate a channel access success of the one or more resources. In an example, a LBT success of a LBT procedure for one or more resources may indicate that the one or more resources are idle during one or more sensing slot durations before a transmission via the one or more resources (e.g., immediately before the transmission via the one or more resources).

[0386] A channel may be/refer to a carrier or carrier or a part of a carrier consisting of a contiguous set of RBs or a radio resource on which a channel access procedure is performed in shared spectrum. For example, a spectrum regulation may determine a size of a channel. For example, a channel (e.g., in 2.4 GHz band) may have 20 MHz bandwidth. A system operating in the channel may determine a size of an RB. A number of RBs in a channel may be determined based on a size of the channel and/or a size of the RB.

[0387] A wireless device may initiate (or acquire) a channel occupancy time for a particular time interval (e.g., that may be referred to as a COT duration) in the shared spectrum. For example, the wireless device may perform a Type 1 channel access procedure on a channel (e.g., a radio resource to transmit the PSSCH). The wireless device may determine that the Type 1 channel access procedure indicates the channel being idle. The wireless device may determine that the wireless device acquires (or initiates) the COT for the COT duration, e.g., after or in response to the Type 1 channel access procedure indicating the PSSCH being idle. The wireless device may determine that the COT is valid and/or spans over an (e.g., entire) LBT subband (e.g., 20 MHz) comprising one or more RBs and/or one or more subchannels that comprise the channel (e.g., PSSCH).

[0388] For shared spectrum/unlicensed operation, terminologies of "channel", "RB set", and "LBT subband" may be used interchangeably. A channel access procedure may be a procedure based on sensing that evaluates the availability of a channel for performing transmissions. A basic unit for sensing may be a sensing slot with a duration T_{sl}=9 μs. The sensing slot duration T_{sl} may be considered to be idle if a wireless device senses the channel during the sensing slot duration and determines that the detected power for at least 4 us within the sensing slot duration is less than energy detection threshold X_{Thresh}. Otherwise, the sensing slot duration T_{sl} is considered to be busy.

[0389] A channel occupancy may be/comprise transmission(s) on channel(s) by wireless device(s) after performing a corresponding channel access procedure. A Channel Occupancy Time (COT) may be/comprise the total time for which the wireless device and any wireless device(s) sharing the channel occupancy perform transmission(s) on a channel after the wireless device performs corresponding channel access procedures. For determining a COT, if a transmission gap is less than or equal to 16 μs, the gap duration is counted in the COT. A wireless device (for example, as an initiating device) may share a COT with one or more corresponding wireless devices. This COT sharing may be referred to as channel occupancy sharing. The wireless device that initiates the COT may be denoted as/referred to as the initiating device. The initiating device may perform a Type 1 channel access to obtain the channel occupancy. A wireless device that shares the COT from the initiating device may be denoted as/referred to a responding device. The responding device may perform a Type 2 channel access to use the channel occupancy.

[0390] Channel occupancy time (COT) sharing may be employed in NR-U or SL-U. COT sharing may be a mechanism by which one or more wireless devices share a channel that is sensed as idle by at least one of the one or more wireless devices. For example, one or more first devices may occupy a channel via an LBT (e.g., the channel is sensed as idle based on CAT4 LBT) and one or more second devices may share the channel using an LBT (e.g., 25 μs LBT) within a maximum COT (MCOT) limit. For example, the MCOT limit may be given per priority class, logical channel priority, and/or wireless device specific.

[0391] COT sharing may allow a concession for UL in unlicensed/shared band. For example, a base station may transmit an uplink grant to a wireless device for a UL transmission. For example, a base station may occupy a channel and transmit to one or more wireless devices a control signal indicating that the one or more wireless devices may use the channel. For example, the control signal may comprise an uplink grant and/or a particular LBT type (e.g., CAT1 LBT and/or CAT2 LBT). The one or more wireless device may determine COT sharing based at least on the uplink grant and/or the particular LBT type. The wireless device may perform UL transmission(s) with dynamic grant and/or configured grant (e.g., Type 1, Type2, autonomous UL) with a particular LBT (e.g., CAT2 LBT such as 25 μs LBT) in the configured period, for example, if a COT sharing is triggered. A COT sharing may be triggered by a wireless device. For example, a wireless device performing UL transmission(s) based on a configured grant (e.g., Type 1, Type2, autonomous UL) may transmit an uplink control information indicating the COT sharing (UL-DL switching within a (M) COT).

[0392] In an example, a starting time of DL transmission (s) in the COT sharing triggered by a wireless device may be indicated in one or more ways. For example, one or more parameters in the uplink control information indicate the starting time. For example, resource configuration(s) of configured grant(s) configured/activated by a base station may indicate the starting time. For example, a base station may be allowed to perform DL transmission(s) after or in response to UL transmission(s) on the configured grant (e.g., Type 1, Type 2, and/or autonomous UL). There may be a delay (e.g., at least 4 ms) between the uplink grant and the UL transmission. The delay may be predefined, semi-statically configured (via an RRC message) by a base station, and/or dynamically indicated (e.g., via an uplink grant) by a base station. The delay may not be accounted in the COT duration.

[0393] In an example, single and multiple DL to UL and UL to DL switching within a shared COT may be supported. Example LBT constraints to support single or multiple switching points, may comprise: for a gap of less than 16 μs: no-LBT may be used; for a gap of above 16 us but does not exceed 25 μs: one-shot LBT may be used; for single switching point, for a gap from DL transmission to UL transmission exceeds 25 μs: one-shot LBT may be used; for multiple switching points, for a gap from DL transmission to UL transmission exceeds 25 μs, one-shot LBT may be used.

[0394] FIG. **33** illustrates an example of channel occupancy operations in an unlicensed/shared spectrum/band/carrier/cell as per an aspect of an example embodiment of the present disclosure.

[0395] Referring to FIG. **32**, in an example of FIG. **33**, the second wireless device may perform a Type 1 channel access procedure on the channel. The second wireless device may perform one or more transmissions based on the second wireless device sensing, according to the Type 1 channel access procedure, that the channel is idle. The second wireless device may transmit an indication of COT #1 to potential responding devices (e.g., the first wireless device and/or the third wireless device). The second wireless device may initiate the COT #1 with the one or more transmissions and/or the indication of COT #1 after performing the Type 1 channel access procedure. This procedure may be referred to as COT initiation. The second wireless device may be referred to as an initiating device of the COT #1. As the initiating device, the second wireless device may share the COT #1 with the potential responding devices.

[0396] Referring to FIG. **32**, in an example of FIG. **33**, the first wireless device may receive the indication of COT #1. Based on the indication of COT #1, the first wireless device may attempt to obtain the channel by performing a Type 2 channel access procedure. The first wireless device may perform transmission from the first wireless device within the COT #1, based on the first wireless device sensing, according to the Type 2 channel access procedure, that the channel is idle. This procedure may be referred to as COT sharing. The first wireless device may be referred to as a responding device of the COT #1.

[0397] Referring to FIG. **32**, in an example of FIG. **33**, the third wireless device may not share the COT #1 and initiate a new COT (e.g., COT #2) for transmission from the third wireless device. Reasons of such scenario may be that the third wireless device does not detect the indication of COT #1, the third wireless device is not an intended receiver of the COT #1 (e.g., the indication of COT #1), and/or a gap between the transmissions from the first wireless device and the third wireless device exceeds 25 μs. The third wireless device may perform a Type 1 channel access procedure on the channel. The third wireless device may perform one or more transmissions, based on the third wireless device sensing, according to the Type 1 channel access procedure, that the channel is idle.

[0398] Referring to FIG. **32**, in an example of FIG. **33**, the Type 1 channel access procedure may comprise a random number of sensing durations. A wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**) may determine the random number based at least on a channel access priority class and/or adjust the random number according to results of channel sensing. In an example, the Type 2 channel access may comprise a fixed number of sensing durations. The wireless device may determine the fixed number according to a subtype (e.g., type 2A, type 2B, or type 2C) of the Type 2 channel access procedure. The wireless device may not change/adjust a number of sensing durations when performing the Type 2 channel access procedure.

[0399] Terminologies "LBT based channel access procedure" and "channel access procedure" may be interchangeably used. Terminologies "LBT based Type 1 channel access procedure" and "Type 1 channel access procedure" may be interchangeably used. Terminologies "LBT based Type 2 channel access procedure" and "Type 2 channel access procedure" may be interchangeably used.

[0400] FIG. **34** illustrates an example of a plurality of resource block (RB) interlaces comprising one or more RB interlaces (e.g., RB interlace 0, . . . , RB interlace M−1 in FIG. **34**). A wireless device may transmit a transmission based on mapping resources of the transmission to one or more of the pluralities of the RB interlaces. In an example, an RB interlace of the plurality of RB interlaces may be defined where RB interlace m E {0, 1, . . . , M−1} consists of resource blocks {m, M+m, 2M+m, 3M+m, . . . } (e.g., common resource blocks, CRB), with M being a quantity/number of the plurality of RB interlaces. The quantity/number of the plurality of RB interlaces may be determined/configured (e.g., by a base station via sending a message to the wireless device) based on a subcarrier spacing (e.g., numerology) for the transmission using one or more of the plurality of RB interlaces. For example, the quantity/number of the plurality of RB interlaces M may be 10, based on the subcarrier spacing (e.g., or numerology) of the transmission being 15 kHz. For example, the quantity/number of the plurality of RB interlaces M may be 5, based on the subcarrier spacing (e.g., or numerology) of the transmission being 30 KHz. A relation between an interlaced resource block $n_{IRB,m}^{\mu} \in \{0, 1, \ldots\}$ in a bandwidth part i and an RB interlace m and a resource block n_{CRB}^{μ} (e.g., a CRB n_{CRB}^{μ}) is given by

$$n_{CRB}^{\mu} = Mn_{IRB,m}^{\mu} + N_{BWP,i}^{start,\mu} + \left(\left(m - N_{BWP,i}^{start,\mu}\right) \bmod M\right),$$

where $N_{BWP,i}^{start,\mu}$ is a resource block (e.g., CRB) where bandwidth part starts relative to resource block 0 (e.g., CRB with an index 0, which is a reference point A in FIG. **34**). An index μ indicates the subcarrier spacing (e.g., numerology) of the transmission. If the subcarrier spacing is 15 kHz, μ=0. If the subcarrier spacing is 30 kHz, μ=1. The wireless device may expect that a number/quantity of resource blocks (e.g., CRBs) in an interlace contained within the bandwidth part i is no less than 10.

[0401] In an example of FIG. **34**, each RB interlace of the plurality of RB interlaces may have an RB interlace index (ID) (e.g., RB interlace 0, RB interlace 1, . . . , RB interlace M−1 in FIG. **34**). In the present disclosure, an RB interlace may be interchangeable with and/or may refer to an interlace.

[0402] FIG. **35** illustrates an example of frequency resource configuration with a common interlace and resource blocks as per an aspect of an example embodiment of the present disclosure.

[0403] In an example of FIG. **35**, one or more configuration parameters may configure a common interlace and one or more RBs for sidelink transmission (e.g., PSFCH transmission) in a sidelink resource pool. For example, the one or more configuration parameters may be (or comprise) a high layer parameter sl-PSFCH-Config. For example, the high layer parameter sl-PSFCH-Config may comprise the one or more configuration parameters. The common interlace may be an RB interlace as shown in FIG. **34**. The one or more configuration parameter may indicate an RB interlace index (e.g., RB interlace 0) as the common interlace. The one or more configuration parameters may configure a plurality of RBs for PSFCH transmission (e.g., transmission of HARQ feedback), from remaining RBs in the sidelink resource pool, after excluding RBs of the common interlace (e.g., CRB m, CRB m+M, CRB m+2M). An PSFCH transmission via an RB of the plurality of RBs, together with transmitting the common interlace, may fulfill occupancy channel bandwidth (OCB) requirements based on regulations of a shared spectrum.

[0404] A wireless device may be indicated by an SCI format scheduling a PSSCH reception to transmit a PSFCH with HARQ-ACK information in response to the PSSCH reception. The wireless device may provide HARQ-ACK information that includes ACK or NACK, or only NACK. The wireless device may expect that a slot t'^{SL}_k ($0 \le k < T'_{max}$) has a PSFCH transmission occasion resource if k mod $N_{PSSCH}^{PSFCH}=0$, where T'_{max} may be a number of slots that belong to the resource pool and N_{PSSCH}^{PSFCH} may be provided by a higher layer parameter (e.g., sl-PSFCH-Period). The wireless device may be indicated by higher layers (e.g., the MAC layer) to not transmit a PSFCH that includes HARQ-ACK information in response to a PSSCH reception. If the wireless device receives a PSSCH in a resource pool and the HARQ feedback enabled/disabled indicator field in an associated SCI format 2-A/2-B/2-C has value 1, the wireless device may provide the HARQ-ACK information in a PSFCH transmission in the resource pool. The wireless device may transmit the PSFCH in a first slot that includes PSFCH resources and is at least a number of slots, provided by a higher layer parameter (e.g., sl-MinTimeGapPSFCH), of the resource pool after a last slot of the PSSCH reception.

[0405] The wireless device may be provided by a higher layer parameter (e.g., sl-PSFCH-RB-Set) a set of M_{PRB}^{PSFCH}, set resource blocks (e.g., PRBs) in a resource pool for PSFCH transmission with HARQ-ACK information in a PRB of the resource pool. For a number of N_{subch} sub-channels for the resource pool, provided by a higher layer parameter (e.g., sl-NumSubchannel), and a number of PSSCH slots associated with a PSFCH slot that is less than or equal to N_{PSSCH}^{PSFCH}, the wireless device may allocate the $[(i+j\cdot N_{PSSCH}^{PSFCH})\cdot M_{subch,\ slot}^{PSFCH},\ (i+1+j\cdot N_{PSSCH}^{PSFCH})\cdot M_{subch,\ slot}^{PSFCH}-1]$ PRBs from the $M_{PRB,\ set}^{PSFCH}$ PRBs to slot i among the PSSCH slots associated with the PSFCH slot and sub-channel j, where $M_{subch,\ slot}^{PSFCH}=M_{PRB,\ set}^{PSFCH}/(N_{subch}\cdot N_{PSSCH}^{PSFCH})$, $0 \le i < N_{PSSCH}^{PSFCH}$, $0 \le j < N_{subch}$, and the allocation starts in an ascending order of i and continues in an ascending order of j. $M_{PRB,\ set}^{PSFCH}$ may be a multiple of $N_{subch}\cdot N_{PSSCH}^{PSFCH}$.

[0406] FIG. **36** illustrates an example of PSFCH transmission occasion and PSFCH resource as per an aspect of an example embodiment of the present disclosure.

[0407] In an example of FIG. **36**, a wireless device may receive a PSSCH #1, a PSSCH #2, and a PSSCH #3. In time domain, the wireless device may determine PSFCH transmission occasion #1 in response to the PSSCH #1 and the PSSCH #2, based on a period of PSFCH transmission occasion (e.g., indicated by sl-PSFCH-Period) and a time gap (e.g., indicated by sl-Min TimeGapPSFCH). The PSFCH transmission occasion #1 may be in a slot that has a PSFCH transmission occasion, wherein the slot is configured by sl-PSFCH-Period and the slot is at least a number of slots (the time gap) after reception of the PSSCH #2. The wireless device may determine PSFCH transmission occasion #2 in response to the PSSCH #3, based on the period of PSFCH transmission occasion (e.g., indicated by sl-PSFCH-Period) and the time gap (e.g., indicated by sl-Min TimeGapPSFCH). The PSFCH transmission occasion #2 may be in a slot that has a PSFCH transmission occasion, wherein the slot is configured by sl-PSFCH-Period and the slot is at least a number of slots (the time gap) after reception of the PSSCH #3. In frequency domain, the wireless device may determine a first frequency resource for PSFCH from a set of resource blocks for PSFCH transmission (e.g., indicated by sl-PSFCH-RB-Set), based on a slot in which the wireless device receives the PSSCH #1. The wireless device may determine a second frequency resource for PSFCH from the set of resource blocks for PSFCH transmission, based on a slot in which the wireless device receives the PSSCH #2. The first frequency resource for PSFCH and the second frequency resource for PSFCH may be a resource block (e.g., a PRB) or a plurality of interlaced resource blocks. The first frequency resource for PSFCH and the second frequency resource for PSFCH may be mutually exclusive. The first wireless device may transmit a PSFCH in response to the PSSCH #1 via the first frequency resource for PSFCH in the PSFCH transmission occasion #1. The first wireless device may transmit a PSFCH in response to the PSSCH #1 via the second frequency resource for PSFCH in the PSFCH transmission occasion #1.

[0408] When a first wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**) receives a PSSCH, to transmit a HARQ feedback in response to reception of the PSSCH, the first wireless device may determine a PSFCH transmission occasion and a frequency resource for PSFCH based on higher layer parameters. The first wireless device may transmit the HARQ feedback via a PSFCH in the PSFCH transmission occasion in time domain and the frequency resource for PSFCH in frequency domain.

[0409] The first wireless device may receive multi-consecutive-slot transmission (MCST) comprising multiple PSSCHs from a second wireless device in sidelink communications, where multiple repetitions of a TB is transmitted via the MOST by the second wireless device. The first wireless device may determine a PSFCH transmission occasion and a frequency resource for PSFCH based on higher layer parameters, for the MCST. The first wireless device may transmit a HARQ feedback corresponding to the TB via the PSFCH transmission occasion.

[0410] A problem arises when determining the PSFCH transmission occasion for the MCST. The PSFCH transmission occasion occurs a number of slots after a slot in which the first wireless device receives the last PSSCH of the MCST. The first wireless device may successfully decode the TB based on a PSSCH before the last PSSCH. The MCST may be associated with multiple PSFCH transmission occasions. For example, in the existing technology, the wireless device may transmit multiple HARQ feedbacks (each corresponds to each of repetitions of the MCST) via the multiple PSFCH transmission occasions. The multiple HARQ feedbacks may comprise one or more HARQ feedbacks indicating a same acknowledgement (e.g., ACK or NACK). The problem causes unnecessary duplicated information transmitted by the first wireless device. For example, the unnecessary duplicated information may increase the battery power consumption of the first wireless device. The problem causes increased latency of sidelink transmission and increased power consumption.

[0411] Example embodiment(s) of present disclosure enhance PSFCH in sidelink communications. In a solution for the problem, the first wireless device may determine an early PSFCH transmission occasion based on successfully decoding of the TB with an early PSSCH in the MCST. The solution prevents the first wireless device from waiting for a PSFCH transmission occasion associated with the last PSSCH of the MCST and thus prevents increased latency of sidelink transmission and increased power consumption.

[0412] FIG. **37** illustrates an example of transmission of HARQ feedback for MCST as per an aspect of an example embodiment of the present disclosure.

[0413] In an example of FIG. **37**, a second wireless device (e.g., transmitting wireless device and/or one of the wireless devices of RAT #2 as shown in FIG. **32**) may transmit multiple repetitions of a TB via a MCST comprising a PSSCH #1, a PSSCH #2, and a PSSCH #3 to a first wireless device (e.g., receiving wireless device and/or one of the wireless devices of RAT #2 as shown in FIG. **32**). The first wireless device may receive the PSSCH #1. The first wireless device may successfully decode the TB based on reception of one of the PSSCH #1, the PSSCH #2, and/or the PSSCH #3. Each of the PSSCH #1, the PSSCH #2, and the PSSCH #3 is associated with PSFCH #1, PSFCH #2, and PSFCH #3, respectively. For example, the wireless device may transmit, via the PSFCH #1, a HARQ feedback (ACK or NACK) on the reception of the PSSCH #1, e.g., if the PSSCH #1 is associated with PSFCH #1. For example, the wireless device may transmit, via the PSFCH #2, a HARQ feedback (ACK or NACK) on the reception of the PSSCH #2, e.g., if the PSSCH #2 is associated with PSFCH #2. For example, the wireless device may transmit, via the PSFCH #3, a HARQ feedback (ACK or NACK) on the reception of the PSSCH #3, e.g., if the PSSCH #3 is associated with PSFCH #3. It may be inefficient to transmit HARQ feedbacks via each of PSFCHs (e.g., PSFCH #1, PSFCH #2, and PSFCH #3) associated with repetitions (e.g., PSSCH #1, PSSCH #2, and PSSCH #3) of the same TB. In example embodiment(s) of the present disclosure, the wireless device may determine a first PSFCH (e.g., one of PSFCH #1, PSFCH #2, and PSFCH #3) among a plurality of PSFCHs (e.g., PSFCH #1, PSFCH #2, and PSFCH #3) for transmitting an HARQ feedback (e.g., a single HARQ feedback). For example, the wireless device may transmit, via the first PSFCH, a single HARQ feedback among the HARQ feedbacks. The first wireless device may not transmit (e.g., may skip transmitting) any HARQ feedback on the TB other than the HARQ feedback transmitted via the first PSFCH. The first wireless device may determine the last PSFCH (e.g., a PSFCH with the latest starting time) of the plurality of PSFCHs as the first PSFCH. The first wireless device may determine a PSFCH associated with the last repletion (e.g., a repetition with the latest starting time) of the multiple repetitions

[0414] In an example of FIG. **37**, the first wireless device may transmit a HARQ feedback in response to reception of the last PSSCH of the MCST (e.g., PSSCH #3). Comparing with transmitting the HARQ feedback via the earliest PSFCH transmission occasion (e.g., PSFCH #1), transmitting the HARQ feedback via the last PSFCH transmission occasion (e.g., PSFCH #3) incurs latency of two slots. In addition, the PSFCH #3 is more likely located outside a COT in which the MSCT is transmitted and thus it is more likely the first wireless device drops the HARQ feedback due to LBT failure before the PSFCH #3.

[0415] FIG. **38** illustrates an example of transmission of HARQ feedback for MCST as per an aspect of an example embodiment of the present disclosure.

[0416] In an example of FIG. **38**, a first wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**) may receive from a second wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**), via a first slot (e.g., a slot 1 in FIG. **38**), a first repetition (e.g., repetition #1 in FIG. **38**) of multiple repetitions (e.g., repetition #1, repetition #2, and repetition #3 in FIG. **38**) of a TB. Each of the multiple repetitions may be associated with a respective physical sidelink feedback channel (PSFCH) transmission occasion of multiple PSFCH transmission occasions. For example, the repetition #1 may be associated with a PSFCH transmission occasion (FTO) #1, the repetition #2 may be associated with a FTO #2, and the repetition #3 may be associated with a FTO #3. The first wireless device may select, among one or more first PSFCH transmission occasions (e.g., the FTO #1, the FTO #2, and the FTO #3 in FIG. **38**) of the multiple PSFCH transmission occasions, a first PSFCH transmission occasion (e.g., the FTO #1 in FIG. **38**) for transmission of a positive hybrid automatic repeat-request (HARQ) feedback (e.g., an ACK) of the TB. The multiple PSFCH transmission occasions may be, for example, the FTO #1, the FTO #2, and the FTO #3 in FIG. **38**. The first PSFCH transmission occasion is one of the one or more first PSFCH transmission occasions. The one or more first PSFCH transmission occasions occur after the first slot. The first wireless device may transmit the positive HARQ feedback (e.g., to the second wireless device) via the first PSFCH transmission occasion. The first wireless device may receive the repetition #1, the repetition #2, and the repetition #3 in the slot 1, a slot 2, and a slot 3, respectively. The FTO #1, the FTO #2, and the FTO #3 may be a number of symbols in a slot 3, a slot 4, and a slot 5, respectively.

[0417] In an example of FIG. **38**, the first wireless device may receive one or more messages comprising a first parameter and a second parameter. The first parameter may indicate a time gap between a PSSCH and a PSFCH, wherein the one or more first PSFCH transmission occasions may occur at least a number of slots, indicated by the time gap, after the first slot. The second parameter may indicate a period of PSFCH transmission occasion resource. For example, the period of PSFCH transmission occasion may be 1 and the time gap may be 2 in FIG. **38**.

[0418] In an example of FIG. **38**, the first wireless device may determine multiple PSFCH transmission occasion resources associated with the multiple repetitions, based on the time gap; the period; and slots in which the first wireless device receives the multiple repetitions.

[0419] In an example of FIG. **38**, a PSFCH transmission occasion resource of the multiple PSFCH transmission occasion resources may comprise a PSFCH transmission occasion in time domain and a frequency resource in frequency domain.

[0420] In an example of FIG. **38**, the frequency resource may comprise one or more resource blocks (e.g., a PRB) and a plurality of interlaced resource blocks.

[0421] In an example of FIG. **38**, the first wireless device may not decode the TB successfully in one or more repetitions, of the multiple repetitions, that occur before the first repetition.

[0422] In an example of FIG. **38**, the first repetition may be a starting (or initial or earliest) repetition of the multiple repetitions.

[0423] In an example of FIG. **38**, the first wireless device may receive the multiple repetitions of the TB in multiple consecutive slots.

[0424] In an example of FIG. **38**, the first wireless device may receive one or more sidelink control information (SCI) formats indicating the multiple repetitions of the TB.

[0425] In an example of FIG. **38**, the first wireless device may determine, based on the one or more SCI formats, for transmission of the TB, a frequency resource assignment, a time resource assignment, and a modulation and coding scheme.

[0426] In an example of FIG. **38**, a HARQ feedback may comprise a positive HARQ feedback indicating a positive acknowledgement (e.g., an ACK) on the TB and a negative HARQ feedback indicating a negative acknowledgement (e.g., a NACK) on the TB.

[0427] In an example of FIG. **38**, the first wireless device may receive the first repetition on a first shared spectrum and may transmit the positive HARQ feedback on a second shared spectrum.

[0428] In an example of FIG. **38**, the first shared spectrum may be the same as the second shared spectrum.

[0429] In an example of FIG. **38**, the first wireless device may perform a channel access procedure on the second shared spectrum before transmitting the positive HARQ feedback. The channel access procedure may comprise a Type 1 channel access procedure and a Type 2 channel access procedure.

[0430] In an example of FIG. **38**, the Type 1 channel access procedure may comprise a random number of slots of channel sensing in time domain. The channel sensing may be energy detection over a shared spectrum in frequency domain.

[0431] In an example of FIG. **38**, the Type 2 channel access procedure may be one of a Type 2A channel access procedure comprising a single channel sensing interval of 25 microseconds; a Type 2B channel access procedure comprising a single channel sensing interval of 16 microseconds; and a Type 2C channel access procedure without channel sensing.

[0432] In an example of FIG. **38**, the first wireless device may drop, based on the channel access procedure indicating that the shared spectrum is busy, the transmitting the positive HARQ feedback via the first PSFCH transmission occasion.

[0433] In an example of FIG. **38**, the first wireless device may attempt to transmit, based on dropping the transmitting the positive HARQ feedback via the first PSFCH transmission occasion, the positive HARQ feedback via a PSFCH transmission occasion that is after the first PSFCH transmission occasion.

[0434] In an example of FIG. **38**, the first wireless device may transmit the positive HARQ feedback via a second PSFCH transmission occasion of the multiple PSFCH transmission occasions. The second PSFCH transmission occasion may be after the first PSFCH transmission occasion.

[0435] In an example of FIG. **38**, the first PSFCH transmission occasion may be before the last PSFCH transmission occasion of the multiple PSFCH transmission occasions.

[0436] In an example of FIG. **38**, the first wireless device may receive the multiple repetitions within a channel occupancy time (COT).

[0437] In an example of FIG. **38**, one or more second PSFCH transmission occasions of the multiple PSFCH transmission occasions may occur within the COT.

[0438] In an example of FIG. **38**, the maximum value of the time gap and the period may be larger than or equal to a quantity of slots in which the multiple repetitions are transmitted.

[0439] In an example of FIG. **38**, the first wireless device may transmit first sidelink data via a first slot. The first slot may be after the first PSFCH transmission occasion and before or overlapping with a slot of the last PSFCH transmission occasion.

[0440] In an example of FIG. **38**, the first wireless device may receive, from the second wireless device, second sidelink data different from the TB via a second slot. The second slot may be after the first PSFCH transmission occasion and before or overlapping with a slot of the last PSFCH transmission occasion.

[0441] FIG. **39** illustrates an example of transmission of HARQ feedback for MCST as per an aspect of an example embodiment of the present disclosure.

[0442] In an example of FIG. **39**, a first wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**) may receive from a second wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**), a first repetition (e.g., a repetition #3 in FIG. **39**) of multiple repetitions (e.g., a repetition #0, a repetition #1, a repetition of #2, and the repetition #3 in FIG. **39**) of a TB. Each of the multiple repetitions may be associated with a respective PSFCH transmission occasion of multiple PSFCH transmission occasions (e.g., a FTO #0, a FTO #1, and a FTO #2 in FIG. **39**). The first wireless device may determine unsuccessfully decoding the TB based on the first repetition and the first repetition being the last repetition of the multiple repetitions. The first wireless device may transmit, based on the determining, a negative hybrid automatic repeat-request (HARQ) feedback (e.g., a NACK) (e.g., to the second wireless device) via a first PSFCH transmission occasion, of the multiple PSFCH transmission occasions, respective to the first repetition.

[0443] In an example of FIG. **39**, the first wireless device may receive a second repetition (e.g., the repetition #2 in FIG. **39**) of the multiple repetitions. The second repetition may be before the first repetition. A second PSFCH transmission occasion (e.g., the FTO #2 in FIG. **39**) of the multiple PSFCH transmission occasions may be associated with the second repetition.

[0444] In an example of FIG. **39**, the first wireless device may skip to transmit (e.g., may not transmit) the negative HARQ feedback via the second PSFCH transmission occasion.

[0445] In an example of FIG. **39**, the first wireless device may transmit the negative HARQ feedback via the second PSFCH transmission occasion.

[0446] In an example, the first wireless device may receive from the second wireless device, the first repetition of the multiple repetitions of the TB. Each of the multiple repetitions may be associated with a respective PSFCH transmission occasion of multiple PSFCH transmission occasions. The first wireless device may determine, based on the first repetition, a value of the HARQ feedback (e.g., an ACK or a NACK) on the TB. The first wireless device may determine, based on the value of the HARQ feedback, to transmit the HARQ feedback via a PSFCH transmission occasion, of the multiple PSFCH transmission occasions, associated with the first repetition. The first wireless device may transmit, to the second wireless device, the HARQ feedback via the PSFCH transmission.

[0447] In an example, the first wireless device may receive from the second wireless device, the first repetition of multiple repetitions of a TB. Each of the multiple repetitions is associated with a respective PSFCH transmission occasion of multiple PSFCH transmission occasions. The first wireless device may determine to skip transmitting (e.g., determine to not transmit) the HARQ feedback via a PSFCH transmission occasion, of the multiple PSFCH transmission occasions, associated with the first repetition. The determining may be based on the first repetition being before a last repetition of the multiple repetitions (e.g., the first repetition being not the last repetition). The first wireless device may receive a second repetition of multiple repetitions. The first wireless device may transmit, based on the second repetition being a last repetition of the multiple repetitions, the HARQ feedback via the PSFCH transmission.

[0448] In an example, the second wireless device may monitor the multiple PSFCH transmission occasions. The second wireless device may receive from the first wireless device, via the multiple PSFCH transmission occasion, one or more HARQ feedbacks on the TB. The second wireless device may determine, based on a first HARQ feedback of the one or more HARQ feedbacks being an ACK (e.g., for unicast, an ACK transmitted by the first wireless device; for groupcast, ACKs from all wireless devices in the group comprising the first wireless device), that the TB is successfully decoded. The second wireless device may determine, based on a second HARQ feedback (e.g., of the one or more HARQ feedbacks) received in the latest PSFCH transmission occasion of the multiple transmission occasions being a NACK, that the TB is not successfully decoded (e.g., a decoding failure of the TB).

[0449] In an example, the second wireless device may determine, based on not receiving any HARQ feedback on the TB in the latest PSFCH transmission occasion of the multiple transmission occasions, that the TB is not successfully decoded (e.g., a decoding failure of the TB).

[0450] In an example, the second wireless device may determine, based on a first condition and a second condition, that the TB is not successfully decoded (e.g., a decoding failure of the TB). The first condition may be the second wireless device not receiving any HARQ feedback on the TB in the latest PSFCH transmission occasion of the multiple transmission occasions. The second condition may be the second wireless device receiving a negative HARQ feedback (e.g., indicating a NACK) on the TB in a PSFCH transmission occasion of the multiple transmission occasions before the latest PSFCH transmission occasion.

[0451] FIG. **40** illustrates an example of transmission of HARQ feedback for MCST as per an aspect of an example embodiment of the present disclosure.

[0452] In an example of FIG. **40**, a first wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**) may receive from a second wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**), via a first slot (e.g., a slot 1 in FIG. **38**), a first repetition (e.g., a repetition #1 in FIG. **40**) of multiple repetitions (e.g., the repetition #1, a repetition #2, a repetition #3 and a repetition #4 in FIG. **40**) of a TB. Each of the multiple repetitions may be associated with a respective physical sidelink feedback channel (PSFCH) transmission occasion of multiple PSFCH transmission occasions. For example, the repetition #1 may be associated with a FTO #2, the repetition #2 and the repetition #3 may be associated with a FTO #3, and the repetition #4 may be associated with a FTO #4. The first wireless device may select, among one or more first PSFCH transmission occasions (e.g., the FTO #2, the FTO #3, and the FTO #4 in FIG. **40**) of the multiple PSFCH transmission occasions, a first PSFCH transmission occasion (e.g., the FTO #2 in FIG. **40**) for transmission of a positive hybrid automatic repeat-request (HARQ) feedback (e.g., an ACK) of the TB. The first PSFCH transmission occasion is one of the one or more first PSFCH transmission occasions. The one or more first PSFCH transmission occasions occur after the first slot. The first wireless device may transmit the positive HARQ feedback (e.g., to the second wireless device) via the first PSFCH transmission occasion. The first wireless device may not transmit (e.g., may skip transmitting) an HARQ feedback via a PSFCH transmission occasion (e.g., the PTO #3 or the PTO #4) after the first PSFCH transmission occasion, in response to transmitting the positive HARQ feedback via the first PSFCH transmission occasion. The first wireless device may receive the repetition #1, the repetition #2, the repetition #3, and the repetition #4 in the slot 1, a slot 2, a slot 3, and a slot 4, respectively. The FTO #2, the FTO #3, and the FTO #4 may be a number of symbols in a slot 3, a slot 5, and a slot 7, respectively.

[0453] FIG. **41** illustrates an example of transmission of HARQ feedback for MCST as per an aspect of an example embodiment of the present disclosure.

[0454] In an example of FIG. **41**, a first wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**) may receive, from a second wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**), a first repetition (e.g., a repetition #1 in FIG. **41**) of multiple repetitions (e.g., the repetition #1, a repetition #2, a repetition #3, and a repetition #4 in FIG. **41**) of a TB. Each of the multiple repetitions may be associated with a respective PSFCH transmission occasion of multiple PSFCH transmission occasions (e.g., a FTO #2, a FTO #3, and a FTO #4 in FIG. **41**). The first wireless device may determine, in response to a decoding failure (e.g., unsuccessfully decoding) of the TB based on the first repetition, to skip transmitting (e.g., not transmit) a first HARQ feedback (e.g., NACK) corresponding to the first repetition via a first PSFCH transmission occasion (e.g., the FTO #2 in FIG. **41**), of the multiple PSFCH transmission occasions, associated with the first repetition. The first wireless device may receive a second repetition (e.g., at least one of the repetition #2 or the repetition #3) of multiple repetitions of the TB. The first wireless device may transmit, in response to a decoding success (e.g., successfully decoding) of the TB based on the second repetition, a positive HARQ feedback (e.g., ACK) corresponding to the second repetition via a second PSFCH transmission occasion (e.g., the FTO #3 in FIG. **41**), of the multiple PSFCH transmission occasions, associated with the second repetition. The transmitting may be based on the second repetition being, among the multiple repetitions, an earliest repetition based on which the first wireless device successfully decodes the TB or the second PSFCH transmission occasion being, among the multiple PSFCH transmission occasions, an earliest PSFCH transmission occasion via which the first wireless device transmits (e.g., to the second wireless device) a positive HARQ feedback of the TB. The first wireless device may receive the repetition #1 via a PSSCH **1** in a slot 1. The first wireless device may receive the repetition #2 via a PSSCH **2** in a slot 2. The first wireless device may receive the repetition #3 via a PSSCH **3** in a slot 3. The first wireless device may receive the repetition #4 via a PSSCH **4** in a slot 4. The first wireless device may determine the FTO #1 in the slot #1, the FTO #2 in the slot #2, the FTO #3 in the slot #3, and the FTO #4 in the slot #4.

[0455] In an example of FIG. **41**, the first wireless device may receive a third repetition (e.g., the repetition #4 in FIG. **41**) of multiple repetitions of the TB. The first wireless device may determine to skip transmitting (e.g., not to transmit) a second HARQ feedback (e.g., ACK or NACK) corresponding to the third repetition via a third PSFCH transmission occasion (e.g., the FTO #4 in FIG. **41**) of the multiple PSFCH transmission occasions, associated with the third repetition. The determining to skip transmitting the third HARQ feedback may be based on transmitting the positive HARQ feedback via the second PSFCH transmission occasions occurring earlier than the third PSFCH transmission occasion.

[0456] In an example of FIG. **41**, the determining to skip transmitting the HARQ feedback (e.g., NACK) corresponding to the first repetition may be further based on the first PSFCH transmission occasion not being a last PSFCH transmission among the multiple PSFCH transmission occasions or the first repetition not being a last repetition of the multiple repetitions.

[0457] In an example, a first wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**) may receive, from a second wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**), a first repetition of multiple repetitions of a TB. Each of the multiple repetitions may be associated with a respective PSFCH transmission occasion of multiple PSFCH transmission occasions. The first wireless device may transmit a positive HARQ feedback corresponding to the first repetition via a first PSFCH transmission occasion, of the multiple PSFCH transmission occasions, associated with the first repetition. The transmitting may be based on the first repetition being, among the multiple repetitions, an earliest repetition based on which the first wireless device successfully decodes the TB or the first PSFCH transmission occasion being, among the multiple PSFCH transmission occasions, an earliest PSFCH transmission occasion via which the first wireless device transmits the positive HARQ feedback of the TB.

[0458] FIG. **42** illustrates an example of transmission of HARQ feedback for MCST as per an aspect of an example embodiment of the present disclosure.

[0459] In an example of FIG. **42**, a first wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**) may receive, from a second wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**), multiple repetitions (e.g., a repetition #1, a repetition #2, a repetition #3, and a repetition #4 in FIG. **42**) of a TB. Each of the multiple repetitions may be associated with a respective PSFCH transmission occasion of multiple PSFCH transmission occasions (e.g., a FTO #2, a FTO #3, and a FTO #4 in FIG. **41**). The first wireless device may fail to decode (e.g., may not decode) the TB, based on the repetitions #1, #2, #3, and #4. The first wireless device may not transmit (e.g., may skip transmitting), via the FTO #2, a HARQ feedback in response to failing to decode the TB based on the repetition #1 and FTO #2 being not the last PSFCH among FTOs #2, #3, and #4. The first wireless device may not transmit (e.g., may skip transmitting), via the FTO #3, an HARQ feedback in response to failing to decode the TB based on the repetition #2 and the repetition #3 and FTO #2 being not the last PSFCH among FTOs #2, #3, and #4. The first wireless device may transmit a negative HARQ feedback (e.g., a NACK) (e.g., to the second wireless device) in response to failing to decode the TB based on the repetitions #2, #3, and #4 and the FTO #4 being the last FTO among FTOs #2, #3, and #4.

[0460] In an example, a first wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**) may receive, from a second wireless device (e.g., one of the wireless devices of RAT #2 as shown in FIG. **32**), multiple repetitions of a TB. Each of the multiple repetitions may be associated with a respective PSFCH transmission occasion of multiple PSFCH transmission occasions. A last PSFCH transmission occasion (e.g., with the latest starting time) of the multiple PSFCH transmission occasions may be associated with a last repetition (e.g., with the latest starting time) of the multiple repetitions. The first wireless device may not transmit (e.g., may skip transmitting), via a PFSCH transmission occasion before the last PSFCH transmission occasion, a first HARQ feedback in response to reception of a repetition before the last repetition. The first wireless device may transmit (e.g., to the second wireless device) a second HARQ feedback (e.g., a NACK or ACK) in response to reception of the last repetition.

[0461] In an example, the first wireless device may receive the multiple repetitions and transmit the second HARQ feedback in unicast communications.

[0462] In an example, the first wireless device may receive the multiple repetitions and transmit the second HARQ feedback in group communications with HARQ feedback comprising ACK and NACK.

[0463] In an example, the first wireless device may receive the multiple repetitions and transmit the second HARQ feedback in group communications with HARQ feedback comprising only NACK.

[0464] FIG. **43** illustrates an example of flow diagram as per an aspect of an embodiment of the present disclosure. At **4301**, the wireless device may receive, via a first slot, a first repetition of multiple repetitions of a transport block (TB), wherein each of the multiple repetitions is associated with a respective physical sidelink feedback channel (PSFCH) transmission occasion of multiple PSFCH transmission occasions. At **4302**, the wireless device may select, among one or more first PSFCH transmission occasions of the multiple PSFCH transmission occasions, a first PSFCH transmission occasion for transmission of a positive hybrid automatic repeat-request (HARQ) feedback of the TB, wherein: the first PSFCH transmission occasion is one of the one or more first PSFCH transmission occasions; and the one or more first PSFCH transmission occasions occur after the first slot; and transmitting the positive HARQ feedback via the first PSFCH transmission occasion.

[0465] FIG. **44** illustrates an example of flow diagram as per an aspect of an embodiment of the present disclosure. At **4401**, the wireless device may receive, via a first slot, a first repetition of multiple repetitions of a transport block (TB), wherein each of the multiple repetitions is associated with a respective PSFCH transmission occasion of multiple PSFCH transmission occasions. At **4402**, the wireless device may determine unsuccessfully decoding the TB based on the first repetition; and the first repetition being the last repetition of the multiple repetitions; and transmit, based on the determining, a negative hybrid automatic repeat-request (HARQ) feedback via a first PSFCH transmission occasion, of the multiple PSFCH transmission occasions, respective to the first repetition.

What is claimed is:

1. A first wireless device comprising:

one or more processors; and

memory storing instructions that, when executed by the one or more processors, cause the first wireless device to:

receive, from a second wireless device and via a slot, a first physical sidelink shared channel (PSSCH) comprising a transport block (TB);

determine, for transmission of a physical sidelink feedback channel (PSFCH) for the TB, a plurality of PSFCH transmission occasions associated with the TB, based on:

a first configuration parameter indicating a number of slots between a slot comprising a PSFCH resource and a last slot of reception of the TB; and

a second configuration parameter indicating a periodicity of the slot comprising the PSFCH resource;

perform a channel access procedure to transmit the PSFCH, via a second PSFCH transmission occasion among the plurality of PSFCH transmission occasions, wherein:

performing the channel access procedure is in response to not transmitting the PSFCH via one or more first PSFCH transmission occasions among the plurality of PSFCH transmission occasions; and

the second PSFCH transmission occasion occurs after the one or more first PSFCH transmission occasions; and

transmit, via the second PSFCH transmission occasion and based on performing the channel access procedure, the PSFCH.

2. The first wireless device of claim **1**, wherein the instructions further cause the first wireless device to drop, based on the channel access procedure indicating that the one or more first PSFCH transmission occasions is busy, transmission of the PSFCH via the one or more first PSFCH transmission occasions.

3. The first wireless device of claim **1**, wherein the instructions further cause the first wireless device to determine multiple PSFCH transmission occasion resources based on:

the first configuration parameter; and

the second configuration parameter.

4. The first wireless device of claim **3**, wherein a PSFCH transmission occasion resource, of the multiple PSFCH transmission occasion resources, comprises:

a PSFCH transmission occasion in time domain; and

a frequency resource in frequency domain.

5. The first wireless device of claim **4**, wherein the frequency resource comprises:

one or more resource blocks; and

a plurality of interlaced resource blocks.

6. The first wireless device of claim **1**, wherein the instructions further cause the first wireless device to determine, based on one or more sidelink control information (SCI) formats and for the TB:

a frequency resource assignment;

a time resource assignment; and

a modulation and coding scheme.

7. The first wireless device of claim **1**, wherein:

the channel access procedure is performed before the PSFCH is transmitted; and

the channel access procedure comprises at least one of:

a Type 1 channel access procedure; or

a Type 2 channel access procedure.

8. The first wireless device of claim **7**, wherein:

the Type 1 channel access procedure comprises a random number of slots for channel sensing in time domain; and

the channel sensing comprises energy detection over a shared spectrum in frequency domain.

9. The first wireless device of claim **7**, wherein the Type 2 channel access procedure is one of:

a Type 2A channel access procedure comprising a single channel sensing interval of 25 micro seconds;

a Type 2B channel access procedure comprising a single channel sensing interval of 16 micro seconds; or

a Type 2C channel access procedure without channel sensing.

10. The first wireless device of claim **1**, wherein the instructions further cause the first wireless device to transmit the PSFCH via at least one of:

at least one of one or more resource blocks; or

a plurality of interlaced resource blocks.

11. A method comprising:

receiving, by a first wireless device from a second wireless device and via a slot, a first physical sidelink shared channel (PSSCH) comprising a transport block (TB);

determining, for transmission of a physical sidelink feedback channel (PSFCH) for the TB, a plurality of PSFCH transmission occasions associated with the TB, based on:

a first configuration parameter indicating a number of slots between a slot comprising a PSFCH resource and a last slot of reception of the TB; and a second configuration parameter indicating a periodicity of the slot comprising the PSFCH resource;

performing a channel access procedure to transmit the PSFCH, via a second PSFCH transmission occasion among the plurality of PSFCH transmission occasions, wherein:

the performing is in response to not transmitting the PSFCH via one or more first PSFCH transmission occasions among the plurality of PSFCH transmission occasions; and

the second PSFCH transmission occasion occurs after the one or more first PSFCH transmission occasions; and

transmitting, via the second PSFCH transmission occasion and based on the performing the channel access procedure, the PSFCH.

12. The method of claim **11**, further comprising dropping, based on the channel access procedure indicating that the one or more first PSFCH transmission occasions is busy, transmission of the PSFCH via the one or more first PSFCH transmission occasions.

13. The method of claim **12**, further comprising determining multiple PSFCH transmission occasion resources based on:

the first configuration parameter; and

the second configuration parameter.

14. The method of claim **13**, wherein a PSFCH transmission occasion resource, of the multiple PSFCH transmission occasion resources, comprises:

a PSFCH transmission occasion in time domain; and

a frequency resource in frequency domain.

15. The method of claim **14**, wherein the frequency resource comprises:

one or more resource blocks; and

a plurality of interlaced resource blocks.

16. The method of claim **11**, further comprising determining, based on one or more sidelink control information (SCI) formats and for the TB:

a frequency resource assignment;

a time resource assignment; and

a modulation and coding scheme.

17. The method of claim **11**, wherein:

the performing the channel access procedure is before the transmitting the PSFCH; and

the channel access procedure comprises at least one of:

a Type 1 channel access procedure; or

a Type 2 channel access procedure.

18. The method of claim **17**, wherein:

the Type 1 channel access procedure comprises a random number of slots for channel sensing in time domain; and

the channel sensing comprises energy detection over a shared spectrum in frequency domain.

19. The method of claim **17**, wherein the Type 2 channel access procedure is one of:

a Type 2A channel access procedure comprising a single channel sensing interval of 25 micro seconds;

a Type 2B channel access procedure comprising a single channel sensing interval of 16 micro seconds; or

a Type 2C channel access procedure without channel sensing.

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

receive, from a second wireless device and via a slot, a first physical sidelink shared channel (PSSCH) comprising a transport block (TB);

determine, for transmission of a physical sidelink feedback channel (PSFCH) for the TB, a plurality of PSFCH transmission occasions associated with the TB, based on:

a first configuration parameter indicating a number of slots between a slot comprising a PSFCH resource and a last slot of reception of the TB; and

a second configuration parameter indicating a periodicity of the slot comprising the PSFCH resource;

perform a channel access procedure to transmit the PSFCH, via a second PSFCH transmission occasion among the plurality of PSFCH transmission occasions, wherein:

performing the channel access procedure is in response to not transmitting the PSFCH via one or more first PSFCH transmission occasions among the plurality of PSFCH transmission occasions; and

the second PSFCH transmission occasion occurs after the one or more first PSFCH transmission occasions; and

transmit, via the second PSFCH transmission occasion and based on performing the channel access procedure, the PSFCH.

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