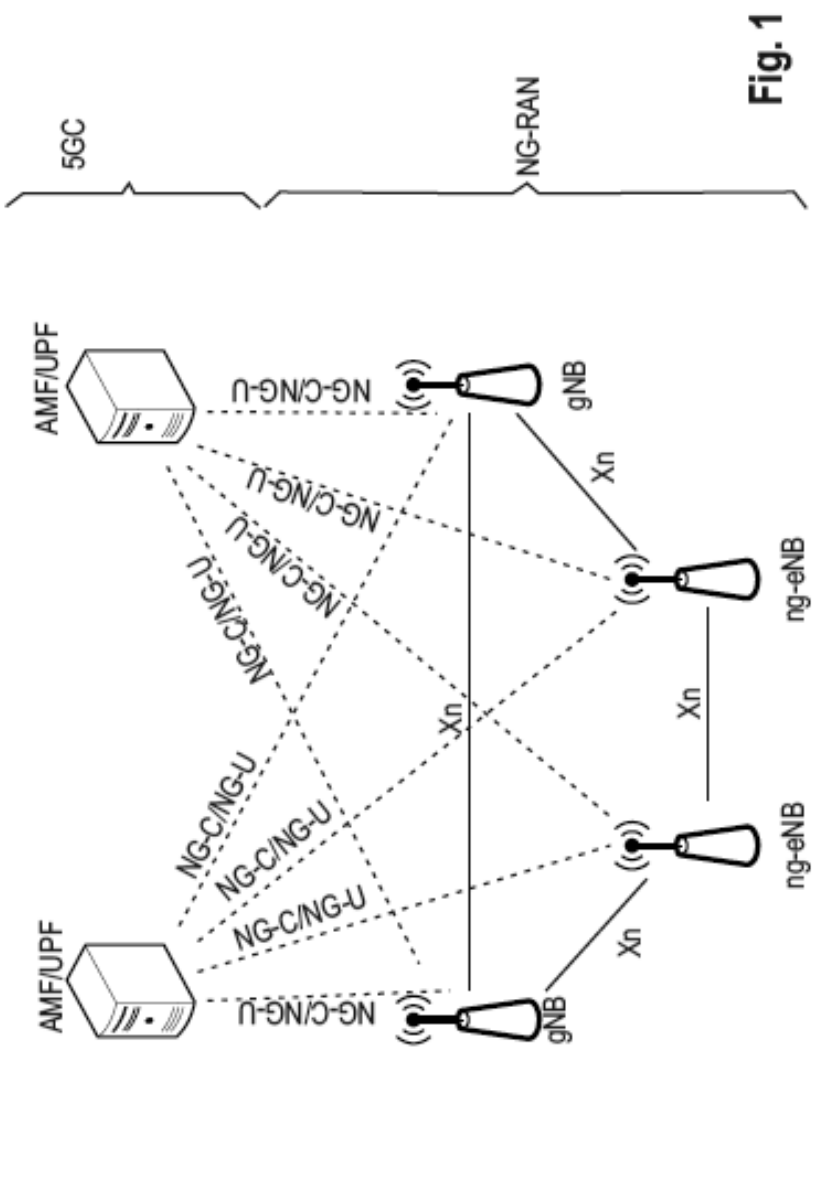

5GC
NG-RAN
AMF/UPF
AMF/UPF
NG-C/NG-U
NG-C/NG-U
NG-C/NG-U
NG-C/NG-U
NG-C/NG-U
NG-C/NG-U
NG-C/NG-U
NG-C/NG-U
gNB
gNB
ng-eNB
ng-eNB
Xn
Xn
Xn
Xn
100

Fig. 1

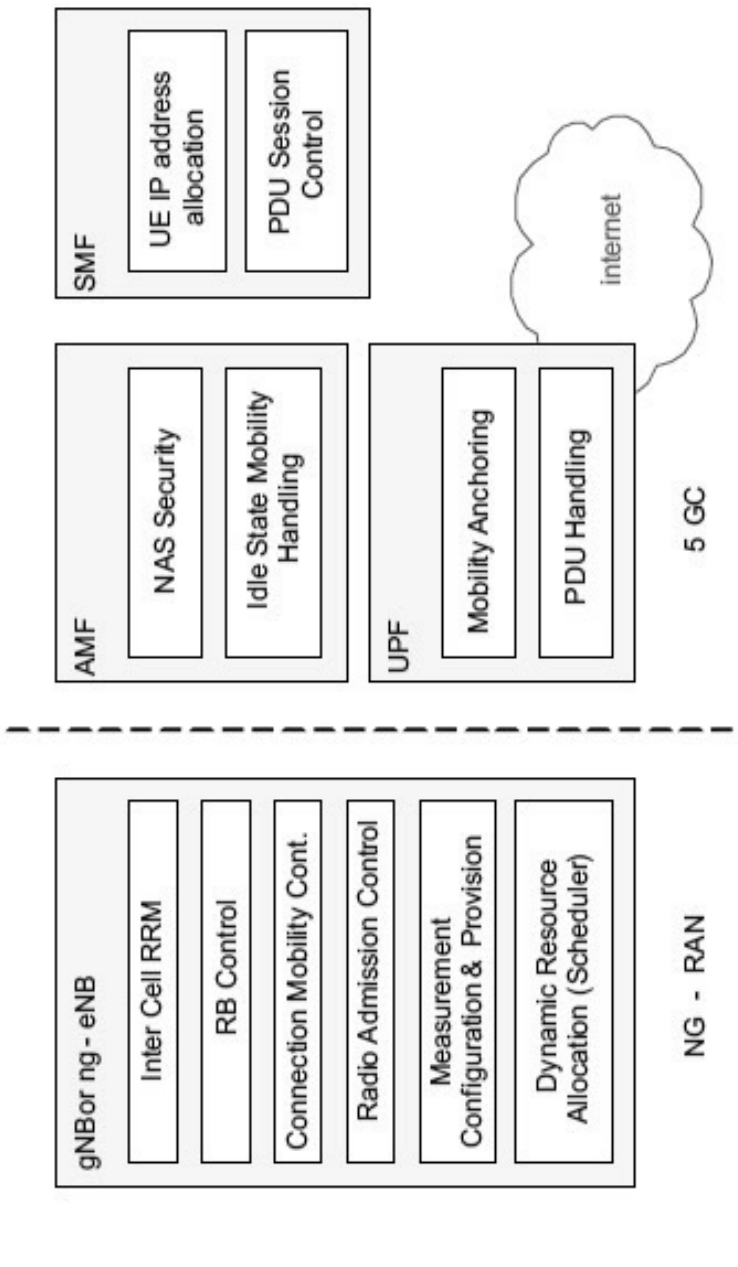

gNBor ng - eNB
Inter Cell RRM
RB Control
Connection Mobility Cont.
Radio Admission Control
Measurement Configuration & Provision
Dynamic Resource Allocation (Scheduler)
NG - RAN
AMF
NAS Security
Idle State Mobility Handling
UPF
Mobility Anchoring
PDU Handling
SMF
UE IP address allocation
PDU Session Control
internet
5 GC
200

Fig. 2

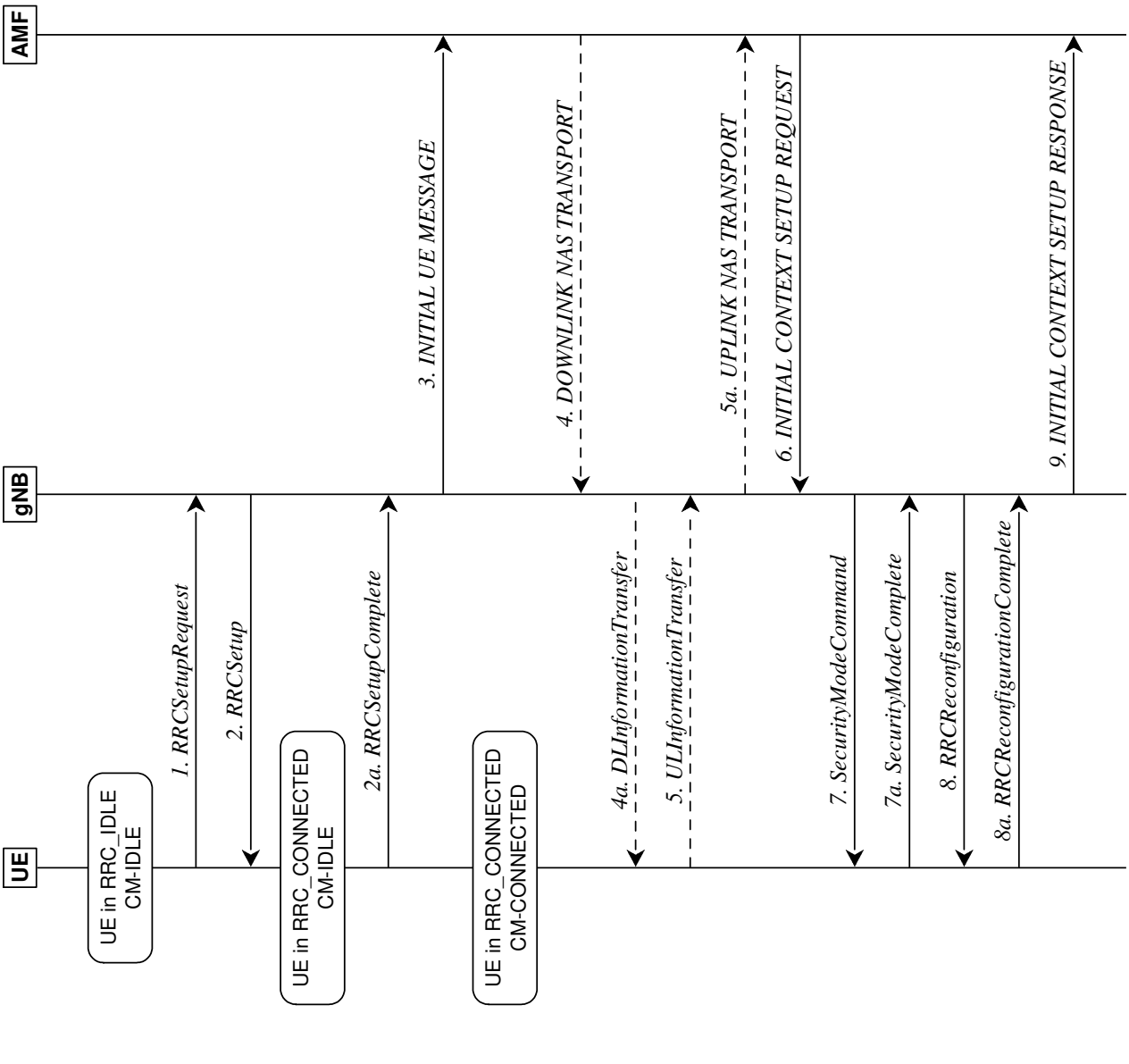

UE
gNB
AMF
UE in RRC_IDLE
CM-IDLE
1. RRCSetupRequest
2. RRCSetup
UE in RRC_CONNECTED
CM-IDLE
2a. RRCSetupComplete
UE in RRC_CONNECTED
CM-CONNECTED
3. INITIAL UE MESSAGE
4. DOWNLINK NAS TRANSPORT
4a. DLInformationTransfer
5. ULInformationTransfer
5a. UPLINK NAS TRANSPORT
6. INITIAL CONTEXT SETUP REQUEST
7. SecurityModeCommand
7a. SecurityModeComplete
8. RRCReconfiguration
8a. RRCReconfigurationComplete
9. INITIAL CONTEXT SETUP RESPONSE
300

Fig. 3

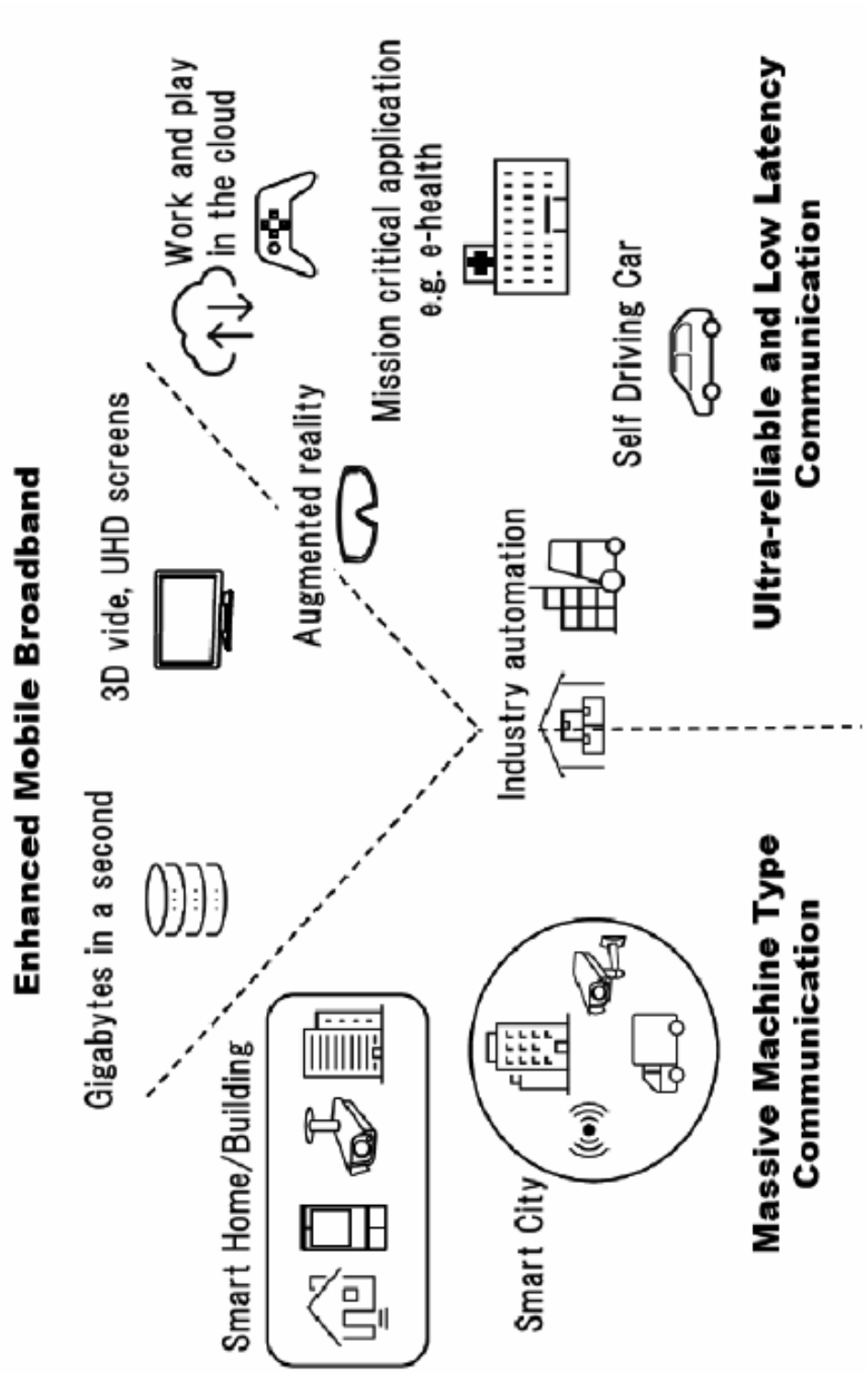

Enhanced Mobile Broadband
Gigabytes in a second
3D vide, UHD screens
Work and play in the cloud
Augmented reality
Mission critical application e.g. e-health
Smart Home/Building
Industry automation
Self Driving Car
Ultra-reliable and Low Latency Communication
Smart City
Massive Machine Type Communication
400

Fig. 4

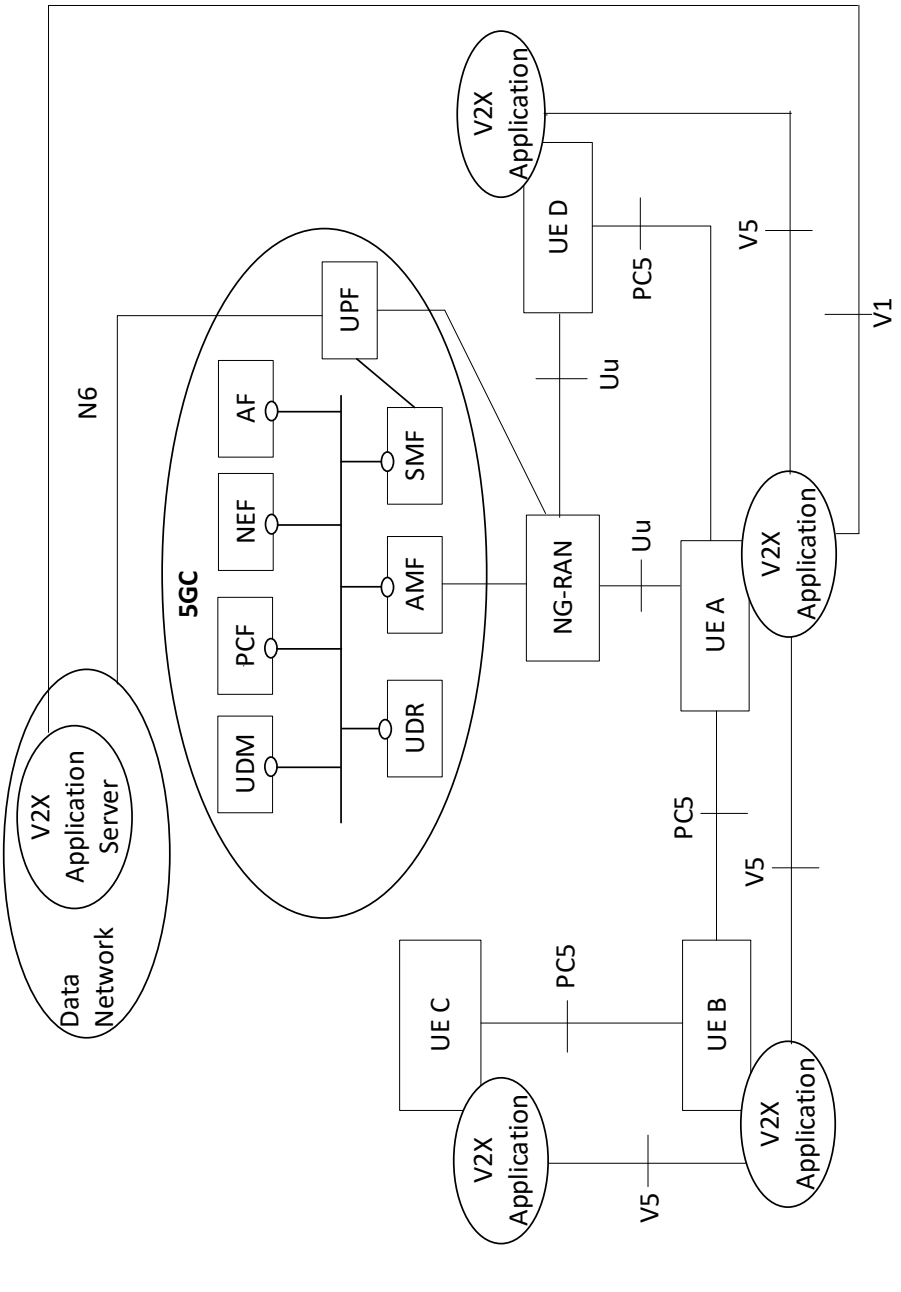

Data Network
V2X Application Server
N6
5GC
UPF
AF
NEF
PCF
UDM
SMF
AMF
UDR
NG-RAN
Uu
Uu
UE D
UE A
UE B
UE C
V2X Application
V2X Application
V2X Application
V2X Application
PC5
PC5
PC5
V5
V5
V5
V1
500

Fig. 5

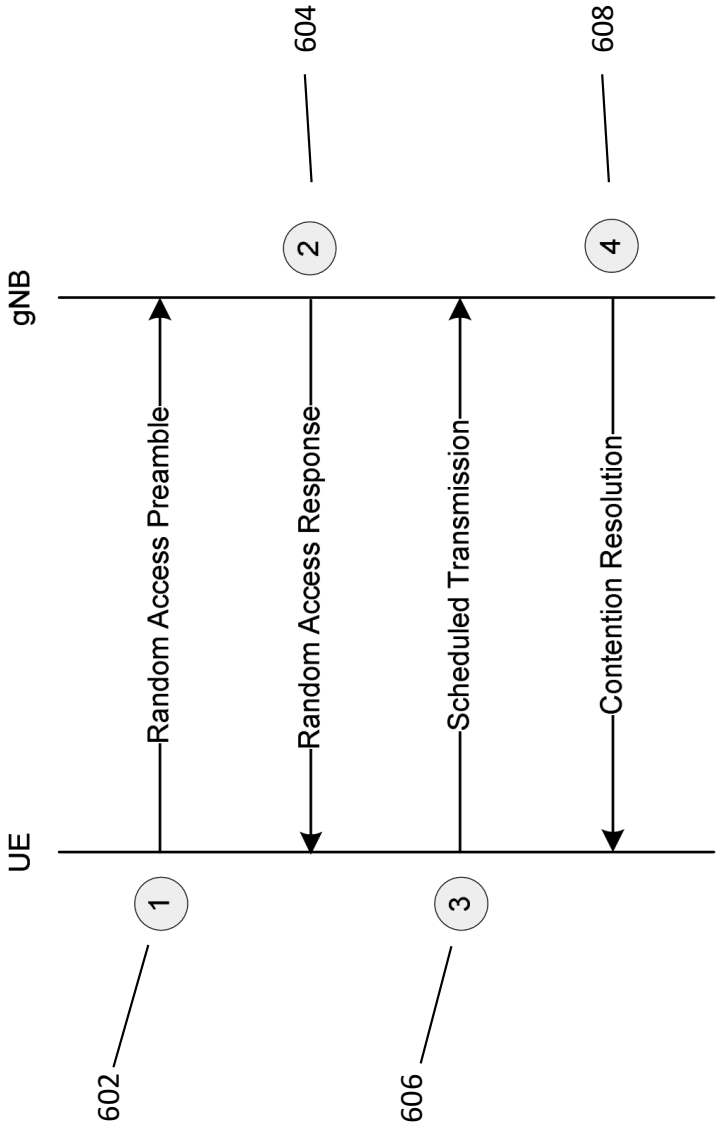

gNB
UE
Random Access Preamble
Random Access Response
Scheduled Transmission
Contention Resolution
1
2
3
4
602
604
606
608
600

Fig. 6

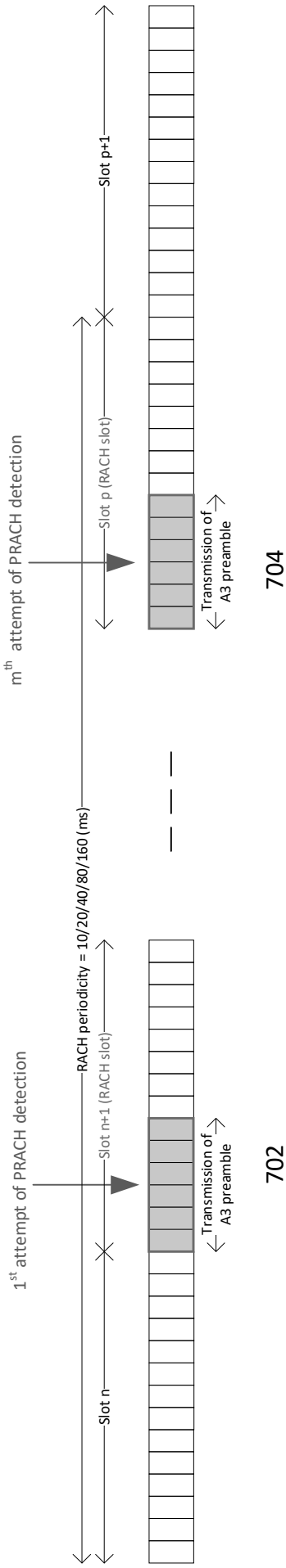

1st attempt of PRACH detection
RACH periodicity = 10/20/40/80/160 (ms)
Slot n
Slot n+1 (RACH slot)
Transmission of A3 preamble
702
mth attempt of PRACH detection
Slot p (RACH slot)
Slot p+1
Transmission of A3 preamble
704
700

Fig. 7

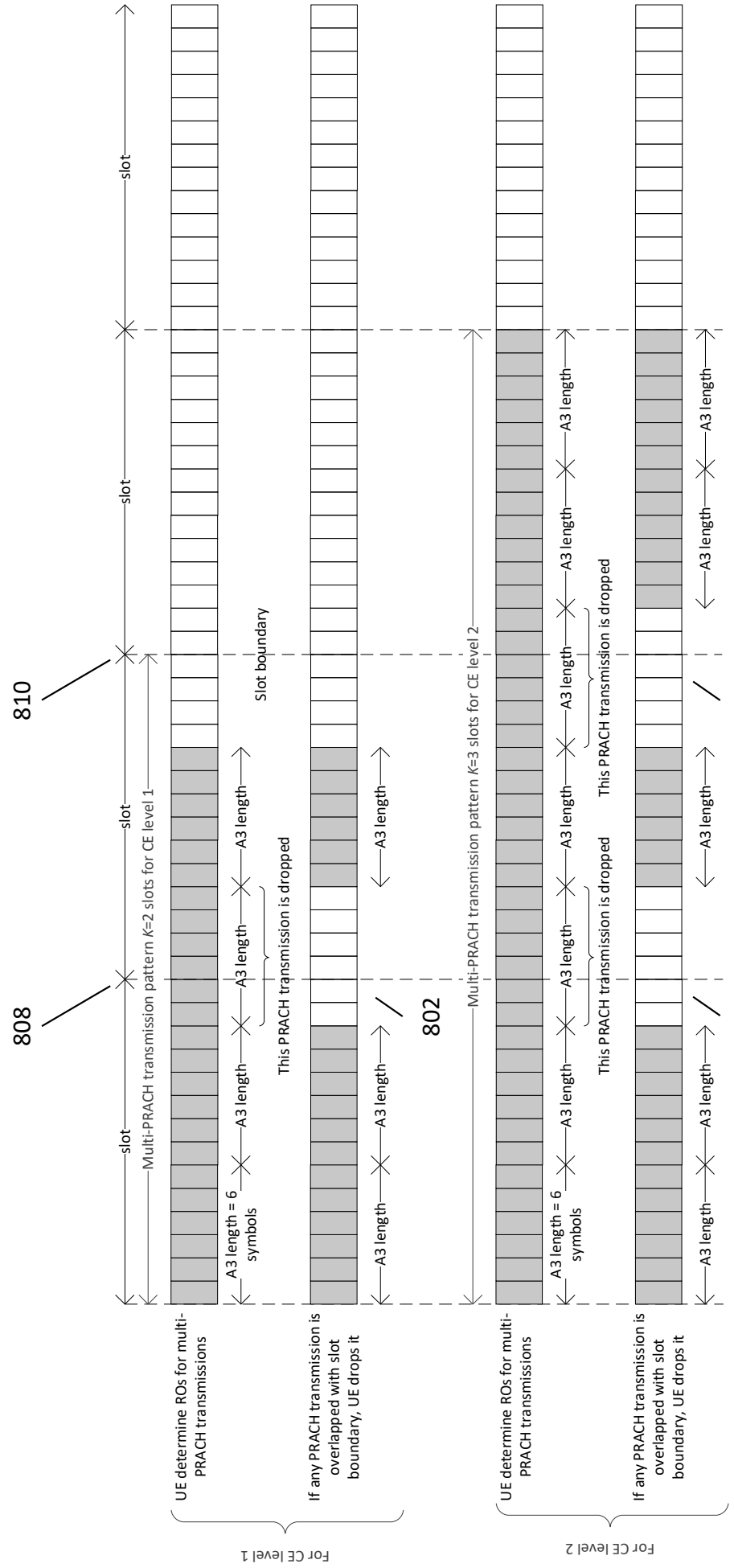

800
808
810
802
804
806
slot
slot
slot
slot
Multi-PRACH transmission pattern K=2 slots for CE level 1
Multi-PRACH transmission pattern K=3 slots for CE level 2
A3 length = 6 symbols
A3 length
Slot boundary
This PRACH transmission is dropped
UE determine ROs for multi-PRACH transmissions
If any PRACH transmission is overlapped with slot boundary, UE drops it
For CE level 1
For CE level 2

Fig. 8A

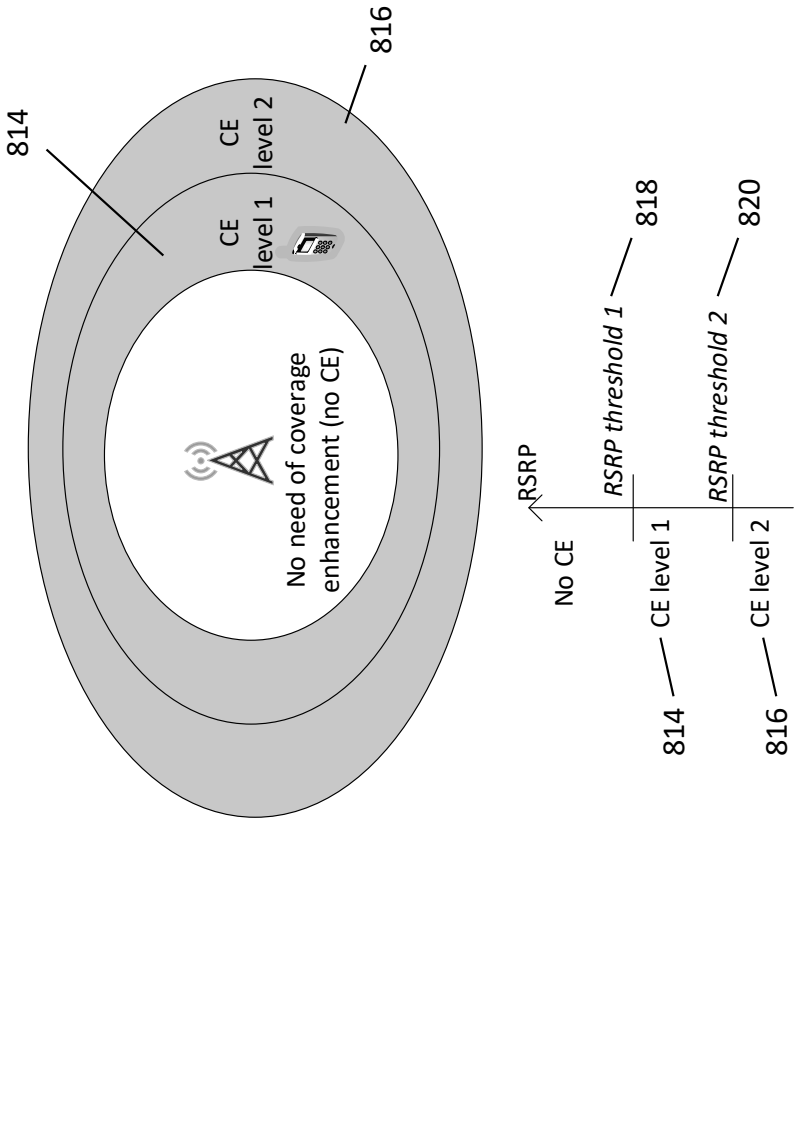

814
816
CE level 2
CE level 1
No need of coverage enhancement (no CE)
RSRP
RSRP threshold 1
818
RSRP threshold 2
820
No CE
CE level 1
CE level 2
814
816
812

Fig. 8B

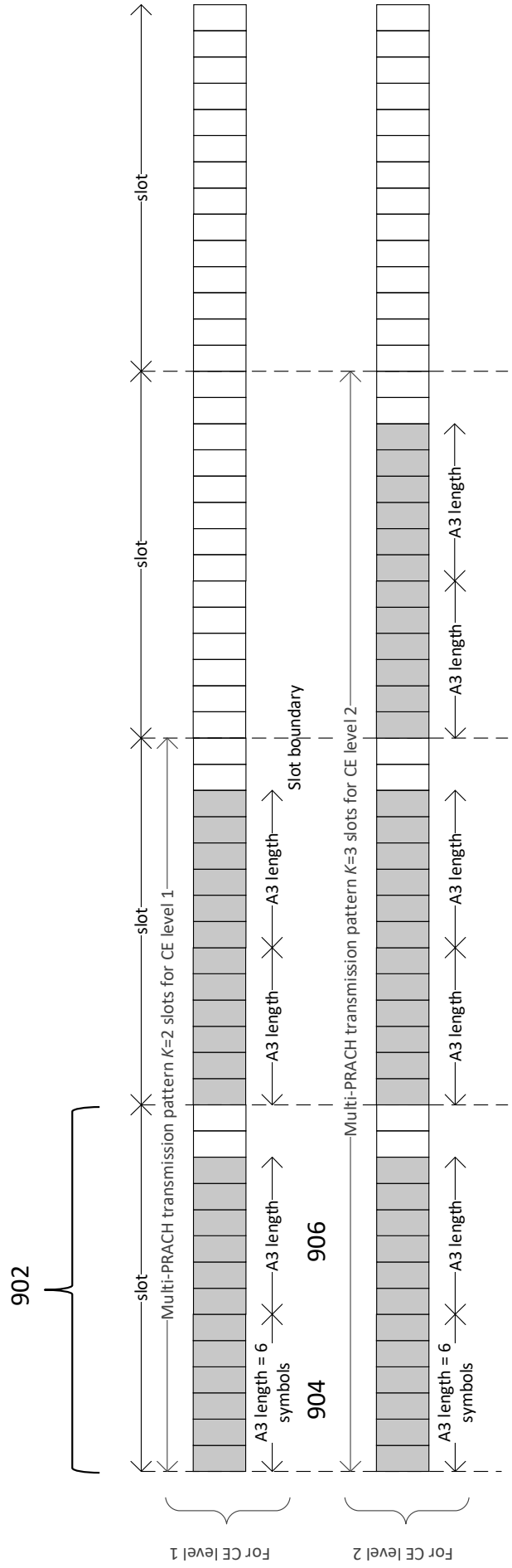

902
slot
slot
slot
Multi-PRACH transmission pattern K=2 slots for CE level 1
Multi-PRACH transmission pattern K=3 slots for CE level 2
A3 length = 6 symbols
A3 length
A3 length
A3 length
A3 length
A3 length
A3 length
A3 length
Slot boundary
904
906
For CE level 1
For CE level 2
900

Fig. 9

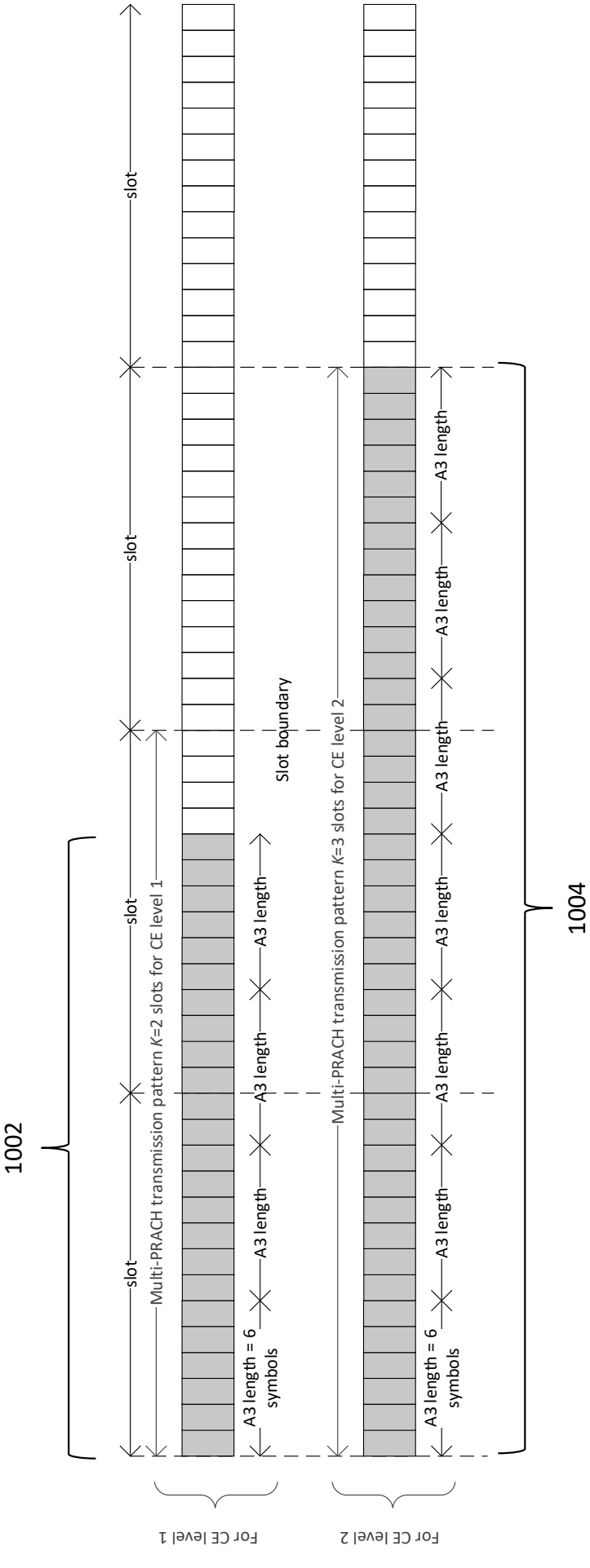

1000
1002
1004
slot
slot
slot
slot
Multi-PRACH transmission pattern K=2 slots for CE level 1
Multi-PRACH transmission pattern K=3 slots for CE level 2
Slot boundary
A3 length
A3 length
A3 length
A3 length
A3 length
A3 length
A3 length
A3 length
A3 length
A3 length = 6 symbols
A3 length = 6 symbols
For CE level 1
For CE level 2

Fig. 10

```
RACH-ConfigGeneric ::= SEQUENCE {
prach-ConfigurationIndex                INTEGER (0..255),
msg1-FDM                                ENUMERATED {one, two, four, eight},
msg1-FrequencyStart                     INTEGER (0..maxNrofPhysicalResourceBlocks-1),
zeroCorrelationZoneConfig               INTEGER(0..15),
preambleReceivedTargetPower             INTEGER (-202..-60),
preambleTransMax                        ENUMERATED {n3, n4, n5, n6, n7, n8, n10, n20, n50, n100, n200},
powerRampingStep                        ENUMERATED {dB0, dB2, dB4, dB6},
ra-ResponseWindow                       ENUMERATED {sl1, sl2, sl4, sl8, sl10, sl20, sl40, sl80},
multi-PRACH-transmission                multi-PRACH-transmission OPTIONAL,
<omitted>
…}

multi-PRACH-transmission ::=  SEQUENCE {
Preamble_Format                         ENUMERATED {A1,A2,A3,B1,B2,B3,B4,C0,C2} OPTIONAL,
RACH_slot_start                         ENUMERATED{0..maxNofPhysicalSlotIndex-1}
Start_Position_in_RACH_slot             INTEGER (0..13)          OPTIONAL,
numberOfPRACH_Repetitions               ENUMERATED {n1, n2, n3, n4, n7, n8, n12, n16} OPTIONAL,
…}
```

1104
1106
1108
1102
1100

Fig. 11A

PRACH Configuration Index	Preamble format	$n_{SFN} \bmod x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_t^{RA,slot}$, number of time domain PRACH occasions within a PRACH slot	N_{dur}^{RA}, PRACH duration	Multi-PRACH transmission	
		x	y						Subframe number for CE level 1	Subframe number for CE level 2
<omitted>										
67	A1	16	1	9	0	2	6	2	9,10	9,10,11
<omitted>										

1112

1110

Fig. 11B

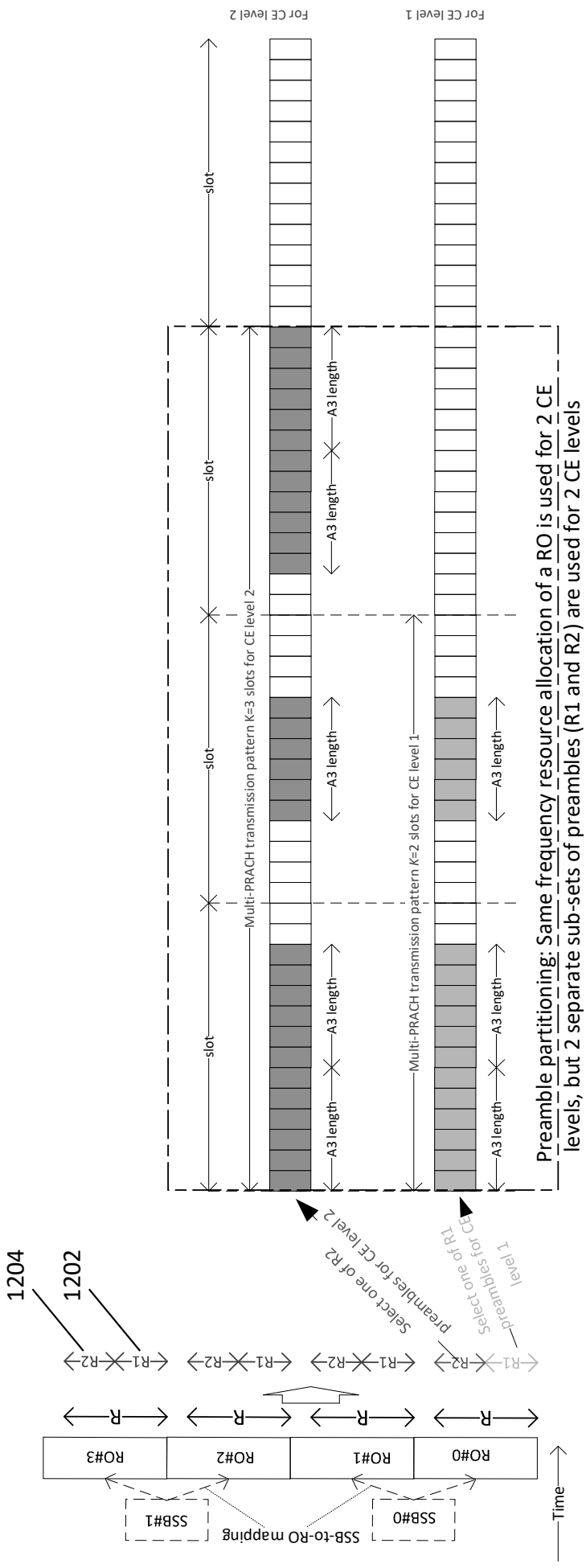
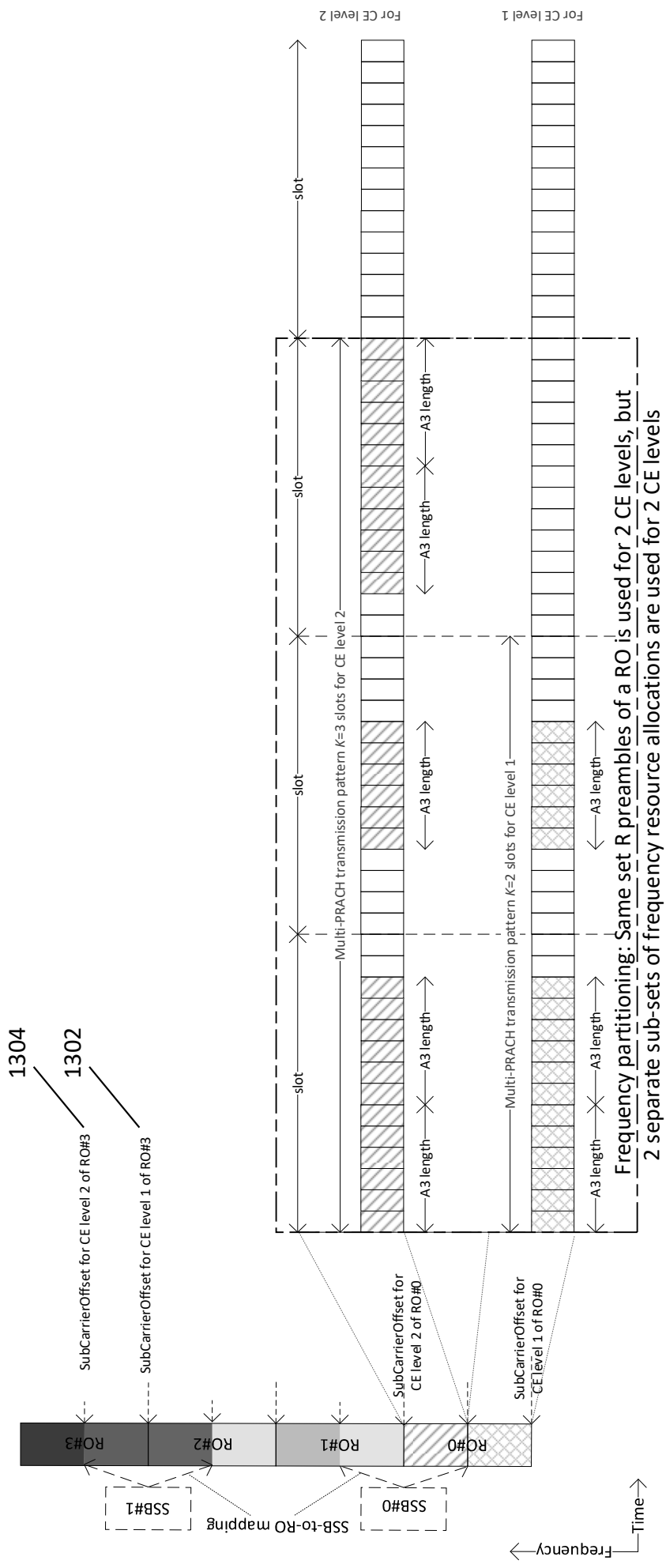

1200
1202
1204
Time
SSB#0
SSB#1
SSB-to-RO mapping
RO#0
RO#1
RO#2
RO#3
R
R1
R2
Select one of R2 preambles for CE level 2
Select one of R1 preambles for CE level 1
Preamble partitioning: Same frequency resource allocation of a RO is used for 2 CE levels, but 2 separate sub-sets of preambles (R1 and R2) are used for 2 CE levels
Multi-PRACH transmission pattern K=3 slots for CE level 2
Multi-PRACH transmission pattern K=2 slots for CE level 1
slot
A3 length
For CE level 1
For CE level 2

Fig. 12


1304
1302
SubCarrierOffset for CE level 2 of RO#3
SubCarrierOffset for CE level 1 of RO#3
RO#3
RO#2
RO#1
RO#0
SSB#1
SSB#0
SSB-to-RO mapping
SubCarrierOffset for CE level 2 of RO#0
SubCarrierOffset for CE level 1 of RO#0
Frequency
Time
For CE level 2
For CE level 1
slot
A3 length
Multi-PRACH transmission pattern K=3 slots for CE level 2
Multi-PRACH transmission pattern K=2 slots for CE level 1
Frequency partitioning: Same set R preambles of a RO is used for 2 CE levels, but
2 separate sub-sets of frequency resource allocations are used for 2 CE levels

1300

Fig. 13

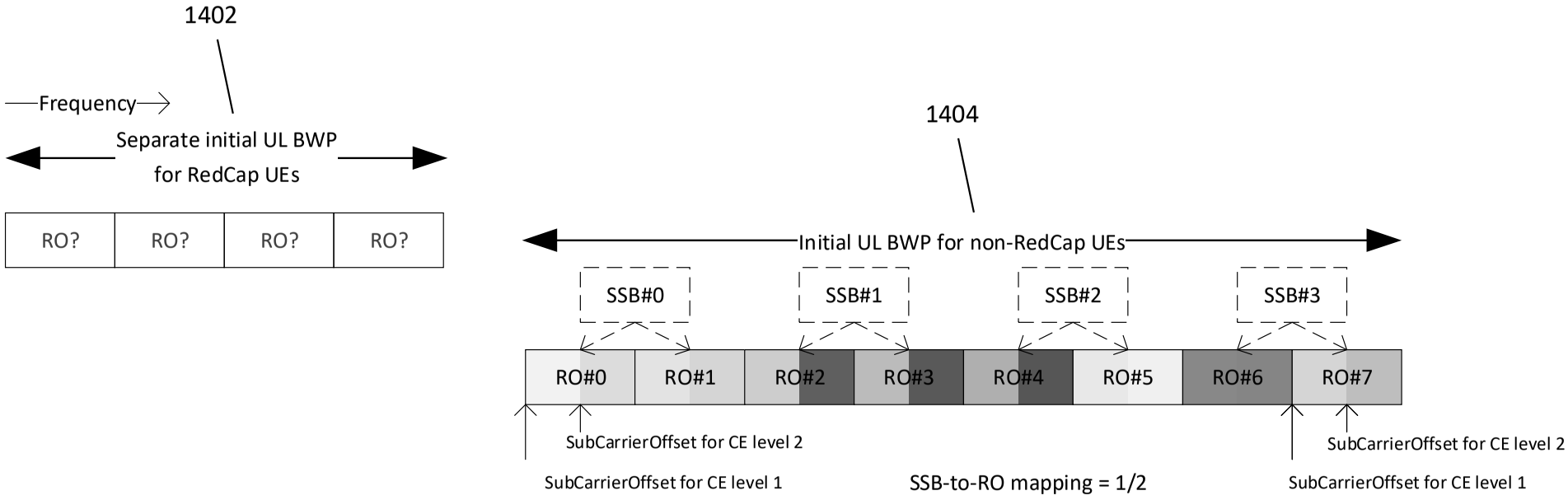

1402
Frequency
Separate initial UL BWP
for RedCap UEs
RO?
RO?
RO?
RO?
1404
Initial UL BWP for non-RedCap UEs
SSB#0
SSB#1
SSB#2
SSB#3
RO#0
RO#1
RO#2
RO#3
RO#4
RO#5
RO#6
RO#7
SubCarrierOffset for CE level 2
SubCarrierOffset for CE level 1
SSB-to-RO mapping = 1/2
SubCarrierOffset for CE level 2
SubCarrierOffset for CE level 1
1400

Fig. 14

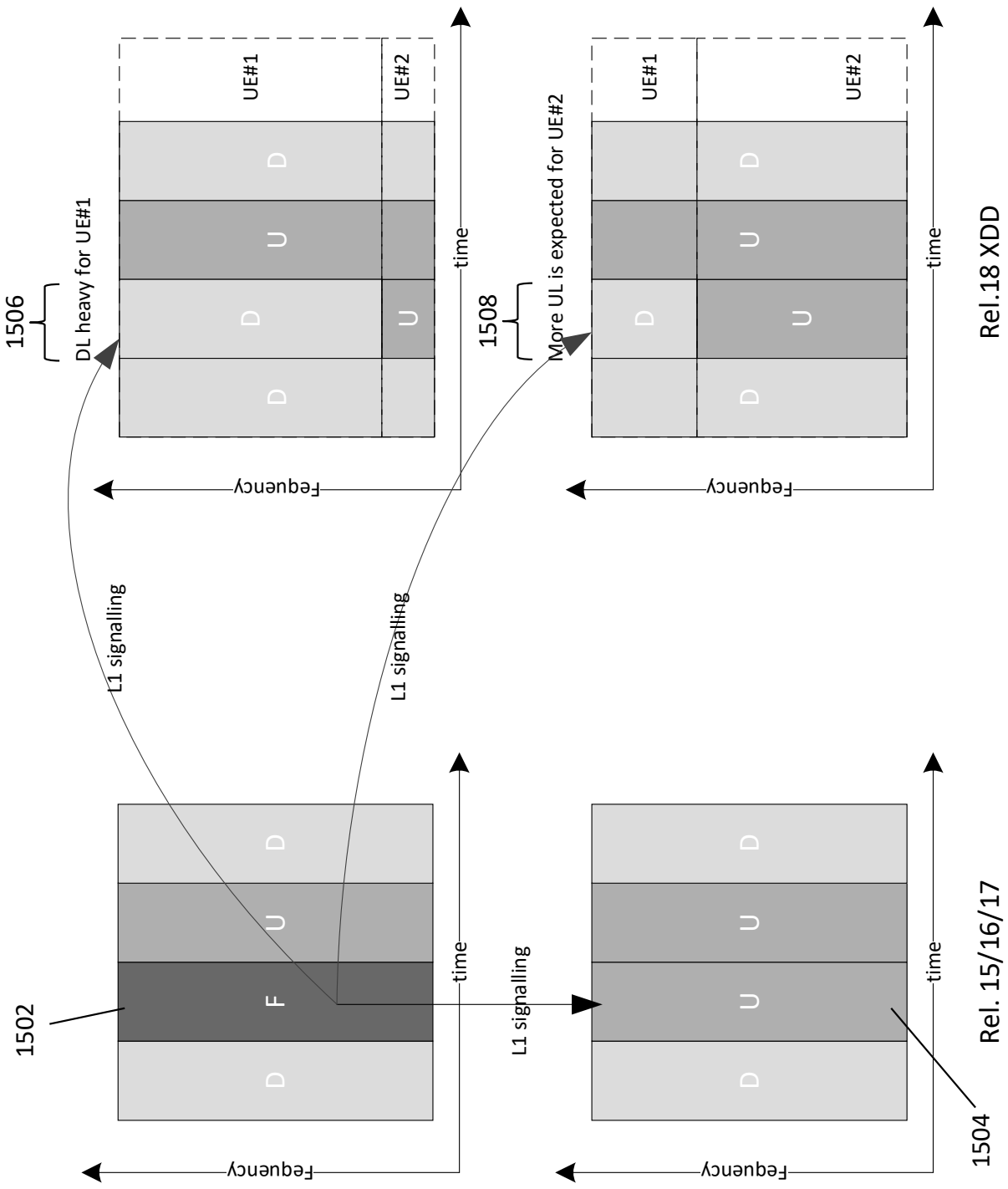

1506
DL heavy for UE#1
UE#1
UE#2
D
D
U
D
U
time
Frequency
1508
More UL is expected for UE#2
UE#1
UE#2
D
U
D
U
time
Frequency
Rel.18 XDD
L1 signalling
L1 signalling
1502
D
U
F
D
time
Frequency
L1 signalling
D
U
U
D
time
Frequency
Rel. 15/16/17
1504
1500

Fig. 15

1604
BW_XDD
fperRO_XDD
D
U
D
D
D
0 1 2 3 4 5 6 7
# # # # # # # #
R R R R R R R R
time
Fequency
1602
iBWP_nonXDD
fperRO_nonXDD
D
U
D
D
D
0 1 2 3 4 5 6 7
# # # # # # # #
R R R R R R R R
time
Fequency
1600

Fig. 16

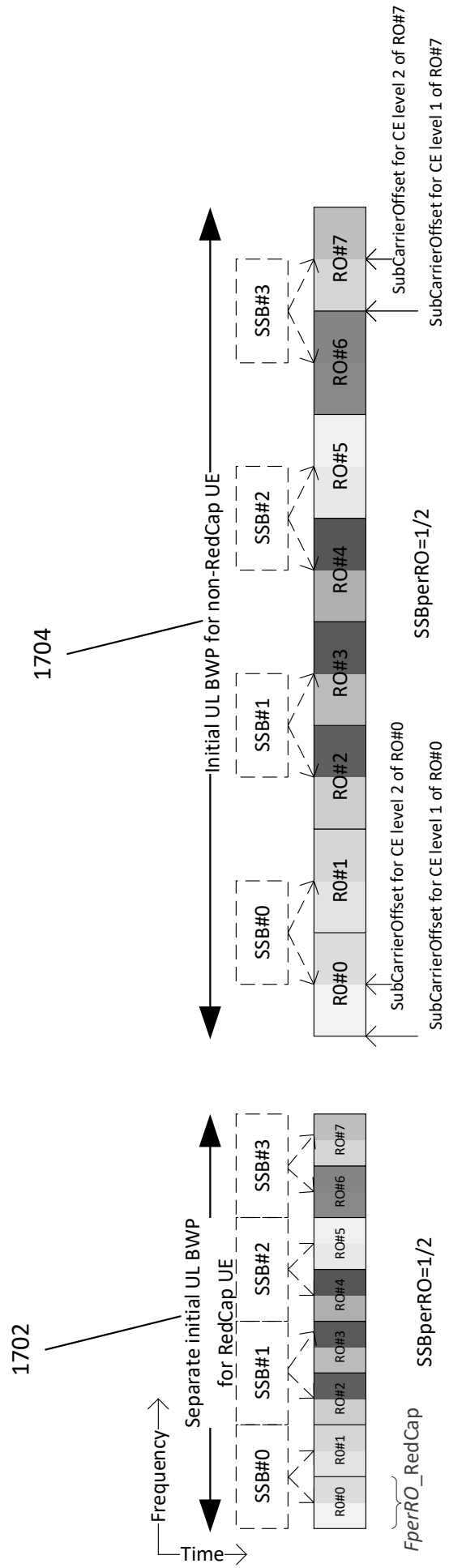

1700
1702
1704
Separate initial UL BWP
for RedCap UE
Initial UL BWP for non-RedCap UE
Frequency
Time
SSB#0
SSB#1
SSB#2
SSB#3
RO#0
RO#1
RO#2
RO#3
RO#4
RO#5
RO#6
RO#7
SSBperRO=1/2
SSBperRO=1/2
SubCarrierOffset for CE level 1 of RO#0
SubCarrierOffset for CE level 2 of RO#0
SubCarrierOffset for CE level 1 of RO#7
SubCarrierOffset for CE level 2 of RO#7
FperRO_RedCap
FperRO_nonRedCap

Fig. 17

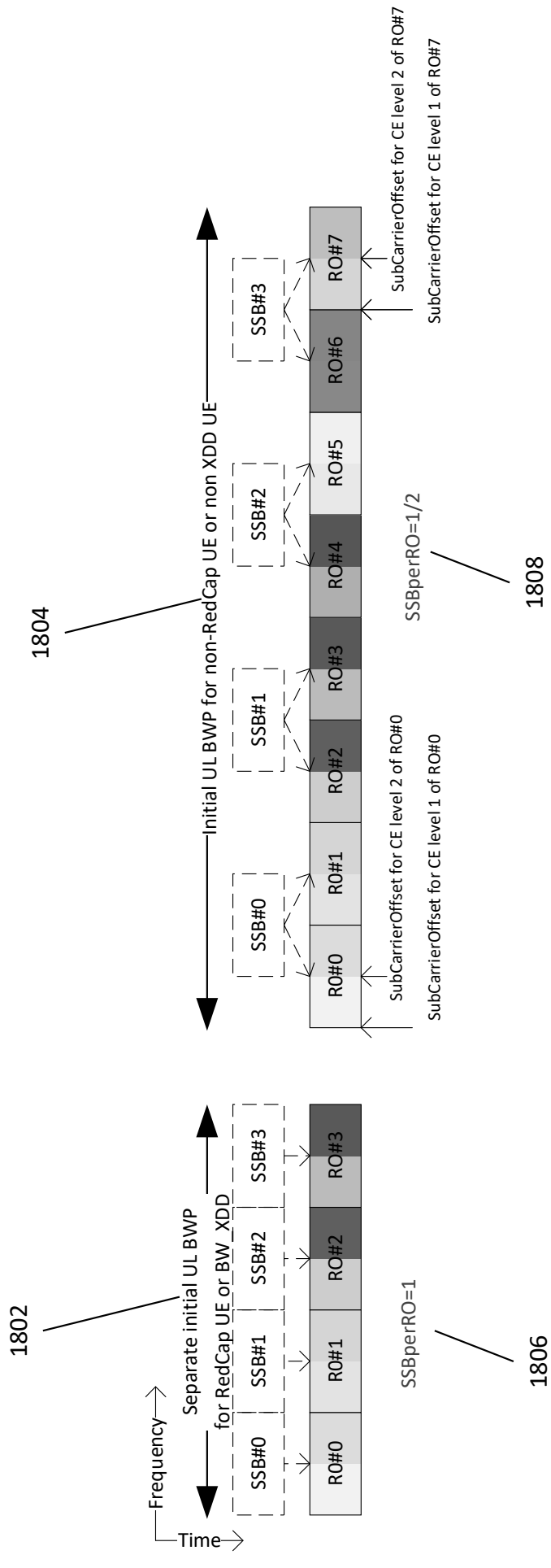

1800
1802
Separate initial UL BWP
for RedCap UE or BW_XDD
SSB#0
SSB#1
SSB#2
SSB#3
R0#0
R0#1
R0#2
R0#3
Frequency
Time
SSBperRO=1
1806
1804
Initial UL BWP for non-RedCap UE or non XDD UE
SSB#0
SSB#1
SSB#2
SSB#3
R0#0
R0#1
R0#2
R0#3
R0#4
R0#5
R0#6
R0#7
SubCarrierOffset for CE level 1 of RO#0
SubCarrierOffset for CE level 2 of RO#0
SubCarrierOffset for CE level 1 of RO#7
SubCarrierOffset for CE level 2 of RO#7
SSBperRO=1/2
1808

Fig. 18

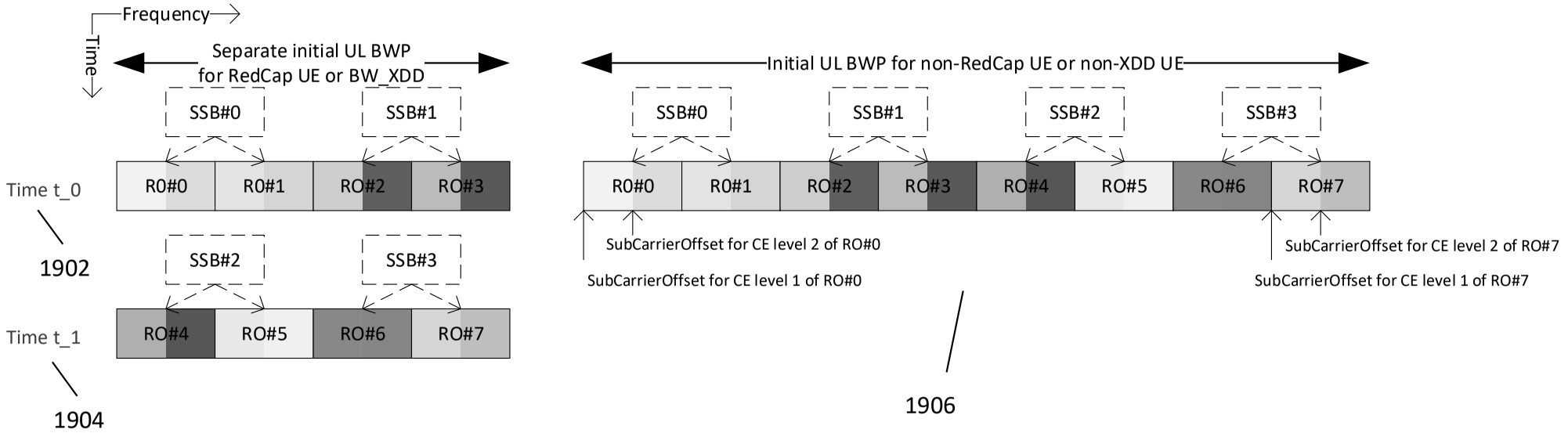

Frequency
Time
Separate initial UL BWP
for RedCap UE or BW_XDD
SSB#0
SSB#1
SSB#2
SSB#3
Time t_0
Time t_1
R0#0
R0#1
RO#2
RO#3
RO#4
RO#5
RO#6
RO#7
1902
1904
Initial UL BWP for non-RedCap UE or non-XDD UE
SubCarrierOffset for CE level 2 of RO#0
SubCarrierOffset for CE level 1 of RO#0
SubCarrierOffset for CE level 2 of RO#7
SubCarrierOffset for CE level 1 of RO#7
1906
1900

Fig. 19A

BW_XDD
FperRO_XDD
1910
1912
1914
1916
1908
t_0
t_1
time
Frequency
D
U
D
FperRO_nonXDD
iBWP_nonXDD
time
Frequency

Fig. 19B

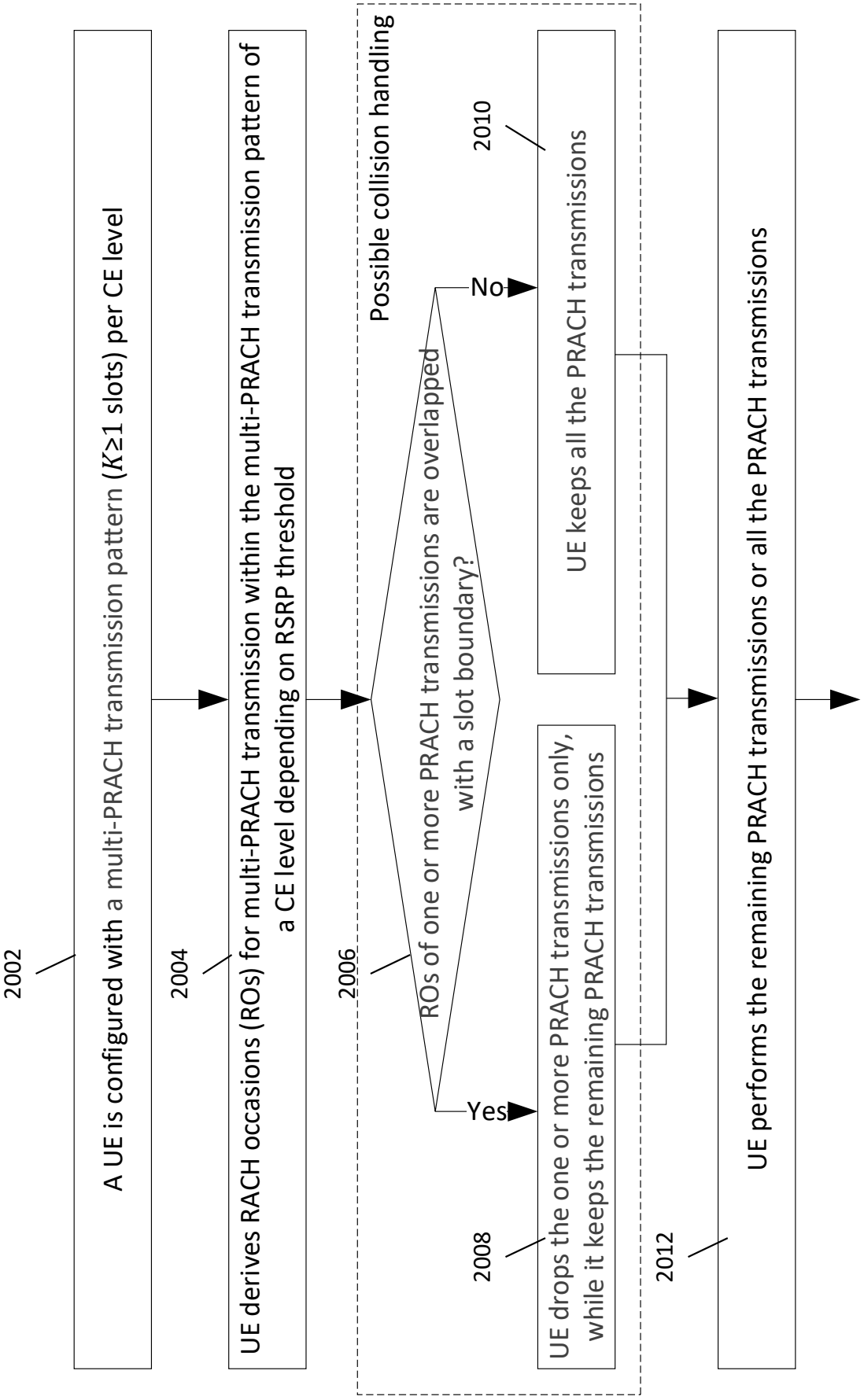

2002
A UE is configured with a multi-PRACH transmission pattern ($K \geq 1$ slots) per CE level
2004
UE derives RACH occasions (ROs) for multi-PRACH transmission within the multi-PRACH transmission pattern of a CE level depending on RSRP threshold
2006
Possible collision handling
ROs of one or more PRACH transmissions are overlapped with a slot boundary?
No
Yes
2010
UE keeps all the PRACH transmissions
2008
UE drops the one or more PRACH transmissions only, while it keeps the remaining PRACH transmissions
2012
UE performs the remaining PRACH transmissions or all the PRACH transmissions
2000

Fig. 20A

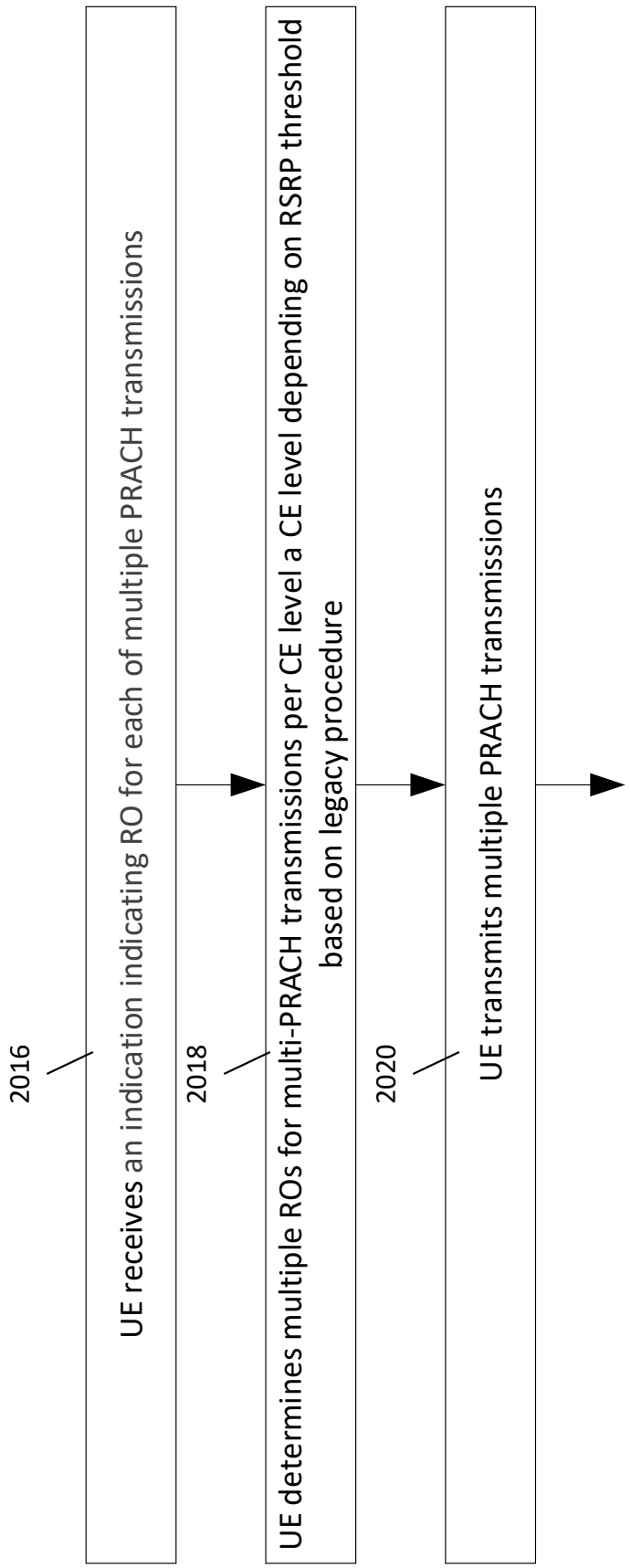

2016
UE receives an indication indicating RO for each of multiple PRACH transmissions
2018
UE determines multiple ROs for multi-PRACH transmissions per CE level a CE level depending on RSRP threshold based on legacy procedure
2020
UE transmits multiple PRACH transmissions
2014

Fig. 20B

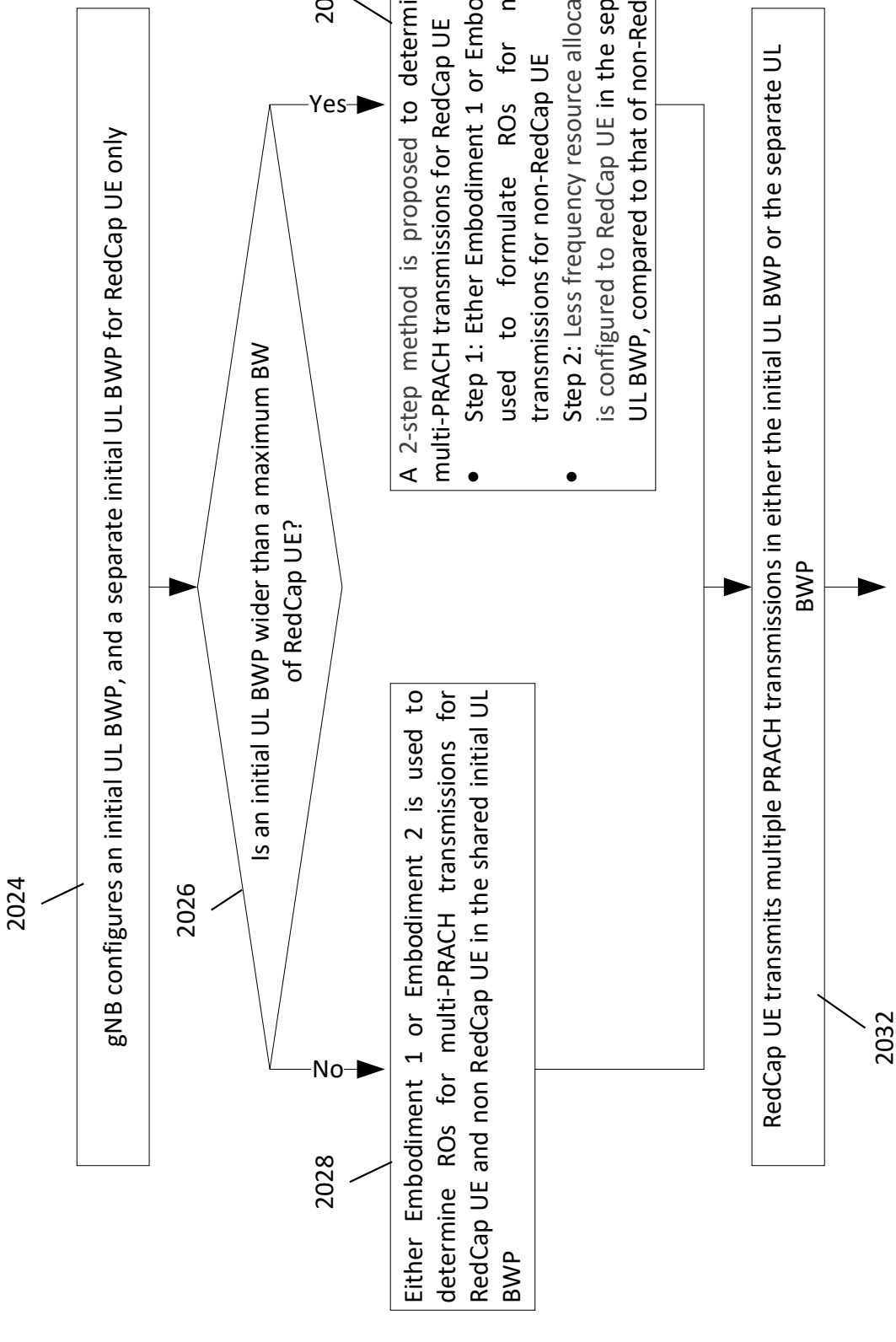

2024
gNB configures an initial UL BWP, and a separate initial UL BWP for RedCap UE only
2026
Is an initial UL BWP wider than a maximum BW of RedCap UE?
Yes
No
2030
A 2-step method is proposed to determine ROs for multi-PRACH transmissions for RedCap UE
Step 1: Ether Embodiment 1 or Embodiment 2 is used to formulate ROs for multi-PRACH transmissions for non-RedCap UE
Step 2: Less frequency resource allocation per RO is configured to RedCap UE in the separate initial UL BWP, compared to that of non-RedCap UE
2028
Either Embodiment 1 or Embodiment 2 is used to determine ROs for multi-PRACH transmissions for RedCap UE and non RedCap UE in the shared initial UL BWP
2032
RedCap UE transmits multiple PRACH transmissions in either the initial UL BWP or the separate UL BWP
2022

Fig. 20C

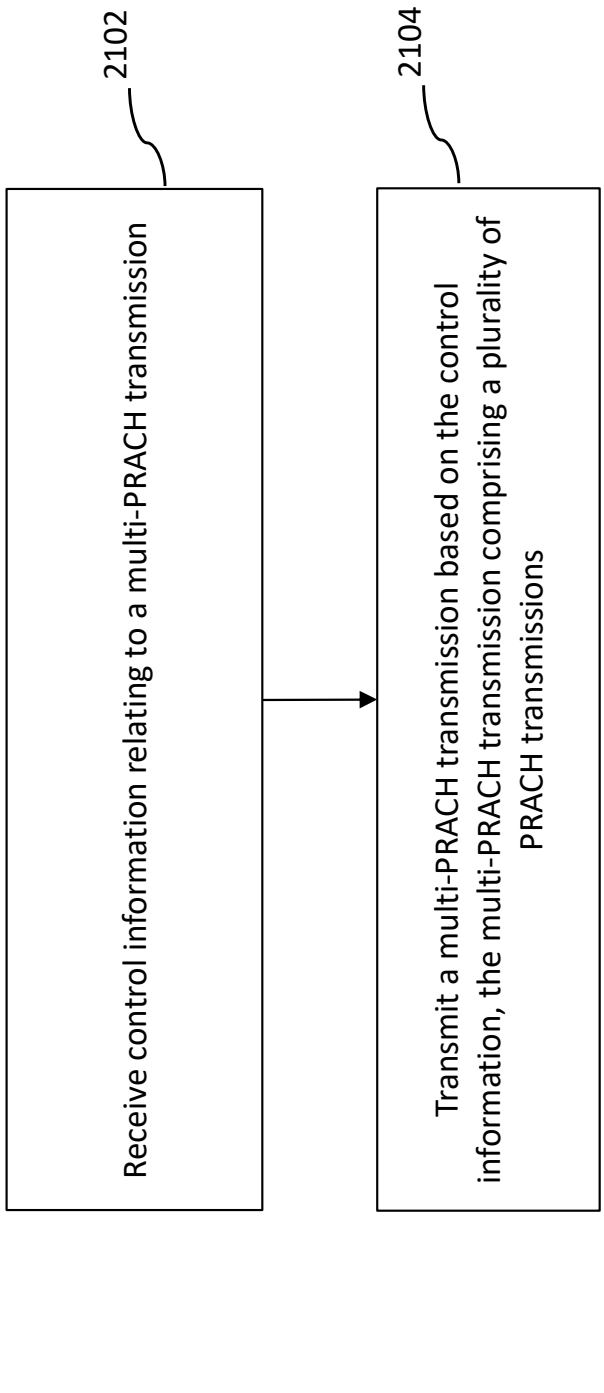

2102
2104
Receive control information relating to a multi-PRACH transmission
Transmit a multi-PRACH transmission based on the control information, the multi-PRACH transmission comprising a plurality of PRACH transmissions
2100

Fig. 21

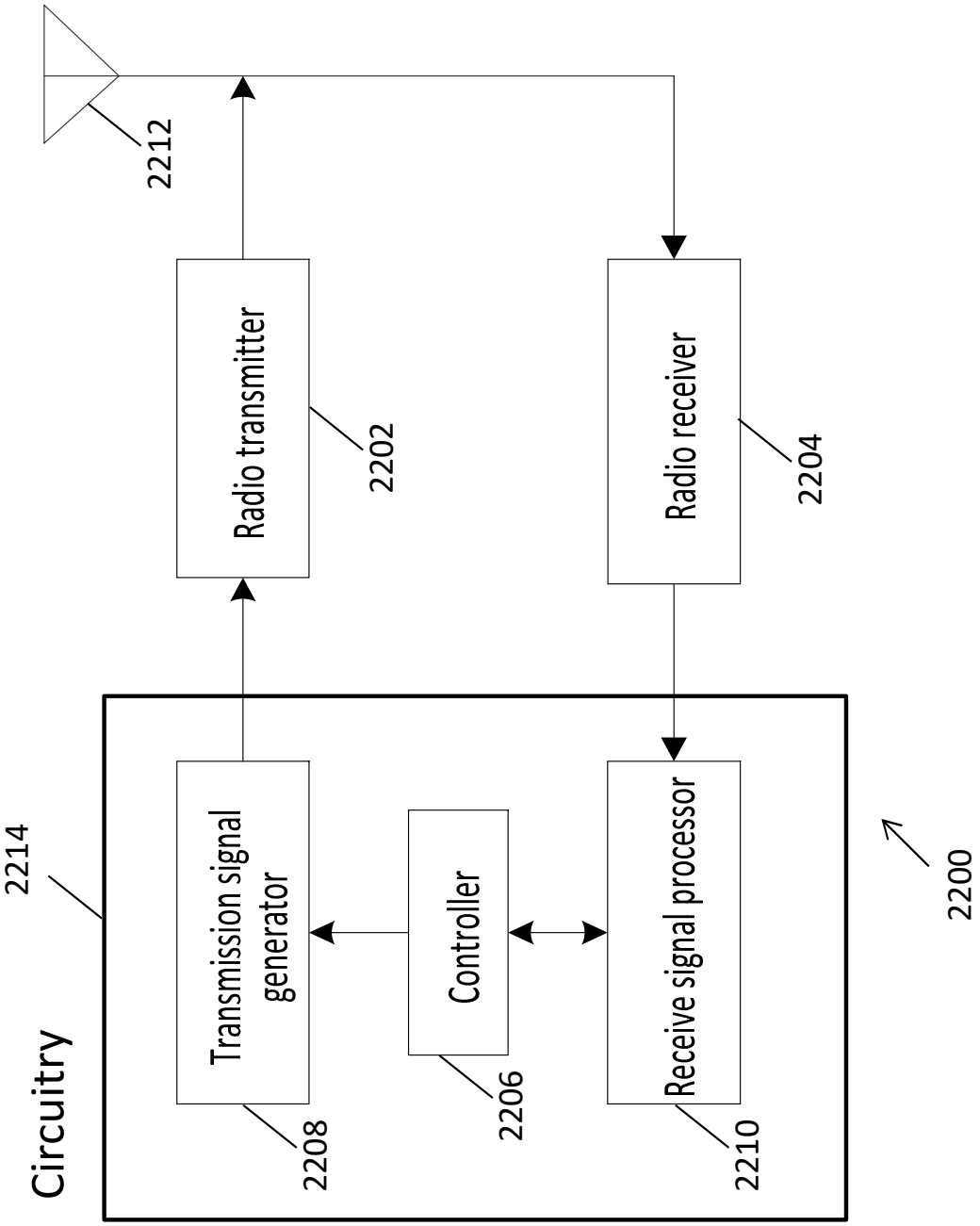

2212
Radio transmitter
2202
Radio receiver
2204
2214
Circuitry
Transmission signal generator
2208
Controller
2206
Receive signal processor
2210
2200

Fig. 22