



5G NR: Initial Access

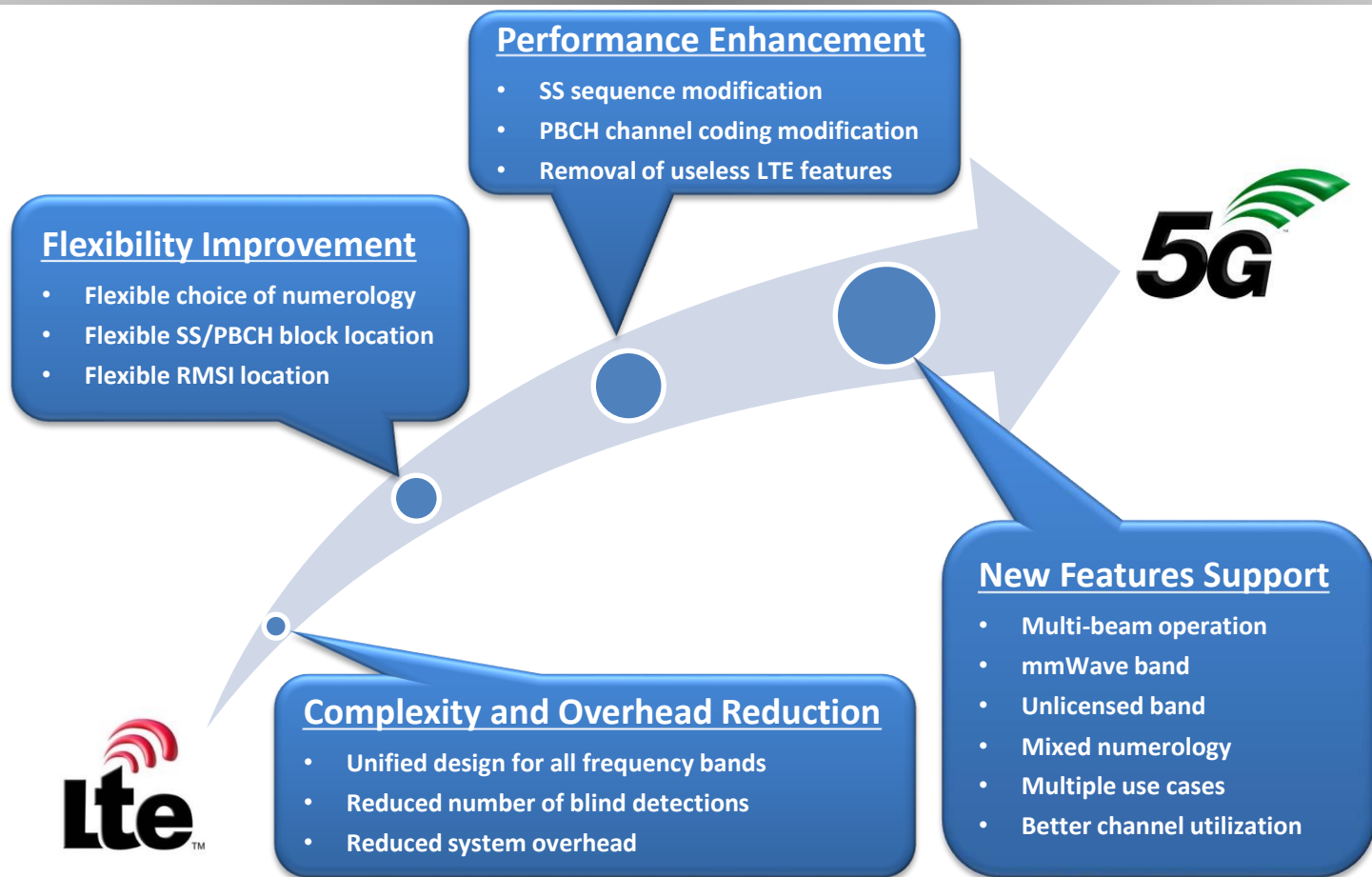
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January 4, 2018

1. Synchronization signals
2. PBCH
3. RMSI/OSI/Paging
4. Random Access

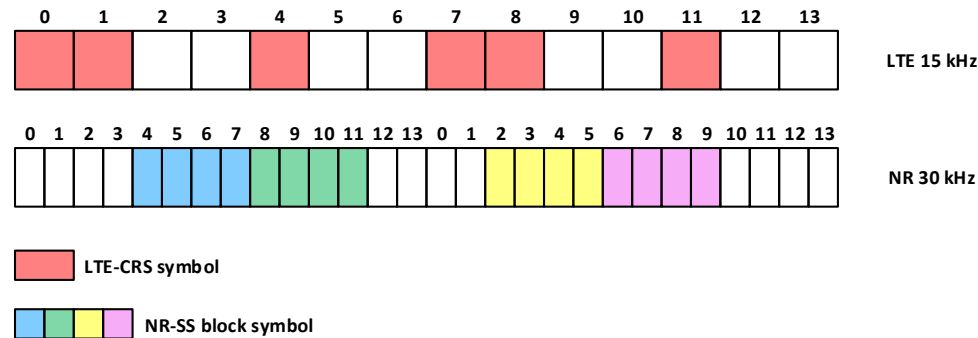
Synchronization signals and PBCH

Overview of Design Principles



■ Synchronization Signals (SS) and Physical Broadcast Channel (PBCH)

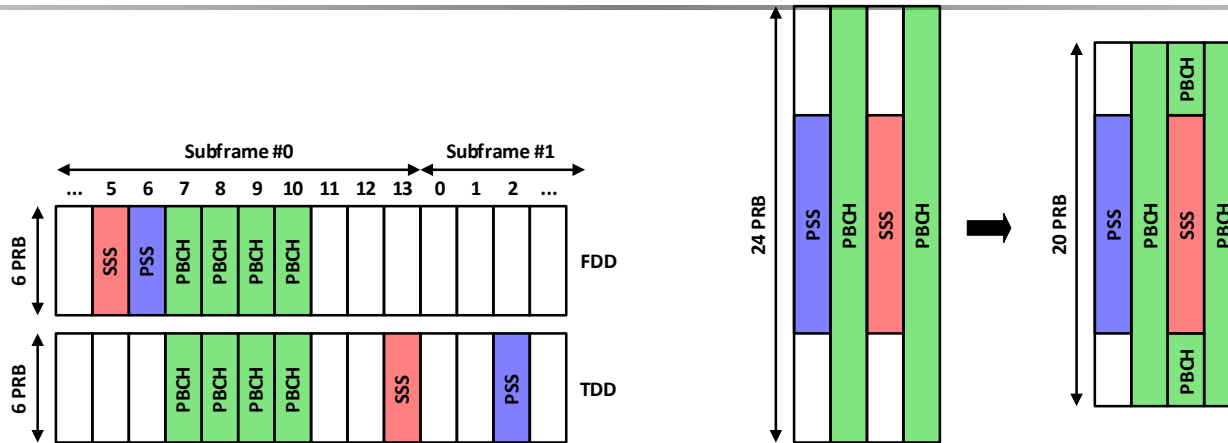
- Single subcarrier spacing per frequency band with following exceptions:
 - 15 kHz and 30 kHz for band n5 and n66; 120 kHz and 240 kHz for band n257 and n260
 - Band n5 and n66 are the LTE/NR DL coexistence band
 - Some operators have limited min channel BW such that 15 kHz is the only choice
 - Some operators want to support NR/LTE coexistence and 30 kHz is the only choice



■ RMSI, Broadcast OSI, and Paging: Indicated in PBCH

- For sub6 GHz, either 15 kHz or 30 kHz; for over6 GHz, either 60 kHz or 120 kHz

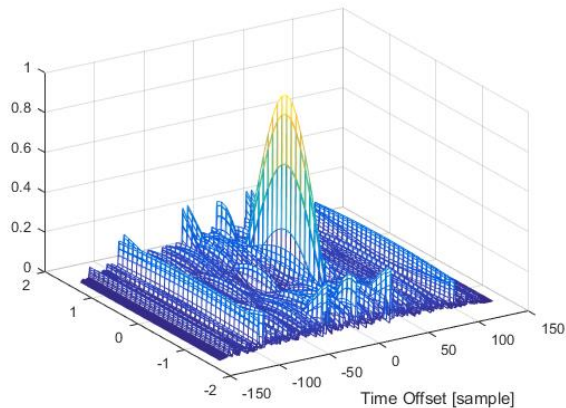
SS/PBCH Block: Structure



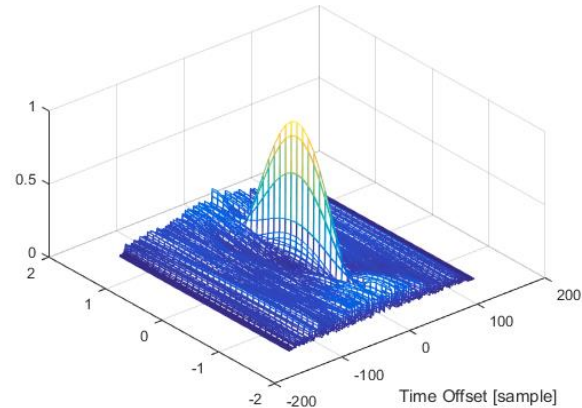
	LTE		NR
	Single	# SS/PBCH blocks	Multiple (per band)
	6 PRBs	SS/PBCH block BW	20 PRBs
	1	# Symbol for PSS	1
	1	# Symbol for SSS	1
	4 for SF #0 and 0 for SF #5	# Symbol for PBCH	2 + 1 multiplexed with SSS
	72	# REs for PSS	144 + 96 empty
	72	# REs for SSS	144
	240	# REs for PBCH	432
	48	# REs for RS	144
	Different	TDD vs FDD	Unified

SS/PBCH Block: PSS sequence

LTE		NR
ZC-sequence	Sequence Type	M-sequence
63	Sequence Length	127
3	# Sequences	3
3 root indices of ZC-sequences	How to Represent Cell ID Info	3 cyclic shifts of single M-sequence
No modulation	Modulation	BPSK
DC subcarrier is truncated (62 REs)	Mapping to REs	DC subcarrier is not truncated (127 REs)



Frequency Offset [subcarrier]

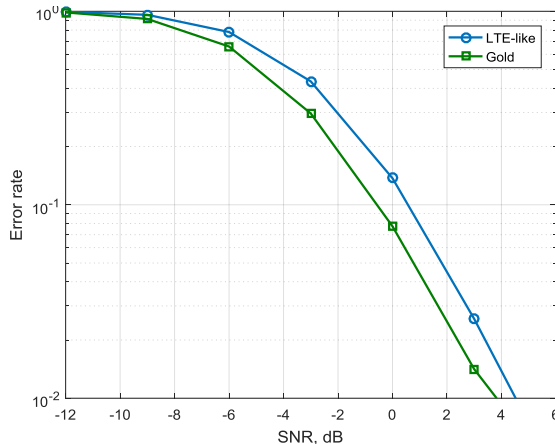


Frequency Offset [subcarrier]

Comparison of cross-correlation of ZC-sequence (left) and M-sequence (right) based PSS design

SS/PBCH Block: SSS sequence

LTE		NR
M-sequence	Sequence Type	Gold-sequence (XOR of 2 M-sequences)
31	Sequence Length	127
Cell ID and half radio frame timing (504*2)	Carried Info (# Sequences)	Cell ID only (1008)
interleaved two M-sequences, where each M-sequence carries part of the cell ID info, and a further scrambling carries the half radio frame timing	Construction Method	each of the M-sequences carries part of the cell ID info
BPSK	Modulation	BPSK
DC subcarrier is truncated (62 REs)	Mapping to REs	DC subcarrier is not truncated (127 REs)



Comparison of cell ID detection performance between LTE-like SSS and Gold-sequence based SSS

SS/PBCH Block: PBCH contents



LTE		NR
8 LSBs of SFN	SFN	10 bits of SFN
3 bits	Channel bandwidth	
3 bits	PHICH configuration	
	Half radio frame timing	1 bit
	MSB of SS/PBCH block index	3 bits (>6 GHz)
	Numerology for RMSI and broadcast OSI	1 bit
	RMSI and its CORESET configuration	8 bits
	First DMRS position configuration for PDSCH	1 bit
	RAN4's input (PRB grid offset)	4 bits +1 bit (<6 GHz)
	RAN2's input (quick identification of UE camping)	2 bits + 1 bit reserved
10 bits	Reserved	1 bit (>6GHz), 2 bits (<6GHz)
16 bits	CRC	24 bits
40 bits	Total payload size	56 bits

SS/PBCH Block: PBCH DMRS and Transmission



■ DMRS of PBCH

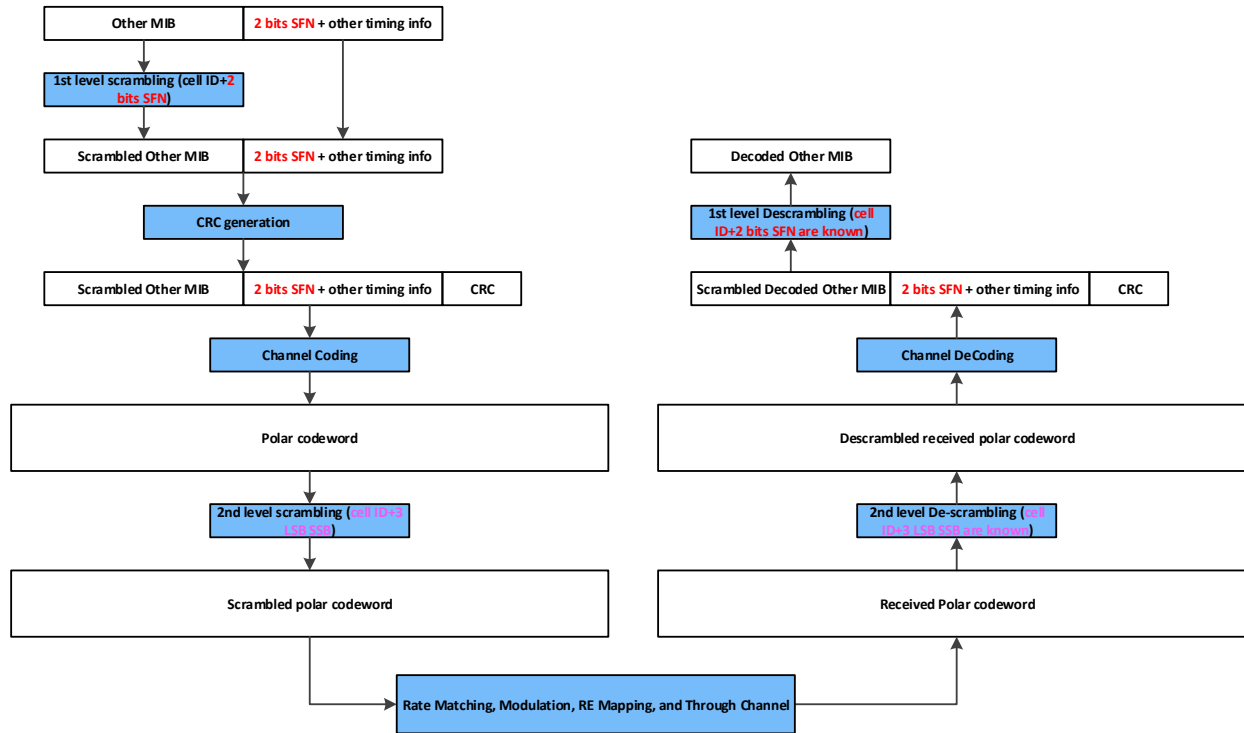
- Carries timing info to obtain the info without reading PBCH
 - 3 LSBs of SS/PBCH block index for over3 GHz;
 - 2 bits of SS/PBCH block index + half radio frame timing for sub3 GHz
- DMRS sequence
 - Cross-correlation property is essential to carry timing info
 - PN-sequence with initial condition $2^{11} \cdot (I_t+1) \cdot ([N_{ID}/4] + 1) + 2^6 \cdot (I_t+1) + \text{mod}(N_{ID}, 4)$

■ PBCH Transmission

	LTE		NR
	TBCC	Channel coding	Polar codes, same as PDCCH
	QPSK	Modulation	QPSK
	Freq-first, time-second	RE Mapping	Freq-first, time-second
	1, 2, and 4 ports, and UE needs to blind detect in CRC mask code	Transmission scheme	1 port, and same as SSS
	40 ms	TTI	80 ms

SS/PBCH Block: PBCH Scrambling

- **1st level scrambling:** before channel coding to avoid blind detection in single-shot
- **2nd level scrambling:** after channel coding to avoid codeword interference



■ Periodicity

- In initial cell search, UE assumes a default periodicity as 20 ms
- In IDLE/CONNECTED and non-standalone cases, the periodicity can be indicated by network from {5, 10, 20, 40, 80, 160} ms

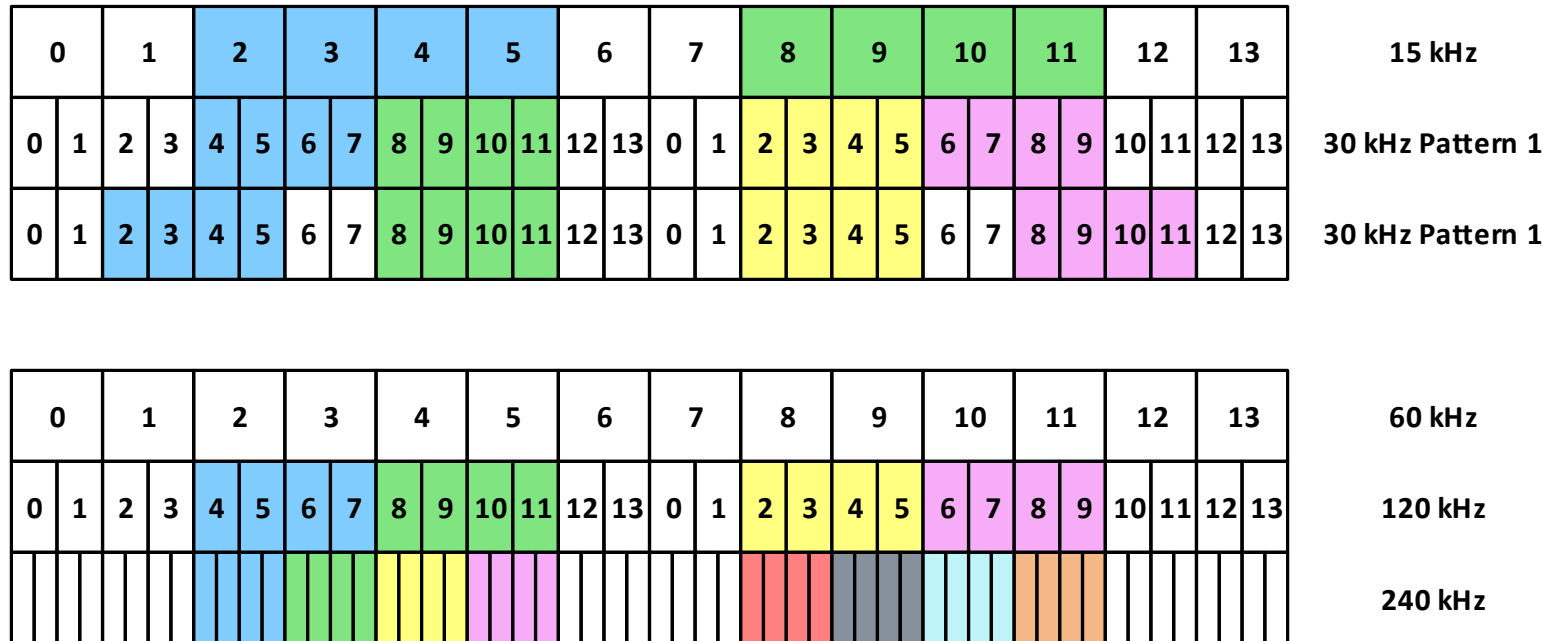
■ Multi-beam Operation

- SS/PBCH blocks within SS burst set is confined to a 5 ms window
- Within this 5 ms window, number of possible candidate SS/PBCH block locations is L
 - For sub3 GHz, L is 4
 - For 3 GHz to 6 GHz, L is 8
 - For over6 GHz, L is 64

SS/PBCH block: Time Domain Mapping

- **Nominal SS/PBCH Block Location within Slot**

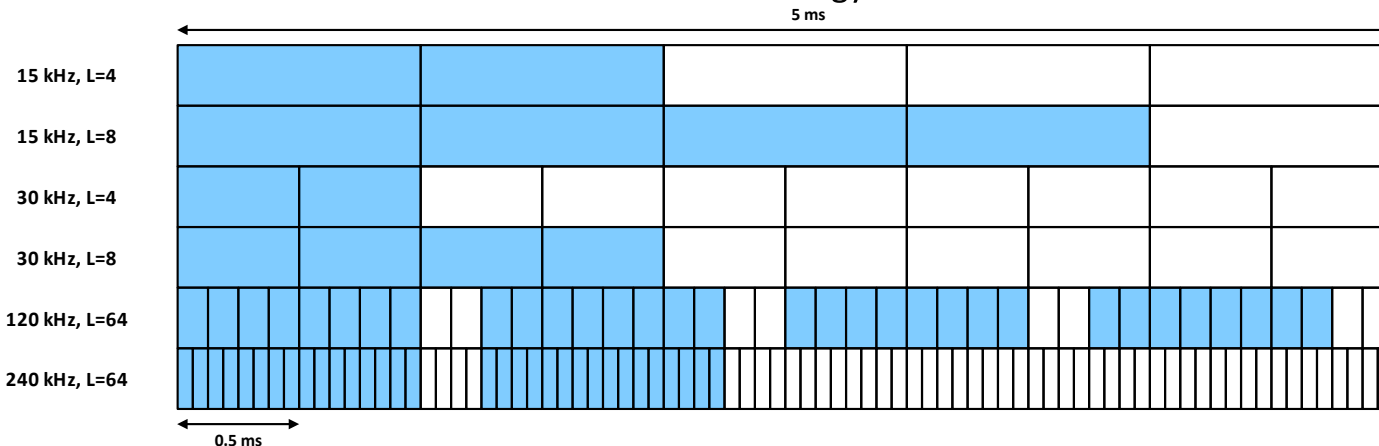
- Design principle: single pattern per band
- Design considerations: avoiding collision with control channels, mixed numerology, URLLC



SS/PBCH block: Time Domain Mapping

Slot (Containing SS/PBCH blocks) Location within 5 ms

- Design considerations:
 - As compact as possible with URLLC consideration
 - Avoid collision with control channels in mixed numerology case



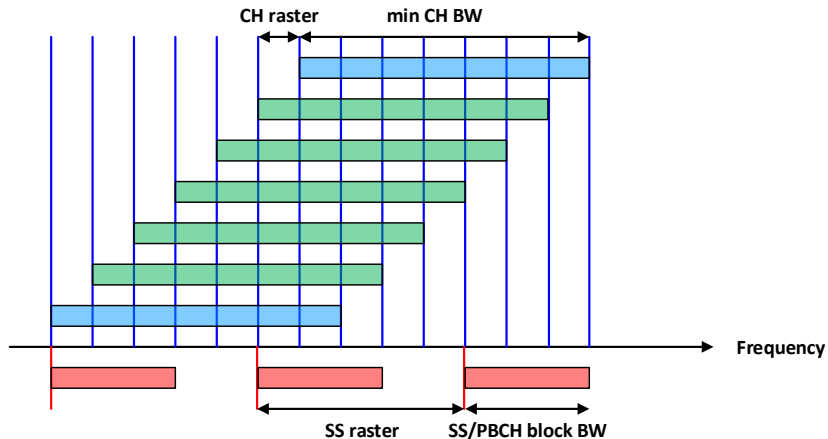
Actually Transmitted SS/PBCH Block Indication

- UE-specific RRC signaling with full bitmap
- RMSI indication with Group-Bitmap(8 bits) + Bitmap in Group (8 bits)

SS/PBCH block: Frequency Domain Mapping

■ Sync Raster and Channel Raster

- RAN1: SS raster is sparser than CH raster to reduce searching complexity
- RAN4: within very min CH BW, there exists only one complete SS/PBCH block
 - $SS \text{ raster} = \min \text{ CH BW} - SS/PBCH \text{ block BW} + \text{CH raster}$

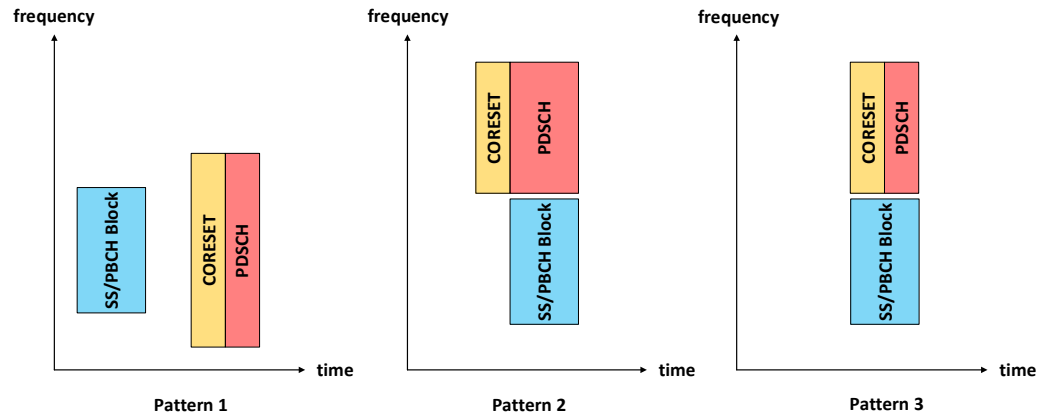


■ Wideband SS/PBCH Block

- Multiple SS/PBCH blocks on a wideband carrier
- A cell is associated with a single SS/PBCH block

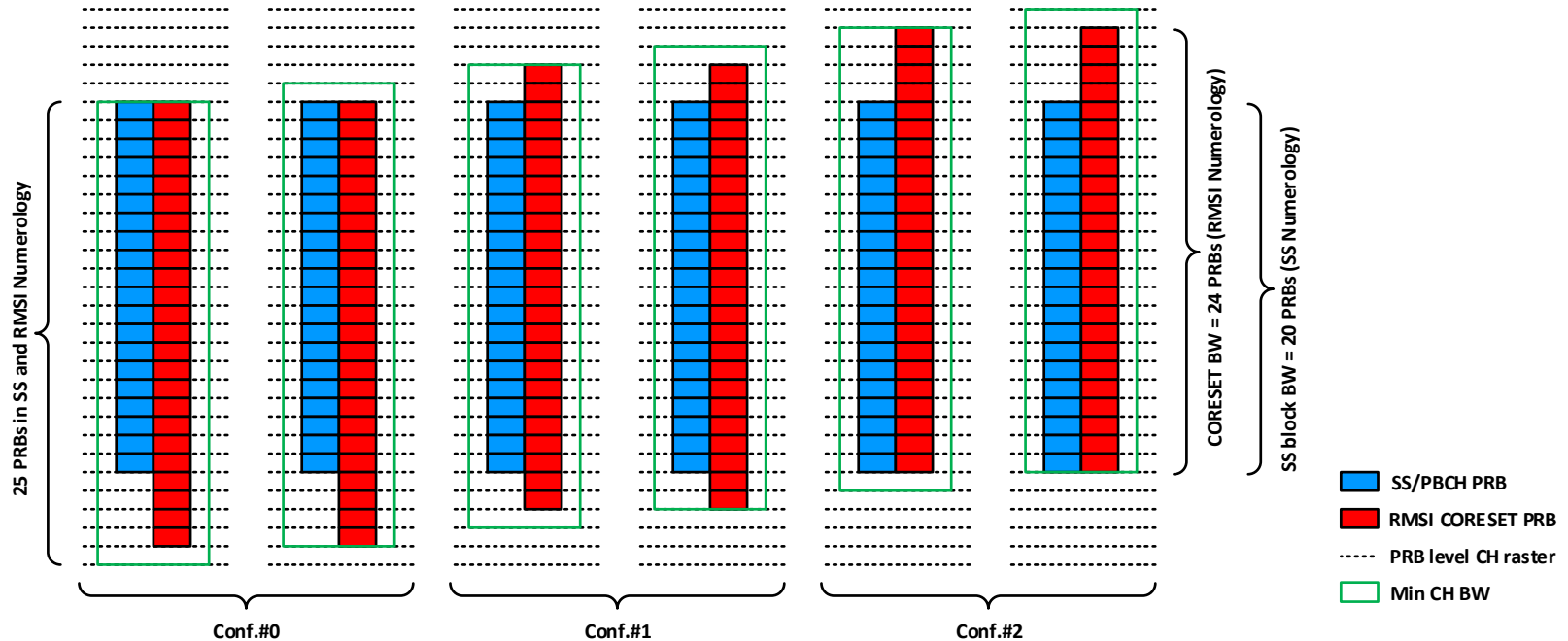
■ RMSI and CORESET configuration in PBCH

- 1 bit for numerology
- 4 bits for joint coding of multiplexing pattern, CORESET BW, number of symbols for CORESET, and PRB-level frequency offset (RE-level offset in separate bits)
- 4 bits for joint coding of time-domain group offset, number of search spaces per slot, and starting symbol location(s)
- Periodicity of monitor window: 20 ms
- Monitor window duration: 2 slots for Pattern 1 and 1 slot for Pattern 2&3



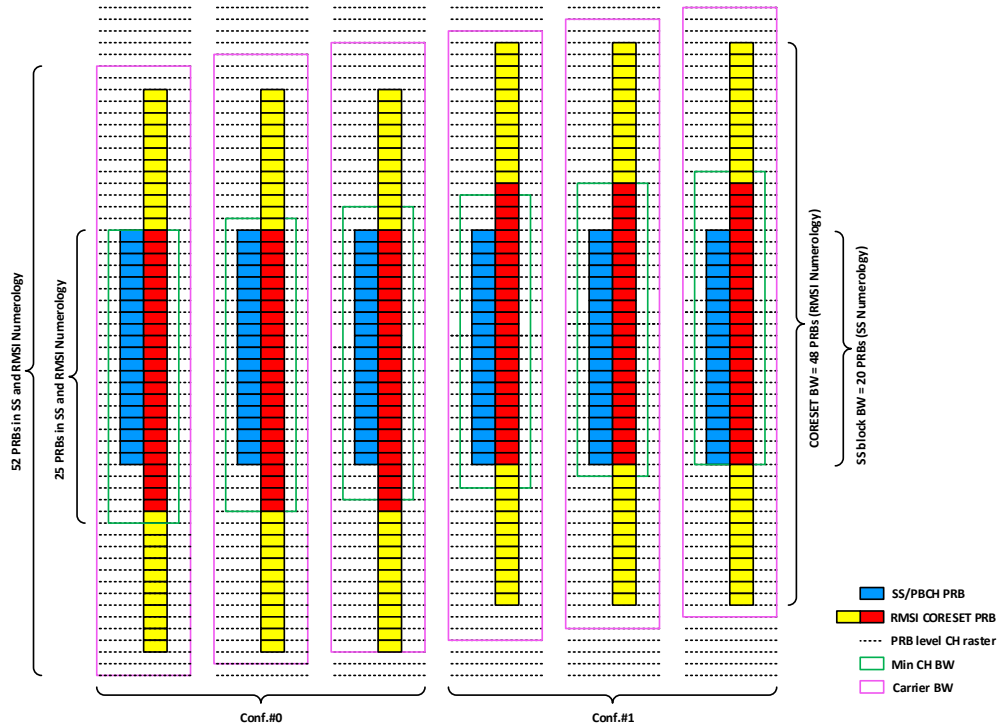
PRB-level Frequency Offset Configuration

- Determined by min CH BW, CORESET BW, and combination of SS/PBCH and RMSI numerology
- Example1: 15 kHz SS SCS, 15 kHz RMSI SCS, 5 MHz BW (min CH BW) = 25 PRBs, and CORESET BW = 24 PRBs. 3 Configurations are sufficient.



PRB-level Frequency Offset Configuration

- Example2: 15 kHz SS SCS, 15 kHz RMSI SCS, 10 MHz BW = 52 PRBs, and CORESET BW = 48 PRBs. 2 Configurations are sufficient.



- **No New Mechanism in Rel-15**

- SS/PBCH block QCLed with broadcast OSI and paging DCI/messages
- CORESET configuration same as RMSI CORESET as indicated in PBCH

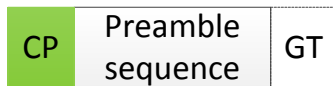
Random Access

Preamble format



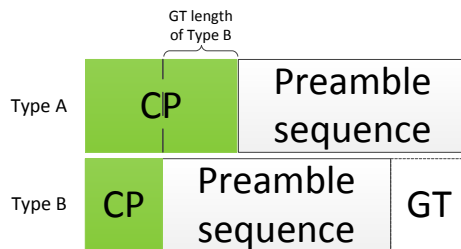
- 64 preambles based on ZC sequence in the cell

- 4 preamble formats for length - 839



Format	L_{RA}	Δf^{RA}	N_u	N_{CP}^{RA}	Support for restricted sets
0	839	1.25 kHz	24576κ	3168κ	Type A, Type B
1	839	1.25 kHz	$2 \cdot 24576\kappa$	21024κ	Type A, Type B
2	839	1.25 kHz	$4 \cdot 24576\kappa$	4688κ	Type A, Type B
3	839	5 kHz	$4 \cdot 6144\kappa$	3168κ	Type A, Type B

- 10 preamble formats for length -139 with {SCS: 15kHz, 30kHz in <6GHz, 60kHz, 120kHz in >6GHz}



Format	L_{RA}	Δf^{RA}	N_u	N_{CP}^{RA}	Support for restricted sets
A1	139	$15 \cdot 2^\mu$ kHz	$2 \cdot 2048\kappa \cdot 2^{-\mu}$	$288\kappa \cdot 2^{-\mu}$	-
A2	139	$15 \cdot 2^\mu$ kHz	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$576\kappa \cdot 2^{-\mu}$	-
A3	139	$15 \cdot 2^\mu$ kHz	$6 \cdot 2048\kappa \cdot 2^{-\mu}$	$864\kappa \cdot 2^{-\mu}$	-
B1	139	$15 \cdot 2^\mu$ kHz	$2 \cdot 2048\kappa \cdot 2^{-\mu}$	$216\kappa \cdot 2^{-\mu}$	-
B2	139	$15 \cdot 2^\mu$ kHz	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$360\kappa \cdot 2^{-\mu}$	-
B3	139	$15 \cdot 2^\mu$ kHz	$6 \cdot 2048\kappa \cdot 2^{-\mu}$	$504\kappa \cdot 2^{-\mu}$	-
B4	139	$15 \cdot 2^\mu$ kHz	$12 \cdot 2048\kappa \cdot 2^{-\mu}$	$936\kappa \cdot 2^{-\mu}$	-
C0	139	$15 \cdot 2^\mu$ kHz	$2048\kappa \cdot 2^{-\mu}$	$1240\kappa \cdot 2^{-\mu}$	-
C2	139	$15 \cdot 2^\mu$ kHz	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$2048\kappa \cdot 2^{-\mu}$	-

- The actually used preamble formats are:

- A1, A2, A3, B1, B4, A1/B1, A2/B2, A3/B3, C0, C2

Cyclic shift value - 839

- For preamble format 0-2 (1.25kHz)

- For preamble format 3 (5kHz)

zeroCorrelationZoneConfig	N_{CS} value		
	Unrestricted set	Restricted set type A	Restricted set type B
0	0	15	15
1	13	18	18
2	15	22	22
3	18	26	26
4	22	32	32
5	26	38	38
6	32	46	46
7	38	55	55
8	46	68	68
9	59	82	82
10	76	100	100
11	93	128	118
12	119	158	137
13	167	202	-
14	279	237	-
15	419	-	-

ZeroCorrelationZoneConfig	Sequence length 839, SCS = 5KHz		
	Unrestricted	Restricted set type A	Restricted set type B
0	0	36	36
1	13	57	57
2	26	72	60
3	33	81	63
4	38	89	65
5	41	94	68
6	49	103	71
7	55	112	77
8	64	121	81
9	76	132	85
10	93	137	97
11	119	152	109
12	139	173	122
13	209	195	137
14	279	216	-
15	419	237	-

Cyclic shift value - 139

- For preamble formats with $SCS = 15 \times 2^\mu$ where $\mu = 0, 1, 2, 3$

zeroCorrelationZoneConfig	N_{CS} value
0	0
1	2
2	4
3	6
4	8
5	10
6	12
7	13
8	15
9	17
10	19
11	23
12	27
13	34
14	46
15	69

- Indicated in the preamble configuration table
 - 4 tables, paired/unpaired spectrum, >6GHz/<6GHz
- The table includes:
 - PRACH Configuration number : (Values: 0-255)
 - Preamble Format
 - Long sequence: 0-3 & Short sequence: A1, A2, A3, A1/B1, A2/B2, A3/B3, B1, B4, C0, C2
 - Configuration period : (Values {1,2,4,8,16} (10ms*Nperiod))
 - SFN mod Config. Period (to indicate which 10ms in the period)
 - Start symbol Index (in Msg1 SCS for short sequence and 15kHz for long sequence):
 - Values {0,2} for short sequence
 - Values {0,6} for format 2 & always be 0 for format 0,1,3
 - for the unpaired spectrum, introducing start symbol(s) larger than 2 for a limited number of entries in the Configuration table.
 - Number of (consecutive) time domain RACH occasions within a RACH slot
 - For preamble format (working assumption), at least the following # of occasions:
 - A1(6), A2(3), A3(2), B4(1), B1(6/7), C0(4), C2(2), A1/B1(6/7), A2/B2(3), A3/B3(2)
 - The value is not applicable (N/A) for format 0-3

PRACH time/frequency resource – cont'd



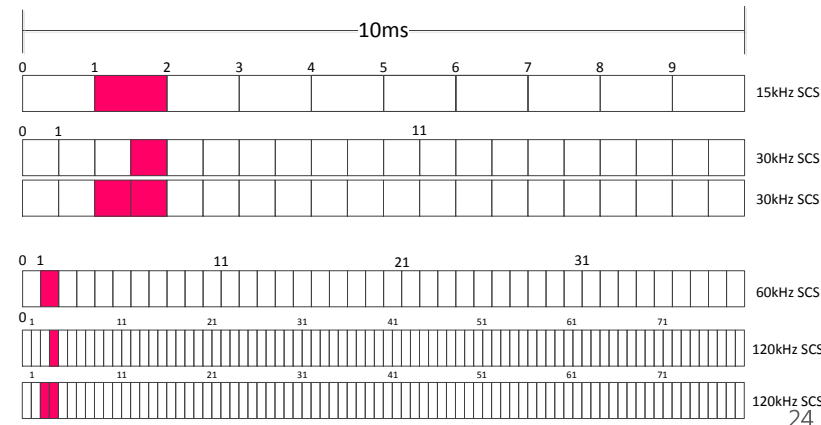
- Sub-frame numbering is used for below 6GHz,
 - Granularity is 1ms, based on 15kHz SCS
 - For short sequence length and SCS = 30kHz, the number of RACH slots in a subframe can be 1 or 2
 - When there is only one RACH slot the second RACH slot is used
 - For short sequence length and SCS = 15kHz, the number of RACH slots in a subframe is 1
- RACH slot number is used for above 6GHz
 - 0.25ms granularity based on SCS = 60kHz
 - For the 120kHz SCS the number of RACH slots in 0.25ms can be 1 or 2
 - When there is only one RACH slot the second RACH slot is used
 - For the 60kHz SCS the number of RACH slots in 0.25ms is 1

One example:

One configuration entry indicates the sub-frame number 1 is used, and the number of the RACH slot in one sub-frame is 1,

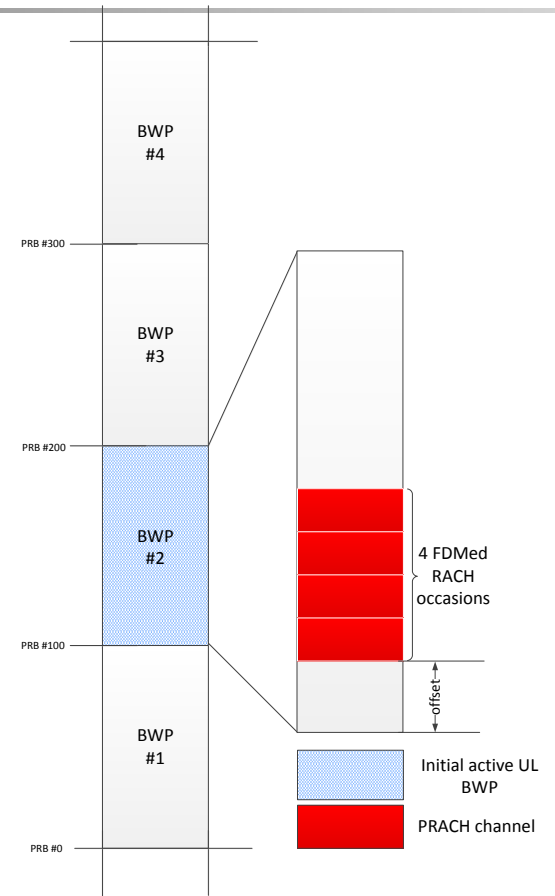
→ For 15kHz, the whole #1 sub-frame is used for RACH;

→ For 30kHz, the second slot inside of the #1 sub-frame is used for RACH.



PRACH time/frequency resource – cont'd

- For the root Zadoff-Chu sequence order of preamble (logical to physical root mapping), use same tables in LTE given by 36.211 Table 5.7.2-4 & 36.211 Table 5.7.2-5
- Some other information which is not in the table:
 - Number of FDMed RACH occasion(s) -> 2 bits indication (4 values)
 - From UE perspective, the FDMed RACH occasion(s) are consecutive
 - Frequency domain offset to the initial active UL BWP(s)

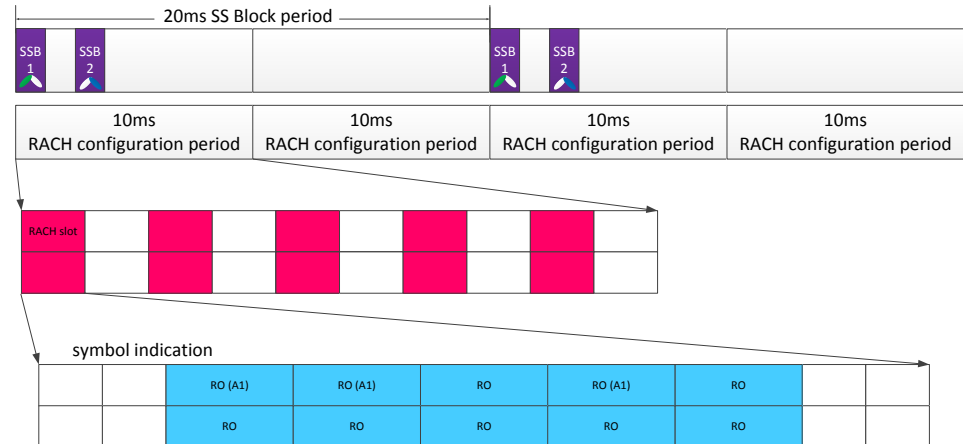


SS/PBCH block association with PRACH

- Number of SS/PBCH block associated with one RACH occasion in indicated.
- Mapping rules:
 - In the order of increasing preamble indices in single RACH occasion and then
 - In the order of increasing the number of frequency multiplexed RACH occasions and then
 - In the order of increasing the number of time multiplexed RACH occasions within a RACH slot
 - In the order of increasing the number of RACH slots

One example:

- 0.5 SSB associated with one RACH occasion (one SSB associated with 2 RACH occasions);
- 2 actually transmitted SSB indicated in RMSI
- SSB#1 maps to the first 2 FDMed ROs & SSB#2 maps to the second 2 FDMed ROs
- Note: if N SSBs associated with one RACH occasion, the 64 preambles will be divided into N groups, and each group will associated with each SSB



How to determine the available resource?



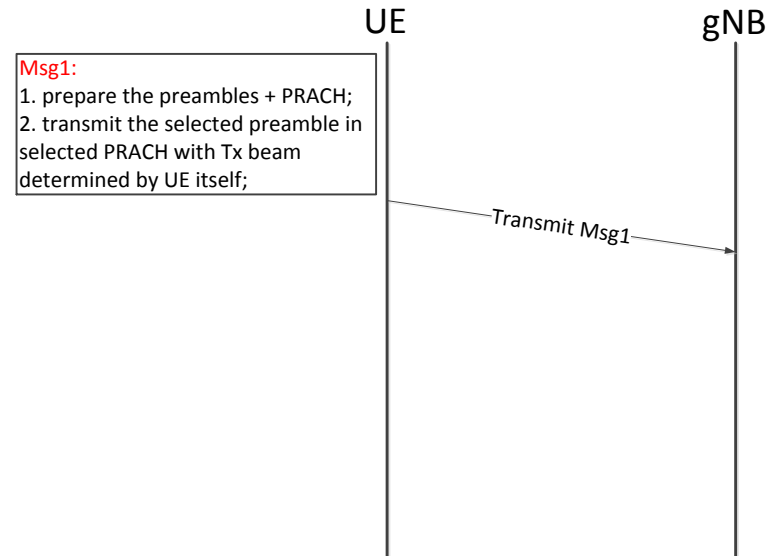
- UE detects and decodes the SS/PBCH Block, find/decode the RMSI, obtain the PRACH configuration,
 - According to a configured SSB RSRP threshold for SUL
 - If the RSRP of received SS Block is smaller than the configured SSB RSRP threshold for SUL → select SUL; otherwise select Common UL;
 - According to a configured SSB RSRP threshold
 - If the RSRP of multiple received SS Blocks are larger than the configured SSB RSRP threshold → up to implementation to select one (preferred DL Tx beam);
 - If none of the RSRP received SS Blocks are larger than the configured SSB RSRP threshold → select the one that could meet the PRACH target receive power
 - According to the association between SSB and PRACH/preamble; PRACH configuration;
→ determine the available PRACH occasion(s),
- In RAN2, it will decide how UE selects the RACH resource (i.e., PRACH and preamble)

* CBRA: Contention Based Random Access

- For 4-step contention based random access.
- The following steps are required for the L1 random access procedure:
 - Layer 1 procedure is triggered upon request of a preamble transmission by higher layers.
 - A preamble index, a target preamble received power(PREAMBLE_RECEIVED_TARGET_POWER), a corresponding RA-RNTI and a PRACH resource are indicated by higher layers as part of the request.
 - A preamble transmission power PPRACH is determined similar as in LTE, e.g., $P_{PRACH} = \min\{P_{max}, PREAMBLE_RECEIVED_TARGET_POWER + PL\}$, P_{max} is up to power control session.
 - A preamble sequence is selected from the preamble sequence set using the preamble index.
 - A single preamble is transmitted using the selected preamble sequence with transmission power P_{PRACH} on the determined PRACH resource.
 - Detection of a PDCCH with the indicated RA-RNTI is attempted in a configured RAR window.
 - If detected, the corresponding PDSCH transport block is passed to higher layers. The higher layers parse the transport block and indicate the UL grant to the physical layer.

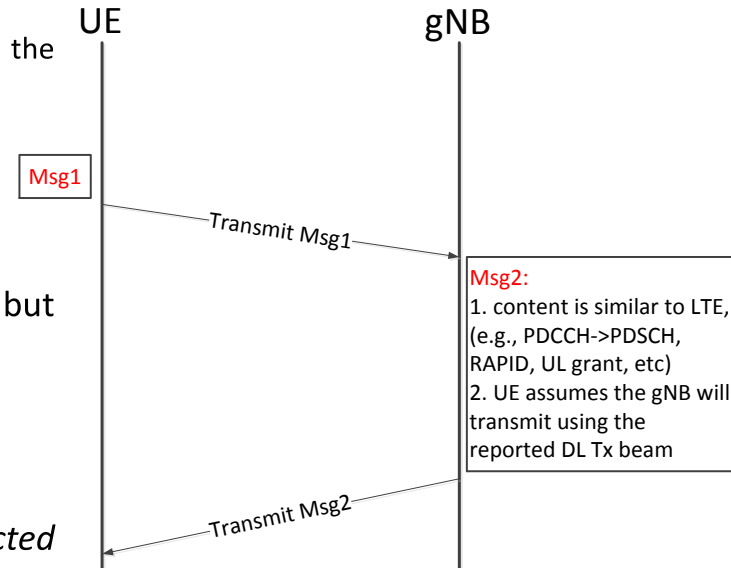
Msg. 1 (re)transmission

- UE transmits the msg.1:
 - Selects the SS/PBCH block (preferred DL Tx beam)
↓
 - Determine the available PRACH resource & preamble indexes. According to the association and procedure defined in RAN2 spec to determine the prepare the preambles + PRACH.
↓
 - Determine the transmit power according the DL path loss estimation, the indicated initial target received power, the power ramping counter value and the power ramp step size comparing with P_{cm}_{ax};
 - If UE changes its Tx beam, power ramping counter unchanged;
 - If UE doesn't change its Tx beam, power ramping counter +1;
↓
 - Determine the UL Tx beam up to UE



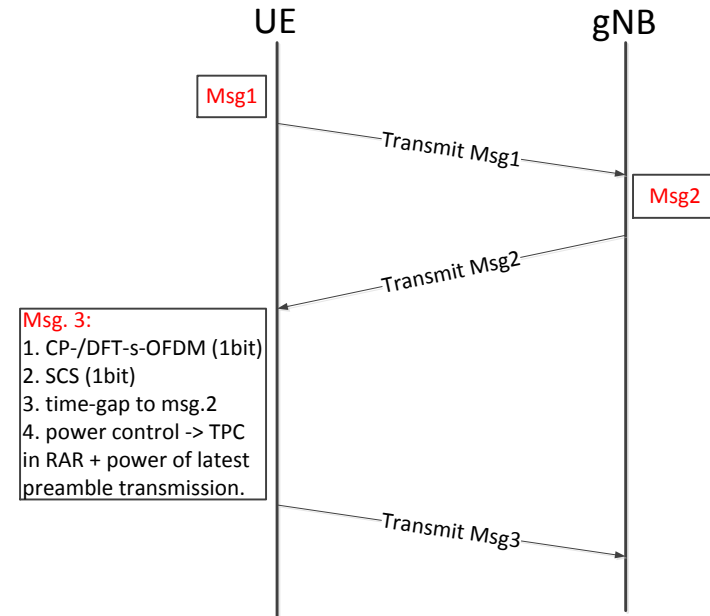
Msg. 2 (random access response)

- gNB side:
 - Transmit RAR on PDSCH addressed by PDCCH scrambled by RA-RNTI
 - For msg.2:
 - RA-RNTI (16bits as same as in LTE), the calculation formula now includes the starting symbol of PRACH formats.
 - $RA-RNTI = 1 + s_id + 14 * (t_id + X * f_id)$
 - TA (12bits), TA granularity-> based on msg.3 SCS
 - UL grant -> up to control session, RAPID (6bits)
 - CORESET configuration -> default value is same as the RMSI corset, but can re-configure in RMSI;
 - Search space configuration-> no default, indicated in RMSI;
- UE side:
 - UE assumes that the DL TX beam of msg.2 is the same as the selected RACH resource associated to;
 - UE is not expected to monitor more than one Msg2/Msg3/Msg4 search space in one slot.



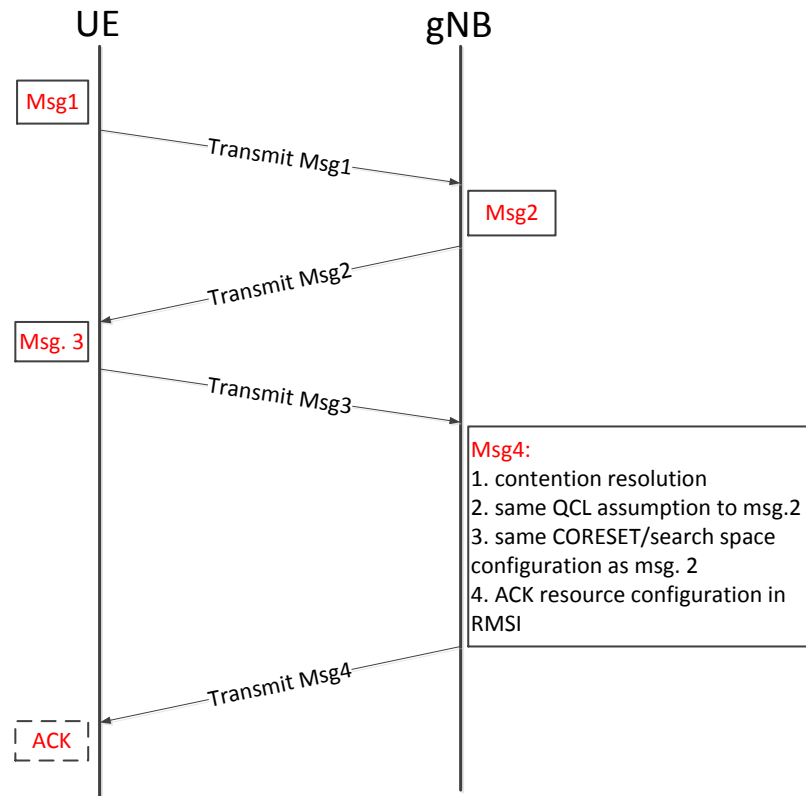
Msg. 3

- For msg.3:
 - Asynchronized msg.3 transmission
 - 1 bit indication of using CP-OFDM or DFT-s-OFDM
 - 1 bit indication of using which SCS
 - <6GHz, 0: 15kHz, 1: 30kHz
 - >6GHz, 0: 60kHz, 1: 120kHz
 - Time gap between msg.2 reception to msg.3 transmission:
 $duration\ of\ N1 + duration\ of\ N2 + L2 + TA$
 - N1, N2 refers to the value determined in control session with front loaded plus additional DMRS and UE capability #1
 - TA is equal to the maximum timing advance value that the 12 bit TA command can provide with respect to the SCS of Msg3
 - L2 refers to the MAC processing
 - L2=500us as a working assumption
 - Power adjustment: TPC in RAR + transmit power of latest preamble transmission
 - Tx beam is determined by UE



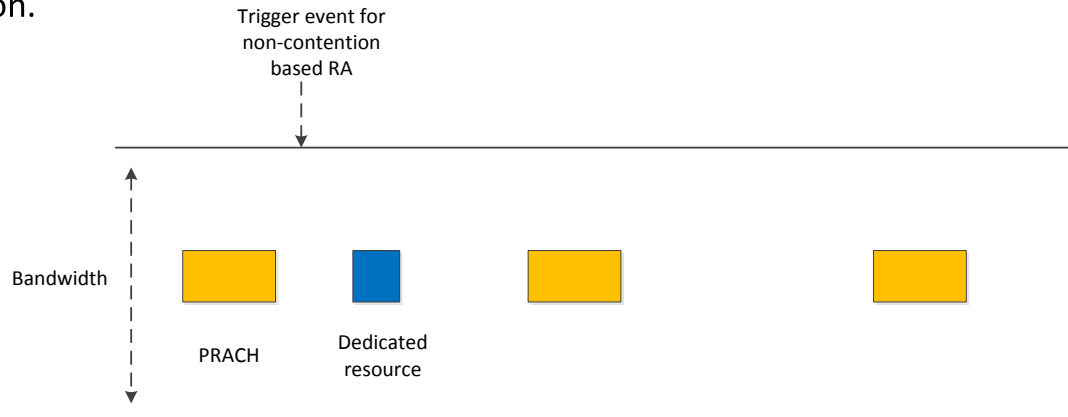
Msg. 4

- gNB side :
 - Contention resolution to the UE with successfully decoded msg. 3;
 - Same QCL assumption of msg.2;
 - Same CORESET/search space configuration as for msg.2;
 - HARQ support like in LTE;
- UE side:
 - Contention resolution identity matches
 - set TC-RNTI to C-RNTI,
 - *Send the ACK according to the 4-bit indication in RMSI of corresponding (PUCCH) resource allocation;*
 - If no contention resolution identity matches and timer is out
 - RA re-attempt (if number of preamble transmission < max)
 - Otherwise, Report RA issue



* CFRA: Contention-Free Random Access

- The new things for CFRA:
 - For handover purpose, the **CSI-RS** association with the RA resource (PRACH and/or preamble) is supported. This implies that the gNB needs to configure this association in addition to the SS block association with RA resource (PRACH and/or preamble).
 - The **dedicated PRACH** could be configured (due to the limited time in the RAN1, we leaves the RAN2 to confirm the details). The intention of RAN1 to introduce this dedicated PRACH is:
 - To assign additional PRACH resource for handover CFRA to facilitate the “fast handover”, e.g., when the target cell has large RACH configuration periodicity, the dedicated/additional PRACH is useful for the handover latency reduction.



THANK YOU