NR PRACH

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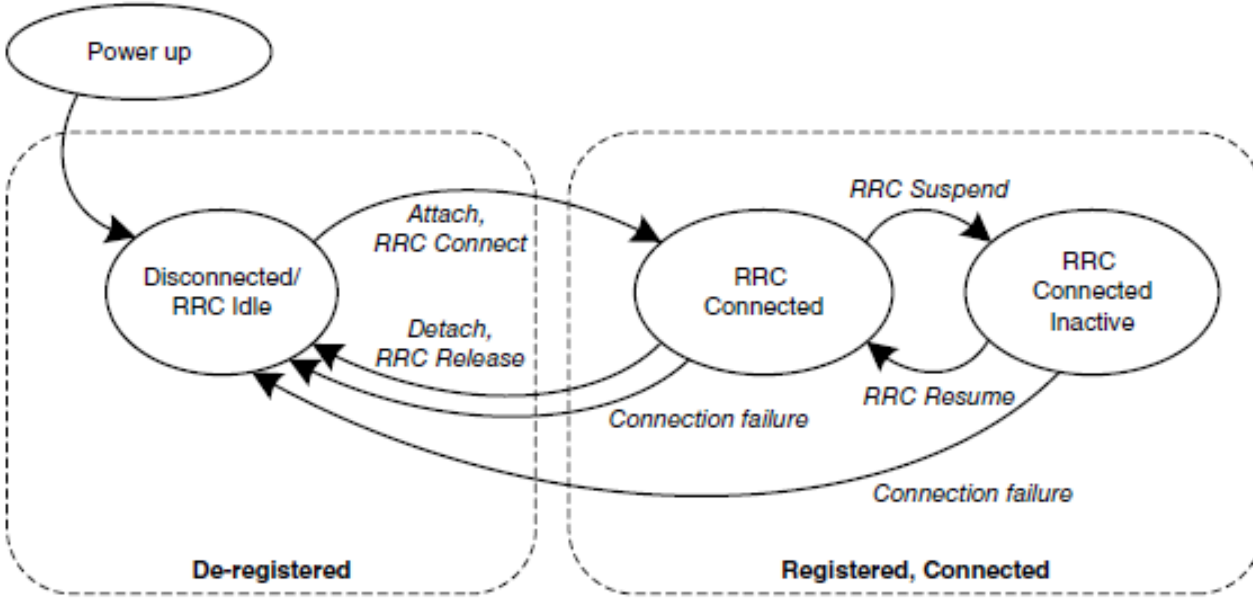
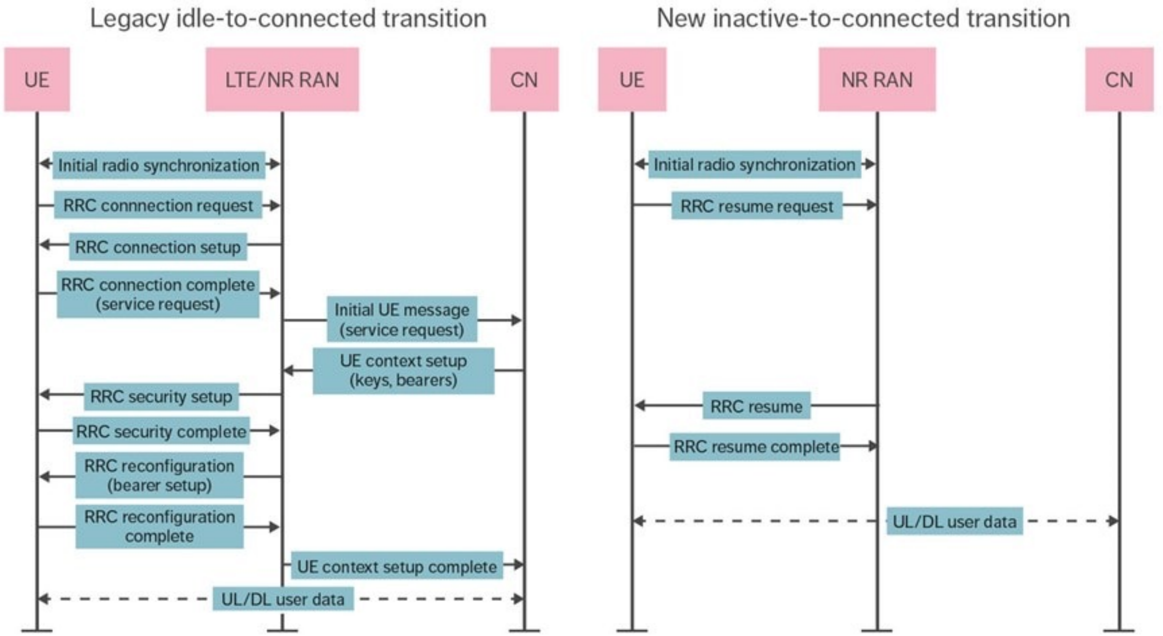
RRC State Machine (NR)





https://www.ericsson.com/en/reports-and-papers/ericsson-technology-review/articles/meeting-5g-latency-requirements-with-inactive-state

Three states

1. RRC_IDLE
   - No connection
2. RRC_INACATIVE [not there in LTE]
   - Connection states saved by the UE and network
3. RRC_CONNECTED
   - Completely connected state

NR timers (NOT Necessary for class)

5G NR Timers	Start	Stop	at Expiry
T304	Reception of RRCReconfiguration message including reconfigurationWithSync	Successful completion of random access on the corresponding SpCell For T304 of SCG, upon SCG release	For T304 of SCG, inform network about the reconfiguration with sync failure by initiating the SCG failure information procedure as specified in 5.7.3 of TS 38.331 (3GPP).
T310	Upon detecting physical layer problems for the SpCell i.e. upon receiving N310 consecutive out-of-sync indications from lower layers.	Upon receiving N311 consecutive in-sync indications from lower layers for the SpCell, upon receiving RRCReconfiguration with reconfigurationWithSync for that cell group, and upon initiating the connection re-establishment procedure. Upon SCG release, if the T310 is kept in SCG.	If the T310 is kept in MCG: If security is not activated: go to RRC_IDLE else: initiate the connection re-establishment procedure. If the T310 is kept in SCG, Inform E-UTRAN/NR about the SCG radio link failure by initiating the SCG failure information procedure as specified in 5.7.3.
T311	Upon initiating the RRC connection re-establishment procedure	Selection of a suitable NR cell or a cell using another RAT.	Enter RRC_IDLE

What is PRACH?

- PRACH stands for Physical Random Access Channel
- PRACH is used for initial access in the uplink
- It is also used for re-synchronization and re-connectivity

Random access channel (PRACH)

- Used for initial access
  - Cannot carry any data
  - Achieve uplink time synchronization
- Design for
  - Low latency
  - Low SNR
- Contention based
  - Random, collisions
- Contention-free
  - Situations 2,3

PRACH is used

- New connection is required
- Synchronization lost in the old connection
- Positioning
- Recovering from link failure

4 Step Process

- UE transmits random-access preamble
  - gNodeB estimates the timing offset
- gNodeB transmits the timing advance command also assigns uplink resources
- Mobile transmits the network identity using ULSCH.
  - Exact content depends on whether it is previously known to the network or not
- Contention-resolution message from the network

Step1: Random Access Preamble Transmission

- Transmission of a RA preamble
  - Signals the gNodeB the presence of a RA attempt
  - Helps in estimating the timing advance
- Time-Frequency resource : PRACH
  - Broadcasted by the network to all the terminals (SIB1)

How is this preamble selected and where is it transmitted? (next set of slides)

ZC Sequence Generation

- Zadoff—Chu sequence is a constant modulus sequence

$$x_u(i) = e^{-j\frac{\pi u i(i+1)}{L_{RA}}},\ i = 0, \ldots, L_{RA} - 1$$

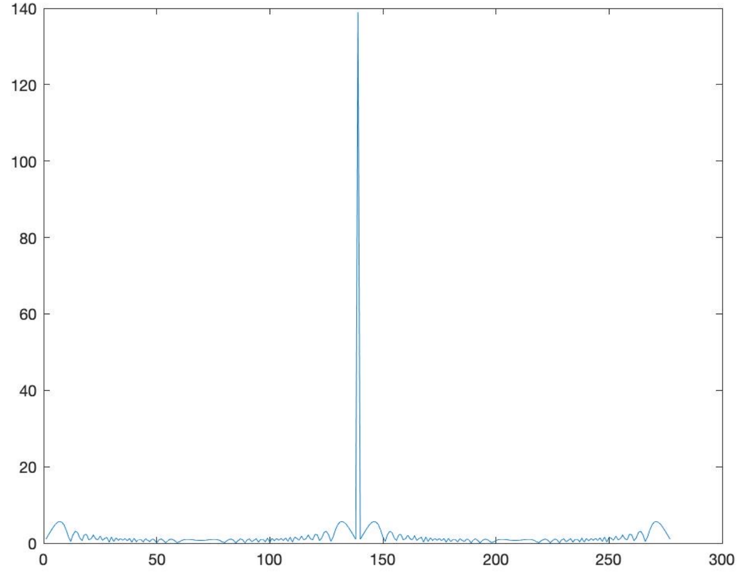
- Each u corresponds to a different base sequence
  - U should be relatively prime to L_{RA}
- For PRACH in NR, two lengths are used
  - L_{RA}=139 and L_{RA}=839 are allowed lengths
  - Since 139 and 839 are primes, all u < 139 (839) can be used for base sequence generation

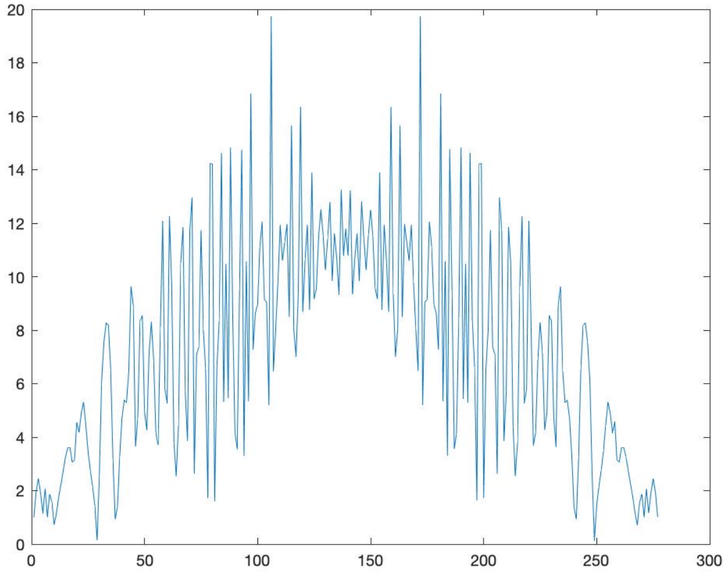
Chu, D. C. (July 1972). "Polyphase codes with good periodic correlation properties". *IEEE Trans. Inf. Theory*. 18

Properties of ZC Sequences

- Constant amplitude signals
- Also known as Constant Amplitude Zero AutoCorrelation (CAZAC) Sequences
- Periodic in L_{RA}.
- Extremely good correlation properties
  - For a given base-sequence all its circular shifts are orthogonal (Zero correlation)
- Different base sequences are non-orthogonal
- DFT of ZC sequence is a scaled ZC sequence

$$X_u[k] = x_u^*[u^{-1}k]X_u[0]$$

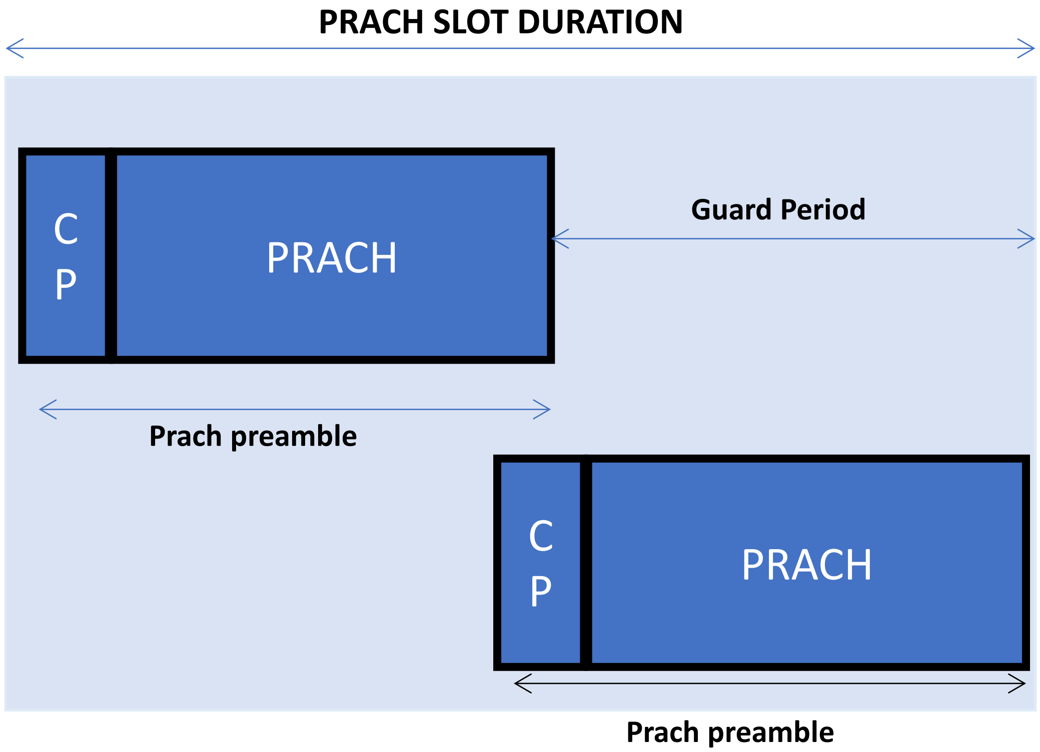




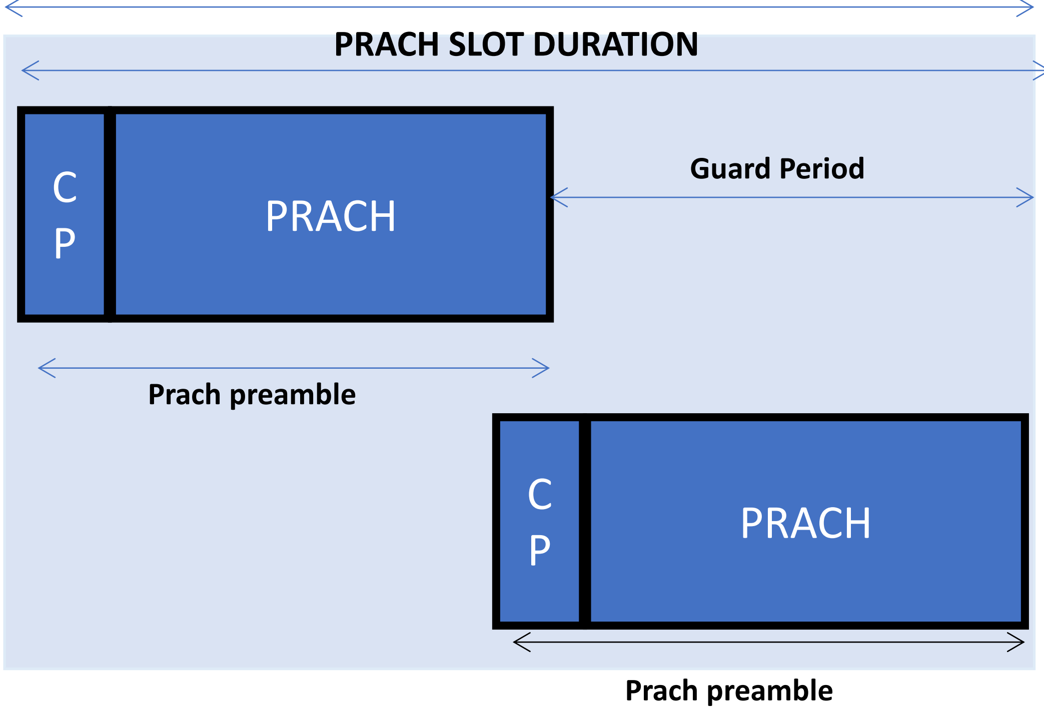
S. Beyme and C. Leung (2009). "Efficient computation of DFT of Zadoff-Chu sequences". *Electron. Lett*. 45

What should be the design principles?

- Fit into a slot
- Maximum round-trip delay
- Subcarrier spacing compatibility
- How should you choose the cyclic shift?



- UE assumes that the TA is zero when transmitting PRACH.
- PRACH slot duration is larger than than the preamble length and some guard period
  - GP for the propagation delay between the UE and the BS.



Sequence generation continued

$x_u(i)$

$x_u((n + C_v) \mod L_{RA})$

$$y_{u,v}(n) = \sum_{m=0}^{L_{RA}-1} x_{u,v}(n) e^{-j2\pi nm/L_{RA}}$$

Basic idea

- BS indicates the base sequence to be used.
- Suppose there are K-UE trying to do random access
  - Each of them chooses a cyclic shift in a random fashion and transmits the sequence
- The BS correlates the sequence with the known base sequence and finds
  - The cyclic shift
  - The Timing advance of each UE.

PRACH L2/L3 Parameters

```
SIB1 ::=        SEQUENCE {
...
servingCellConfigCommon          ServingCellConfigCommonSIB    OPTIONAL,   -- Need R
...
```

```
ServingCellConfigCommonSIB ::=     SEQUENCE {
...
uplinkConfigCommon               UplinkConfigCommonSIB   OPTIONAL,    -- Need R
...
```

```
UplinkConfigCommonSIB ::=              SEQUENCE {
    frequencyInfoUL                    FrequencyInfoUL-SIB,
    initialUplinkBWP                   BWP-UplinkCommon,
    timeAlignmentTimerCommon           TimeAlignmentTimer
}
```

```
BWP-UplinkCommon ::=             SEQUENCE {
    genericParameters                BWP,
    rach-ConfigCommon                SetupRelease { RACH-ConfigCommon }     OPTIONAL,
    pusch-ConfigCommon               SetupRelease { PUSCH-ConfigCommon }    OPTIONAL,
    pucch-ConfigCommon               SetupRelease { PUCCH-ConfigCommon }    OPTIONAL,
    ...
}
```

```
RACH-ConfigCommon ::=            SEQUENCE {
  rach-ConfigGeneric             RACH-ConfigGeneric,
  totalNumberOfRA-Preambles          INTEGER (1..63)                              OPTIONAL,   -- Need S
  ssb-perRACH-OccasionAndCB-PreamblesPerSSB   CHOICE {
    oneEighth                    ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32,n36,n40,n44,n48,n52,n56,n60,n64},
    oneFourth                    ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32,n36,n40,n44,n48,n52,n56,n60,n64},
    oneHalf                      ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32,n36,n40,n44,n48,n52,n56,n60,n64},
    one                          ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32,n36,n40,n44,n48,n52,n56,n60,n64},
    two                          ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32},
    four                         INTEGER (1..16),
    eight                        INTEGER (1..8),
    sixteen                      INTEGER (1..4)
  }                                                                           OPTIONAL,   -- Need M

  groupBconfigured               SEQUENCE {
    ra-Msg3SizeGroupA               ENUMERATED {b56, b144, b208, b256, b282, b480, b640,
                                    b800, b1000, b72, spare6, spare5,spare4, spare3, spare2, spare1},
    messagePowerOffsetGroupB        ENUMERATED { minusinfinity, dB0, dB5, dB8, dB10, dB12, dB15, dB18},
    numberOfRA-PreamblesGroupA      INTEGER (1..64)
  }                                                                           OPTIONAL,   -- Need R
  ra-ContentionResolutionTimer      ENUMERATED { sf8, sf16, sf24, sf32, sf40, sf48, sf56, sf64},
  rsrp-ThresholdSSB                 RSRP-Range                                OPTIONAL,   -- Need R
  rsrp-ThresholdSSB-SUL             RSRP-Range                                OPTIONAL,   -- Cond SUL
  prach-RootSequenceIndex           CHOICE {
    l839                         INTEGER (0..837),
    l139                         INTEGER (0..137)
  },
  msg1-SubcarrierSpacing            SubcarrierSpacing                         OPTIONAL,   -- Cond L139
  restrictedSetConfig               ENUMERATED {unrestrictedSet, restrictedSetTypeA, restrictedSetTypeB},
  msg3-transformPrecoder            ENUMERATED {enabled}                      OPTIONAL,   -- Need R
  ...
}
```

L2/L3 Messages (contd)

```
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 (-200..-74),
    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}
}
```

L2/L3 message description

RACH-ConfigCommon field descriptions
messagePowerOffsetGroupB Threshold for preamble selection. Value in dB. Value minusinfinity corresponds to –infinity. Value dB0 corresponds to 0 dB, dB5 corresponds to 5 dB and so on. (see TS 38.321 [3], clause 5.1.2)
msg1-SubcarrierSpacing Subcarrier spacing of PRACH (see TS 38.211 [16], clause 5.3.2). Only the values 15 or 30 kHz (<6GHz), 60 or 120 kHz (>6GHz) are applicable (see TS 38.211 [16], section FFS_Section). If absent, the UE applies the SCS as derived from the prach-ConfigurationIndex in RACH-ConfigGeneric (see tables Table 6.3.3.1-1 and Table 6.3.3.2-2, TS 38.211 [16]). The value also applies to contention free random access (RACH-ConfigDedicated), to SI-request and to contention-based beam failure recovery (CB-BFR). But it does not apply for contention free beam failure recovery (CF-BFR) (see BeamFailureRecoveryConfig).
msg3-transformPrecoder Enables the transform precoder for Msg3 transmission. If the field is absent, the UE disables the transformer precoder (see TS 38.213 [13], clause 8.3)
numberOfRA-PreamblesGroupA The number of CB preambles per SSB in group A. This determines implicitly the number of CB preambles per SSB available in group B. (see TS 38.321 [3], clause 5.1.1). The setting should be consistent with the setting of ssb-perRACH-OccasionAndCB-PreamblesPerSSB.
prach-RootSequenceIndex PRACH root sequence index (see TS 38.211 [16], clause 6.3.3.1). The value range depends on whether L=839 or L=139. The short/long preamble format indicated in this IE should be consistent with the one indicated in prach-ConfigurationIndex in the RACH-ConfigDedicated (if configured).
ra-ContentionResolutionTimer The initial value for the contention resolution timer (see TS 38.321 [3], clause 5.1.5). Value sf8 corresponds to 8 subframes, value sf16 corresponds to 16 subframes, and so on.
ra-Msg3SizeGroupA Transport Blocks size threshold in bit below which the UE shall use a contention-based RA preamble of group A. (see TS 38.321 [3], clause 5.1.2)
rach-ConfigGeneric Generic RACH parameters
restrictedSetConfig Configuration of an unrestricted set or one of two types of restricted sets, see TS 38.211 [16], clause 6.3.3.1.
rsrp-ThresholdSSB UE may select the SS block and corresponding PRACH resource for path-loss estimation and (re)transmission based on SS blocks that satisfy the threshold (see TS 38.213 [13])
rsrp-ThresholdSSB-SUL The UE selects SUL carrier to perform random access based on this threshold (see TS 38.321 [3], clause 5.1.1). The value applies to all the BWPs.
ssb-perRACH-OccasionAndCB-PreamblesPerSSB The meaning of this field is twofold: the CHOICE conveys the information about the number of SSBs per RACH occasion (L1 parameter 'SSB-per-rach-occasion'). Value oneEight corresponds to one SSB associated with 8 RACH occasions, value oneFourth corresponds to one SSB associated with 4 RACH occasions, and so on. The ENUMERATED part indicates the number of Contention Based preambles per SSB (L1 parameter 'CB-preambles-per-SSB'). Value n4 corresponds to 4 Contention Based preambles per SSB, value n8 corresponds to 8 Contention Based preambles per SSB, and so on. The total number of CB preambles in a RACH occasion is given by CB-preambles-per-SSB * max(1, SSB-per-rach-occasion).
totalNumberOfRA-Preambles Total number of preambles used for contention based and contention free random access in the RACH resources defined in RACH-ConfigCommon, excluding preambles used for other purposes (e.g. for SI request). If the field is absent, the all 64 preambles are available for RA. The setting should be consistent with the setting of ssb-perRACH-OccasionAndCB-PreamblesPerSSB, i.e. it should be a multiple of the number of SSBs per RACH occasion.

Conditional Presence	Explanation
L139	The field is mandatory present if prach-RootSequenceIndex L=139, otherwise the field is absent.
SUL	The field is mandatory present in initialUplinkBWP in supplementaryUplink; otherwise, the field is absent.

L2/L3 message description (cont....)

RACH-ConfigGeneric field descriptions
msg1-FDM The number of PRACH transmission occasions FDMed in one time instance. (see TS 38.211 [16], clause 6.3.3.2)
msg1-FrequencyStart Offset of lowest PRACH transmission occasion in frequency domain with respective to PRB 0. The value is configured so that the corresponding RACH resource is entirely within the bandwidth of the UL BWP. (see TS 38.211 [16], clause 6.3.3.2).
powerRampingStep Power ramping steps for PRACH (see TS 38.321 [3],5.1.3).
prach-ConfigurationIndex PRACH configuration index. For prach-ConfigurationIndex configured under beamFailureRecovery-Config, the prach-ConfigurationIndex can only correspond to the short preamble format, (see TS 38.211 [16], clause 6.3.3.2).
preambleReceivedTargetPower The target power level at the network receiver side (see TS 38.213 [13], clause 7.4, TS 38.321 [3], clauses 5.1.2, 5.1.3). Only multiples of 2 dBm may be chosen (e.g. -202, -200, -198, ...).
preambleTransMax Max number of RA preamble transmission performed before declaring a failure (see TS 38.321 [3], clauses 5.1.4, 5.1.5).
ra-ResponseWindow Msg2 (RAR) window length in number of slots. The network configures a value lower than or equal to 10 ms (see TS 38.321 [3], clause 5.1.4). UE ignores the field if included in SCellConfig.
zeroCorrelationZoneConfig N-CS configuration, see Table 6.3.3.1-5 in TS 38.211 [16]

Preamble Formats

- There are 13 different preamble formats, each with different lengths, different SCS, and different CP lengths.
- The preamble format is chosen by higher layer parameter
  - prach-RootSequenceIndex. Given by the choice option: You understand the length of the sequence
  - prach-ConfigurationIndex : Among other parameters, format is also specified
    - This index is the index in Table 6.3.3.2.2 which specifies the format (among other things)

Table 6.3.3.1-1: PRACH preamble formats for $L_{\mathrm{RA}} = 839$ and $\Delta f^{\mathrm{RA}} \in \{1.25, 5\}$ kHz.

Format	L_{RA}	Δf^{RA}	N_{u}	$N_{\mathrm{CP}}^{\mathrm{RA}}$	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

Table 6.3.3.1-2: Preamble formats for $L_{\mathrm{RA}} = 139$ and $\Delta f^{\mathrm{RA}} = 15 \cdot 2^{\mu}$ kHz where $\mu \in \{0,1,2,3\}$

Format	L_{RA}	Δf^{RA}	N_{u}	$N_{\mathrm{CP}}^{\mathrm{RA}}$	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	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$2048\kappa \cdot 2^{-\mu}$	

Table 6.3.3.2.2

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
		x	y					
0	0	16	1	1	0	-	-	0
1	0	16	1	4	0	-	-	0
2	0	16	1	7	0	-	-	0
3	0	16	1	9	0	-	-	0
4	0	8	1	1	0	-	-	0
5	0	8	1	4	0	-	-	0
6	0	8	1	7	0	-	-	0
7	0	8	1	9	0	-	-	0
8	0	4	1	1	0	-	-	0
9	0	4	1	4	0	-	-	0
10	0	4	1	7	0	-	-	0
86	3	1	0	0,1,2,3,4,5,6,7,8,9	0	-	-	0
87	A1	16	0	4,9	0	1	6	2
88	A1	16	1	4	0	2	6	2
89	A1	8	0	4,9	0	1	6	2
90	A1	8	1	4	0	2	6	2
91	A1	4	0	4,9	0	1	6	2
92	A1	4	1	4,9	0	1	6	2
93	A1	4	0	4	0	2	6	2
94	A1	2	0	4,9	0	1	6	2
95	A1	2	0	1	0	2	6	2
96	A1	2	0	4	0	2	6	2
97	A1	2	0	7	0	2	6	2
98	A1	1	0	4	0	1	6	2
99	A1	1	0	1,6	0	1	6	2
100	A1	1	0	4,9	0	1	6	2
101	A1	1	0	1	0	2	6	2

Choosing the random sequences by the UE

- There will be a set of 64 sequences (maximum) from which a sequence is randomly selected (the number comes from L2 parameter totalNumberOfRA-Preambles).
  - Will be divided between for contention based and contention free random access
- These sequences are cyclic shifts of a multiple base sequences
- We get two parameters from the higher layers
  - Prach-RootSequenceIndex (Logical index)
    - Used for choosing u (the base sequence)
  - NCs (chosen from a table based on ZeroCorrelationZoneConfig parameter that comes from the higher layer)
  - The circular shift used for the sequences

zeroCorrelationZoneConfig	Ncs value for unrestricted set
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

- Prach-RootSequenceIndex
  - It is the logical index and is mapped to the base sequence number (u) in the table 6.3.3.1-3
- ZeroCorrelationZoneConfig comes from the idea of ZeroCorrelationZone
  - As discussed earlier all cyclic shifts cannot be allowed since
    - Multipath (delay spread)
    - Doppler due to mobility
      - Doppler causes frequency shift and this will lead to confusion between various sequences.

64 Sequence Set (example of 139 length ZC seq)

- The *Prach-RootSequenceIndex* (i) and NCs are obtained from higher layer
- Table 6.3.3.1-4 (for 139 length) is

i	Sequence number u in increasing order of i																			
0 – 19	1	138	2	137	3	136	4	135	5	134	6	133	7	132	8	131	9	130	10	129
20 – 39	11	128	12	127	13	126	14	125	15	124	16	123	17	122	18	121	19	120	20	119
40 – 59	21	118	22	117	23	116	24	115	25	114	26	113	27	112	28	111	29	110	30	109
60 – 79	31	108	32	107	33	106	34	105	35	104	36	103	37	102	38	101	39	100	40	99
80 – 99	41	98	42	97	43	96	44	95	45	94	46	93	47	92	48	91	49	90	50	89
100 – 119	51	88	52	87	53	86	54	85	55	84	56	83	57	82	58	81	59	80	60	79
120 – 137	61	78	62	77	63	76	64	75	65	74	66	73	67	72	68	71	69	70	-	-
138 – 837	N/A																			

- Suppose i = 4 (From higher layer) and NCs = 10 (zoneconfig =5. See the table in the last slide)
  - Then the starting base sequence is generated using u=3.
    - i=4 corresponds to 1st row and 5th column
  - For u=3 sequence, the possible shifts can be obtained using the formula (Sec 6.3.3.1)

$$C_v = \begin{cases} vN_{CS} & v = 0,1,\ldots,\lfloor L_{RA}/N_{CS} \rfloor - 1, N_{CS} \neq 0 & \text{for unrestricted sets} \\ 0 & N_{CS} = 0 & \text{for unrestricted sets} \\ d_{start}\lfloor v/n_{shift}^{RA} \rfloor + (v \bmod n_{shift}^{RA})N_{CS} & v = 0,1,\ldots,w-1 & \text{for restricted sets type A and B} \\ \overline{\overline{d}}_{start} + (v-w)N_{CS} & v = w,\ldots,w+\overline{\overline{n}}_{shift}^{RA}-1 & \text{for restricted sets type B} \\ \overline{\overline{\overline{d}}}_{start} + (v-w-\overline{\overline{n}}_{shift}^{RA})N_{CS} & v = w+\overline{\overline{n}}_{shift}^{RA},\ldots,w+\overline{\overline{n}}_{shift}^{RA}+\overline{\overline{\overline{n}}}_{shift}^{RA}-1 & \text{for restricted sets type B} \end{cases}$$

$$w = n_{shift}^{RA} n_{group}^{RA} + \overline{n}_{shift}^{RA}$$

64 Sequence Set (example of 139 length ZC seq) Contd…

- For unrestricted sets (and NCS=10)
  - Cv = 0, 10, 20,30,40,50,60,70,80,90,100,110,120 (13 cyclically shifted sequences)
- The first base sequence (i=4→u=3) gives 13 sequences.
- Second base sequence (i=5→ u= 136) gives 13 sequences
- Third base sequence (i=6 → u =4) gives 13 sequences
- Fourth base sequence (i=7 → u =135) gives 13 sequences
- Fifth base sequence (i=8 → u =5) gives 12 sequences
- The total sequences are hence 64 = (13+13+13+13+12)
- Also, recall that sequences generated from different base sequences are not orthogonal.

Mapping to Physical Resources

$$a_k^{(p,\mathrm{RA})} = \beta_{\mathrm{PRACH}} y_{u,v}(k)$$
$$k = 0,1,\ldots, L_{\mathrm{RA}} - 1$$

- Single port transmission
  - Port 4000
- Specified in equation 5.2 in 38.211
  - Different equation compared to OFDM generation

Frequency Allocation

$$s_l^{(p,\mu)}(t) = \sum_{k=0}^{L_{RA}-1} a_k^{(p,RA)} e^{j2\pi(k+Kk_1+\bar{k})\Delta f_{RA}(t-N_{CP,l}^{RA}T_c-t_{start}^{RA})}$$
$$K = \Delta f / \Delta f_{RA}$$
$$k_1 = k_0^{\mu} + (N_{BWP,i}^{start} - N_{grid}^{start,\mu})N_{sc}^{RB} + n_{RA}^{start}N_{sc}^{RB} + n_{RA}N_{RB}^{RA}N_{sc}^{RB} - N_{grid}^{size,\mu}N_{sc}^{RB}/2$$
$$k_0^{\mu} = (N_{grid}^{start,\mu} + N_{grid}^{size,\mu}/2)N_{sc}^{RB} - (N_{grid}^{start,\mu_0} + N_{grid}^{size,\mu_0}/2)N_{sc}^{RB}2^{\mu_0-\mu}$$

- Frequency resources are allocated by L2 parameter *msg1-FrequencyStart*
- The number of repetitions in the frequency domain is given by n_{RA} (IE msg1-FDM)
- K_0^u =0 if only one numerology is supported (No need to worry too much about it)
  - Otherwise it is centering with respect to the highest numerology
- The starting reference is the start RB (0th RB) of the initial active uplink bandwidth part
  - $(N_{BWP,i}^{start} - N_{grid}^{start,\mu})N_{sc}^{RB}$ denotes the number of RE for the start of the initial UL BWP with respect to the absolute location (PointA)
- $n_{RA}^{start}N_{sc}^{RB}$ denotes the number of RE (with respect to the 0th RE of the UL BWP) and is given by *msg1-FrequencyStart (in terms of RB)*

Frequency allocation (contd)

$$s_l^{(p,\mu)}(t) = \sum_{k=0}^{L_{RA}-1} a_k^{(p,RA)}\, e^{j2\pi(k+Kk_1+\bar{k})\Delta f_{RA}\left(t-N_{CP,l}^{RA}T_c-t_{start}^{RA}\right)}$$

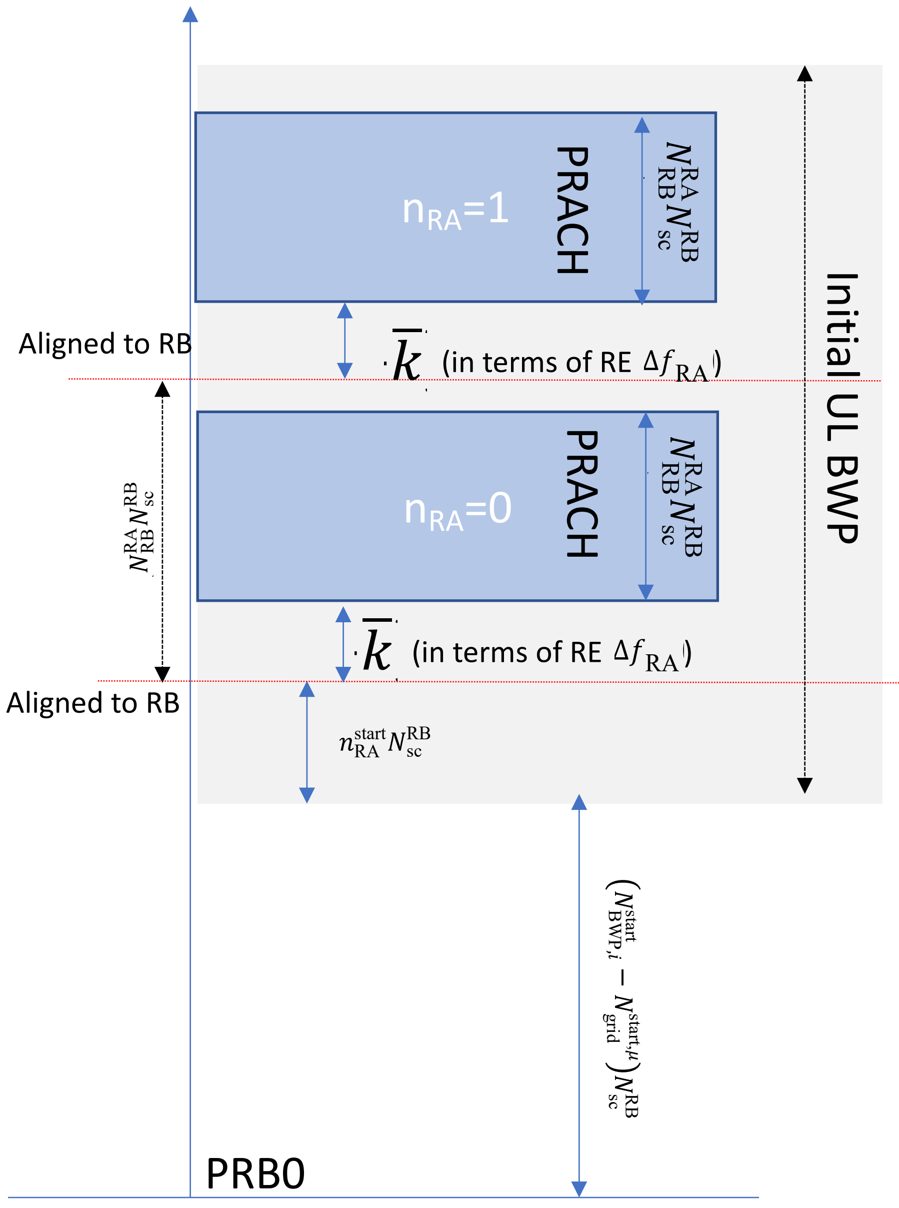
$$K = \Delta f/\Delta f_{RA}$$

$$k_1 = k_0^\mu + \left(N_{BWP,i}^{start} - N_{grid}^{start,\mu}\right)N_{sc}^{RB} + n_{RA}^{start}N_{sc}^{RB} + n_{RA}N_{RB}^{RA}N_{sc}^{RB} - N_{grid}^{size,\mu}\, N_{sc}^{RB}/2$$

$$k_0^\mu = \left(N_{grid}^{start,\mu} + N_{grid}^{size,\mu}/2\right)N_{sc}^{RB} - \left(N_{grid}^{start,\mu_0} + N_{grid}^{size,\mu_0}/2\right)N_{sc}^{RB}2^{\mu_0-\mu}$$

- $N_{RB}^{RA}N_{sc}^{RB}$ denotes the length of the RACH in terms of RE (See next slide)
- n_{RA} is a set and equals {0, 1, … M-1 }, where M equals one, two, four and eight and is given by the IE msg1-FDM
- $N_{grid}^{size,\mu}\, N_{sc}^{RB}/2$ is the frequency shift (FFT shift) of the final thing

Example for M=2



(All of the above (except k) are with respect to SCS and not PRACH Freq)

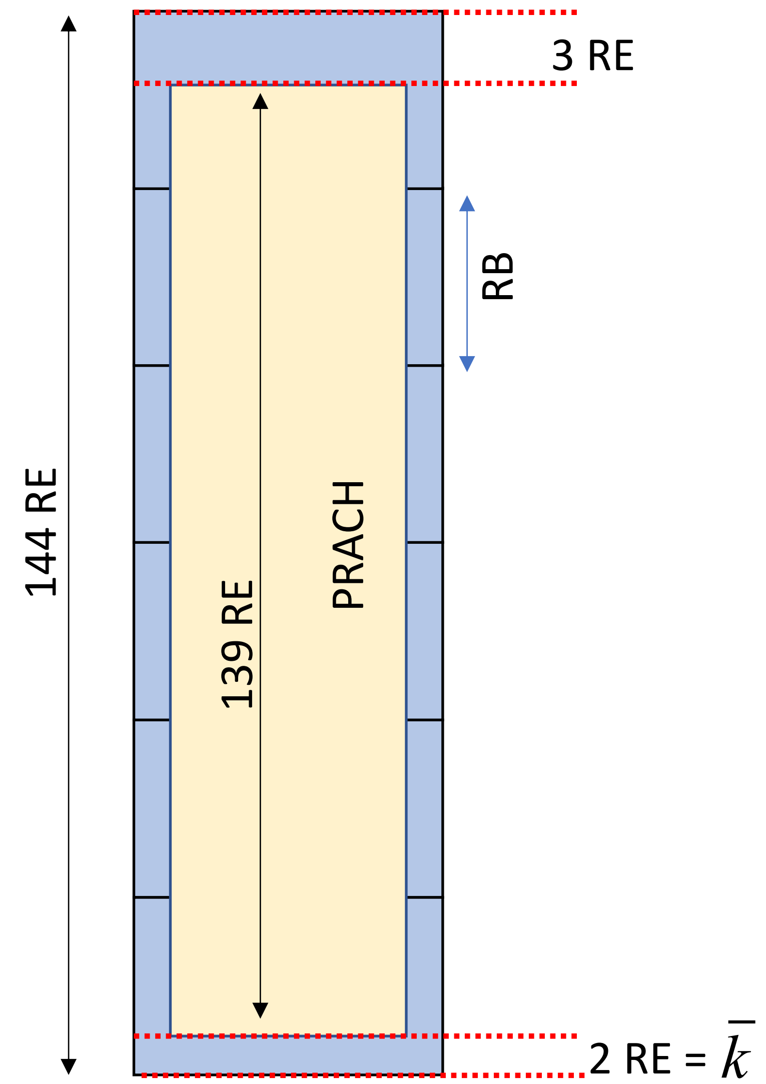
Supported PRACH Δf and Δf^{RA}

Table 6.3.3.2-1: Supported combinations of Δf^{RA} and Δf, and the corresponding value of $\bar{k}$.

L_{RA}	Δf^{RA} for PRACH	Δf for PUSCH	$N_{\text{RB}}^{\text{RA}}$, allocation expressed in number of RBs for PUSCH	$\bar{k}$
839	1.25	15	6	7
839	1.25	30	3	1
839	1.25	60	2	133
839	5	15	24	12
839	5	30	12	10
839	5	60	6	7
139	15	15	12	2
139	15	30	6	2
139	15	60	3	2
139	30	15	24	2
139	30	30	12	2
139	30	60	6	2
139	60	60	12	2
139	60	120	6	2
139	120	60	24	2
139	120	120	12	2

Observe that the PRACH length fits into the number of RBS allocated

- Consider Δf^{RA} =30 and Δf =30
  - 12 RB are allocated = > 144 RE (139 sequence fits)
- Consider Δf^{RA} =1.25 and Δf =15
  - 6 RE are allocated (in terms of Δf =15). This implies a total of 6x 12x (15/1.25) = 864 (839 sequence fits)



Example: 139 sequence with Δf^{RA} =30 and Δf =30.

Time Allocation

- Configured by the higher layer parameter
    - *prachConfigurationIndex*
    - Depends on FR1 or FR2
- n_{SFN} : System frame number (0 to 1023)
- E.g., *prachConfigurationIndex =70*
    - Odd number frames have PRACH
    - Implies PRACH frequency is 20 ms

FR1

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
		x	y					
65	3	1	0	1,4,6,9	0	-	-	0
66	3	1	0	1,3,5,7,9	0	-	-	0
67	A1	16	1	9	0	2	6	2
68	A1	8	1	9	0	2	6	2
69	A1	4	1	9	0	1	6	2
70	A1	2	1	9	0	1	6	2
71	A1	2	1	4,9	7	1	3	2
72	A1	2	1	7,9	7	1	3	2
73	A1	2	1	7,9	0	1	6	2
74	A1	2	1	8,9	0	2	6	2
75	A1	2	1	4,9	0	2	6	2
76	A1	2	1	2,3,4,7,8,9	0	1	6	2
77	A1	1	0	9	0	2	6	2
78	A1	1	0	9	7	1	3	2
79	A1	1	0	9	0	1	6	2
80	A1	1	0	8,9	0	2	6	2
81	A1	1	0	4,9	0	1	6	2
82	A1	1	0	7,9	7	1	3	2

Time allocation

$$s_l^{(p,\mu)}(t) = \sum_{k=0}^{L_{\mathrm{RA}}-1} a_k^{(p,\mathrm{RA})}\, e^{j2\pi(k+Kk_1+\bar{k})\Delta f_{\mathrm{RA}}\left(t-N_{\mathrm{CP},l}^{\mathrm{RA}}T_c-t_{\mathrm{start}}^{\mathrm{RA}}\right)}$$

$$K = \Delta f / \Delta f_{\mathrm{RA}}$$

$$k_1 = k_0^{\mu} + \left(N_{\mathrm{BWP},i}^{\mathrm{start}} - N_{\mathrm{grid}}^{\mathrm{start},\mu}\right)N_{\mathrm{sc}}^{\mathrm{RB}} + n_{\mathrm{RA}}^{\mathrm{start}}N_{\mathrm{sc}}^{\mathrm{RB}} + n_{\mathrm{RA}}N_{\mathrm{RB}}^{\mathrm{RA}}N_{\mathrm{sc}}^{\mathrm{RB}} - N_{\mathrm{grid}}^{\mathrm{size},\mu}N_{\mathrm{sc}}^{\mathrm{RB}}/2$$

$$k_0^{\mu} = \left(N_{\mathrm{grid}}^{\mathrm{start},\mu} + N_{\mathrm{grid}}^{\mathrm{size},\mu}/2\right)N_{\mathrm{sc}}^{\mathrm{RB}} - \left(N_{\mathrm{grid}}^{\mathrm{start},\mu_0} + N_{\mathrm{grid}}^{\mathrm{size},\mu_0}/2\right)N_{\mathrm{sc}}^{\mathrm{RB}}2^{\mu_0-\mu}$$

where $t_{\mathrm{start}}^{\mathrm{RA}} \le t < t_{\mathrm{start}}^{\mathrm{RA}} + \left(N_{\mathrm{u}} + N_{\mathrm{CP},l}^{\mathrm{RA}}\right)T_c$ and

Table 6.3.3.1-1: PRACH preamble formats for $L_{\mathrm{RA}} = 839$ and $\Delta f^{\mathrm{RA}} \in \{1.25, 5\}$ kHz.

Format	L_{RA}	Δf^{RA}	N_{u}	$N_{\mathrm{CP}}^{\mathrm{RA}}$	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

Table 6.3.3.1-2: Preamble formats for $L_{\mathrm{RA}} = 139$ and $\Delta f^{\mathrm{RA}} = 15 \cdot 2^{\mu}$ kHz where $\mu \in \{0,1,2,3\}$.

Format	L_{RA}	Δf^{RA}	N_{u}	$N_{\mathrm{CP}}^{\mathrm{RA}}$	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	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$2048\kappa \cdot 2^{-\mu}$	

Example: A1 sequence, PRACH: 30 KHZ, SCS: 30 KHZ

- Normal OFDM symbol length is $2048\kappa \cdot 2^{-\mu}$
- Normal CP length is $\{144\kappa \cdot 2^{-\mu} + 16\kappa$
  - 16k is for the first OFDM symbol in slot.
- We see that N_u is for two OFDM symbols and the length of CP is for 2 OFDM symbols
- So you have the CP (of twice the length of normal CP) in the beginning followed by the PRACH (repeating twice)
  - PRACH repeats twice since, the complex exponential is periodic (in t) with a time period of $1/\Delta f_{RA}$.
  - Hence the number of repetitions equal

$$\mathrm{Ts}\ \frac{2.2048\kappa.2^{-\mu}}{\Delta f_{RA}^{-1}}$$

  - which in the case of 30KHZ =2;

CP	Seq	Seq

No of times the sequence repeats (for SCS 15, 30,60,120)

Time allocation (CP Length)

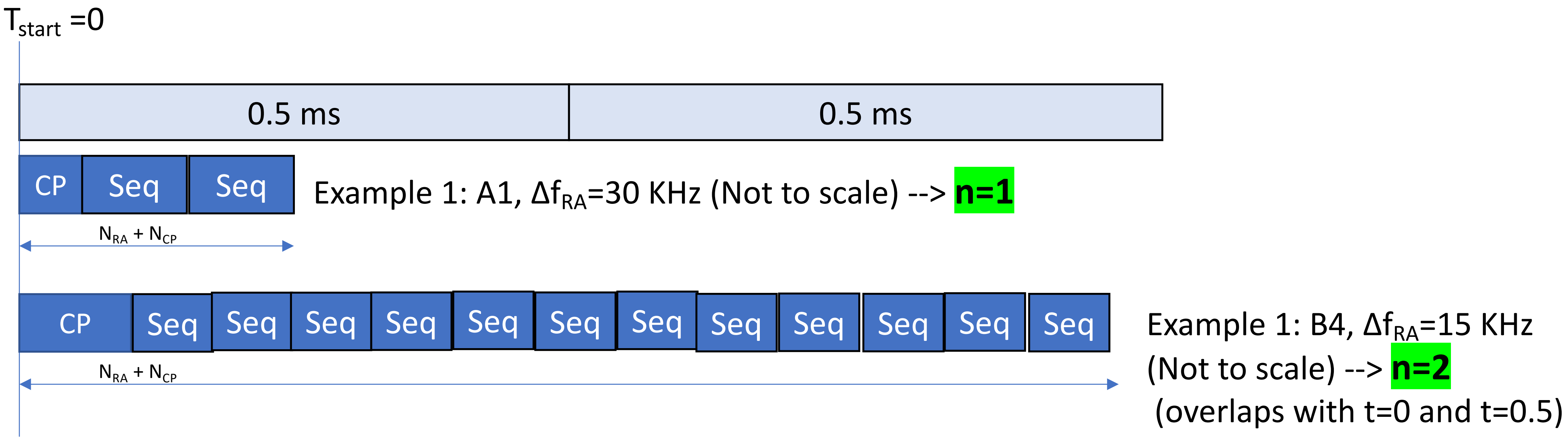
$$s_l^{(p,\mu)}(t) = \sum_{k=0}^{L_{RA}-1} a_k^{(p,RA)} e^{j2\pi(k+Kk_1+\bar{k})\Delta f_{RA}(t-N_{CP,l}^{RA}T_c - t_{start}^{RA})}$$
$$K = \Delta f/\Delta f_{RA}$$
$$k_1 = k_0^\mu + (N_{BWP,i}^{start} - N_{grid}^{start,\mu})N_{sc}^{RB} + n_{RA}^{start}N_{sc}^{RB} + n_{RA}N_{RB}^{RA}N_{sc}^{RB} - N_{grid}^{size,\mu}N_{sc}^{RB}/2$$
$$k_0^\mu = (N_{grid}^{start,\mu} + N_{grid}^{size,\mu}/2)N_{sc}^{RB} - (N_{grid}^{start,\mu_0} + N_{grid}^{size,\mu_0}/2)N_{sc}^{RB}2^{\mu_0-\mu}$$

where $t_{start}^{RA} \le t < t_{start}^{RA} + (N_u + N_{CP,l}^{RA})T_c$ and

$$N_{CP,l}^{RA} = N_{CP}^{RA} + n \cdot 16\kappa$$

- n=0 for Δf_{RA} ϵ {1.25,5}
- For Δf_{RA} ϵ {15,30,60,120}
  - It is the number of times $\left[t_{start}^{RA}, t_{start}^{RA} + (N_u^{RA} + N_{CP}^{RA})T_c\right[$ overlaps with time instant 0 or time instant 0.5 ms.

Recall: Even for normal OFDM 5G grid, every 0.5 ms require 16k extra CP length so that everything snugly fits in the 0.5 ms slot.



Guard period for different formats (in a PRACH slot)

Format	A= PRACH Length	B= TOTAL OFDM symbol length (closest number)	GP = (B-A)
A1	288k + 2048k + 2048 k	2*(144k + 2048k)	0
A2	4*(144k+2048k)	4*(144k + 2048k)	0
A3	6*(144k+2048k)	6*(144k+2048k)	0
B1	2*2048k+ 216k	2*(144k + 2048k)	$72k*2^{-u}$
B2	4*2048k+360k	4*(144k + 2048k)	$216k*2^{-u}$
B3	6*2048k+504k	6*(144k + 2048k)	$360k*2^{-u}$
B4	12*2048k + 936k	12*(144k + 2048k)	$792k*2^{-u}$
C0	2048*k +1240*k	2*(144k + 2048k)	$1096k*2^{-u}$
C2	4*2048+2048k	6*(144k + 2048k)	$2912k*2^{-u}$
2	4*24576k + 4688k	HOW??	

Table 6.3.3.1-1: PRACH preamble formats for $L_{RA} = 839$ and $\Delta f^{RA} \in \{1.25, 5\}$ kHz

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

Table 6.3.3.1-2: Preamble formats for $L_{RA} = 139$ and $\Delta f^{RA} = 15 \cdot 2^{\mu}$ kHz where $\mu \in \{0,$

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	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$2048\kappa \cdot 2^{-\mu}$	

Time allocation

- The start of the PRACH OFDM symbols coincides exactly with the start of the Global frame
- $$l = l_0 + n_t^{\mathrm{RA}} N_{\mathrm{dur}}^{\mathrm{RA}} + 14 n_{\mathrm{slot}}^{\mathrm{RA}}$$
- l_0 is the starting symbol
- N_{dur}^{RA} is the duration (in number of symbols) of the PRACH
- n_t^{RA} takes values from 0 to number of time-domain prach occasions with a PRACH slot -1
- For u = {30,120} Khz,
  - If no of PRACH slots withan a sub frame =1
    - Then n_{slot}^{RA} =1
    - Else, n_{slot}^{RA} ={0,1}
- For other u, n_{slot}^{RA} =0

PRACH Configuration Index	Preamble format	$n_{\mathrm{SFN}} \bmod x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_{\mathrm{t}}^{\mathrm{RA,slot}}$, number of time-domain PRACH occasions within a PRACH slot	$N_{\mathrm{dur}}^{\mathrm{RA}}$, PRACH duration
		x	y					
65	3	1	0	1,4,6,9	0	-	-	0
66	3	1	0	1,3,5,7,9	0	-	-	0
67	A1	16	1	9	0	2	6	2
68	A1	8	1	9	0	2	6	2
69	A1	4	1	9	0	1	6	2
70	A1	2	1	9	0	1	6	2
71	A1	2	1	4,9	7	1	3	2
72	A1	2	1	7,9	7	1	3	2
73	A1	2	1	7,9	0	1	6	2
74	A1	2	1	8,9	0	2	6	2
75	A1	2	1	4,9	0	2	6	2
76	A1	2	1	2,3,4,7,8,9	0	1	6	2

Time allocation Example(s)

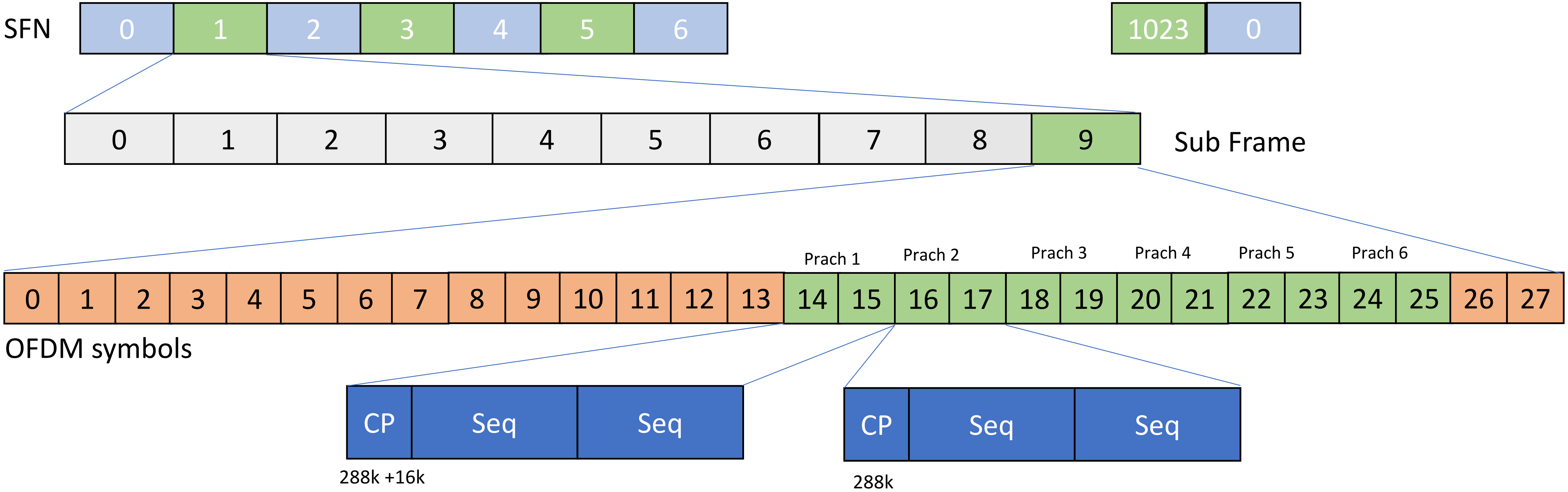
Let us assume the following parameters

- PRACH configuration index =70
  - Preamble format A1
  - X=2, y=1
  - Subframe number 9
  - Starting symbol =0
  - Number of prach slots within a sub-frame = 1
  - Number of time domain PRACH occasions within a PRACH slot = 6
  - PRACH duration=2
- Length 139, 30 KHz PRACH, 30 KHZ SCS

- ODD Frames
- $n_t^{RA}=\{0,1,2,3,4,5\}$
- $N_{dur}^{RA}=2$
- l0=0;
- $n_{slot}^{RA}=1$

$$l = l_0 + n_t^{RA} N_{dur}^{RA} + 14 n_{slot}^{RA}$$

PRACH Configuration Index	Preamble format	$n_{SFN} \bmod x = y$ 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
65	3	1	0	1,4,6,9	0	-	-	0
66	3	1	0	1,3,5,7,9	0	-	-	0
67	A1	16	1	9	0	2	6	2
68	A1	8	1	9	0	2	6	2
69	A1	4	1	9	0	1	6	2
70	A1	2	1	9	0	1	6	2
71	A1	2	1	4,9	7	1	3	2
72	A1	2	1	7,9	7	1	3	2
73	A1	2	1	7,9	0	1	6	2
74	A1	2	1	8,9	0	2	6	2
75	A1	2	1	4,9	0	2	6	2
76	A1	2	1	2,3,4,7,8,9	0	1	6	2
77	A1	1	0	9	0	2	6	2
78	A1	1	0	9	7	1	3	2
79	A1	1	0	9	0	1	6	2
80	A1	1	0	8,9	0	2	6	2
81	A1	1	0	4,9	0	1	6	2
82	A1	1	0	7,9	7	1	3	2



Time allocation Example(s)

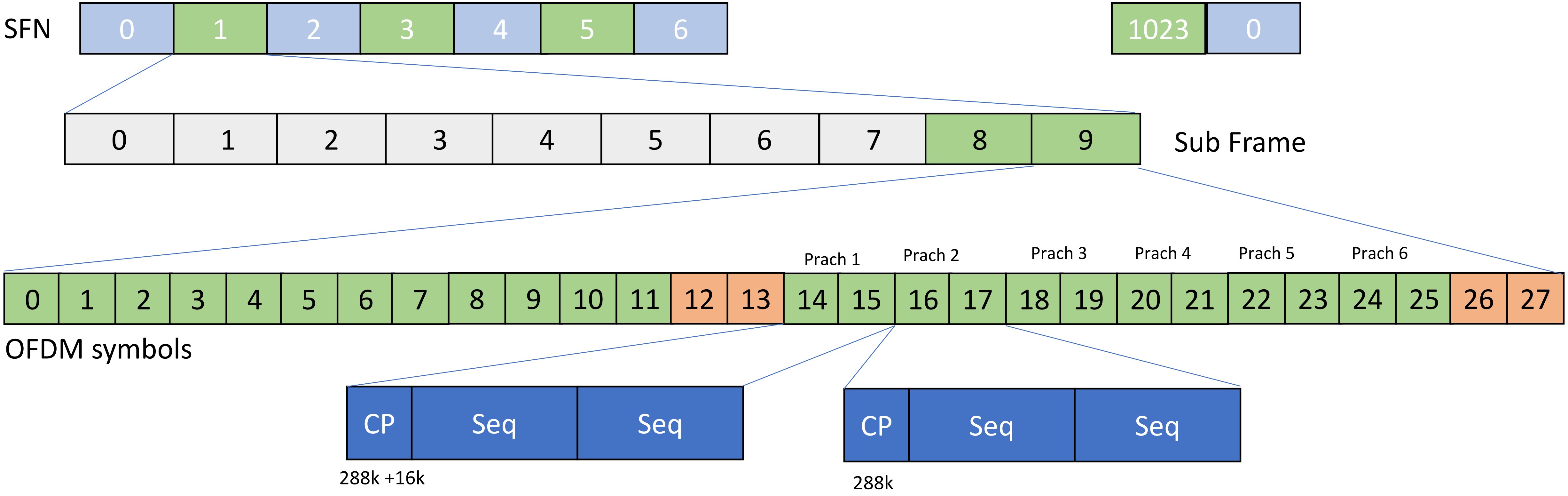
Let us assume the following parameters

- PRACH configuration index =74
  - Preamble format A1
  - X=2, y=1
  - Subframe number =8,9
  - Starting symbol =0
  - Number of prach slots within a sub-frame = 2
  - Number of time domain PRACH occasions within a PRACH slot = 6
  - PRACH duration=2
- Length 139, 30 KHz PRACH, 30 KHZ SCS

- ODD Frames
- n_t^{RA}={0,1,2,3,4,5}
- N_{dur}^{RA}=2
- l0=0;
- n_{slot}^{RA} ={0,1}

$$l = l_0 + n_t^{\text{RA}} N_{\text{dur}}^{\text{RA}} + 14 n_{\text{slot}}^{\text{RA}}$$

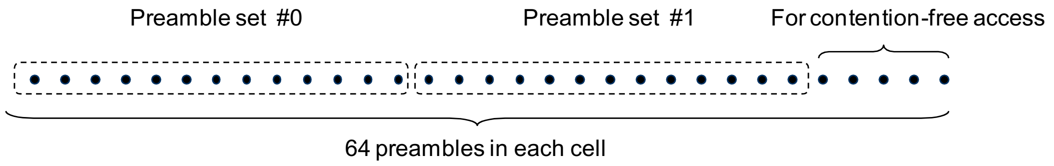
PRACH Configuration Index	Preamble format	$n_{\text{SFN}} \bmod x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_t^{\text{RA,slot}}$, number of time-domain PRACH occasions within a PRACH slot	$N_{\text{dur}}^{\text{RA}}$, PRACH duration
		x	y					
65	3	1	0	1,4,6,9	0	-	-	0
66	3	1	0	1,3,5,7,9	0	-	-	0
67	A1	16	1	9	0	2	6	2
68	A1	8	1	9	0	2	6	2
69	A1	4	1	9	0	1	6	2
70	A1	2	1	9	0	1	6	2
71	A1	2	1	4,9	7	1	3	2
72	A1	2	1	7,9	7	1	3	2
73	A1	2	1	7,9	0	1	6	2
74	A1	2	1	8,9	0	2	6	2
75	A1	2	1	4,9	0	2	6	2
76	A1	2	1	2,3,4,7,8,9	0	1	6	2
77	A1	1	0	9	0	2	6	2
78	A1	1	0	9	7	1	3	2
79	A1	1	0	9	0	1	6	2
80	A1	1	0	8,9	0	2	6	2
81	A1	1	0	4,9	0	1	6	2
82	A1	1	0	7,9	7	1	3	2



PRACH PROCEDURE (38.213)

Step1: Random Access Preamble Transmission

- Transmission of a RA preamble
  - Signals the gNodeB the presence of a RA attempt
  - Helps in estimating the timing advance
- Time-Frequency resource : PRACH
  - Broadcasted by the network to all the terminals (SIB-1)



- Information encoded
  - Location of the preamble
  - Circular shift

38.211, 8.2

Step2: Random access response

- gNodeB transmits a message on the DL-SCH
  - Index of the random-access preamble that the network detected
  - The timing correction
  - A scheduling grant (27 bits)
  - A temporary identity: TC-RNTI is assigned.
- Multiple RA attempts from different users are combined
  - DL-SCH and indicated on the PDCCH using RA-RNTI
  - Monitored by the UE
- Terminal adjusts its timing and proceeds to step 3

- Preamble index is called the RAPID

Table 8.2-1: Random Access Response Grant Content field size

RAR grant field	Number of bits
Frequency hopping flag	1
PUSCH frequency resource allocation	14
PUSCH time resource allocation	4
MCS	4
TPC command for PUSCH	3
CSI request	1

38.321, 6.2.2

MAC PDU

<table>
<tr><td>E</td><td>T</td><td colspan="2">RAPID</td></tr>
<tr><td>R</td><td colspan="3">Timing Advance Command</td></tr>
<tr><td colspan="3">Timing Advance Command</td><td>UL Grant</td></tr>
<tr><td colspan="4">UL Grant</td></tr>
<tr><td colspan="4">UL Grant</td></tr>
<tr><td colspan="4">UL Grant</td></tr>
<tr><td colspan="4">Temporary C-RNTI</td></tr>
<tr><td colspan="4">Temporary C-RNTI</td></tr>
</table>

Step 2 (Details)

- DCI format 1_0
  - RNTI = RA-RNTI [TS 38.321, 11]
  - $$\text{RA-RNTI} = 1 + s\_id + 14 \times t\_id + 14 \times 80 \times f\_id + 14 \times 80 \times 8 \times ul\_carrier\_id$$

where s_id is the index of the first OFDM symbol of the PRACH occasion ($0 \le s\_id < 14$), t_id is the index of the first slot of the PRACH occasion in a system frame ($0 \le t\_id < 80$), f_id is the index of the PRACH occasion in the frequency domain ($0 \le f\_id < 8$), and ul_carrier_id is the UL carrier used for Random Access Preamble transmission (0 for NUL carrier, and 1 for SUL carrier).

  - If RAPID is found by the higher layers before the timer expires
    - Timer (possible values)
      - {sl 1, sl 2, sl 4, sl 8, sl 10, sl 20, sl 40, sl 80} (SLOTS)
    - Uplink scheduling is indicated

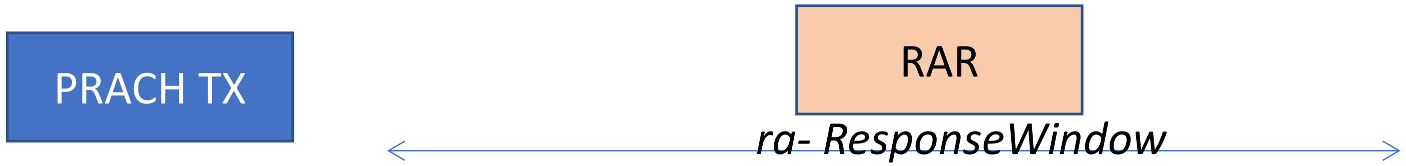
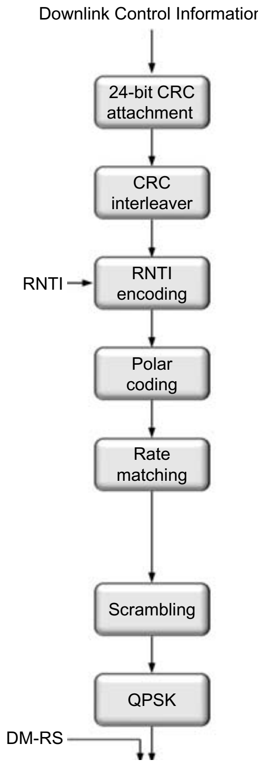


Table 10.1 DCI Formats 1–0 and 1–1 for Downlink Scheduling

Field		Format 1–0	Format 1–1
Format identifier		•	•
Resource information	CFI		•
	BWP indicator		•
	Frequency domain allocation	•	•
	Time-domain allocation	•	•
	VRB-to-PRB mapping	•	•
	PRB bundling size indicator		•
	Reserved resources		•
	Zero-power CSI-RS trigger		•
Transport-block related	MCS	•	•
	NDI	•	•
	RV	•	•
	MCS, 2nd TB		•
	NDI, 2nd TB		•
	RV, 2nd TB		•
Hybrid-ARQ related	Process number	•	•
	DAI	•	•
	PDSCH-to-HARQ feedback timing	•	•
	CBGTI		•
	CBGFI		•
Multi-antenna related	Antenna ports		•
	TCI		•
	SRS request		•
	DM-RS sequence initialization		•
PUCCH-related information	PUCCH power control	•	•
	PUCCH resource indicator		•



Step3: Terminal identification

- Terminal transmits using the UL-SCH in the second step
  - Includes terminal identity
    - If connected, the C-RNTI is used
    - Otherwise, a core network terminal identifier is used
  - UE_specific scrambling
    - TC-RNTI

Step 4: Contention Resolution

- If multiple UEs use the same preamble in the first step
- The UE identity (sent in step 3) is contained in the message.
  - All other UE’s understand that there is a collision and restart their RA procedure again.

Summary of the 4 steps

Step	UE	Direction	BS	Where
1	Sends RACH Preambles	→	Computes CR and TA. Also computes RA-RNTI	PRACH SLOT
2	Checks if RAPID belongs to the UE. Adjusts its TA and reads TC-RNTI	←	Random access response. Sends TC-RNTI -- TA, RAPID and UL schedule on PDSCH	PDCCH and PDSCH
3	Scrambles using TC-RNTI Sends a global UE identifier for the core network	→	If decoded, the BS will have an idea of the UE identity . Collision might happen. One or more UE's can be detected. BS can pick one UE.	PUSCH
4	UE(s) decode this DCI and checks for the UE identity. Only the UE for which the identity matches proceed further.	←	BS transmits DCI message with the chosen TC RNTI. Also has information about the chosen UE identity.	PDCCH
5	UE sends a HARQ	→		PUCCH

PRACH Power allocation

- Initial estimates based on estimates of path-loss combined with target power
- For i-th transmission occasion

$$P_{\mathrm{PRACH},b,f,c}(i) = \min\left\{P_{\mathrm{CMAX},f,c}(i),\ P_{\mathrm{PRACH,target},f,c} + PL_{b,f,c}\right\} \quad [\mathrm{dBm}],$$

Max power. 38.101-1/-2

Computed by using SSB

- For every preamble failure (38.321) (**only after the first time**)

preambleReceivedTargetPower (i+1) =preambleReceivedTargetPower(i) + DELTA_PREAMBLE + (PREAMBLE_POWER_RAMPING_COUNTER – 1) × PREAMBLE_POWER_RAMPING_STEP

```
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 (-200..-74),
  preambleTransMax               ENUMERATED {n3,n4,n5,n6,n7,n8,n10,n20,n50,n100,n2
  powerRampingStep               ENUMERATED {dB0, dB2, dB4, dB6},
  ra-ResponseWindow              ENUMERATED {sl1, sl2, sl4, sl8, sl10, sl20, sl40, sl80}
}
```

38.321, 6.2.2

Table 7.3-2: DELTA_PREAMBLE values for short preamble formats.

Preamble Format	DELTA_PREAMBLE values (dB)
A1	$8 + 3 \times \mu$
A2	$5 + 3 \times \mu$
A3	$3 + 3 \times \mu$
B1	$8 + 3 \times \mu$
B2	$5 + 3 \times \mu$
B3	$3 + 3 \times \mu$
B4	$3 \times \mu$
C0	$11 + 3 \times \mu$
C2	$5 + 3 \times \mu$

Path-loss computation (ideas)

```
ServingCellConfigCommon ::=          SEQUENCE {
    physCellId                           PhysCellId                                                  OPTIONAI
    downlinkConfigCommon                 DownlinkConfigCommon                                        OPTIONAI

    uplinkConfigCommon                   UplinkConfigCommon                                          OPTIONAI
    supplementaryUplinkConfig            UplinkConfigCommon                                          OPTIONAI
    n-TimingAdvanceOffset                ENUMERATED { n0, n25600, n39936 }                           OPTIONAI
    ssb-PositionsInBurst                 CHOICE {
        shortBitmap                          BIT STRING (SIZE (4)),
        mediumBitmap                         BIT STRING (SIZE (8)),
        longBitmap                           BIT STRING (SIZE (64))
    }
    ssb-periodicityServingCell           ENUMERATED { ms5, ms10, ms20, ms40, ms80, ms160, spare2, spare1 }
    dmrs-TypeA-Position                  ENUMERATED {pos2, pos3},
    lte-CRS-ToMatchAround                SetupRelease { RateMatchPatternLTE-CRS }
    rateMatchPatternToAddModList         SEQUENCE (SIZE (1..maxNrofRateMatchPatterns)) OF RateMatchPattern
    rateMatchPatternToReleaseList        SEQUENCE (SIZE (1..maxNrofRateMatchPatterns)) OF RateMatchPatternId
    subcarrierSpacing                    SubcarrierSpacing
    tdd-UL-DL-ConfigurationCommon        TDD-UL-DL-ConfigCommon
    ss-PBCH-BlockPower                   INTEGER (-60..50),
    ...
}
```

- SIB1 has the value of the pBCH-BlockPower (for the SSS sequence)
- Based on this and the received power, the UE can compute the path loss.

ss-PBCH-BlockPower
Average EPRE (energy per resource element) of the resources elements that carry secondary synchronization signals in dBm that the NW used for SSB transmission. The UE uses it to estimate the RA preamble TX power. (see TS 38.213 [13], clause 7.4)

PRACH SSB Association

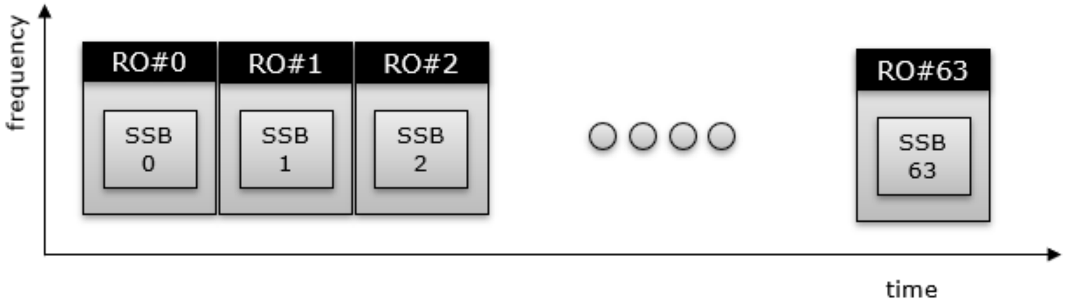
- Unlike LTE, NR has many possible RACH locations.
- Recall that multiple SSBlocks are possible for a half frame.
  - For mmwae systems (or even sub-6), each SSBlock might correspond to a different direction.
  - How does the UE convey which direction (or which SSBlock index) it was able to decode so that the BS knows the direction?
    - Use different PRACH locations to convey this information.
- A specific mapping between SSB and RACH occasions (RO)
- Two parameters
  - Msg1-fdm
  - ssb-perRACH-OccasionAndCB-PreamblesPerSSB

```
ssb-perRACH-OccasionAndCB-PreamblesPerSSB   CHOICE {
    oneEighth                               ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32,n36,n40,n44,n48,n52,n56,n60,n64},
    oneFourth                               ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32,n36,n40,n44,n48,n52,n56,n60,n64},
    oneHalf                                 ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32,n36,n40,n44,n48,n52,n56,n60,n64},
    one                                     ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32,n36,n40,n44,n48,n52,n56,n60,n64},
    two                                     ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32},
    four                                    INTEGER (1..16),
    eight                                   INTEGER (1..8),
    sixteen                                 INTEGER (1..4)
}
```

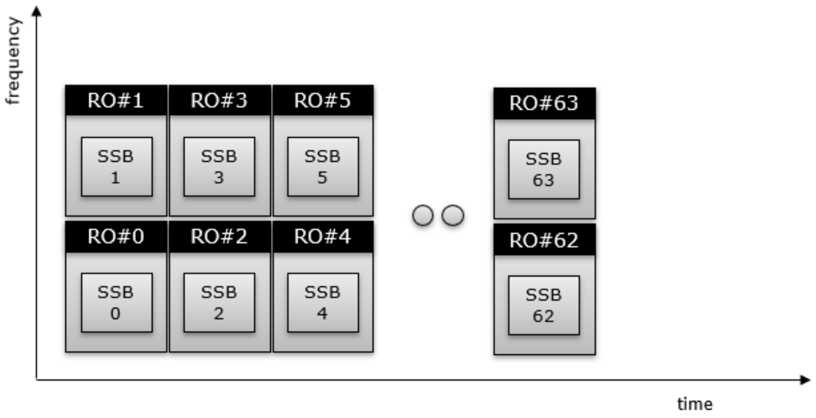
- msg-FDM specifies how many RO are allocated in frequency domain (at the same location in time domain)
- ssb-perRACH-OccasionAndCB-PreamblesPerSSB specifies how many SSB can be mapped to one RO and how many premable index can be mapped to single SSB.
  - First, in increasing order of preamble indexes within a single PRACH occasion
  - Second, in increasing order of frequency resource indexes for frequency multiplexed PRACH occasions
  - Third, in increasing order of time resource indexes for time multiplexed PRACH occasions within a PRACH slot
  - Fourth, in increasing order of indexes for PRACH slots

Examples

- msg1-FDM = one
- ssb-perRACH-OccasionAndCB-PreamblesPerSSB = one

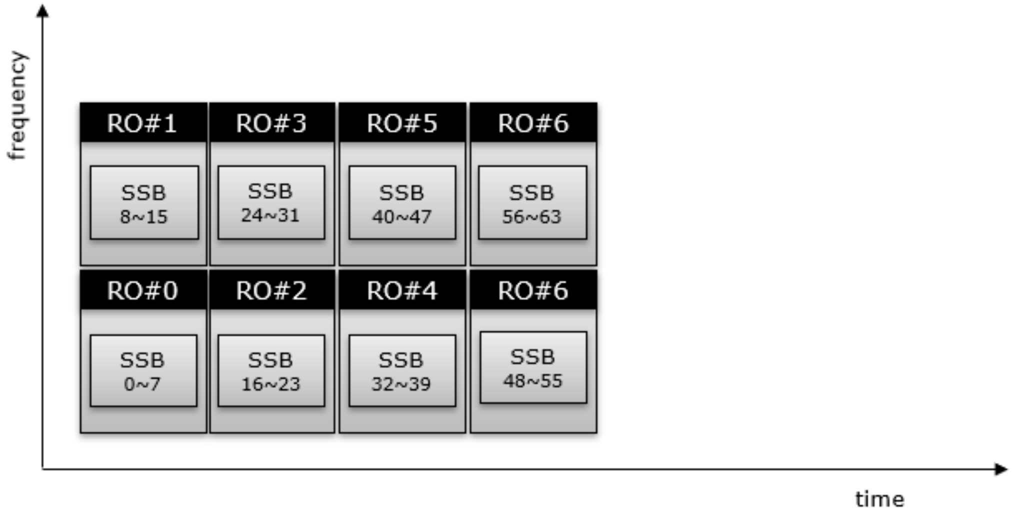


- msg1-FDM = two
- ssb-perRACH-OccasionAndCB-PreamblesPerSSB = one

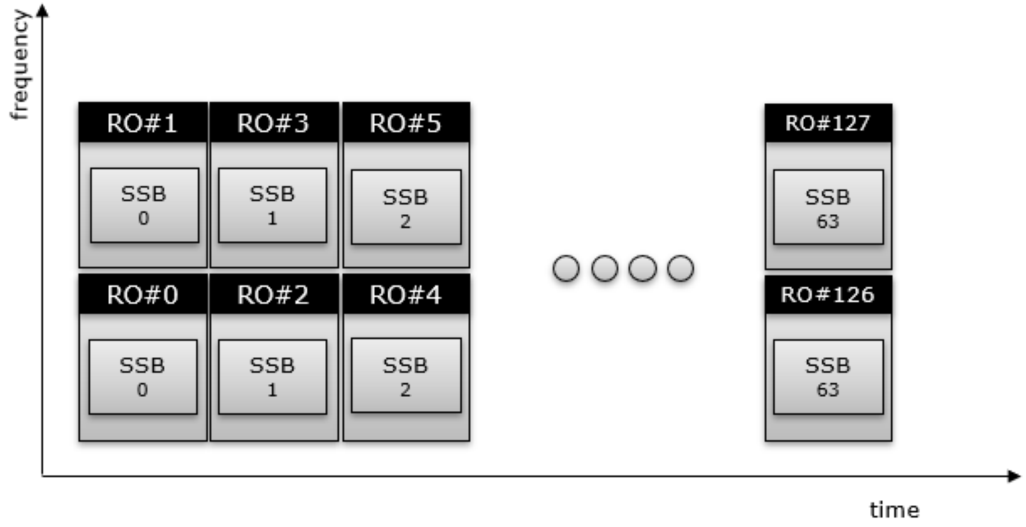


Examples (contd…)

- msg1-FDM = two
- ssb-perRACH-OccasionAndCB-PreamblesPerSSB = eight



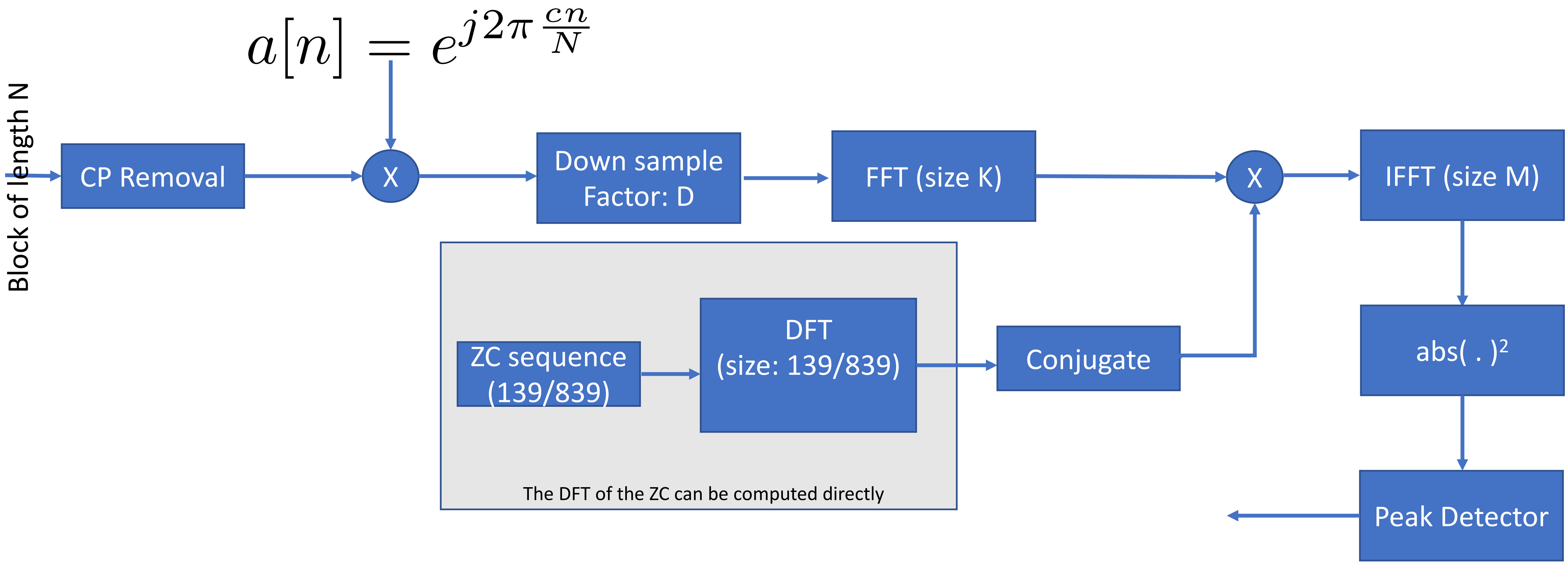
- msg1-FDM = two
- ssb-perRACH-OccasionAndCB-PreamblesPerSSB = oneHalf



PRACH Response time

Extra Slides

Decoding Strategies [FFT based correlation, hybrid approach]



How to choose the parameters c, D, K and M?

Choosing the parameters

- C is chosen so that c Δf = frequency difference between the center frequency of PRACH and the center frequency of the Grid (DC sub carrier).
  - This operation of multiplying with a[n], would center the PRACH at DC.

- D is chosen so that the output length K= N/D is a power of 2.
  - Also D should be chosen so that there is no aliasing, *i.e,*

$$D \leq \frac{f_s(\text{sampling frequency})}{\text{Prach BW}}$$

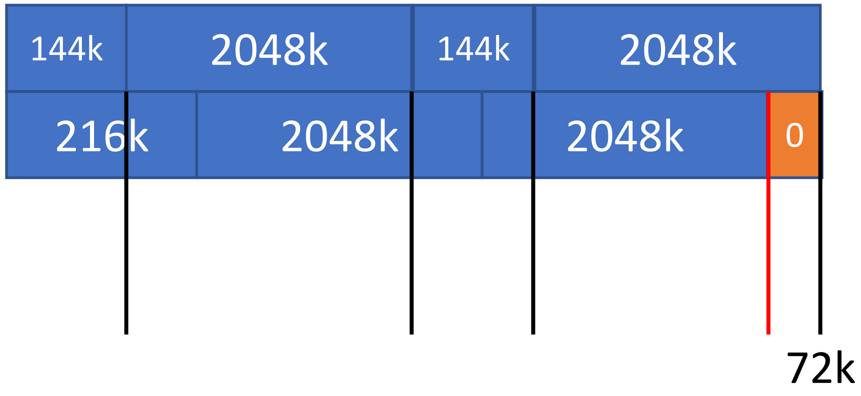
- FFT M is chosen so that the output resolution is enough $\frac{1}{M\Delta f_{RC}} < T_r$

Table 8.4.2.1-1: Time error tolerance for AWGN and TDLC300-100 [38.104]

PRACH preamble	PRACH SCS (kHz)	Time error tolerance	
		AWGN	TDLC300-100
0	1.25	1.04 us	2.55 us
A1, A2, A3, B4, C0, C2	15	0.52 us	2.03 us
	30	0.26 us	1.77 us

Parameters for A1 format (PRACH index 70)

- D = 16
- K= 4096/16 =256
- M=256



B1 Format....