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Qualcomm

Introduction to 5G NR

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Agenda

- Overview
- Numerologies
- Protocol Stack
- Initial Access
- Control Channels
- Data Channels
- Beam Management
- Bandwidth Part

This presentation focuses on 3GPP **Release 15.**
Thanks for my colleagues in ESG for providing the content.

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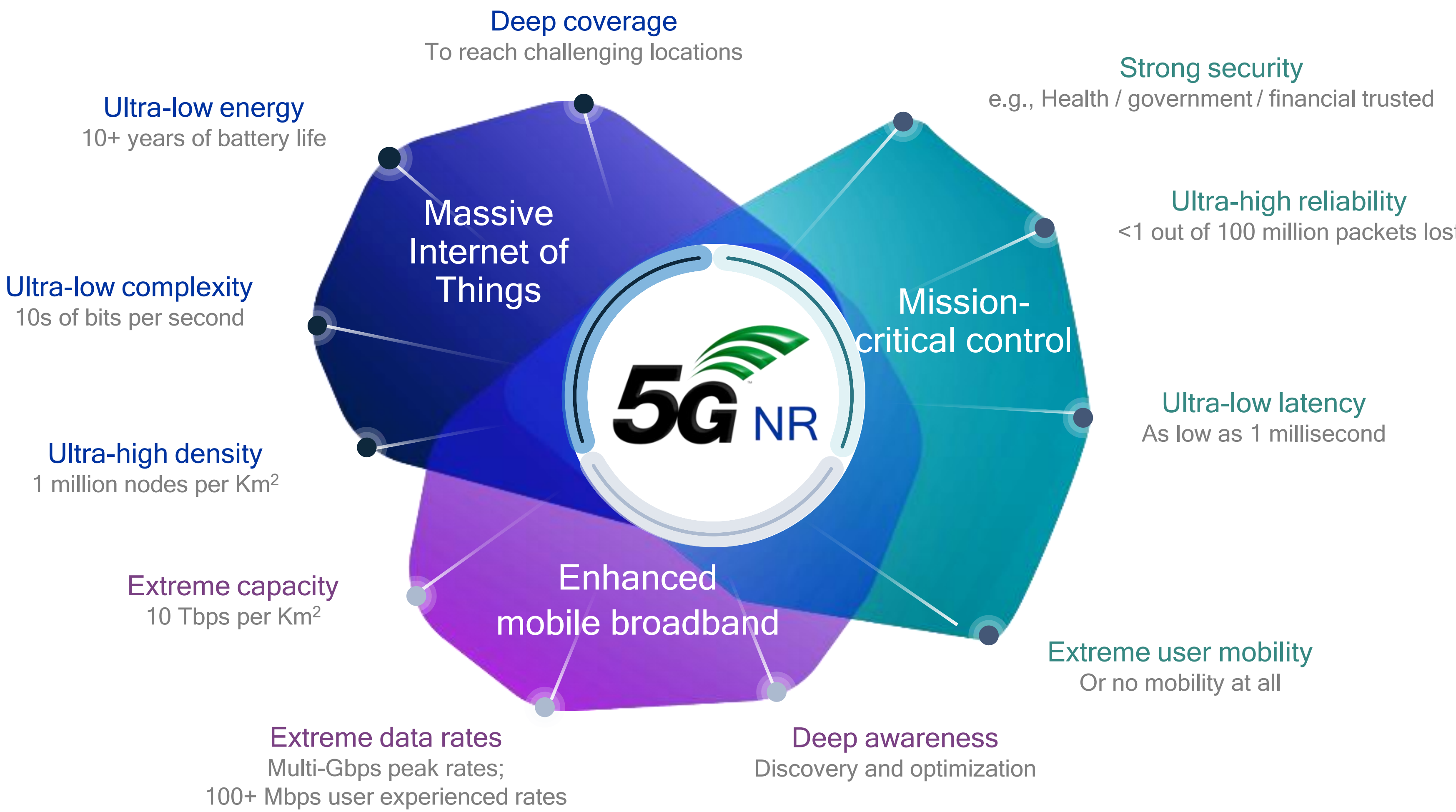
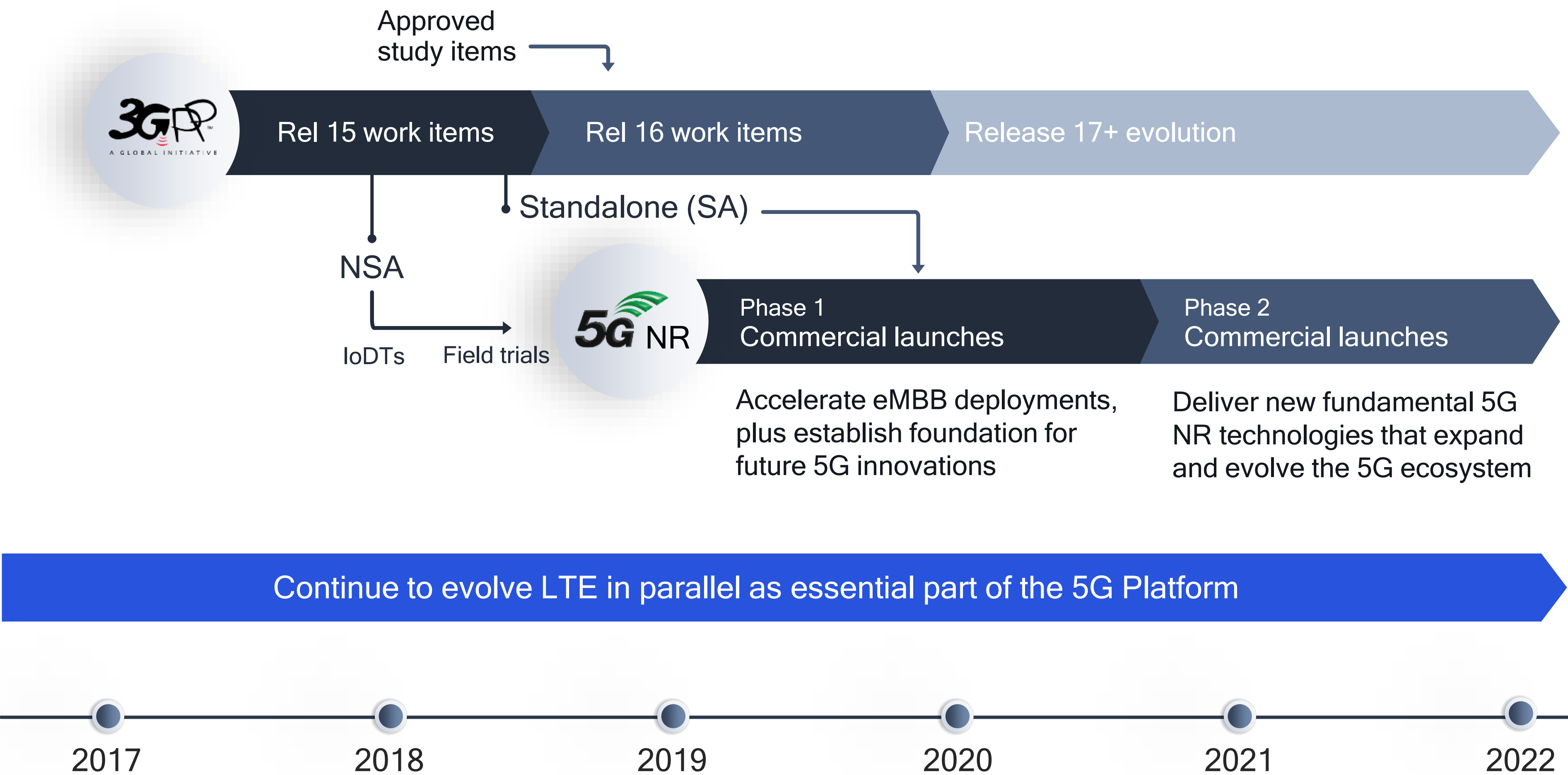
5G: Motivation and Driver

Scalability to address diverse service and devices

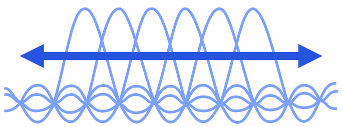


5G NR Specifications Timeline



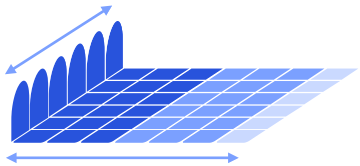
Key Air Interface Enablers

Scalable OFDM-based air interface



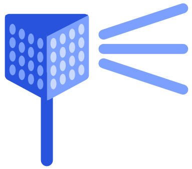
Efficiently address diverse spectrum, deployments/services

Flexible slot-based framework



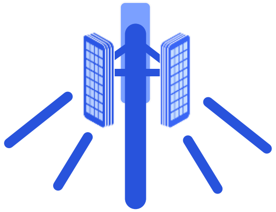
Key enabler to low latency, URLLC and forward compatibility

mmWave Spectrum



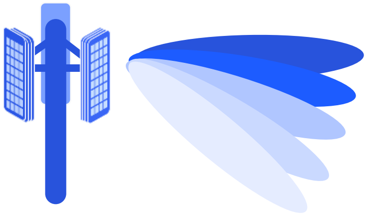
Enables wide bandwidths for extreme capacity and throughput

Massive MIMO



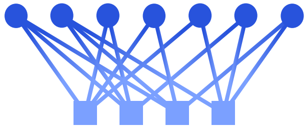
Efficiently utilize a large number of antennas to increase coverage and capacity

Beam Sweeping



Enables the coverage of a sector-wide area using a set of narrow and high gain beams

Advanced channel coding



Efficiently support large data blocks and a reliable control channel

Scalable Numerologies

5G NR supports multiple OFDM Sub-Carrier Spacing (SCS)

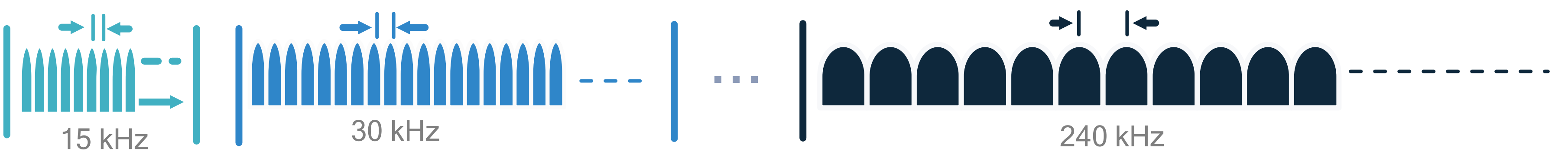
- 15, 30, 60, 120, and 240 kHz is supported

Sub-6 GHz

Sub-carrier Spacing (kHz)	Cyclic Prefix	Data / SSB
15	Normal	SSB, Data
30	Normal	SSB, Data
60	Normal, Extended	Data

mmWave

Sub-carrier Spacing (kHz)	Cyclic Prefix	Data / SSB
60	Normal, Extended	Data
120	Normal	SSB, Data
240	Normal	SSB



Channel Bandwidth

Supported combinations and number of Resource Blocks (RB)

- Rel 15 supports max 275 PRBs and limit the per-carrier bandwidth to 400 MHz, resulting in the maximum carrier bandwidths of 50/100/200/400 MHz for 15/30/60/120 kHz SCS

Sub-6 GHz – Channel BW and number of RBs

SCS (kHz)	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz	40 MHz	50 MHz	60 MHz	80 MHz	90 MHz	100 MHz
15	25	52	79	106	133	160	216	270	-	-	-	-
30	11	24	38	51	65	78	106	133	162	217	245	273
60	-	11	18	24	31	38	51	65	79	107	121	135

mmWave – Channel BW and number of RBs

SCS (kHz)	50 MHz	100 MHz	200 MHz	400 MHz
60	66	132	264	-
120	32	66	132	264

Resource Block is defined as 12 consecutive OFDM subcarriers in frequency, regardless of the numerology.

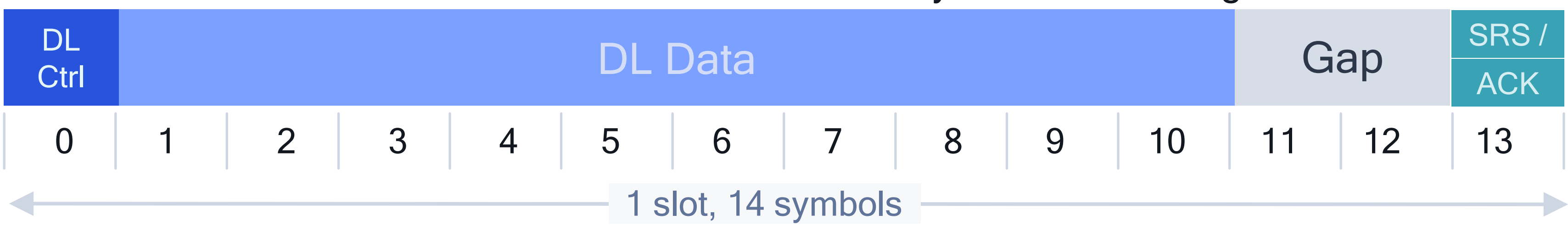
Self-Contained Slots

Motivations and Use Cases

- Motivation ➔ Support low latency communications (e.g., URLLC)

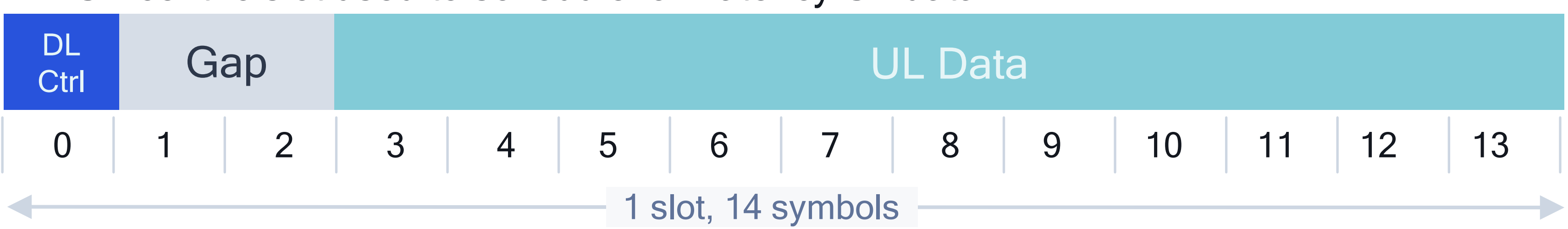
Use case 1 ➔ DL data and UL (N)ACK in the same slot

- DL-centric slot used to transfer DL data with a very fast acknowledgment



Use case 2 ➔ DL grant and UL data transmission in the same slot

- UL-centric slot used to schedule low latency UL data



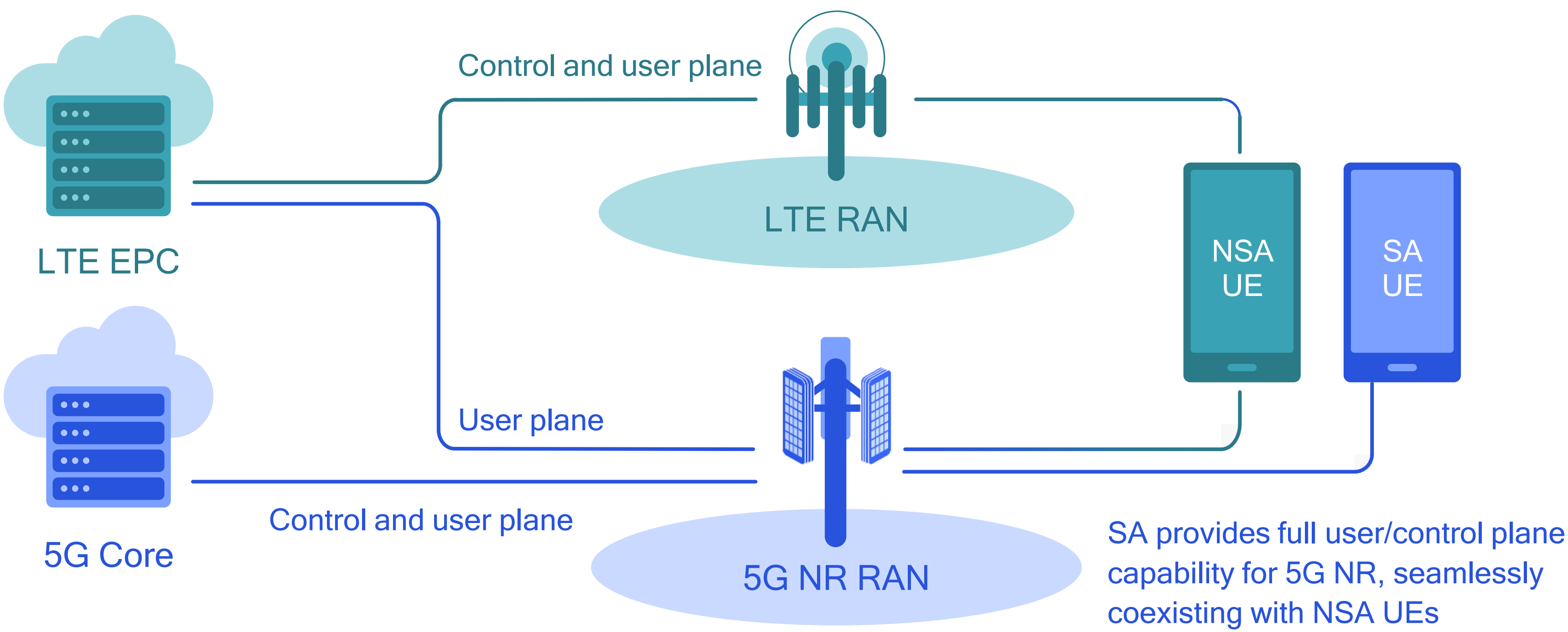
5G Standalone (SA) and Non-standalone (NSA)

Standalone

- Control plane and user plane are provided by 5G RAN

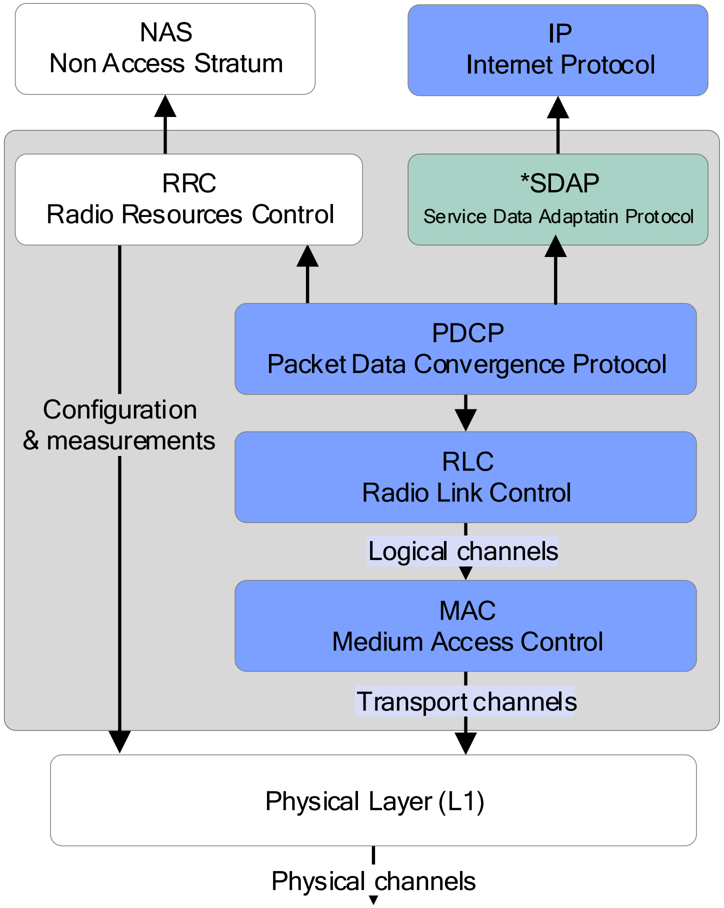
Non-standalone

- Control plane is provided by E-UTRAN
- Only user plane is provided by 5G RAN



Protocol Layer Overview

5G NR has a similar protocol structure as LTE with a new AS sublayer - *SDAP (Service Data Adaptation Protocol)



NR Radio Bearer Configuration

- CN association indicate that the bearer is associated with the eps-bearer ID (when connected to EPC) or sdap-Config (when connected to 5GC).

**Note: The new SDAP layer is only applicable to the connection with 5GC (i.e., SA mode)*

SDAP Overview

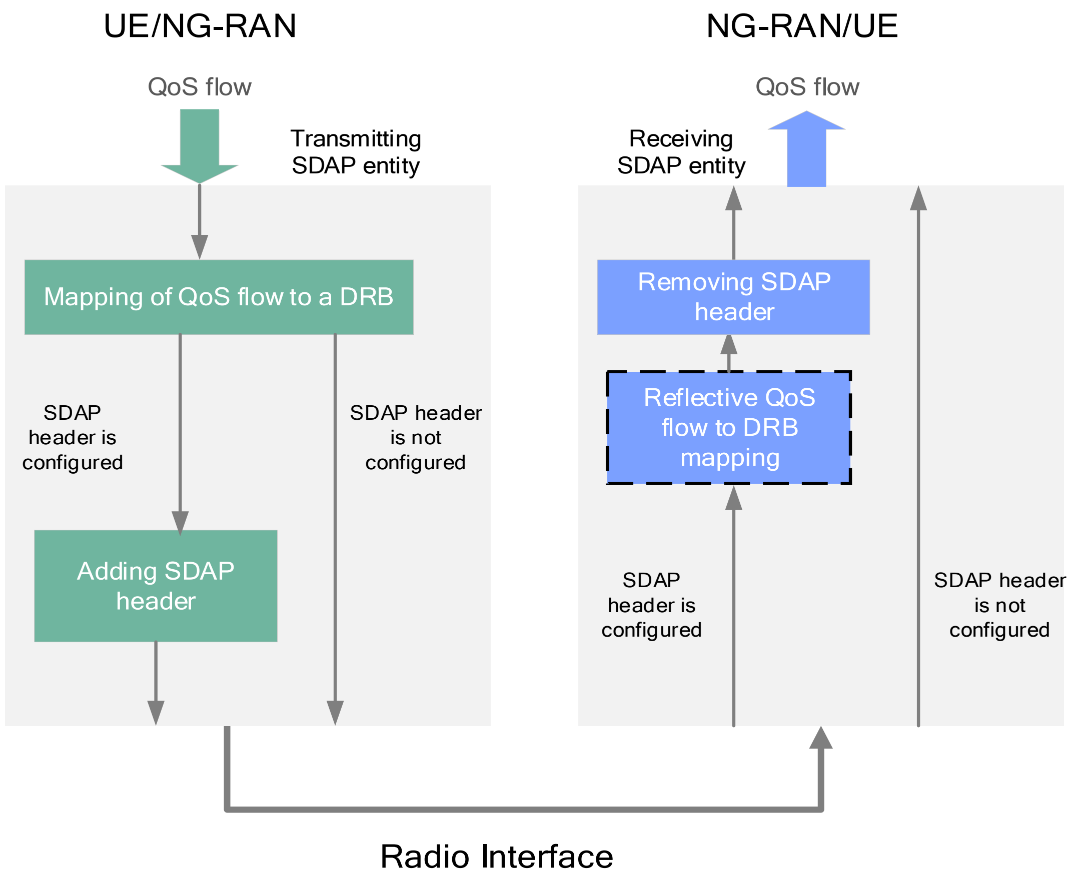
SDAP : Service Data Adaptation Protocol

The SDAP sublayer is configured by RRC and maps QoS flows to DRBs

- The SDAP entities are located in the SDAP sublayer
- There is a SDAP entity configured for each individual PDU session

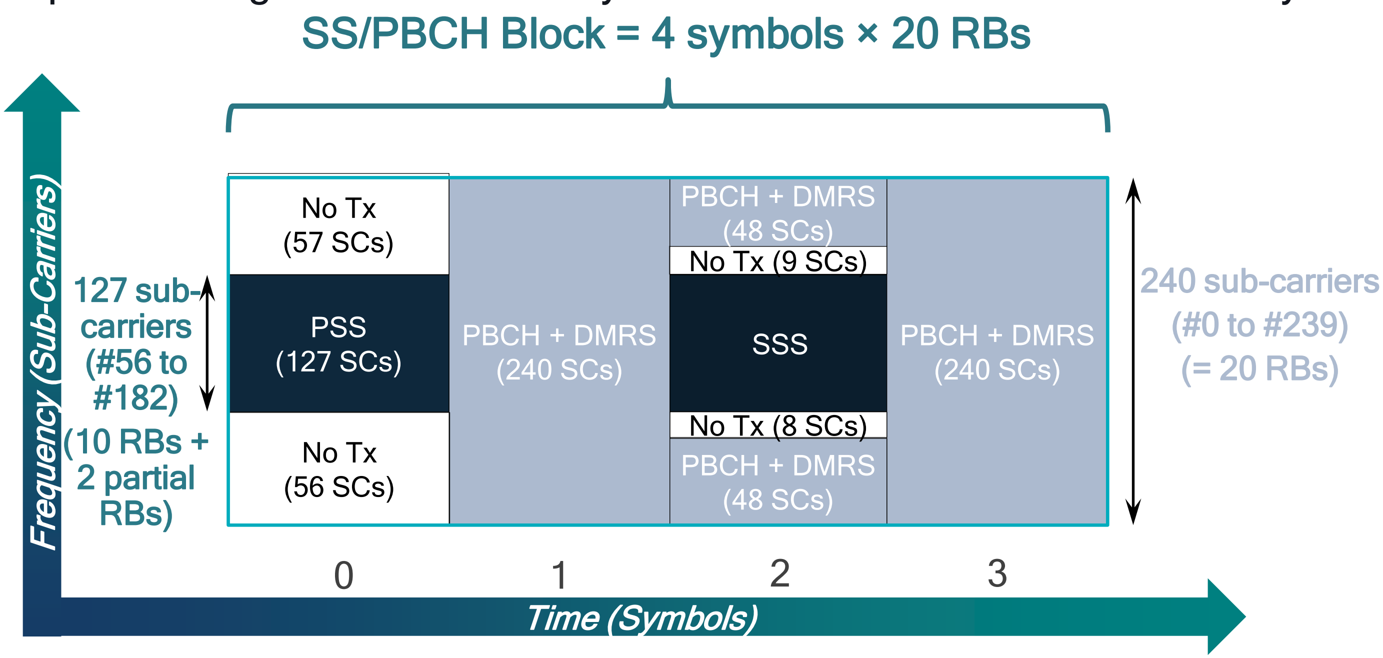
SDAP Major Functions

- Transfer of user plane data
- Mapping between a QoS flow and a DRB for both DL and UL
- Reflective QoS flow to DRB mapping for the UL SDAP data PDUs



SS/PBCH Block

- PSS, SSS and PBCH is encapsulated in 4 consecutive symbols which build an SS/PBCH block
  - "No Tx" subcarriers (with zero energy) next to PSS and SSS regions ease sync signal detection
- PBCH spans through 3 consecutive symbols and has embedded DMRS symbols



- SCS is the same within SS/PBCH block

Carrier Frequency	SS/PBCH Block	SCS for SS/PBCH Block
≤ 6 GHz	Type A	15 or 30 kHz
> 6 GHz (mmWave)	Type B	120 or 240 kHz

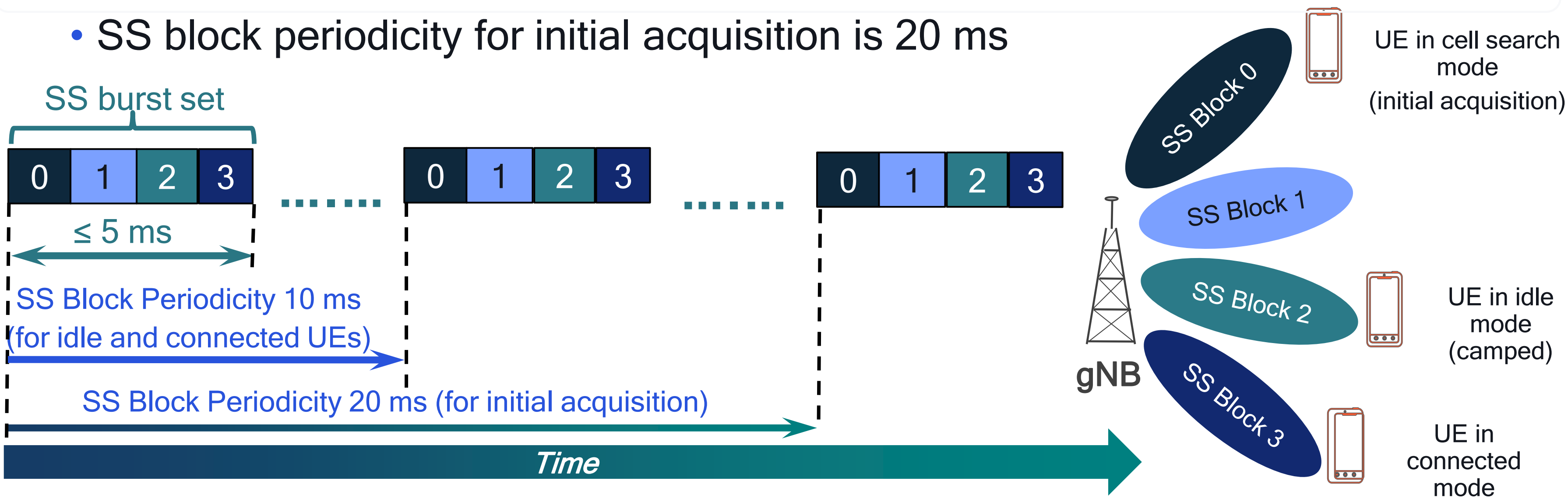
SSB Burst set and Periodicity

SS burst set is a collection of SS blocks broadcast in the cell

- Within a maximum 5 ms window (i.e., within a half-frame)
- Contains one or more SS blocks
- Maximum number (“L”) is frequency dependent
- SS block index (0, 1, … , L-1) is encoded in the PBCH DMRS (and in the PBCH payload, for mmWave)

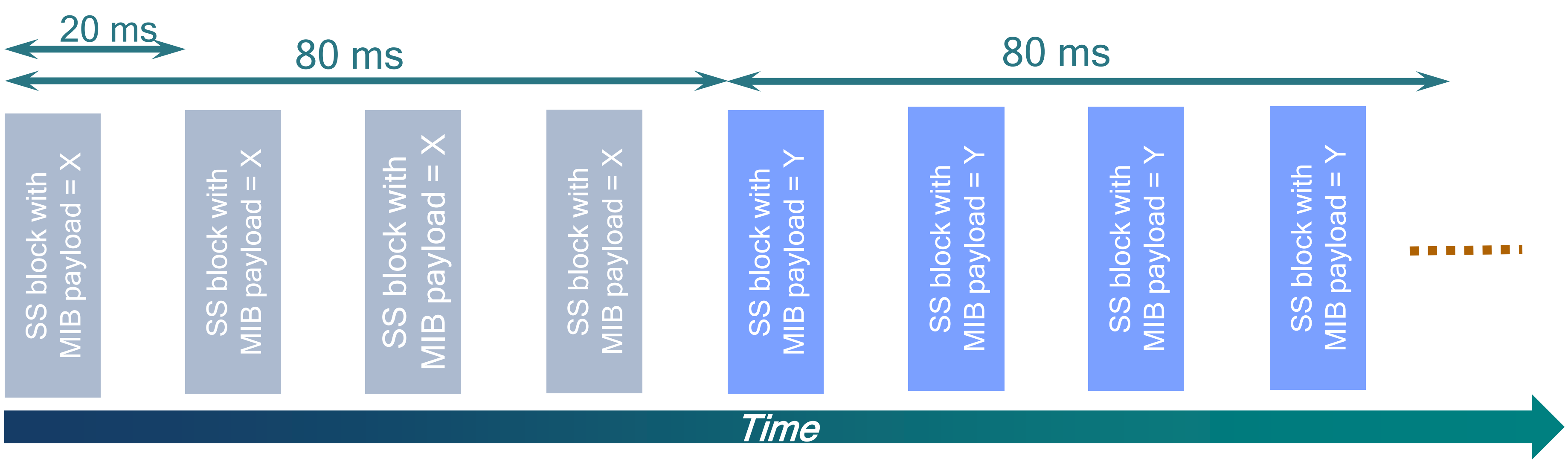
SSB periodicity is configurable (5 to 160 ms)

- SS block periodicity for initial acquisition is 20 ms



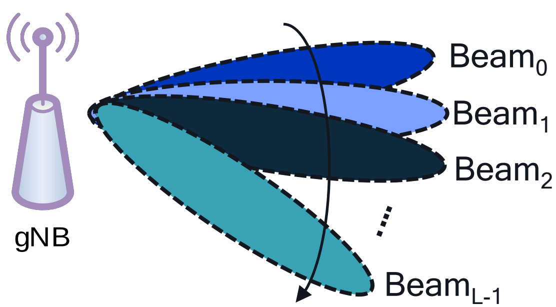
PBCH: Payload

- Each SS block carries complete PBCH payload (self-decodable).
  - PBCH payload has MIB, physical bits and 3 bits from DMRS scrambling sequences.
- Identical MIB for the same and different SSB is transmitted 4 times in 80 ms to ease decoding with soft combining.
  - UE can soft-combine these repetitions: similar design to LTE.

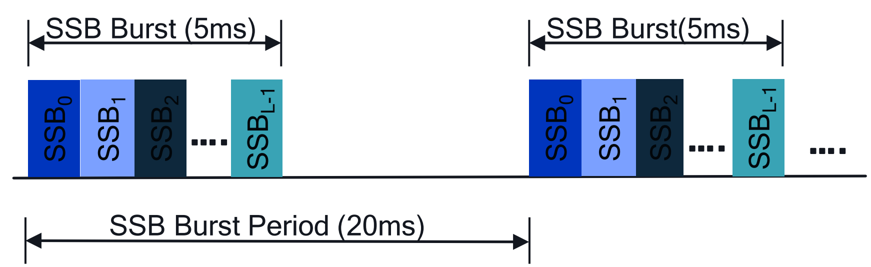


RACH Resource Selection via Association

- gNB transmits SSBs in a beam-sweeping manner.
- **RMSI are transmitted in a beam sweeping manner** using the same beams as the SSBs.
  - RACH parameters are provided in RMSI*
- PRACH resources are determined via **association between SSB index and resources of that index**, specified in RMSI.
- UE decodes RMSI and **extracts the RACH resources** associated with the received SSB.



Beam-sweeping



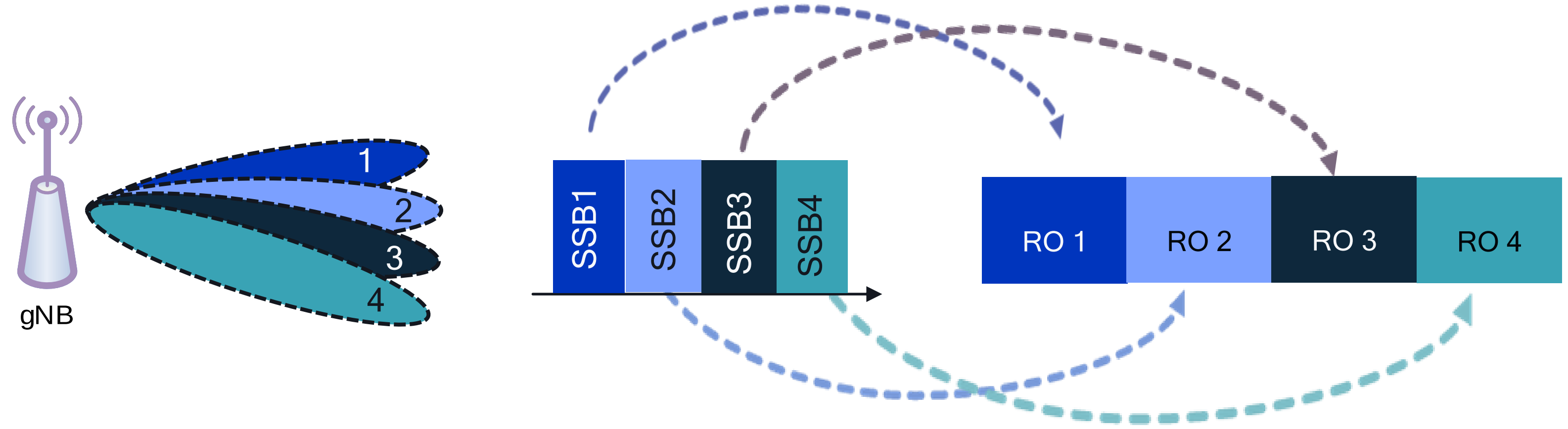
SSB Bursts

*RMSI = Remaining Minimum System Information

RACH Occasions and Association with SSBs

RACH Occasions (RO) - Time and frequency resources used for sending PRACH

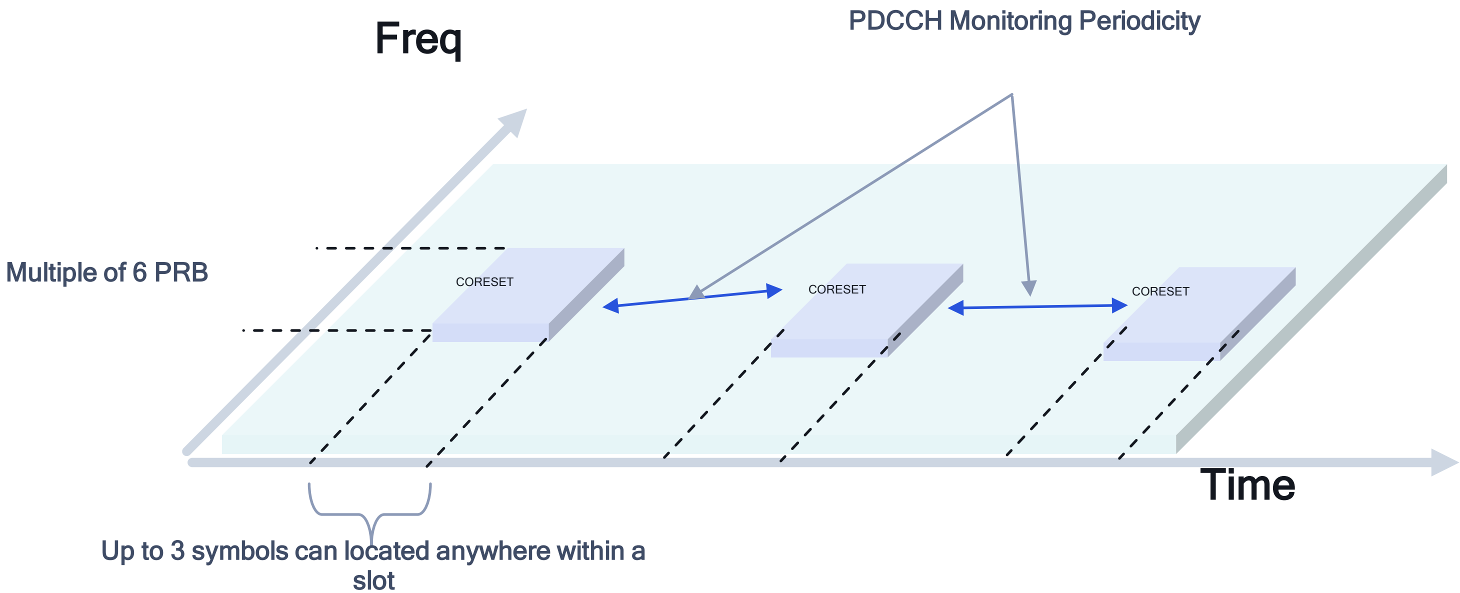
- RACH configuration is given in the RMSI.
- Number of RACH occasions per time instance varies and is configured by the networks (details given later).
- SS blocks and RACH preamble index / RACH resource association is based on SS blocks actually transmitted
    - RRC Reconfiguration in NSA and RMSI in SA indicate bitmap with actually transmitted SSB indices.



Control Channel Structure

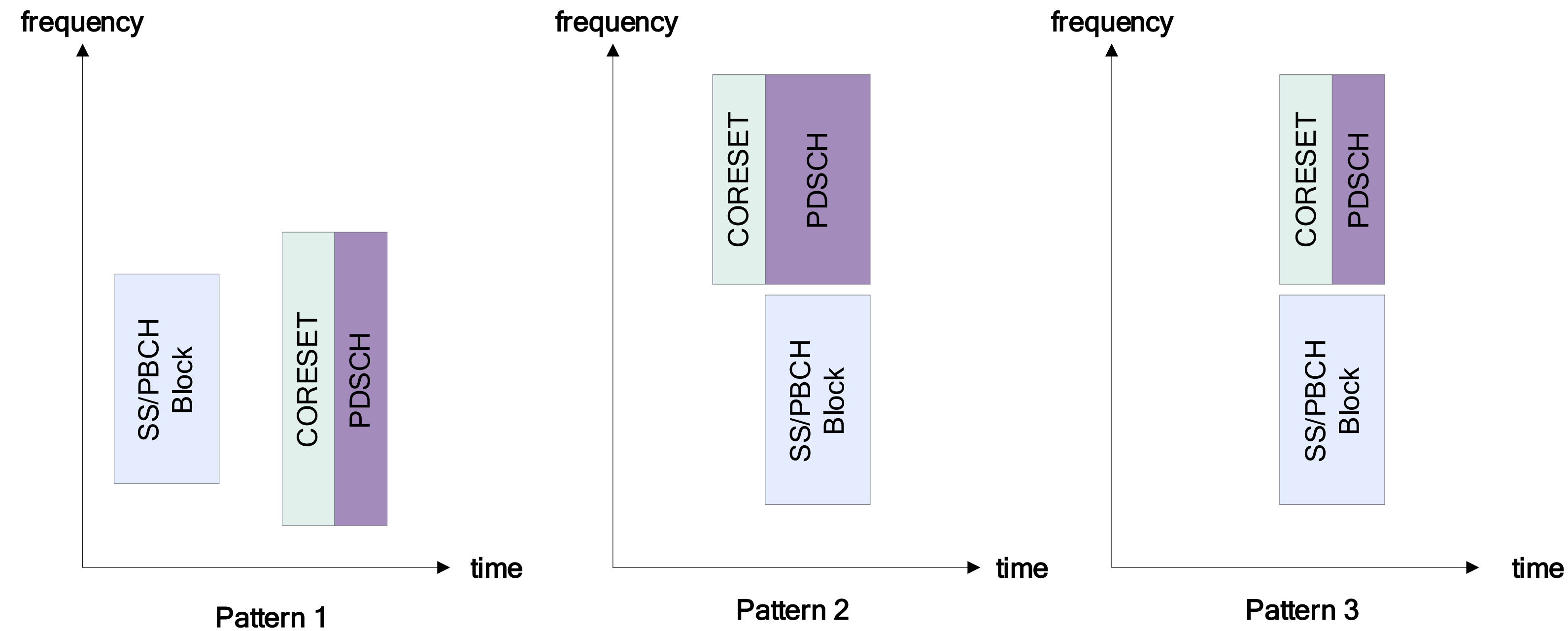
CORESET

- Semi-Statically configured by RRC (size, location and periodicity, etc.).
- Occupy up to **3 symbols** in the time domain and a **multiple of 6 PRBs** in the frequency domain.
- CORESET might not exist in all BWP as it is a cell level configuration and UE specific.
- User data can be allocated in unused CORESET.



CORESET for RMSI PDCCH

CORESET size and time/frequency position relative to cell defined SSB for RMSI is indicated by pdcch-ConfigSIB1 in MIB.

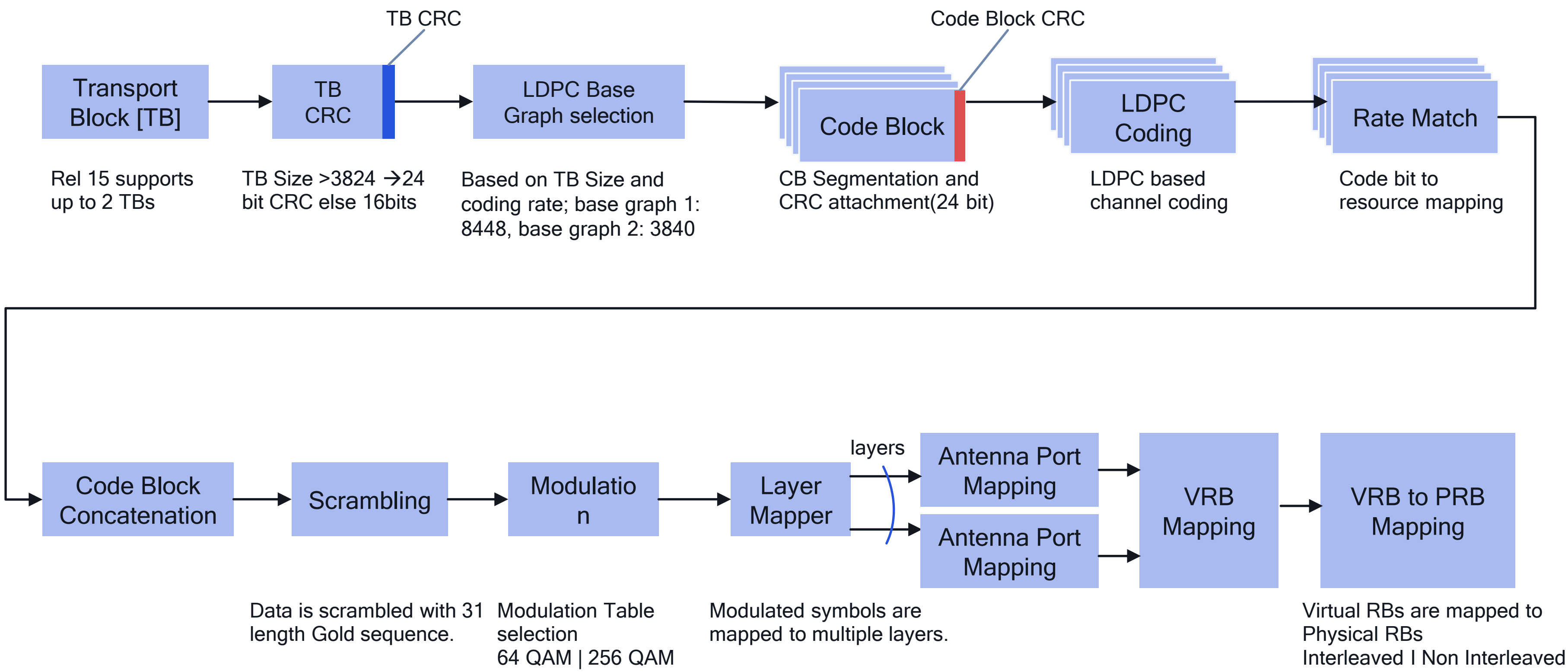


SS block and RMSI CORESET occur at **different** time instances (TDM)

SS block and RMSI CORESET **have different numerologies**, occur at the **same** time instances (FDM)

SS block and RMSI CORESET have the **same numerology**, occur at the **same time instance** (FDM)

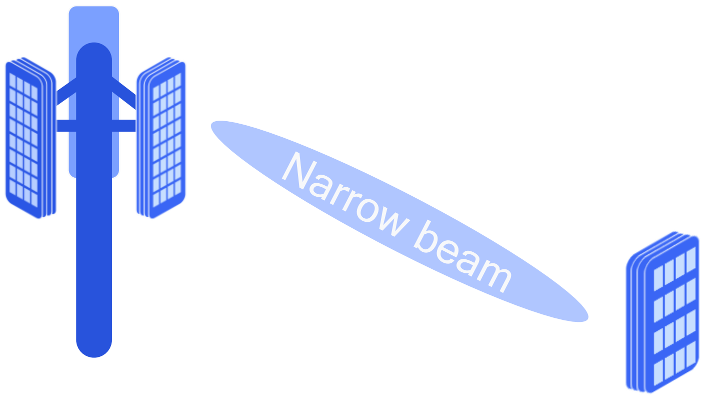
Data Channel Processing: PDSCH/PUSCH



Massive MIMO and Beam Sweeping

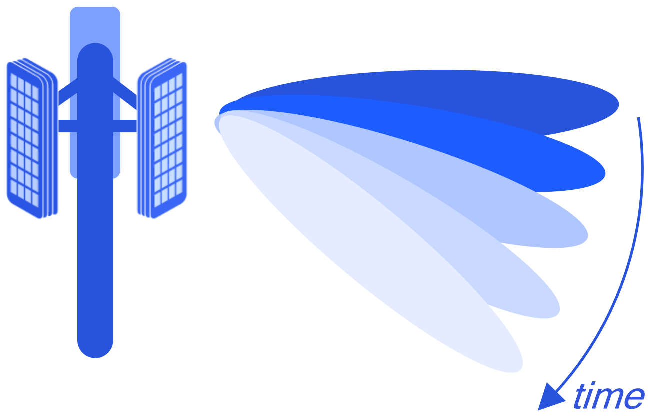
Massive MIMO

- 5G NR employs massive MIMO to mitigate the disadvantages of high frequency propagation.
- Massive MIMO antenna arrays, with large number of elements, intrinsically create narrow beams.



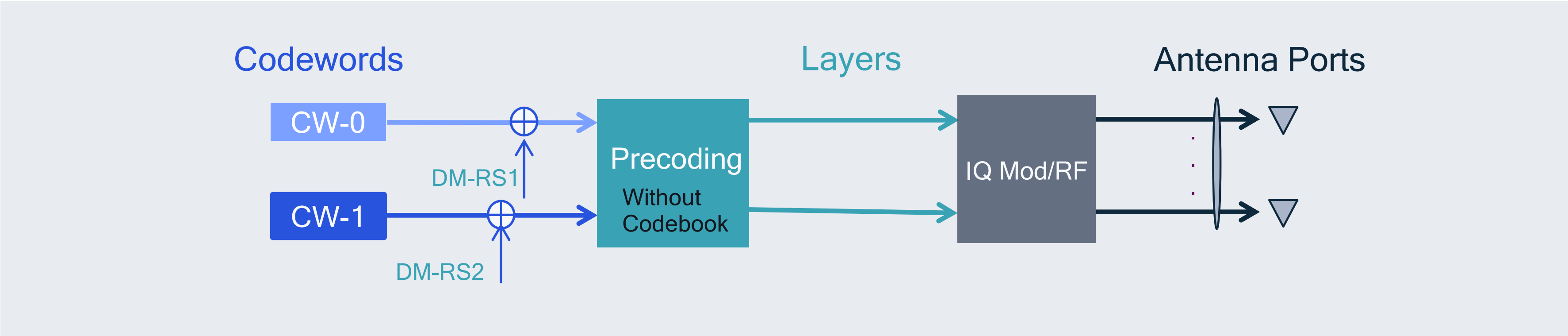
Beam sweeping

- A narrow beam does not provide coverage over a cell area.
- Beam sweeping allows the gNB to periodically steer one narrow beam in different directions to cover a wide area.



DL Transmission Scheme

- 5G NR supports only one transmission scheme (TS1) for DL data operation.
- Data and DMRS are transmitted with the same precoding matrix.
  - UE data demodulation does not need knowledge of the precoding matrix that was used at the transmitter.



PUSCH Transmission: Codebook Based

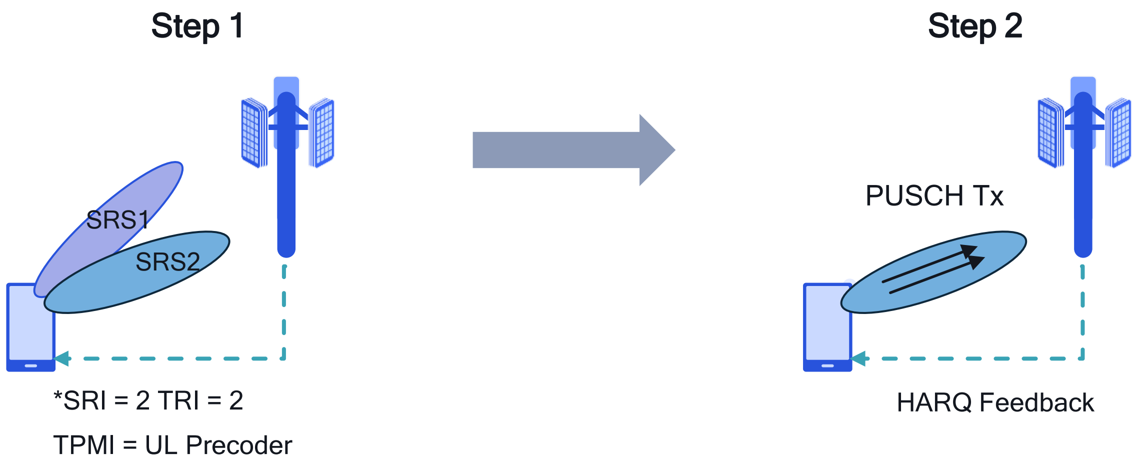
RRC signaling can select codebook based transmission via IE “*ulTxConfig*” = ‘Codebook’

- gNB configures UE with SRS resources based on UE Capability – codebook restriction.
- UE transmits SRS with configured resources and gNB estimates UL channel estimation.

*Note: SRI: Sounding Reference Signal Resource Index
TRI: Transmission rank indicator
TPMI: Transmission Precoder Metrix Index

- UL beam and its precoder and rank is determined by gNB based on UL SRS channel estimation and Codebook subset restriction.
- TPMI (Transmit Precoding Matrix Indicator), SRI (SRS Resource Indicator) is indicated to the UE in DCI grant.
- UE transmits PUSCH using precoder index given in DCI grant.

Codebook Based PUSCH Transmission



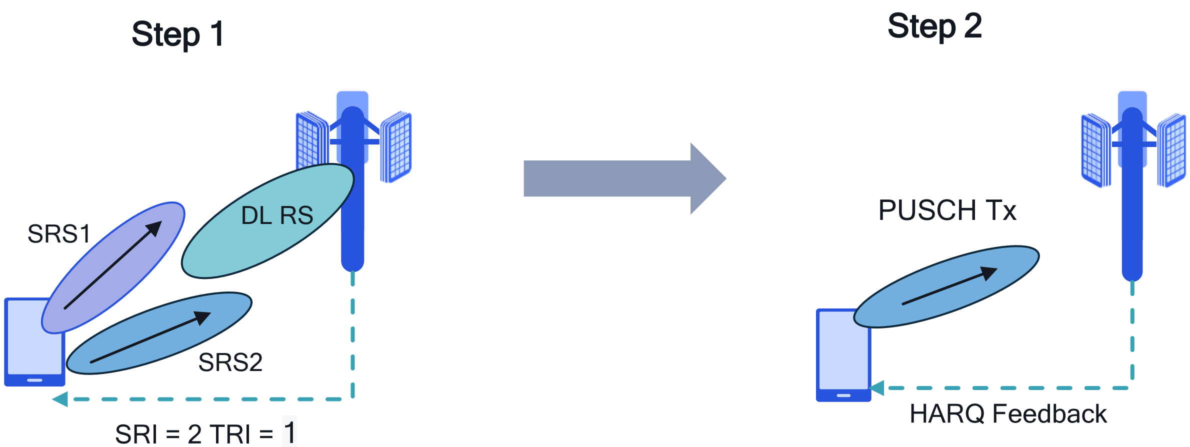
Usage Scenario: UL/DL channel reciprocity is not present

PUSCH Transmission: Non-codebook Based

RRC signaling can select non-codebook based transmission via IE "*ulTxConfig*" = 'Non-codebook'

- gNB configures UE with SRS resources, CSI RS Resources and Spatial association b/w CSI RS and SRS based on UE Capability - Coherence and Number of Ports.
- UE calculates UL precoders based on transmitted DL CSI RS.
- gNB selects the subset of SRS resources (SRI) and indicates in DCI grant (no PMI is provided).
- UE transmits PUSCH as per the DCI grant using precoder that is used for one or more SRS resource.

Non-codebook Based PUSCH Transmission



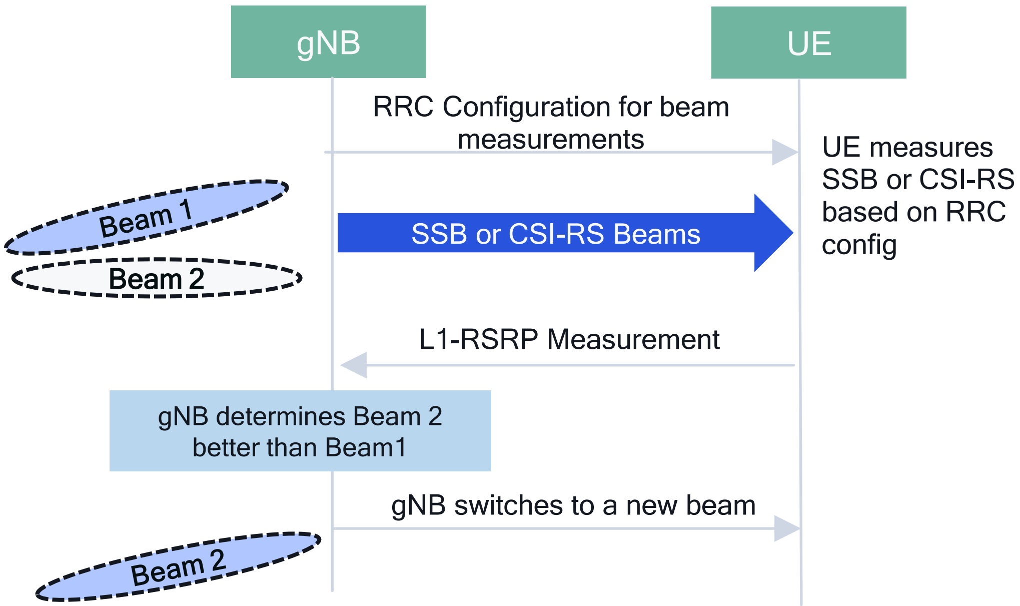
Usage Scenario: UL/DL channel reciprocity is present (TDD)

Beam Switching - DL gNB Beam Switching

DL gNB beam switching is based on UE reporting

DL gNB beam switching steps

1. gNB configures UE to measure and report based on SSB, CSI-RS or both combined.
2. UE sends L1-RSRP measurements of the strongest beams.
3. gNB takes the decision to switch the beam serving the UE.
   - Switching the DL gNB beam is done by the indication of a new TCI state (covered later in this section).
   - If CSI-RS is used, its transmission and the corresponding L1-RSRP reporting may be periodic, aperiodic, or semi-persistent.
   - L1-RSRP contains beam indexes and the corresponding RSRP.

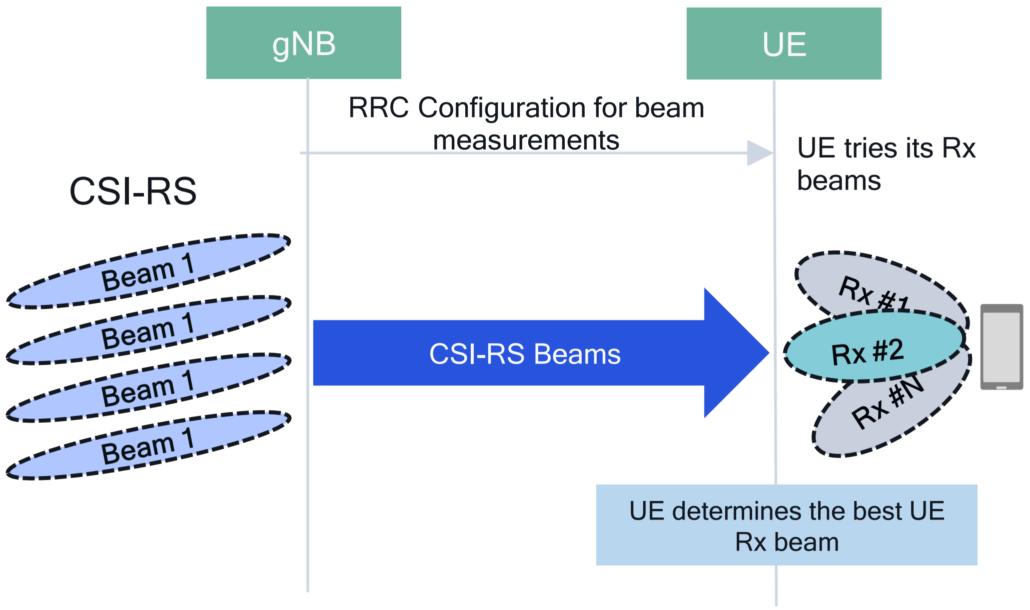


Beam Switching - DL UE Rx Beam Switching

DL UE beam switching is based on repeating CSI-RS

DL UE beam switching steps

1. gNB configures UE to measure repeating CSI-RS.
2. gNB sends repeated CSI-RS (over the same beams).
3. UE tries different Rx beams to determine the best one.
   - There is no need for the UE to communicate the UE Rx beam to the gNB.
   - Repeating CSI-RS are explicitly configured by RRC with the flag *Repetition=ON*.



Bandwidth Part (BWP)

Definitions

- BWP ➔ Set of contiguous PRBs within one carrier

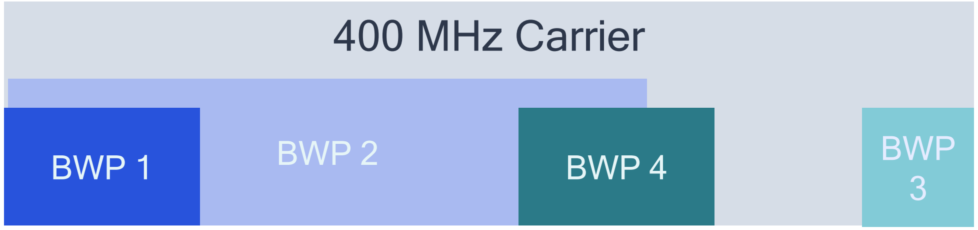
BWP Configurations

- Each BWP has an associated numerology, bandwidth and frequency location
- UE can be configured with up to 4 BWPs[1]
  - Only one BWP is active at any moment [2]
- BWP configuration is UE-specific

BWP use cases and examples

- Support BW limited UE, UE may not support the entire carrier bandwidth
- Support different numerologies within one carrier
- UE battery saving

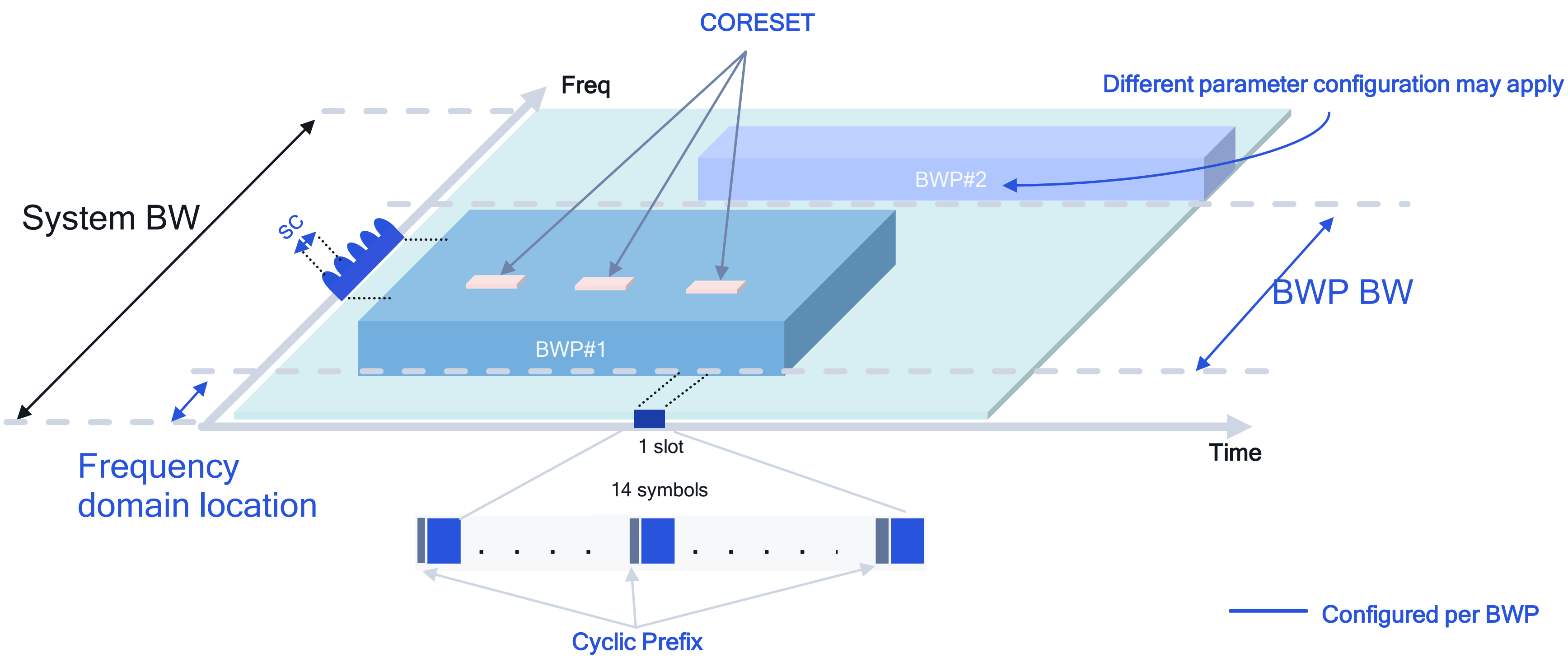
Example of BWPs configuration for one UE



BWP Configuration

DL and UL BWP Parameters

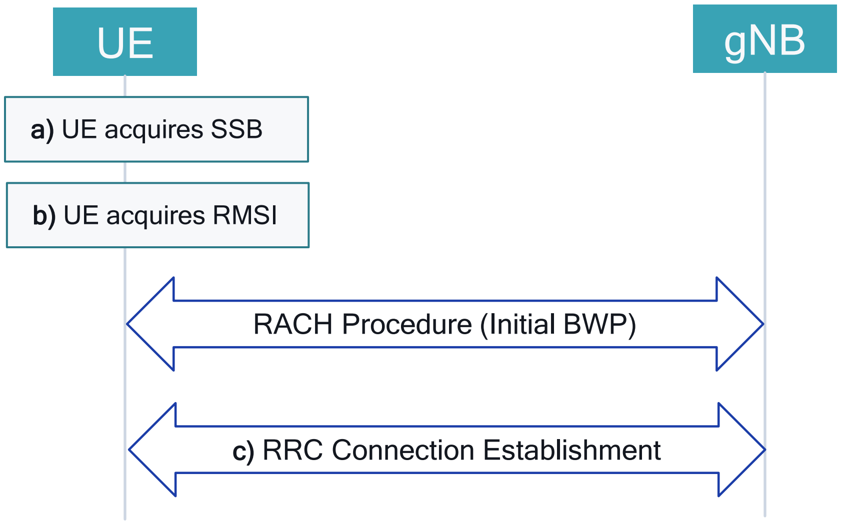
- **Cyclic Prefix**: Indicates whether to use the extended cyclic prefix for this bandwidth part.
- **Location and Bandwidth:** Frequency domain location and bandwidth.
- **Subcarrier Spacing:** Subcarrier spacing to be used in this BWP.
- **CORESET:** Not an IE for the BWP; however CORESET configuration is provided at the BWP level, which includes time/frequency resources and periodicity.



BWP Types

3 BWP types have been defined

1. Initial BWP:
    - Always carries the BWP ID = 0
    - It carries the SSB and System Information
    - The SCS provided by the MIB
    - Other common configurations provided by the RMSI
2. Default BWP
    - It is the BWP to fall back on, when UE is active on a different BWP and BWP inactivity timer expires
    - Only defined in the DL
3. First Active BWP
    - The first BWP the UE becomes active at, upon the reception of the RRC message carrying the BWP ID



a) SCS value for *Initial BWP* is provided (*UE is on Initial BWP*).

b) Remaining of the *Initial BWP* common parameters is provided (*UE is still on Initial BWP*).

c) UE is configured with the rest of the BWP's (up to 3 BWP, in addition to the Initial BWP) where common and dedicated parameters are provided. Upon Configuration *UE may switch to the First Active BWP if configured*.

Common Configuration such as: RACH resources, PUSCH/PUCCH common config, PDCCH/PDSCH common config

Dedicated Configuration such as: PDCCH/PUSCH/PUCCH/PDSCH UE dedicated configuration, SPS, RLM monitoring configuration

Thank you

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