IEE2650: Cellular Communication Technologies

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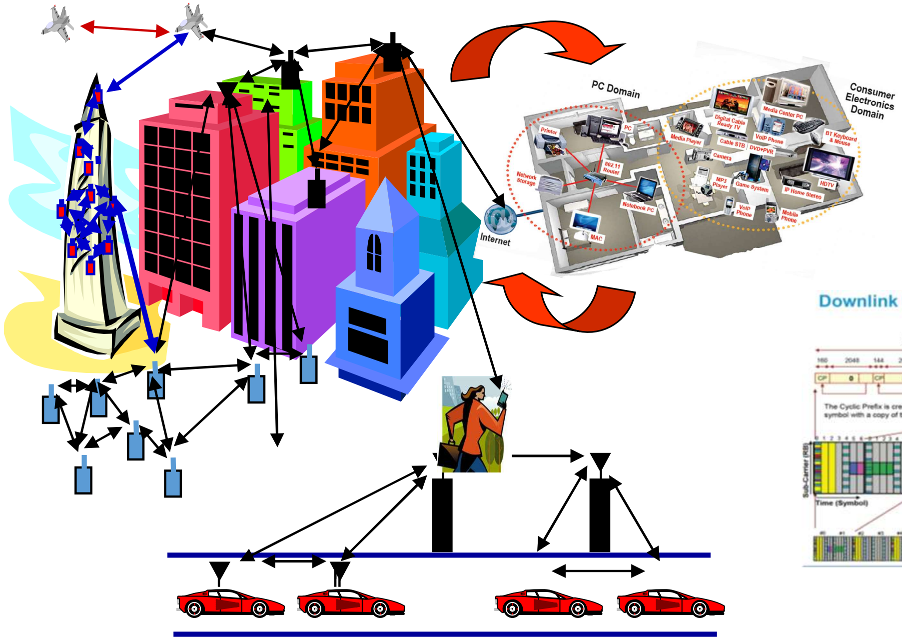
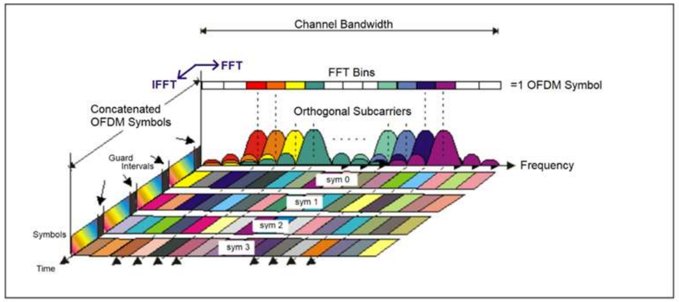
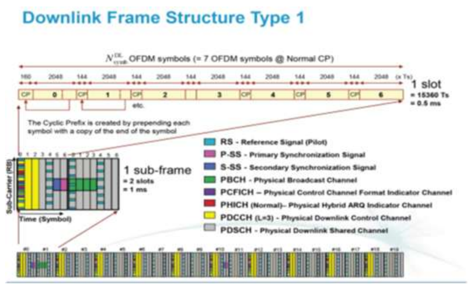
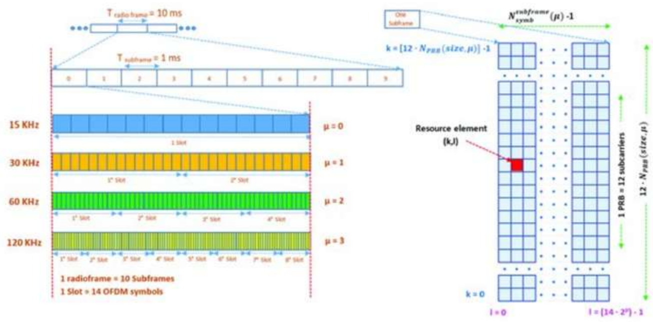




Frequency-Time Representative of an OFDM signal





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5G NR Physical Resource

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1 Overview

2 Details about 5G NR Channels and Signals

Important Definition

System Information (SI) provides information (e.g., system frame number, PLMN code, Cell identity) to access the network.

System Information Blocks (SIBs) are broadcast messages from the eNodeB to the UEs that contain essential information about the LTE system. SIBs are transmitted on the Broadcast Channel (BCCH), which is a dedicated control channel that is always available

Master Information Block (MIB) is an essential component of the Long-Term Evolution (LTE) wireless communication system. It is a control channel message transmitted by the eNodeB that provides necessary information for User Equipment (UE) to synchronize with the network and access the cell.

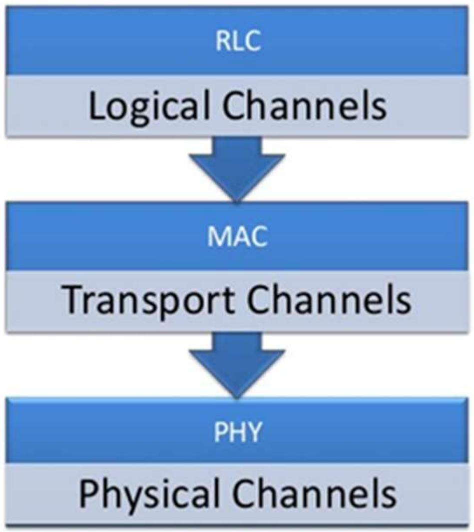
SS Block(SSB) stands for **Synchronization Signal Block** and in reality it refers to Synchronization/PBCH block because Synchnronization signal and PBCH channel are packed as a single block that always moves together

LTE Channels

LTE channel types

- There are three categories into which the various data channels may be grouped.
- ***Physical channels:*** These are transmission channels that carry user data and control messages.
- ***Transport channels:*** The physical layer transport channels offer information transfer to Medium Access Control (MAC) and higher layers.
- ***Logical channels:*** Provide services for the Medium Access Control (MAC) layer within the LTE protocol structure.

LTE Channel Architecture



1. RLC layer passes data to the MAC layer as logical channels.
2. The MAC layer formats and sends the logical channel data as transport channel.
3. The physical layer encodes the transport channel data to physical channels.

LTE Logical channels

- ***Control channels:*** these LTE control channels carry the control plane information:
  - ***Broadcast Control Channel (BCCH) :*** This control channel provides system information to all mobile terminals connected to the eNodeB.
  - ***Paging Control Channel (PCCH) :*** This control channel is used for paging information (https://ltebasics.wordpress.com/2015/06/29/what-is-paging-in-lte/) when searching a unit on a network.
  - ***Common Control Channel (CCCH) :*** This channel is used for random access information, e.g. for actions including setting up a connection.
  - ***Multicast Control Channel (MCCH) :*** This control channel is used for Information needed for multicast reception.
  - ***Dedicated Control Channel (DCCH) :*** This control channel is used for carrying user-specific control information, e.g. for controlling actions including power control, handover, etc..

LTE system information blocks

- The system information is very essential and the same is broadcasted by LTE eNB over logical channel BCCH.
- This logical channel information is further carried over transport channel BCH or carried by DL-SCH.
- There are two parts in SI static part and dynamic part.
  - Static part is called as MIB and is transmitted using BCH and carried by PBCH once every 40ms. MIB carries useful information which includes:
    - Channel bandwidth,
    - PHICH configuration details; transmit power, no. of antennas
    - SIB scheduling information transmitted along with other information on the DL-SCH.
  - Dynamic part is called as SIB and is mapped on LTE Radio Resource Control (RRC) System Information (RRC SI) messages (SI-1,2,3,4,5,6,7,8,9,10,11) over DL-SCH and transmitted using PDSCH at periodic intervals.
    - SI-1 transmitted every 80ms, SI-2 every 160ms and SI-3 every 320 ms.

LTE transport channels

- The LTE transport channels vary between the uplink and the downlink as each has different requirements and operates in a different manner. Physical layer transport channels offer information transfer to medium access control (MAC) and higher layers.
- ***Downlink:***
  - ***Broadcast Channel (BCH) :*** The LTE transport channel maps to Broadcast Control Channel (BCCH)
  - ***Downlink Shared Channel (DL-SCH) :*** This transport channel is the main channel for downlink data transfer. It is used by many logical channels.
  - ***Paging Channel (PCH) :*** To convey the PCCH
  - ***Multicast Channel (MCH) :*** This transport channel is used to transmit MCCH information to set up multicast transmissions.
- ***Uplink:***
  - ***Uplink Shared Channel (UL-SCH) :*** This transport channel is the main channel for uplink data transfer. It is used by many logical channels.
  - ***Random Access Channel (RACH) :*** This is used for random access requirements.

Downlink Physical Signals and Channels in LTE/4G

Physical signals	Physical channels
Primary synchronization signal	Physical downlink shared channel (PDSCH)
Secondary synchronization signal	Physical broadcast channel (PBCH)
Cell-specific reference signal (CRS)	Physical downlink control channel (PDCCH)
MBSFN reference signal	Physical multicast channel (PMCH)
UE-specific reference signal	Physical control format indicator channel (PCFICH)
Positioning reference signal (PRS)	Physical hybrid automatic request (ARQ) indicator channel (PHICH)
Channel state information (CSI) reference signal (CSI-RS)	

PHYSICAL Channels - Downlink (1/4)

- Two types of physical layer channels are defined:
  - physical channels, which carry information originating from higher layers
  - physical signals, which are generated in the physical layer and are used for system synchronization, cell identification, and radio channel estimation.
- The LTE physical channels vary between the uplink and the downlink as each has different requirements and operates in a different manner.
- ***Downlink:***
  - ***Physical Broadcast Channel (PBCH):*** This physical channel carries system information for UEs requiring to access the network. It only carries what is termed as Master Information Block, MIB, messages.
    - The modulation scheme is always QPSK and the information bits are coded and rate matched (https://ltebasics.wordpress.com/2013/12/24/rate-matching-in-pdsch/)
    - The bits are then scrambled using a scrambling sequence specific to the cell to prevent confusion with data from other cells.
    - The MIB message on the PBCH is mapped onto the "central 72 subcarriers or six central resource blocks" regardless of the overall system bandwidth.
    - A PBCH message is "repeated every 40 ms", i.e. one transmission time interval (TTI) of PBCH includes four radio frames.
    - The PBCH transmissions has 14 information bits, 10 spare bits, and 16 CRC bits.

PHYSICAL Channels – Downlink (2/4)

- ***Physical Control Format Indicator Channel (PCFICH) :*** As the name implies the PCFICH informs the UE about the format of the signal being received (https://ltebasics.wordpress.com/2013/08/06/what-is-pcfich/).
- It indicates the number of OFDM symbols used for the PDCCHs.
- PCFICH conveys the number of control symbols in the current subframe.
  - Since a subframe in LTE FDD can have upto 14 symbols for normal CP scenario, among the 14 OFDM symbols there can be upto 3 control symbols, depending on the amount of control data the eNodeB has to transmit. The number of controls symbols can be 1, 2 or 3. It can also be 4 incase of lower bandwidth systems such as 3MHz or less. Every subframe must have atleast one control symbol.
- Whether 1, 2, or 3. The information within the PCFICH is essential because the UE does not have prior information about the size of the control region.
- A PCFICH is transmitted on the first symbol of every sub-frame and carries a Control Format Indicator, CFI, field.
  - The CFI contains a 32 bit code word that represents 1, 2, or 3.
  - The PCFICH Encoding: Uses 32 bit,2 block coding which results in a 1/16 coding rate, and it always uses QPSK modulation to ensure robust reception.

PHYSICAL Channels – Downlink (3/4)

- ***Physical Downlink Control Channel (PDCCH) :*** The main purpose of this physical channel is to carry mainly scheduling information of different types:

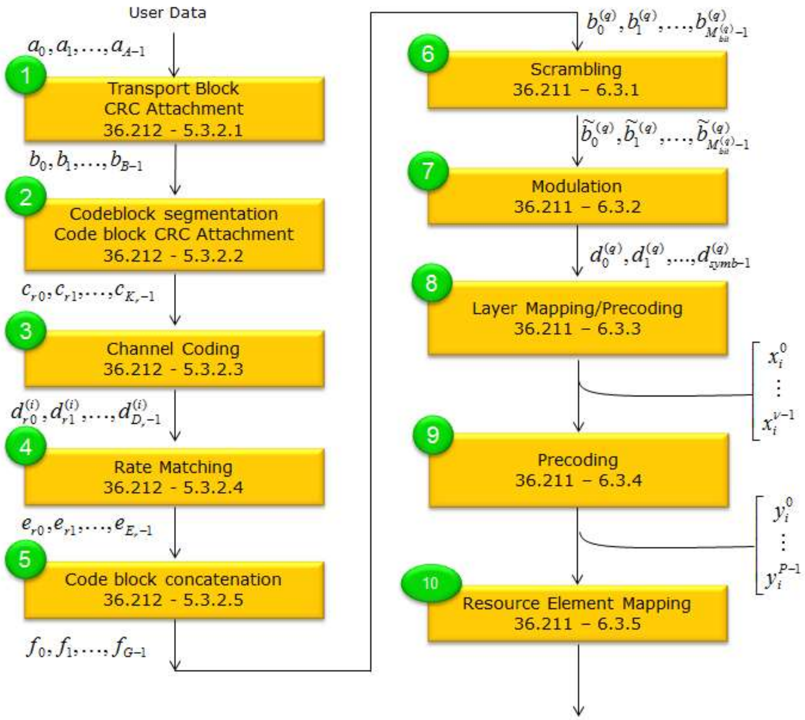
- Downlink resource scheduling
- Uplink power control instructions
- Uplink resource grant
- Indication for paging or system information
- The PDCCH contains a message known as the Downlink Control Information, DCI which carries the control information for a particular UE or group of UEs.

PHYSICAL Channels – Downlink (4/4)

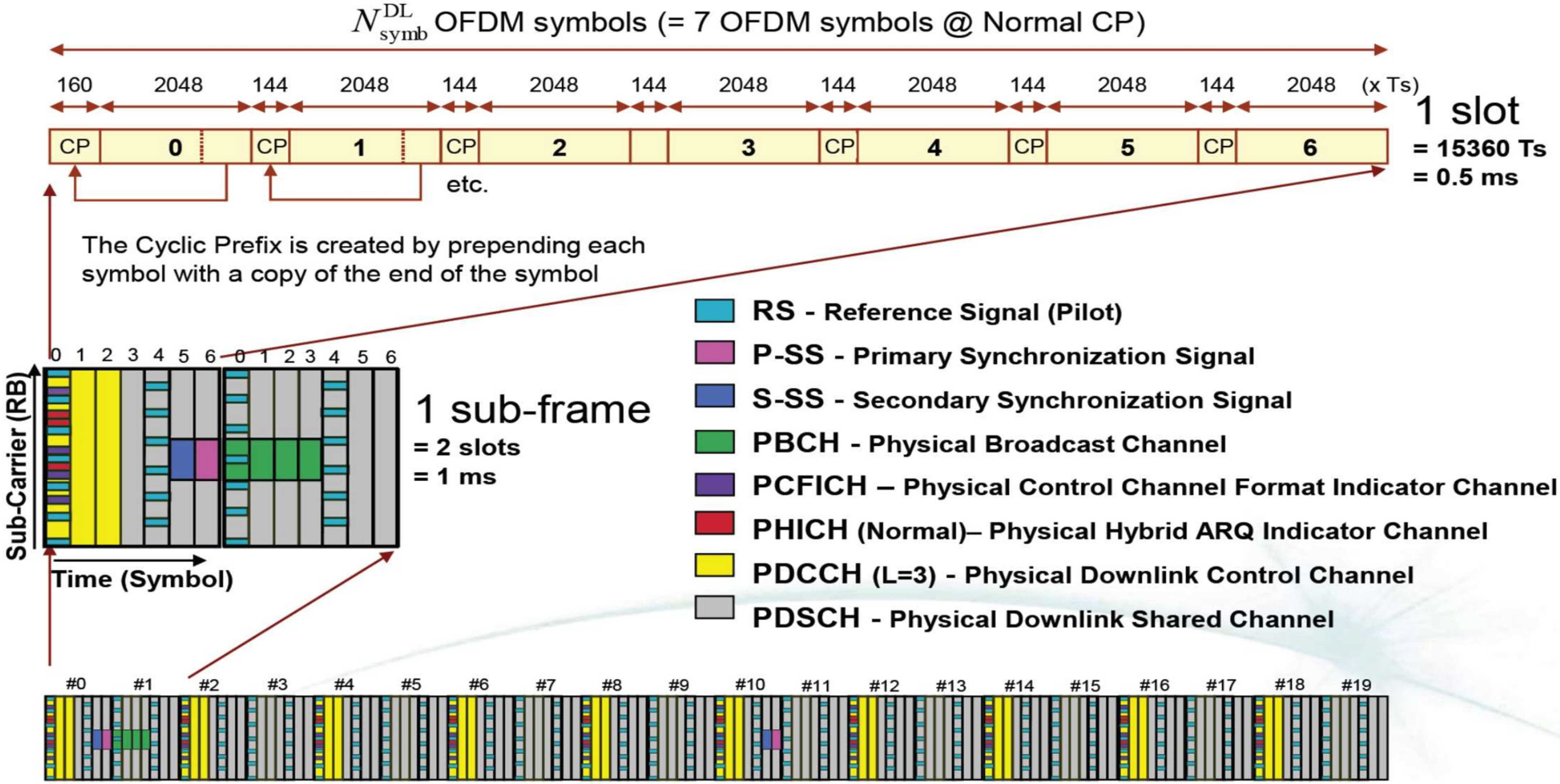
- ***Physical Hybrid ARQ Indicator Channel (PHICH) :*** As the name implies, this channel is used to report the Hybrid ARQ status. It carries the HARQ ACK/NACK signal indicating whether a transport block has been correctly received.
- The HARQ indicator is 1 bit long - "0" indicates ACK, and "1" indicates NACK.
- The PHICH is transmitted within the control region of the sub-frame and is typically only transmitted within the first symbol.
- If the radio link is poor, then the PHICH is extended to a number of symbols for robustness.

PDSCH (Physical Downlink Shared Channel)

- PDSCH is a physical channel that carries user data.
  - Carries user specific data (DL Payload).
  - Carries Random Access Response Message in case of PDSCH mapped to RACH channel.
  - It is using AMC with QPSK, 16 QAM and 64 QAM. The modulation scheme for each PDSCH for each user is determined by modulation and coding scheme (MCS) value in **downlink control information**.



Downlink Frame Structure Type 1



SYNCHRONIZATION SEQUENCES

A User Equipment wishing to access the LTE system follows a cell search procedure which includes a series of synchronization stages by which the UE determines time and frequency parameters that are necessary to demodulate downlink signals, to transmit with correct timing and to acquire some critical system parameters.

There are three synchronization requirements in LTE:

- symbol timing acquisition by which the correct symbol start is determined;
- carrier frequency synchronization, which mitigates the effect of frequency errors resulting from Doppler shift and errors from electronics;
- sampling clock synchronization.

There are two cell search procedures in LTE:

- One for initial synchronization
- Another for detecting neighbor cells in preparation for handover.

In both cases, the UE uses two special signals broadcast on each cell:

- Primary Synchronization Sequence (PSS)
- and Secondary Synchronization Sequence (SSS).

The detection of these signals allows the UE to complete time and frequency synchronization and to acquire useful system parameters such as cell identity, cyclic prefix length, and access mode (FDD/TDD).

At this stage, the UE can also decode the Physical Broadcast Control Channel (PBCH) and obtain important system information.

Cell ID Detection and System Information Detection

What is happening at the very first when you first power on (or Switching Airplane Mode On to Off) is to detect a cell around the UE (e.g, mobile phone). This would be the most important process happening inside of the UE in terms of celluar protocol point of view. The overall procedure of the initial detection of a cell can be described as below.

i) Frequency Aquisition
ii) Primary Sync Signal Aquisition (Slot Timing Aquired, Secondary Sync Signal Scrambling Code Aquired). From this, N_id_2 is found.
iii) Secondary Sync Signal Aquisition (Frame timing Aquired, Cell Group ID sequence aquired). From this, N_id_1 is found.
iv) with PSS(N_id_2) and SSS(N_id_1), Cell ID can be calculated
v) with Cell ID, Reference Signal Location is detected
vi) With the help of Reference Signal, PBCH (MIB) can be detected
vii) From MIB, SFN and System BW can be detected
viii) Decode PCFICH and detect how many symbols are allocated for PDCCH.
ix) Decode DCI for SIB1 from PDCCH.
x) Decode SIB1 and get the scheduling information for other SIBs
xi) Decode SIBs (other than SIB1)

One of the most important step is to check whether UE successfully complete the time-sync (step i) and ii)).
One way to easily check whether UE succeeded in time-sync or not is to check from **UE log whether UE successfully decoded Cell ID or not**. If UE successfully detected Cell ID, it means UE successfully completed the time-sync.

Drawbacks of LTE System Information (SI) design

LTE MIB, SIB1 and SIB2 are mandatory for the UE to access a cell and all system information is periodically transmitted by the network.

This approach of broadcasting SI periodically over entire cell area is energy inefficient in cases for example when there are no UEs in the cell. *Moreover, this approach in 5G could lead to excessive signaling overhead in cases where several beams are used to broadcast SI* to be able to reach the entire coverage area of the cell.

A different approach is adopted in NR which is explained below.

NR System Information

The most important signal that UE has to detect before trying connection in NR SA are MIB and SIB1.

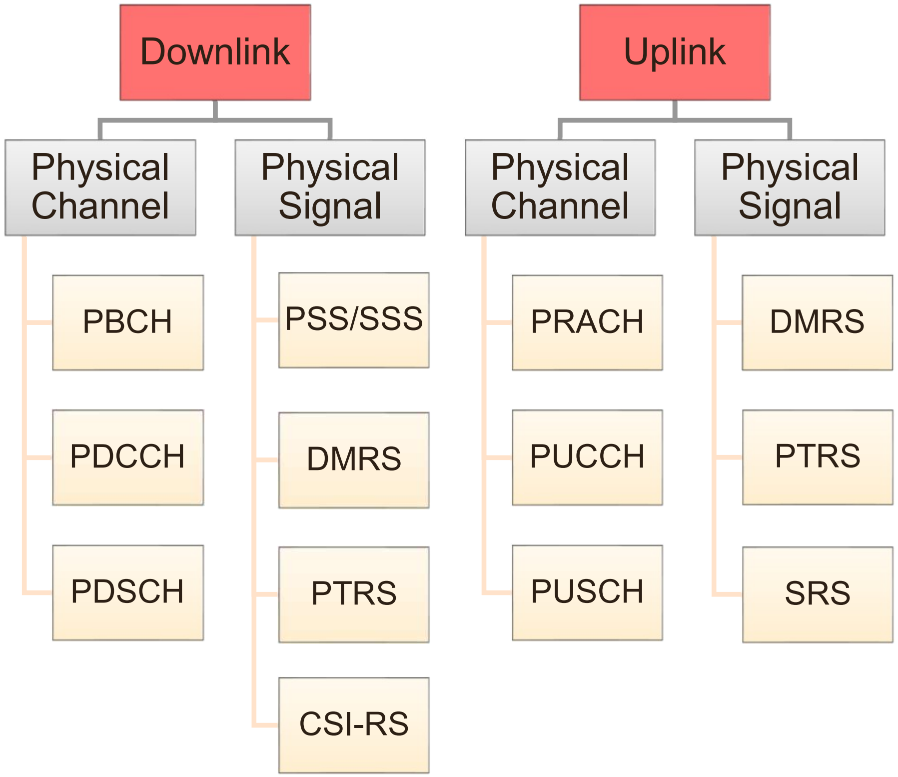
System Information (SI) in NR consists of a MIB and a number of SIBs, which are divided into Minimum SI and Other SI. Minimum SI carries basic information required for initial access and for acquiring any other SI. Minimum SI consists of MIB and SIB1 (called RMSI). For a UE to be allowed to camp on a cell, it must have acquired the contents of the Minimum SI from that cell.

As MIB and SIB1 are called as 'minimum SI', SIB1 alone is known as ***'Remaining Minimum System Information' (RMSI).***

Other SI consists of all SIBs not broadcast in the Minimum SI. The UE does not need to receive these SIBs before accessing the cell. *Other SI is also known as On-Demand SI because gNB transmits/broadcasts these SIBs when explicitly requested by UE(s).*

This approach enhances network energy performance and reduces singalling overhead in the cell by transmitting SI only when explicitly requested by UE(s). This (for example) implies the network can completely avoid transmitting 'Other SI' when there is no UE in the cell.

NR Physical Channels and Signals Overview

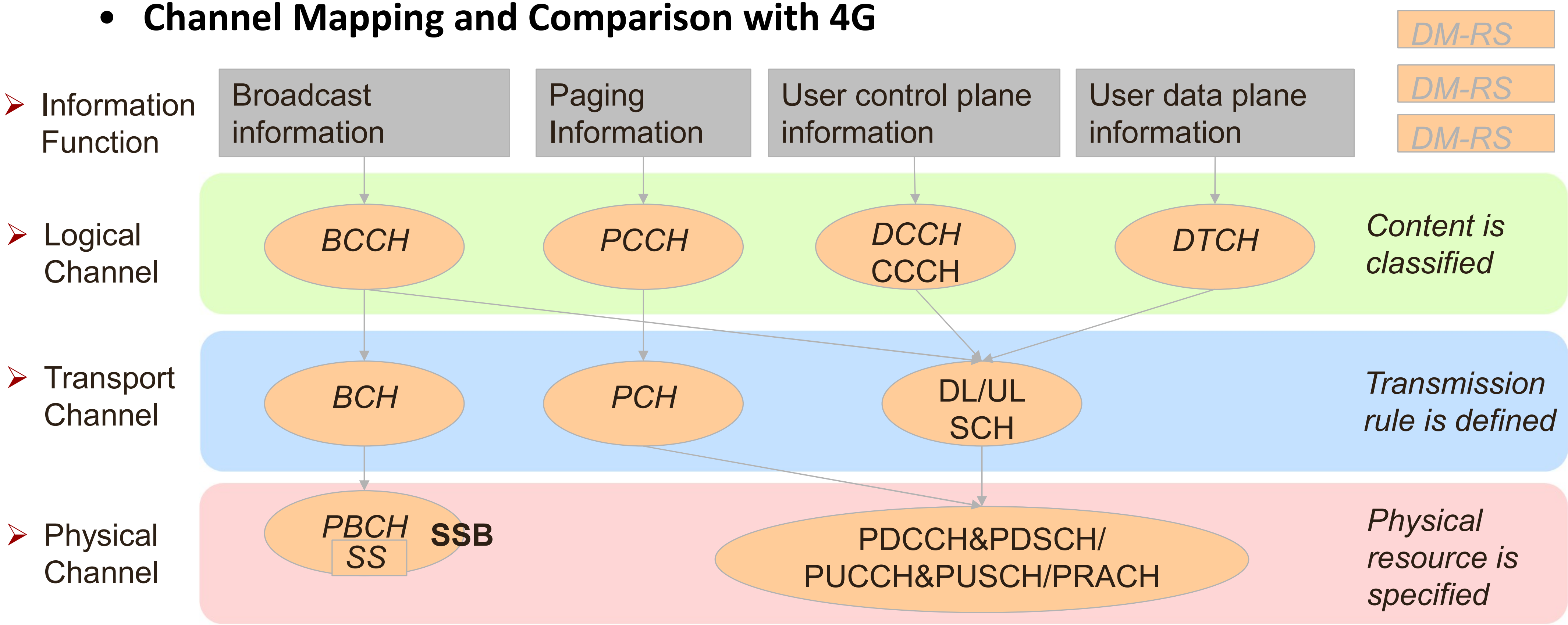


Downlink Physical Channel/Signal Functions	
SS	Used for time-frequency synchronization and cell search.
PBCH	Carries system information to be broadcast.
PDCCH	Transmits control signaling, such as signaling for uplink and downlink scheduling and power control.
PDSCH	Carries downlink user data.
DMRS	Used for downlink data demodulation and time-frequency synchronization.
PTRS	Tracks and compensates downlink phase noise.
CSI-RS	Used for downlink channel measurement, beam management, RRM/RLM measurement, and refined time-frequency tracking.

Uplink Physical Channel/Signal Function	
PRACH	Carries random access request information.
PUCCH	Transmits L1/L2 control signaling, such as signaling for HARQ feedback, CQI feedback, and scheduling request indicator.
PUSCH	Carries uplink user data.
DMRS	Used for uplink data demodulation and time-frequency synchronization.
PTRS	Tracks and compensates uplink phase noise.
SRS	Used for uplink channel measurement, time-frequency synchronization, and beam management.

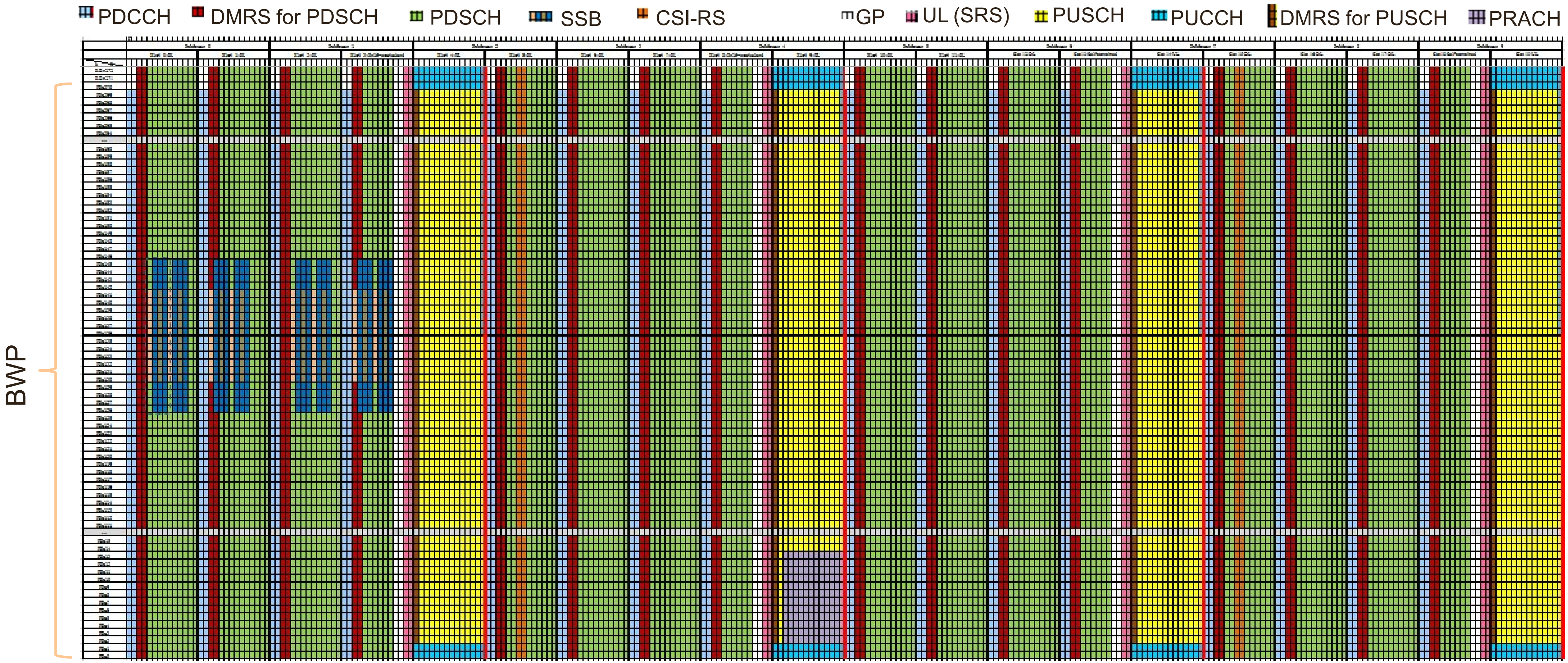
The Basic Functions of NR Air Interface

- **Channel Mapping and Comparison with 4G**



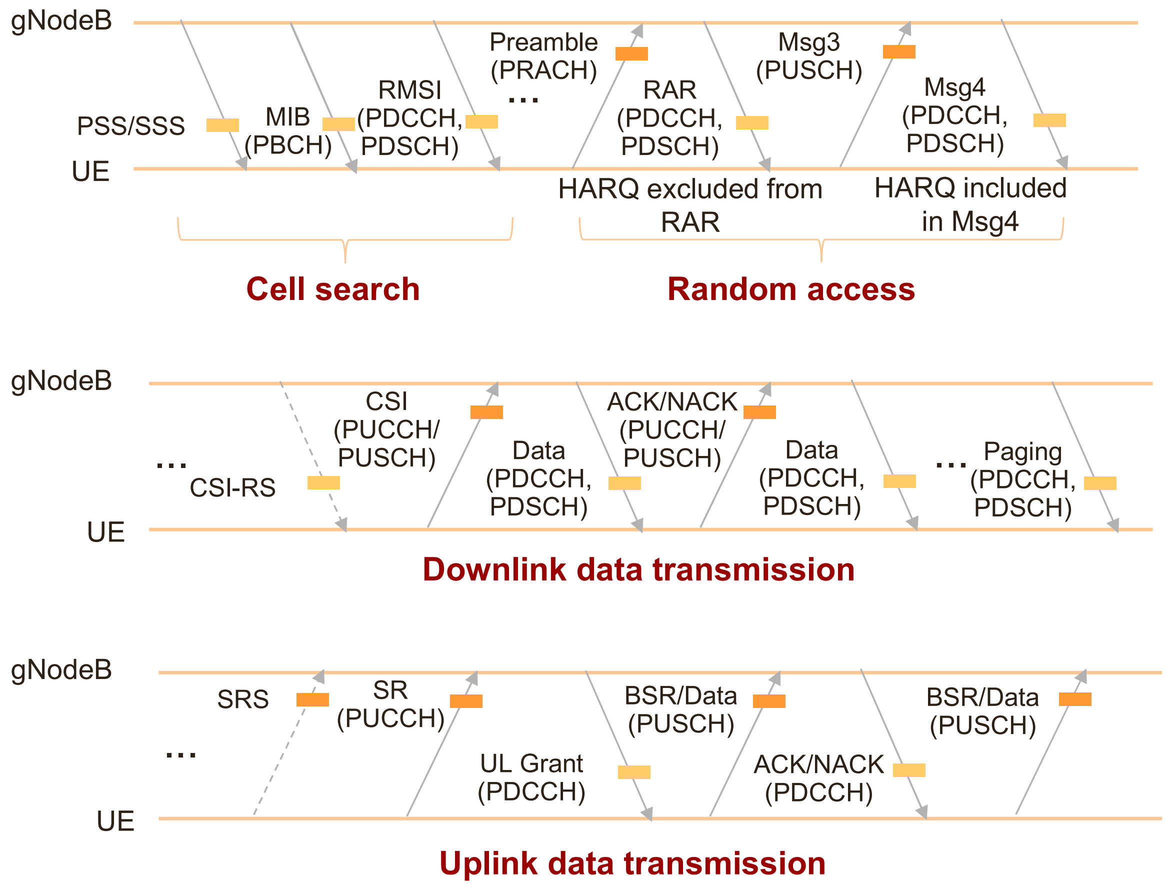
Time-Frequency Domain Distribution

- **Schedulable and configurable resources through flexible physical channel and signal design.**



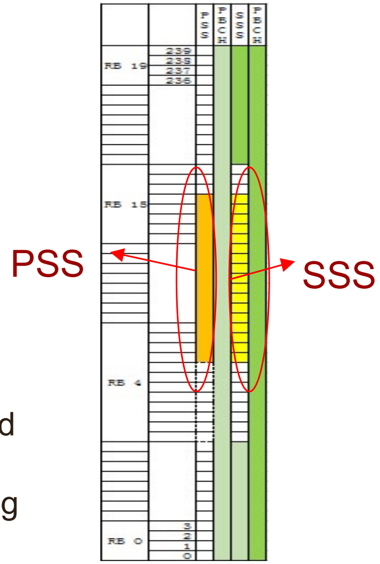
Application of NR Physical Channels

- **Physical channels involved in cell search**
  - PSS/SSS -> PBCH -> PDCCH -> PDSCH
- **Physical channels involved in random access**
  - PRACH -> PDCCH -> PDSCH -> PUSCH
- **Physical channels involved in downlink data transmission**
  - PDCCH -> PDSCH -> PUCCH/PUSCH
- **Physical channels involved in uplink data transmission**
  - PUCCH -> PDCCH -> PUSCH -> PDCCH



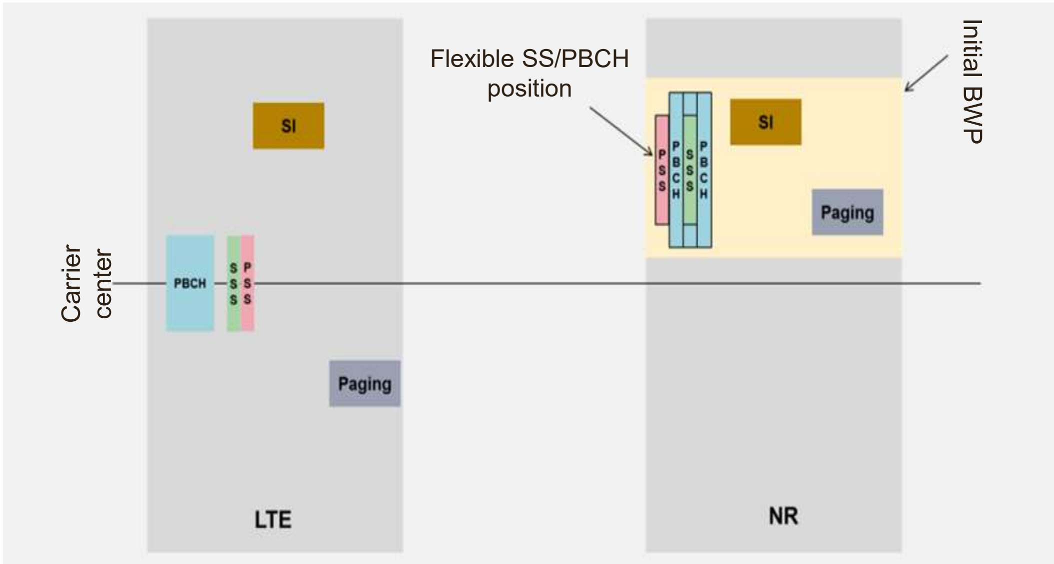
PSS/SSS: Introduction

- **Main functions**
  - Used by a UE for downlink synchronization,
  - Used for obtaining physical cell IDs (PCI)
- **Resource allocation**
  - A SS occupies 1 symbol in the time domain and 127 REs in the frequency domain.

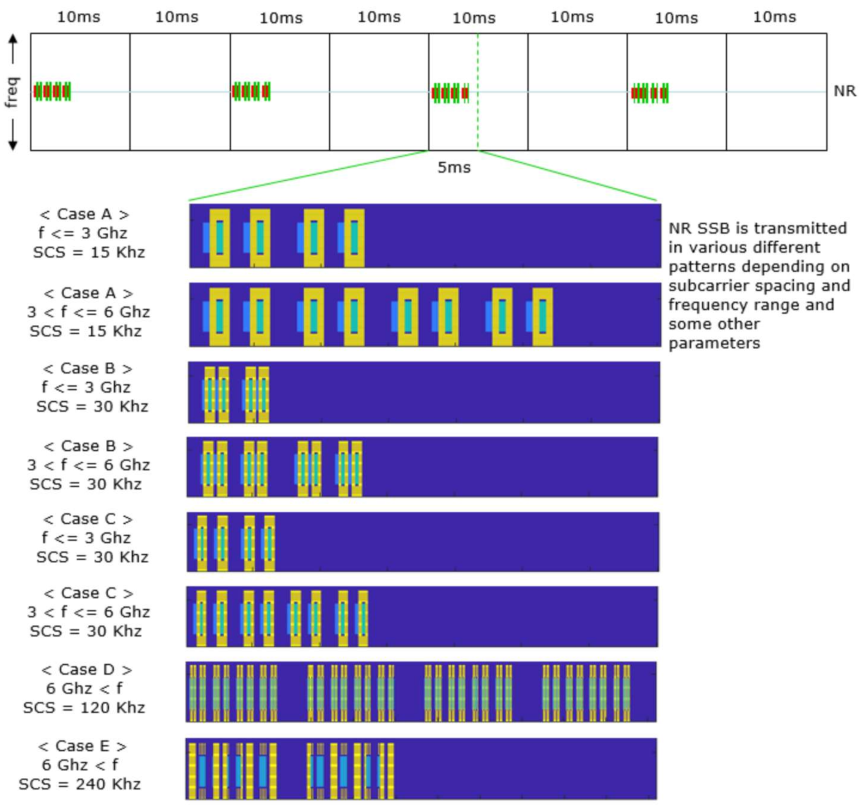


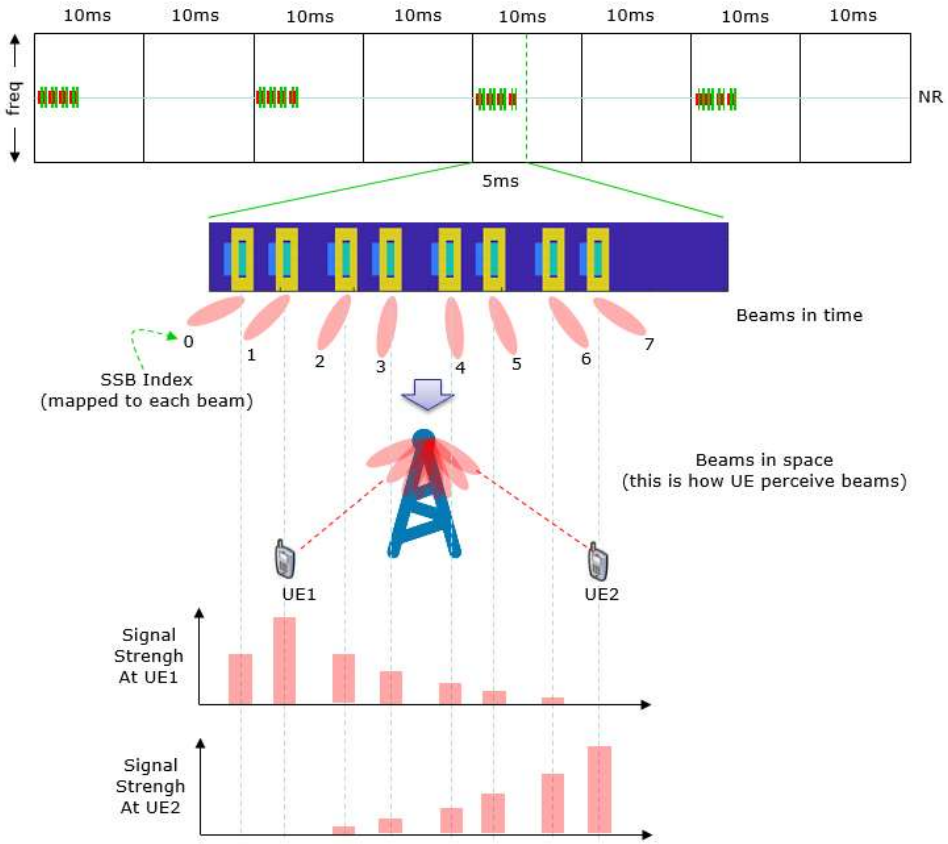
❖ Different from LTE with 504 PCIs, NR physical cell IDs are numbered from 0 to 1007 and divided into 3 groups, with each group containing 336 cell IDs.

- **Differences with LTE**
  - SS in NR can be flexibly configured in any position on the carrier and do not need to be positioned at the center frequency.
  - Subcarrier spacings for the PSS/SSS vary with operating frequency bands and are specified by 3GPP.



Transmission of SSB (1/2)



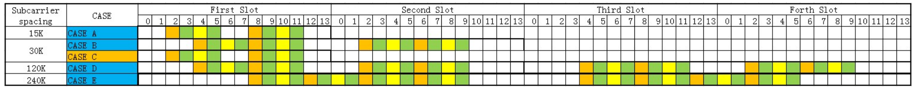


Transmission of SSB (2/2)

- **The PSS/SSS and the PBCH are combined as an SSB block in 5G to allow for massive MIMO.**

➢ SSB configuration varies with SCS

-- SSB block position within the slot



-- Slot numbers for SSB blocks with different subcarrier spacings and different beams

Subcarrier Spacing	Frequency Range	n																		
15K	(0 GHz, 3 GHz]	0	1																	
	(3 GHz, 6 GHz]	0	1	2	3															
30K	(0 GHz, 3 GHz]	0																		
	(3 GHz, 6 GHz]	0	1																	
	(0 GHz, 3 GHz]	0	1																	
	(3 GHz, 6 GHz]	0	1	2	3															
120K	(6 GHz, ~ GHz]	0	1	2	3		5	6	7	8		10	11	12	13		15	16	17	18
240K	(6 GHz, ~ GHz]	0	1	2	3		5	6	7	8										

❖ To fasten UL sync. in larger bandwith in NR, sync. rasters with 900 kHz, 1.44 MHz, and 17.28 MHz are defined.

➢ SSB transmission in 18B

-- Broadcast information is scheduled every 80ms

-- PBCH is transmitted every 20ms with 8 beams each time