VIETTEL HIGH TECHNOLOGY

VIETTEL 5G TALENT 2023

5G RAN PART 1
LAYER 1: PHYSICAL CHANNELS & PROCEDURES

Hà Nội 04/2023

AGENDA

5G RAN Part 1
Layer 1: Physical Channels & Procedures

08:00-08:30
VHT & 5G Layer 1 team introduction

08:30-09:00
Signal processing overview

09:00-09:30
Physical layer overview

09:30-10:00
Physical downlink channels

10:00-10:15
Break time

10:15-10:45
Physical uplink channels

10:45-11:30
Physical procedures

11:30-12:00
Free talk

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VHT INTRODUCTION

NETWORK OPERATOR

Viettel Telecom
Service Provider

Viettel Network
Network Management

VTT

VTNet

VHT

Viettel Hi-Tech Industries Corporation (VHT)
High-tech products in Telecom and IoT Industries

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Theo cách của bạn

VDS

Viettel Digital Services Corporation
Provision of digital solutions
Digital Transformation

VTS

Viettel business solutions corporation
Provision of Business Solutions

VTG

Viettel Global Investment Joint Stock Company
Foreign ICT Business Investment

VT Security

Viettel Cyber Security Company
ICT Security

Others
...

- Viettel Cyberspace Center
- Viettel Post Joint Stock Corporation
- ....

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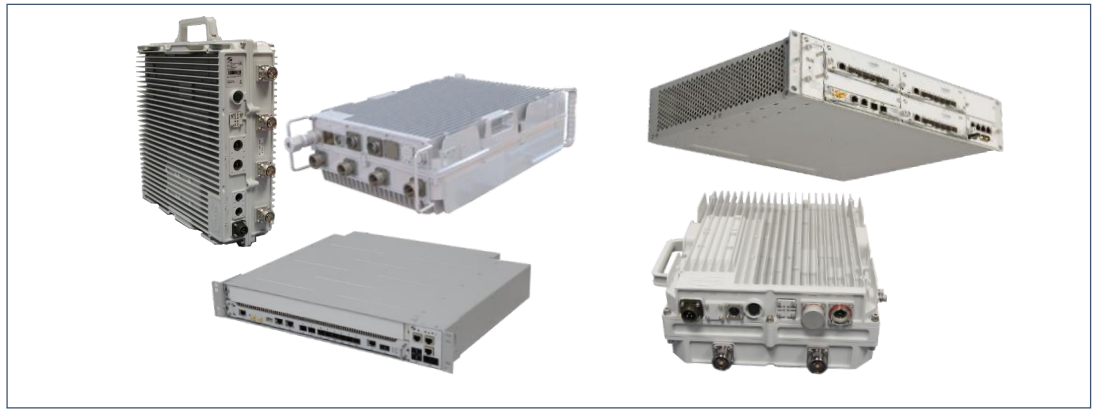
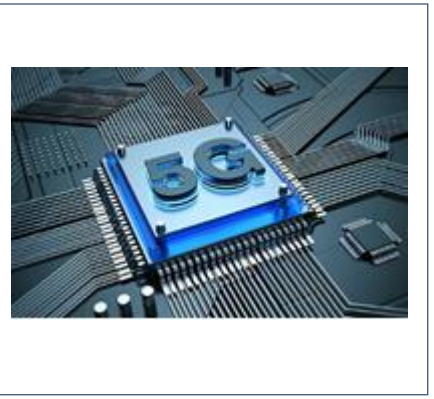
VHT ACCESS LAYER PRODUCTS

5G gNodeB 64T64R and 8T8R



4G eNodeB 4T4R and 2T2R



CHIP 5G

4G eNodeB Smallcell and Picocell

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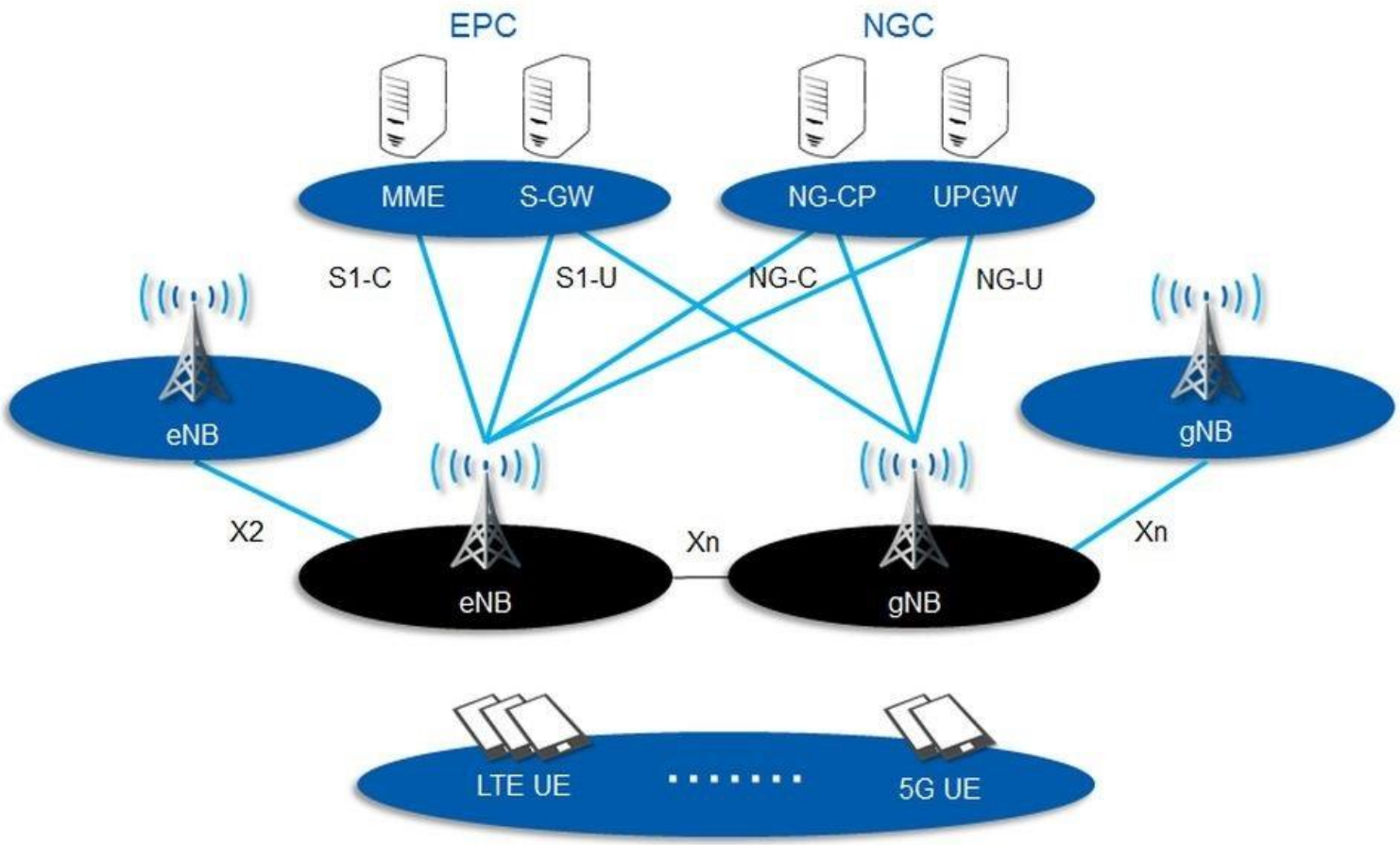
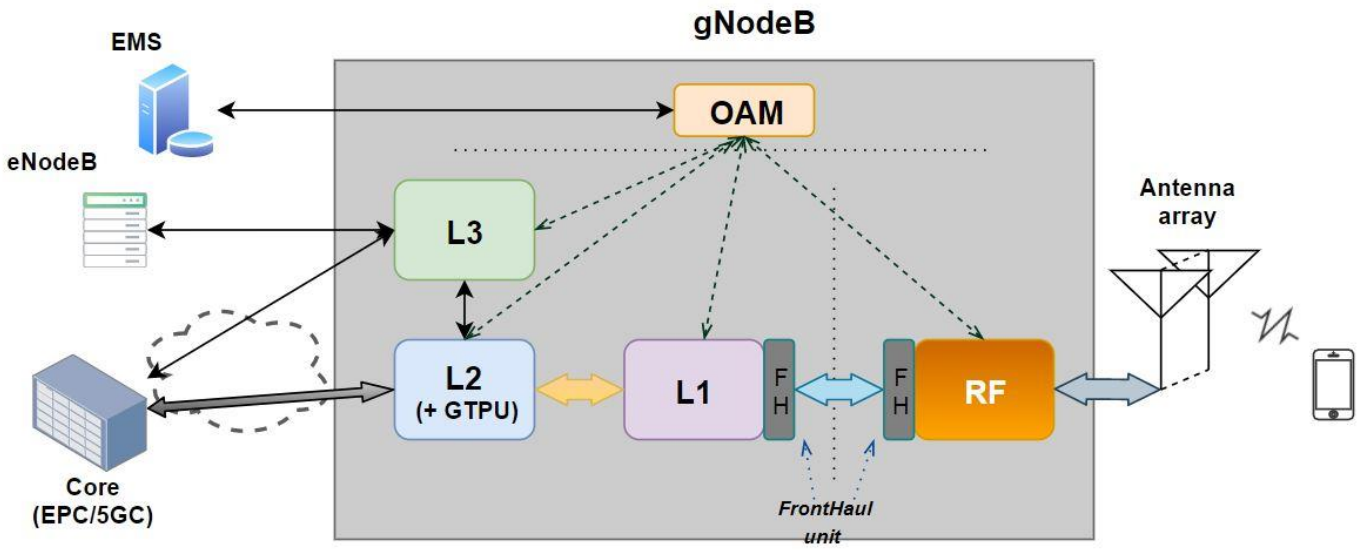
TELECOM INFRASTRUCTURE

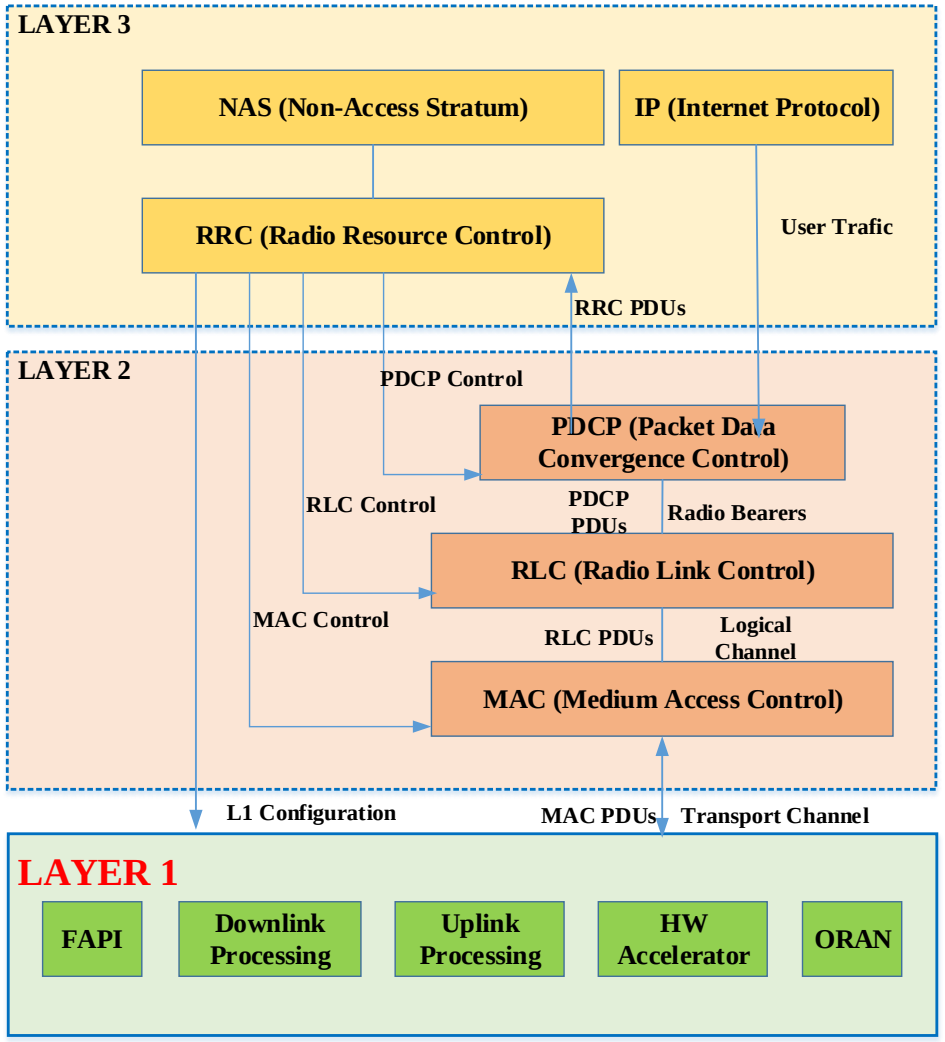


5G GNODEB ARCHITECTURE & SW PROTOCOL STRUCTURE

WHERE IS LAYER 1?

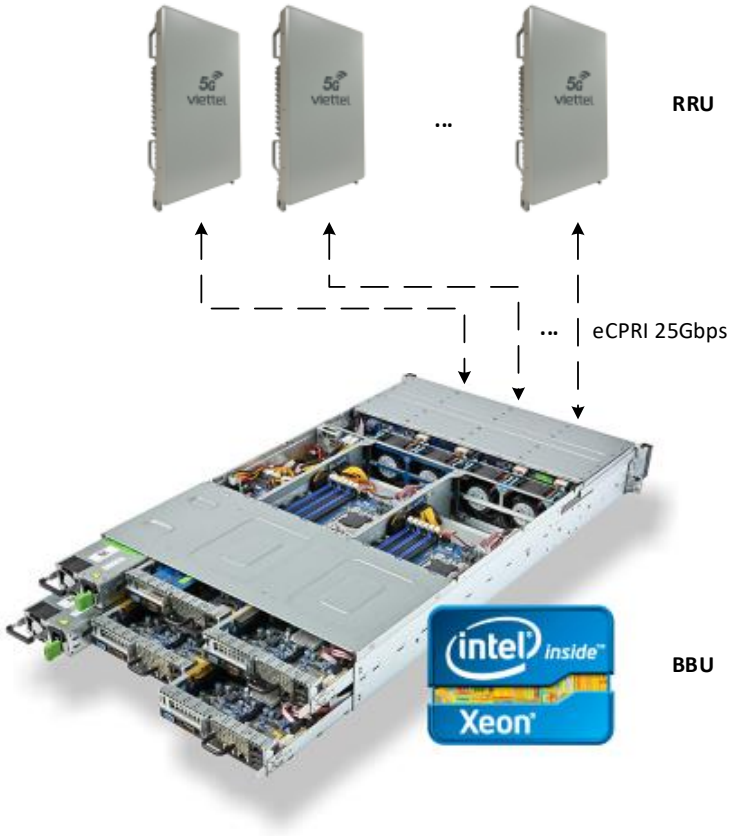


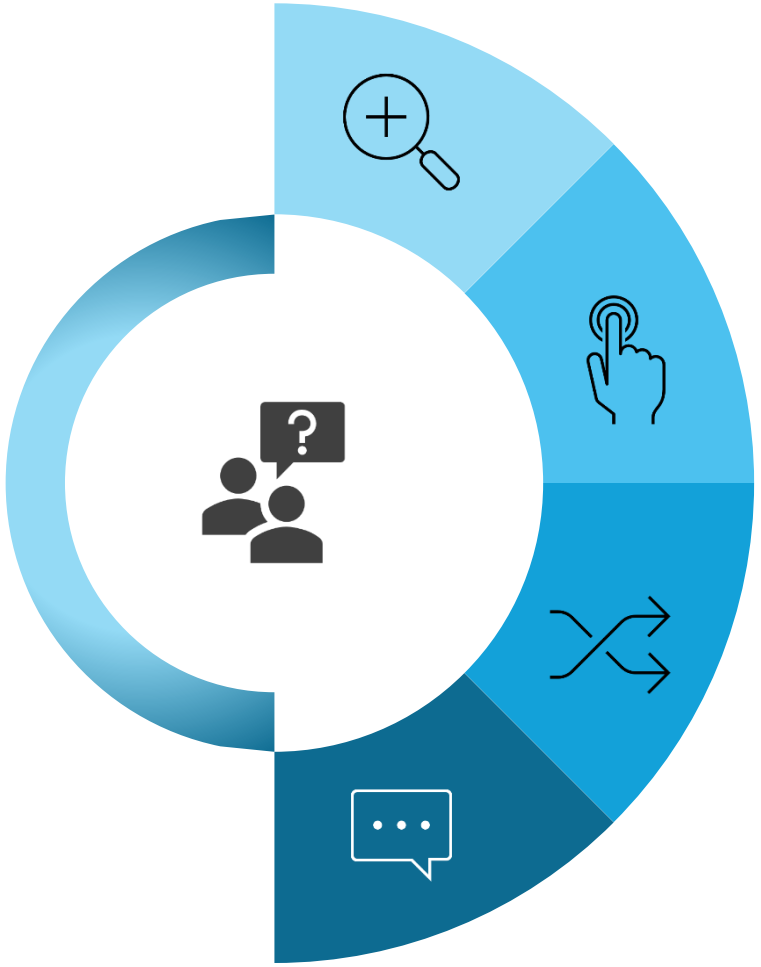
GNODEB ARCHITECTURE



GNODEB SOFTWARE PROTOCOL

5G LAYER 1 JOB DESCRIPTION





PROJECT

4G/5G

HW PLATFORM

Intel
Qualcom, NXP
Xilinx

WORK ITEM

Research, Development
Integration, testing, debugging
Optimization

ACKNOWLEDGE & SKILL

Signal processing
C/Matlab, Linux
Test equipments

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5G BASEBAND SIGNAL PROCESSING (LAYER 1) TEAM

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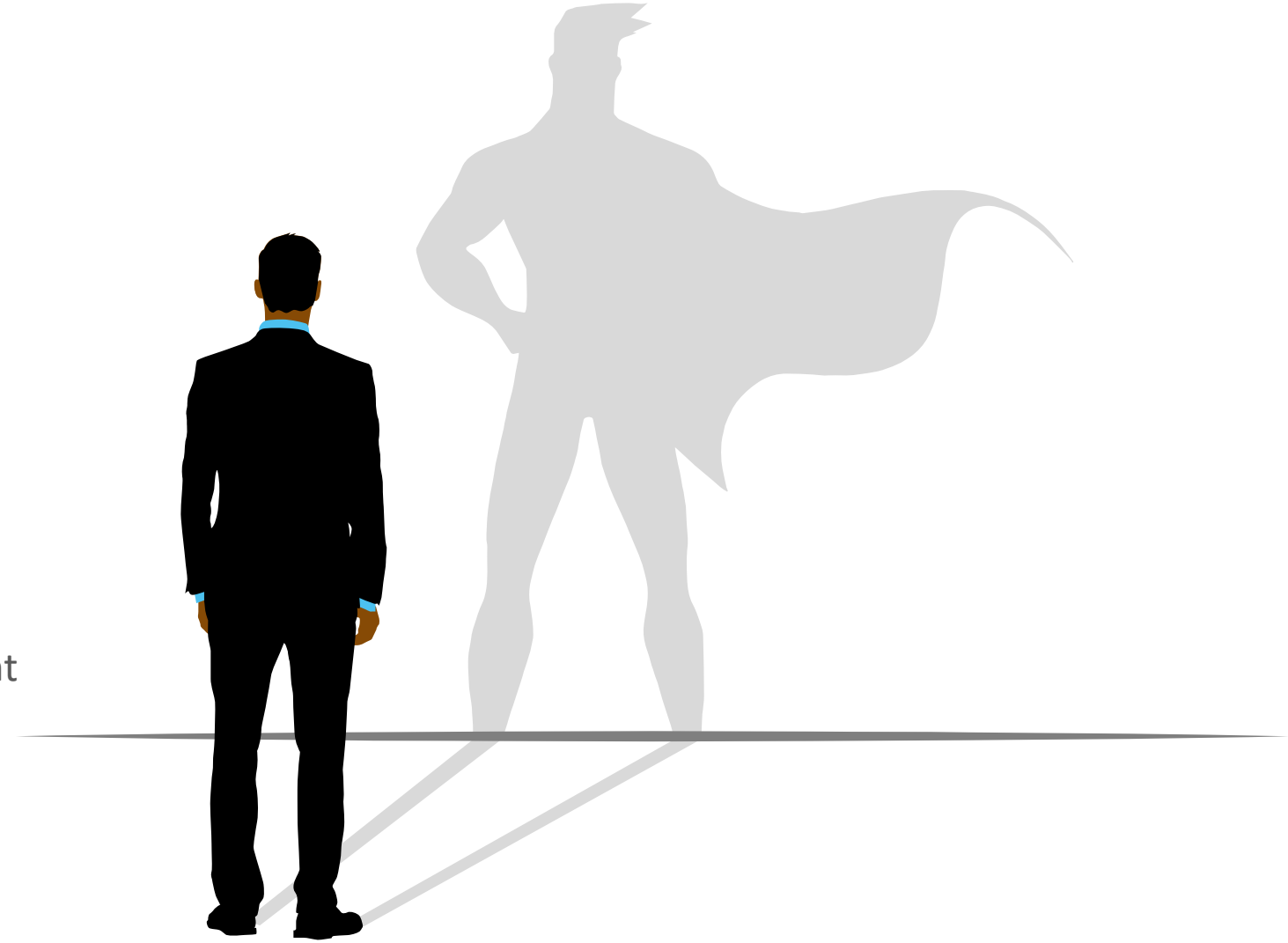
5G LAYER 1 EMPLOYEE TRAINING

DURATION

- 2 months – 6 months

TRAINING TOPIC

- Matlab, C language
- Linux OS, Linux programming
- Intrinsic command
- Baseband signal processing
- 5G Physical layer algorithm
- Test and measurement equipment
- SW integration
- System integration



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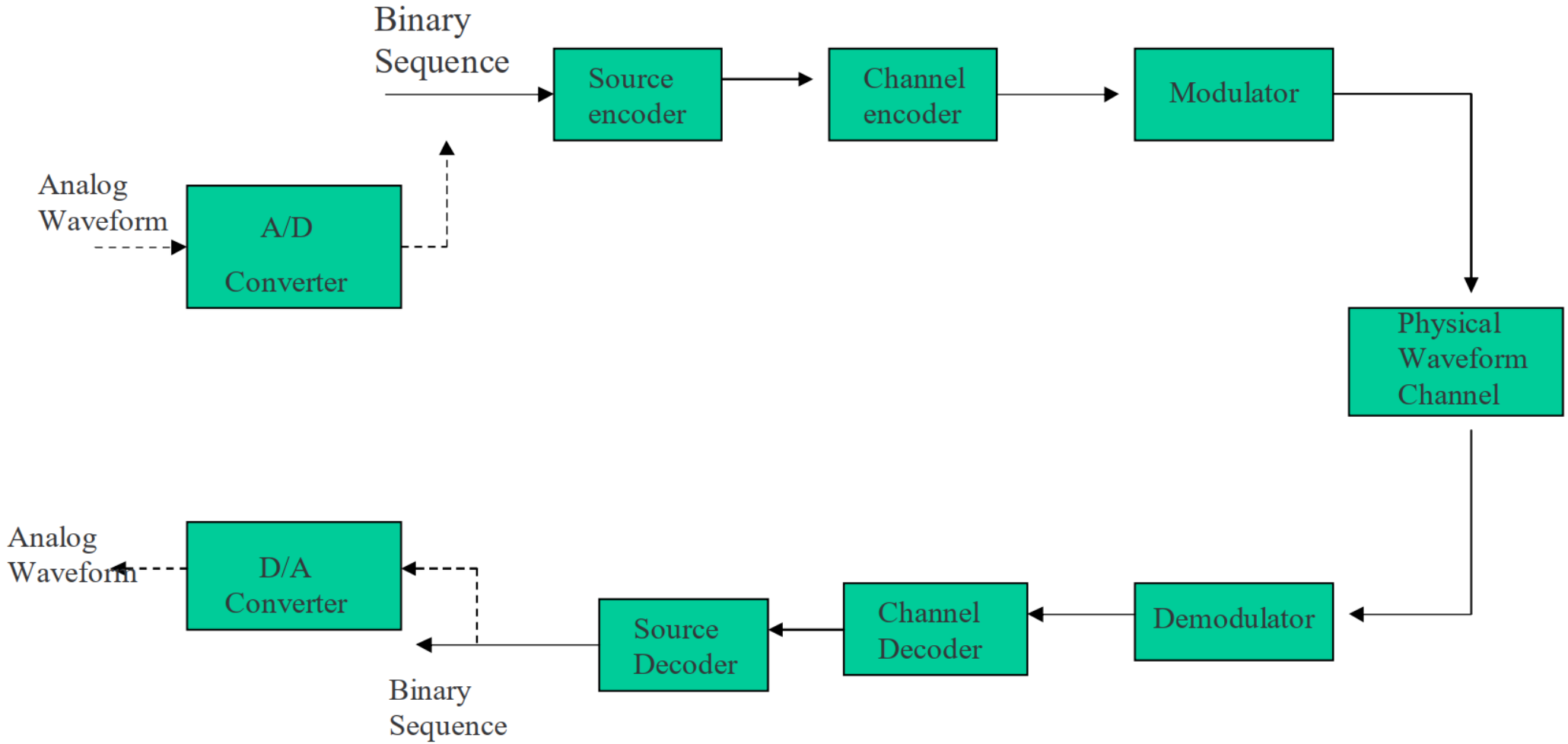
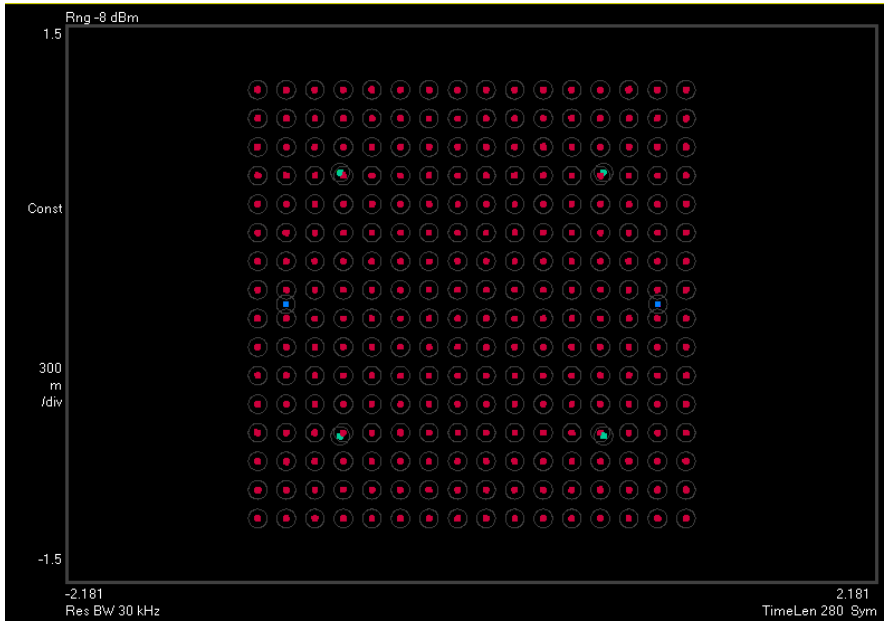
SIGNAL PROCESSING OVERVIEW

- Digital information transfer system

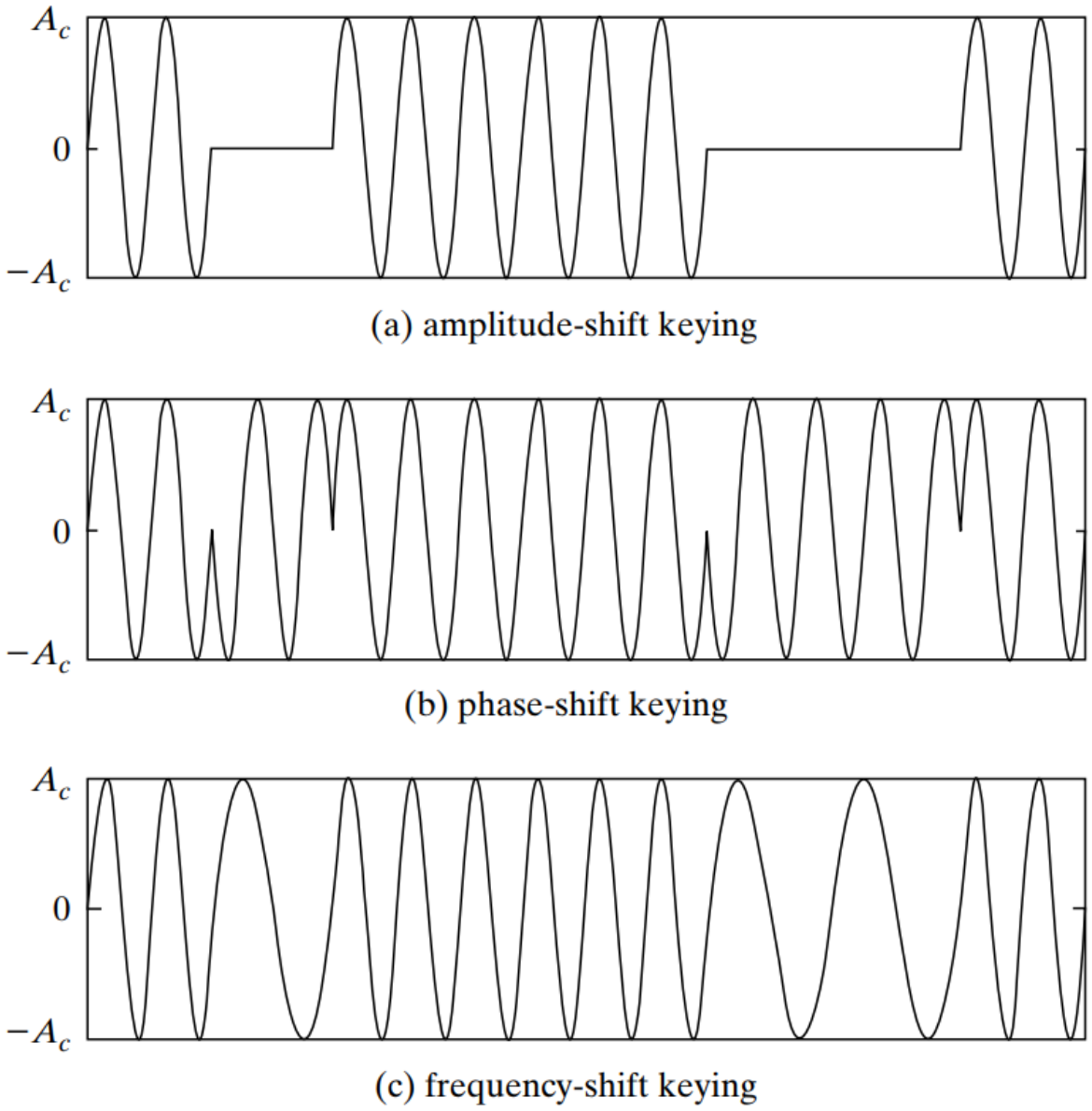


DIGITAL MODULATION

- Amplitude shift keying (ASK)
- Phase shift keying (PSK)
- Frequency shift keying (FSK)
- Quadrature Amplitude Modulation (QAM)
  - Combine amplitude and phase-shift keying

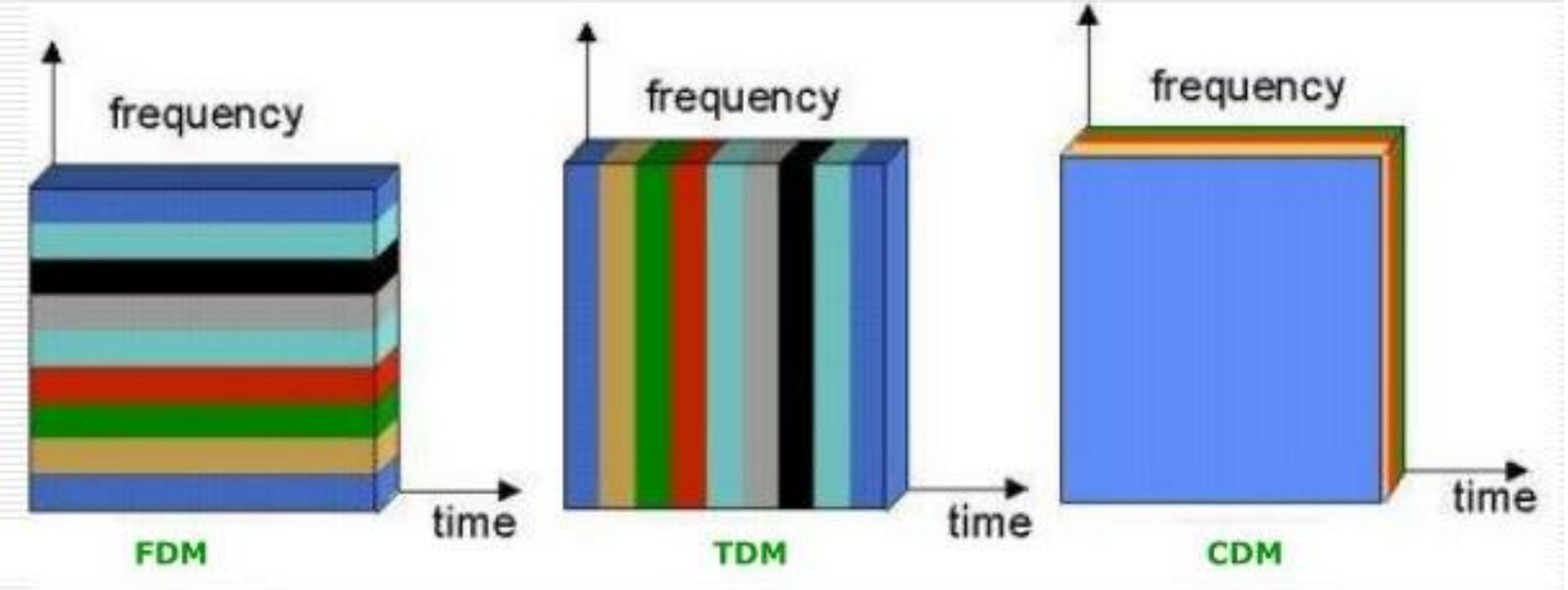


256QAM constellation



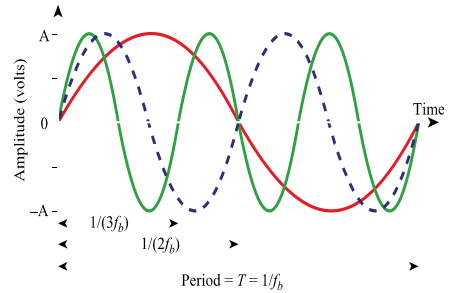
OFDM (ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING)

- Multiplexing: Carrying multiple signals on a single medium
  - Frequency-division multiplexing (FDM)
  - Time-division multiplexing (TDM)
  - Code-division multiplexing (CDM)

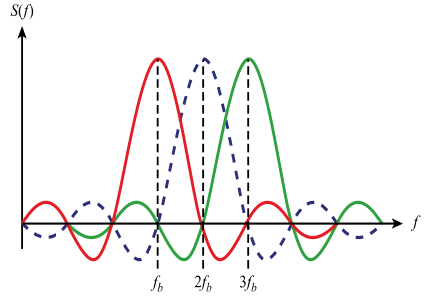


OFDM (ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING)

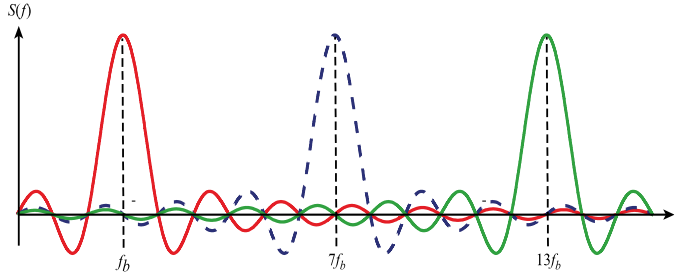
- OFDM:
  - A special case of FDM (Frequency Division Multiplexing)
  - Multicarrier modulation
  - OFDM splits into N parallel data streams – called subcarriers
  - OFDM allows overlap which greatly increases capacity



(a) Three subcarriers in time domain



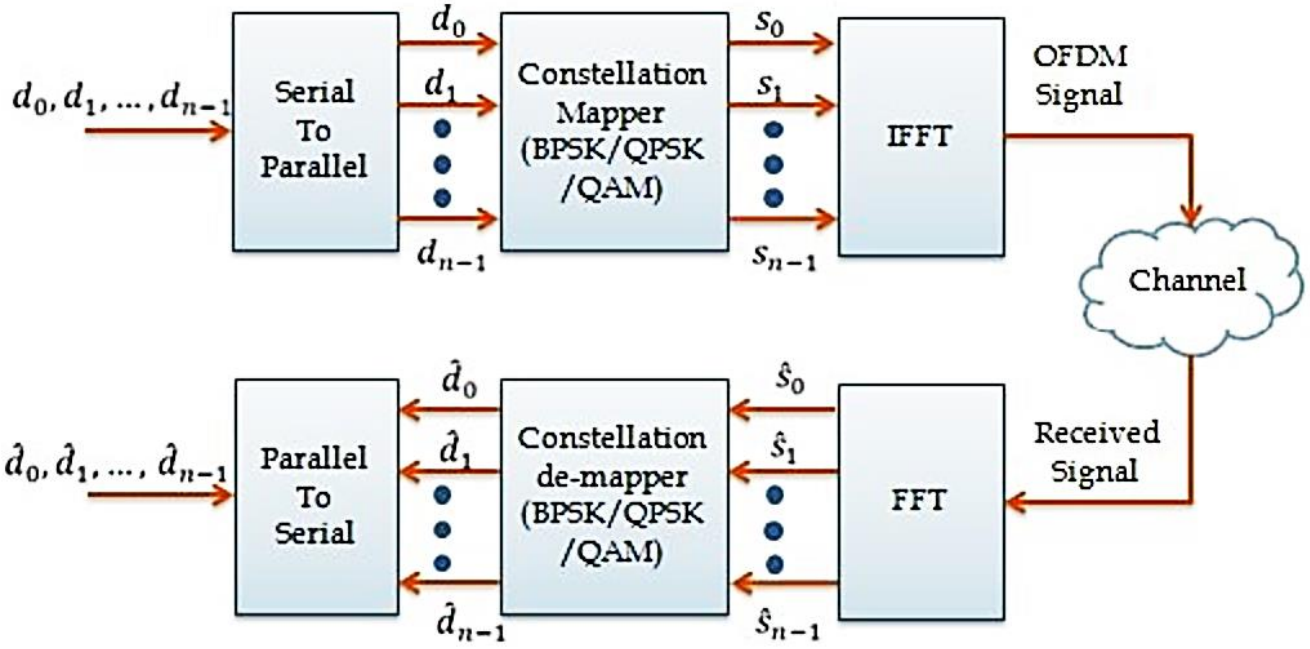
(b) Three orthogonal subcarriers in frequency domain



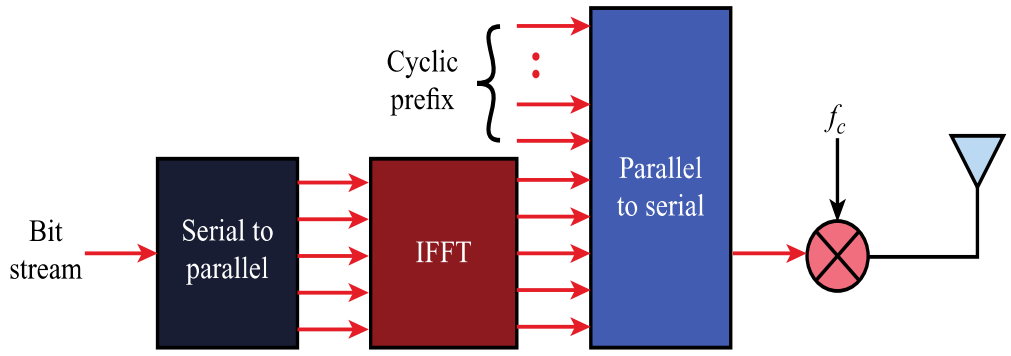
(c) Three carriers using traditional FDM

OFDM (ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING)

- OFDM Implementation:
  - IFFT/FFT Transform
  - Cyclic prefix (CP): Overcome ISI



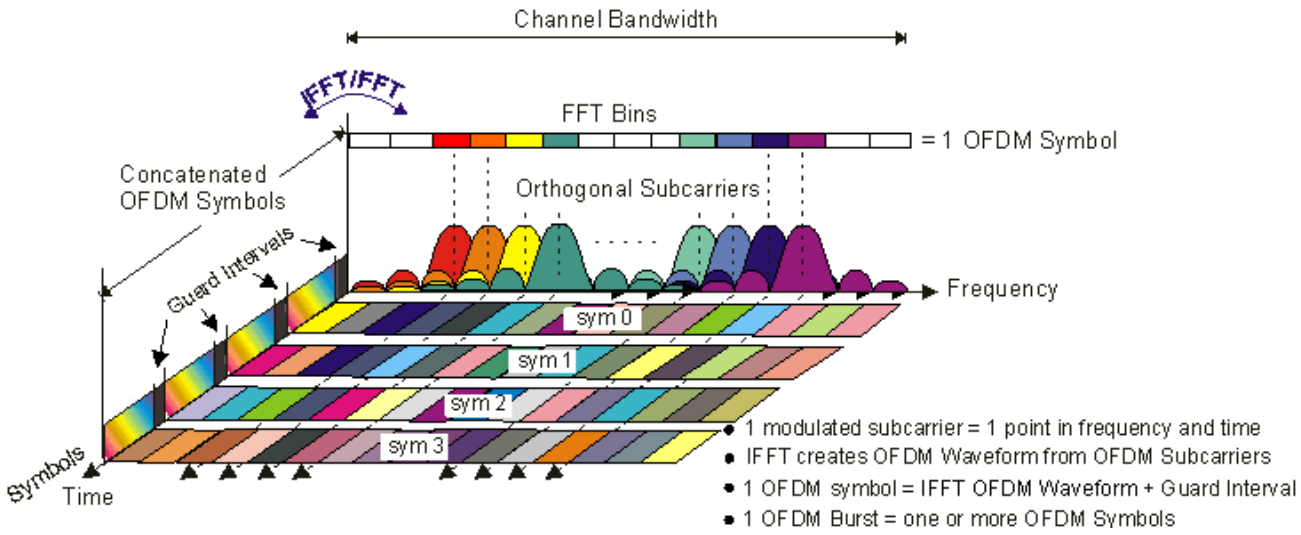
OFDM System Block diagram

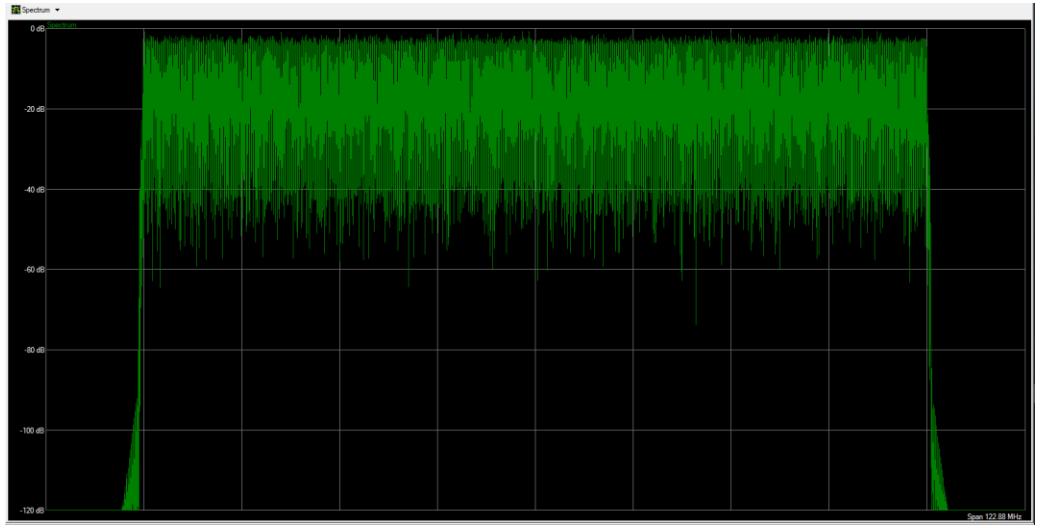


OFDM Block diagram showing CP

OFDM (ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING)

❑ OFDM signal





Frequency-Time representative of an OFDM signal

A real OFDM signal in spectrum analyzer

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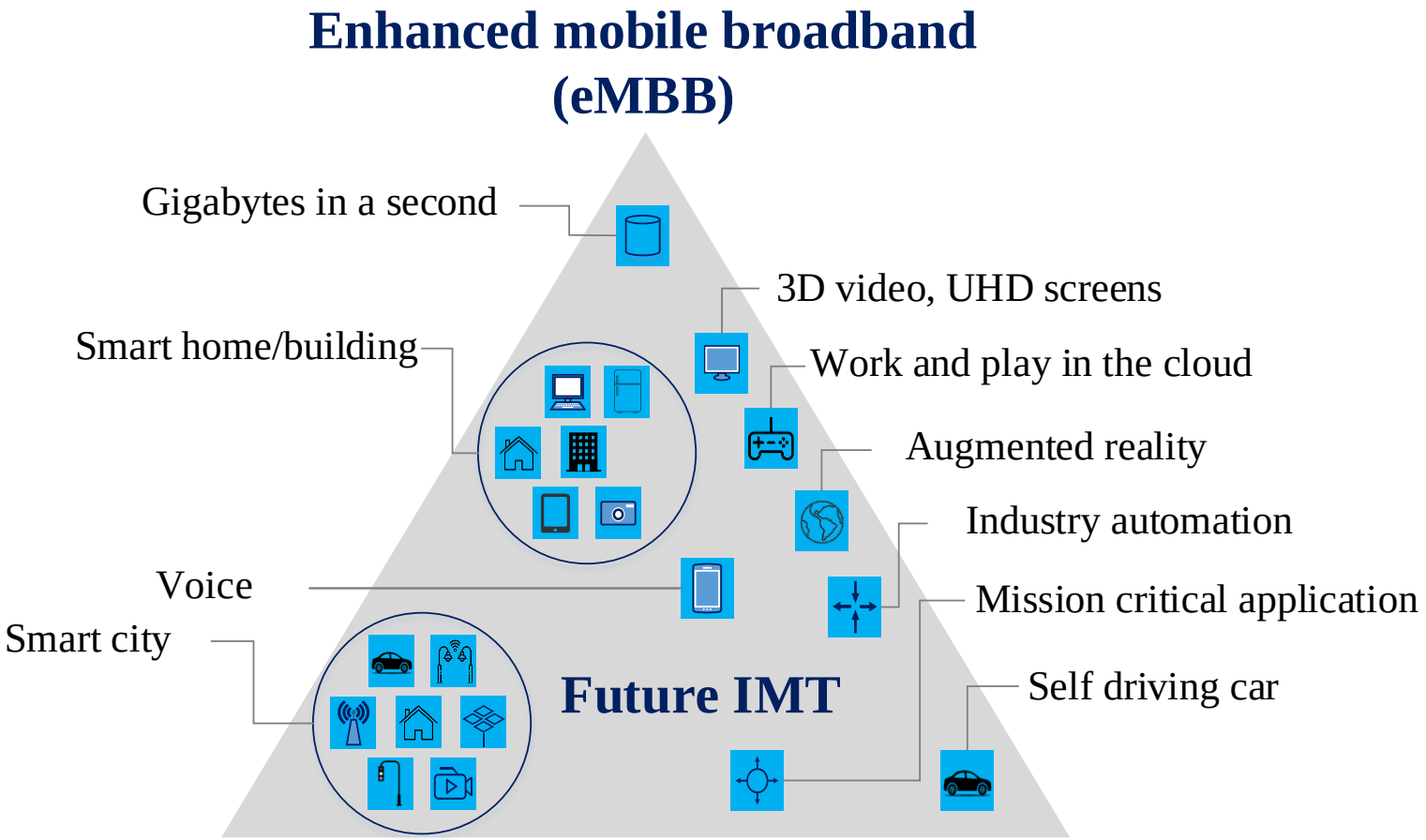
5G NR USE CASES



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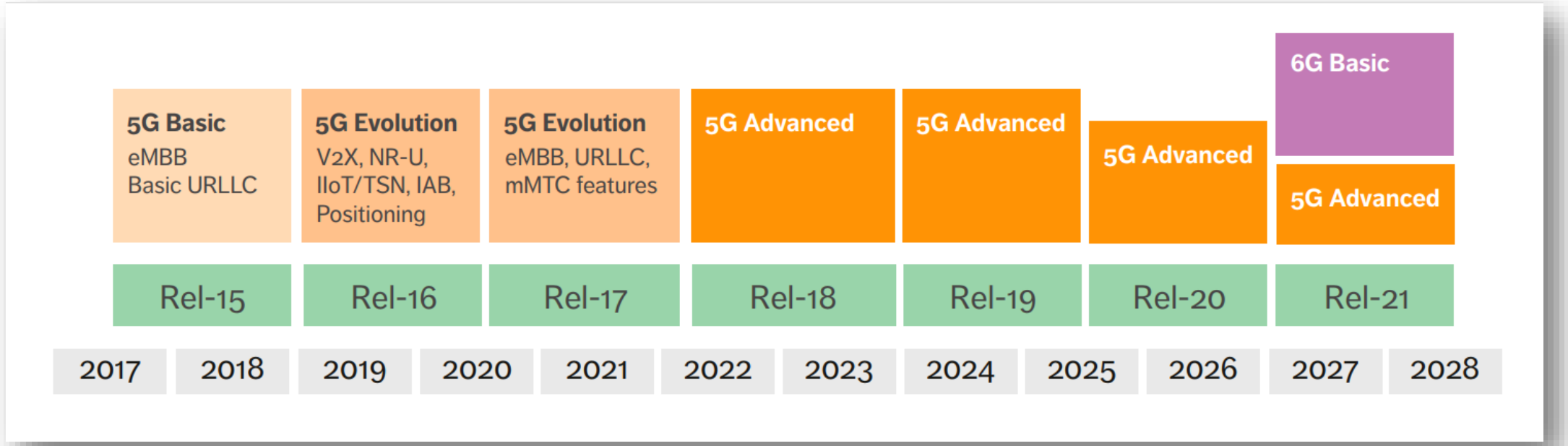
3GPP SPECIFICATION FOR 5G NR LAYER 1



3GPP TS 38.201	Physical Layer – General Description
3GPP TS 38.202	Services provided by the physical layer
3GPP TS 38.211	Physical channels and modulation
3GPP TS 38.212	Multiplexing and channel coding
3GPP TS 38.213	Physical layer procedures for control
3GPP TS 38.214	Physical Layer Procedures for Data
3GPP TS 38.215	Physical layer measurements

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5G VS LTE: MAIN PHYSICAL LAYER DIFFERENCES

	LTE	5G
Use cases	Mobile broadband access (MTC later)	More use cases: eMBB, mMTC, URLLC
Latency	~10 ms	<1 ms
Band	Below 6 GHz	Up to 60 GHz
Bandwidth	Up to 20 MHz	Up to 100 MHz below 6 GHz (FR1) Up to 400 MHz above 6 GHz (FR2)
Subcarrier spacing	Fixed	Variable
Freq allocation	UEs need to decode the whole BW	Use of bandwidth parts
“Always on” signals	Used: Cell specific RS, PSS,SSS, PBCH	Avoid always on signals, the only one is the SS block

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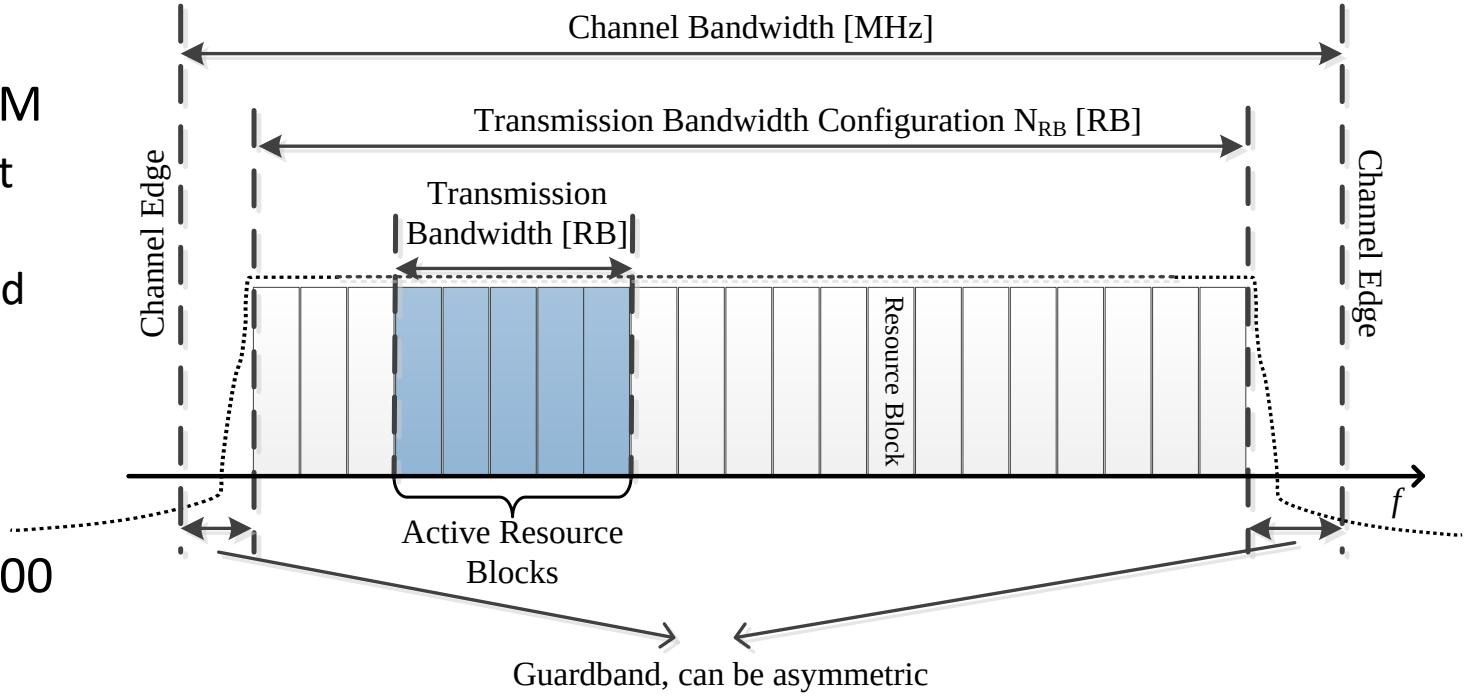
5G NR WAVEFORM AND BANDWIDTH

- Waveform:
  - DL Waveform: CP-OFDM
  - UL Waveform: CP-OFDM + DFT-s-OFDM
    - CP-OFDM targeted at high throughput scenarios
    - DFT-s-OFDM targeted at power limited scenarios
- Bandwidth
  - Maximum CC bandwidth is 400 MHz
  - Maximum number of subcarriers is 3300
  - Maximum number of CCs is 16



Channel bandwidth and the transmission bandwidth

5G NR NUMEROLOGY

- Numerology:
  - Scalable: $\Delta f = 2^{\mu} \times 15$ (kHz) => Support different services (eMBB, mMTC, URLLC)
  - Defined by:
    - Subcarrier spacing (i.e. μ parameter)
    - Cyclic prefix (i.e. Normal/Extended)

Sync < 6GHz
Cell size: Large
Delay spread: Long

μ	$\Delta f = 2^{\mu} \times 15$	Cyclic Prefix
0	15 kHz	Normal
1	30 kHz	Normal
2	60 kHz	Normal, Extended
3	120 kHz	Normal
4	240 kHz	Normal

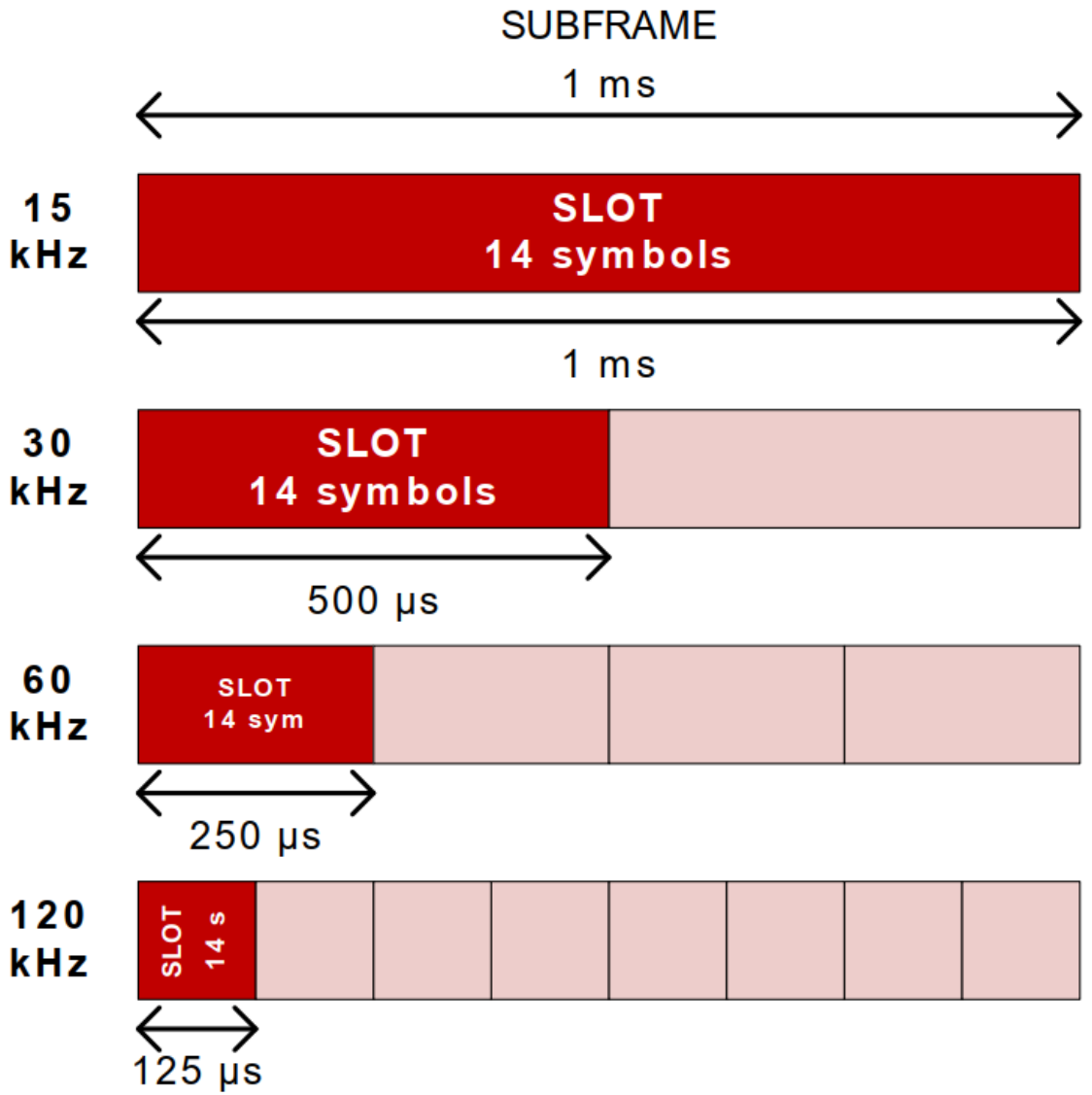
Data < 6GHz

Data > 6GHz

Sync > 6GHz
Cell size: Small
Delay spread: Short
Large subcarrier: Reduce frequency-error and phase noise

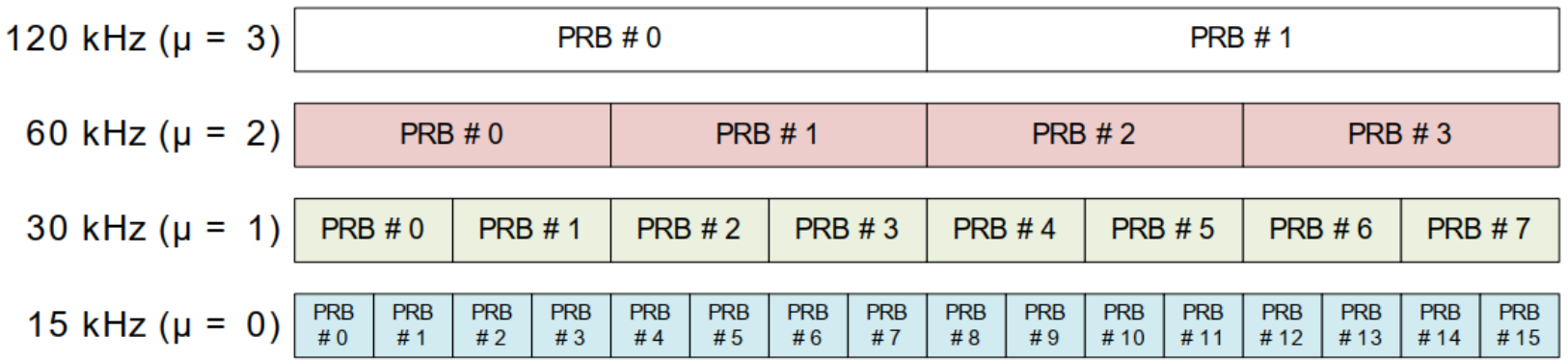
5G NR FRAME STRUCTURE

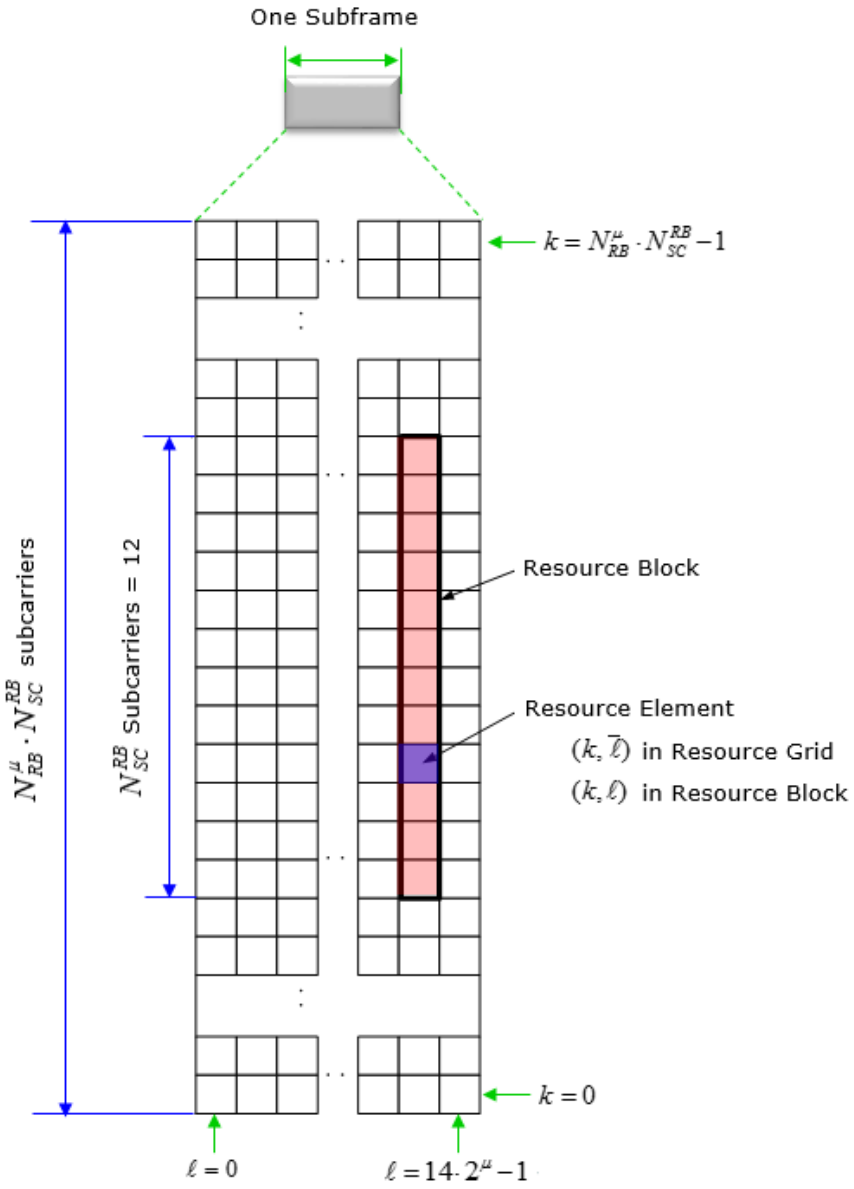
- Frame: 10ms
- Subframe: 1ms
- Slot (slot based scheduling)
  - 14 OFDM symbols
  - Slot length = 1ms/2^{μ} (scales with the subcarrier spacing)
- Mini-Slot (non-slot based scheduling)
  - 7, 4 or 2 OFDM symbols
  - To meet short latency requirements in UR case.



5G NR RESOURCE GRID

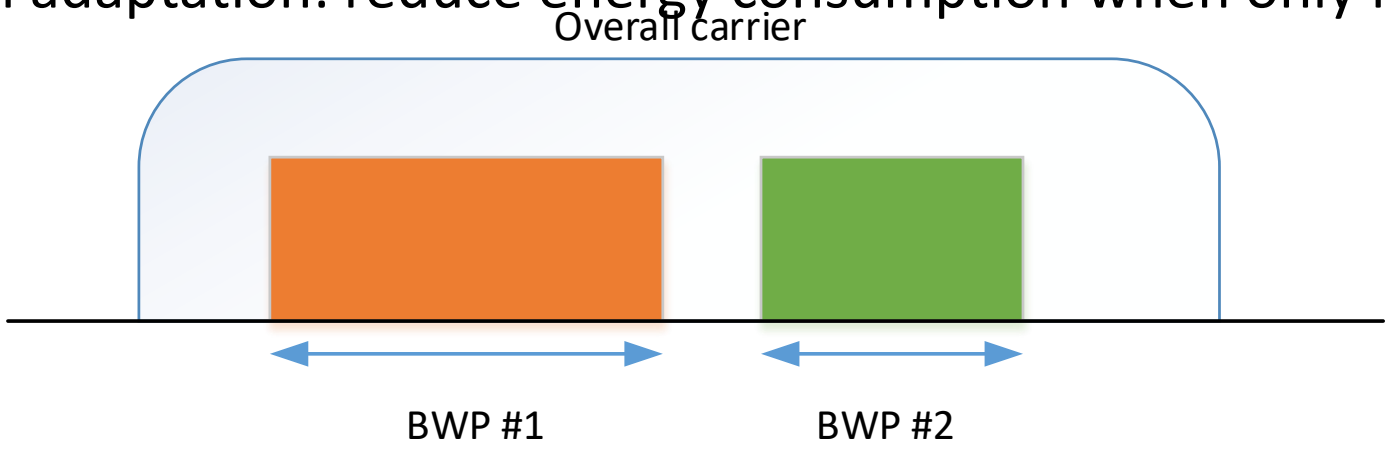
- Resource grid: defined by $N_{RB}^{\mu}.N_{sc}^{RB}$ subcarriers and $N_{symb}^{subframe,\mu}$ OFDM symbols. The dimension varies depending on μ.
- Resource elements: an element in resource grid
- Resource block: N_{sc}^{RB}=12 subcarriers





5G NR BANDWIDTH PARTS (BWP)

- A subset of contiguous RBs on a carrier.
- A UE can be configured with up to 4 BWP, but only one BWP is active at a time
- UE is not expected to receive data outside of active BWP
- BWPs address the following issues:
  - Devices may not be able to receive the full BW
  - Bandwidth adaptation: reduce energy consumption when only narrow bandwidth is required



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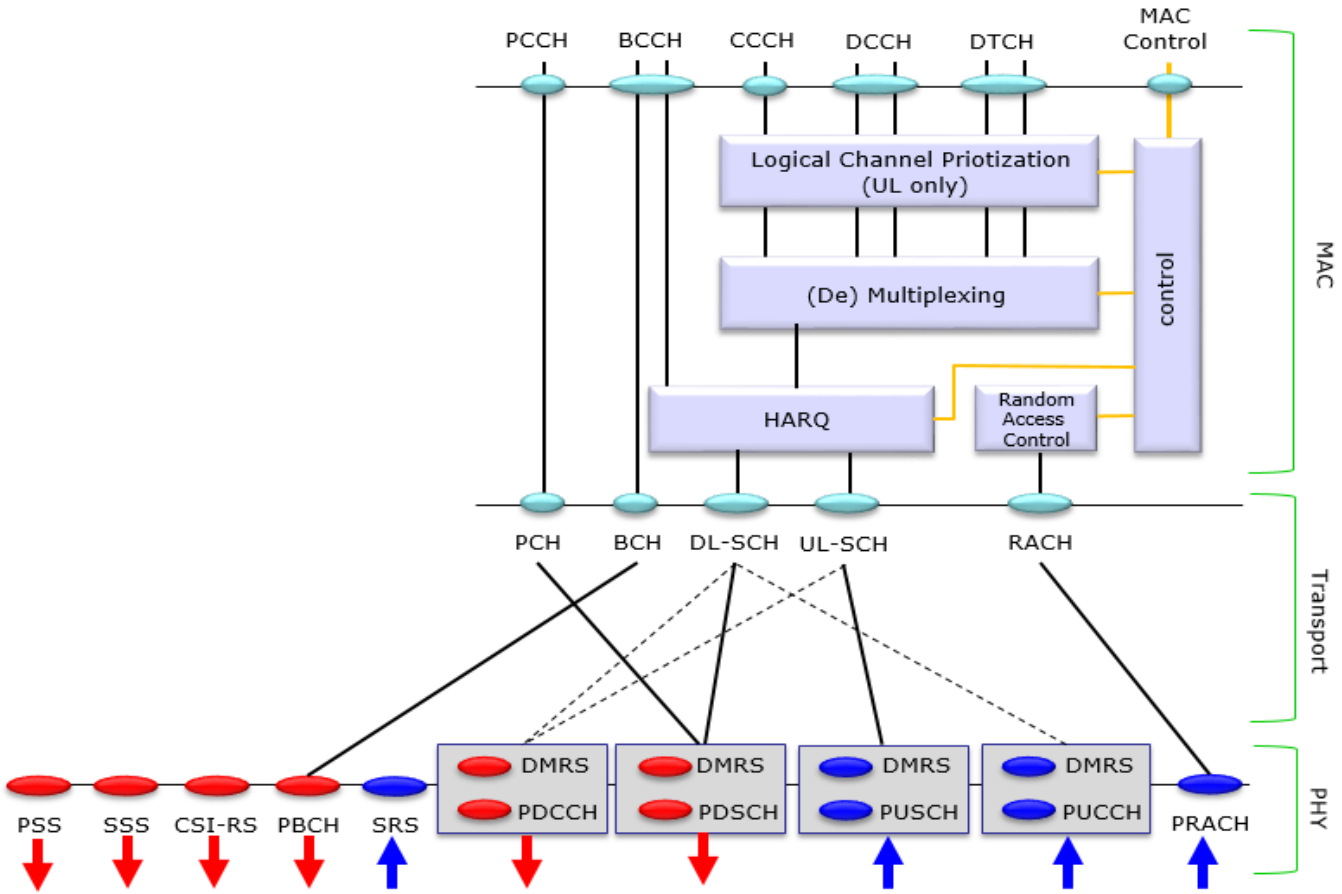
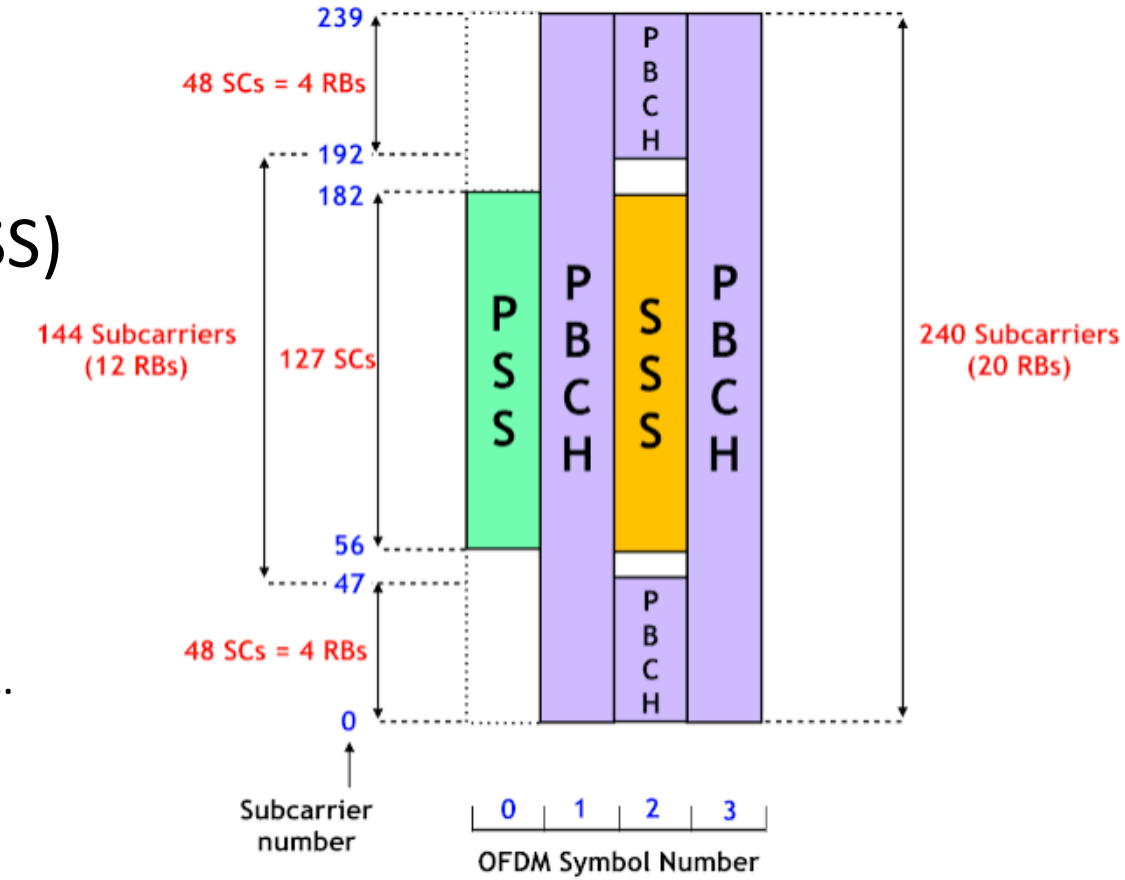
DOWNLINK PHYSICAL CHANNELS AND SIGNALS

- DL physical channels: PBCH, PDSCH, PDCCH
- DL physical signal: PSS/SSS, DM-RS, CSI-RS, PT-RS.



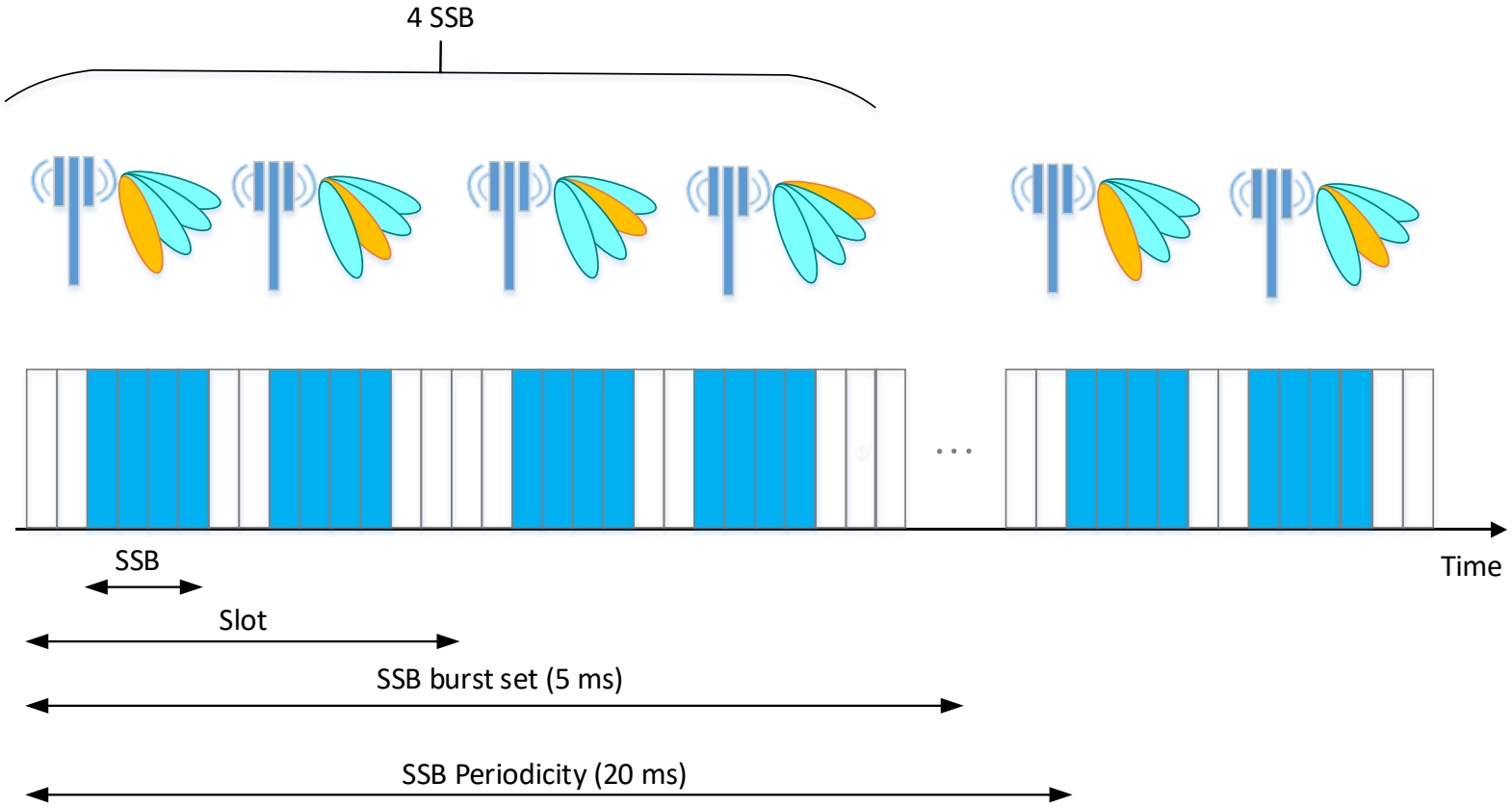
SYNCHRONIZATION SIGNAL BLOCK (SSB)

- Primary Synchronization Sequence (PSS)
  - One of 3 possible sequences
  - Provides timing estimate
- Secondary Synchronization Sequence (SSS)
  - One of 336 possible sequences
  - Provides cell ID (one of 3*336 = 1008)
- Broadcast Channel (PBCH) and DMRS
  - Contains MIB = Master Information Block:
    - Cell barred flag, SIB1 numerology, SFN, DMRS position…
  - Includes basic information to take next step: decode SIB1 (System Information Block)



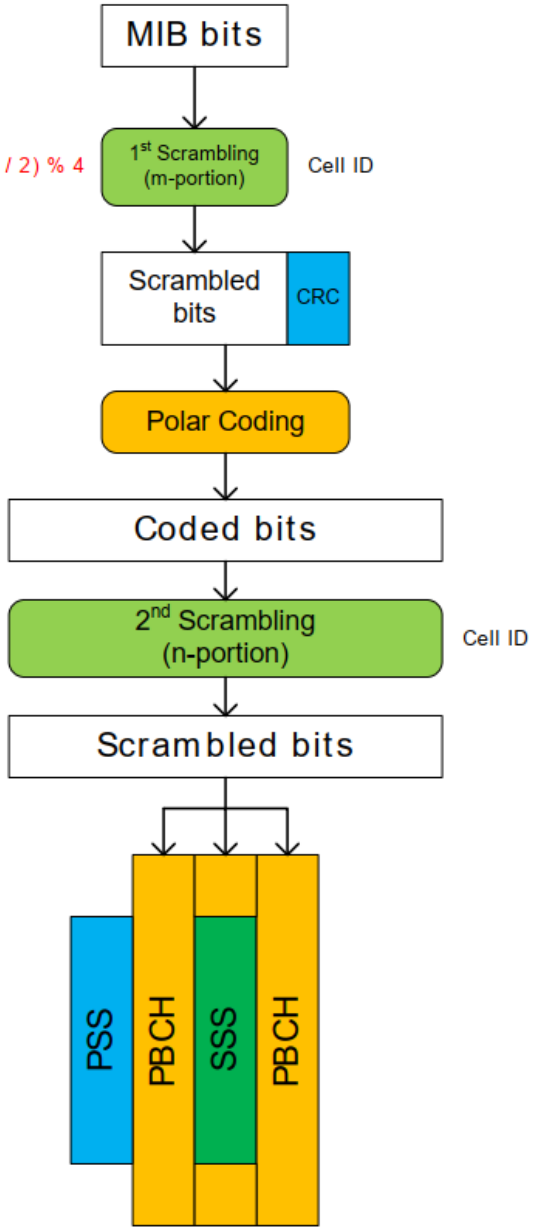
SYNCHRONIZATION SIGNAL BLOCK (SSB)

- Max number of SSB: 4 (f<3GHz), 8 (f<6GHz), 64 (f>6GHz)
- Each SSB is beamformed with a different beam
- UE sees different beams with different signal strengths



SYNCHRONIZATION SIGNAL BLOCK (SSB)

- PBCH coded bits of the PBCH code block(s) are mapped across resource elements in PBCH
  - Two scambling operations
  - Channel Coding: polar code
  - Modulation: QPSK



PDCCH (PHYSICAL DOWNLINK CONTROL CHANNEL)

❑Carriers DCI (Downlink Control Information)

- Carries control information used to schedule user data (PDSCH or PUSCH)
- Indicates: Where is the data for a user? (time/freq), Modulation and coding scheme, number of layers, HARQ informaiton
- Users need to decode DCI before they can decode or transmit data

DCI Format	Usage
Format 0_0	Scheduling of PUSCH in one cell
Format 0_1	Scheduling of PUSCH in one cell
Format 1_0	Scheduling of PDSCH in one cell DCI format 1_0 with CRC scrambled by C-RNTI DCI format 1_0 with CRC scrambled by RA-RNTI DCI format 1_0 with CRC scrambled by TC-RNTI
Format 1_1	Scheduling of PDSCH in one cell
Format 2_0	Notifying a group of UEs of the slot format
Format 2_1	Notifying a group of UEs of the PRB(s) and OFDM symbol(s) where UE may assume no transmission is intended for the UE
Format 2_2	Transmission of TPC commands for PUCCH and PUSCH
Format 2_3	Transmission of a group of TPC commands for SRS transmissions by one or more UEs

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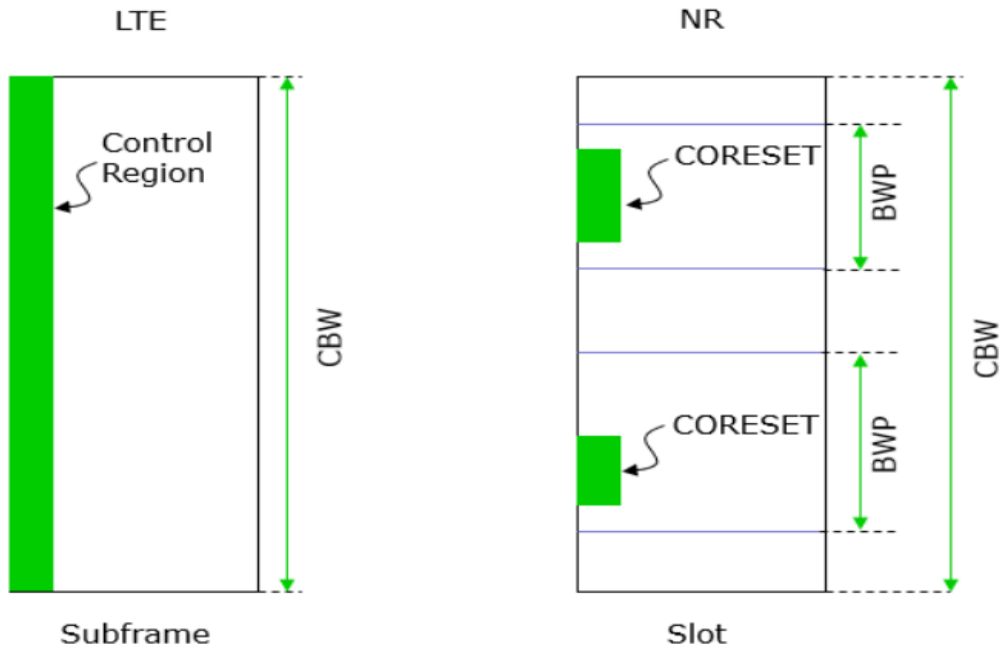
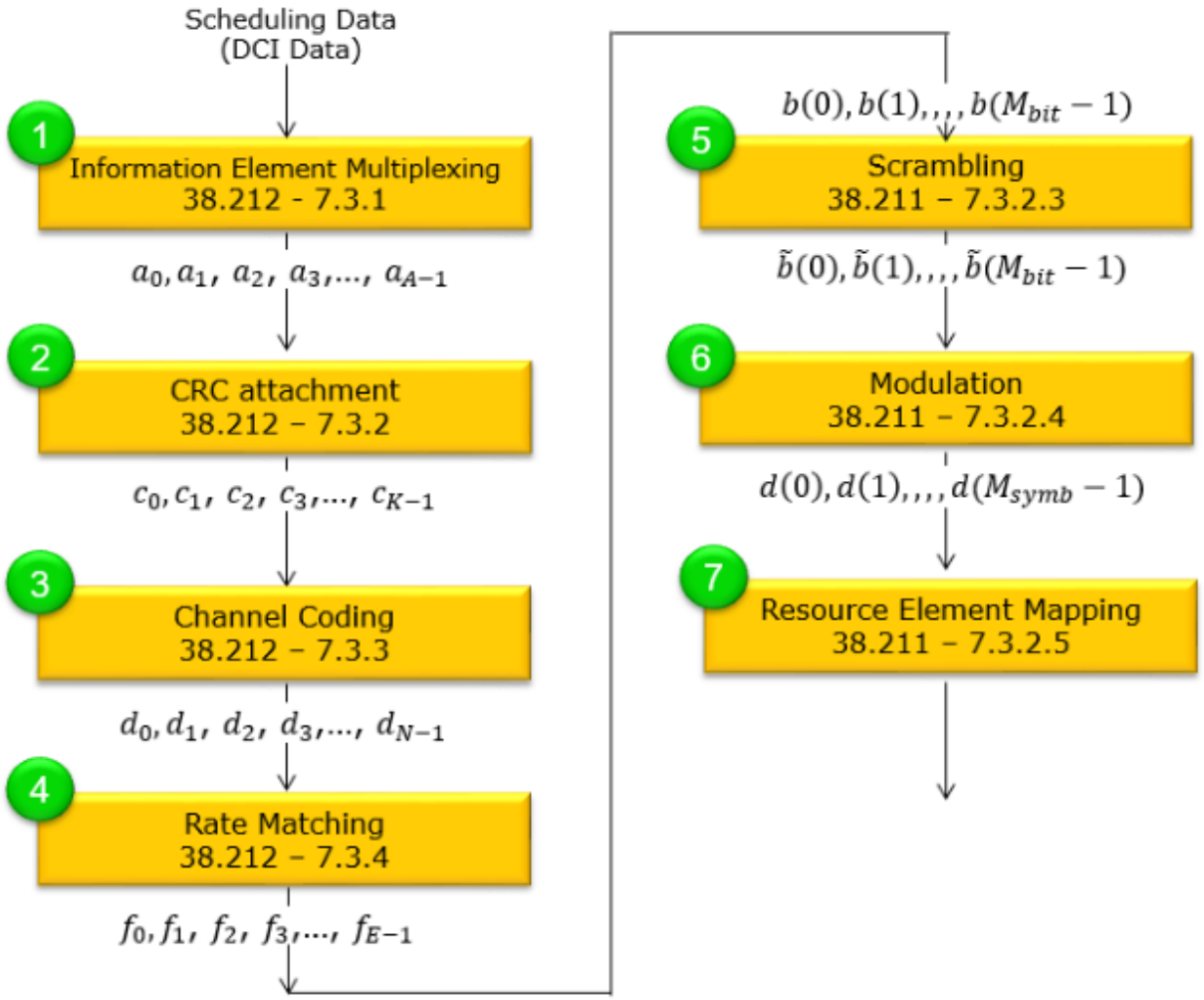
PDCCH (PHYSICAL DOWNLINK CONTROL CHANNEL)

- CORESETs (Control Resource Sets)
  - Set of time/frequency resources where PDCCH **can** be transmitted
  - There can be many CORESETs in a carrier
  - Max length of 3 symbols
  - Compare to LTE: Does not span the whole bandwidth
    - Supports limited bandwidth capabilities
    - Saves power



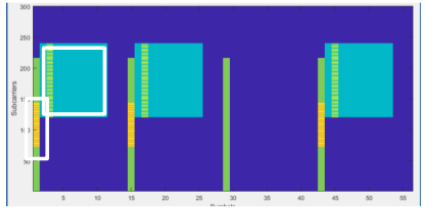
PDCCH (PHYSICAL DOWNLINK CONTROL CHANNEL)

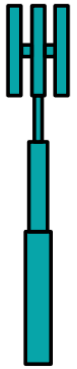
- PDCCH transport process
  - Channel Coding: polar code
  - Modulation: QPSK



PDCCH (PHYSICAL DOWNLINK CONTROL CHANNEL)

❑ PDSCH/PUSCH scheduling





DL transmission (PDCCH, PDSCH …)

Decode PDCCH

Parse **DCI**

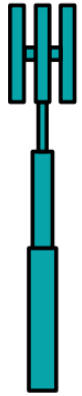
Decode PDSCH

- Where is the data for a user? (time/frequency)
- MCS
- HARQ infor (RV, process number, new data indicator)
- Number of layers

Scheduling request

Uplink grant: **DCI**

PUSCH using parameters specified in DCI



- Where is the data for a user? (time/frequency)
- MCS
- HARQ infor (RV, process number, new data indicator)
- Number of layers
- Precoding
- CSI request

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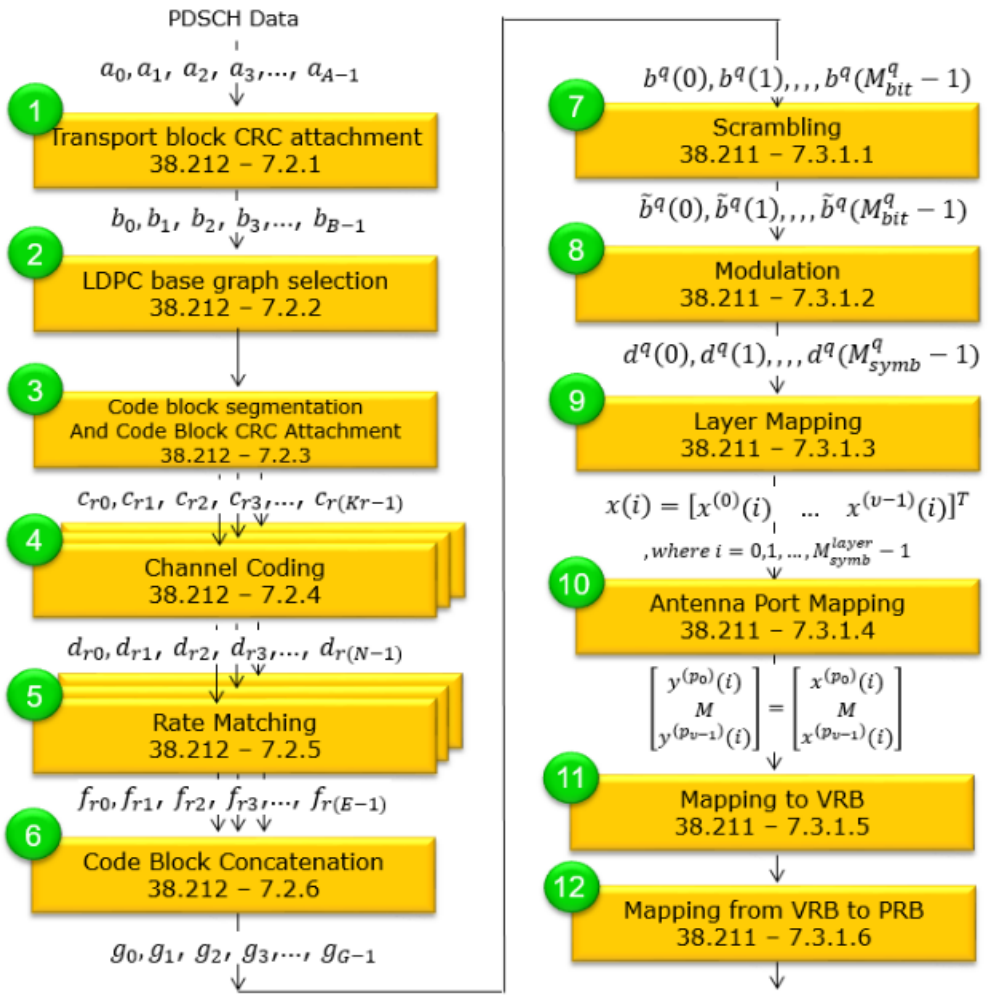
PDSCH (PHYSICAL DOWNLINK SHARED CHANNEL)

- Carrier user data
- Can also carry the System Information Block (SIB)
- Main difference with LTE: use of LDPC coding
- Up to 8 layers = MIMO support
- Parameters are configured by:
  - DCI (Downlink Control Information)
  - RRC message (Radio Resource Control)

PDSCH (PHYSICAL DOWNLINK SHARED CHANNEL)

- PDSCH Transport Procedure
  - Channel Coding: LDPC code
  - Modulation: QPSK, 16/64/256QAM
  - Antenna port mapping:
    - Precoding and beamforming => Achieves beamforming and spatial multiplexing
    - Uses a precoding matrix $\mathbf{W}_{\text{Nantennas x Nlayers}}$
    - DM-RS has to go through the same precoding operation
  - PDSCH mapping:
    - Type A: slot based
    - Type B: mini-slot

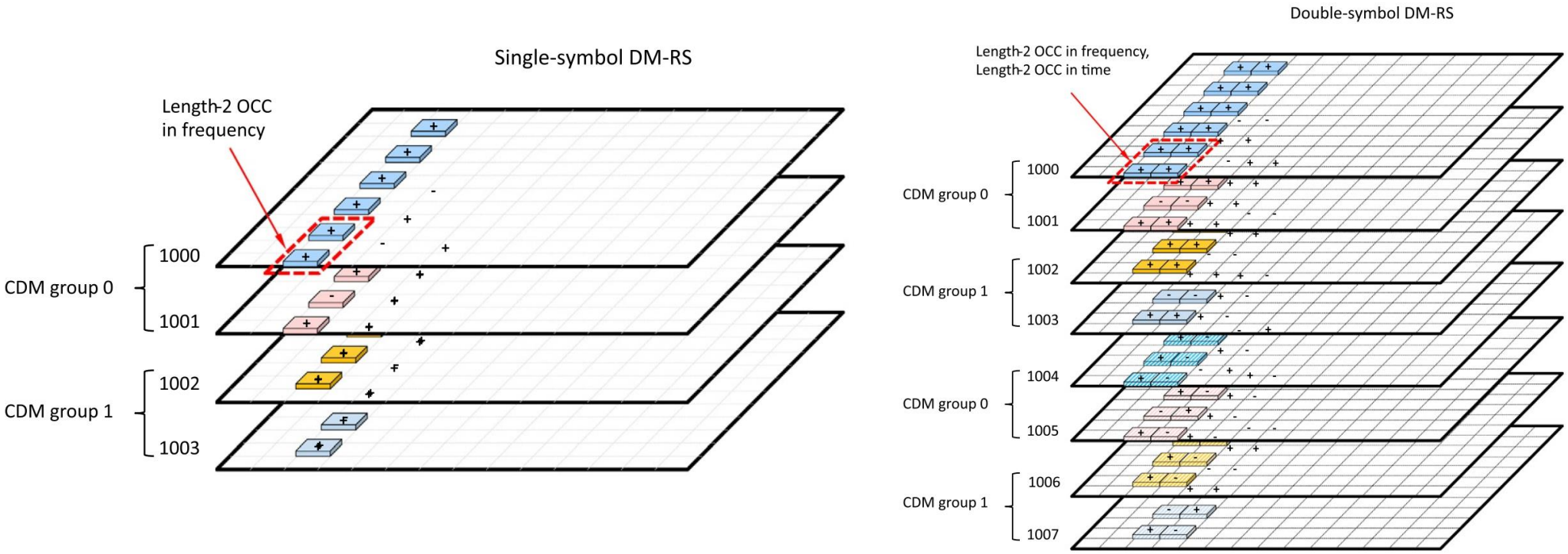


DOWNLINK PHYSICAL SIGNAL

- PSS/SSS (Primary/Secondary synchronization signal)
  - Used for synchronization, cell and beam search
- DM-RS (Demodulation reference signals) for PBCH/PDCCH/PDSCH
  - Used for channel estimation and demodulation of physical channels
- PT-RS (Phase-tracking reference signals): FR2 only
  - Phase noise impact compensation for high frequency (mmWave)
- CSI-RS (Channel-state information reference signal)
  - Used for getting CSI and for beam management

PDSCH DM-RS

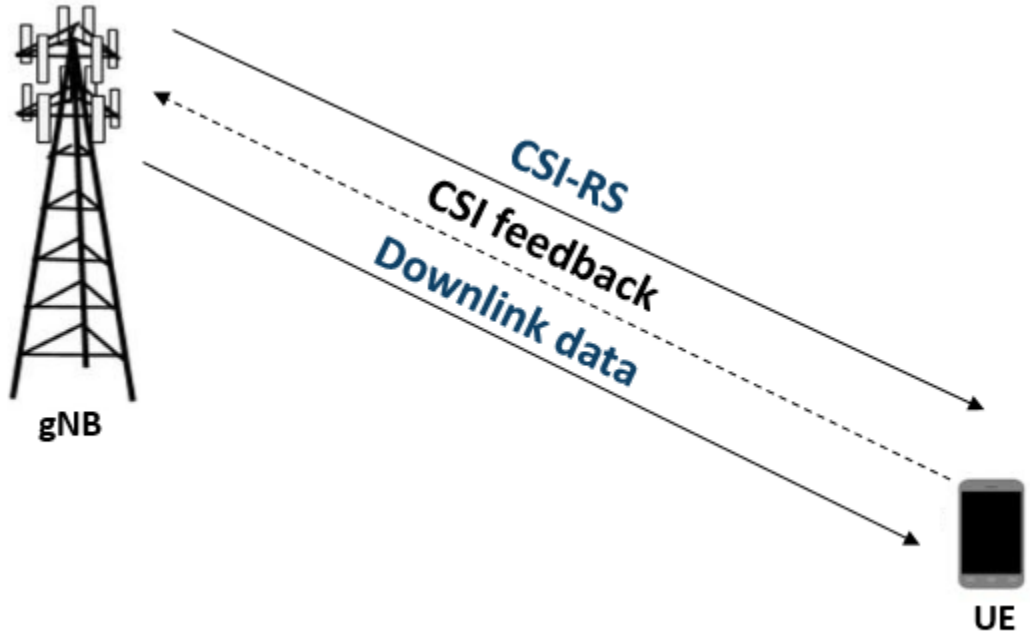
- ❑ Appear only in PDSCH resource blocks
- ❑ Needed for channel estimation for PDSCH decoding
- ❑ Flexible allocation: single/double, type1/type2…
- ❑ 1 to 4 dmrs symbols per slot.



DMRS type 1: single and double symbols

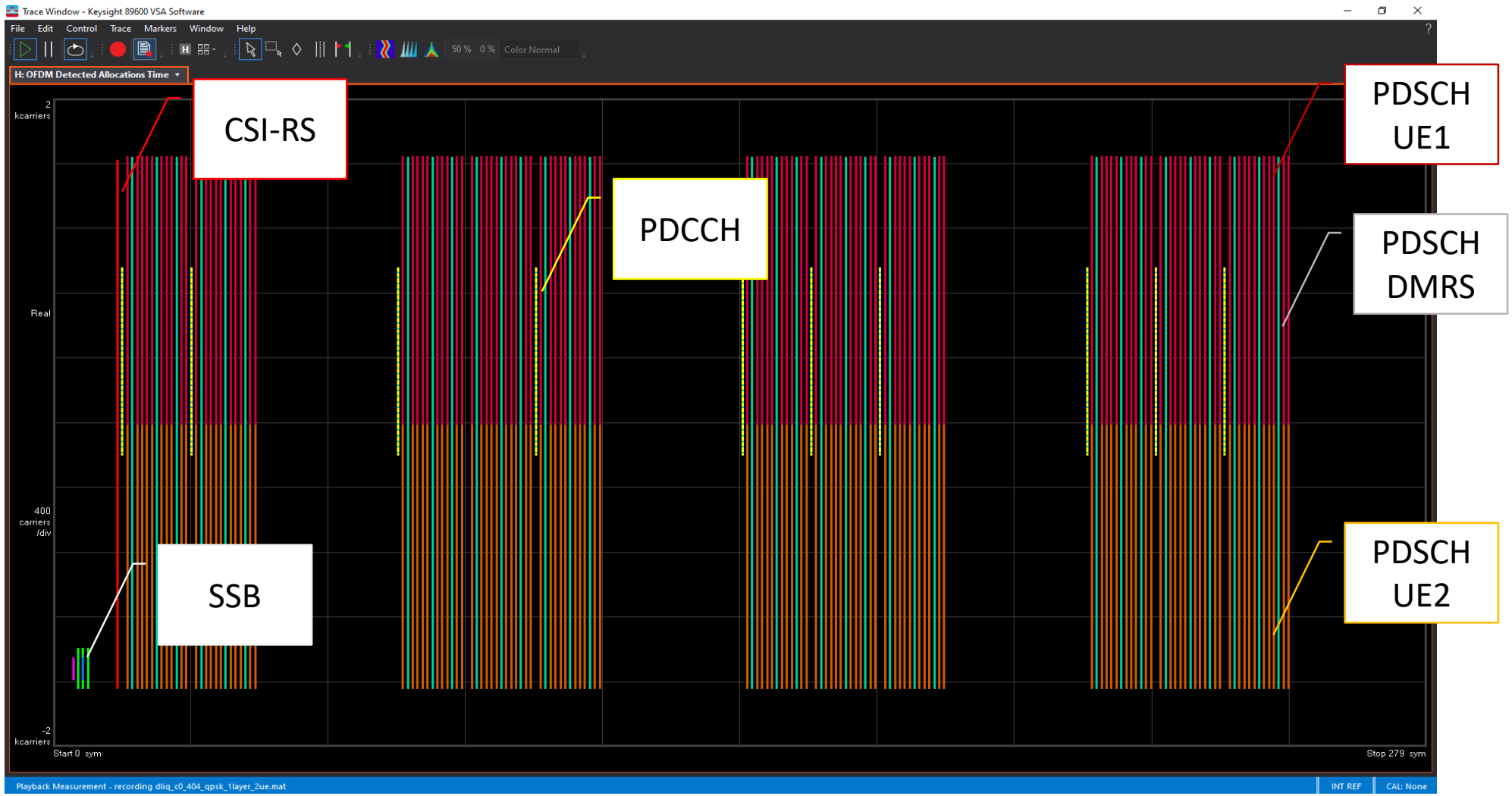
CSI-RS AND CSI REPORT

- CSI-RS:
  - CSI acquisition
  - Beam management
- CSI Report:
  - RI: Number of layers
  - CQI: indicator of channel quality
  - PMI: precoding matrix
  - CRI: CSI-RS Indicator



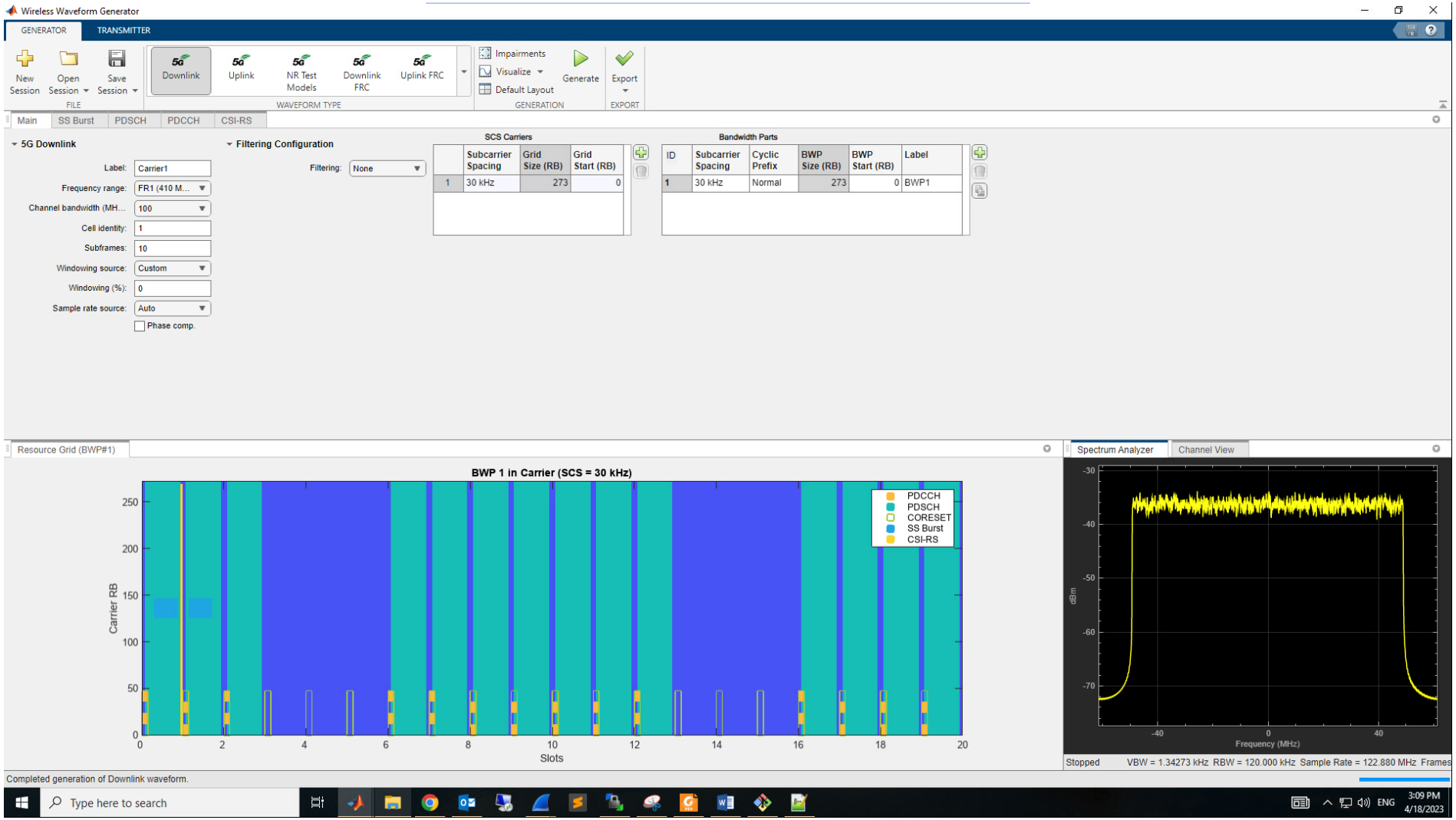
DOWNLINK RESOURCE ALLOCATION

- DL physical channels and signals on TDD resource



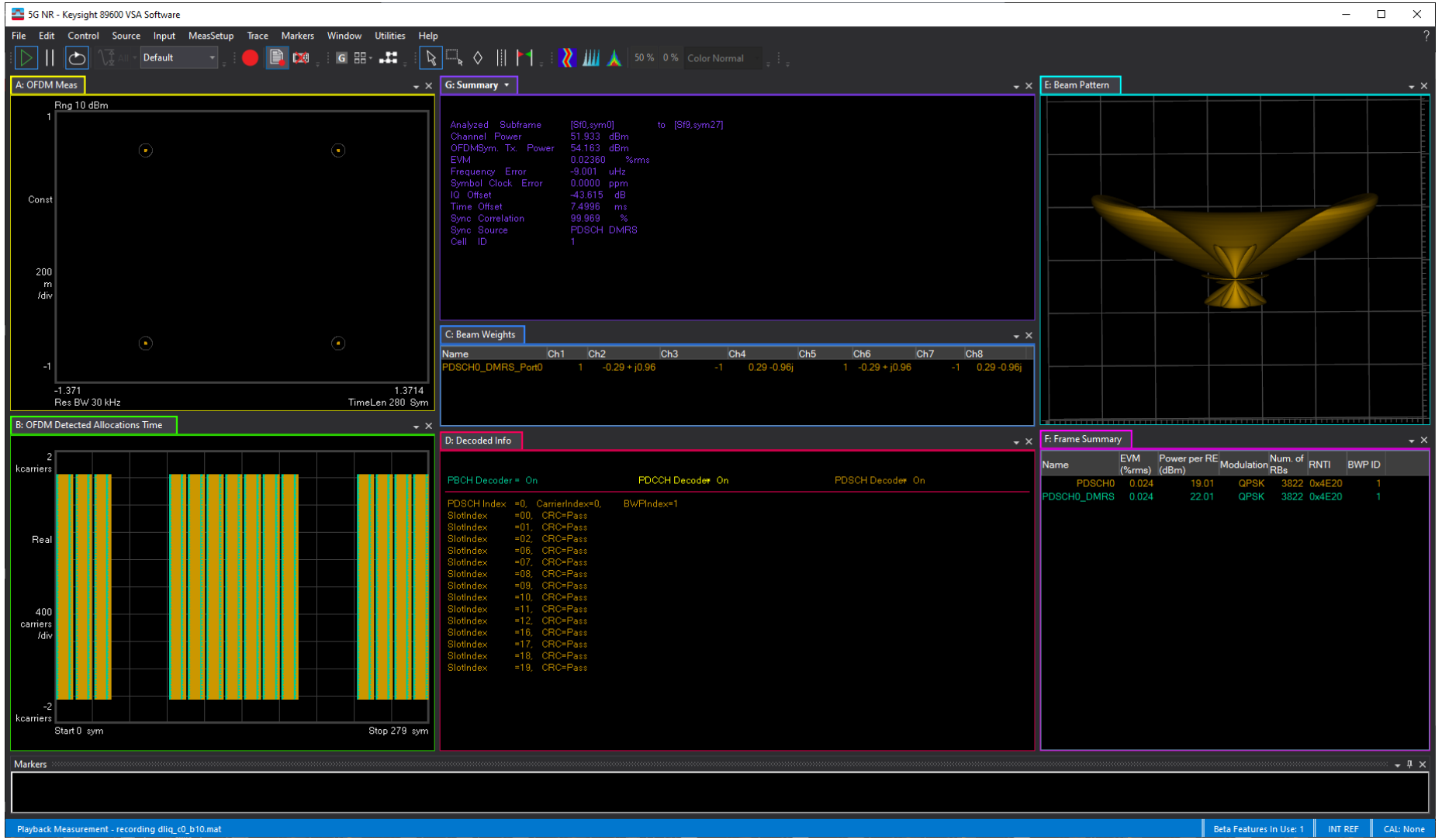
DOWNLINK SIGNAL GENERATION AND VERIFICATION

- Matlab 5G Toolbox: Generate 5G DL signal with UI or matlab code



DOWNLINK SIGNAL GENERATION AND VERIFICATION

- Keysight VSA for 5G: Analyze 5G NR signal



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UPLINK CHANNELS

- Uplink Channel:
  - Transmit from UE to gNodeB, include 3 channel and 3 signal
    - 3 Channel
      - ✓ PRACH
      - ✓ PUCCH
      - ✓ PUSCH
    - 2 Signal
      - ✓ DMRS
      - ✓ PTRS (optional)
      - ✓ SRS (optional)

UPLINK CHANNELS

- RACH:
  - The main purpose of RACH:
    - Achieve UP link synchronization between UE and gNodeB
    - Obtain the resource for Message 3
  - When we need RACH
    - Initial access
    - RRC Connection
    - Handover
    - When UL is non-synchronized, Re-establishment procedure.
    - To establish time alignment at S-Cell addition
    - Beam failure recovery.

UPLINK CHANNELS

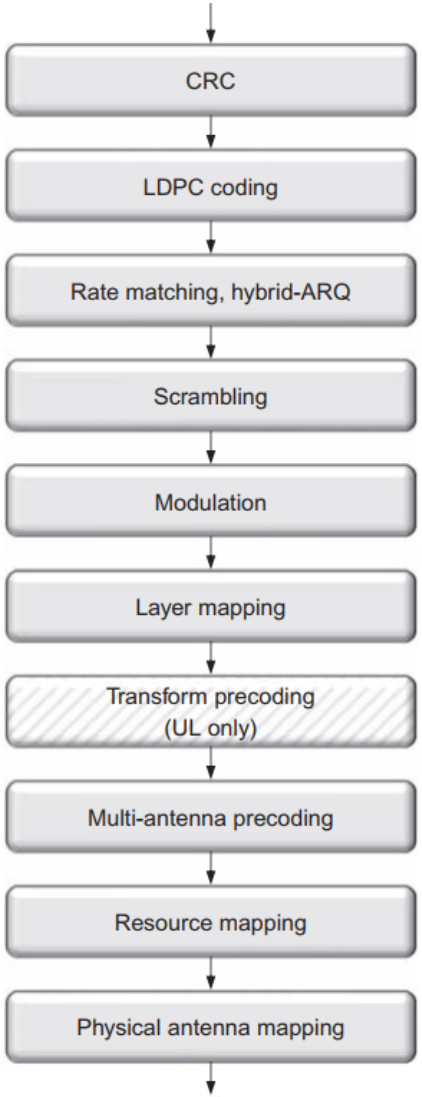
- PUCCH:
  - The main purpose of PUCCH:
    - Carries UCI (Uplink Control Information)
  - Difference between PDCCH and PUCCH
    - PDCCH carries configuration for PDSCH/PUSCH
    - PUCCH carries UCI
  - What is UCI?
    - ACK/NACK
    - Scheduling Request (SR)
    - CSI

UPLINK CHANNELS

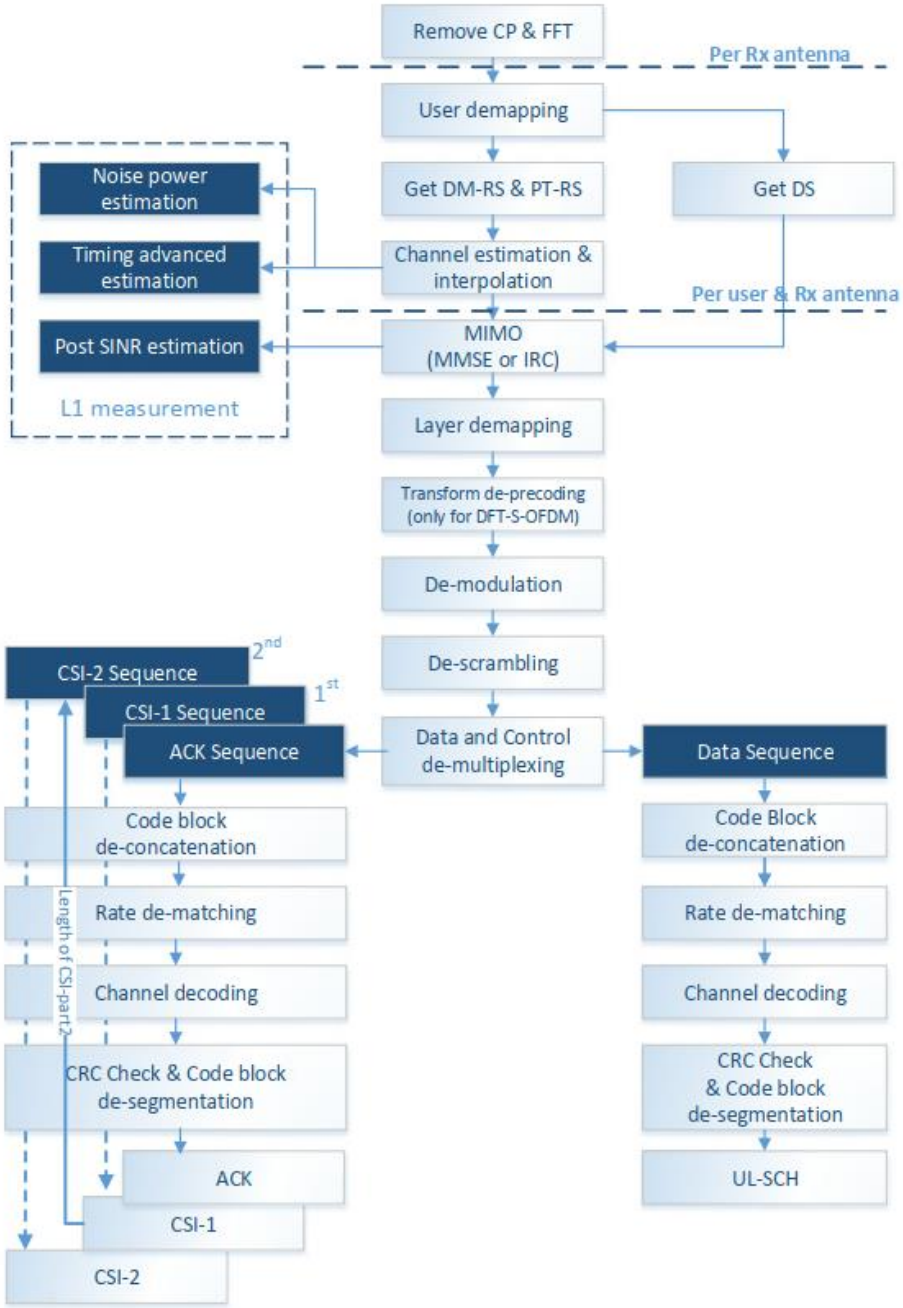
- PUSCH:
  - The most complicated channel in UL
  - The main purpose of PUSCH:
    - Carries User Data
    - Carries UCI

UPLINK CHANNELS

- PUSCH:



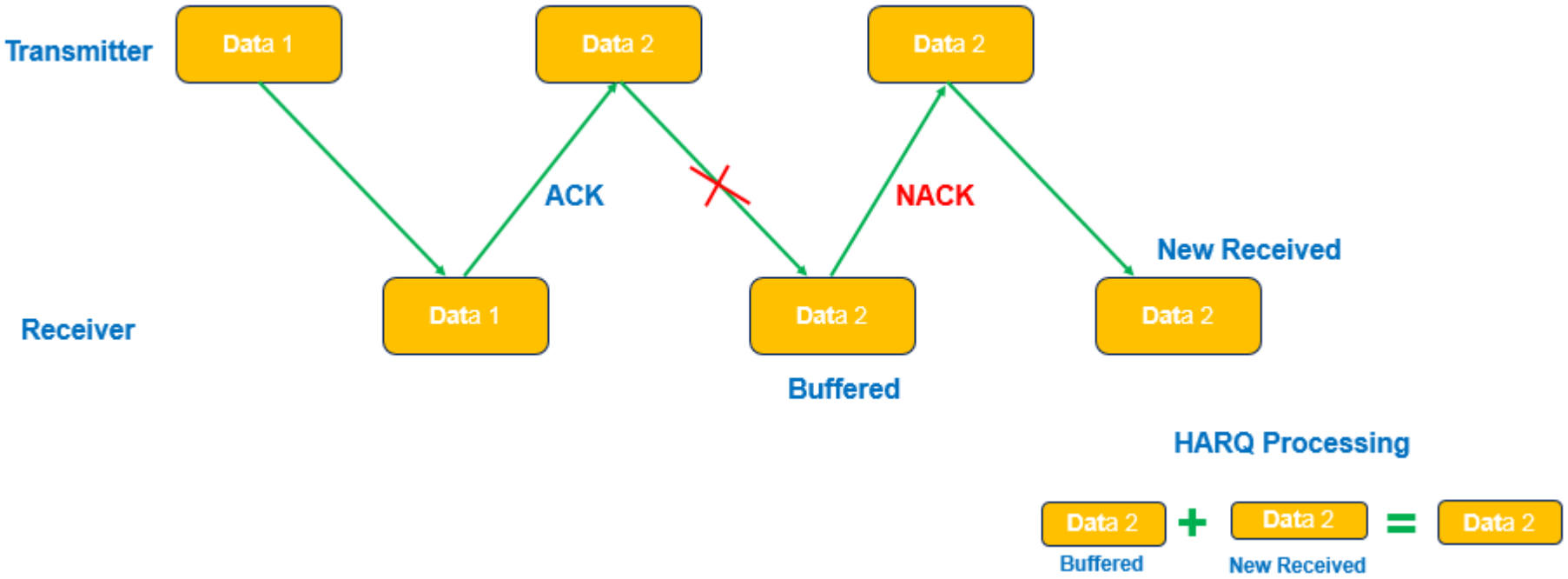
Encode



Decode

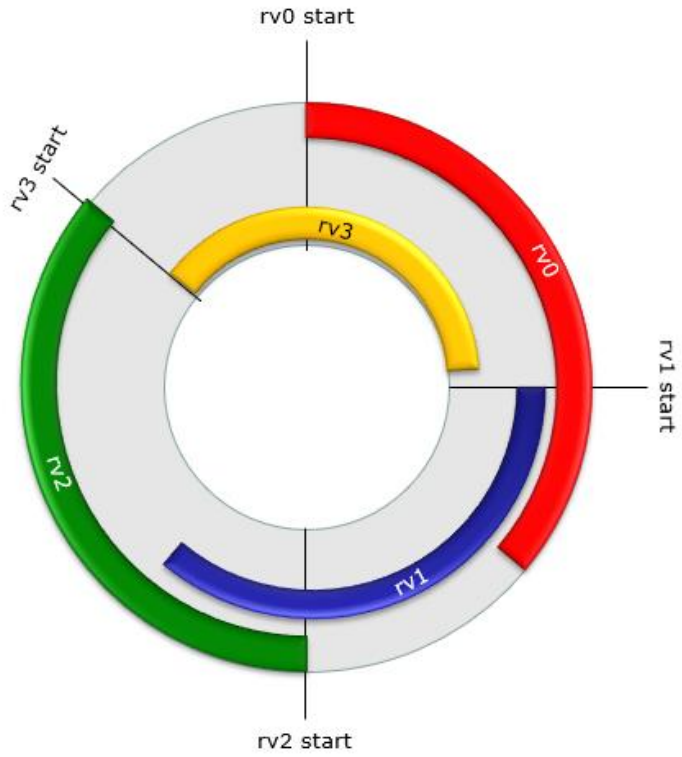
UPLINK CHANNELS

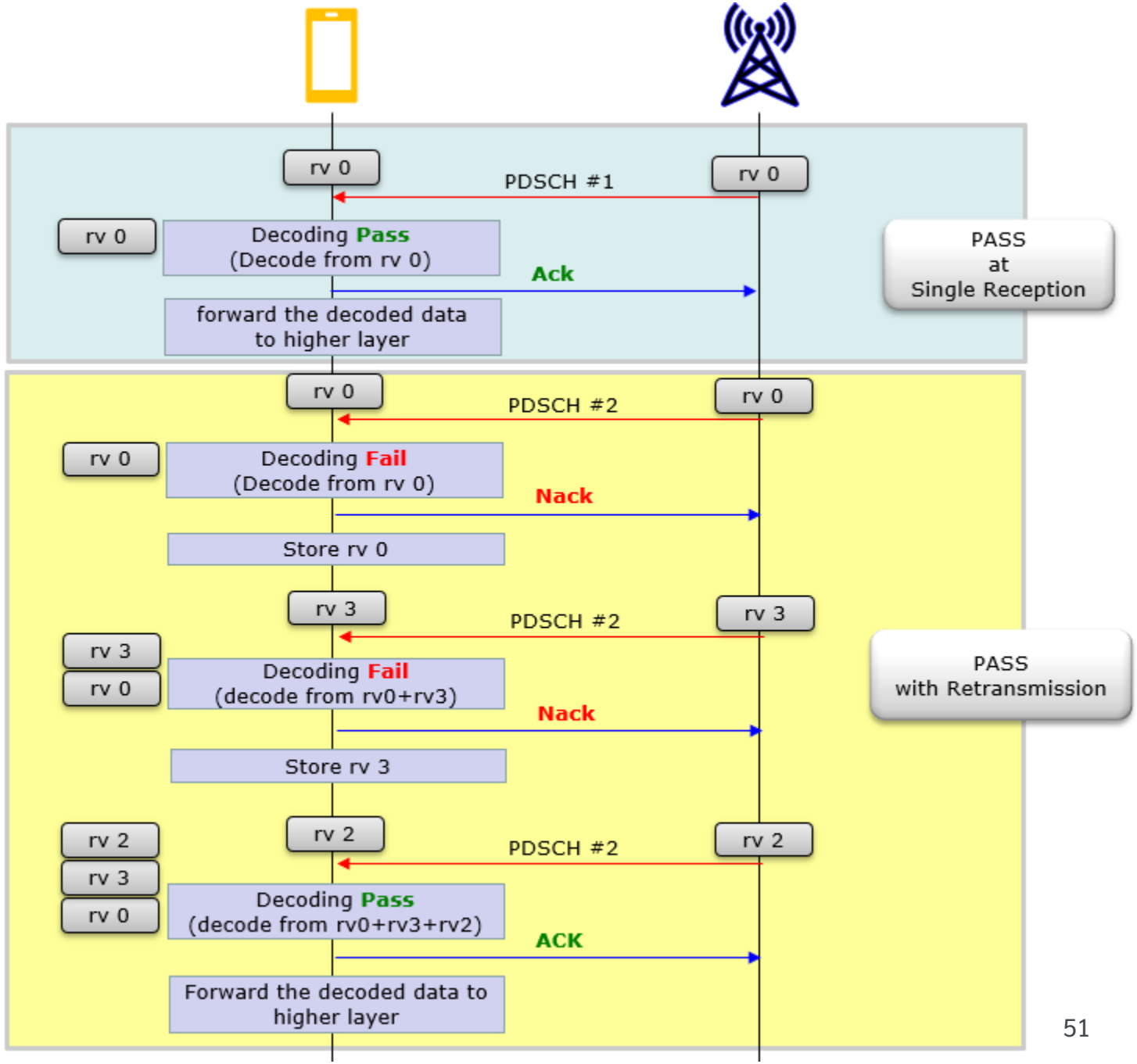
- PUSCH/PDSCH HARQ (Hybrid Automatic Repeat Request)



UPLINK CHANNELS

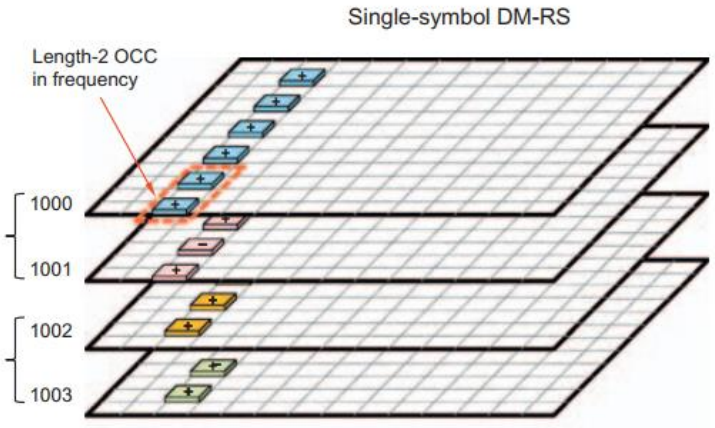
- PUSCH/PDSCH HARQ (Hybrid Automatic Repeat Request)

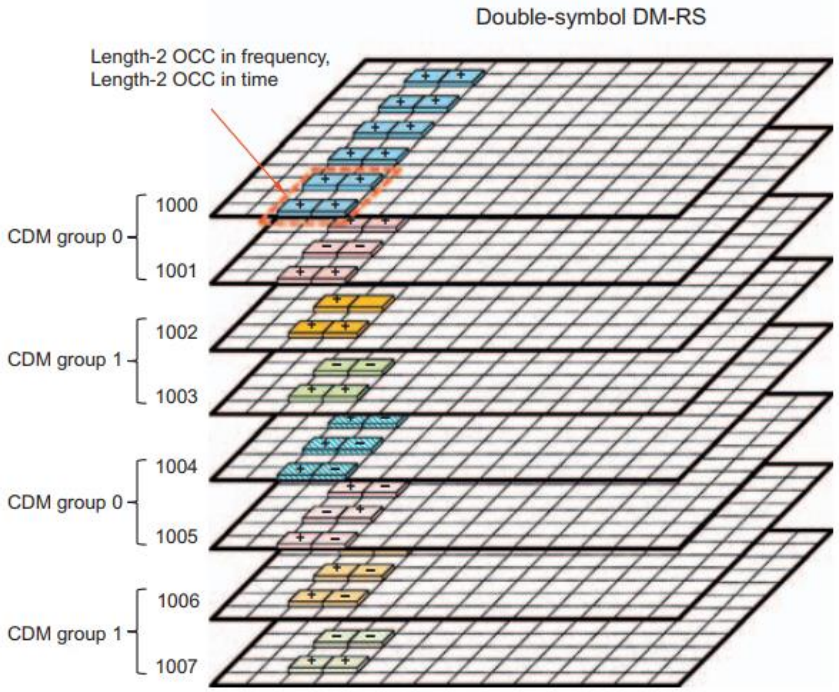




UPLINK CHANNELS

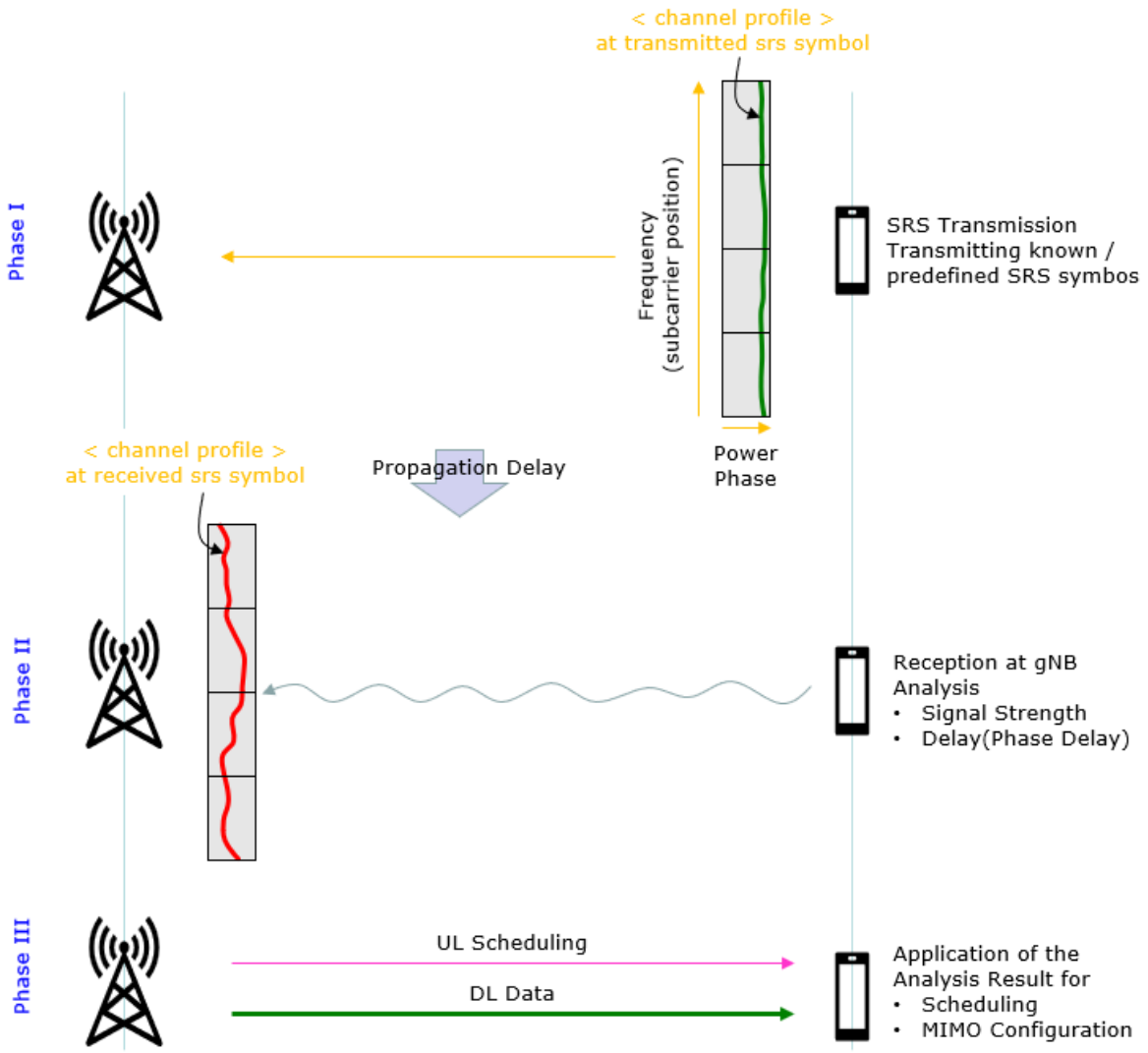
- DMRS (Demodulation Reference Signal)
  - Why we need DMRS?
    - Signal transmit from UE to gNodeB through channel
    - Fading, Time offset, frequency offset
    - Doppler
    - Pilot for Channel estimation
  - Where DMRS?
    - PUSCH
    - PUCCH (optional)





UPLINK CHANNELS

- SRS (Sound Reference Signal)
  - Why we need SRS?
    - Beam forming
    - Massive MIMO



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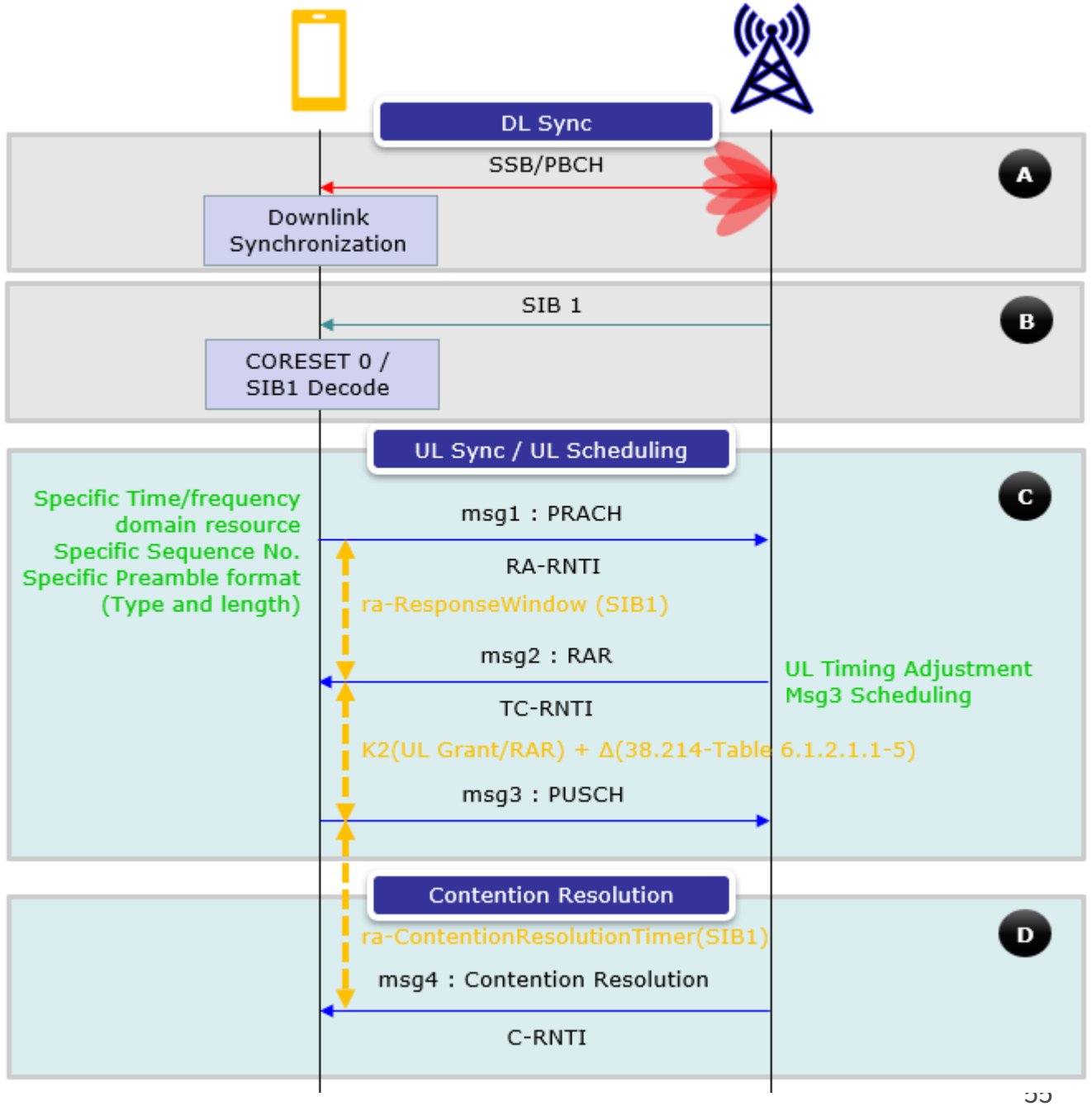
PHYSICAL PROCEDURES

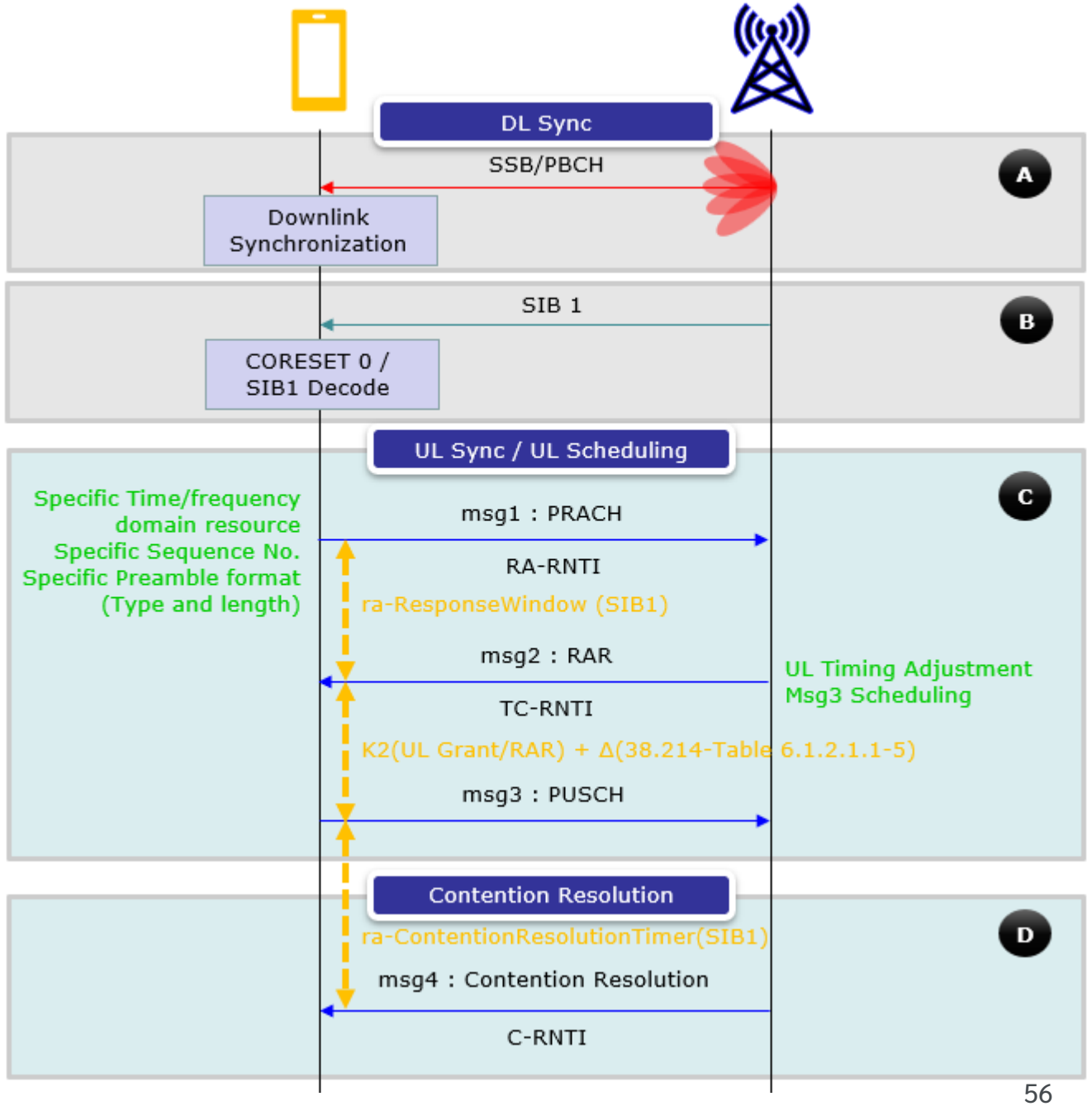
- Why need procedure
  - As rules for all vendor follow
- Initiation procedure in 5G
  - Cell search
  - UE Attach



PHYSICAL PROCEDURES

❑ Initiation procedure in 5G (NSA)

1. 4G said to UE: “we have 5G, use it if you want better performance”
2. gNodeB transmit SSB/PBCH
3. UE scan 5G frequency and receive SSB/PBCH based on 4G suggestion.
4. UE transmit RACH (MSG1) to gNodeB.
5. gNodeB receive RACH and send RACH response (MSG2) to UE through PDCCH (DCIDL)/PDSCH
6. UE decode PDCCH to get configuration of PDSCH

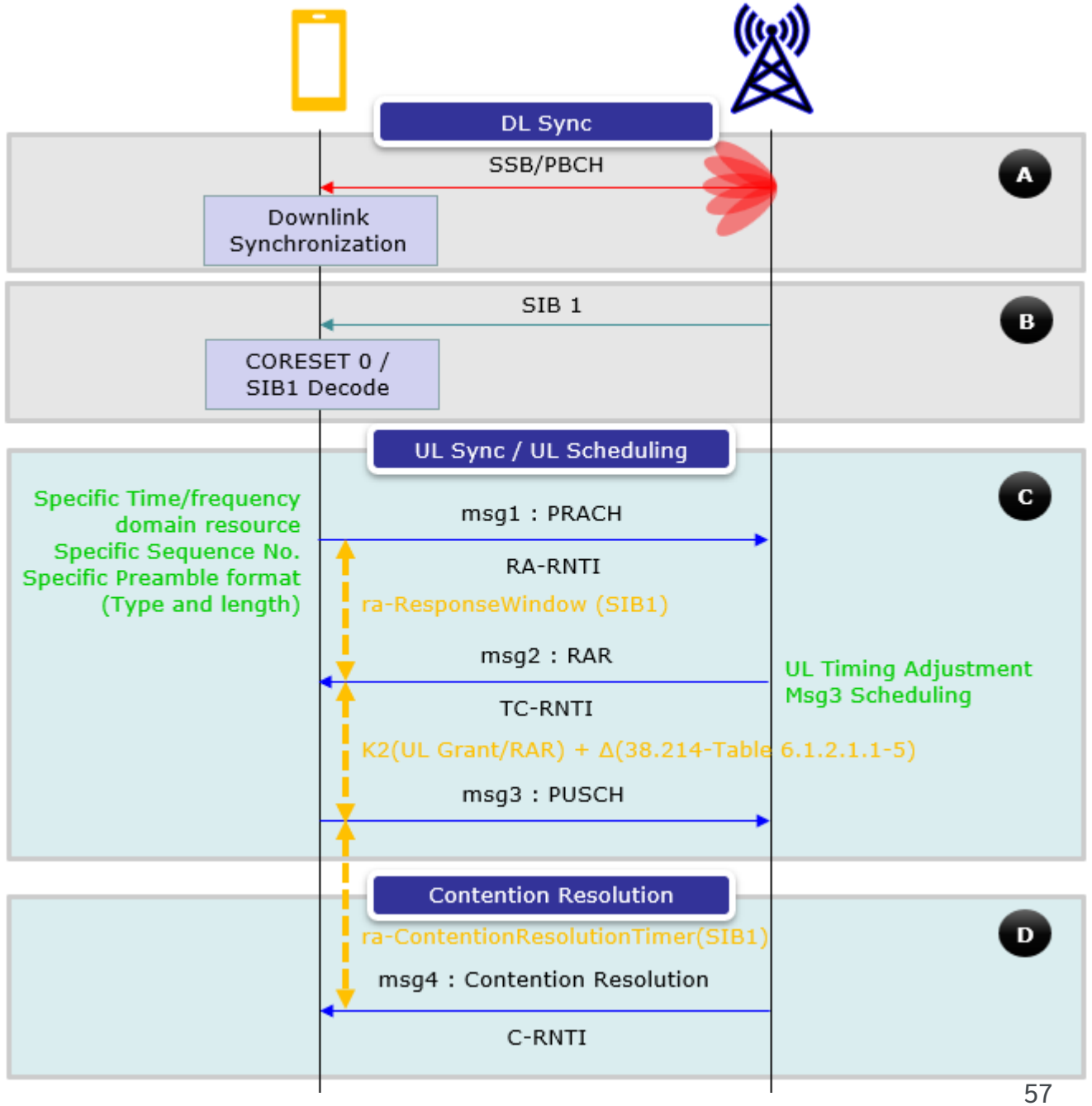


PHYSICAL PROCEDURES

❑ Initiation procedure in 5G (NSA)

7. UE decode PDSCH, after decode successfully, UE will show 5G symbol in screen.
8. UE send PUSCH (MSG3) with init config of MSG3, no need DCI_UL.
9. gNodeB receive PUSCH (decode pass) and send Contention Resolution (MSG4) through PDCCH (DCIDL)/PDSCH to UE.
10. UE receive and decode pass MSG4

=> Attach successfully



THANKS!!!