5G Boot Camp

UNDERSTANDING 5G NEW RADIO RELEASE 15/16 STANDARDS

Keysight Technologies

NOV 2019

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KEYSIGHT TECHNOLOGIES

Understanding 5G NR Standards

AGENDA

- **Technology Overview & Timeline**

5G Scenarios and Use Cases

BROAD RANGE OF NEW SERVICES AND PARADIGMS

Amazingly Fast	Great Service in a Crowd	Best Experience Follows You	Ubiquitous Things Communicating	Real-time & Reliable Communications

eMBB

Mobile Broadband Access

- All data, all the time
- 2 billion people on social media

mMTC

Massive Machine Communication

- 30 billion ‘things’ connected
- Low cost, low energy

URLLC

Mission-Critical Machine Communication

- Ultra-high reliability
- Ultra-low latency

5G Specifications

ALIGNED WITH IMT VISION

- IMT 2020 are still defining specs
- IMT: International Mobile Telecommunications Initiative (by ITU)

Phase 1 – mid 2018

- Focus on eMBB and low latency aspects
- Minimized changes to core architecture (LTE-EPC) – NSA operation initially
- 5G RAT - focus on “conventional” frequency channels

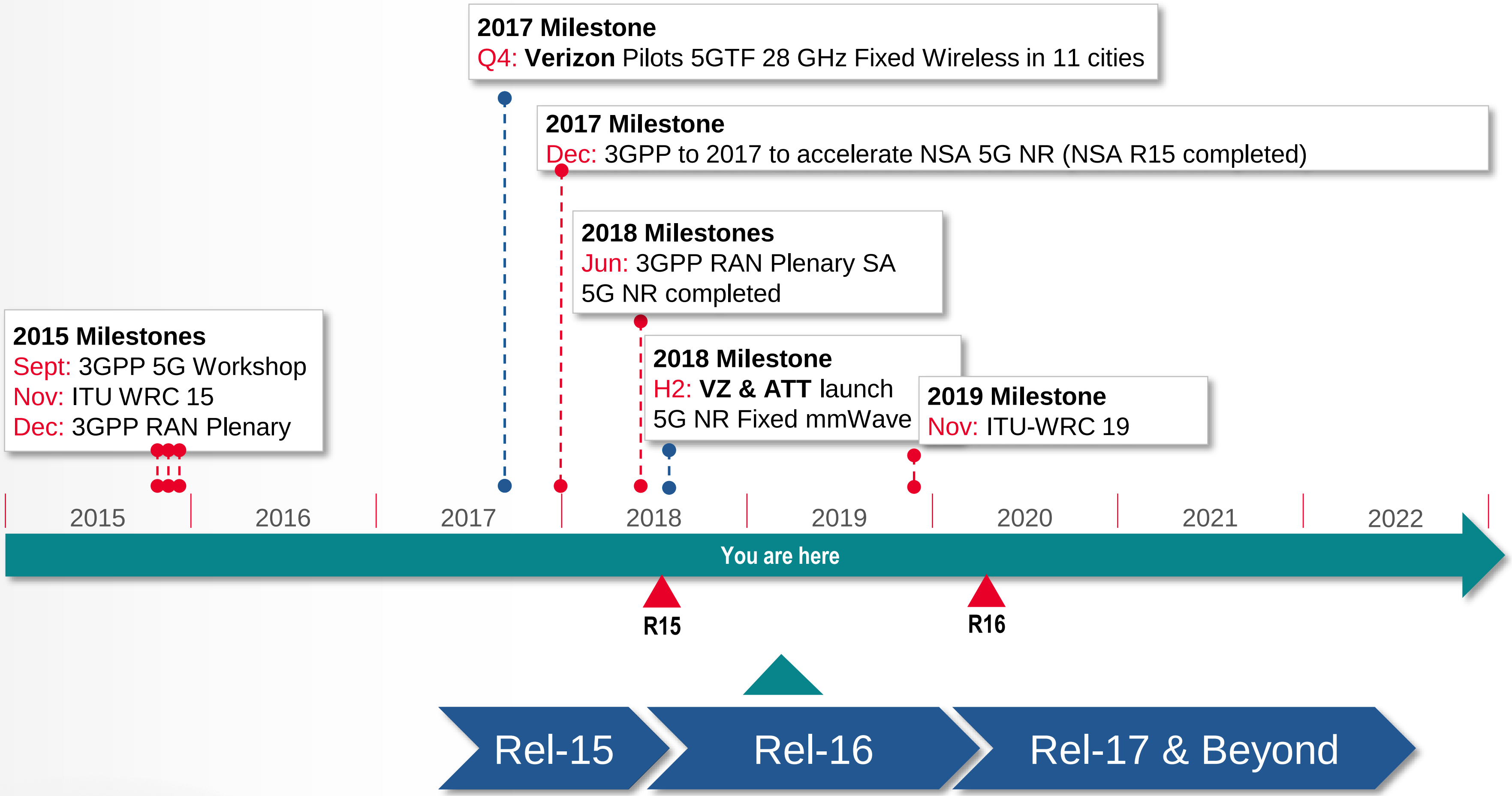
Phase 2 – mid 2020

- Focus on new verticals (IIoT, V2X, etc.)
- Novel layers and architecture to allow full 5G potential (vehicular and multicast services)
- “mmWave” 28, 37, 39 GHz channels and unlicensed spectrum

KEYSIGHT TECHNOLOGIES

5G Timing: Drivers

KEY MILESTONES AND CARDINAL DATES



Commercialization Announcements

- **Verizon:** Fixed mmWave in 2018
- **AT&T:** Fixed mmWave in 2018
- **T-Mobile:** Sub-6 GHz 5G in 2019
- **Sprint:** Sub-6 GHz 5G in 2019
- **KT:** 5G in 2019
- **DOCOMO:** 5G in 2020
- **China Mobile:** 5G in 2020

- Timelines more aggressive than in previous generations
- Scope and difficulty higher than in previous generations

As of March 2019 with *no scope change*:

- 3-month delay in Rel-16 and Late Drop of Rel-15.

5G New Radio

AT A GLANCE – KEY DISTINCTIVE FEATURES

- 2 frequency ranges:
  - **FR1 (410 MHz – 7.125 GHz)**
    - Bands numbered from 1 to 255
    - *No longer can be commonly referred to as sub-6 GHz!*
  - **FR2 (24.250 - 52.600 GHz)** → *Soon to be extended to* ***114.25 GHz***
    - Bands numbered from 257 to 511
    - Commonly referred to as mmWave

3GPP TS 38.521-2 Table 5.3.5-1

FR2: NR band / SCS / UE Channel bandwidth					
NR Band	SCS kHz	50 MHz	100 MHz	200 MHz	400 MHz
n257	60	Yes	Yes	Yes	N/A
	120	Yes	Yes	Yes	Yes
n258	60	Yes	Yes	Yes	N/A
	120	Yes	Yes	Yes	Yes
n260	60	Yes	Yes	Yes	N/A
	120	Yes	Yes	Yes	Yes
n261	60	Yes	Yes	Yes	N/A
	120	Yes	Yes	Yes	Yes

3GPP 5G Channel Bandwidth Requirements

- For FR1, 100 MHz is the maximum channel bandwidth specified
- For FR2, 50, 100, 200 and 400 MHz channel bandwidths are specified

3GPP TS 38.521-1 Table 6.1-1

Channel Bandwidth
5 MHz
10 MHz
15 MHz
20 MHz
25 MHz
30 MHz
40 MHz
50 MHz
60 MHz
80 MHz
100 MHz

3GPP TS 38.521-2 Table 5.3.5-1

NR Band / SCS / UE Channel Bandwidth					
NR Band	SCS kHz	50 MHz	100 MHz	200 MHz	400 MHz
n257	60	Yes	Yes	Yes	N/A
	120	Yes	Yes	Yes	Yes
n258	60	Yes	Yes	Yes	N/A
	120	Yes	Yes	Yes	Yes
n260	60	Yes	Yes	Yes	N/A
	120	Yes	Yes	Yes	Yes
n261	60	Yes	Yes	Yes	N/A
	120	Yes	Yes	Yes	Yes

KEYSIGHT TECHNOLOGIES

Sub-6 GHz & mmWave 5G Frequency Allocations (eMBB)

AVAILABILITY OF GREENFIELD TDD SPECTRUM

5G Spectrum Availability < 6GHz

Region	New		Existing		BW	Total BW
	F_{LOW}	F_{HIGH}	F_{LOW}	F_{HIGH}	MHz	MHz
Korea	3400	3700			300	300
Europe			2570	2620	50	450
	3400	3800			400	
Japan			2496	2690	194	1494
	3600	4200	3400	3600	800	
	4400	4900			500	
US			2496	2690	191	344
	3550	3700 (1)			150	
China			2300	2400	100	700
			2555	2655	100	
	3300	3600	3400	3600	300	
	4800	5000			200	
Un-licensed			5725	5875	150	150

5G Spectrum Availability mmWave

Region	New		Existing		BW	Total BW
	F_{LOW}	F_{HIGH}	F_{LOW}	F_{HIGH}	GHz	GHz
Korea	26.5	29.5			3.00	3.00
Europe	24.25	27.5			3.25	7.85
	31.8	33.40			1.6	
	40.5	43.5			3.00	
Japan	27.50	29.50			2.0	2.0
US	27.50	28.35			0.85	3.85
	37.00	38.60			1.6	
	38.6	40.00			1.4	
China	24.75	27.5			2.75	8.25
	37.00	42.5			5.5	
Un-licensed	43.5	47			3.5	3.5 (China)
	64.0	71.0	57.0	64.0	7.0	14.0

Adapted from IWPC 5G UE, SWKS Mar 2017 (David Pehlke)

* T-Mobile plans to use 600MHz spectrum which is an FDD band

Understanding 5G NR Standards

AGENDA

- Technology Overview & Timeline
- **Numerology & Frame Structure**

Waveform, Multiple Access & Coding

Waveform:

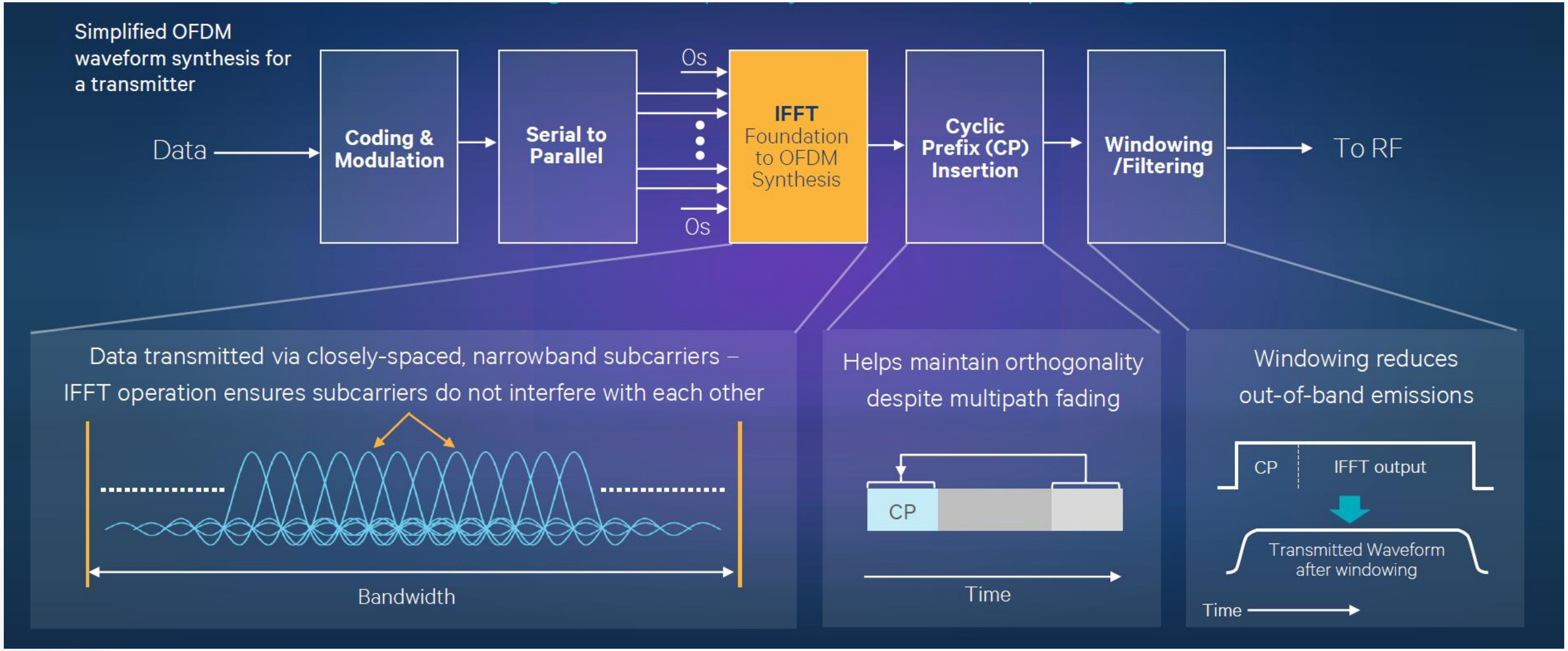
- Downlink: CP-OFDM
- Uplink: CP-OFDM + DFT-s-OFDM (Discrete Fourier Transform spread OFDM)
  - CP-OFDM targeted at high throughput scenarios
  - DFT-s-OFDM targeted at power limited scenarios

Waveform

WAVEFORM, NUMEROLOGY AND FRAME STRUCTURE

- DL Waveform : CP-OFDM
  - intended for MIMO (multiple layer, high data rates)
  - Modulations : QPSK, 16QAM , 64QAM , and 256 QAM

Ref :5G Waveform & Multiple Access Techniques - Qualcomm

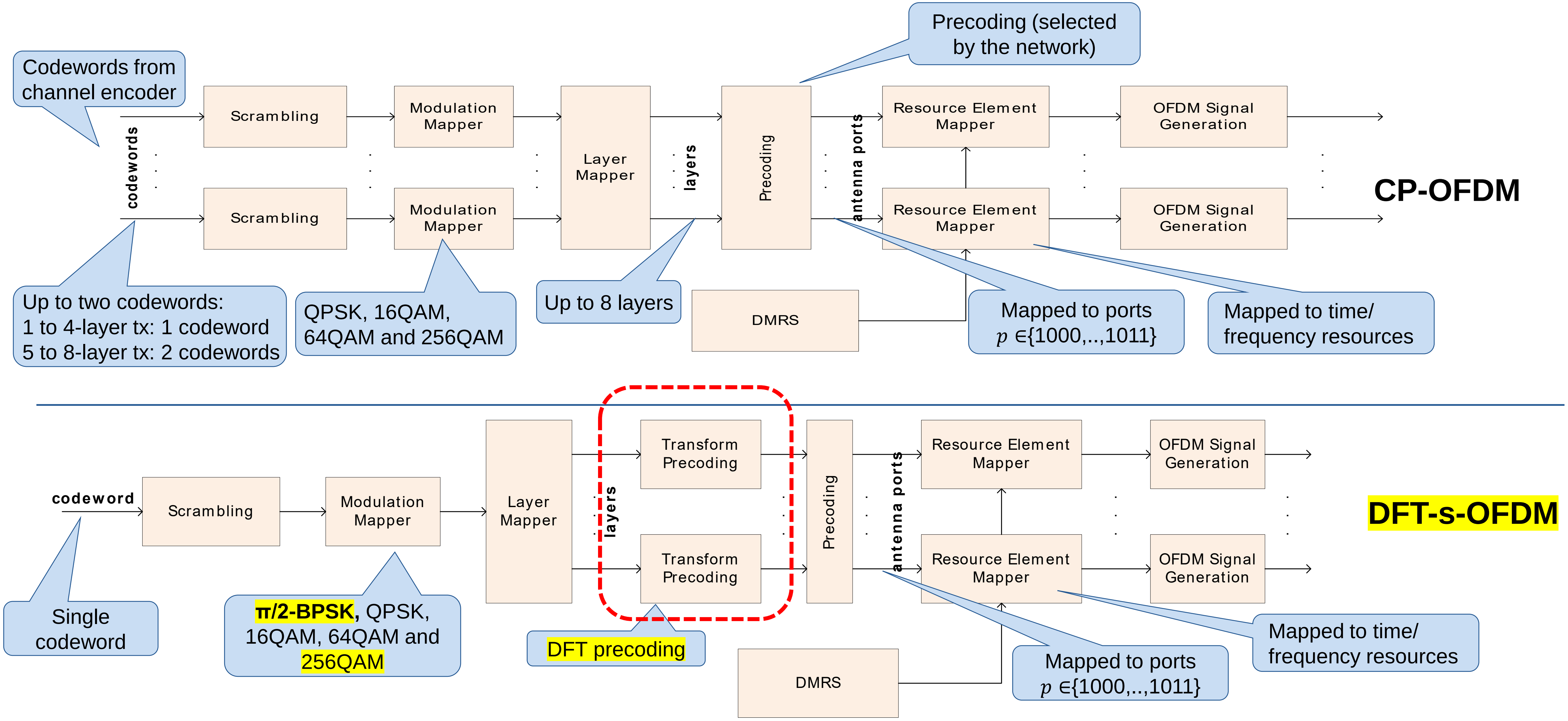


Waveform

WAVEFORM, NUMEROLOGY AND FRAME STRUCTURE

- UL Waveform
  - Option 1 : CP-OFDM: intended for MIMO (multiple layer, high data rates)
    - Modulation: QPSK, 16, 64, and 256 QAM
  - Option 2: DFT-s-OFDM: only for single layer transmissions (link budget limited cases)
    - Modulation : π/2-BPSK, 16, 64 and 256 QAM

PUSCH Processing Chain



KEYSIGHT TECHNOLOGIES

Waveform, Multiple Access & Coding

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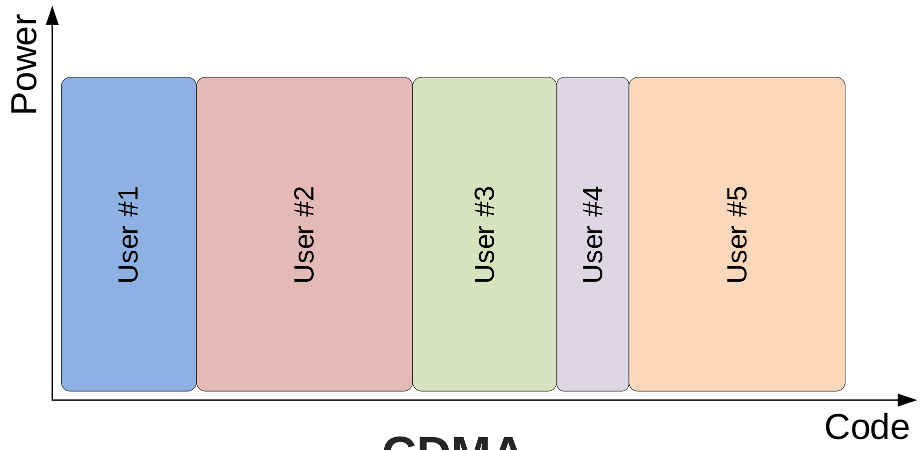
Multiple Access:

- Orthogonal Multiple Access (OFDMA) (R-15)
- NOMA defined in R16

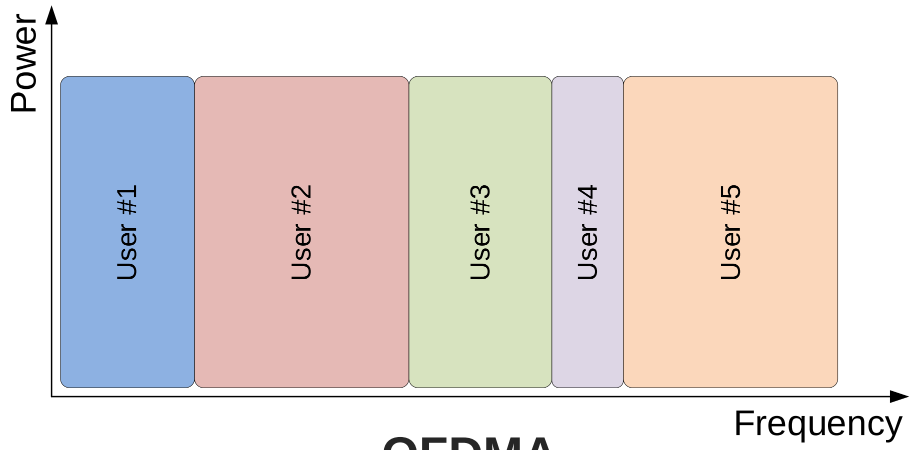
NOMA

NR RELEASE 16 OVERVIEW

- **Orthogonal Multiple Access**
  - Resource assignment is orthogonal between users
  - **CDMA**
    - All power assigned to users
    - Each user is assigned different codes
  - **OFDMA**
    - All power assigned to users
    - Each user is assigned different frequency resources



CDMA

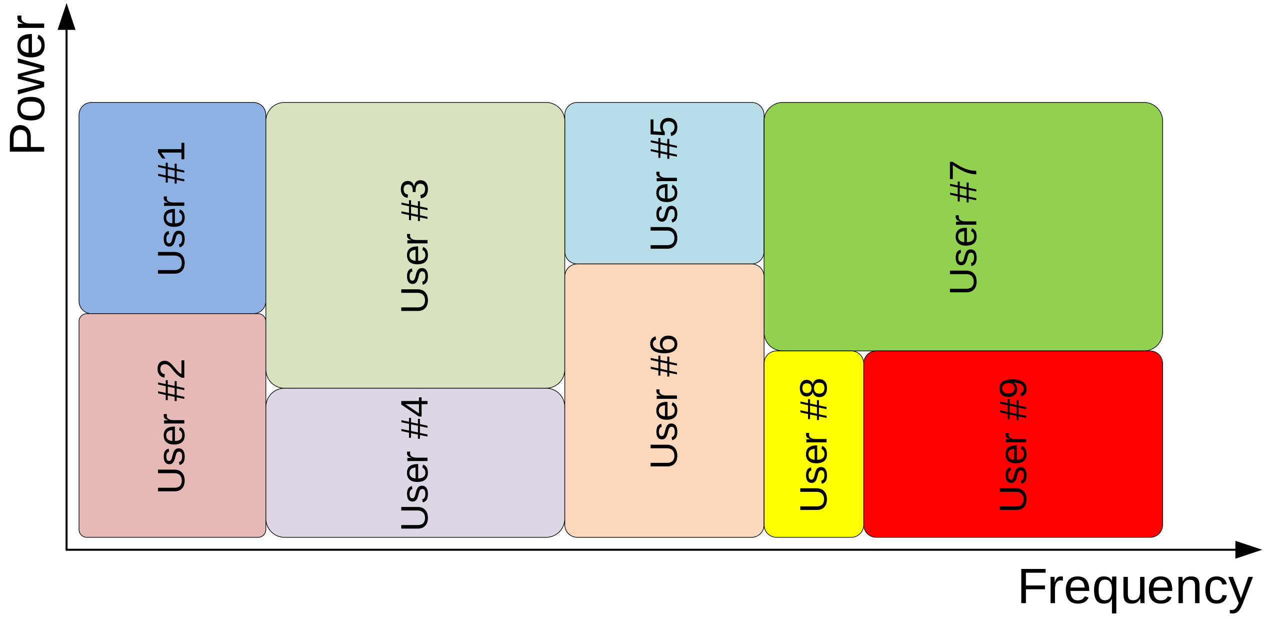


OFDMA

NOMA

NR RELEASE 16 OVERVIEW

- **Non-Orthogonal Multiple Access**
  - Resource assignment is not orthogonal between users
  - Users transmit on the same time and frequency resources
  - Power is shared between users
  - Superposition and power allocation
- NOMA is mainly used in UL
- The most significant gain of NOMA over MU-MIMO can be achieved in the following scenarios:
  - Contention-based, grant-free transmission
  - Small data transmission from RRC_INACTIVE state



Waveform, Multiple Access & Coding

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Multiple Access:

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Coding:

- Orthogonal Multiple Access (OFDMA)
- Network selects coding scheme to match instantaneous channel conditions
  - Optimization of capacity with a reasonable BLER
  - Reduction of latency but possibly lower throughput rate (some methods take longer to encode)
- eMBB Traffic - Low Density Parity Check (LDPC)
- PBCH & Control - Polar Code

Numerology Definition

SCALABLE SUB-CARRIER SPACING (SCS) - ΔF

FR1 Operation

Initial Access: μ = 0, 1 — Data: μ = 0, 1, 2

μ	$\Delta f = 2^{\mu} \cdot 15$ kHz	Cyclic Prefix	$N_{RB}^{max,\mu}$	$N_{slot}^{subframe,\mu}$
0	15 kHz	Normal	275	1
1	30 kHz	Normal	275	2
2	60 kHz	Normal, Extended	275	4

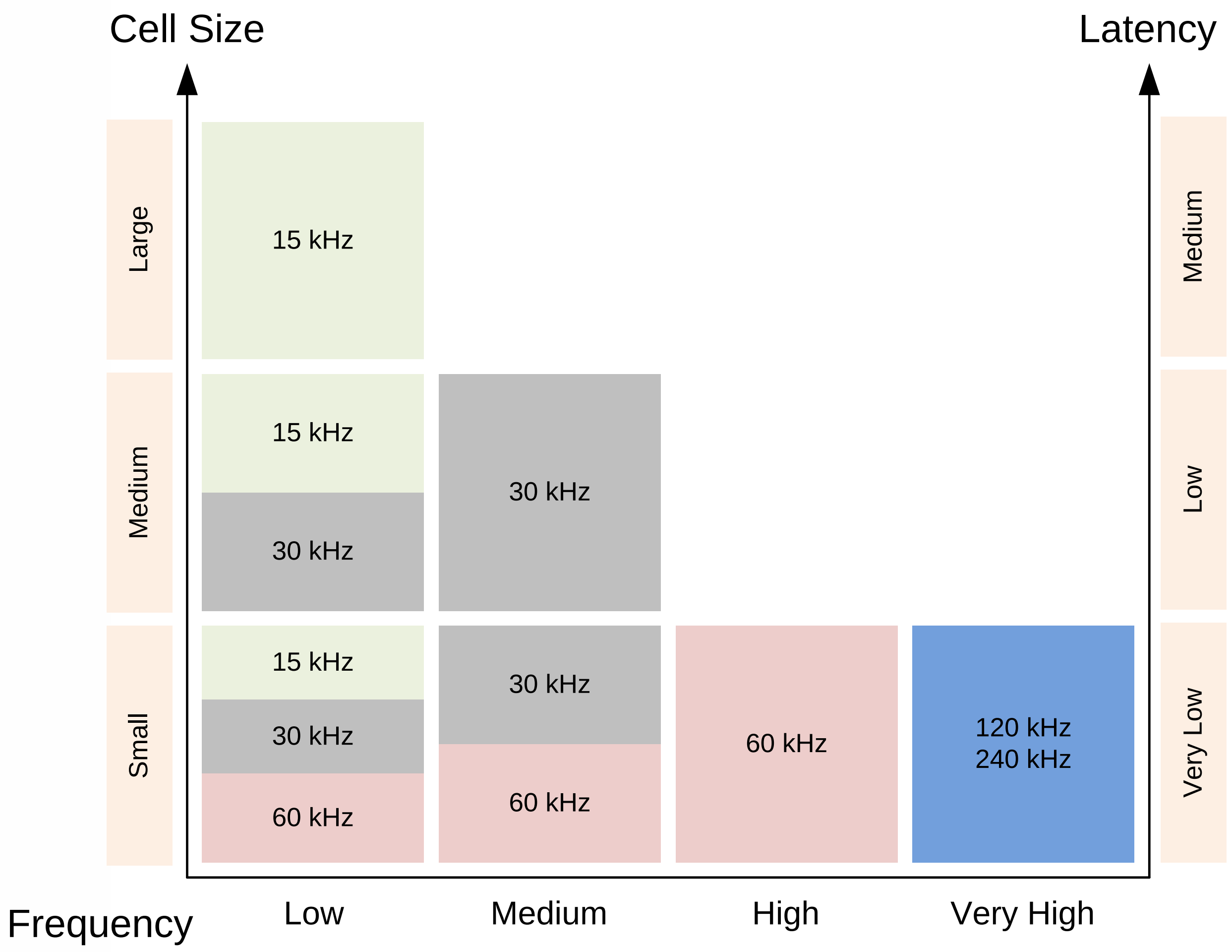
FR2 Operation

Data: μ = 2, 3 — Initial Access: μ = 3, 4

μ	$\Delta f = 2^{\mu} \cdot 15$ kHz	Cyclic Prefix	$N_{RB}^{max,\mu}$	$N_{slot}^{subframe,\mu}$
2	60 kHz	Normal, Extended	275	4
3	120 kHz	Normal	275	8
4	240 kHz	Normal	138	16
5	480 kHz	Normal	69	32

Use Cases for Different Subcarrier Spacing

WAVEFORM, NUMEROLOGY AND FRAME STRUCTURE



Flexible Numerology

MAXIMUM TRANSMISSION BANDWIDTH CONFIGURATION NRB

Spectrum utilization for **FR1** (450 MHz – 6 GHz): 3GPP 34.38.521-1 table 5.3.2-1

SCS	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	40 MHz	50 MHz	60 MHz	80 MHz	100 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}
15 kHz	25	52	79	106	133	216	270	N/A	N/A	N/A
30 kHz	11	24	38	51	65	106	133	162	217	273
60 kHz	N/A	11	18	24	31	51	65	79	107	135

Spectrum utilization for **FR2 (**24.25 GHz – 52.6 GHz): 3GPP 34.38.521-2 table 5.3.2-1

SCS	50 MHz	100 MHz	200 MHz	400 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}
60 kHz	66	132	264	N/A
120 kHz	32	66	132	264

5G NR Max number of Sub Carriers = 3276 (273 PRBs)

Flexible Numerology

Ref : 3GPP TS 38.101-1 5.3.3

MINIMUM GUARDBAND

5.3.3 Minimum guardband and transmission bandwidth configuration

The minimum guardband for each UE channel bandwidth and SCS is specified in Table 5.3.3-1,

Table 5.3.3-1: Minimum guardband for each UE channel bandwidth and SCS (kHz)

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	242.5	312.5	382.5	452.5	522.5	592.5	552.5	692.5	N/A	N/A	N/A	N/A
30	505	665	645	805	785	945	905	1045	825	925	885	845
60	N/A	1010	990	1330	1310	1290	1610	1570	1530	1450	1410	1370

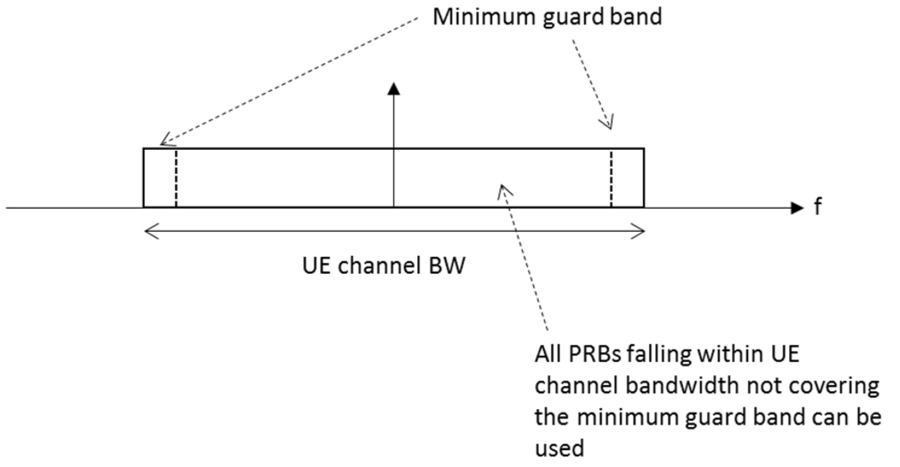


Figure 5.3.3-2: UE PRB utilization

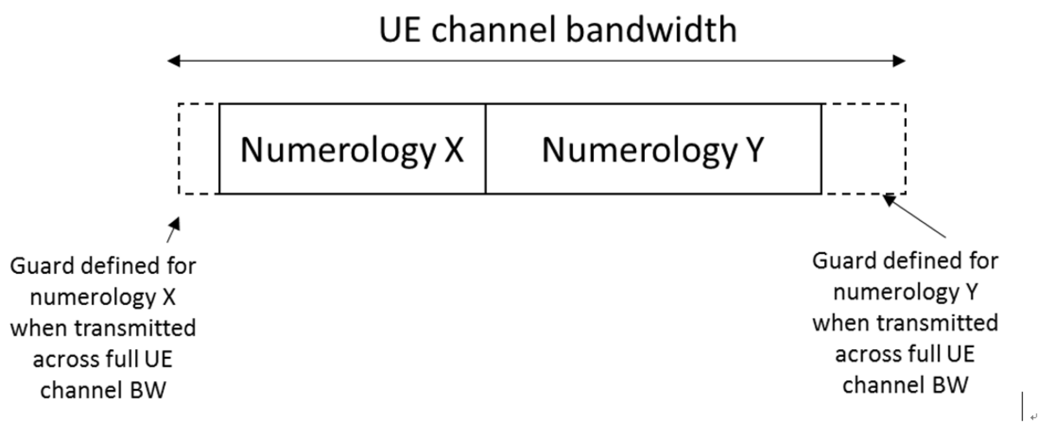
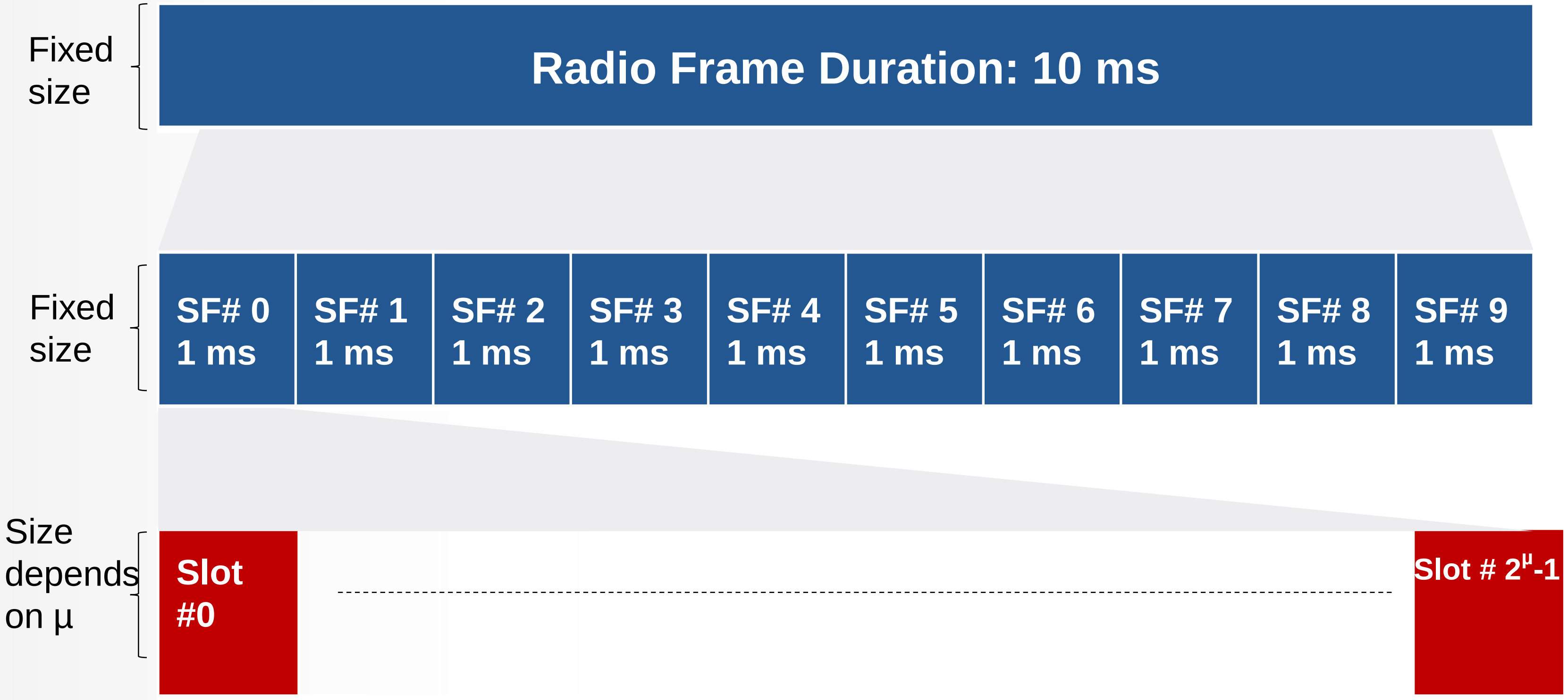


Figure 5.3.3-3 Guard band definition when transmitting multiple numerologies

Frame Structure

WAVEFORM, NUMEROLOGY AND FRAME STRUCTURE



µ	N_{symb}^{slot}	$N_{slot}^{subframe,\mu}$	$N_{slot}^{frame,\mu}$	Slot duration
0 *15 kHz*	14	1	10	1 ms
1 *30 kHz*	14	2	20	500 µs
2 *60 kHz* *(normal CP)*	14	4	40	250 µs
2 *60 kHz* *(extended CP)*	12	4	40	250 µs
3 *120 kHz*	14	8	80	125 µs
4 *240 kHz*	14	16	160	62.5 µs

A slot is one possible scheduling unit.
Mini-Slot is a minimum scheduling unit with 7, 4 or 2 OFDM symbols

Ref : 3GPP TS 38.211 4.3

Slot Format Indication

WAVEFORM, NUMEROLOGY AND FRAME STRUCTURE

- Slot Format Indication informs the UE whether an OFDM symbol is ***Downlink***, ***Uplink*** or ***Flexible***
- SFI can indicate link direction over one or many slots (configured through RRC)
- The SFI carries an index to a pre-configured UE-specific table (configured through RRC)
- SFI can be either:
  - **Dynamic** (i.e. through a DCI)
    - UE assumes there is no conflict between dynamic SFI and DCI DL/UL assignments
  - **Static** or **semi-static** (i.e. through RRC)

5G NR Slots Formats

TS 38.211 TABLE 4.3.2-3: SLOT FORMATS

D: Downlink symbol
U: Uplink symbol
X: Flexible symbol

Format	Symbol number in a slot													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	D	D	D	D	D	D	D	D	D	D	D	D	D	X
4	D	D	D	D	D	D	D	D	D	D	D	D	X	X
5	D	D	D	D	D	D	D	D	D	D	D	X	X	X
6	D	D	D	D	D	D	D	D	D	D	X	X	X	X
7	D	D	D	D	D	D	D	D	D	X	X	X	X	X
8	X	X	X	X	X	X	X	X	X	X	X	X	X	U
9	X	X	X	X	X	X	X	X	X	X	X	X	U	U
10	X	U	U	U	U	U	U	U	U	U	U	U	U	U
11	X	X	U	U	U	U	U	U	U	U	U	U	U	U
12	X	X	X	U	U	U	U	U	U	U	U	U	U	U
13	X	X	X	X	U	U	U	U	U	U	U	U	U	U
14	X	X	X	X	X	U	U	U	U	U	U	U	U	U
15	X	X	X	X	X	X	U	U	U	U	U	U	U	U
16	D	X	X	X	X	X	X	X	X	X	X	X	X	X
17	D	D	X	X	X	X	X	X	X	X	X	X	X	X
18	D	D	D	X	X	X	X	X	X	X	X	X	X	X
19	D	X	X	X	X	X	X	X	X	X	X	X	X	U
20	D	D	X	X	X	X	X	X	X	X	X	X	X	U
21	D	D	D	X	X	X	X	X	X	X	X	X	X	U
22	D	X	X	X	X	X	X	X	X	X	X	X	U	U
23	D	D	X	X	X	X	X	X	X	X	X	X	U	U
24	D	D	D	X	X	X	X	X	X	X	X	X	U	U
25	D	X	X	X	X	X	X	X	X	X	X	U	U	U
26	D	D	X	X	X	X	X	X	X	X	X	U	U	U
27	D	D	D	X	X	X	X	X	X	X	X	U	U	U
28	D	D	D	D	D	D	D	D	D	D	D	D	X	U
29	D	D	D	D	D	D	D	D	D	D	D	X	X	U
30	D	D	D	D	D	D	D	D	D	D	X	X	X	U
31	D	D	D	D	D	D	D	D	D	D	D	X	U	U
32	D	D	D	D	D	D	D	D	D	D	X	X	U	U
33	D	D	D	D	D	D	D	D	D	X	X	X	U	U
34	D	X	U	U	U	U	U	U	U	U	U	U	U	U
35	D	D	X	U	U	U	U	U	U	U	U	U	U	U
36	D	D	D	X	U	U	U	U	U	U	U	U	U	U
37	D	X	X	U	U	U	U	U	U	U	U	U	U	U
38	D	D	X	X	U	U	U	U	U	U	U	U	U	U
39	D	D	D	X	X	U	U	U	U	U	U	U	U	U
40	D	X	X	X	U	U	U	U	U	U	U	U	U	U
41	D	D	X	X	X	U	U	U	U	U	U	U	U	U
42	D	D	D	X	X	X	U	U	U	U	U	U	U	U
43	D	D	D	D	D	D	D	D	D	X	X	X	X	U
44	D	D	D	D	D	D	X	X	X	X	X	X	U	U
45	D	D	D	D	D	D	X	X	U	U	U	U	U	U
46	D	D	D	D	D	D	X	D	D	D	D	D	D	X
47	D	D	D	D	D	X	X	D	D	D	D	D	X	X
48	D	D	X	X	X	X	X	D	D	X	X	X	X	X
49	D	X	X	X	X	X	X	D	X	X	X	X	X	X
50	X	U	U	U	U	U	U	X	U	U	U	U	U	U
51	X	X	U	U	U	U	U	X	X	U	U	U	U	U
52	X	X	X	U	U	U	U	X	X	X	U	U	U	U
53	X	X	X	X	U	U	U	X	X	X	X	U	U	U
54	D	D	D	D	D	X	U	D	D	D	D	D	X	U
55	D	D	X	U	U	U	U	D	D	X	U	U	U	U
56	D	X	U	U	U	U	U	D	X	U	U	U	U	U
57	D	D	D	D	X	X	U	D	D	D	D	X	X	U
58	D	D	X	X	U	U	U	D	D	X	X	U	U	U
59	D	X	X	U	U	U	U	D	X	X	U	U	U	U
60	D	X	X	X	X	X	U	D	X	X	X	X	X	U
61	D	D	X	X	X	X	U	D	D	X	X	X	X	U
62 – 255	Reserved													

Ref : 3GPP TS 38.211 Table 4.3.2-3

KEYSIGHT TECHNOLOGIES

5G NR TDD Slot Format Combinations Examples

SOURCE: ERICSSON

DL symbol

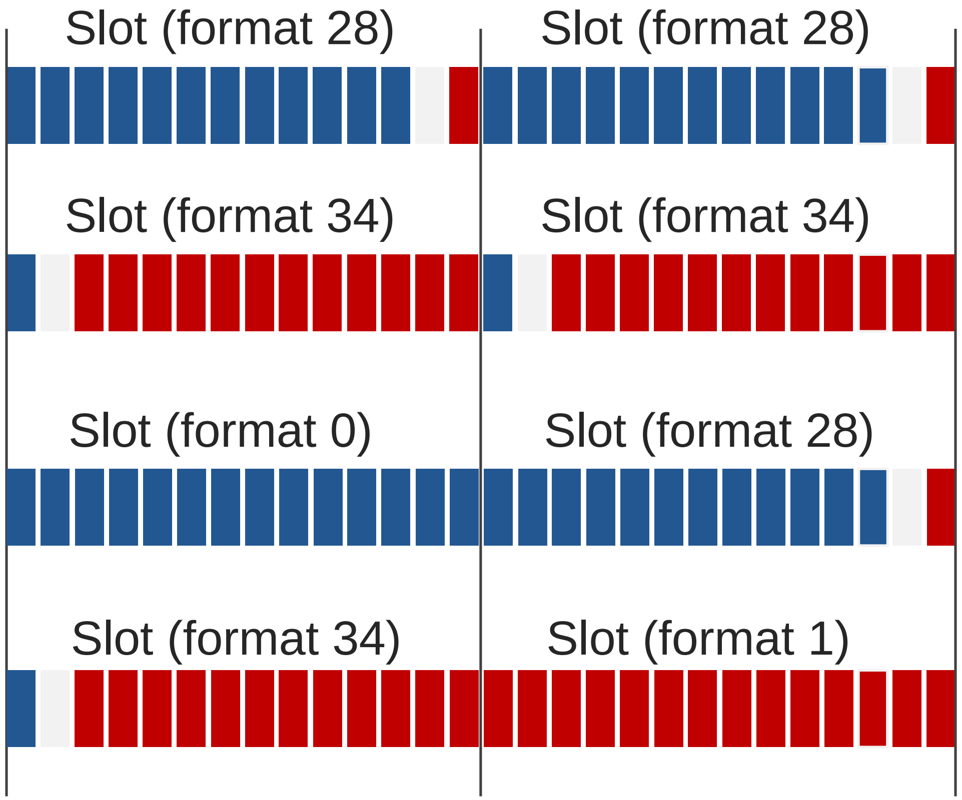
UL symbol

DL-heavy transmission with UL part

UL-heavy transmission with DL Control

Slot aggregation for DL-heavy transmission (e.g, for eMBB)

Slot aggregation for UL-heavy transmission (e.g, for eMBB)

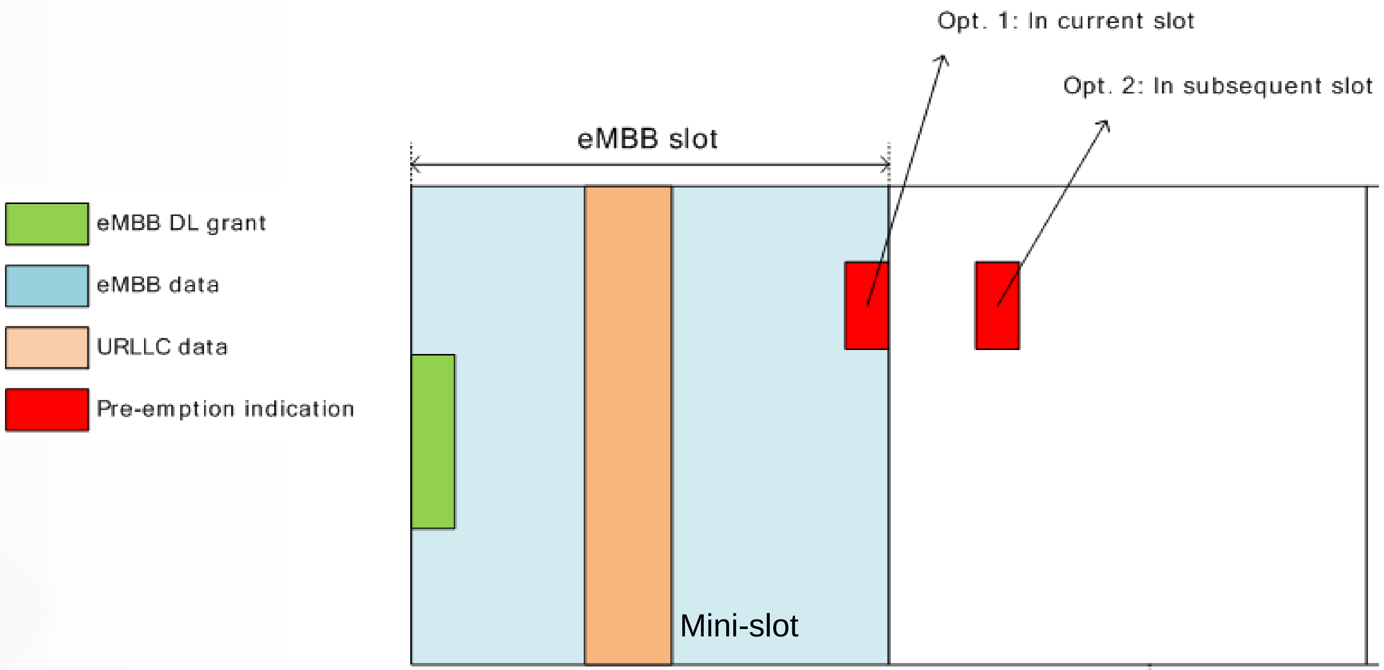


KEYSIGHT TECHNOLOGIES

Multiplexing eMBB and URLLC data (on PDSCH)

- Dynamic resources sharing between high data rate and low latency traffic
  - **Using *pre-emption* by scheduling URLLC services on overlapping time/frequency resources**
    - If the code block was affected by pre-emption, the buffer should be flushed (and not combined)
  - **Or without pre-emption by scheduling on non-overlapping time/frequency resources**

- Indication to UEs of the impacted eMBB resources is made via using group-common PDCCH



Understanding 5G NR Standards

AGENDA

5G

- Technology Overview & Timeline
- Numerology & Frame Structure
- **Carrier Aggregation & Bandwidth Adaptation**

Bandwidth Part

3GPP TS 38 SERIES STANDARD

- Up to 4 bandwidth part configurations for each component carrier can be semi-statically signaled to a UE
  - **Only one BWP** in DL and one in UL **is active** at a given time instant
- Configuration parameters include:
  - **Numerology**: CP type, subcarrier spacing
  - **Frequency location**: the offset between BWP and a reference point is implicitly or explicitly indicated to UE based on common PRB index for a give numerology
  - **Bandwidth size**: in terms of PRBs
  - **CORESET**: required for each BWP configuration in case of single active DL bandwidth part for a given time instant

Ref : 3GPP TR 38.802 V14.2.0

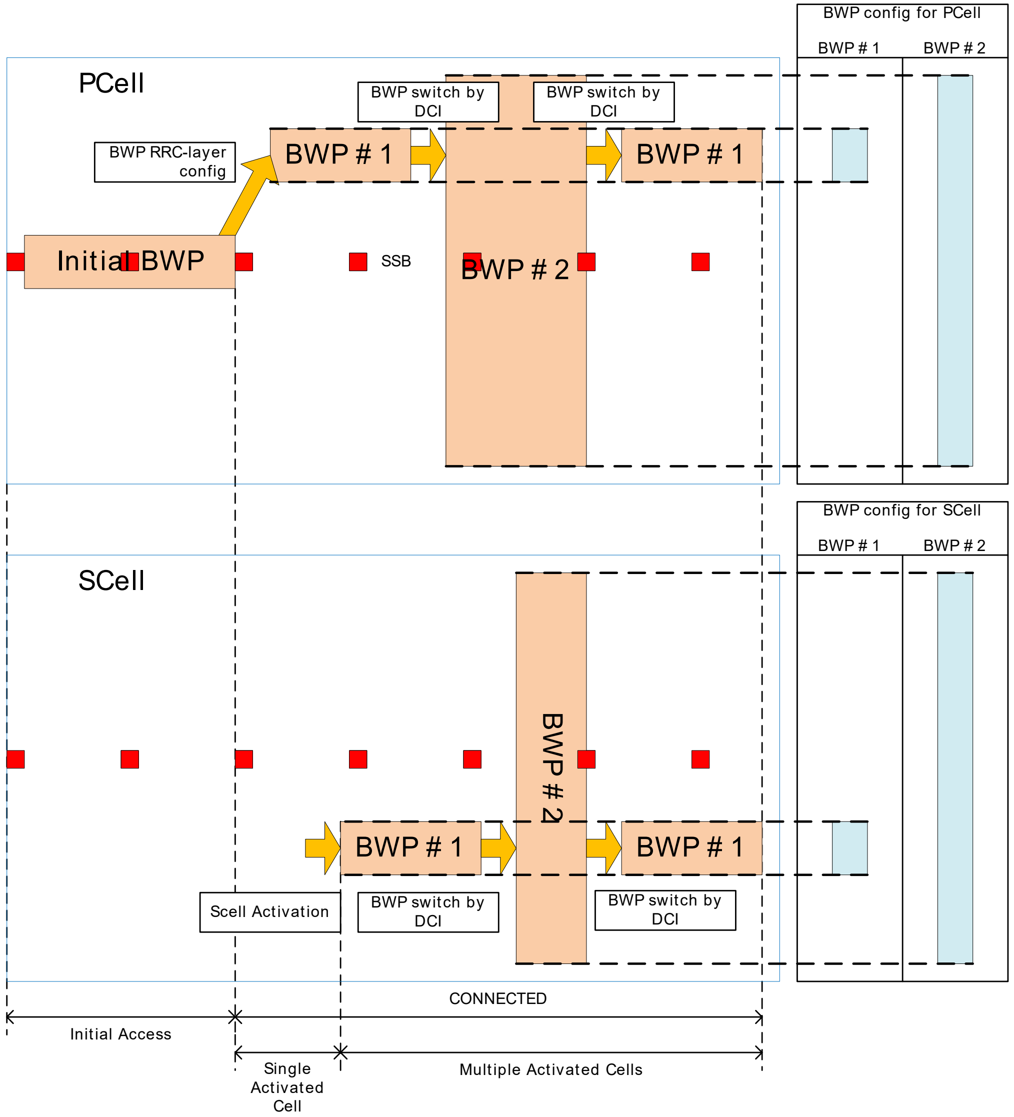
Bandwidth Part

- NR provides a means of operating UEs with smaller BW than the configured CBW, which makes NR an ***energy efficient*** solution despite the support of wideband operation.
- The BW of a BWP cannot exceed the configured CC BW for the UE.
- The BW of the BWP must be at least as large as one SS block BW, but the BWP may or may not contain SS block.
- The granularity of BW configuration is one PRB.
- For each serving cell, DL and UL BWPs are configured separately and independently for paired spectrum and up to four BWPs can be configured for DL and UL each. For unpaired spectrum, a DL BWP and a UL BWP are jointly configured as a pair and up to 4 pairs can be configured.
- There can be maximally 4 UL BWPs configured for a supplemental UL (SUL) as well.
- The HARQ retransmission across different BWPs is supported when a UE's active BWP is switched.

Ref : 3GPP TR 38.802 V14.2.0

Example of Bandwidth Part Operation

BANDWIDTH PARTS



Resource Block Index

CRB / PRB

Ref : 3GPP TS 38.211 V15.0.0
4.4 Physical resources
Ref: Link

Common resource blocks

$$n_{\mathrm{CRB}}^{\mu} = \left\lfloor \frac{k}{N_{\mathrm{sc}}^{\mathrm{RB}}} \right\rfloor$$

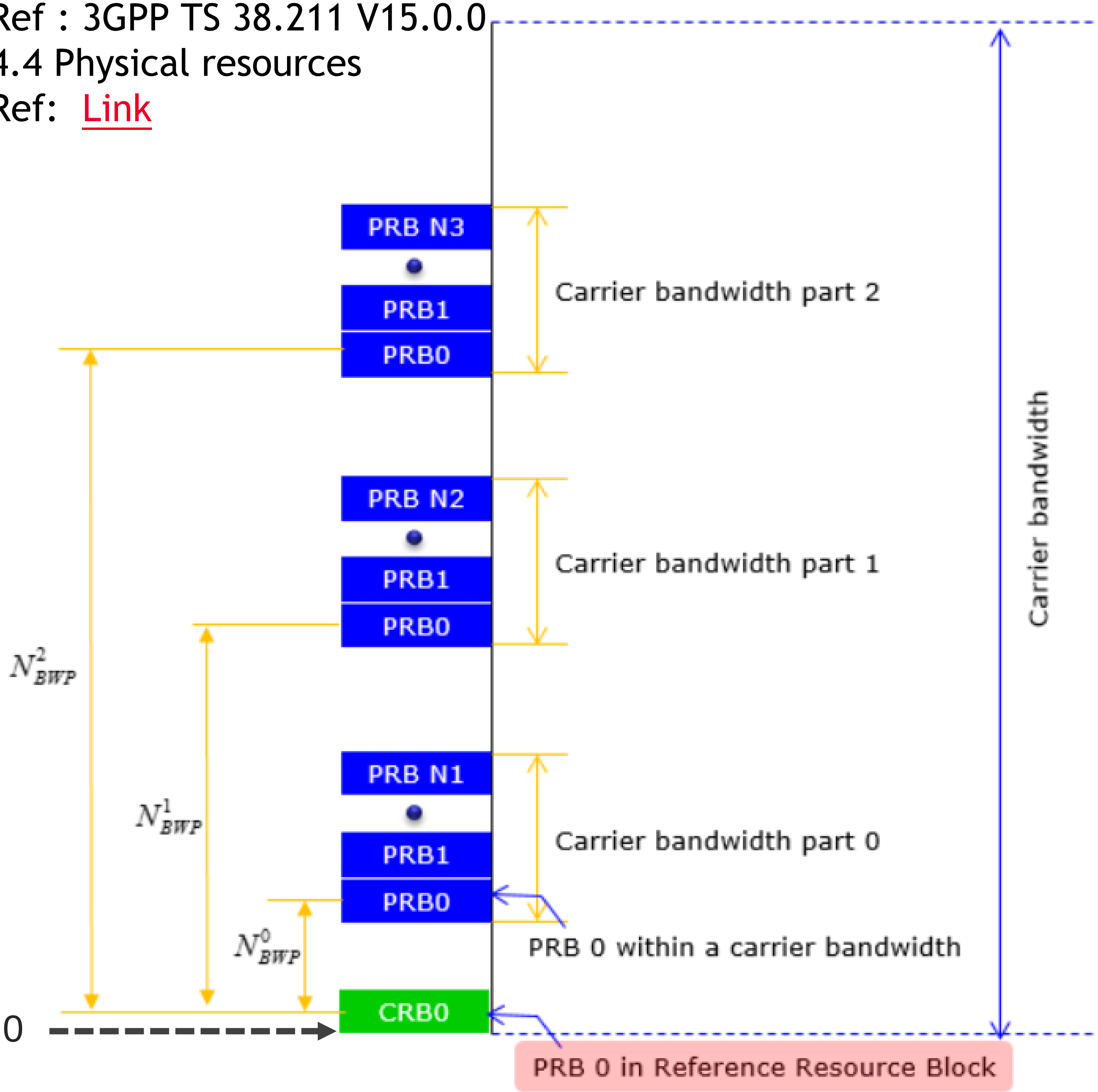
Physical resource blocks

from 0 to $N_{\mathrm{BWP},i}^{\mathrm{size}} - 1$

$$n_{\mathrm{CRB}} = n_{\mathrm{PRB}} + N_{\mathrm{BWP},i}^{\mathrm{start}}$$

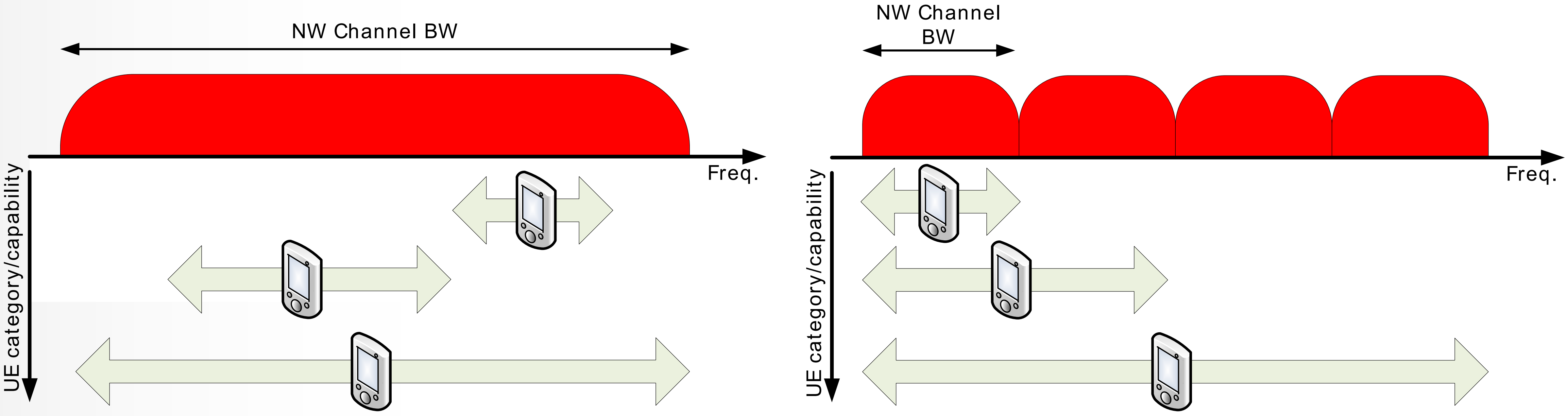
Point A

Subcarrier 0 in CRB 0



Single-Carrier and Multi-Carrier Operation

- Maximum single-CC bandwidth is 400 MHz
- Maximum number of CCs is 8

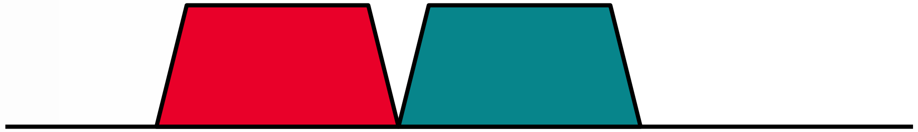


Single-Carrier Operation

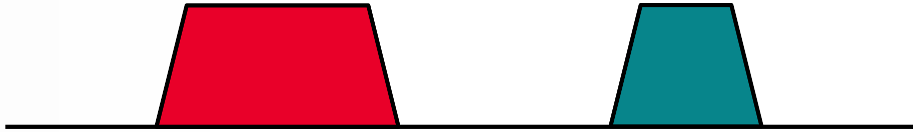
Multi-Carrier Operation

Carrier Aggregation Types

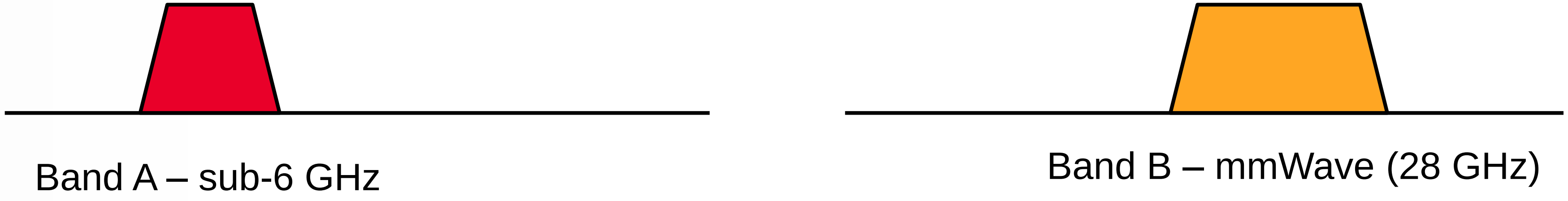
- Component Carriers may be in the same band and adjacent



- Or they could be in the same band, non-contiguous

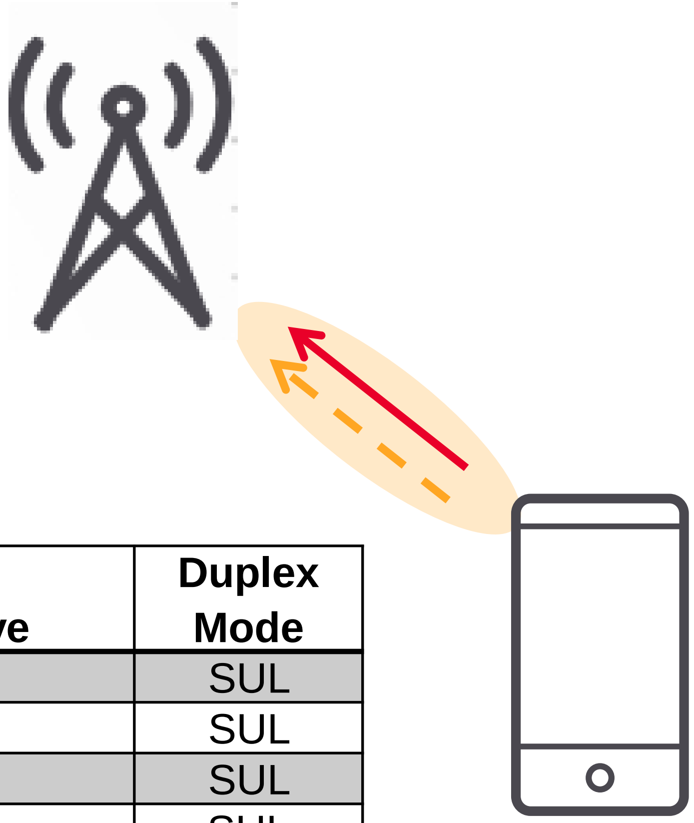


- Or in different bands



Supplemental Uplink

- The UE may be configured with additional **supplemental uplink**
  - An additional **lower frequency band** UL carrier
  - Enhances data rate and deployment range in NSA mode
  - Improve performance at cell edge in SA mode
- Supplemental uplink is different from carrier aggregation because the UE may transmit on
  - The supplemental uplink OR
  - UL component carrier
    (but not on both at the same time)



Operating Band	Uplink (UL) BS Receive / UE Transmit	Downlink (DL) BS Transmit / UE Receive	Duplex Mode
n80	1710 – 1785 MHz	N/A	SUL
n81	880 – 915 MHz	N/A	SUL
n82	832 – 862 MHz	N/A	SUL
n83	703 – 748 MHz	N/A	SUL
n84	1920 – 1980 MHz	N/A	SUL
n86	1710 – 1780 MHz	N/A	SUL

MR-DC Frequency Notation

Table 4.1-2: Example notation for SUL and NR-LTE coexistence.

Representation	Corresponding functionality
SUL_n78-n81	Band combination of NR band n78 and band n81(SUL) for NR operation.
DC_3-SUL_n78-n80	LTE-NR DC between LTE Band 3, and NR bands n80 (SUL) and n78 including NR-LTE coexistence with UL sharing.

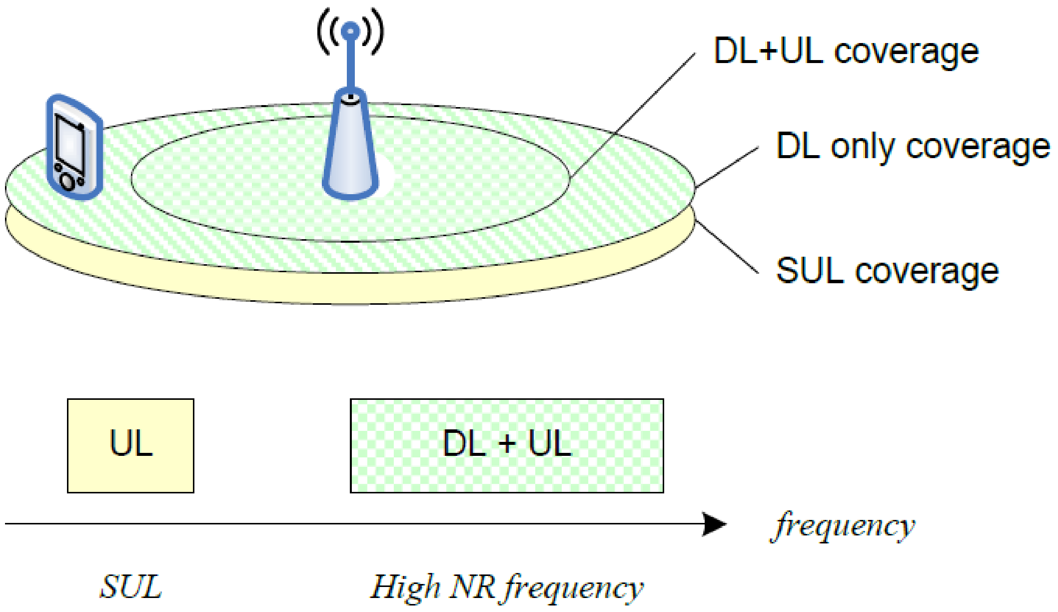


Figure B.1-1: Example of Supplementary Uplink

- Supplemental uplink differs from the aggregated uplink in that the UE may be scheduled to transmit either on the supplemental uplink or on the uplink of the carrier being supplemented, but not on both at the same time.

Ref : 3GPP TS 38.300

Ref : 3GPP TS 38.300 Annex B

Understanding 5G NR Standards

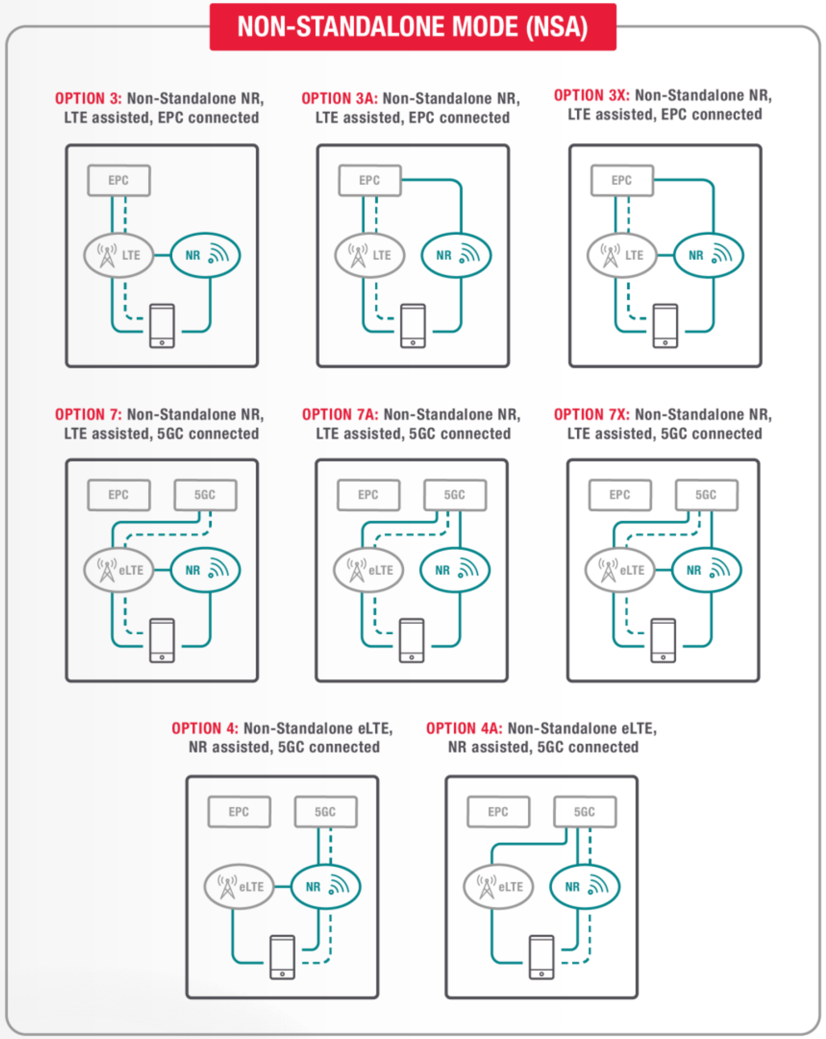
5G

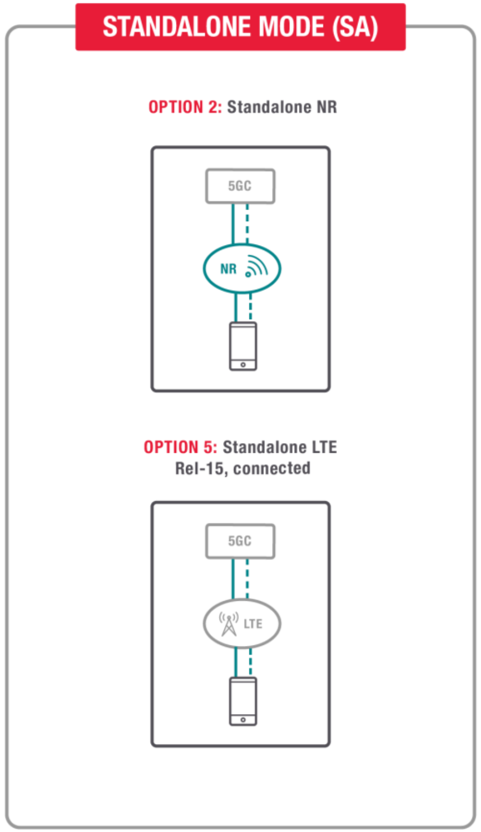
AGENDA

- Technology Overview & Timeline
- Numerology & Frame Structure
- Protocol Structures, Layers, Signals & Channels
- **Network Architecture, Deployment Options**

5G NR Deployment Options

START WITH NSA





A GLOBAL INITIATIVE

Rel-15 Early Drop (December 2017)
- NR NSA – eNB as master node
- 4G Core Network (EPC)
- Enhanced LTE (eLTE)

Rel-15 (June 2018)
- 5G Core Network
- Enhanced LTE (eLTE)
- NR SA and NSA Combinations

KEYSIGHT TECHNOLOGIES

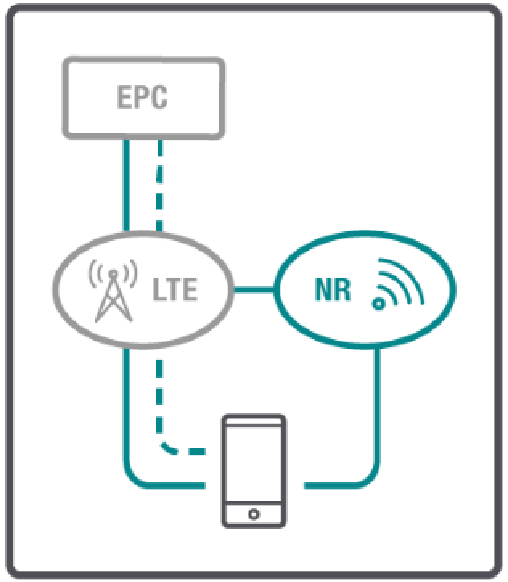
Multi-RAT Dual Connectivity with LTE Core (EPC)

OPTIONS 3/3A/3X

- Dual Connectivity with EPC: **E**-UTRA-**NR** **D**ual **C**onnectivity (**EN-DC**)
  - Master Node: eNB (LTE)
  - Secondary Node: gNB (5G NR)

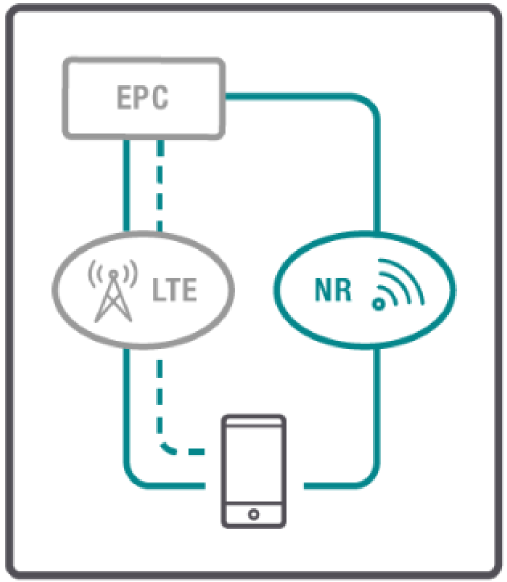
x2 interface

OPTION 3: Non-Standalone NR, LTE assisted, EPC connected



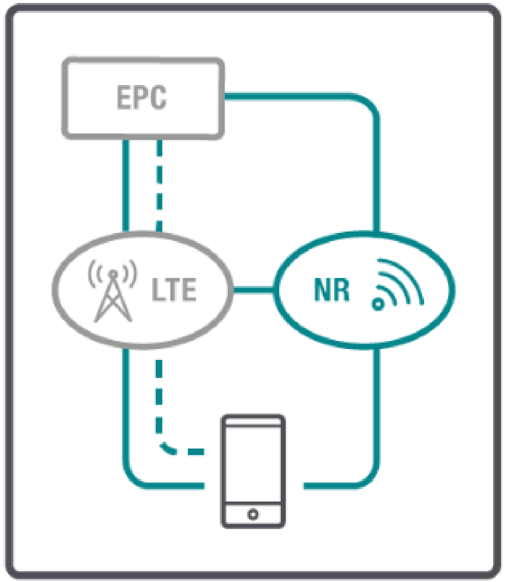
No load-sharing

OPTION 3A: Non-Standalone NR, LTE assisted, EPC connected



PDCP split

OPTION 3X: Non-Standalone NR, LTE assisted, EPC connected

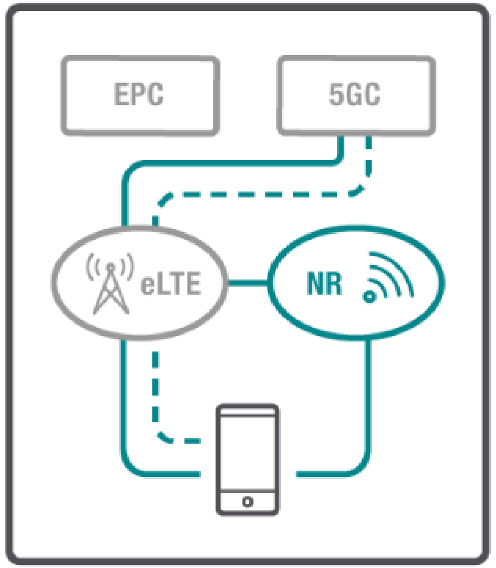


Multi-RAT Dual Connectivity with 5G Core (5GC)

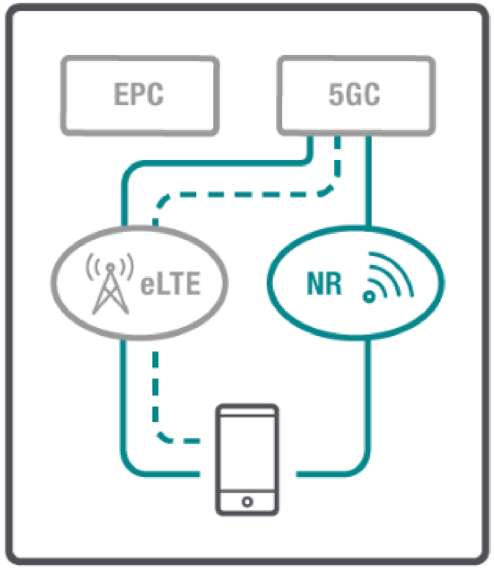
OPTIONS 7/7A/7X

- Dual Connectivity with NG-RAN: **NG**-RAN **E**-UTRA-**NR** **D**ual **C**onnectivity (**NGEN-DC**)
  - Master Node: ng-eNB (eLTE) – eNB evolved (eLTE)
  - Secondary Node: gNB (5G NR)

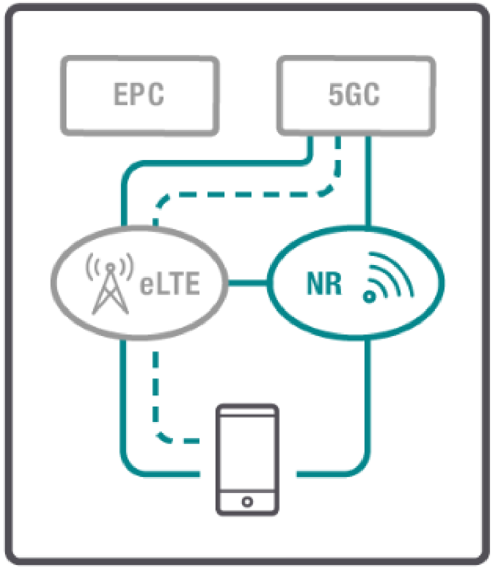
OPTION 7: Non-Standalone NR, LTE assisted, 5GC connected



OPTION 7A: Non-Standalone NR, LTE assisted, 5GC connected



OPTION 7X: Non-Standalone NR, LTE assisted, 5GC connected

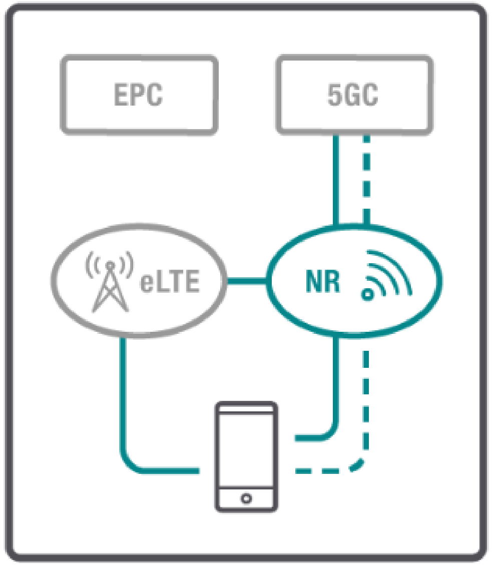


Multi-RAT Dual Connectivity with 5G Core

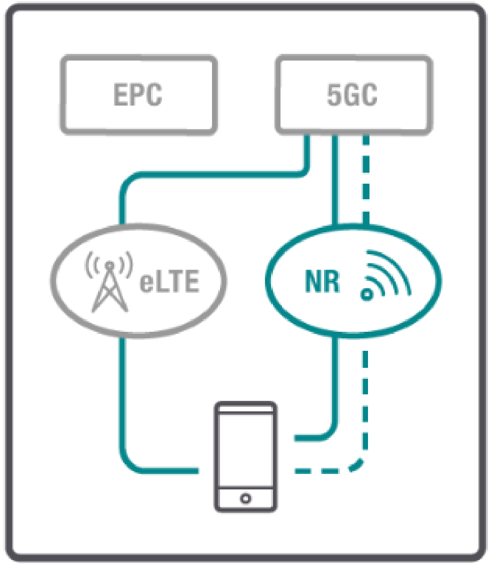
OPTIONS 4/4A

- Dual Connectivity with NG-RAN: **N**R-**E**-UTRA **D**ual **C**onnectivity (**NE-DC**)
  - Master Node: gNB (5G NR)
  - Secondary Node: ng-eNB (eLTE)

OPTION 4: Non-Standalone eLTE, NR assisted, 5GC connected



OPTION 4A: Non-Standalone eLTE, NR assisted, 5GC connected



Summary

Table 4.3-1: Definition of suffixes

Clause suffix	Variant
None	Single Carrier
A	Carrier Aggregation (CA)
B	Dual-Connectivity (DC)
C	Supplement Uplink (SUL)
D	UL MIMO

Understanding 5G NR Standards

AGENDA

- Technology Overview & Timeline
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- Network Architecture, Deployment Options
- **Beams, Beamforming & Beam Management**

Moving to mmWave Change Everything

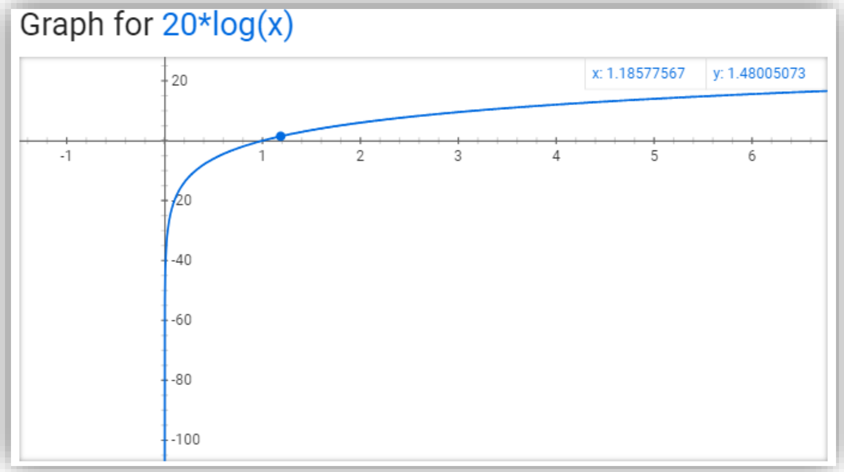
Question: Is it better to have high gain or low gain antenna?

The plan to introduce cellular services in frequency bands >6 GHz is driving an **abrupt and unprecedented change** in how devices and systems have to be designed, operated and tested.

- To overcome these losses and provide a realistic link budget, it is necessary to use high gain antennas comprised of multiple elements at both ends of the link
- High gain antennas create narrow beam width signals
- **Radio propagation at mmWave is very different: very sparse and spatially dynamic,** unlike rich multipath with Rayleigh fading

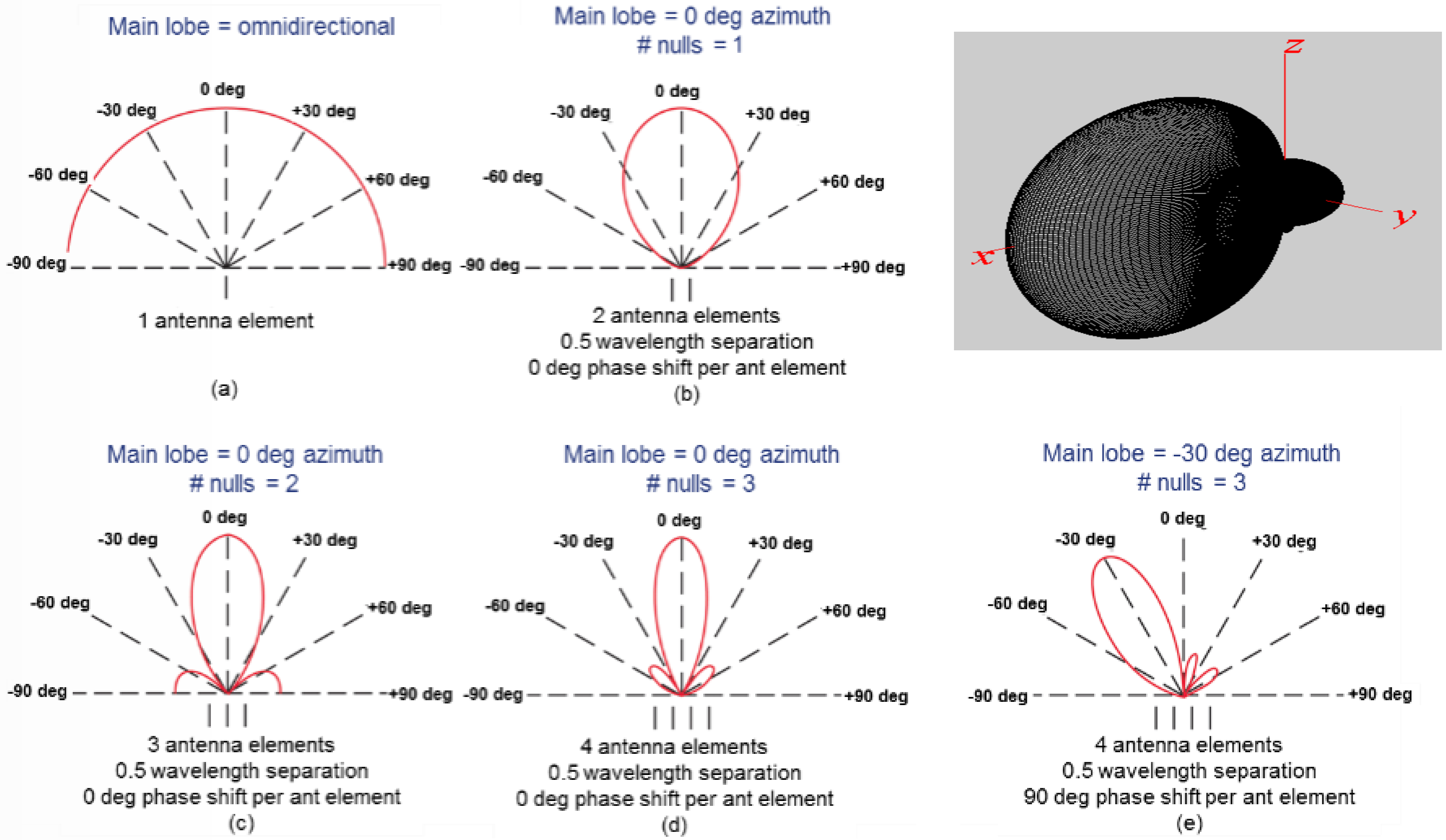
The Friis propagation equation predicts losses at mmWave frequencies:

$$P_r = P_t + G_t + G_r + 20\log_{10}\left(\frac{\lambda}{4\pi R}\right)$$



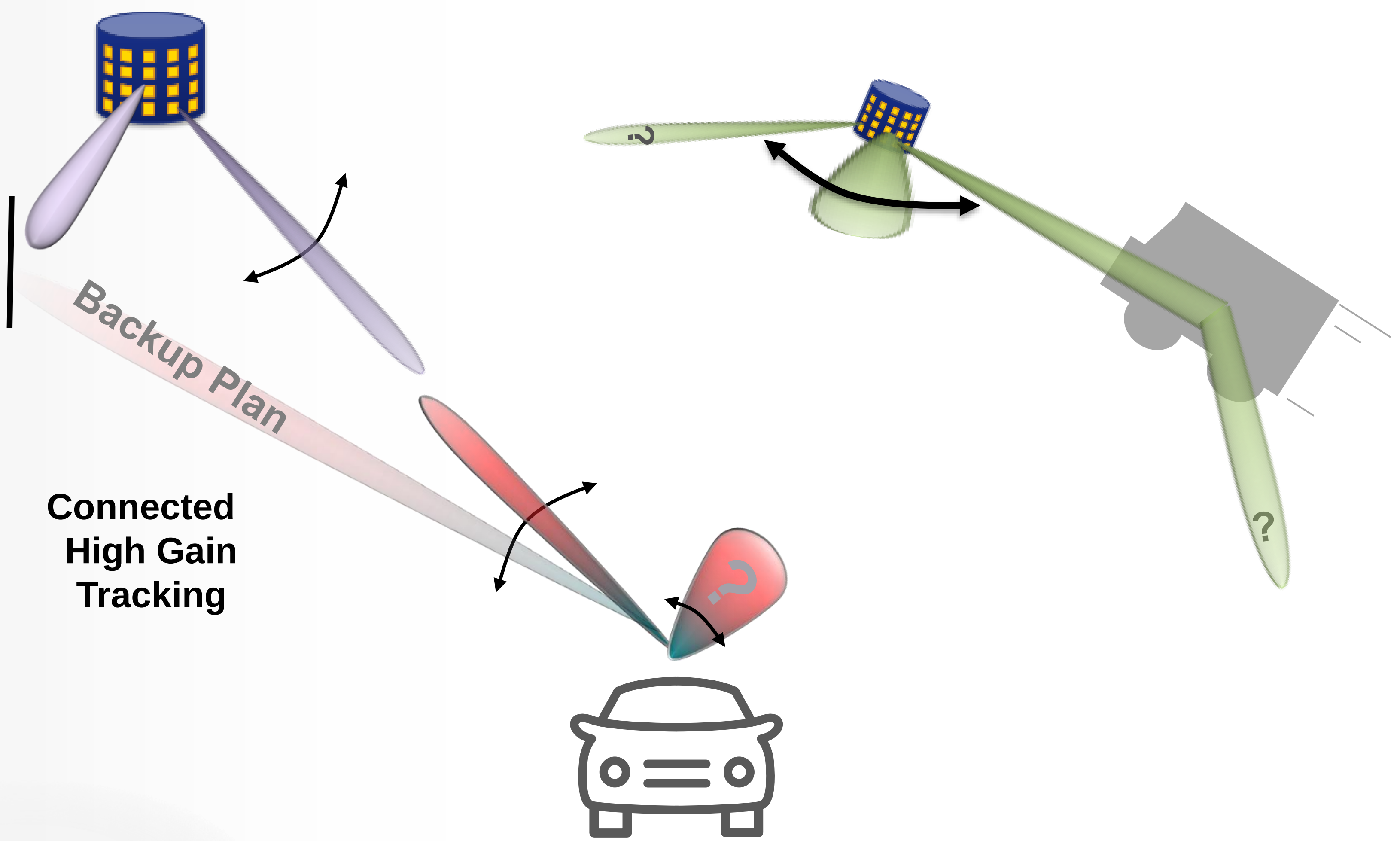
Path Loss ~ f^2

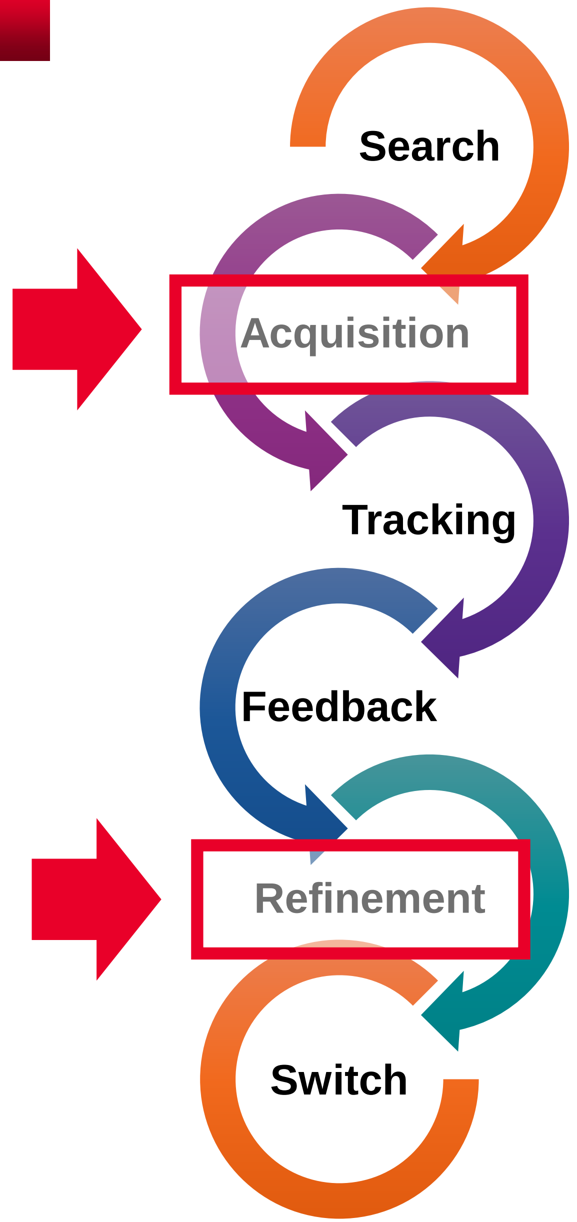
Antenna Patterns vs. Number of Elements



New Radio mmWave Spatial Domain Optimization

MOBILITY AND THE CHALLENGE OF DIRECTIONAL ANTENNAS

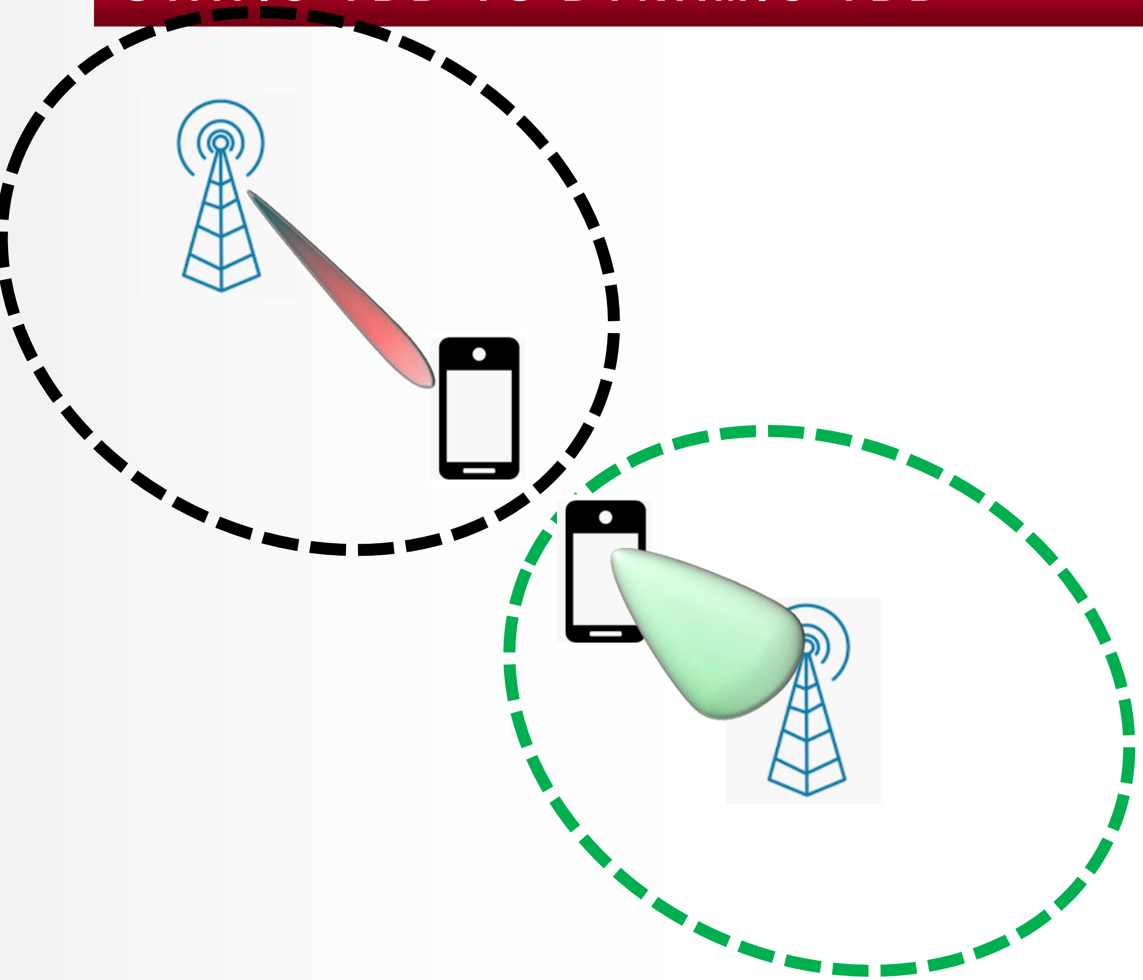


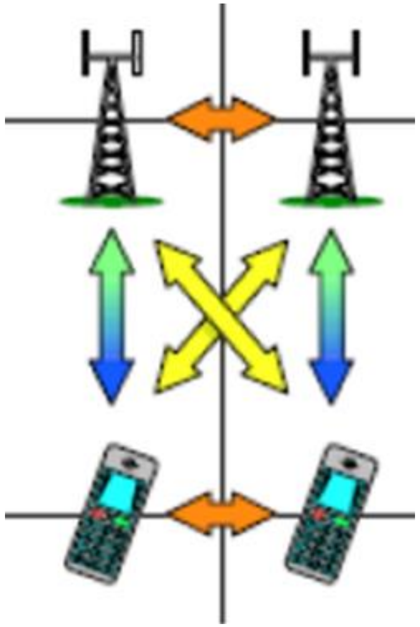


KEYSIGHT TECHNOLOGIES

Enter the Spatial Domain

STATIC TDD VS DYNAMIC TDD

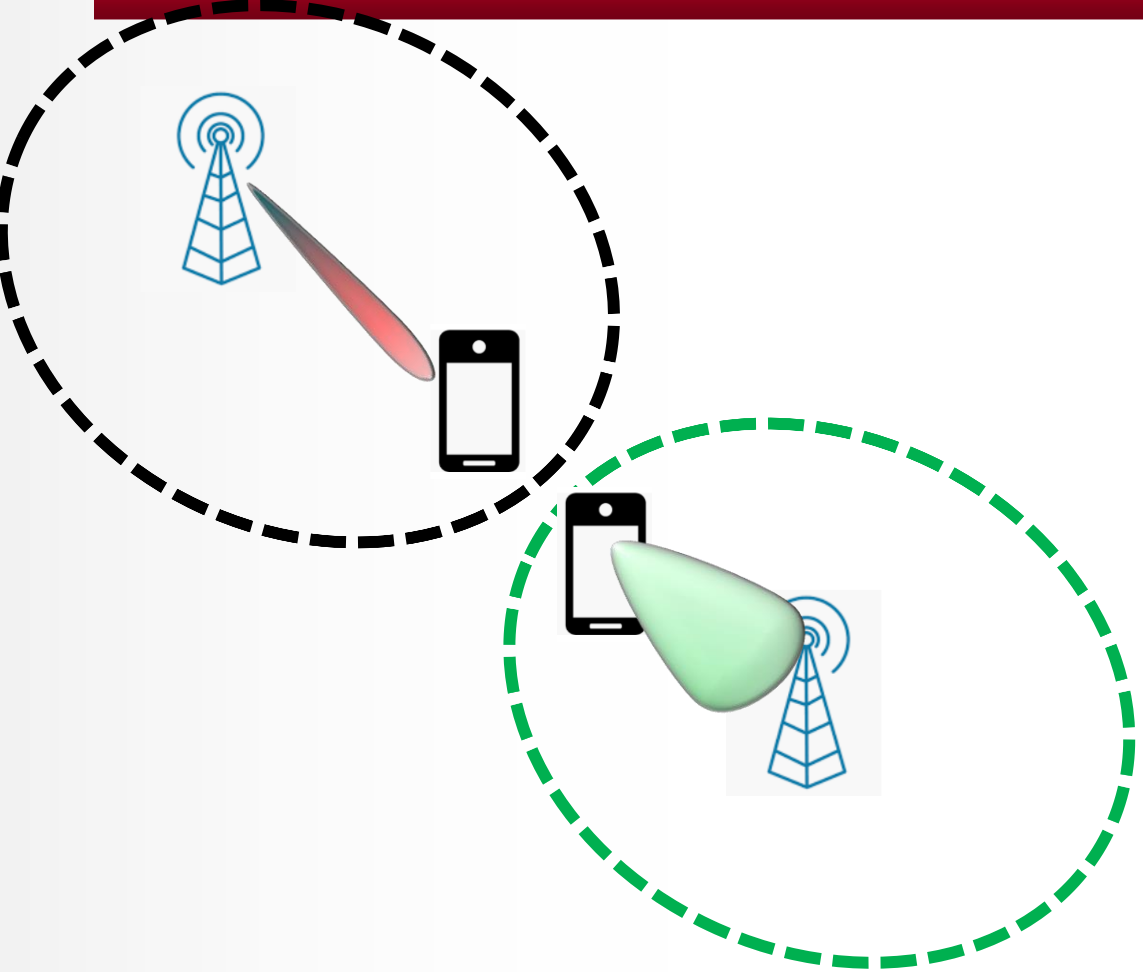




- In Static-TDD, transmission and reception of data occur at the same frequency band, through allocating distinct time slots for UL and DL. Moreover, the transmission bandwidth of each one of the links is fixed depending on the average traffic load.

Enter the Spatial Domain

STATIC TDD VS DYNAMIC TDD

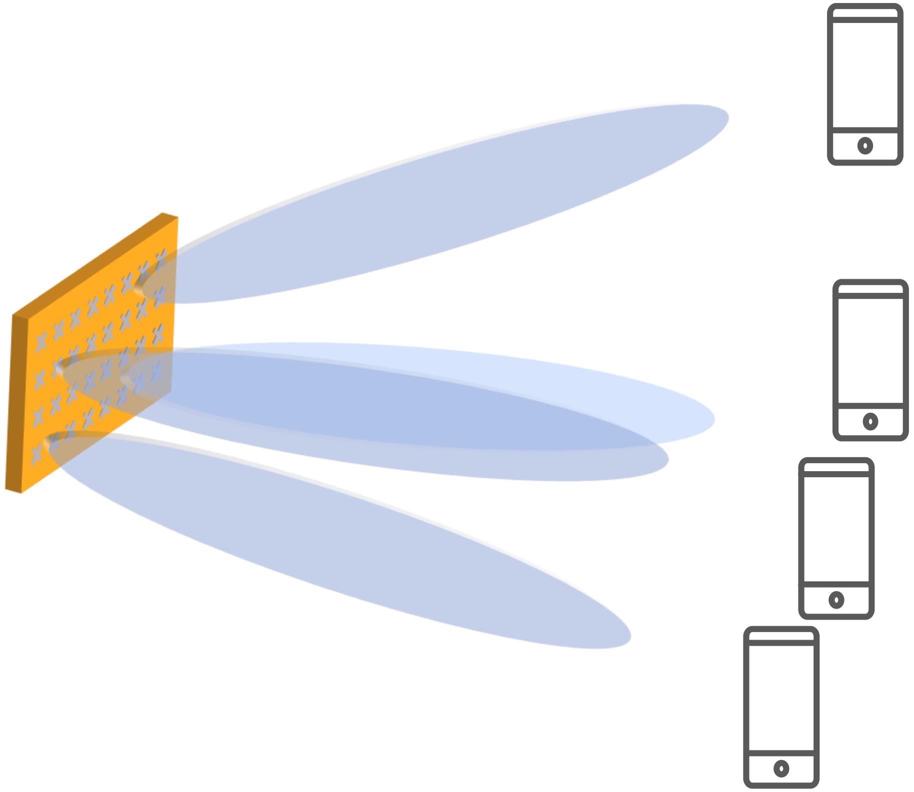


- In Dynamic TDD enables efficient and flexible asymmetric services, which improves the spectral efficiency of wireless networks.

Format	Symbol number in a slot													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	D	D	D	D	D	D	D	D	D	D	D	D	D	X
4	D	D	D	D	D	D	D	D	D	D	D	D	X	X
5	D	D	D	D	D	D	D	D	D	D	D	X	X	X
6	D	D	D	D	D	D	D	D	D	D	X	X	X	X
7	D	D	D	D	D	D	D	D	D	X	X	X	X	X
8	X	X	X	X	X	X	X	X	X	X	X	X	X	U
9	X	X	X	X	X	X	X	X	X	X	X	X	U	U
10	X	U	U	U	U	U	U	U	U	U	U	U	U	U
11	X	X	U	U	U	U	U	U	U	U	U	U	U	U
12	X	X	X	U	U	U	U	U	U	U	U	U	U	U
13	X	X	X	X	U	U	U	U	U	U	U	U	U	U
14	X	X	X	X	X	U	U	U	U	U	U	U	U	U
15	X	X	X	X	X	X	U	U	U	U	U	U	U	U
16	D	X	X	X	X	X	X	X	X	X	X	X	X	X
17	D	D	X	X	X	X	X	X	X	X	X	X	X	X
18	D	D	D	X	X	X	X	X	X	X	X	X	X	X
19	D	X	X	X	X	X	X	X	X	X	X	X	X	U
20	D	D	X	X	X	X	X	X	X	X	X	X	X	U
21	D	D	D	X	X	X	X	X	X	X	X	X	X	U
22	D	X	X	X	X	X	X	X	X	X	X	X	U	U
23	D	D	X	X	X	X	X	X	X	X	X	X	U	U
24	D	D	D	X	X	X	X	X	X	X	X	X	U	U
25	D	X	X	X	X	X	X	X	X	X	X	U	U	U
26	D	D	X	X	X	X	X	X	X	X	X	U	U	U
27	D	D	D	X	X	X	X	X	X	X	X	U	U	U
28	D	D	D	D	D	D	D	D	D	D	D	D	X	U
29	D	D	D	D	D	D	D	D	D	D	D	X	X	U
30	D	D	D	D	D	D	D	D	D	D	X	X	X	U
31	D	D	D	D	D	D	D	D	D	D	D	X	U	U
32	D	D	D	D	D	D	D	D	D	D	X	X	U	U
33	D	D	D	D	D	D	D	D	D	X	X	X	U	U
34	D	X	U	U	U	U	U	U	U	U	U	U	U	U
35	D	D	X	U	U	U	U	U	U	U	U	U	U	U
36	D	D	D	X	U	U	U	U	U	U	U	U	U	U
37	D	X	X	U	U	U	U	U	U	U	U	U	U	U
38	D	D	X	X	U	U	U	U	U	U	U	U	U	U
39	D	D	D	X	X	U	U	U	U	U	U	U	U	U
40	D	X	X	X	U	U	U	U	U	U	U	U	U	U
41	D	D	X	X	X	U	U	U	U	U	U	U	U	U
42	D	D	D	X	X	X	U	U	U	U	U	U	U	U
43	D	D	D	D	D	D	D	D	D	X	X	X	X	U
44	D	D	D	D	D	D	X	X	X	X	X	X	U	U
45	D	D	D	D	D	D	X	X	U	U	U	U	U	U
46	D	D	D	D	D	D	X	D	D	D	D	D	D	X
47	D	D	D	D	D	X	X	D	D	D	D	D	X	X
48	D	D	X	X	X	X	X	D	D	X	X	X	X	X
49	D	X	X	X	X	X	X	D	X	X	X	X	X	X
50	X	U	U	U	U	U	U	X	U	U	U	U	U	U
51	X	X	U	U	U	U	U	X	X	U	U	U	U	U
52	X	X	X	U	U	U	U	X	X	X	U	U	U	U
53	X	X	X	X	U	U	U	X	X	X	X	U	U	U
54	D	D	D	D	D	X	U	D	D	D	D	D	X	U
55	D	D	X	U	U	U	U	D	D	X	U	U	U	U
56	D	X	U	U	U	U	U	D	X	U	U	U	U	U
57	D	D	D	D	X	X	U	D	D	D	D	X	X	U
58	D	D	X	X	U	U	U	D	D	X	X	U	U	U
59	D	X	X	U	U	U	U	D	X	X	U	U	U	U
60	D	X	X	X	X	X	U	D	X	X	X	X	X	U
61	D	D	X	X	X	X	U	D	D	X	X	X	X	U
62 – 255	Reserved													

To Conclude: Beamforming/Management

- The network and device will use beamforming antennas (maybe as low as 12 degrees?)
- Narrow beams increase the received power (Signal-to-Noise) level
- Beams to different UEs can re-use the same time and frequency resources
- All common and dedicated channels are transmitted (and received) over beams
- Beams are bilateral for (t, f, (x,y,z)) – TDD operation only



To Conclude: 5G Operation at mmWave Frequencies

- mmWave has great potential (spectrum!)
- mmWave signals do not bend around corners (diffract) and are easily blocked or attenuated
- mmWave signals act more like light rays so can be directed using special antennas
- Path loss through the air is much greater at mmWave than at LTE bands
- Changing from 1 GHz to 28 GHz path loss increases by 28 dB over 1 m

Cables are lossy and expensive, galvanic connectors may not be exposed/available, 3GPP requires FR2 tests to be radiated

Therefore, testing will be mostly performed over the air

Understanding 5G NR Standards

AGENDA

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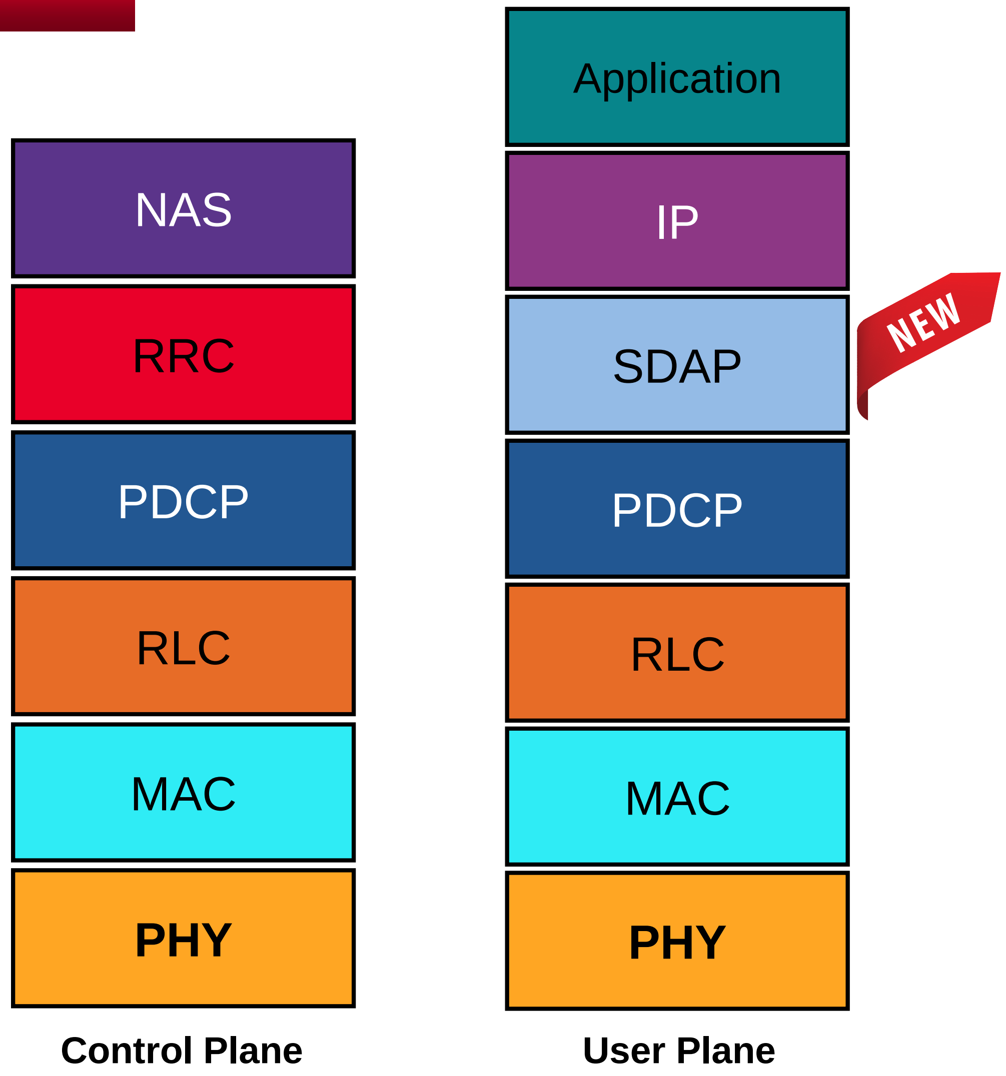
- **Protocol Structures, Layers, Signals & Channels**

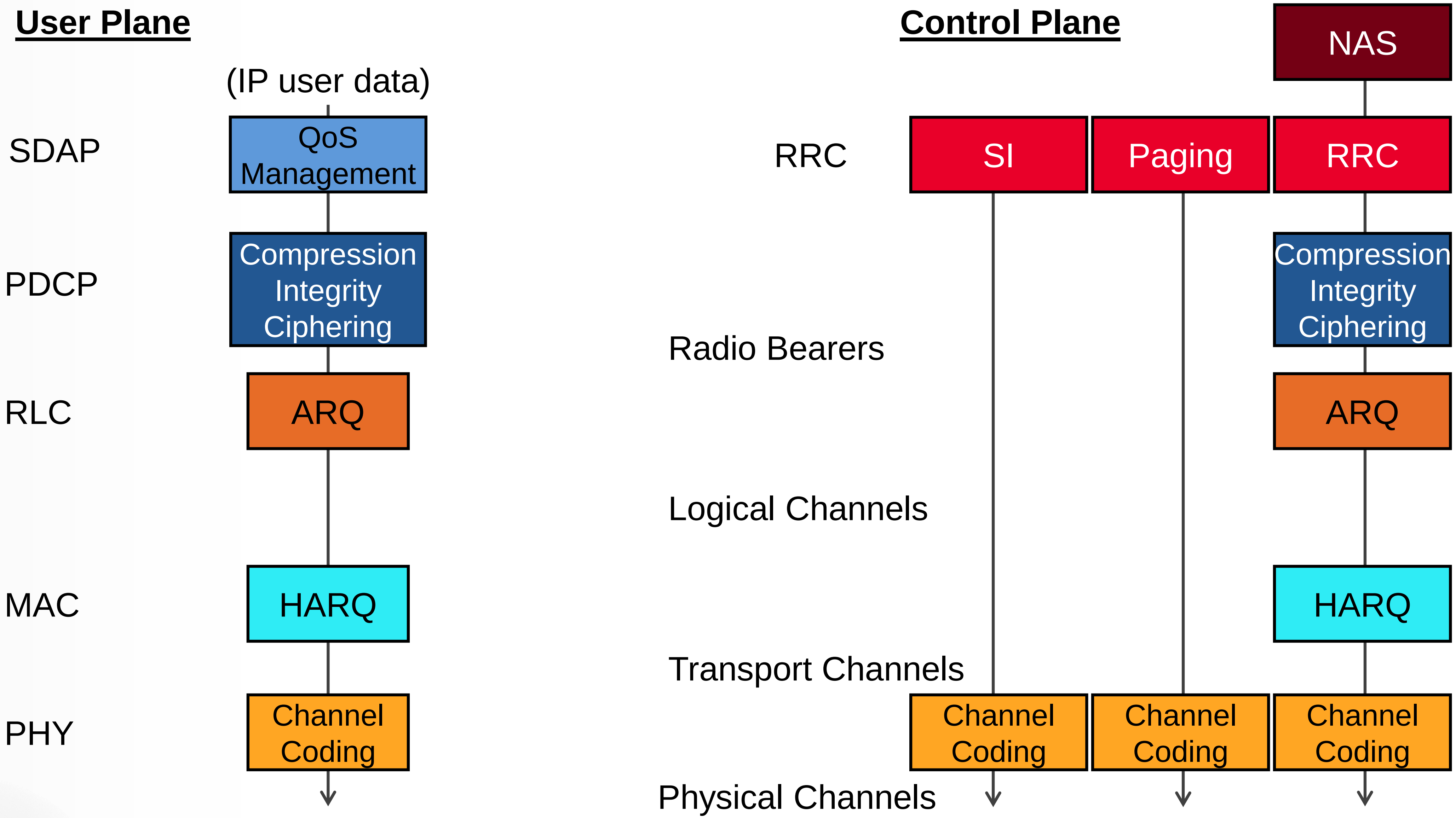
Protocol Structure

5G NR PROTOCOL LAYERS

- Higher protocol layers based on LTE
  - User data all IP
  - Registration, mobility, session management, handovers
  - Additions for lower layer enhancements (beamforming)
- Enhancements to security in NAS and PDCP
  - **Service Data Adaptation Protocol**: new protocol layer to take care of QoS
- **PHY sees the largest area of change**

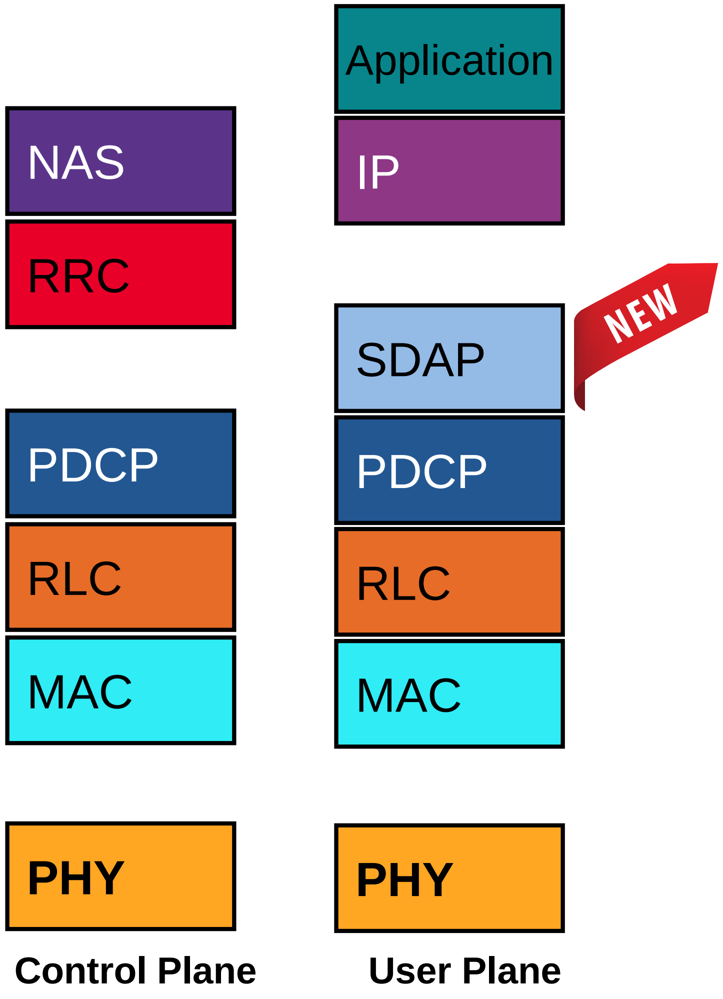


5G NR Protocol Structure



Layer 2 Changes

- New SDAP layer for QoS management in User Plane
  - Mapping between QoS flow and data radio bearer and marking QoS flow ID in DL and UL packets, all the way to 5GC
- PDCP duplication configuration: “legs” added
  - Map PDUs to more than 1 logical channel (duplicated PDCP PDUs) would be sent over **different component carriers**
- RLC/MAC
  - Support for beam management procedures and transmission modes using different numerologies and/or TTI duration
  - Reduction of processing latency:
    Concatenation is performed in MAC by placing the MAC headers immediately in front of the corresponding MAC SDUs
    Hence, no concatenation required in RLC



Signals, Channels & Mapping

PHYSICAL CHANNELS & SIGNALS

	NR Channels/Signals	Description	LTE Equivalent
Uplink	PUSCH PUSCH-DMRS, PUSCH-PTRS	Physical Uplink Shared Channel	PUSCH PUSCH-DMRS
	PUCCH PUCCH-DMRS	Physical Uplink Control Channel	PUCCH
	PRACH	Physical Random Access Channel	PRACH
	SRS	Sounding Reference Signal	SRS
Downlink	PDSCH PDSCH-DMRS, PDSCH-PTRS	Physical Downlink Shared Channel	PDSCH PDSCH-DMRS
	PBCH PBCH-DMRS	Physical Broadcast Channel	PBCH
	PDCCH PDCCH-DMRS	Physical Downlink Control Channel	PDCCH, EPDCCH EPDCCH-DMRS
	CSI-RS	Channel-State Information Reference Signal	CSI-RS
	PSS	Primary Synchronization Signal	PSS
	SSS	Secondary Synchronization Signal	SSS

Red = New NR channels/signals vs. LTE
Note: LTE ONLY channels such as PCFICH, PHICH, C-RS, etc. are not shown

Downlink Signals & Physical Channels

Signals
PSS, SSS: Primary and secondary synchronisation signals
DM-RS: Demodulation Reference signals (for PDSCH/PDCCH, PBCH)
PT-RS: Phase Tracking Reference Signal (for PDSCH)
CSI-RS: Channel State Information Reference Signal

Channels
PBCH: Physical Broadcast Channel
PDCCH: Physical Downlink Control Channel
PDSCH: Physical Downlink Shared Channel

- **DM-RS** for acquisition of PBCH, PDCCH and PDSCH
  - DM-RS for PBCH is spread over the same bandwidth as the PBCH (on the same symbols)

- **CSI-RS** for connected state beam management
  - Refinement of the beam when a UE is in the connected state (and moving)

- **PT-RS** is for phase tracking and phase noise compensation NEW
  - Fine time and frequency tracking
  - Path delay spread and Doppler spread

Uplink Signals & Physical Channels

Signals
DM-RS: Demodulation Reference signals (for PUSCH/PUCCH)
PT-RS: Phase Tracking Reference Signal (for PUSCH) NEW
SRS: Sounding Reference Signal

Channels
PUCCH: Physical Uplink Control Channel
PUSCH: Physical Uplink Shared Channel
PRACH: Physical Random Access Channel

- **DM-RS:** Provides synchronisation and uplink channel estimation
  - Separate DMRS for PUSCH and PUCCH
  - Sent in 1 or 2 symbols every timeslot for PUSCH

- **SRS:** Sent by the mobile upon request of the gNB to allow uplink channel estimation when no other transmissions are scheduled (on PUSCH or PUCCH)
  - Periodicity and subframe offset are configurable

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- **Take Away**

LTE vs. NR Comparison

	LTE (Based on 3GPP Rel-15)	New Radio (Based on 3GPP Rel-15)
Frequency Band	Sub-6 GHz	FR1, FR2
Max Bandwidth (CC)	20 MHz	FR1: 5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 100 MHz FR2: 50, 100, 200, 400 MHz
Max CCs	5 (Rel-10) / 32 (Rel-12). 5 current implementation	8
Subcarrier Spacing	15 kHz	**$2^n \cdot 15$ kHz**
Waveform	CP-OFDM for DL; SC-FDMA for UL	CP-OFDM (DL); CP-OFDM and DFT-s-OFDM (UL)
Modulation	Up to 256 QAM DL (moving to 1024 QAM); Up to 64 QAM UL	Up to 256 QAM UL & DL
Max Number of Subcarriers	1200	3276
Subframe Length	1 ms (moving to 0.5 ms)	1 ms
Latency (Air Interface)	10 ms (moving to 5 ms)	1 ms
Slot Length	7 symbols in 500 µs	14 symbols (duration depends on SC spacing) 2, 4 and 7 symbols for mini-slots
Channel Coding	Turbo Code (data); TBCC (control)	LDPC (data); Polar Codes (control)
Initial Access	No beamforming	Beamforming
MIMO	Up to 8x8	Up to 8x8
Reference signals	UE Specific DMRS and Cell Specific RS	Front-loaded DMRS (UE-specific)
Duplexing	FDD, Static TDD	FDD, Static TDD, Dynamic TDD

3GPP 5G NR Specification

SINGLE SPECIFICATION COVERING FR1 AND FR2

	FR1 – Frequency Range 1	FR2 – Frequency Range 2
Spec	5G NR NSA and SA	5G NR NSA
Frequency	450 MHz ~ 7125 MHz e.g. 3.4 – 3.7 GHz, 4.4 – 4.9 GHz	24.520 GHz ~ 52.600 GHz e.g. 39 GHz (3 GHz of spectrum), 28 GHz (800 MHz)
Bandwidth (cc)	Up to 100 MHz	Up to 400 MHz
Maximum CCs	8	8
DL MIMO	8x8	2x2
Numerology (subcarrier spacing)	$2^n \cdot 15$ kHz n = {0, 1, 2} 15 kHz (n=0, 1x LTE), 30 kHz (n=1, 2x LTE)	$2^n \cdot 15$ kHz n = {2, 3, 4}; 60 kHz (n=2, 4x LTE) 120 kHz (n=3, 8x LTE), 240 kHz (n=4, 16x LTE)
Waveform	DL: CP-OFDM / UL: CP-OFDM or DFT-s-OFDM	DL: CP-OFDM / UL: CP-OFDM or DFT-s-OFDM
Subcarriers	3276	3276
Subframe length	1ms	1ms
Slot length (t)	Max @60 kHz SCS: 250µs	Max @240 kHz SCS: 62.5 µs

Specifications – www.3gpp.org

Specification	Title
38.300	Overall Description
38.902	Study on New Radio Access Technology
38.211	Physical Channels and Modulation
38.212	Multiplexing and Channel Coding
38.213	Physical Layer Procedures for Control
38.214	Physical Layer Procedures for Data
38.321	NR Medium Access Control (MAC)
38.322	NR Radio Link Control (RLC)
38.323	NR Packet Data Convergence Protocol (PDCP)
37.324	NR Service Data Protocol (SDAP)
38.331	NR Radio Resource Control (RRC)
24.301	Non-Access Stratum (NAS)
33.501	Security Architecture and Procedures for 5G
37.340	NR Multi-connectivity Overall Description

Key Takeaways

UNDERSTANDING THE ROAD AHEAD

- Standards will continue to evolve through Rel-16 and beyond: your test solutions need to be flexible and scalable
- Higher frequencies, wider channel bandwidths, and dual connectivity increase the number of test cases and test complexity
- mmWave and MIMO introduce new OTA test requirements for 5G NR devices and base stations
- New initial access and control procedures will require more testing

KEYSIGHT TECHNOLOGIES