5G Boot Camp

UNDERSTANDING 5G NEW RADIO RELEASE 15/16 STANDARDS

Keysight Technologies | ***DEC 2019***

Understanding 5G NR Standards

AGENDA

5G

- **Technology Overview & Timeline**
- Carrier Aggregation & Bandwidth Adaptation
- Numerology & Frame Structure
- Waveforms & Modulations
- Beams, Beamforming & Beam Management
- Initial Access Procedure, Example Call Flows
- Network Architecture, Deployment Options
- New Features Coming in Rel-16

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

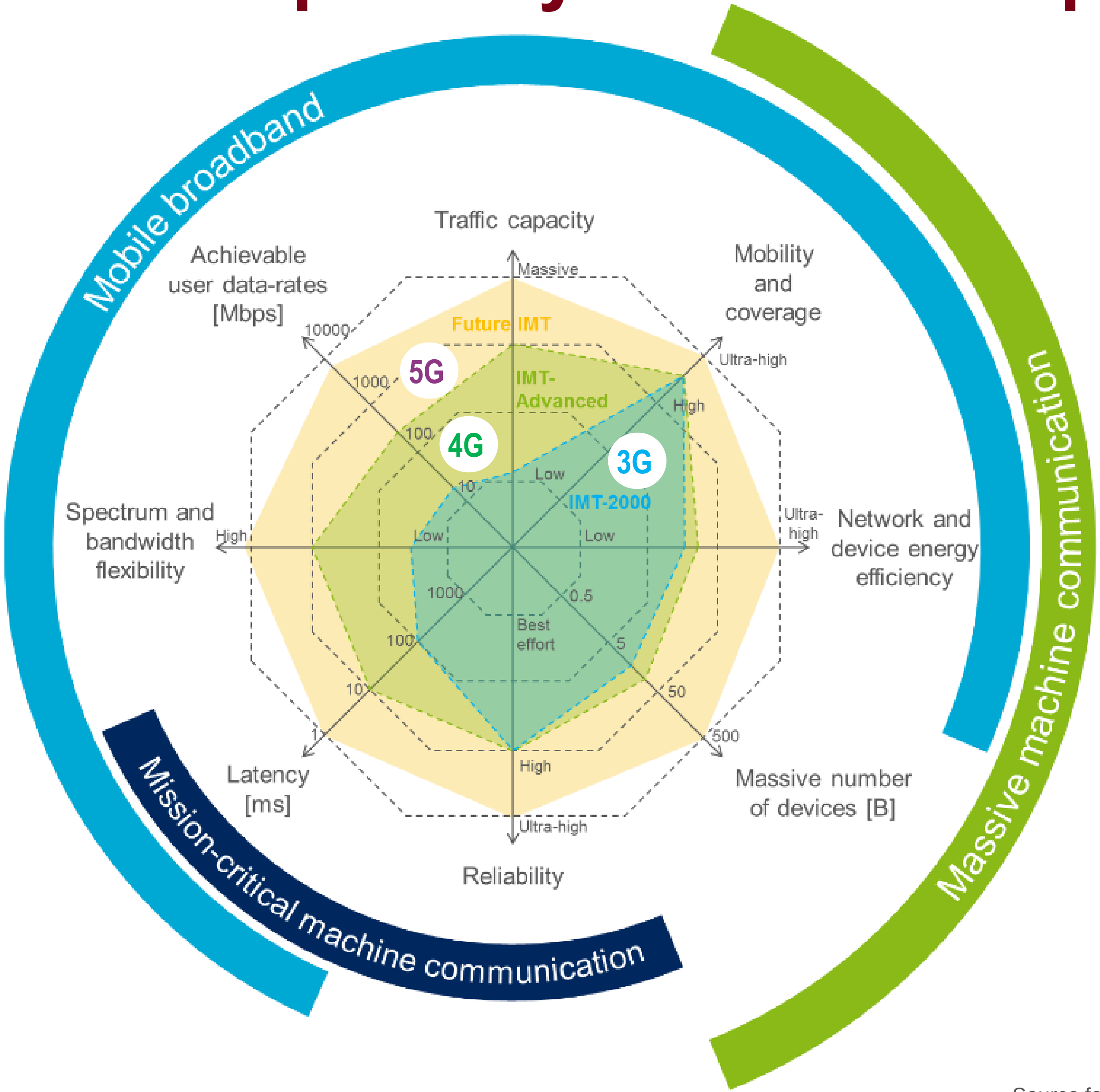
- 30 billion 'things' connected
- Low cost, low energy

URLLC

Mission-Critical Machine Communication

- Ultra-high reliability
- Ultra-low latency

5G Scalability and Adaptability- Brief / Example



Source for Spider Diagram: ITU: 5D/TEMP/390-E

5G Specifications

ALIGNED WITH IMT VISION

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

Phase 1 – mid 2018

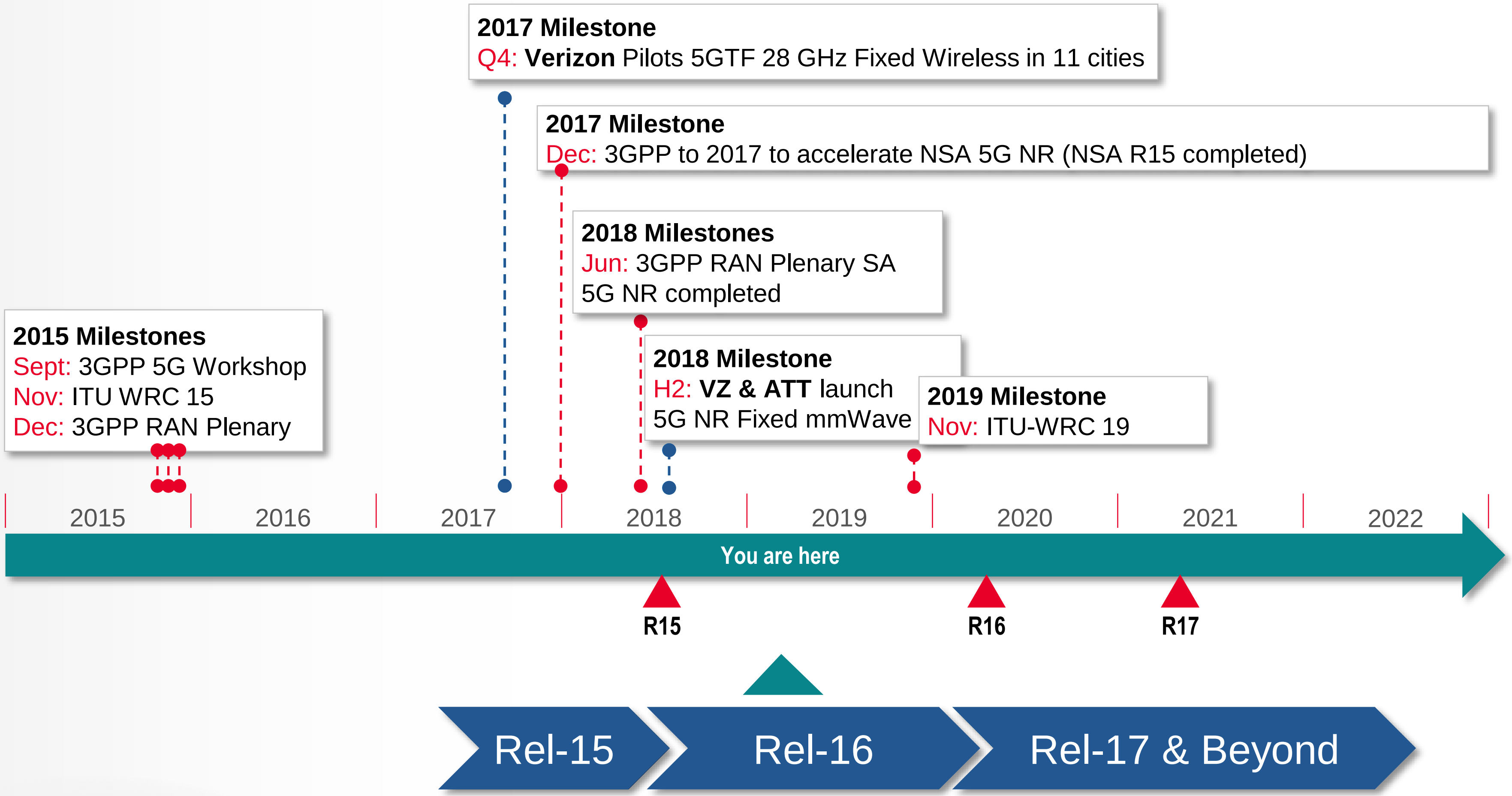
- Focus on eMBB and low latency aspects
- Minimized changes to core architecture (LTE-EPC) – NSA operation initially
- 5G RAT - focus on “conventional” frequency channels

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

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.

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

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*** NEW
    - 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

- Scalability required for different use cases/frequency bands
  - Scalable numerology - sub-frame structure and component carrier bandwidth
  - Introduction of mini-slots for low latency
- Channel bandwidths up to 400 MHz for single component carrier
- 3D **Beamforming** antennas - MU-MIMO steerable on per UE basis, massive MIMO
- Layer 3 (OTA) based on 4G but enhanced for control plane efficiency
- Lower layers / 5G NR greatly enhanced for the required data rates, latency, and efficiency

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

3GPP RAN Working Groups Overview

RAN Plenary is responsible for all Radio Access Networks, including their internal structures and functions, of systems for evolved GERAN, UTRAN, E-UTRAN, 5GC and beyond. All groups participate in plenary meetings.

RAN WG	Responsibilities
RAN1 **Radio Layer 1**	Specification of the physical layer of the radio interface – channels structures, mapping transport channels to physical channels, multiplexing, modulation schemes, etc
RAN2 **Radio Layer 2 and Layer 3**	Specification of the radio interface architecture and radio interface protocols – interface between architecture and protocols
RAN3 **Core, O&M Requirements**	Overall architecture and radio interface protocols – defines next generation interface protocols
RAN4 **Radio Performance and Protocol**	Development of UE and base station specifications, base station conformance test specifications, and specifications for electromagnetic compatibility (EMC)
RAN5 **Mobile Terminal Conformance Tests**	Development of UE conformance test specifications including signaling and protocol test cases, and inter-RAT procedures

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	410 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

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

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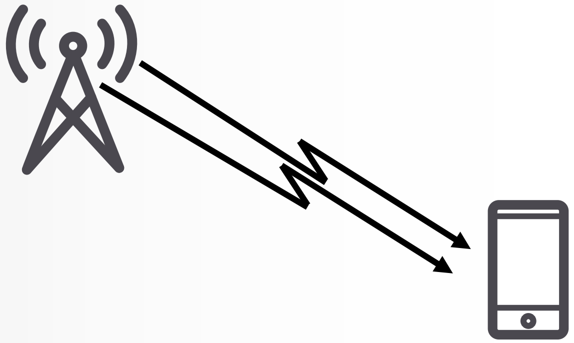
n261	60	Yes	Yes	Yes	N/A
	120	Yes	Yes	Yes	Yes

MIMO Variants

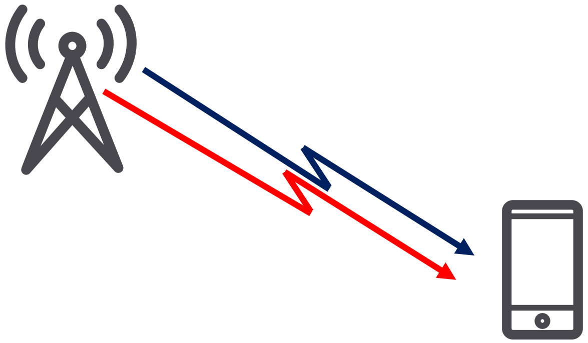
NO ARBITRARY DECISION – DRIVEN BY PROPERTIES OF CHANNEL

	FR1	FR2
Deployment Scenario	Macro cells High user mobility	Small cells Low user mobility
MIMO Order	Up to 8x8	Typically 2x2
Number of Simultaneous Users	Tens of users Large coverage area	A few users Small coverage area
Main Benefit	Spatial multiplexing, MU-MIMO	Beamforming for single user
Channel Characteristics	Rich multipath propagation	A few propagation paths
Spectral Efficiency	High due to the spatial multiplexing	Low spectral efficiency (few users, high path loss)

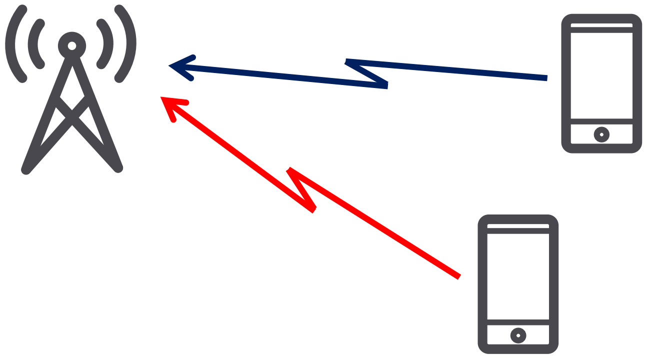
Multi-antenna Transmissions



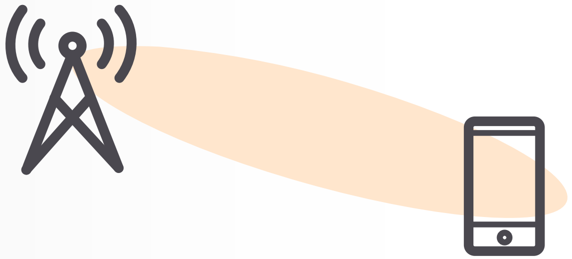
Transmit diversity for improved quality



MIMO multi-layer transmission for higher data rates



Multi-user MIMO (UL/DL) more users per cell



Beamforming to increase received power and SNR

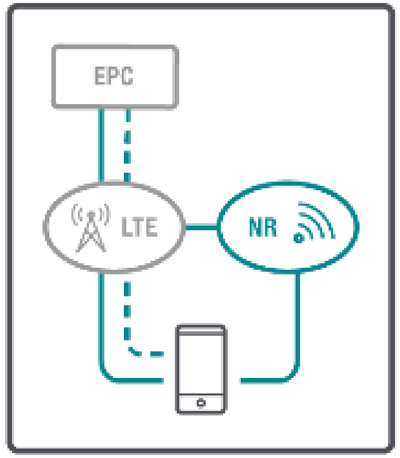
Spatial multiplexing more users per cell

Non-Standalone (NSA) and Standalone (SA) Modes

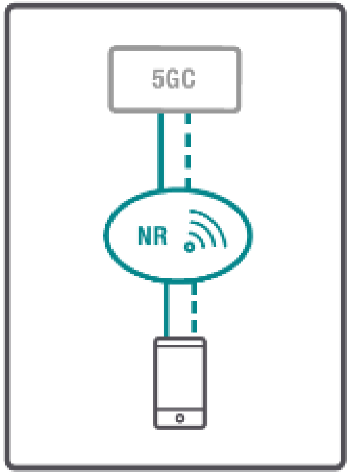
JUST AN INTRO: MORE DISCUSSED LATER

- LTE coverage
  - Large existing network deployment
  - Wide coverage due to lower frequency range
- 5G network
  - System deployment will take time
  - Range is more restricted in higher frequency bands
- NSA - Dual Connectivity (DC) uses both systems for evolution, reliability and geographical coverage
  - Expectation: slow and smooth transition into 5G

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



OPTION 2: Standalone NR



NSA: Dual Connectivity Across LTE and NR

RAT	NSA	SA
	Connection to both LTE and 5G mandatory	Can work with 5G only (LTE not necessary)
Control (Location Registration)	5G focused on U-Plane alone, LTE used for control including call origination/termination, location registration, etc.	5G used for both U-Plane and C-Plane
5G radio control parameters	5G radio control parameters exchanged through LTE, functions added to eNB	5G radio control parameters exchanged through 5G
Paging Channels	UE monitors paging channels on LTE	UE monitors paging channels on 5G

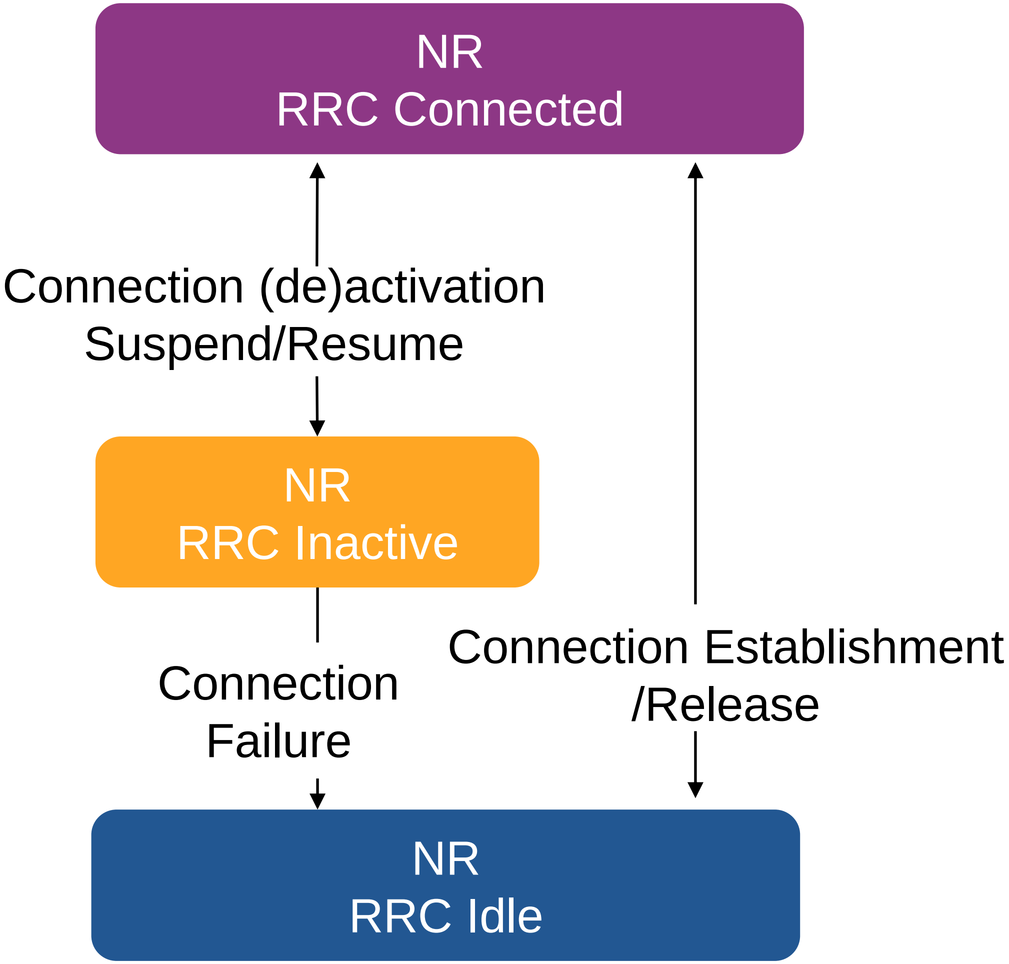
Radio Resource Control (RRC) States

5G NR SA

- **Device**
- monitors control channels for data scheduling
- provides channel quality estimate to gNB
- provides neighbor cell measurements

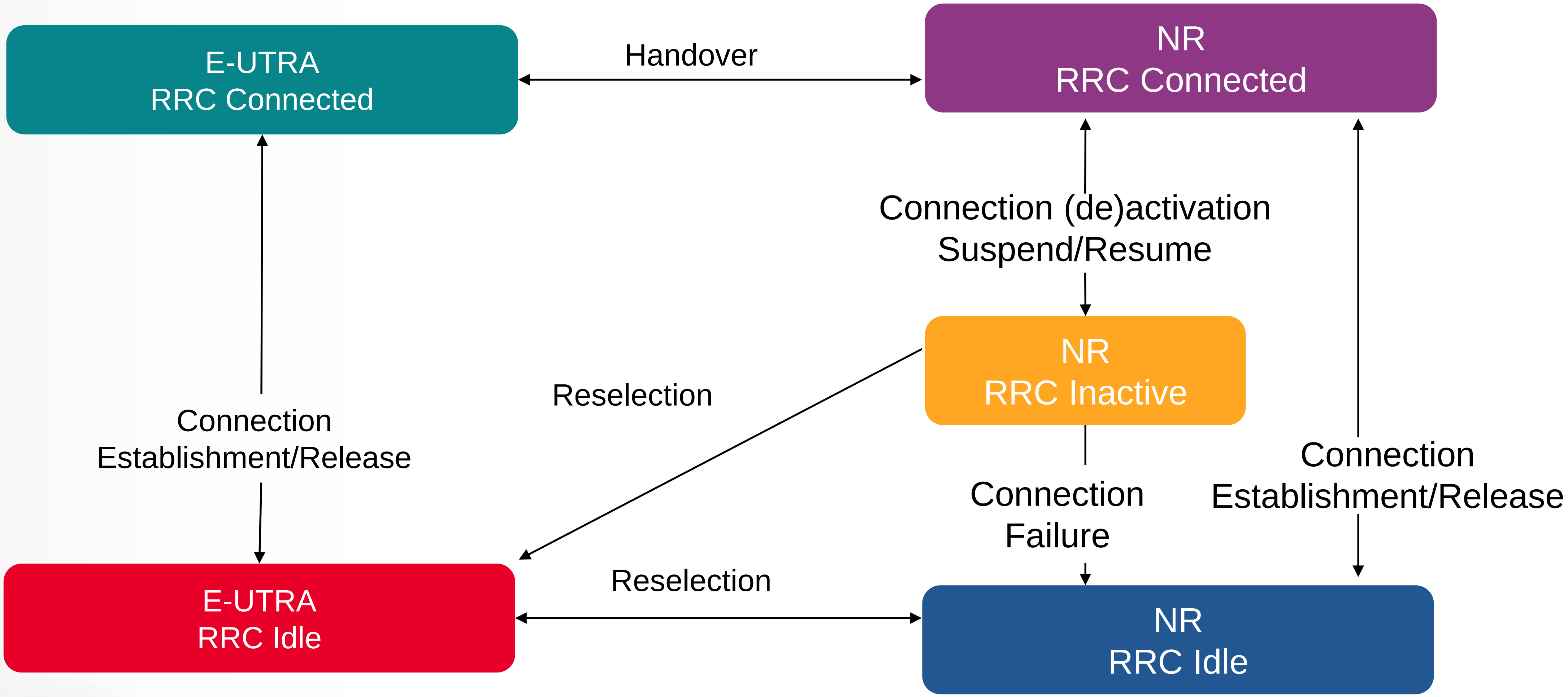
- **Device**
- performs RAN based notification area updates when moving outside the notification area
- stores the AS context

- **Device**
- acquires SI
- monitors paging
- performs neighbor cell measurements
- performs cell (re-)selection



RRC States NR to E-UTRA

5G NR SA



KEYSIGHT TECHNOLOGIES

Understanding 5G NR Standards

5G

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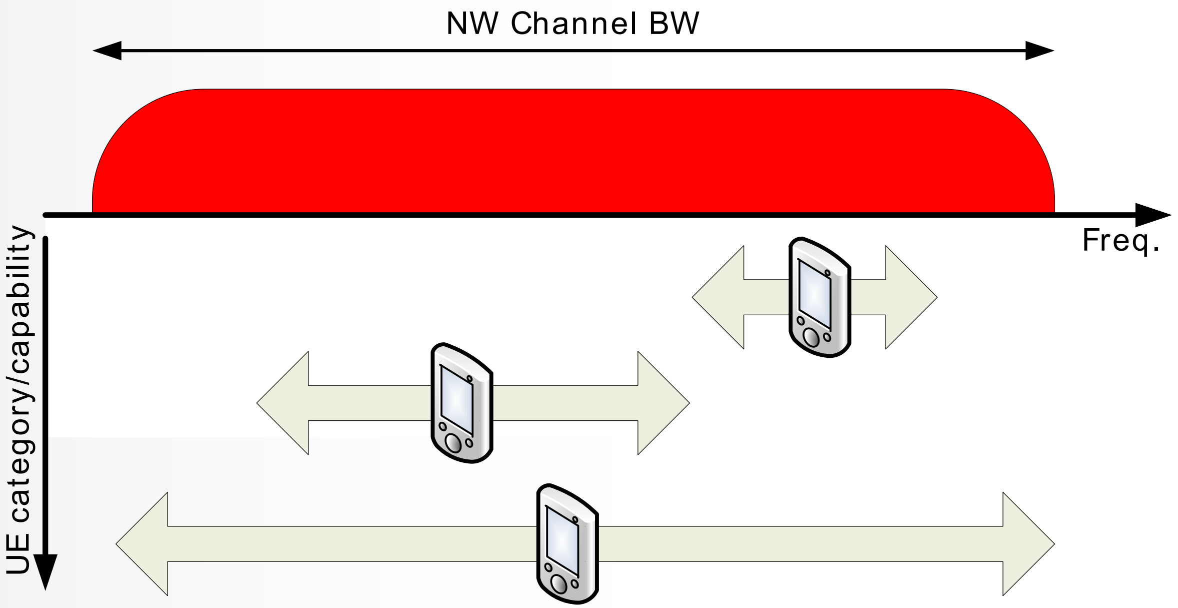
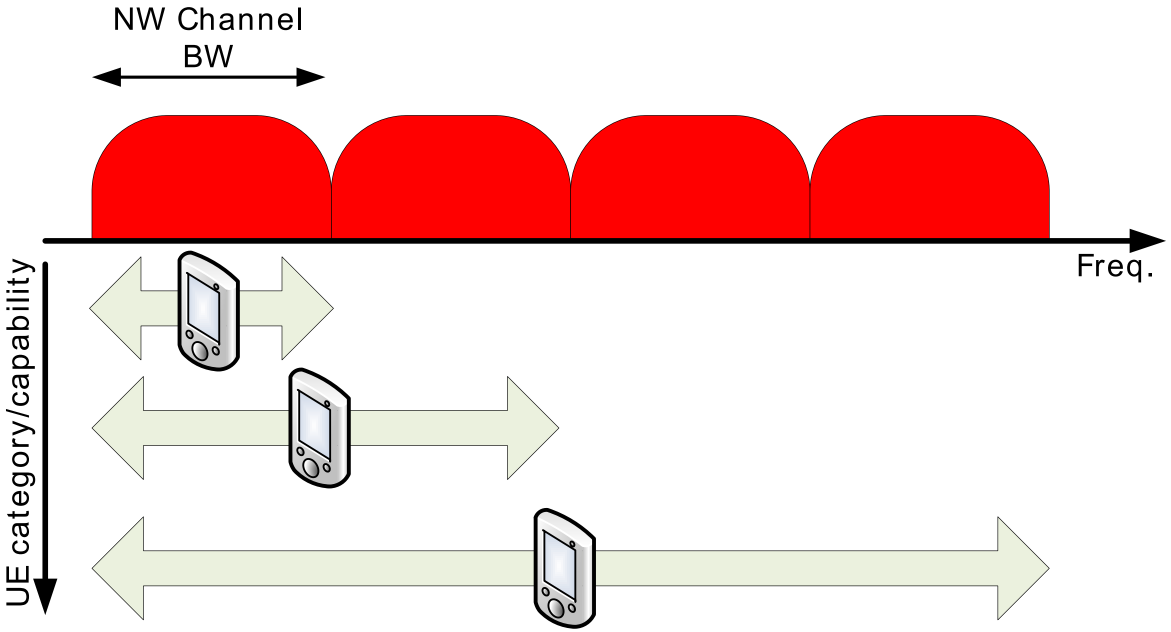
Single-Carrier and Multi-Carrier Operation

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



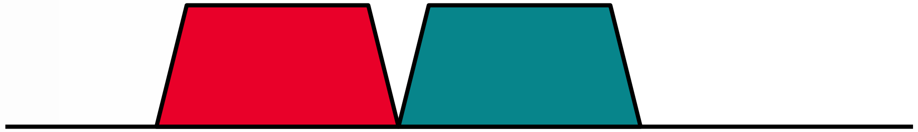
Single-Carrier Operation



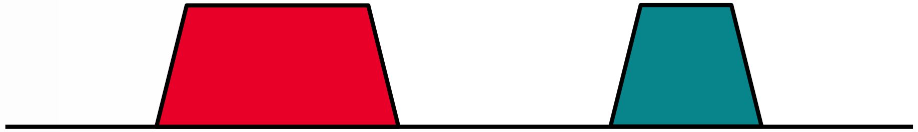
Multi-Carrier Operation

Carrier Aggregation Types

- Component Carriers may be in the same band and adjacent



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



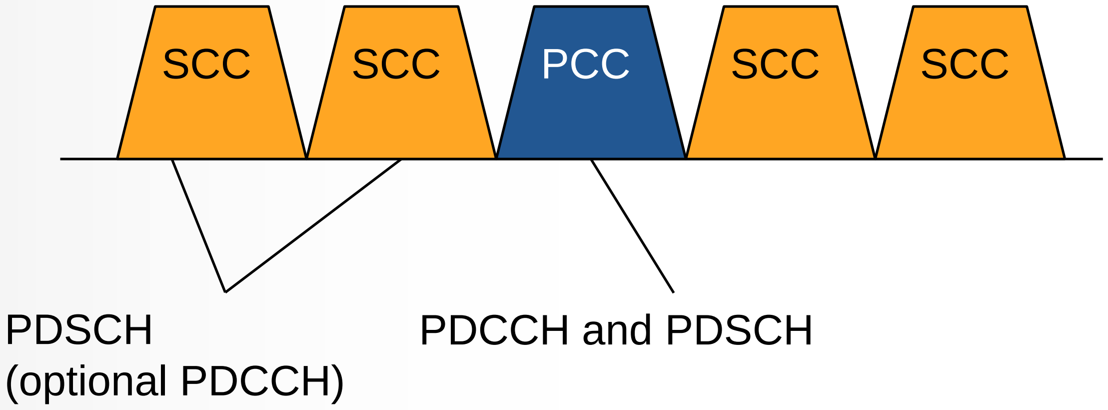
- Or in different bands

Band A – sub-6 GHz

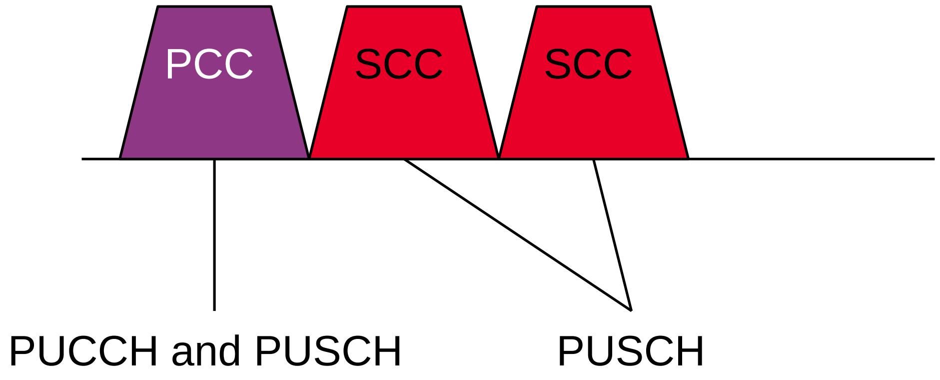
Band B – mmWave (28 GHz)

Channel Allocation

- RRC Connection and Registration only performed on Primary Component Carrier (PCC)
- Control channels (PDCCH and PUCCH) on Primary CC
- Data channels (PDSCH and PUSCH) on all component carriers



Downlink



Uplink

Bandwidth Part

CONTIGUOUS PHYSICAL RESOURCE BLOCKS (PRBS)

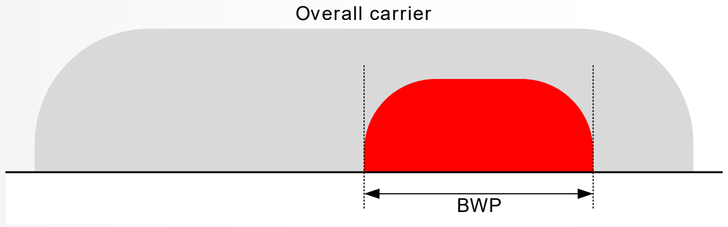
- An **Initial Bandwidth Part** is signaled by PBCH
- It contains CORESET (Control Resource Set) and PDSCH
- The bandwidth part may or may not contain (Beamforming) SS/PBCH block
- Reserved resources can be configured within the bandwidth part
- One or multiple bandwidth part configurations for each 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

- Other configuration parameters include:
  - **Numerology**: CP type, subcarrier spacing
  - **Frequency location**: the offset between BWP and a reference point within cell BW
  - **Bandwidth size**: in terms of PRBs

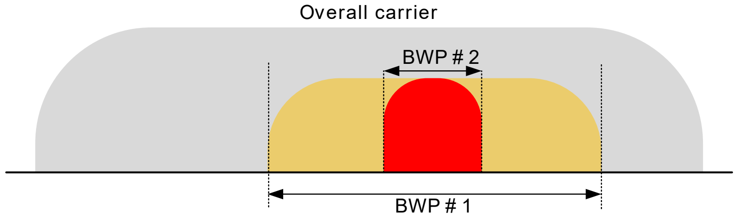
Bandwidth Part

BANDWIDTH PART USE CASES

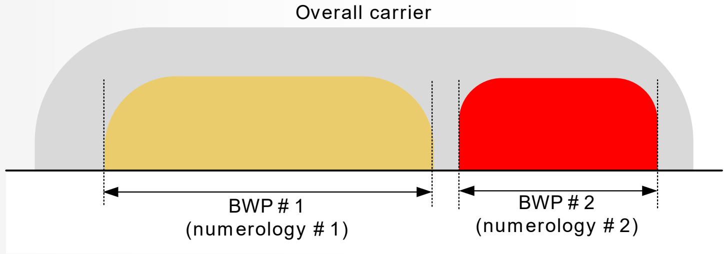
1. Supporting Reduced UE Bandwidth Capability



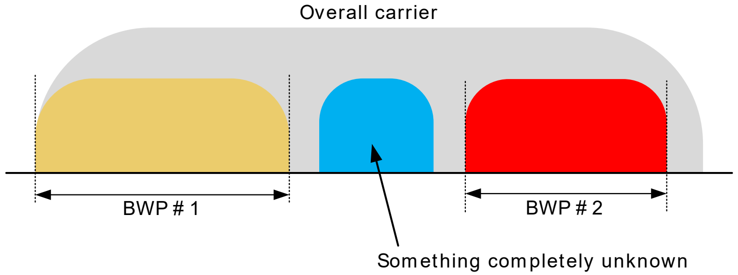
2. Supporting Reduced UE Energy Consumption



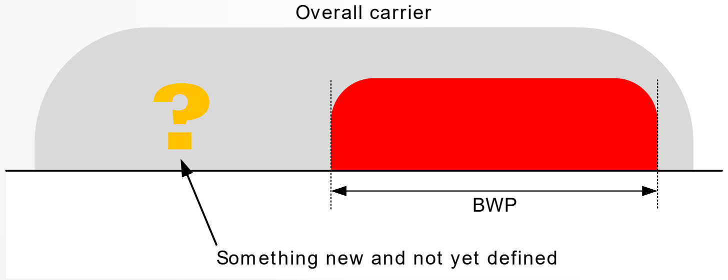
3. Supporting Different Numerologies



4. Supporting Non-contiguous Spectrum



5. Supporting Forward Compatibility

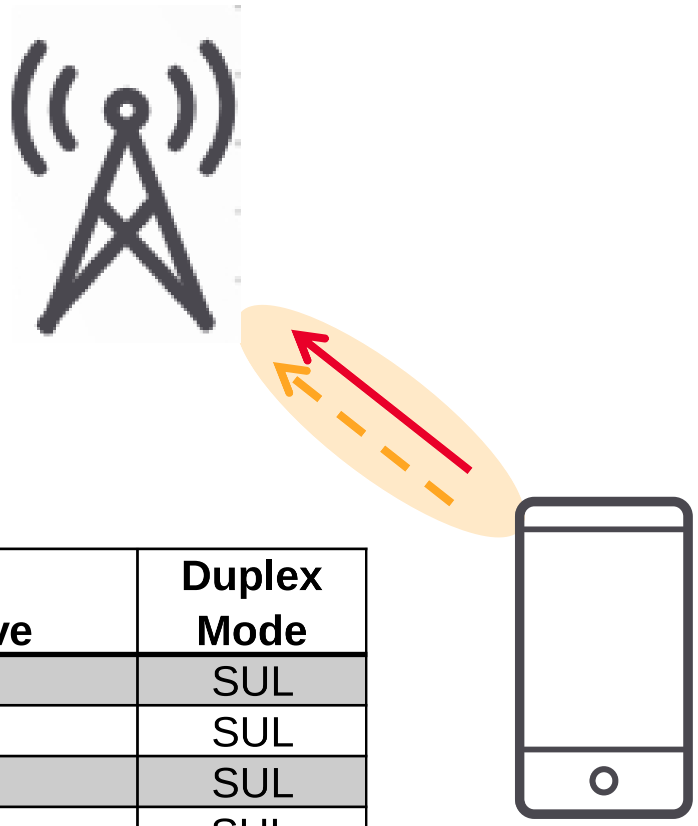


BWP activation/deactivation:

- UE may be configured with up to 4 DL and 4 UL bandwidth parts
- Activation by dedicated RRC signaling
- Activation/deactivation by DCI with explicit indication
- Activation/deactivation by a timer for a UE to switch its active DL BWP to a default BWP

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

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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

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

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

Flexible Numerology

MAXIMUM TRANSMISSION BANDWIDTH CONFIGURATION NRB

Spectrum utilization for **FR1** (410 MHz – 7.125 GHz): 3GPP 34.38.521-1 table 5.3.2-1

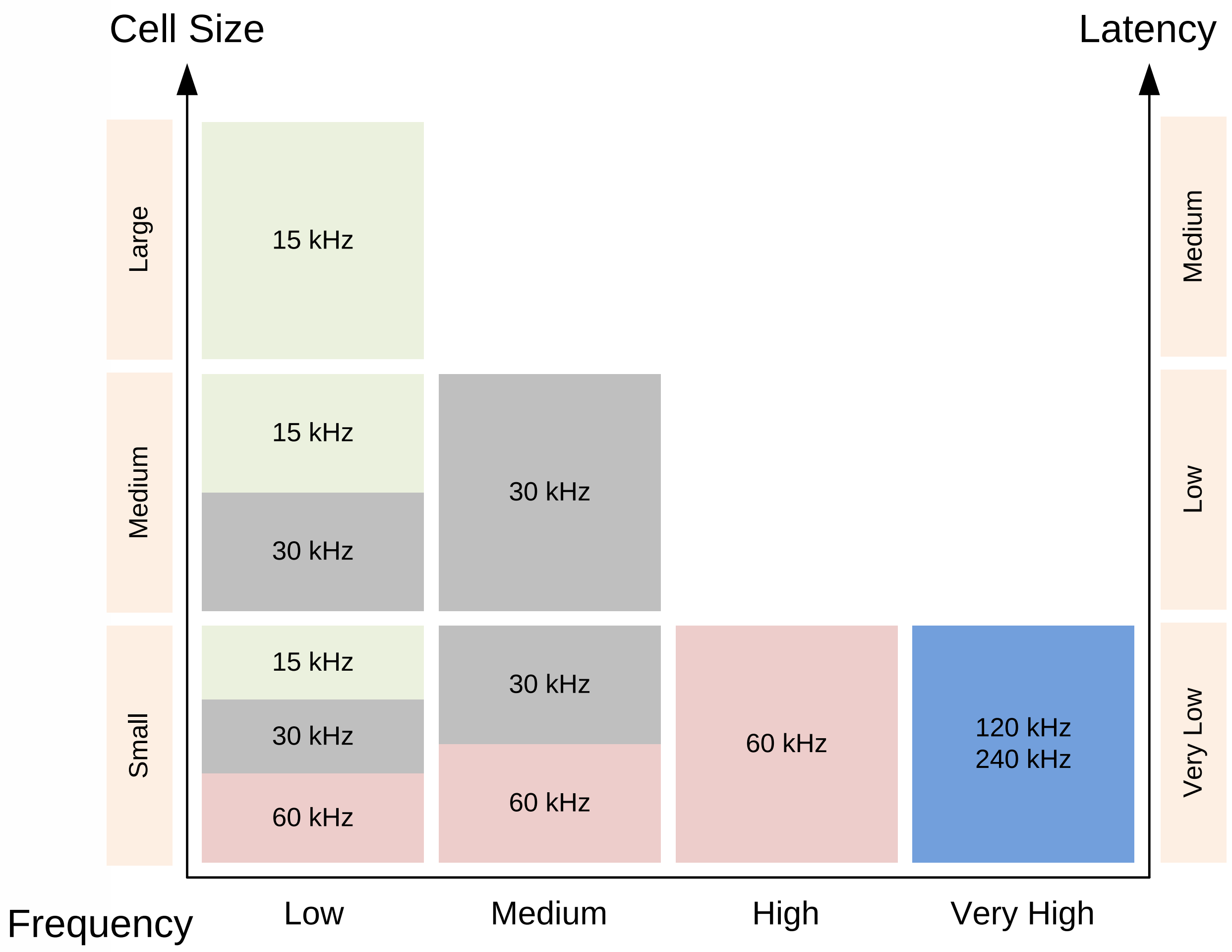
SCS	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	40 MHz	50 MHz	60 MHz	80 MHz	100 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}
15 kHz	25	52	79	106	133	216	270	N/A	N/A	N/A
30 kHz	11	24	38	51	65	106	133	162	217	273
60 kHz	N/A	11	18	24	31	51	65	79	107	135

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)

Use Cases for Different Subcarrier Spacing

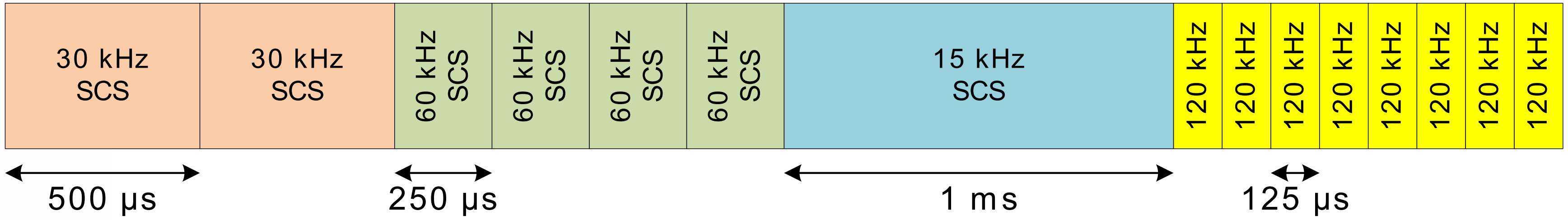


KEYSIGHT TECHNOLOGIES

Scalable Sub-Carriers – Variable Numerology (μ)

- **Sub-carrier spacing = 2^{μ} x 15 kHz**
- Slot is 14 symbols - slot length decreases as subcarrier spacing increases

μ	Subcarrier spacing	Slot length	Number of slots per subframe	Usage	
0	15 kHz	1 ms	1	Outdoor large cell <3 GHz	FR1
1	30 kHz	500 μs	2	Outdoor small cell >3 GHz	FR1
2	60 kHz	250 μs	4	Indoor wideband cell 5 GHz Small cell above 6 GHz	FR1 (5 GHz) / FR2 (above 6 GHz)
3	120 kHz	125 μs	8	Very small cell 28 GHz	FR2
4	240 kHz	62.5 μs	16	Indoor very small cell mmWave	FR2



Frame Structure

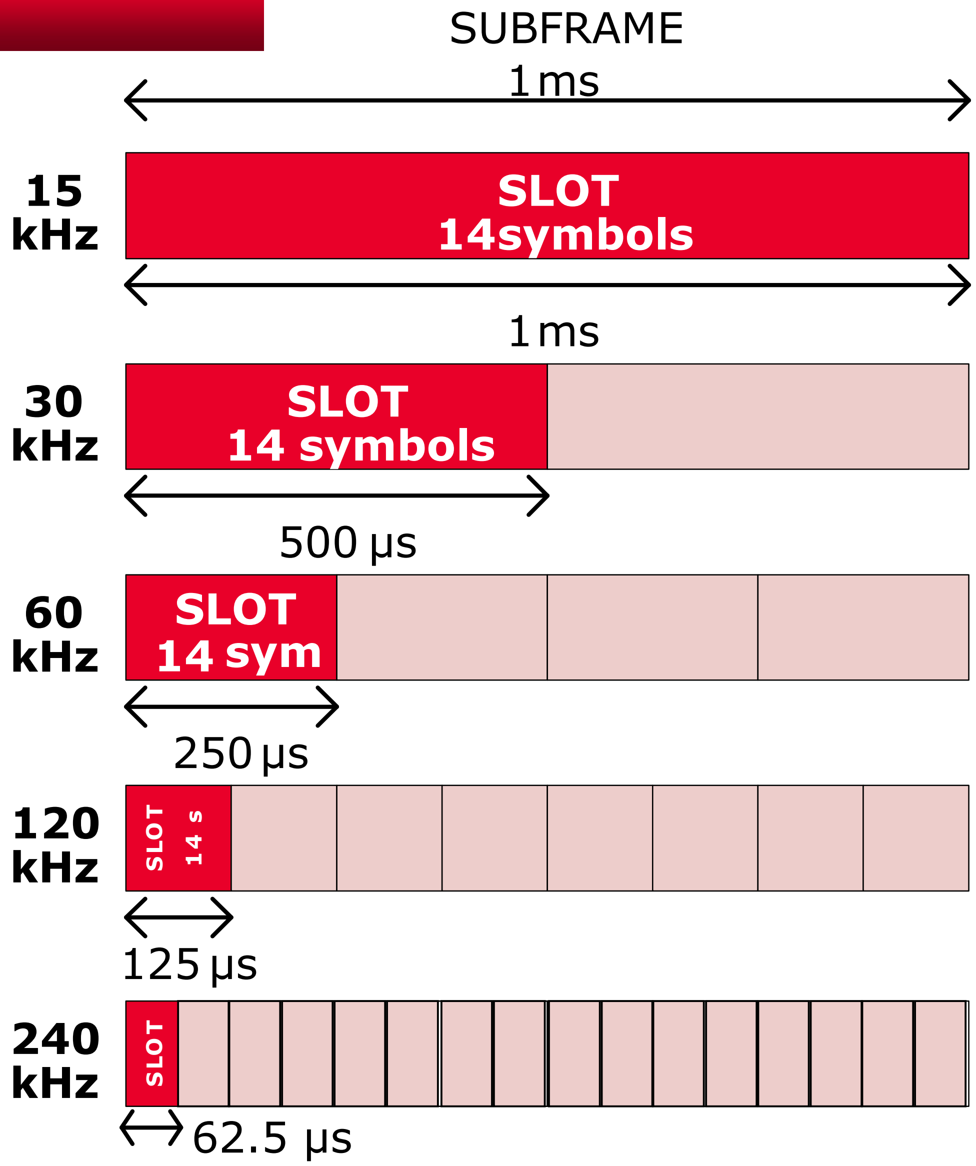
FRAME STRUCTURE & NUMEROLOGY

Slot structure is flexible to provide for better spectrum utilization

- **SCS**: 15 kHz*2^n
- **Frame: 10 ms**
- Subframe: Reference period of 1 ms
- **Slot (slot based scheduling)**
  - **14 OFDM symbols**, or 12 with extended CP
  - One possible scheduling unit
  - Slot length scales with the subcarrier spacing

NEW

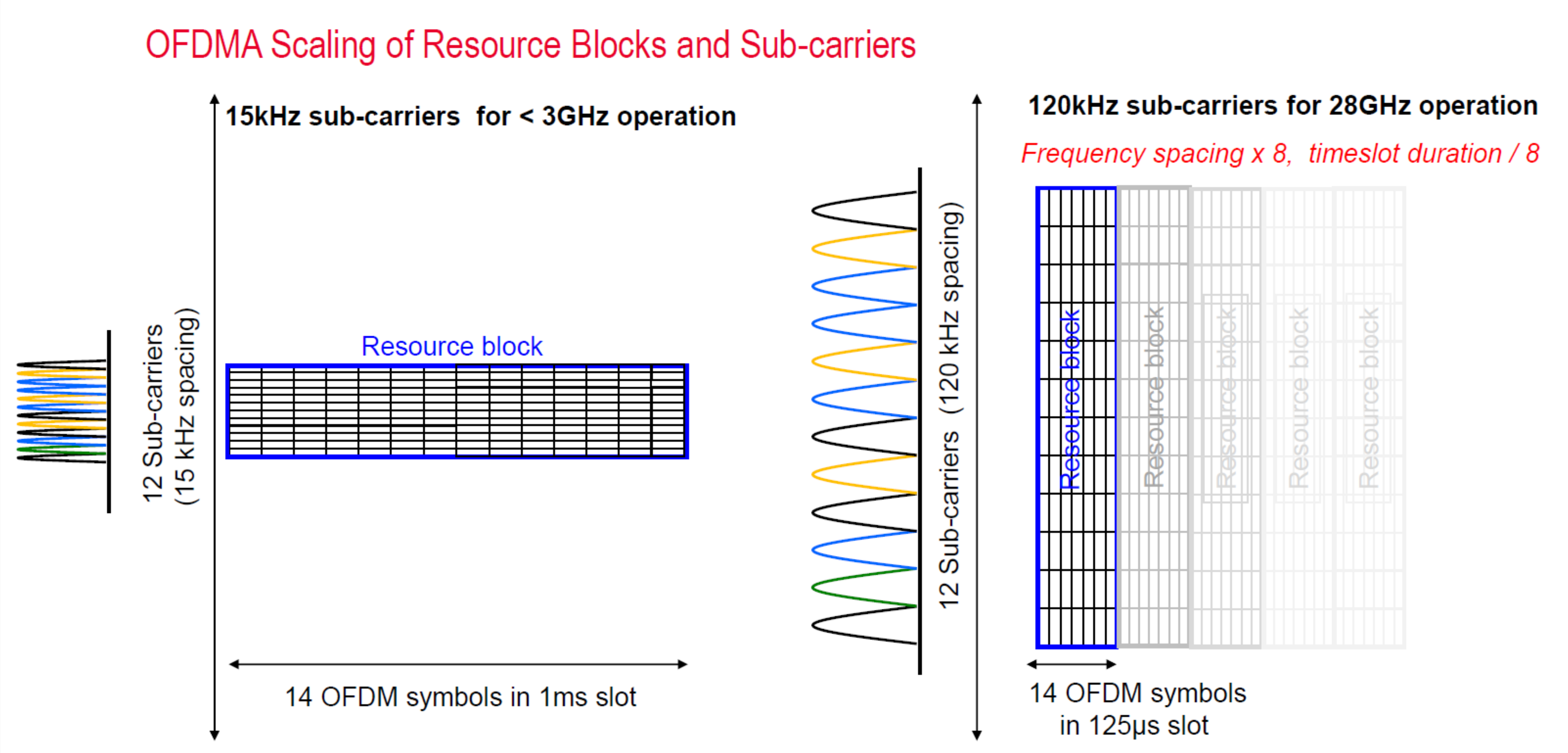
- **Mini-Slot (non-slot based scheduling)**
  - DL: 7, 4 or 2 OFDM symbols, can start immediately
  - UL: any length
  - Minimum scheduling unit



KEYSIGHT TECHNOLOGIES

Scaling of Resource Blocks and Subcarriers

15 KHZ VS 120 KHZ SUBCARRIER SPACING



Slot Usage

FDD AND TDD SLOTS, AND A MIX OF

Slot Format Indication (SFI) informs the UE of the current format (56 formats defined)

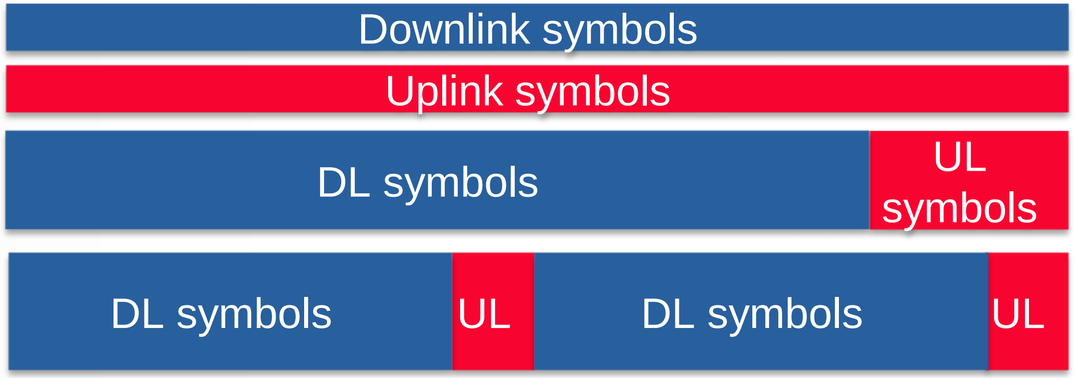
- Downlink only (Slot Format 0, used in FDD)
- Uplink only (Slot Format 1, Used in FDD)
- Flexible: Downlink and Uplink (static, semi-static (RRC) or dynamically scheduled (DCI))

Examples:

FDD at 700 MHz

TDD at 3 GHz

TDD at 28 GHz



Not tied to the frame structure

Release 15 86 3GPP TS 38.213 V15.5.0 (2019-03)

Table 11.1.1-1: Slot formats for normal cyclic prefix

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	F	F	F	F	F	F	F	F	F	F	F	F	F	F
3	D	D	D	D	D	D	D	D	D	D	D	D	D	F
4	D	D	D	D	D	D	D	D	D	D	D	D	F	F
5	D	D	D	D	D	D	D	D	D	D	D	F	F	F
6	D	D	D	D	D	D	D	D	D	D	F	F	F	F
7	D	D	D	D	D	D	D	D	D	F	F	F	F	F
8	F	F	F	F	F	F	F	F	F	F	F	F	F	U
9	F	F	F	F	F	F	F	F	F	F	F	F	U	U
10	F	U	U	U	U	U	U	U	U	U	U	U	U	U
11	F	F	U	U	U	U	U	U	U	U	U	U	U	U
12	F	F	F	U	U	U	U	U	U	U	U	U	U	U
13	F	F	F	F	U	U	U	U	U	U	U	U	U	U
......														
52	D	F	F	F	F	F	U	D	F	F	F	F	F	U
53	D	D	F	F	F	F	U	D	D	F	F	F	F	U
54	F	F	F	F	F	F	F	D	D	D	D	D	D	D
55	D	D	F	F	F	U	U	U	D	D	D	D	D	D
56 – 254	Reserved													
255	UE determines the slot format for the slot based on *TDD-UL-DL-ConfigurationCommon*, or *TDD-UL-DL-ConfigDedicated* and, if any, on detected DCI formats													

Reduced Latency – Comparation with LTE

LTE – Fixed FDD or TDD operation

<-------- 1 ms sub-frame -------->

5G NR – Self-contained Integrated Slot

Downlink-centric Slot

Uplink-centric Slot

- Data is transmitted **preceded** by the grant for the acknowledgement: the entire process is complete within a single time transmission interval (TTI).
- TTI = # of symbols * symbol length

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Moving to mmWave Change Everything

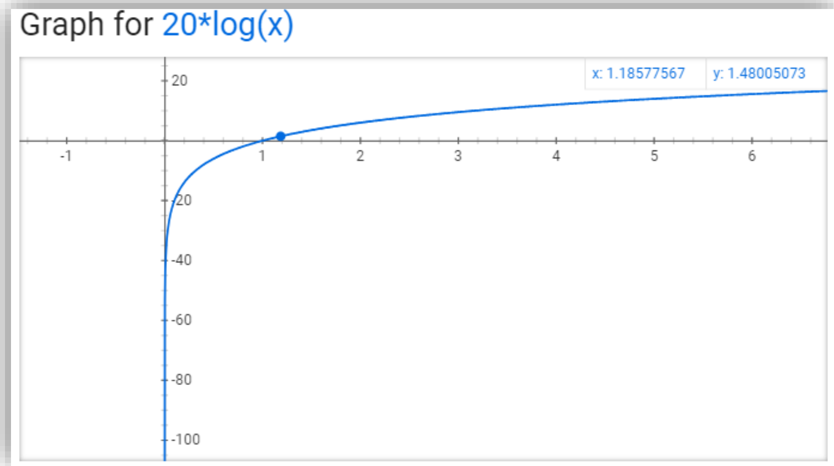
Question: Is it better to have high gain or low gain antenna?

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:

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



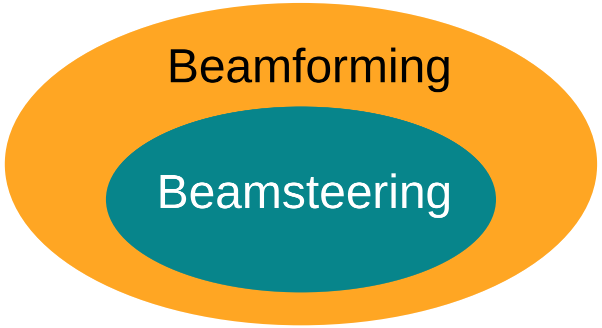
Path Loss ~ $\mathbf{f}^{\,2}$

KEYSIGHT TECHNOLOGIES

Enter the Spatial Domain

BEAMSTEERING VS. BEAMFORMING

- The simplest use of large antenna arrays at the base station is beamsteering – create narrow beams within the cell to direct signals to specific locations, possibly with reflections involved
- A key difference between beamsteering and beamforming is steering only needs to know the direction of the user while **beamforming requires precise real-time channel state information (CSI)**
- To then exploit the channel, **beamforming requires full digital control of the amplitude and phase of every antenna element** while beamsteering can be done using simple analog phase shifters
- In a predominantly line of sight channel with several users in different locations, beamforming would simultaneously generate a beam towards each user much like beamsteering
- The benefits of beamforming become more apparent as the channel becomes more scattered, which is when simpler beamsteering is less effective

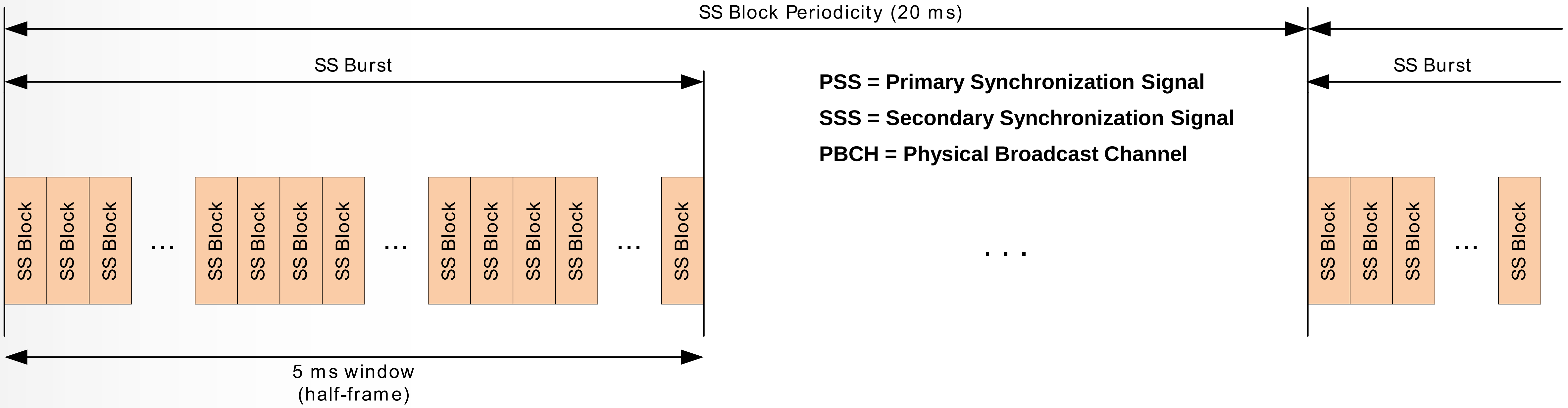


5G New Radio Initial Access

DOWNLINK SYNCHRONIZATION SIGNAL (SS) BLOCKS, BURSTS, AND SETS

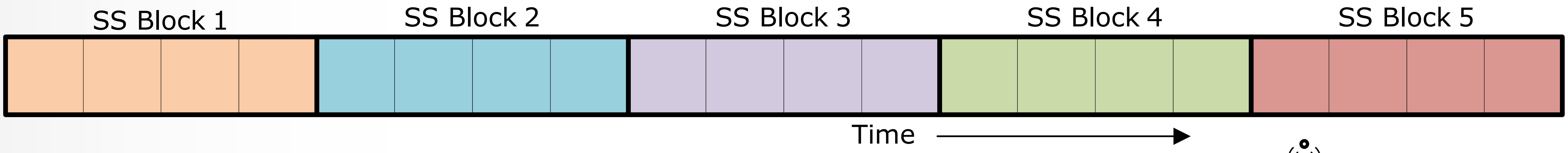
SS Block
-1 symbol PSS
-1 symbol SSS
-2 symbols PBCH

SS Burst
-Multiple SS Blocks
-Transmission is periodic (20 ms by default)
-Confined within a 5 ms window

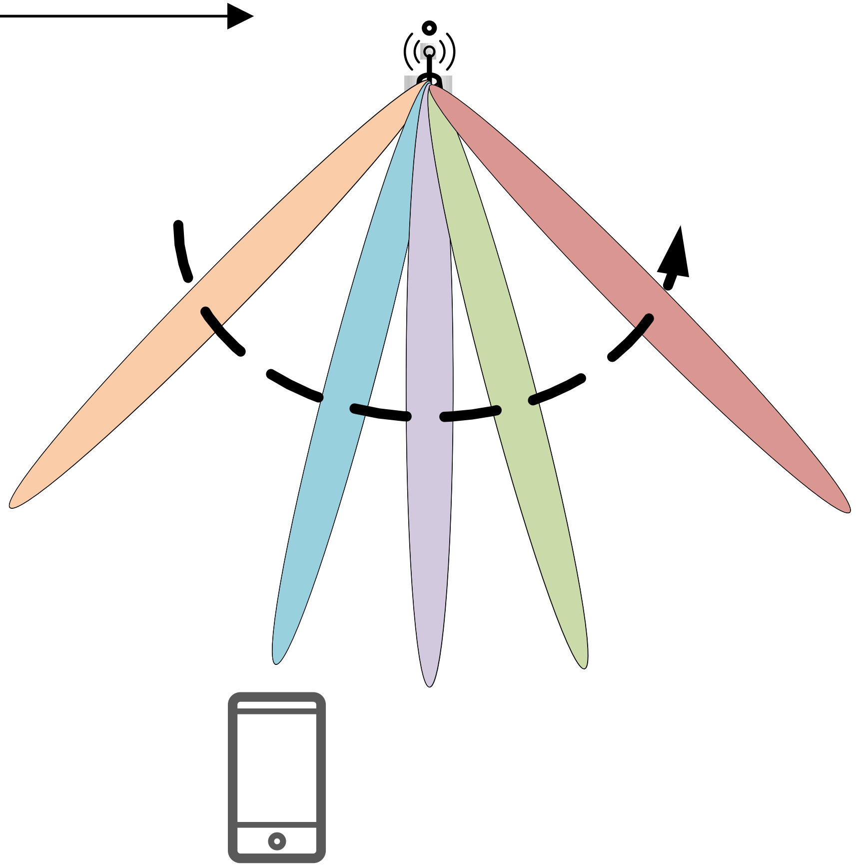


5G New Radio Initial Access – SS Burst

BEAM SWEEPING

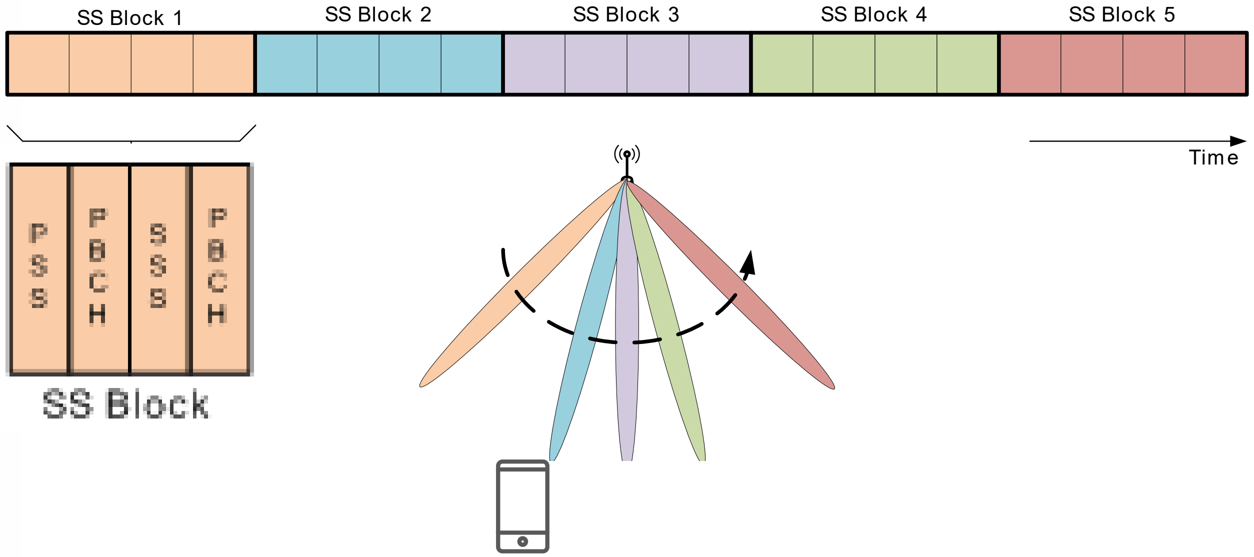


- All SSB are transmitted on the same single-antenna port
- Each SSB within a SS Burst Set is potentially transmitted on a different beam
- The same beam pattern is repeated for each SSB within the SS Burst Set period (20 ms by default)
- The UE identifies a SSB within the Burst Set by using:
  - The time index carried by the PBCH DMRS
  - The rest of the SSB index carried by the PBCH data
- The best SSB is used to respond to with the PRACH

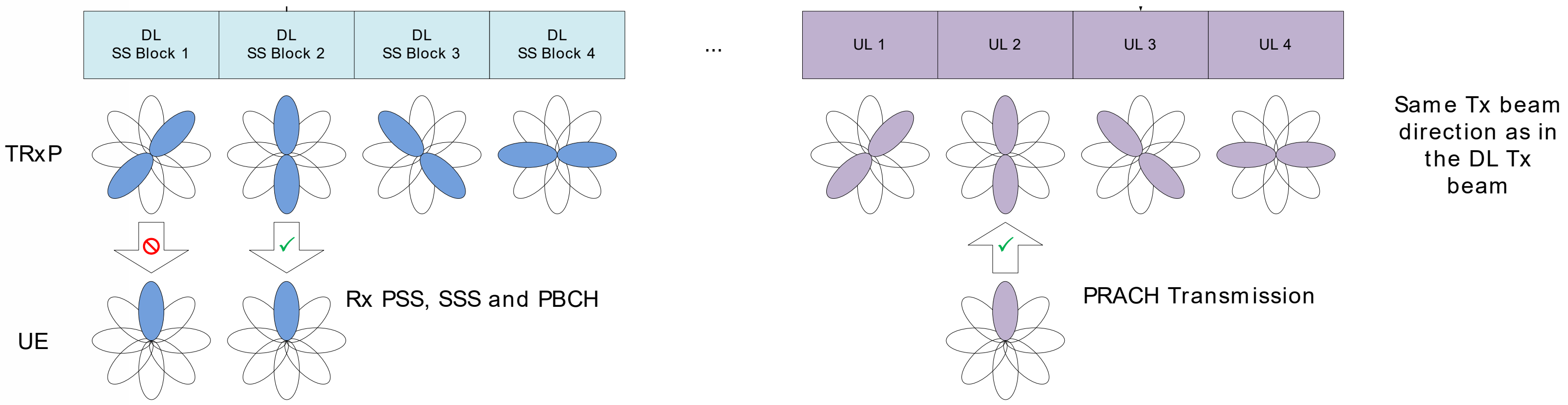


KEYSIGHT TECHNOLOGIES

Initial Access & Beamforming: SS/PBCH Block

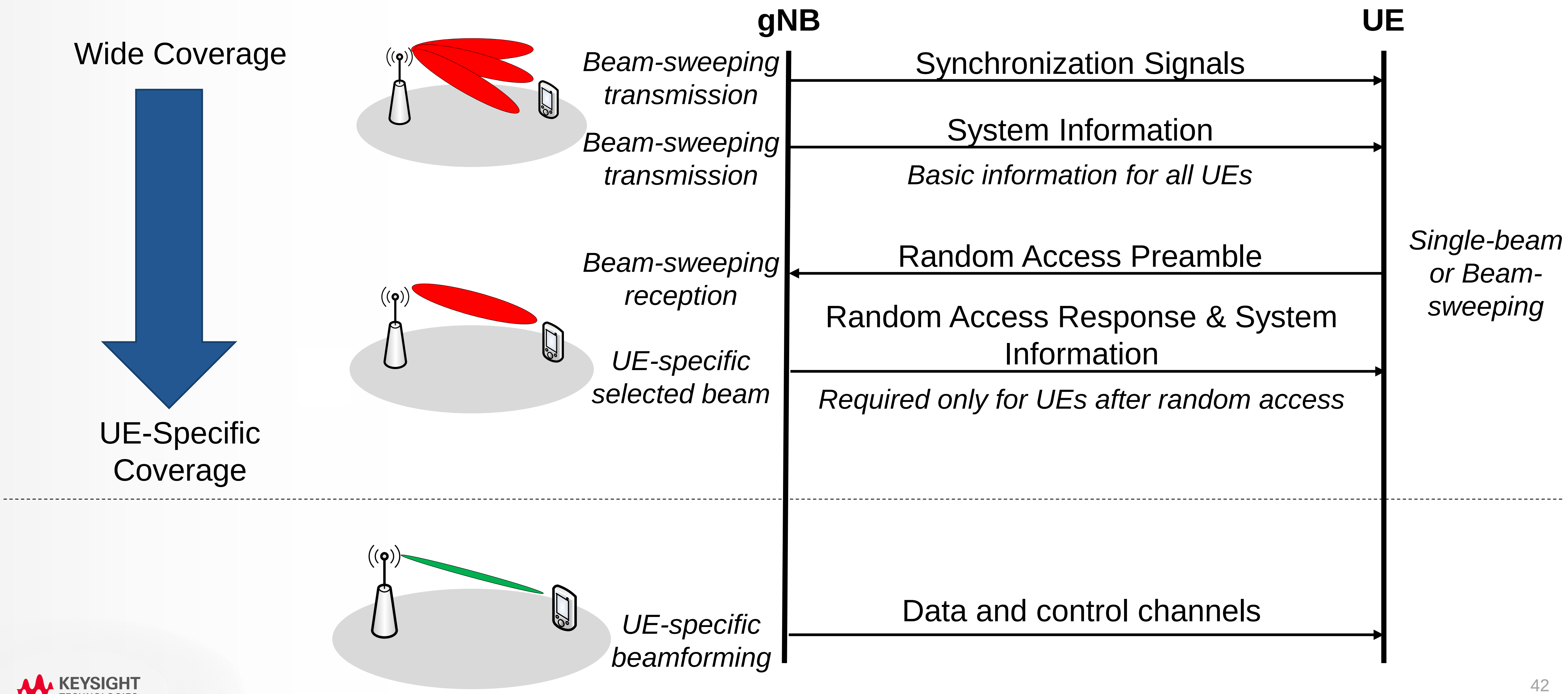


Mapping between DL SS Blocks and corresponding UL resources for PRACH



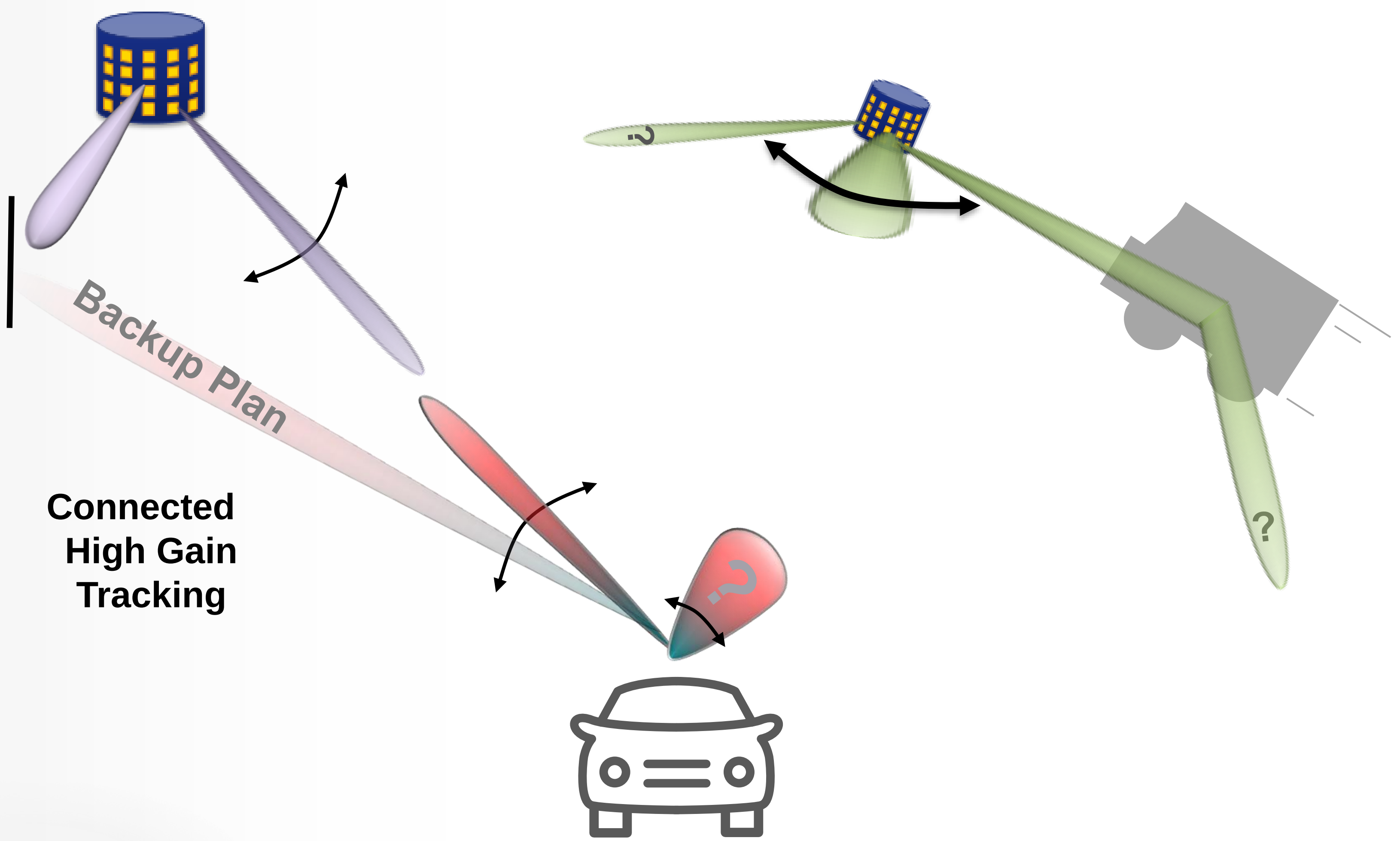
5G New Radio Initial Access

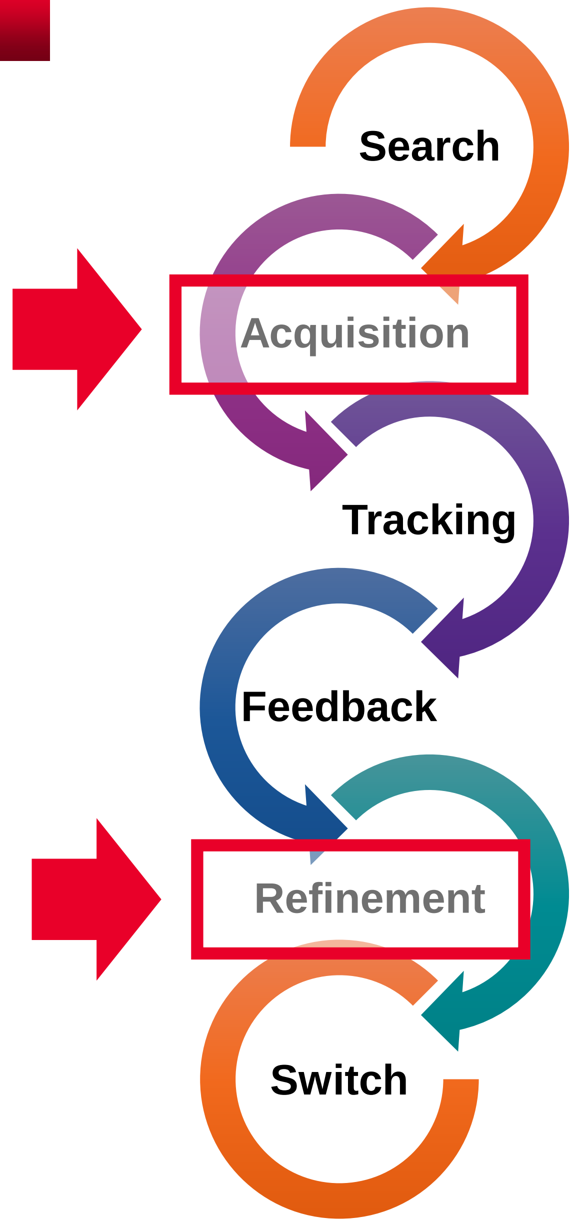
SYNCHRONIZATION, RANDOM ACCESS AND UE-SPECIFIC BEAMFORMING



New Radio mmWave Spatial Domain Optimization

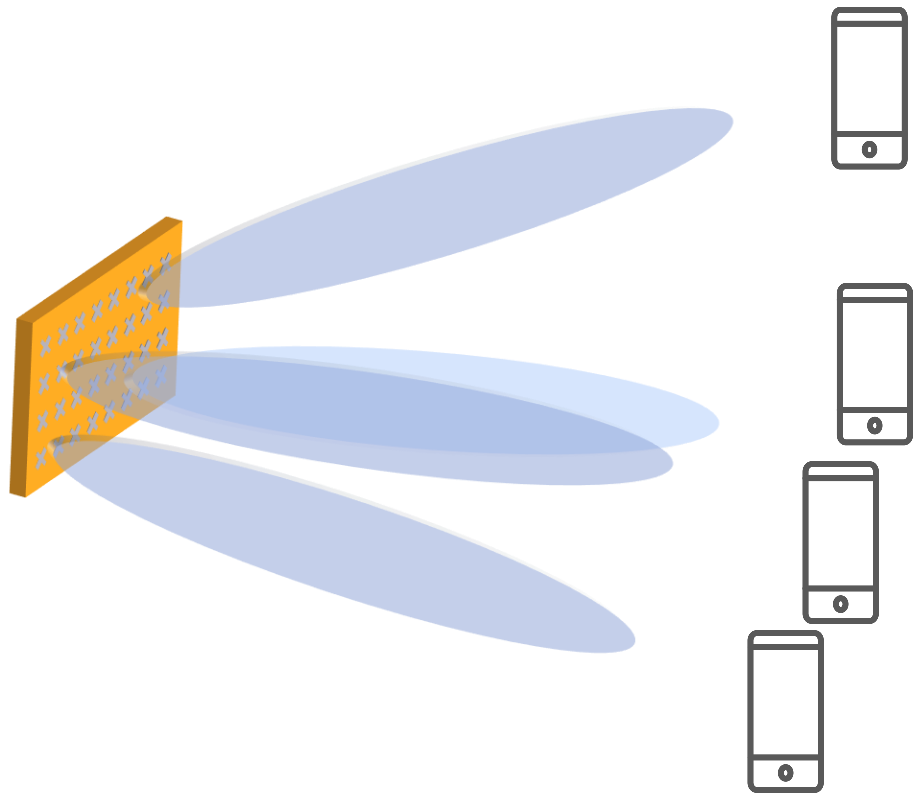
MOBILITY AND THE CHALLENGE OF DIRECTIONAL ANTENNAS





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 do bounce (reflect) readily giving rise to local scattering (multipath)
- 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

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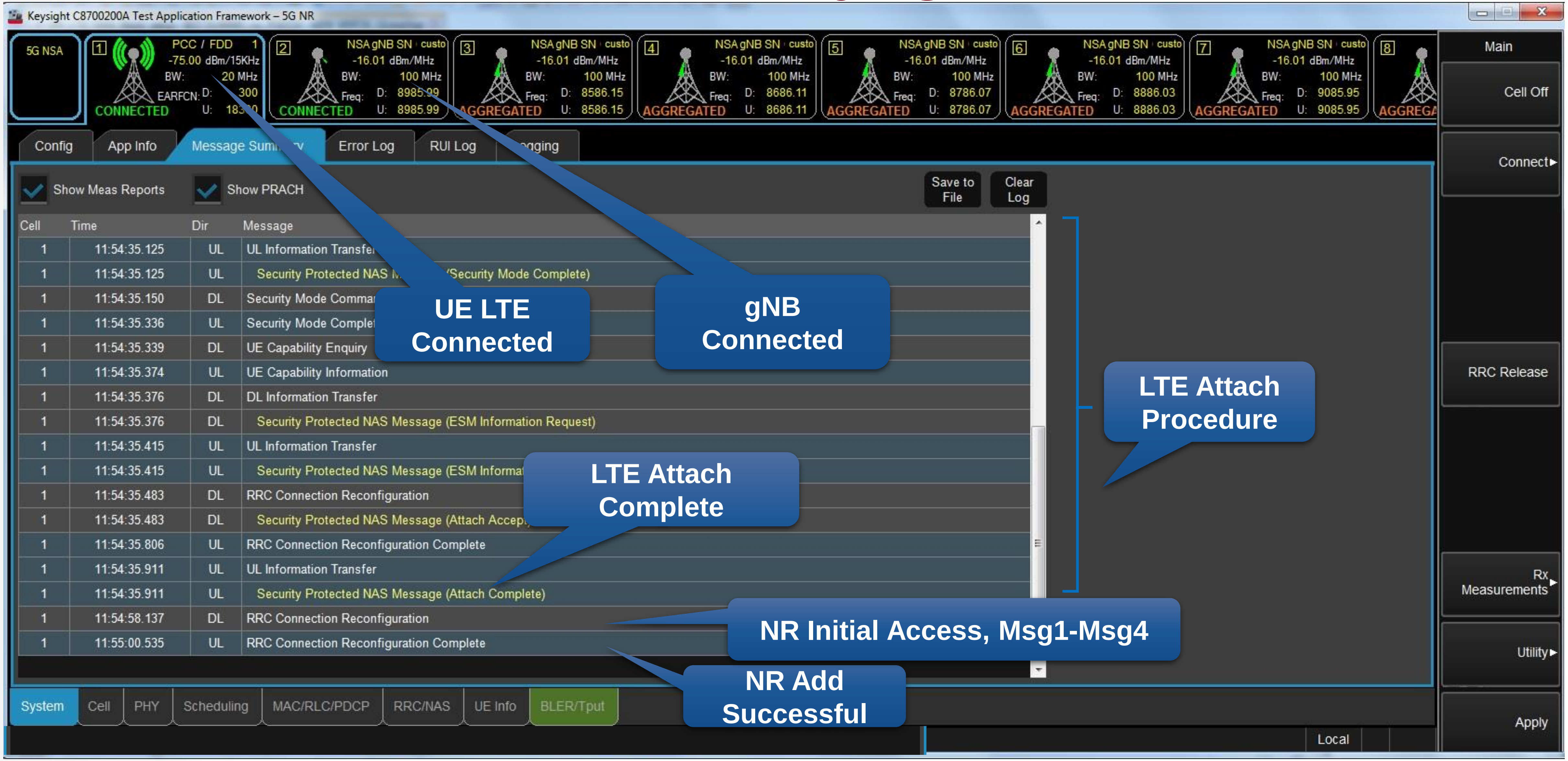
- New Features Coming in Rel-16

NR NSA Attach Procedure – Keysight Test Application



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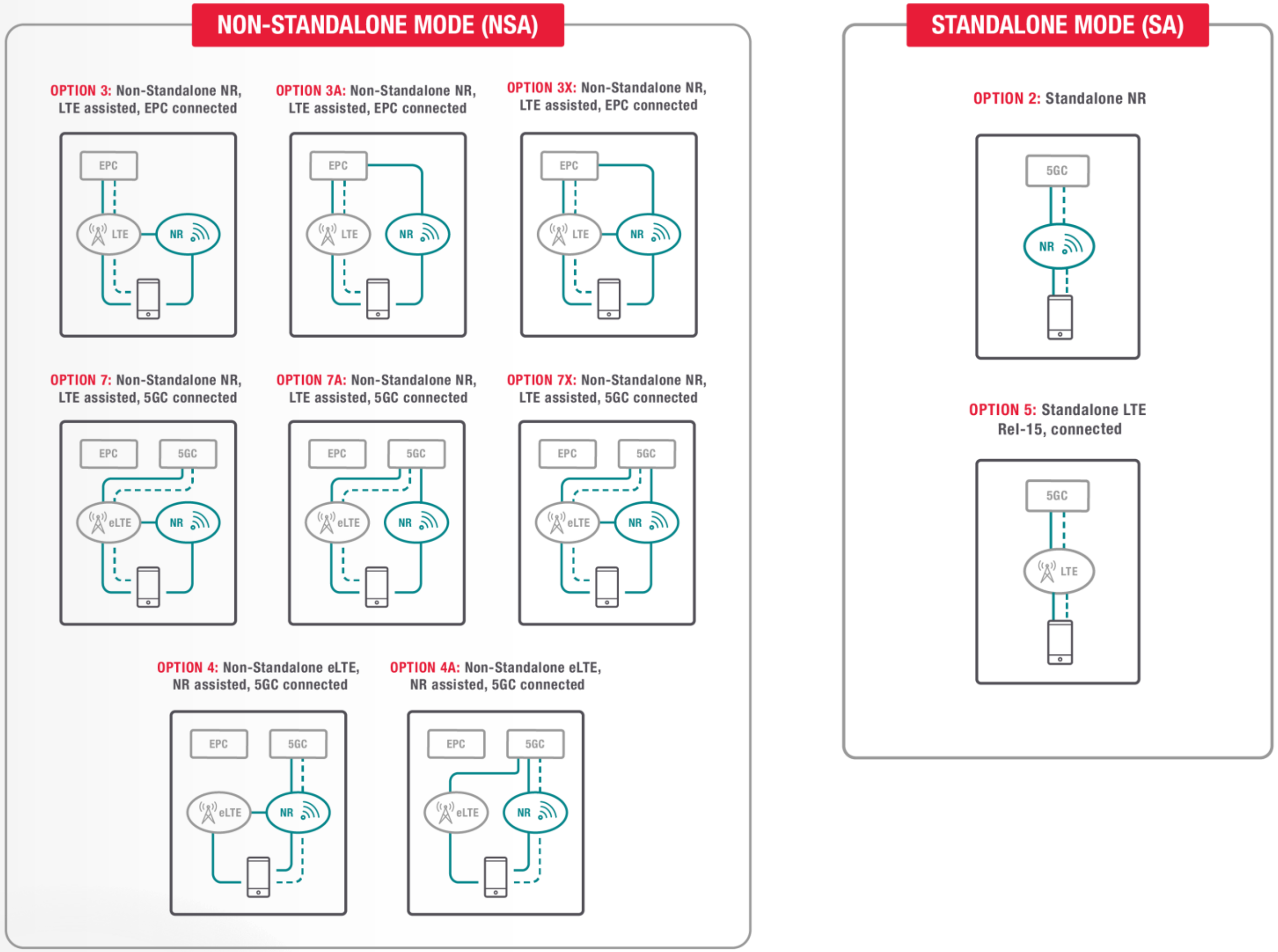
5G

5G NR Deployment Options

START WITH NSA



Rel-15 Early Drop (December 2017)

- NR NSA – eNB as master node
- 4G Core Network (EPC)
- Enhanced LTE (eLTE)

Rel-15 (June 2018)

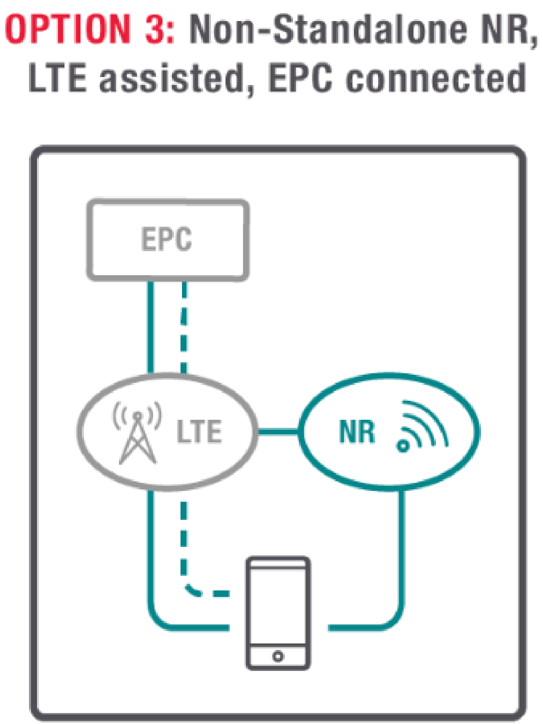
- 5G Core Network
- Enhanced LTE (eLTE)
- NR SA and NSA Combinations

Multi-RAT Dual Connectivity with LTE Core (EPC)

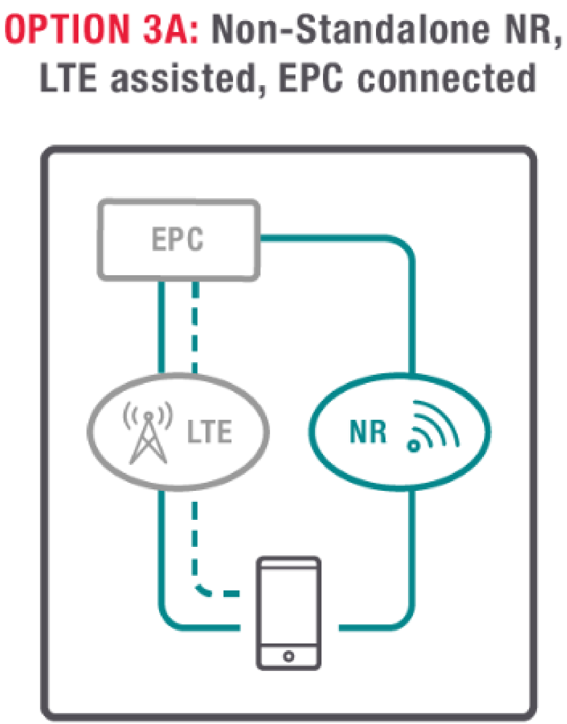
OPTIONS 3/3A/3X

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

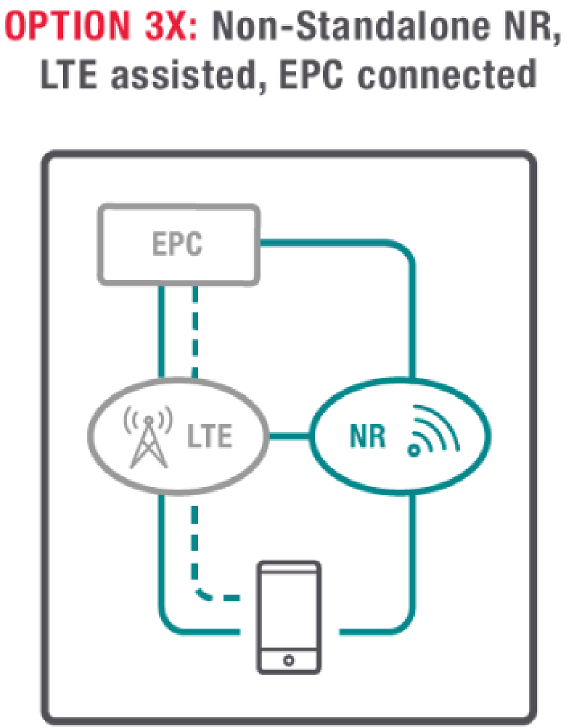
x2 interface



No load-sharing



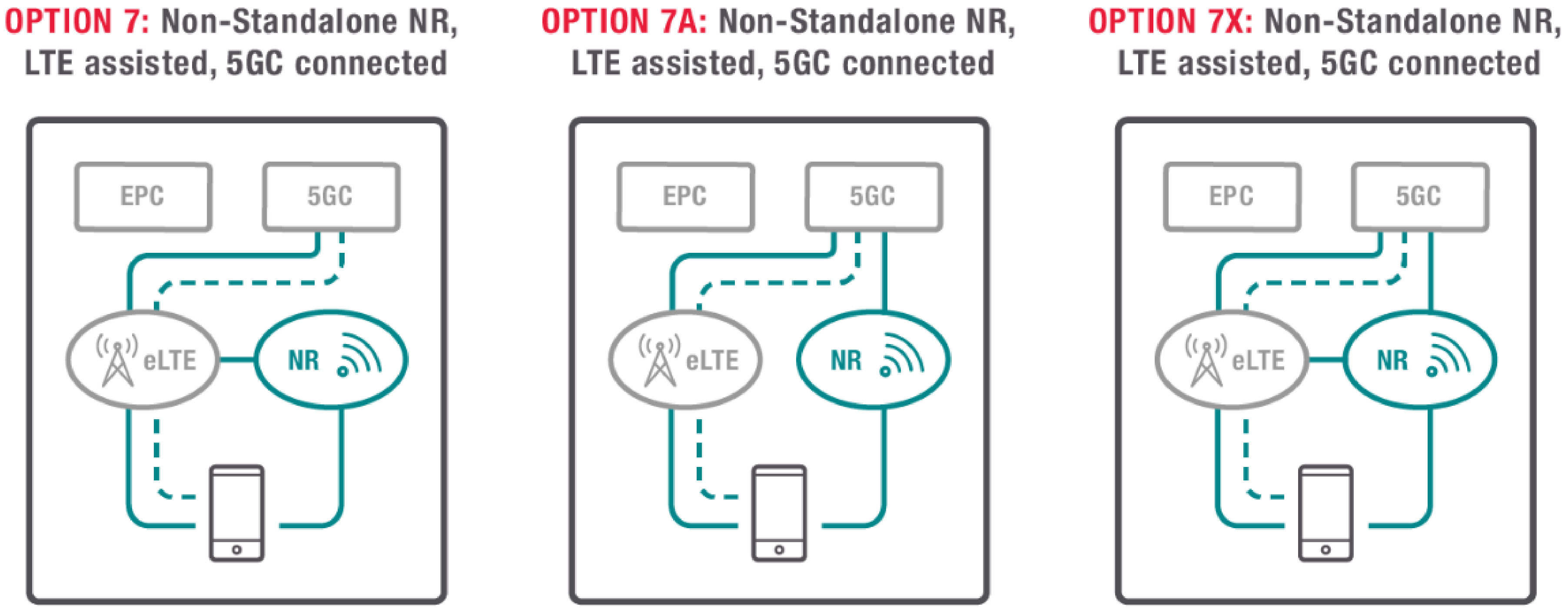
PDCP split



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)



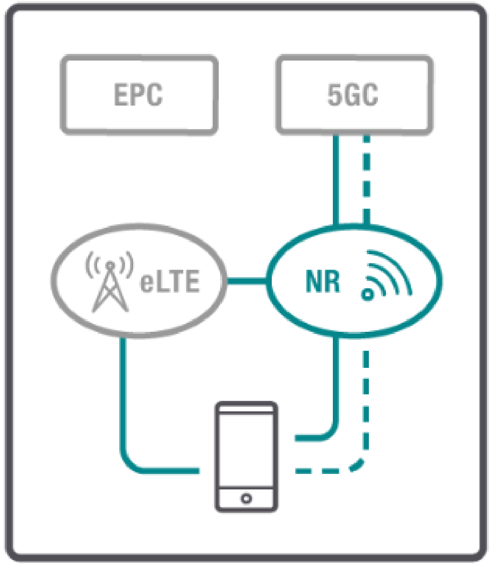
KEYSIGHT TECHNOLOGIES

Multi-RAT Dual Connectivity with 5G Core

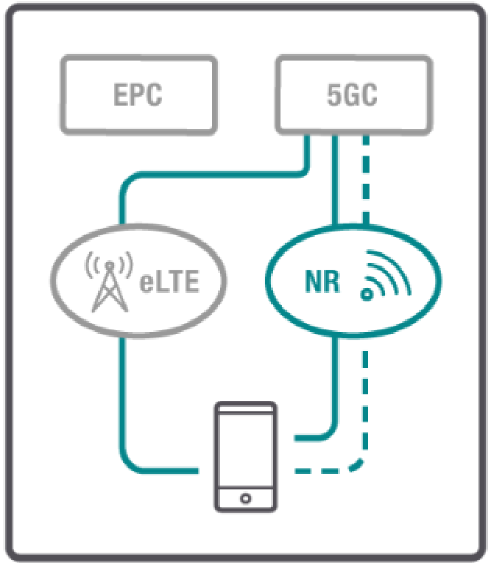
OPTIONS 4/4A

- 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



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Rel-16 Content Summary

UPDATE ON RAN1 ROADMAP

NR Rel-16

Rel-16 TEIs

Rel-16 new features

Capacity and operational efficiency

- MIMO enhancements
- MR-DC (i.e. Multi-RAT Dual Connectivity)
- IAB (i.e. Integrated Access and Backhaul)
- Mobility enhancements
- CLI/RIM (i.e. Cross Link Interference/Remote Interference Management)
- UE power savings

Vertical expansion

- IIoT (i.e. Industrial IoT)
- URLLC (i.e. Ultra Reliable Low Latency)
- 2-step RACH
- NR positioning
- NR unlicensed
- V2X (i.e. Vehicle to Everything)

Rel-17 Work Areas

UPDATE ON RAN1 ROADMAP

Not all these work areas will be included in the final approved Rel-17 package

- ***NR-Light and Small Data Transfer Optimization***
  - NR optimization for MTC type of devices
  - Mostly related to power saving aspects and inactive data transmission
- ***Sidelink enhancements for NR***
  - Focus on areas relating to V2X services, commercial and critical communications
  - Frequency Range 2
- ***NR for above 52.6GHz***
  - Will include discussions and decisions on waveforms for frequencies higher than currently standardized
  - Inclusion of 60GHz unlicensed spectrum
- ***Coverage enhancements***
  - Work on clarifications for all scenarios which are focusing on extreme coverage including both indoor and wide area

Rel-17 Work Areas

UPDATE ON RAN1 ROADMAP

Not all these work areas will be included in the final approved Rel-17 package

- ***NB-IoT, eMTC, Industrial IoT, URLLC enhancements***
  - Enhancements related to current commercial needs and deployments
  - Small leftovers from Rel-16 (e.g. header compression)
- ***NR for Non-Terrestrial Networks and Integrated Access Backhaul (IAB) enhancements***
  - Should include mobile IAB,
- ***RAN data collection enhancements***
  - Focuses on data collection related to enabling of Artificial Intelligence
- ***Power Saving Enhancements***
  - Focus on power saving related to smartphones and network-related power saving aspects
- ***Positioning Enhancements***
  - Include further adjustments for more accurate positioning services (e.g. 3D-positioning and cm-level accuracy, latency and reliability improvements)
  - Specific areas: IoT, V2X, factory positioning

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

Acronym Decoder

- 3GPP – Third Generation Partnership Project
- 5G NR – 5th Generation New Radio
- BI – Beam Index
- BLER – Block Error Rate
- BW – Bandwidth
- CPE – Customer Premise Equipment
- CSI-RS - Channel State Information Reference Signal
- DL – Downlink
- eNB – eNodeB
- FCC – Federal Communications Commission
- gNB – gNodeB
- KPI – Key Performance Indicator
- MAC – Media Access Control
- MCS – Modulation and coding scheme
- MIMO – Multiple Input Multiple Output
- mmWave – Millimeter-wave
- NEM – Network Equipment Manufacturer
- OFDM – Orthogonal Frequency Division Multiplexing
- PBCH – Primary Broadcast Channel
- PBCH DMRS – PBCH Demodulation Reference Signal
- PDSCH – Physical Downlink Shared Channel
- PRACH – Physical Random Access Channel
- PRB – Physical Resource Block
- PSS – Primary Synchronization Signal
- QoE – Quality of Experience
- QoS – Quality of Service
- RACH – Random Access Channel
- RAN – Radio Access Network
- RAT – Radio Access Technology
- RRC – Radio Resource Control
- SCS – Sub-carrier spacing
- SRS (UL) - Sounding Reference Signal
- SSB – Synchronization Signal Block
- SS-RSRP – SS Reference Signal Received Power
- SS-RSRQ – SS Reference Signal Received Quality
- SS-SINR – SS Signal-to-Noise and Interference Ratio
- SSS – Secondary Synchronization Signal
- TRS – Tracking Reference Signal
- TX – Transmitter
- UE – User Equipment
- UL – Uplink

Keysight 5G Solutions for All Parts of the Ecosystem

5G Network Test

- Drive Test and Analytics
- UE Emulation & Load Test
- Network Simulation & Test

5G Signaling Validation Test

- 5G NR Protocol Validation
- Radio Signaling Test
- 5G NR Conformance Test

Physical Layer Design and Test Solutions

- System-Level Simulation
- Component Characterization
- Digital Conformance Test
- Parametric Signal Test
- RF and mmWave OTA Test
- Manufacturing Test Automation

Questions and Resources

- 3GPP Webpage www.3gpp.org
- Keysight Solutions www.keysight.com/find/5G
- Testing 5G NR Device OTA Throughput
  Download Application Note
- Copy of these slides
  www.keysight.com/find/5GBootCampPresentations

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TECHNOLOGIES