5G New Radio
Fundamentals, procedures, testing aspects

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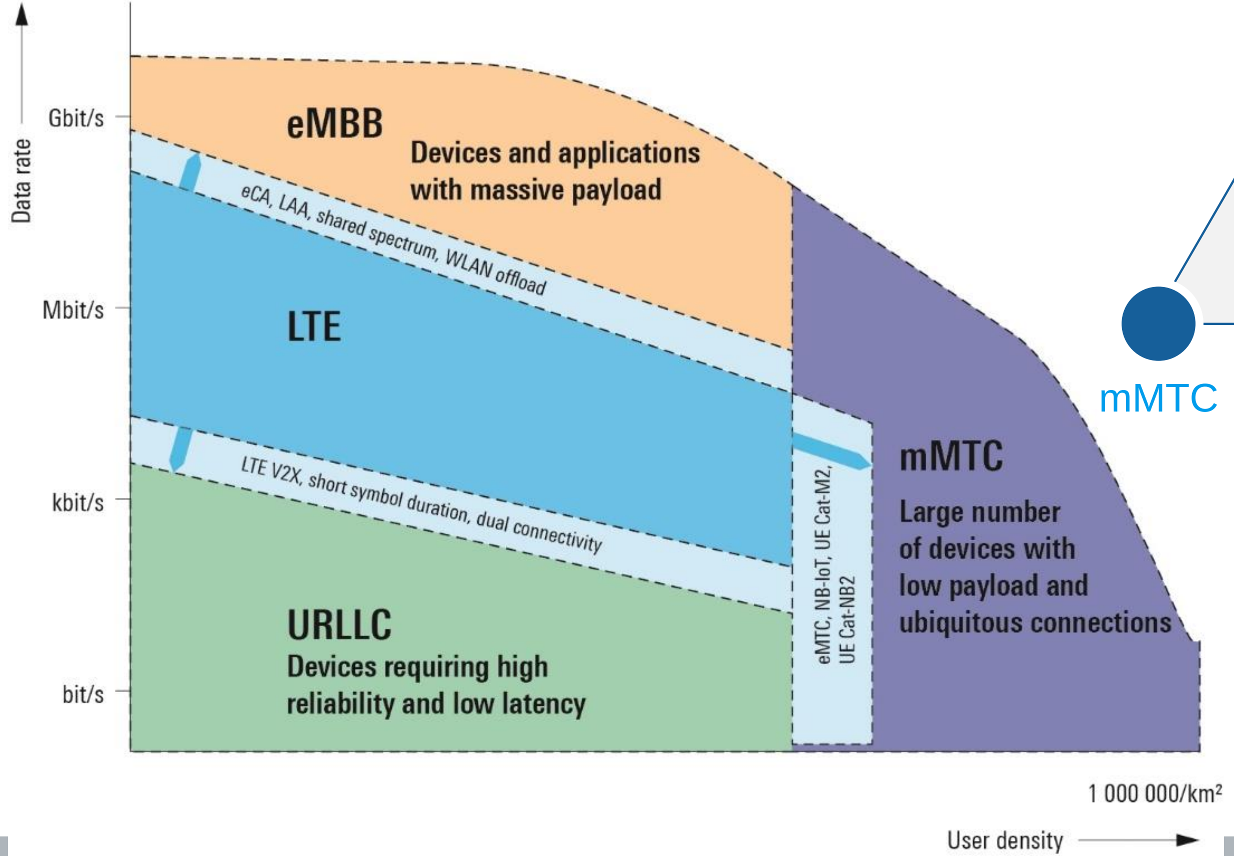
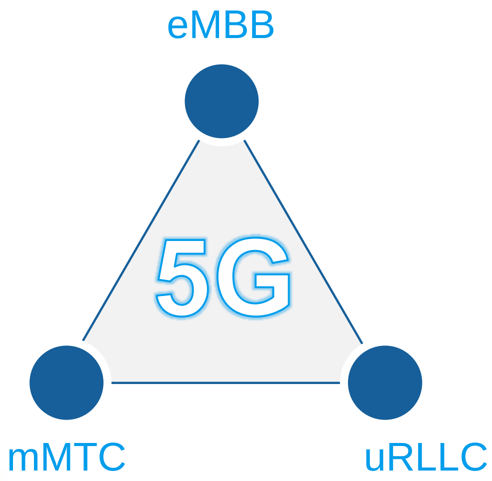
5G stretching the use case of LTE





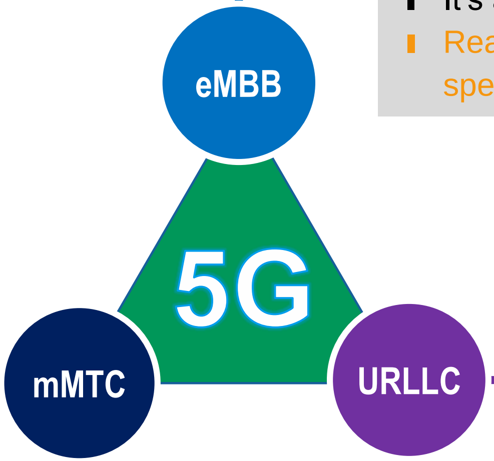
Review of 5G Use Cases

eMBB remains priority 1 but …

Massive IoT

- A diverse ecosystem (operators, manufacturers, local authorities, certification only for some technologies)
- Mix of technologies (GSM, Lora, Zigbee, WLAN, Bluetooth, Cat M, NB-IoT,…)
- It's all about cost efficiency and massive connectivity
- 3GPP: No NR based solution; will be addressed by evolving LTE-M (eMTC) and NB-IoT

enhanced Mobile Broadband



Massive Machine Type Communication

Ultra reliable & low latency communication

eMBB – the known playground

- Established ecosystem (operators, manufacturers, certification of devices)
- Evolution from existing technologies and revolutionary additions (cm- / mm-wave)
- It's all about data (speed and capacity)
- Realizing and facing the challenges of cm-wave spectrum and OTA testing; 3.5GHz is important!

URLLC

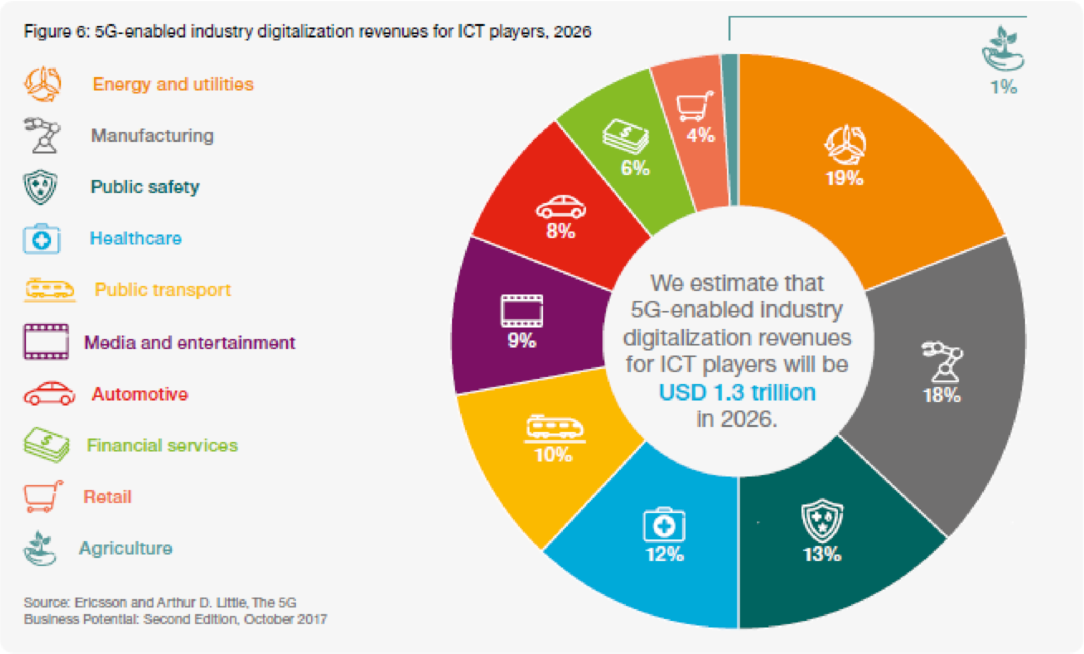
- A significantly enhanced and diverse ecosystem (operators (?), manufacturers, verticals, certification not existing (yet))
- Principal support with high SCS and self-contained slots
- It's all about reliability and security (data and capacity)

… the URLLC potential is the future!

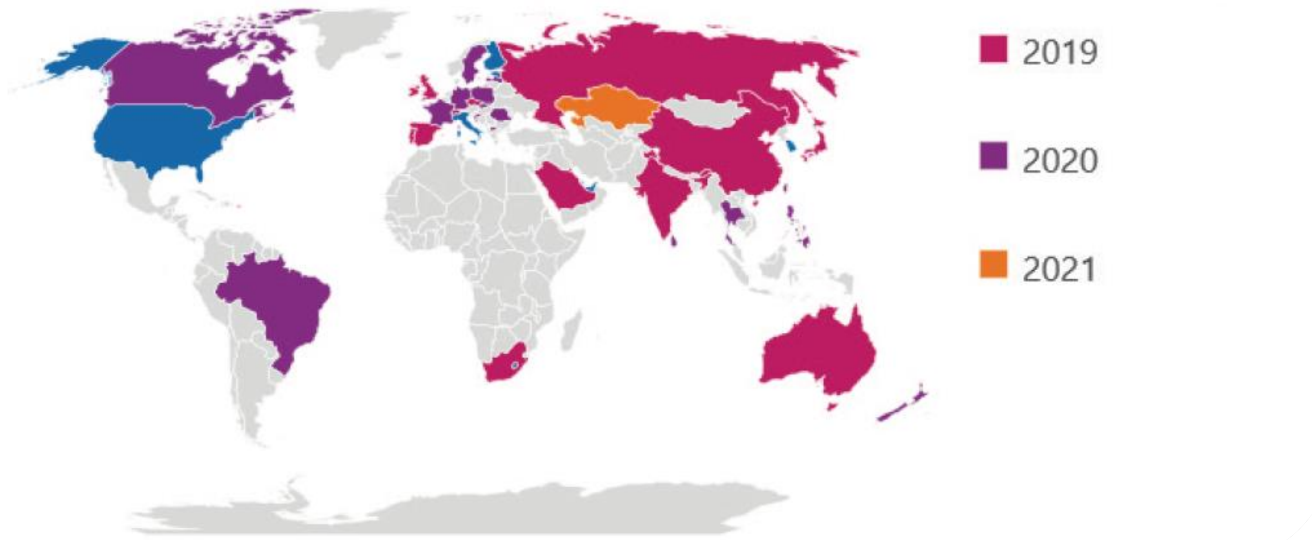
5G – A problem solver

- Ericsson conducted a survey of large companies (with a minimum of 1,000 employees) across 10 key industries during October and November 2017.
- Each of the 10 industries identified key areas that could be resolved through business process transformation with respect to 5G.
- **The survey revealed that, across all sectors, 5G technology will improve issues that center around data security, connectivity issues, and automating processes.**

Source: Ericsson report



Expected 5G commercial launch dates (mobile or FWA)

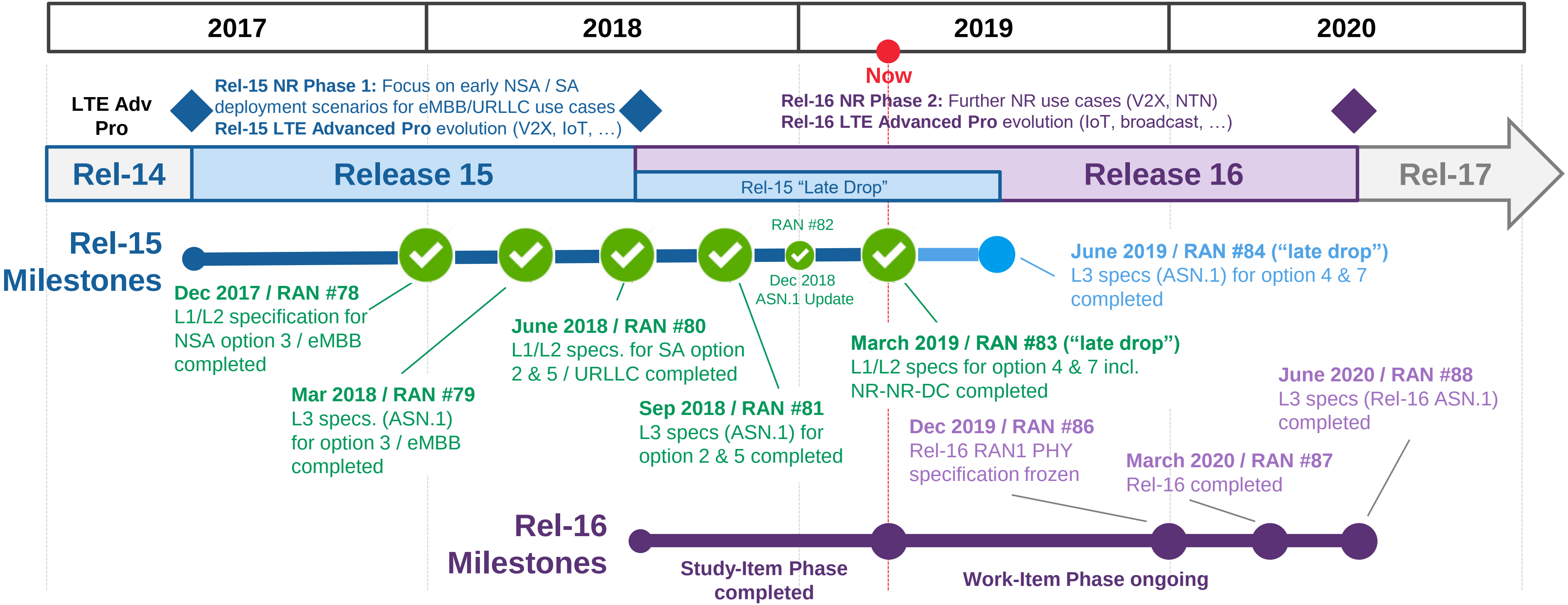


Source: GSA report: Evolution from LTE to 5G: Global Market Status, January 2019

3GPP RAN NR Standardization Overview

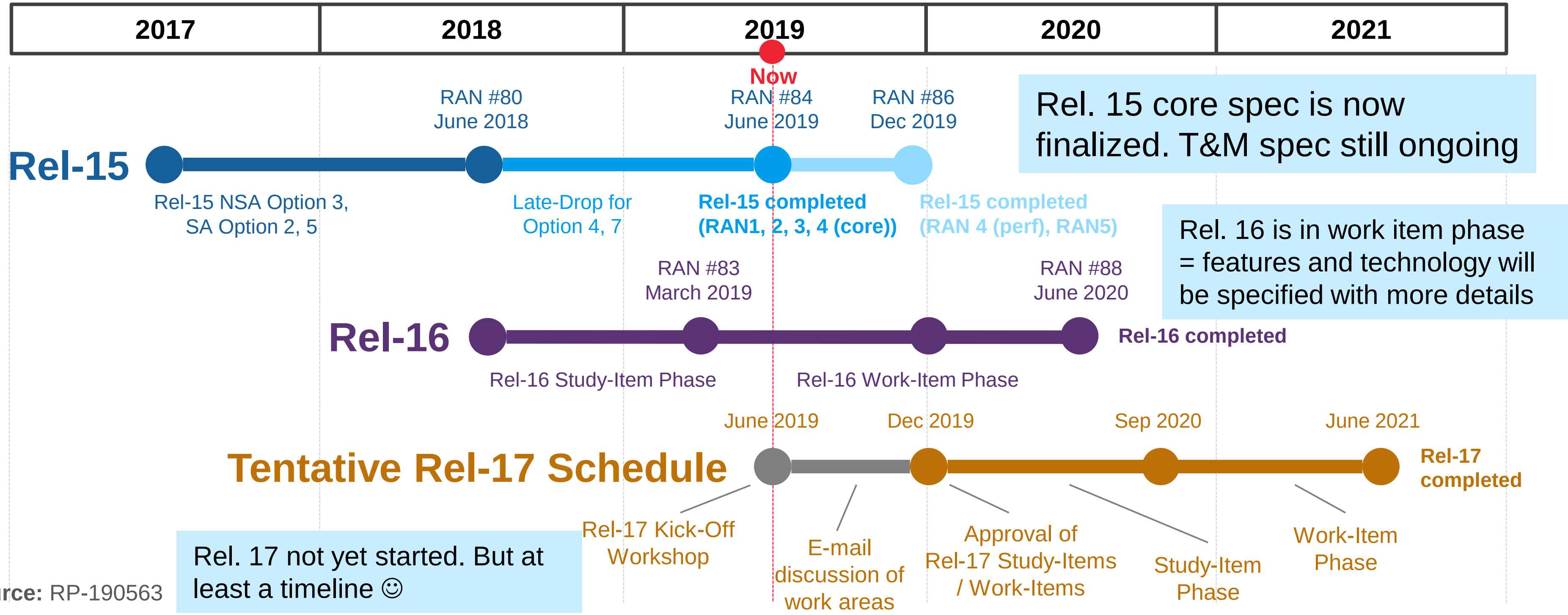
Status after 3GPP RAN #83 (March 2019)

NR: New Radio
SA: Standalone
NSA: Non Standalone
eMBB: Enhanced Mobile Broadband
URLLC: Ultra-Reliable Low Latency Communication
mMTC: Massive Machine Type Communication



3GPP RAN NR Standardization Overview

Status (June 2019)

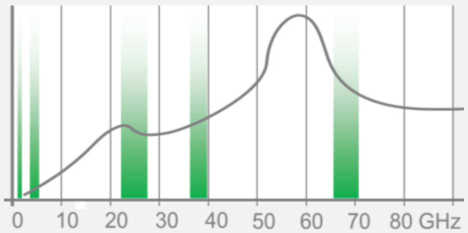


Source: RP-190563

5G Key Technology Components

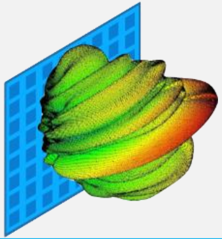
NR builds on four main pillars

New Spectrum



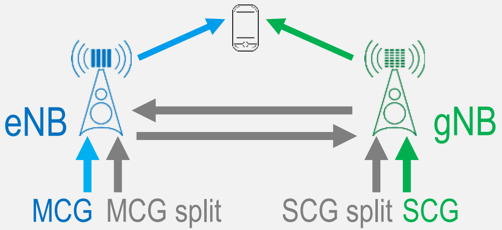
- < 1GHz
- ~ 3.5 GHz
- ~ 26/28/39 GHz

Massive MIMO & Beamforming



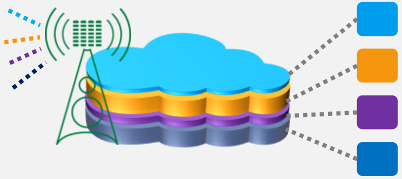
- Hybrid beamforming
- > 6GHz also UE is expected to apply beam steering

Multi-Connectivity



Initially based on Dual Connectivity with E-UTRA as master

Network flexibility - virtualization



- Flexible physical layer numerology
- Network Slicing
- NFV/SDN

5G Network Architecture Vocabulary

LTE Core = EPC

MME SGW
EPC

5G Core = 5GC

AMF UPF
5GC

Data
Control

MME = Mobility Management Entity
S-GW = Serving Gateway

AMF = Access and Mobility Management Function
UPF = User Plane Function

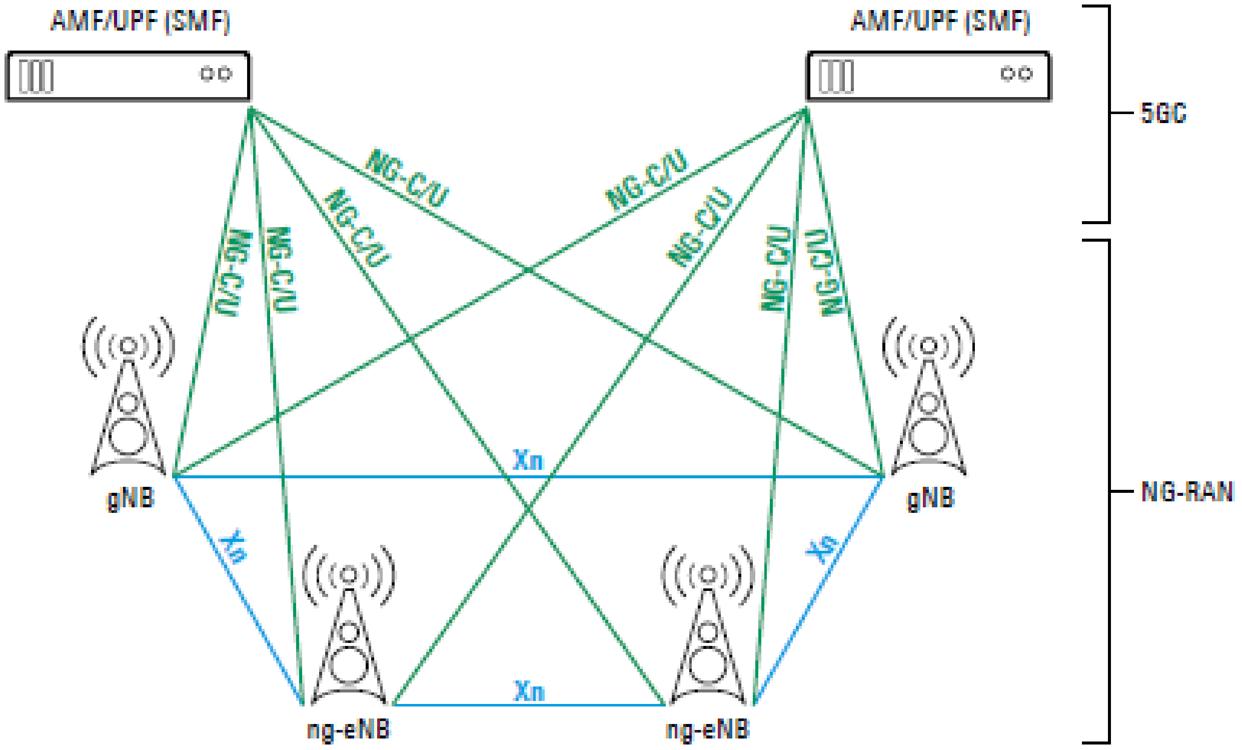
LTE BS = eNB
(connected to EPC)

LTE BS = NG-eNB
(connected to 5GC)

5G BS = gNB

A base station in a DC (= Dual Connectivity) connection with the UE may have different roles:
MN = Master Node
or
SN = Secondary Node

5GC overall architecture

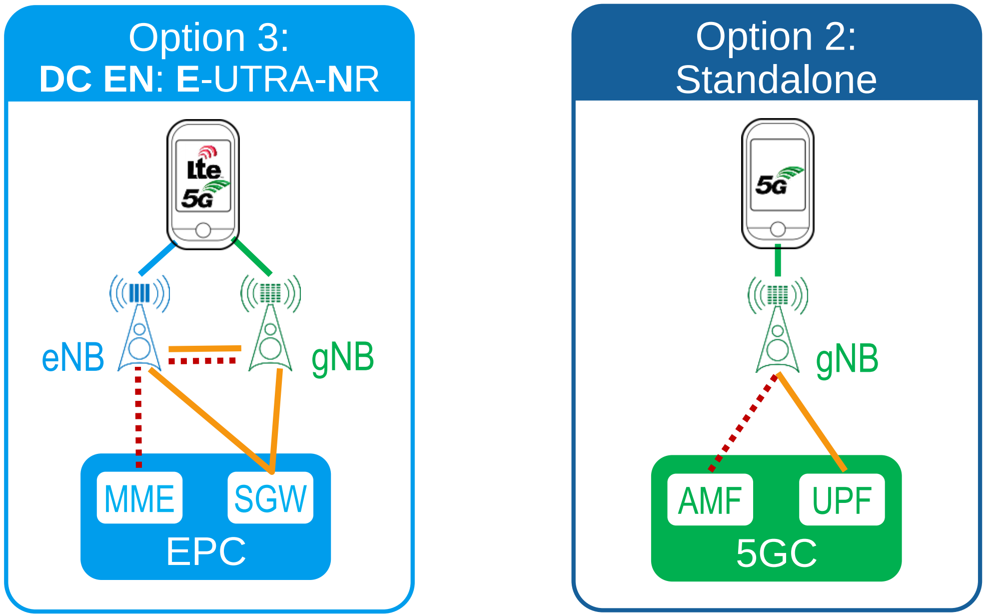


Architecture Options

Option 3 is priority 1 in 3GPP, followed by Option 2

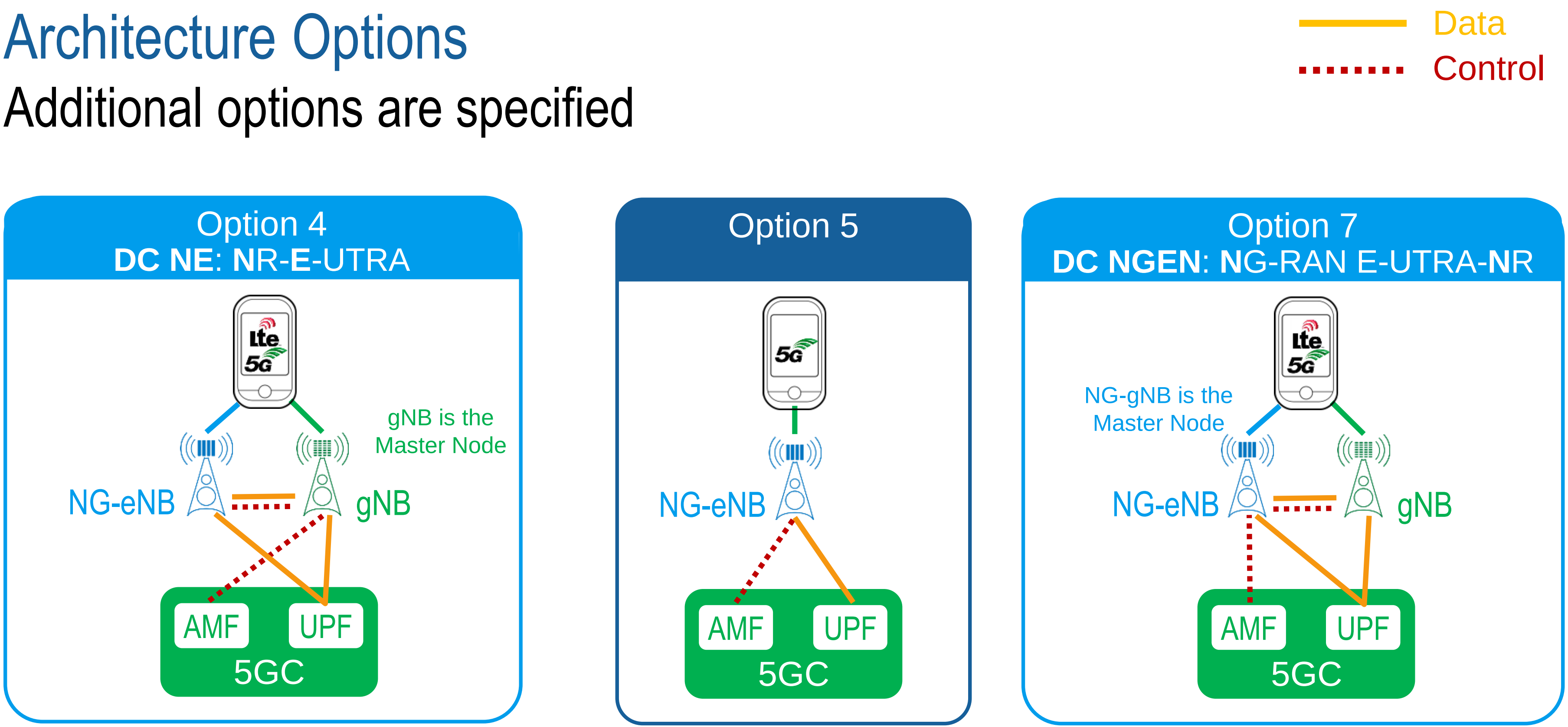
Data
Control

eNB is the Master Node



Architecture Options

Additional options are specified



CMWflexx with CMX500 – modular concept, highest flexibility

Why extend CMWflexx setups???

Benefit from rock-solid LTE support

NSA Mode (e.g. Option3) **always needs an LTE** anchor cell. NR Cell is just an extension to an existing LTE Network like CMX500 is an extension to existing LTE Setups

Secure Investment

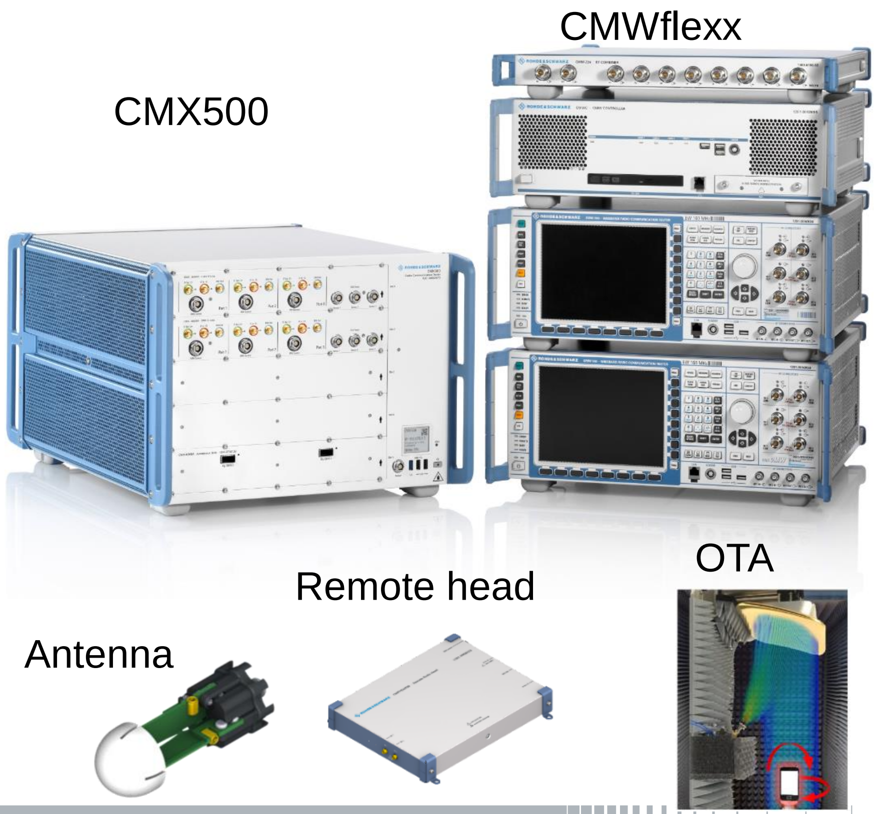
Re-use of existing CMW500 – investment is secured by just upgrading CMW500 to its latest HW revision (160MHz TRX)

Full Legacy Support

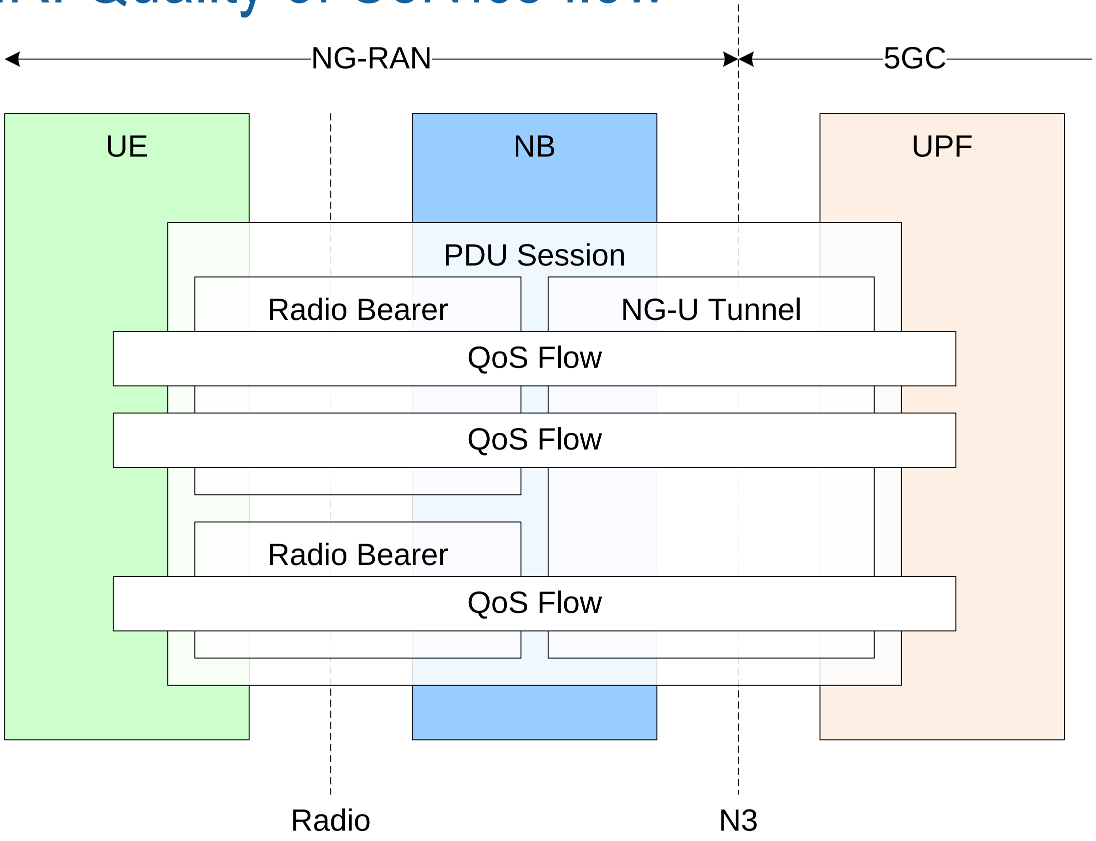
Setups remain **functional for all LTE-only** / legacy testing needs

CMW500 Multi Technology Platform

Flexible use of CMW500 as **either sub6-NR or LTE–cell** within the setup → covers complicated iterations between LTE CA and Sub6 CA scenarios within a single setup

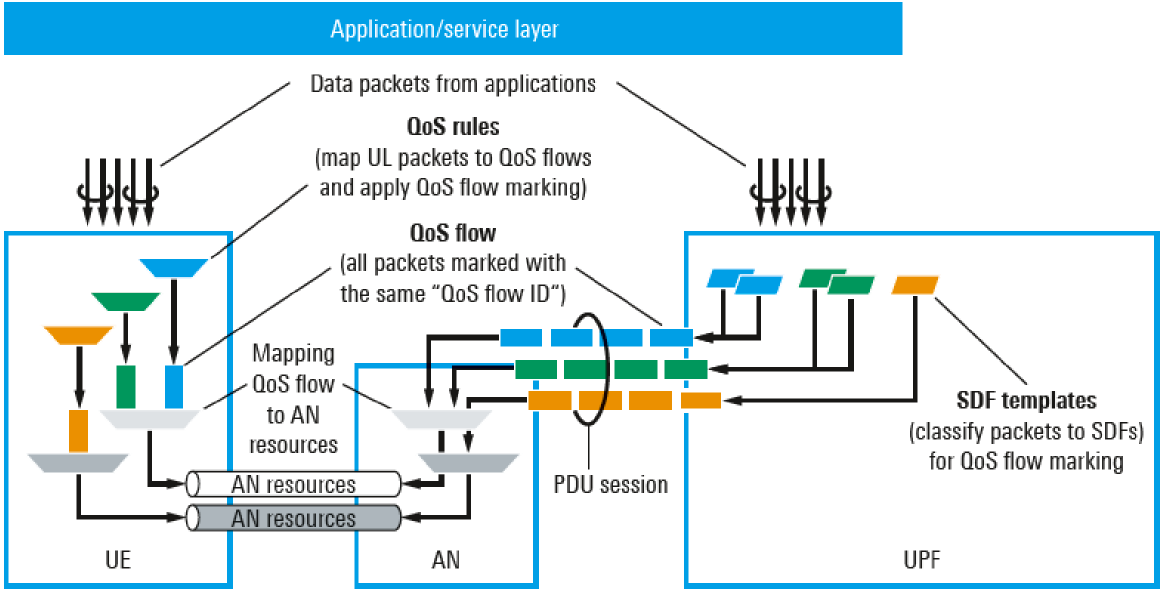


5G NR: Quality of Service flow



5G NR quality of service flow classification

TS 23.501 defines standardized 5QI for GBR, non-GBR and latency critical GBR



5QI value	Resource type	Default priority level	Packet delay budget	Packet error rate	Default maximum data burst volume	Default averaging window	Example services
1	GBR	20	100 ms	10^{-2}	N/A	2000 ms	Conversational voice
2		40	150 ms	10^{-3}	N/A	2000 ms	Conversational video (live streaming)
3		30	50 ms	10^{-3}	N/A	2000 ms	Real time gaming, V2X messages, electricity distribution – medium voltage, process automation – monitoring
4		50	300 ms	10^{-6}	N/A	2000 ms	Non-conversational video (buffered streaming)
65		7	75 ms	10^{-2}	N/A	2000 ms	Mission critical user plane Push To Talk voice (e.g., MCPTT)
66		20	100 ms	10^{-2}	N/A	2000 ms	Non mission critical user plane Push To Talk voice
67		15	100 ms	10^{-3}	N/A	2000 ms	Mission critical video user plane
75		25	50 ms	10^{-2}	N/A	2000 ms	V2X messages
5	Non-GBR	10	100 ms	10^{-6}	N/A	N/A	IMS signaling
6		60	300 ms	10^{-6}	N/A	N/A	Video (buffered streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		70	100 ms	10^{-3}	N/A	N/A	Voice, video (live streaming), interactive gaming
8		80	300 ms	10^{-6}	N/A	N/A	Video (buffered streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9		90					
69		5	60 ms	10^{-6}	N/A	N/A	Mission critical delay sensitive signaling (e.g., MC-PTT signaling)
70		55	200 ms	10^{-6}	N/A	N/A	Mission critical data (e.g. example services are the same as QCI 6/8/9)
79		65	50 ms	10^{-2}	N/A	N/A	V2X messages
80		68	10 ms	10^{-6}	N/A	N/A	Low latency eMBB applications augmented reality
82	Delay critical GBR	19	10 ms	10^{-4}	255 bytes	2000 ms	Discrete automation
83		22	10 ms	10^{-4}	1358 bytes	2000 ms	Discrete automation
84		24	30 ms	10^{-3}	1354 bytes	2000 ms	Intelligent transport systems
85		21	5 ms	10^{-3}	255 bytes	2000 ms	Electricity distribution- high voltage

5G NR data rate calculation

$$\text{data rate (in Mbps)} = 10^{-6} \cdot \sum_{j=1}^{J} \left(v_{Layers}^{(j)} \cdot Q_m^{(j)} \cdot f^{(j)} \cdot R_{\max} \cdot \frac{N_{PRB}^{BW(j),\mu} \cdot 12}{T_s^{\mu}} \cdot \left(1 - OH^{(j)}\right) \right)$$

$$T_s^{\mu} = \frac{10^{-3}}{14 \cdot 2^{\mu}}$$

Source: 3GPP TS 38.306 V15.2.0 (2018-06)

FR1 example for single layer 15kHz SCS in DL with 256QAM:

Number of Carriers “J”

Bits per Symbol from modulation scheme “Qm”

Sub carrier per RB

Numerology “μ“

Data rate = 10^{-6} *** 1 * 1 * 8 * 1 * (948/1024) * (270 * 12) * (14 *** 2^{0}**) /** 10^{-3} *** (1 - 0.14) = 288.9 Mbps**

Number of Layers “v”

Max. coderate “Rmax”

Average OFDM symbol duration “Ts”

Adjustment to Mbps

Scaling factor “f”

values 1, 0.8, 0.75, 0.4
signaled per band

Max. number of RBs “N”

270 for FR1 with 15kHz SCS
273 for FR1 with 30kHz SCS
135 for FR1 with 60kHz SCS
264 for FR2 with 60kHz SCS
264 for FR2 with 120kHz SCS

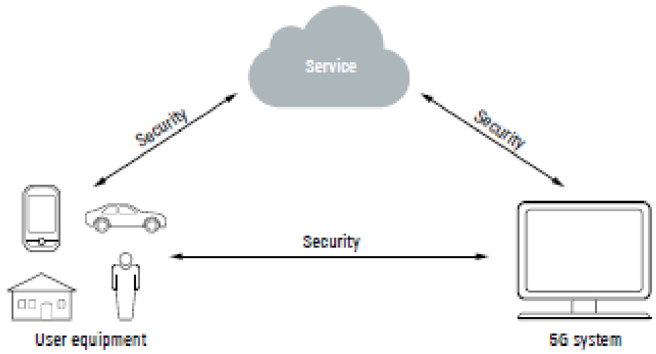
Overhead “OH”

0.14 for DL frequency range FR1
0.18 for DL frequency range FR2
0.08 for UL frequency range FR1
0.10 for UL frequency range FR2

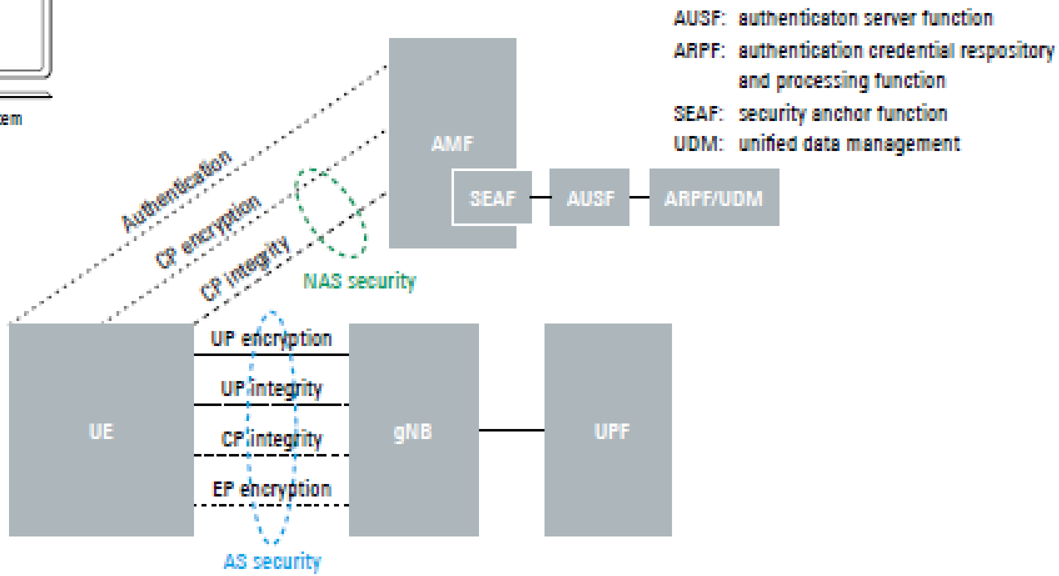
Maximum 5G NR data rate per layer

Frequency Range	SCS	Bandwidth	DL	UL	Efficiency DL	Efficiency UL
FR1	15 kHz	50 MHz	288.9 Mbps	309.1 Mbps	5.78 bps/Hz	6.18 bps/Hz
FR1	30 kHz	100 MHz	584.3 Mbps	625 Mbps	5.84 bps/Hz	6.25 bps/Hz
FR1	60 kHz	100 MHz	577.8 Mbps	618.1 Mbps	5.78 bps/Hz	6.18 bps/Hz
FR2	60 kHz	200 MHz	1.08 Gbps	1.18 Gbps	5.40 bps/Hz	5.90 bps/Hz
FR2	120 kHz	400 MHz	2.15 Gbps	2.37 Gbps	5.38 bps/Hz	5.93 bps/Hz
Compare to LTE	15 kHz	20 MHz	100 Mbps	100 Mbps	5.00 bps/Hz	5.00 bps/Hz

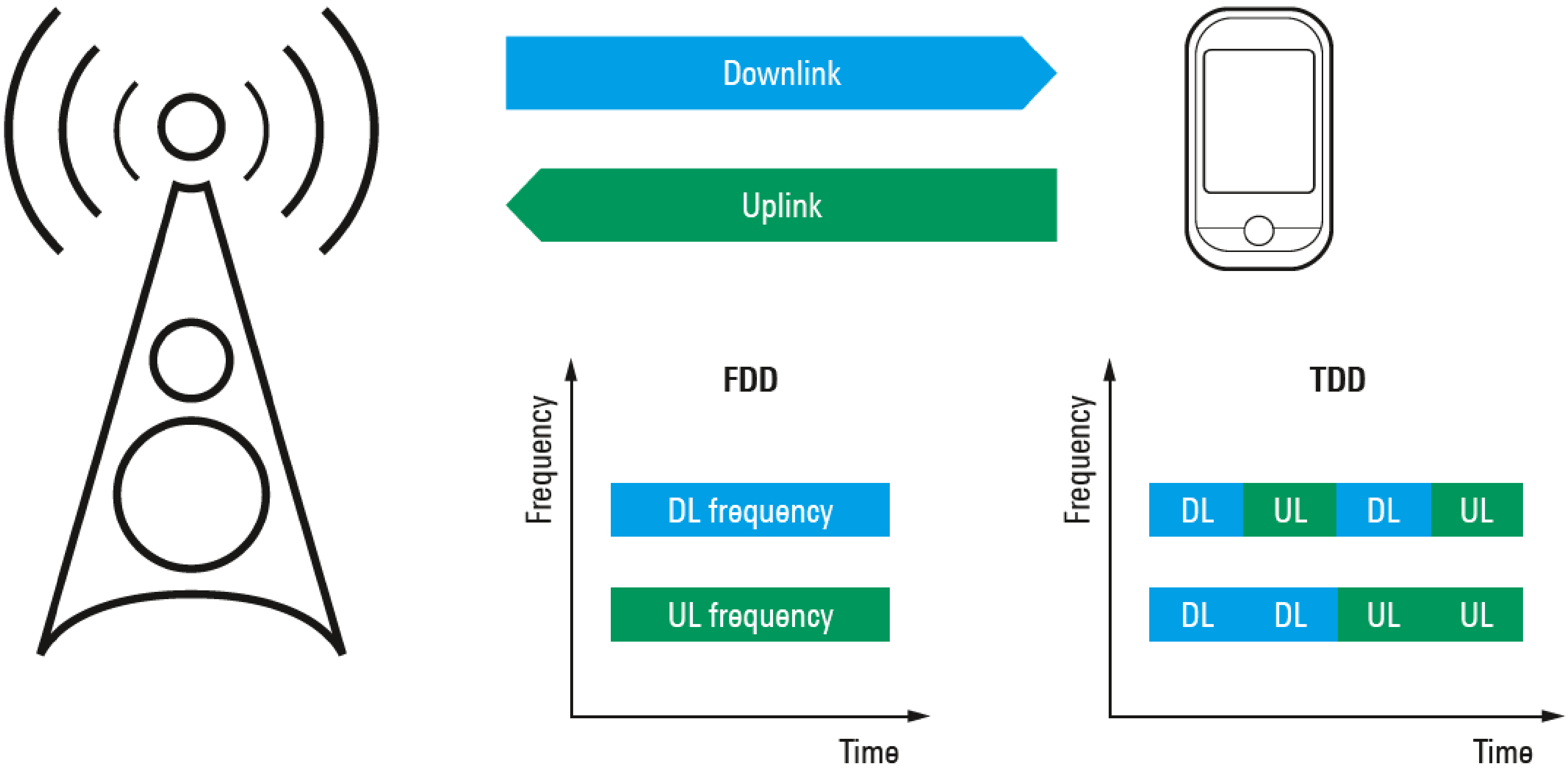
5G NR security mechanisms



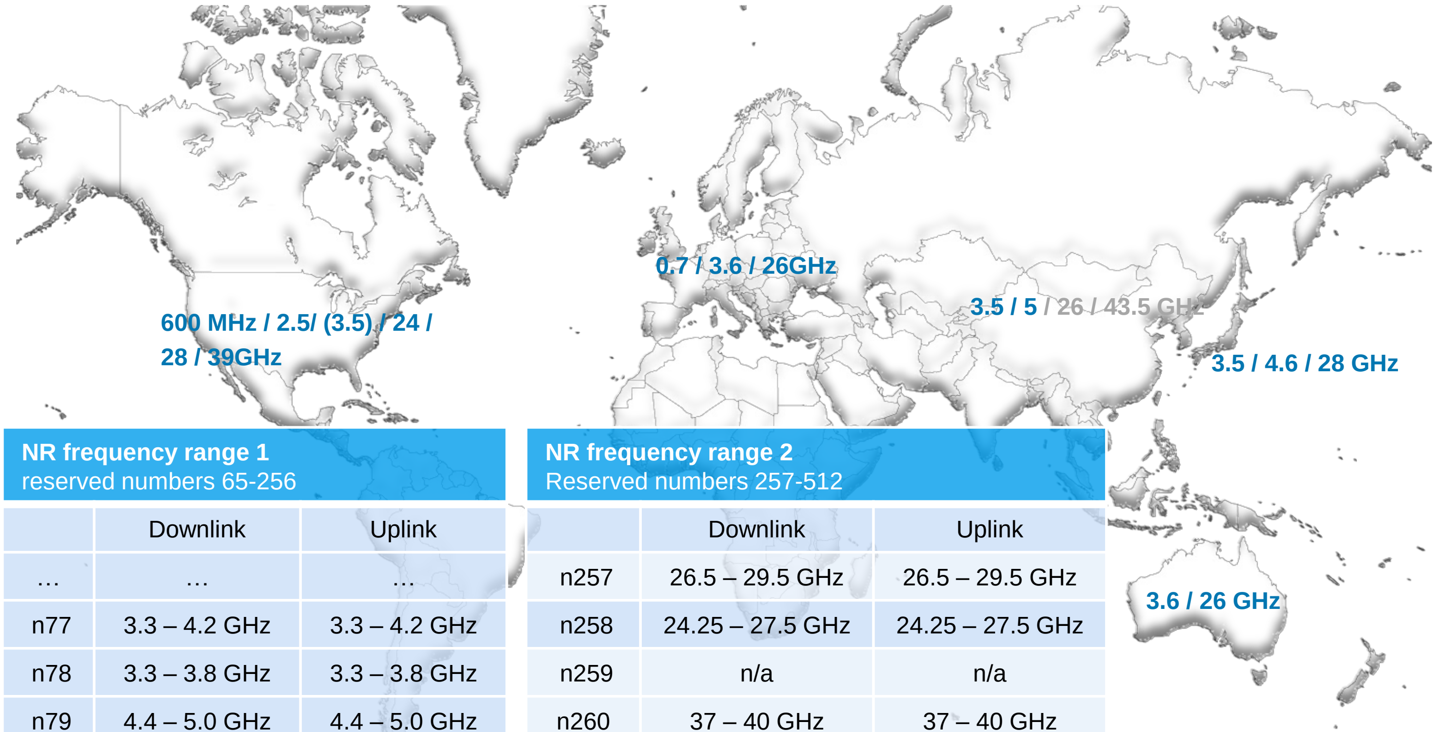
5G NR applies independent security functions for UP and CP:
- Authentication
- Encryption
- Integrity protection



5G NR – physical layer aspects



Frequency trends for 5G



NR frequency range 1
reserved numbers 65-256

	Downlink	Uplink
…	…	…
n77	3.3 – 4.2 GHz	3.3 – 4.2 GHz
n78	3.3 – 3.8 GHz	3.3 – 3.8 GHz
n79	4.4 – 5.0 GHz	4.4 – 5.0 GHz
…	…	…

NR frequency range 2
Reserved numbers 257-512

	Downlink	Uplink
n257	26.5 – 29.5 GHz	26.5 – 29.5 GHz
n258	24.25 – 27.5 GHz	24.25 – 27.5 GHz
n259	n/a	n/a
n260	37 – 40 GHz	37 – 40 GHz

Europe
- 700 MHz
- 3.4 - 3.8 GHz
- 24.25 - 27.5 GHz

China
- 2.5 – 2.6 GHz
- 3.3 - 3.6 GHz
- 4.8 - 5.0 GHz
- 24.75 - 27.5GHz (study)
- 37 - 43.5 GHz (study)

US
- 600 MHz
- 2.4 GHz
- [CBRS band (3.5GHz)]
- 27.5 - 28.35 GHz
- 37.0 - 40 GHz

Australia
- 3.6 GHz
- 26 GHz

Korea
- 3.42 - 3.7 GHz
- 26.5 – 28.9 GHz

Japan
- 4.4 - 4.9 GHz
- 28 GHz

5G NR Basics

- Two basic frequency ranges (FR1 and FR2) are used in 3GPP specifications
  - **FR1: 450 MHz to 7.125 GHz, FR 2: 24.25 to 52.6 GHz** for 3GPP Release 15
- Note that requirements throughout the RF specifications are in many cases defined separately for these different frequency ranges.
- RAN4 definition for reference frequencies (channel raster, synchronization raster):

frequency-band specific
(equal or greater than ΔF_{Global})

$$F_{REF} = F_{REF\text{-}Offs} + \Delta F_{Global}(N_{REF} - N_{REF\text{-}Offs})$$

NR-ARFCN

Frequency range	ΔF_{Global}	$F_{REF\text{-}Offs}$	$N_{REF\text{-}Offs}$	Range of N_{REF}
0 – 3000 MHz	5 kHz	0 MHz	0	0 – 599999
3000 – 24250 MHz	15 kHz	3000 MHz	600000	600000 – 2016666
24250 – 100000 MHz	60 kHz	24250.08 MHz	2016667	2016667 - 3279165

Source: TS 38.104

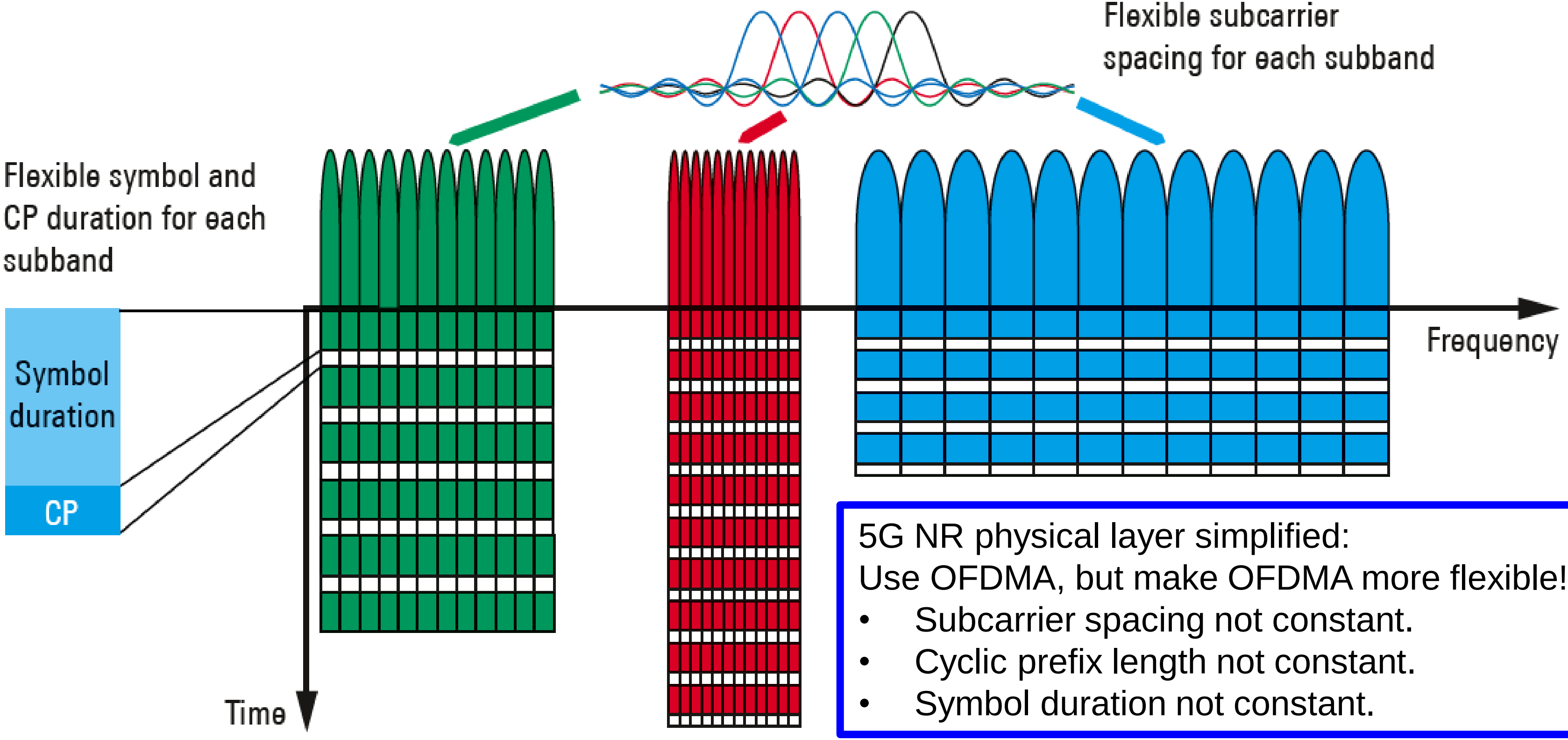
5G NR spectrum: operating bands in FR1 (<24GHz)

NR Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
n1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
n2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
n3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
n5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
n7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
n8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
n20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	FDD
n28	703 MHz	–	748 MHz	758 MHz	–	803 MHz	FDD
n38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
n41	2496 MHz	–	2690 MHz	2496 MHz	–	2690 MHz	TDD
n50	1432 MHz	–	1517 MHz	1432 MHz	–	1517 MHz	TDD
n51	1427 MHz	–	1432 MHz	1427 MHz	–	1432 MHz	TDD
n66	1710 MHz	–	1780 MHz	2110 MHz	–	2200 MHz	FDD
n70	1695 MHz	–	1710 MHz	1995 MHz	–	2020 MHz	FDD
n71	663 MHz	–	698 MHz	617 MHz	–	652 MHz	FDD
n74	1427 MHz	–	1470 MHz	1475 MHz	–	1518 MHz	FDD
n75	N/A			1432 MHz	–	1517 MHz	SDL
n76	N/A			1427 MHz	–	1432 MHz	SDL
n78	3300 MHz	–	3800 MHz	3300 MHz	–	3800 MHz	TDD
n77	3300 MHz	–	4200 MHz	3300 MHz	–	4200 MHz	TDD
n79	4400 MHz	–	5000 MHz	4400 MHz	–	5000 MHz	TDD
n80	1710 MHz	–	1785 MHz	N/A			SUL
n81	880 MHz	–	915 MHz	N/A			SUL
n82	832 MHz	–	862 MHz	N/A			SUL
n83	703 MHz	–	748 MHz	N/A			SUL
n84	1920 MHz	–	1980 MHz	N/A			SUL

5G NR spectrum: operating bands in FR2 (>24GHz)

NR Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
n257	26500 MHz	–	29500 MHz	26500 MHz	–	29500 MHz	TDD
n258	24250 MHz	–	27500 MHz	24250 MHz	–	27500 MHz	TDD
n260	37000 MHz	–	40000 MHz	37000 MHz	–	40000 MHz	TDD
n261	27500 MHz	-	28350 MHz	27500 MHz	-	28350 MHz	TDD

5G NR – physical layer aspects, general idea behind F-OFDMA



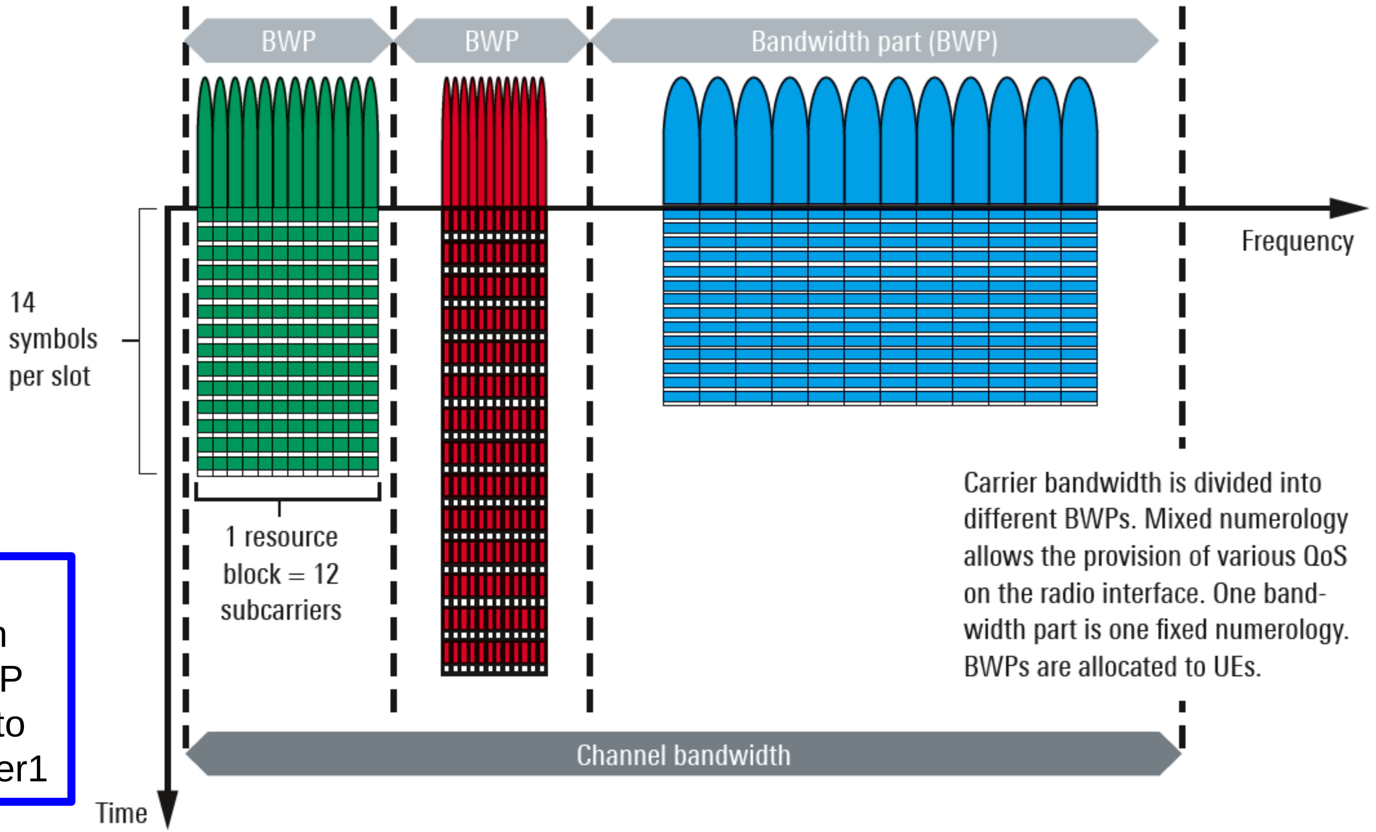
5G NR physical layer simplified:
Use OFDMA, but make OFDMA more flexible!

- Subcarrier spacing not constant.
- Cyclic prefix length not constant.
- Symbol duration not constant.

5G NR F-OFDMA features flexible numerologies

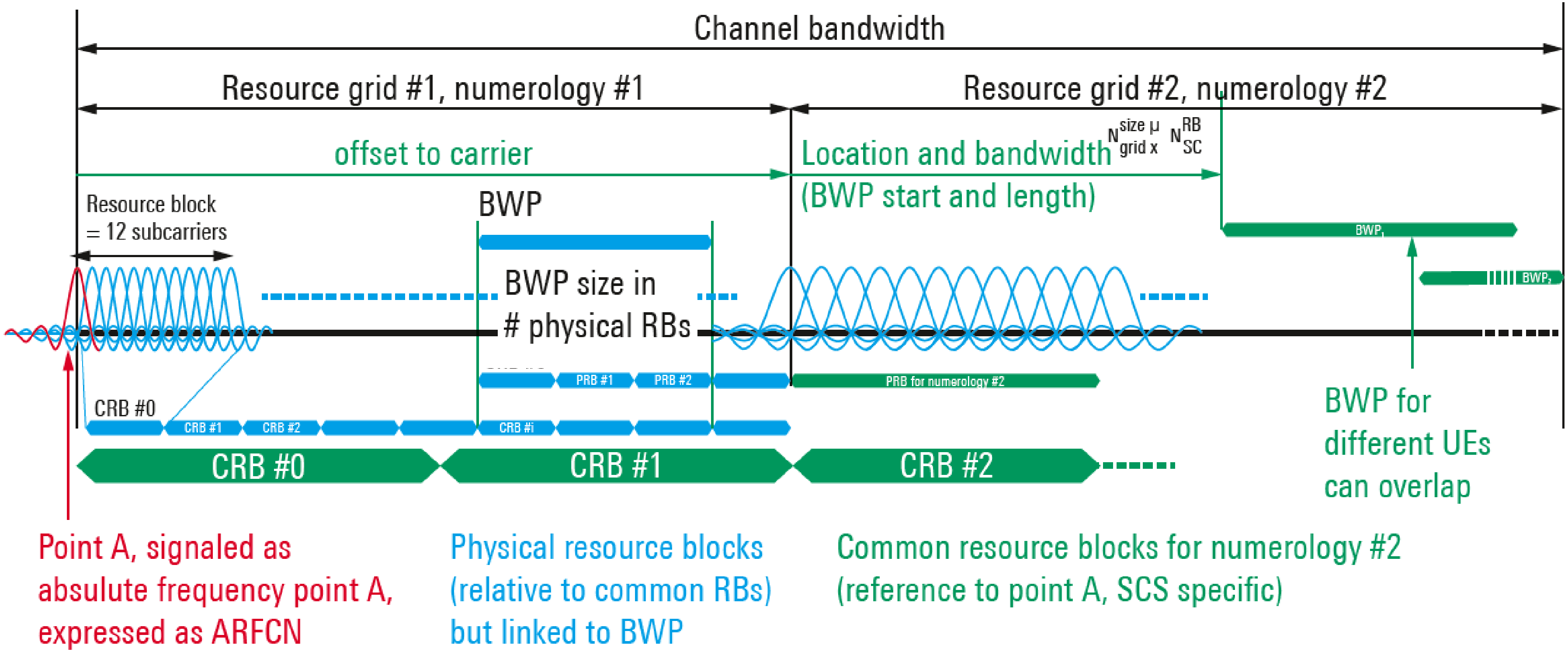
Subcarrier spacing (kHz)	15	30	60	120	240
Symbol duration (µs)	66.7	33.3	16.7	8.33	4.17
CP duration (µs)	4.7	2.3	1.2 (normal) 4.13 (extended)	0.59	0.29
Max. nominal bandwidth (MHz)	50	100	100 for FR1 200 for FR2	400	400
Max. FFT size	4096	4096	4096	4096	4096
Symbols per slot	14	14	14 12 (extended CP)	14	14
Slots per subframe	1	2	4	8	16
Slots per frame	10	20	40	80	160

5G NR F-OFDMA flexibility in spectrum, bandwidth parts

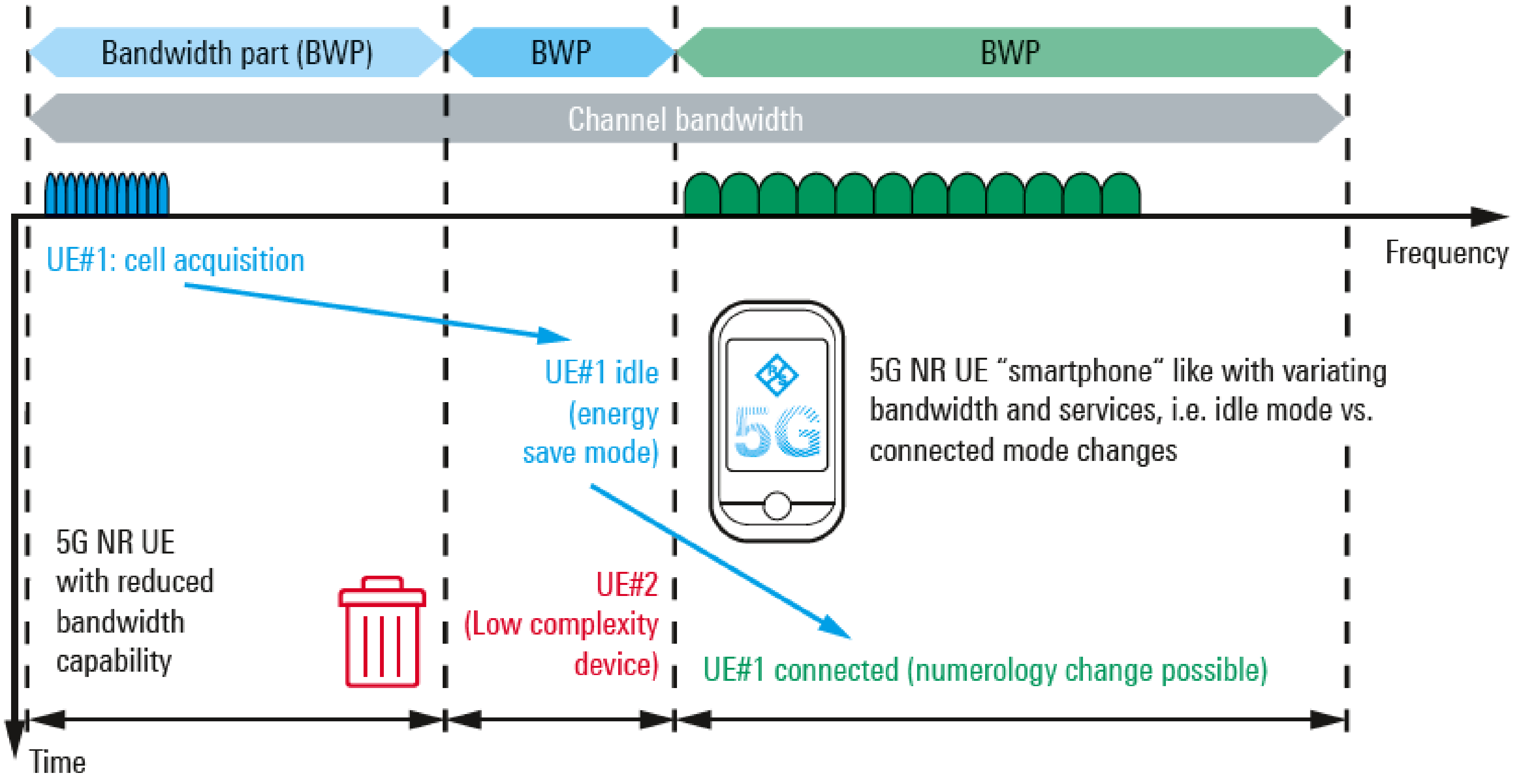


5G NR idea:
Channel bandwidth
Using different BWP
and numerologies to
enable QoS on layer1

5G NR – resource grid details

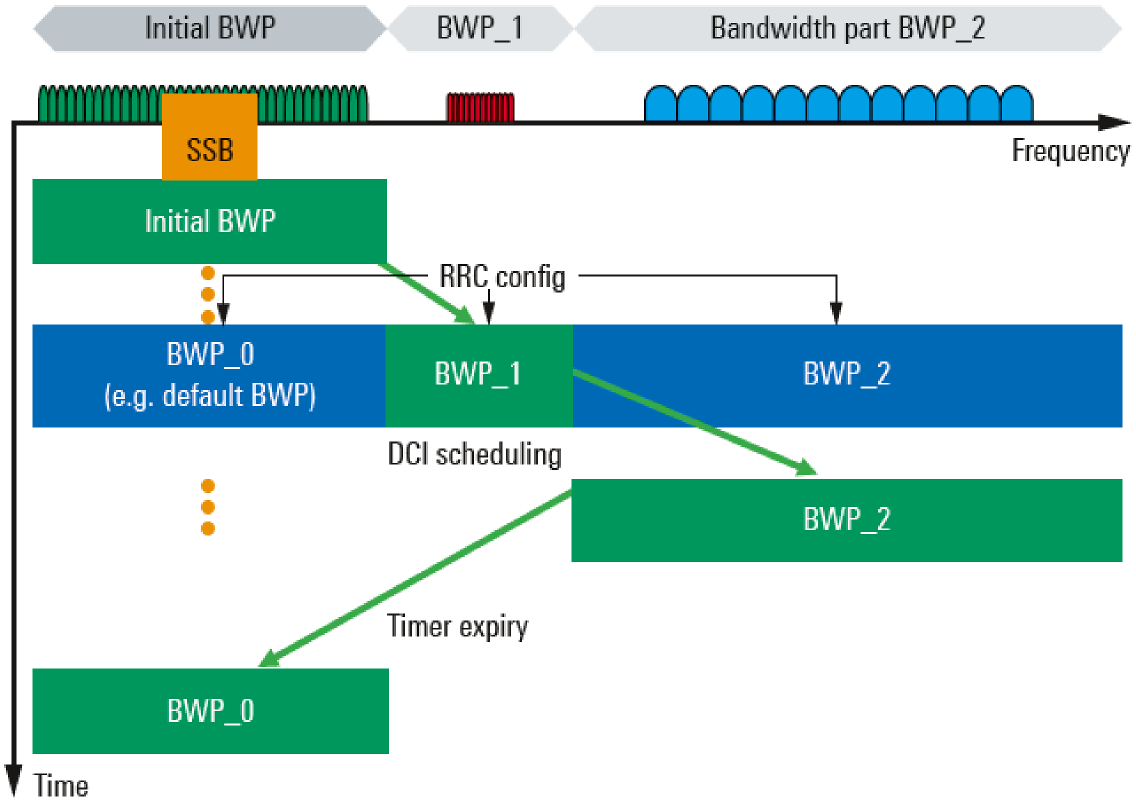


Bandwidth part scenarios



Bandwidth part switching

1. UE acquires cell on initial BWP
2. Connection setup, RRC configures up to 4 BWPs e.g. BWP_1 activated
3. During connection BWP can be changed via DCI scheduling
4. BWP change due to timer expiry



5G New Radio (NR) offers a flexible air interface

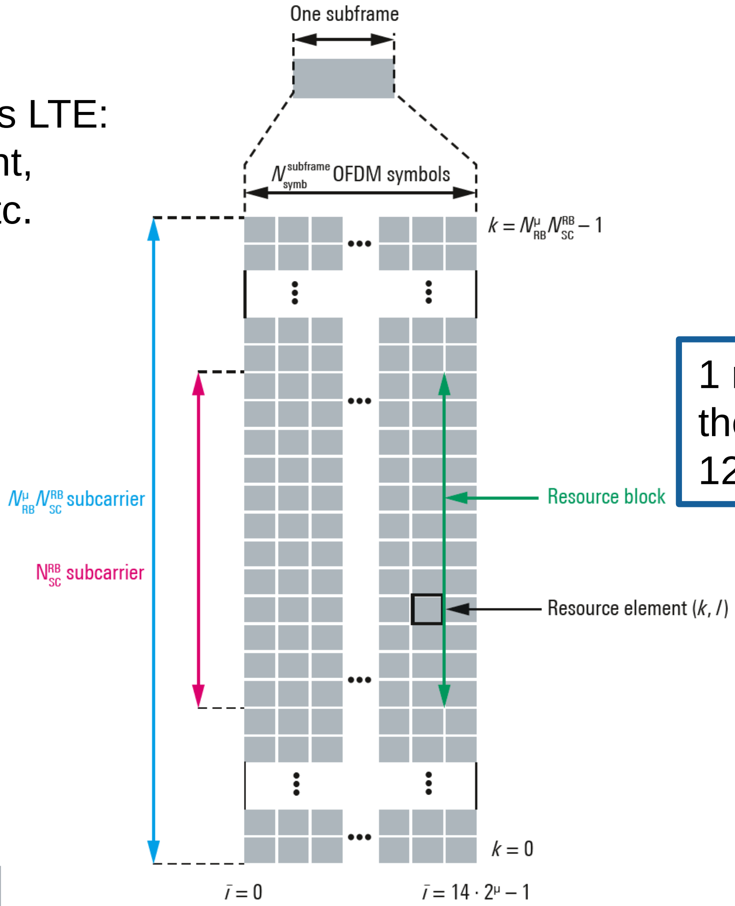
Summary of key parameters

Changed to 7.125 GHz

Parameter	FR1 (450 MHz – ~~6 GHz~~)	FR2 (24.25 – 52.6 GHz)
Carrier aggregation	Up to 16 carriers	
Bandwidth per carrier	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100MHz	50, 100, 200, 400 MHz
Subcarrier spacing	15, 30, 60 kHz	60, 120, 240 (not for data) kHz
Max. number of subcarriers	3300 (FFT4096 mandatory)	
Modulation scheme	QPSK, 16QAM, 64QAM, 256QAM; uplink also supports π/2-BPSK (only DFT-s-OFDM)	
Radio frame length	10ms	
Subframe duration	1 ms (alignment at symbol boundaries every 1 ms)	
MIMO scheme	Max. 2 codewords mapped to max 8 layers in downlink and to max 4 layers in uplink	
Duplex mode	TDD, FDD	TDD
Access scheme	DL: CP-OFDM; UL: CP-OFDM, DFT-s-OFDM	

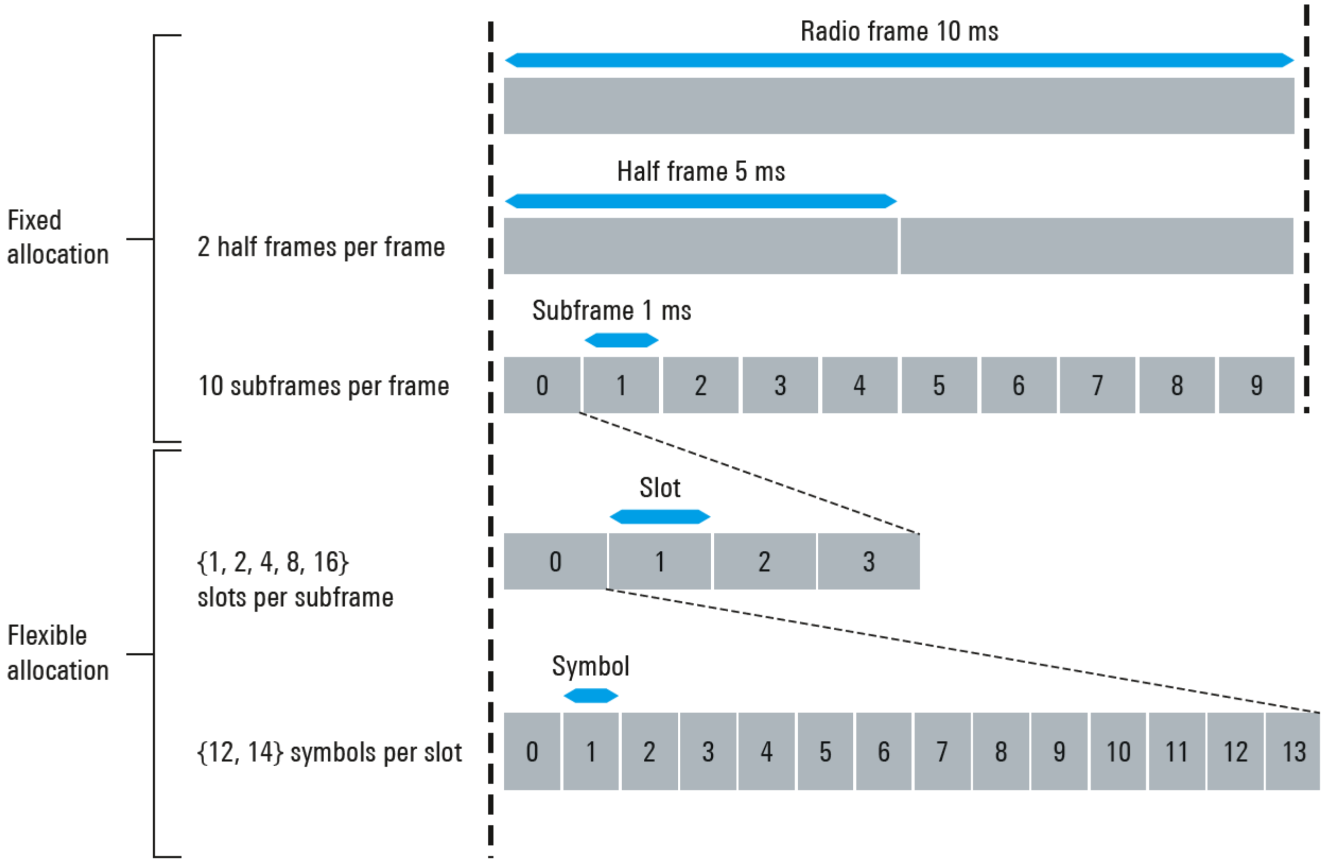
5G NR – physical layer resources

5G NR uses similar terms as LTE: Subcarrier, resource element, resource block, subframe etc.

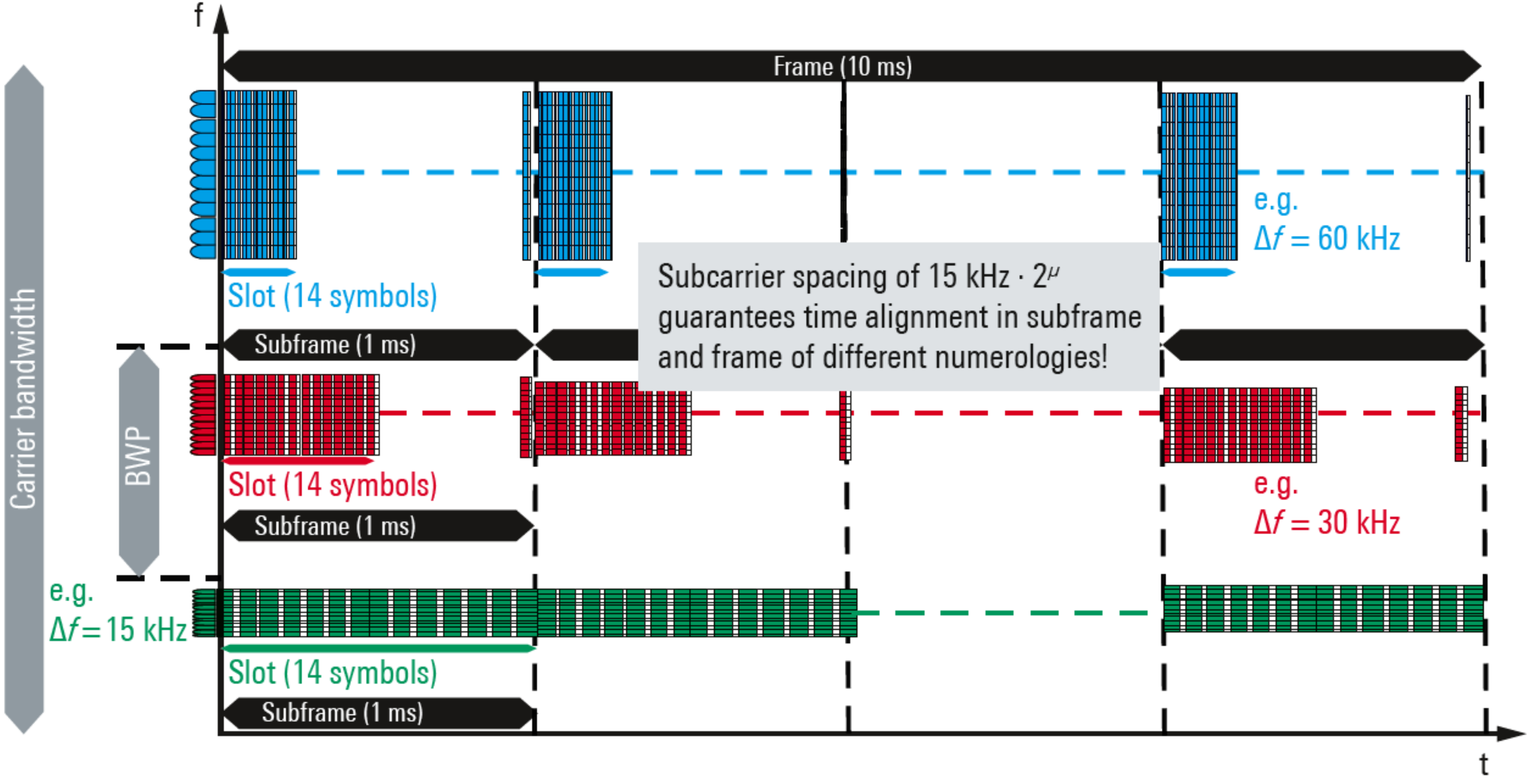


1 resource block is defined only in the frequency domain!
12 subcarriers = 1 resource block

5G NR – frame structure

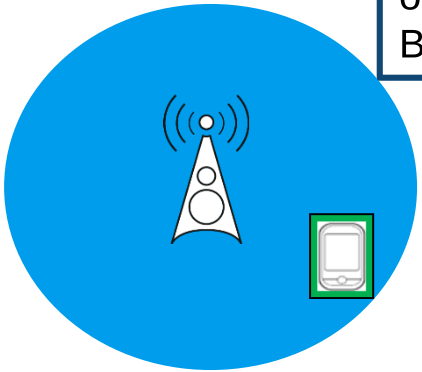


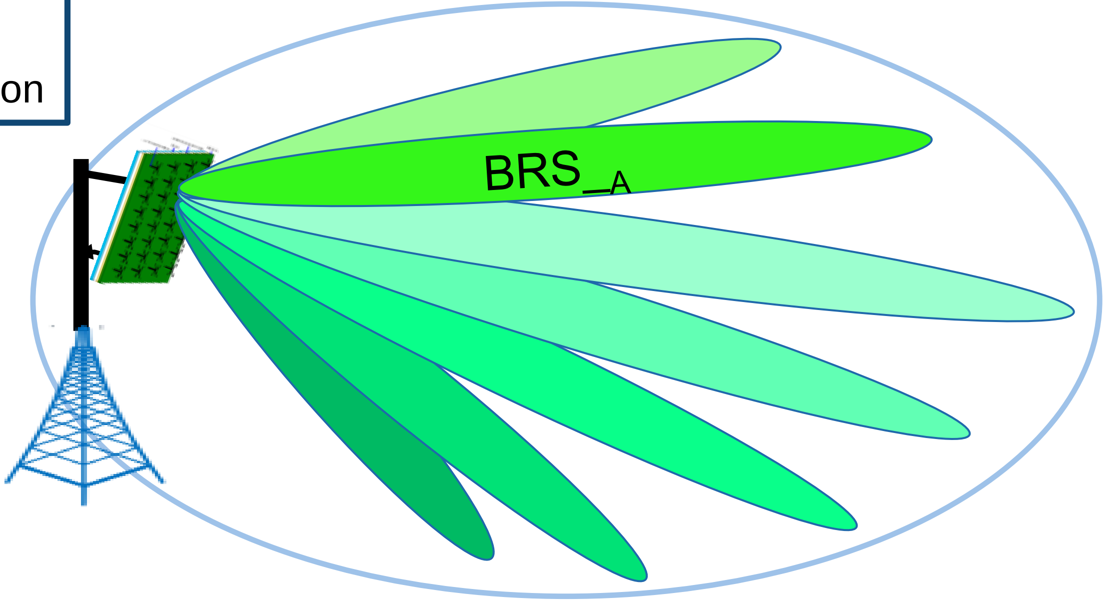
5G NR – frame structure, interworking with multiple numerologies



5G air interface aspects: beam sweeping for initial access

traditional approach: omnidirection TX of BCCH for cell detection





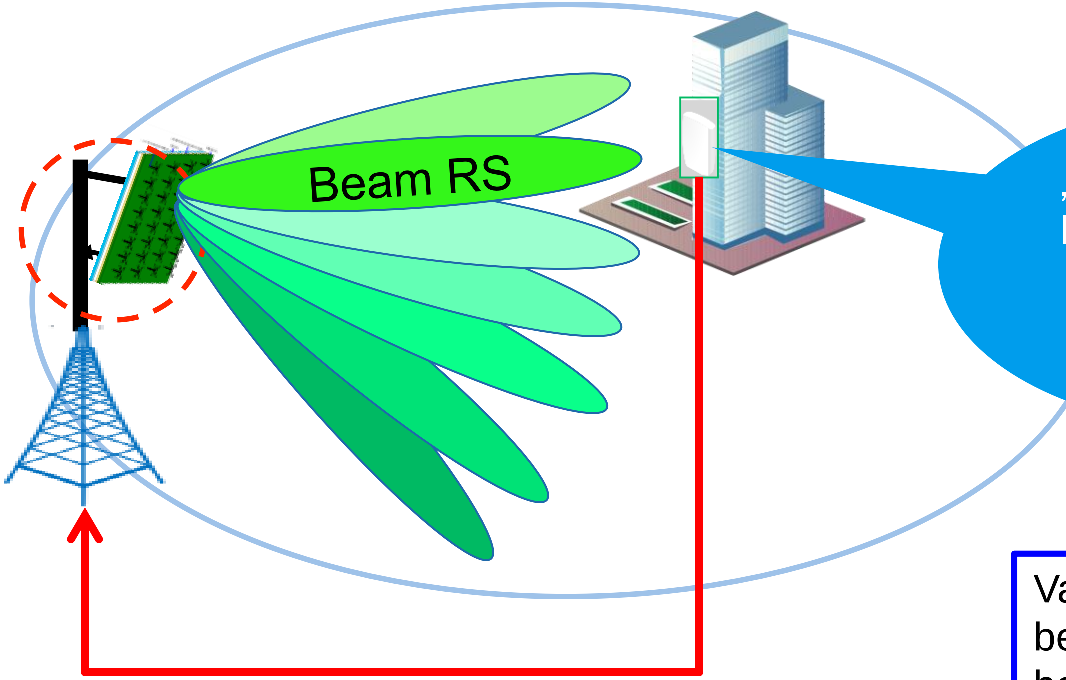
Friis equation

$$\frac{P_{Rx}}{P_{Tx}} = G_{antenna}\left(\frac{c}{4\pi \boldsymbol{f} d}\right)^{\gamma}$$

At higher frequencies: Free space path loss is high -> beamforming with high gain

Beam sweeping procedure for power efficiency and cell detection

5G air interface: beam reporting, general aspects

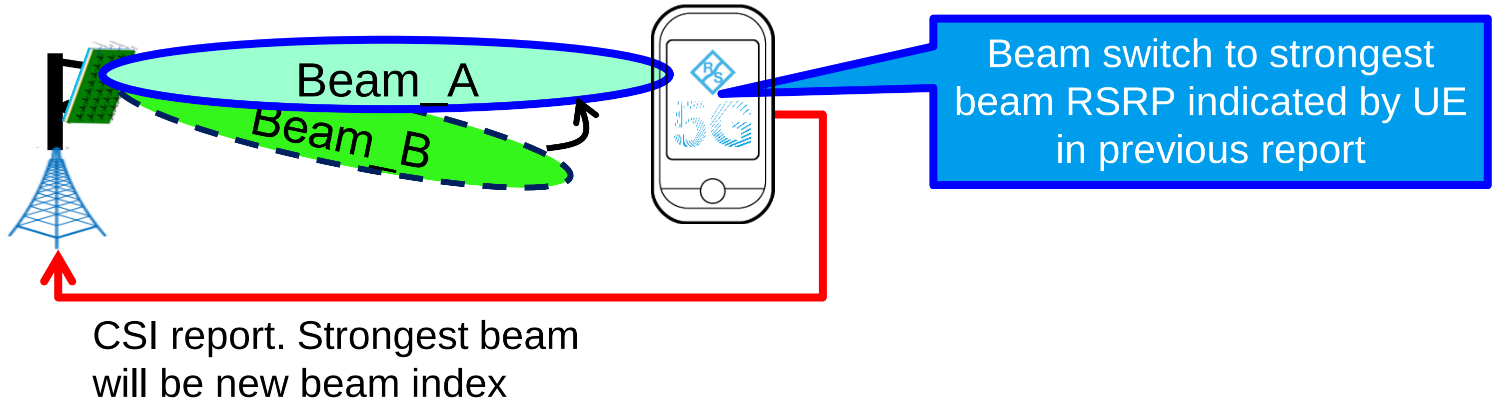


„the received power level on the specific beam is …. (define RSRP based on beams)“

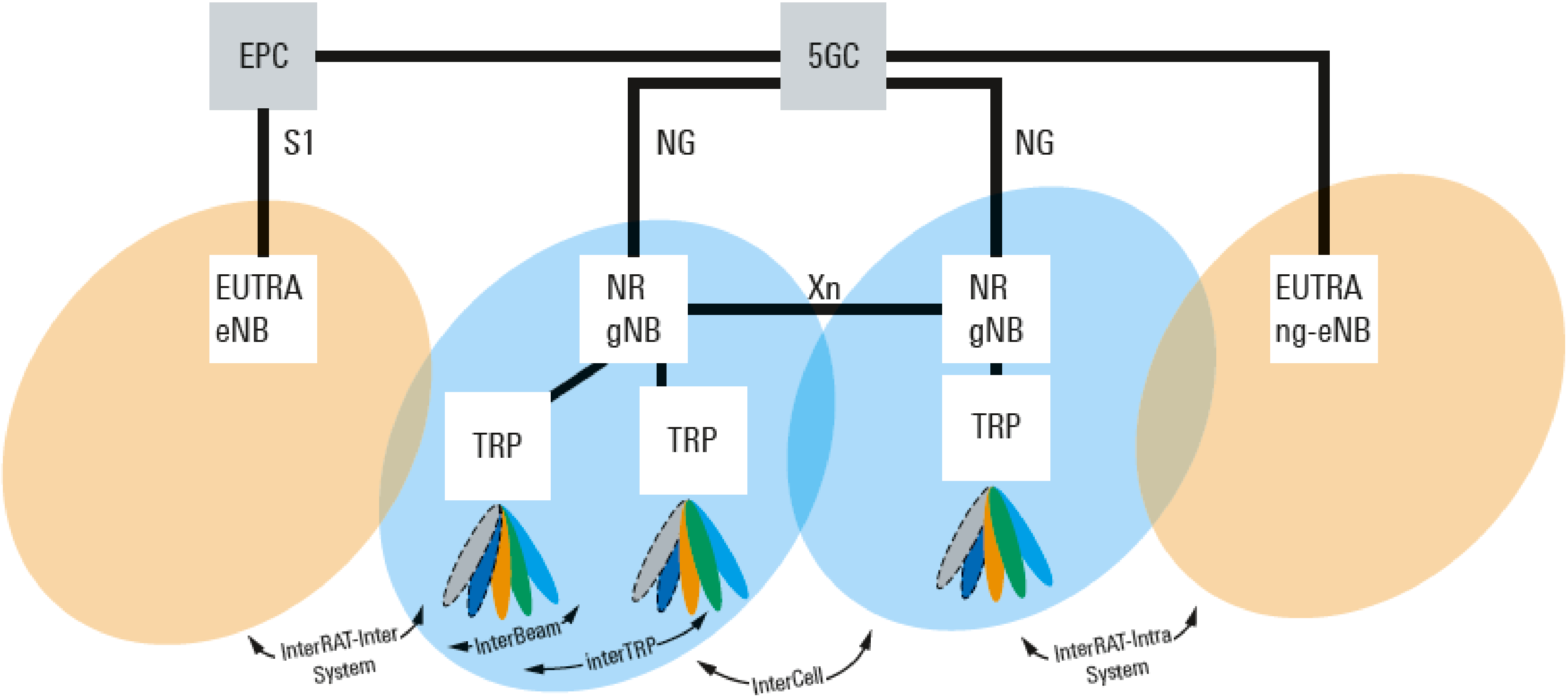
Various beams have to be distinguished. Idea of beam specific reference Signals (CSI-RS)

UE reports the beam status via CSI reports

5G NR air interface aspects: beam switching procedure



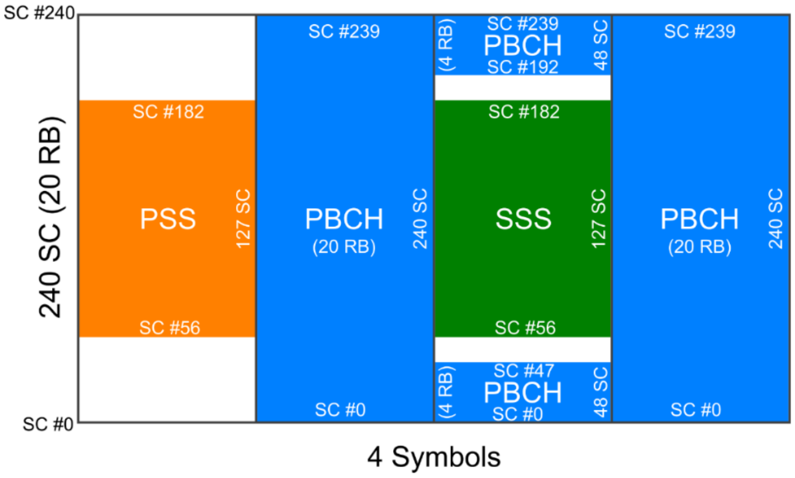
5G-NR mobility scenarios



SS/PBCH Blocks

- In the time domain, an SS/PBCH block consists of 4 OFDM symbols, numbered in increasing order from 0 to 3 within the SS/PBCH block, where PSS, SSS, and PBCH with associated DM-RS occupy different symbols
- In the frequency domain, an SS/PBCH block consists of 240 contiguous subcarriers with the subcarriers numbered in increasing order from 0 to 239 within the SS/PBCH block.
- Two SS/PBCH block types:
  - Type A (15kHz and 30kHz)
  - Type B (120 and 240 kHz)

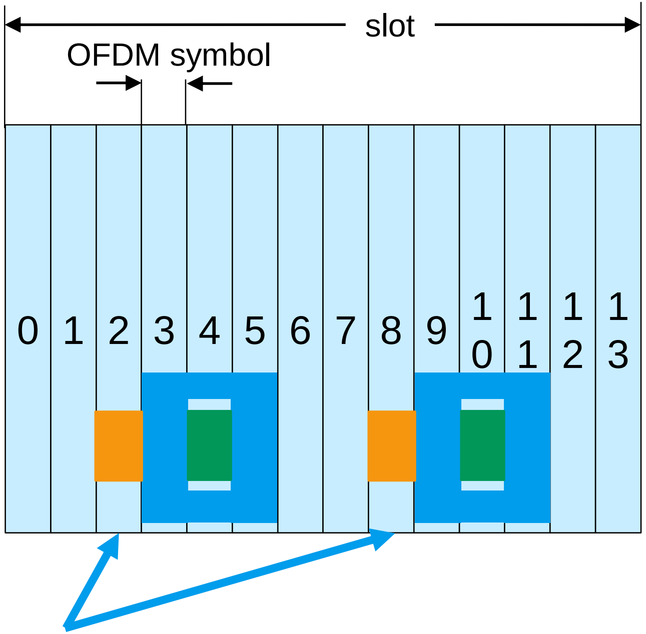
SS/PBCH block



- Like in LTE the Cell ID can be determined from the used PSS/SSS sequences

SS/PBCH Blocks

Occurrence in the frame depends on SCS



SC spacing	f_c < 3GHz (L_{max} = 4)	3GHz < f_c < 6GHz (L_{max} = 8)	f_c > 6GHz (L_{max} = 64)
Case A: 15 kHz	2,8,16,22	2,8,16,22,30,38,44,50	N/A
Case B: 30 kHz	4,8,16,20	4,8,16,20,32,36,44,48	N/A
Case C: 30 kHz	2,8,16,22	2,8,16,22,30,38,44,50	N/A
Case D: 120 kHz	N/A	N/A	4,8,16,20, …, 508,512,520,524
Case E: 240 kHz	N/A	N/A	8,12,16,20,…, 480,484,488,492

Start symbol of SSB depends on SC spacing

SS/PBCH Blocks details

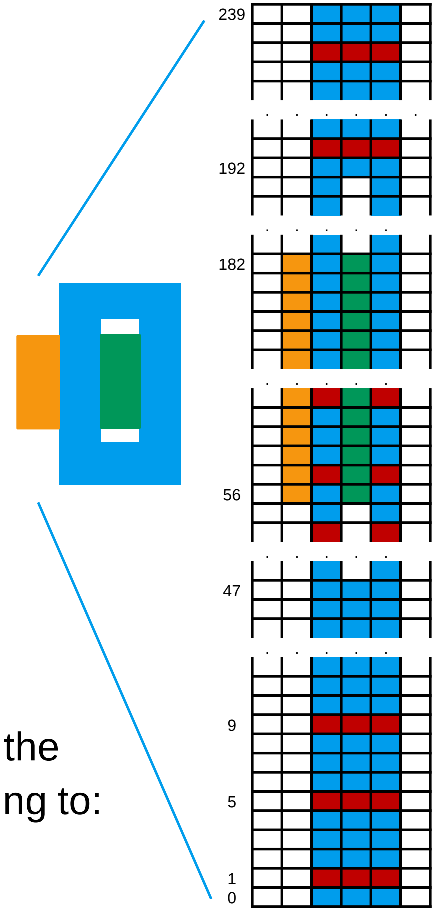
Resources PSS, SSS, PBCH, and DM-RS for PBCH

- The sequence used for DM-RS in PBCH depends on the cell ID, the number of the half frame the PBCH is transmitted in the frame and the SS/PBCH index (details in TS38.213, section 4.1)
- This essentially allows to transmit L_{max} different “common” beams

Channel or signal	OFDM symbol number *l* relative to the start of an SS/PBCH block	Subcarrier number *k* relative to the start of an SS/PBCH block
PSS	0	56, 57, …, 182
SSS	2	56, 57, …, 182
Set to 0	0	0, 1, …, 55, 183, 184, …, 236
	2	48, 49, …, 55, 183, 184, …, 191
PBCH	1, 3	0, 1, …, 239
	2	0, 1, …, 47, 192, 193, …, 239
DM-RS for PBCH	1, 3	0+ν, 4+ν, 8+ν, …, 236+ν
	2	0+ν, 4+ν, 8+ν, …, 44+ν 192+ν, 4+ν, 196+ν, …, 236+ν

- ν depends on the cell ID according to:

$$\nu = N_{\mathrm{ID}}^{\mathrm{cell}} \bmod 4$$



Example with ν =1

SS/PBCH demodulation reference signals

Each SS/PBCH block has its own DMRS sequence, depending on cell ID

$$r(m)=\frac{1}{\sqrt{2}}\left(1-2\cdot c(2m)\right)+j\frac{1}{\sqrt{2}}\left(1-2\cdot c(2m+1)\right)$$

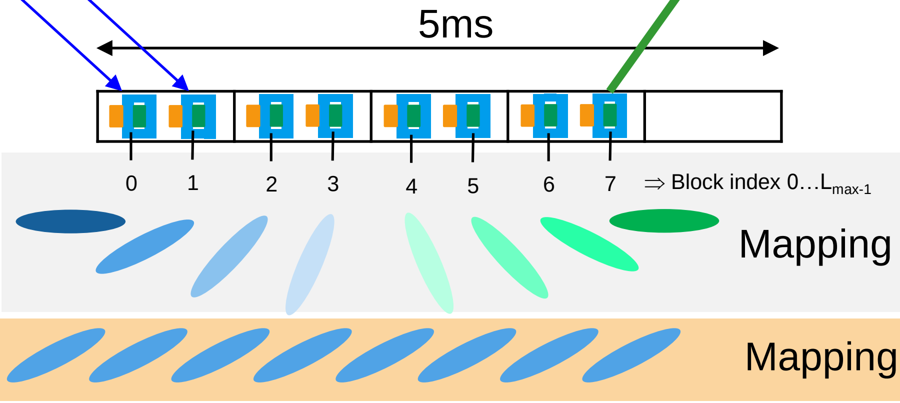
With initials

$$c_{\text{init}}=2^{11}\left(\bar{i}_{\text{SSB}}+1\right)\left(\left\lfloor N_{\text{ID}}^{\text{cell}}/4\right\rfloor+1\right)+2^{6}\left(\bar{i}_{\text{SSB}}+1\right)+\left(N_{\text{ID}}^{\text{cell}} \bmod 4\right)$$

$$\bar{i}_{\text{SSB}}=4i_{\text{SSB}}+n_{\text{hf}}$$

SSB index within half frame will init sequence generation $\boxed{r(0),\ldots,r(143)}$

Different DMRS sequences



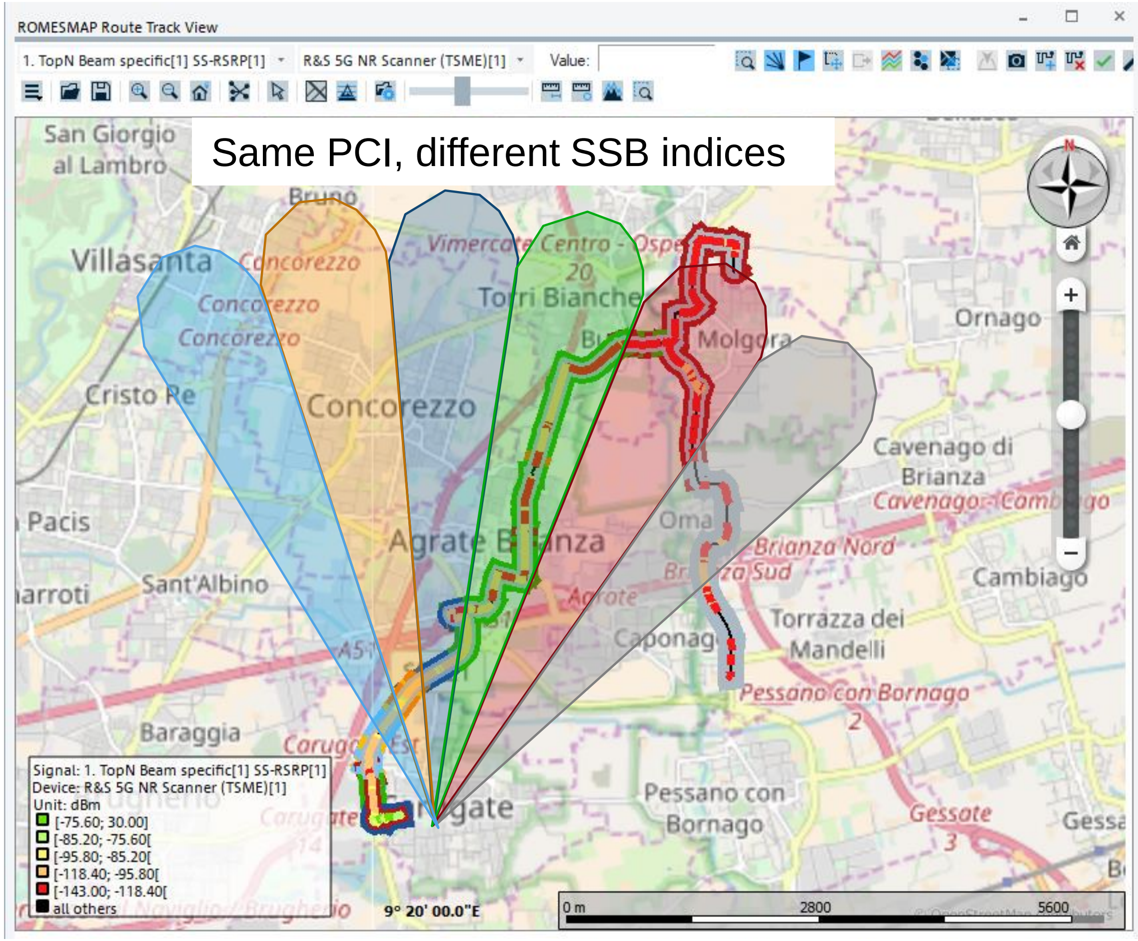
SSB blocks can be mapped onto antenna ports individually

Mapping of SSB onto antenna: beam sweeping

Mapping of SSB onto antenna: static beam

Field measurements:
Exp.: SSB / beam ranking

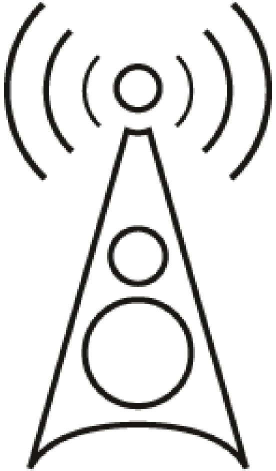
- **SSB / beam index visualized over time (history) and on the map**
- **Surprisingly good match with horizontal "micro sectors" (SSB beam indices)** ✓



Architecture Options, LTE and 5G NR

Difference between sectorized eNB and SSB-beamformed sectorized gNB cells

5G NR – physical channels



Physical downlink control channel PDCCH:
Downlink and uplink scheduling decisions

Physical downlink shared channel PDSCH:
Downlink data

Physical broadcast channel PBCH:
Providing master information block

Physical uplink shared channel PUSCH:
Uplink data + UCI optionally

Physical uplink control channel PUCCH:
ACK/NACK for downlink packets, scheduling requests, channel status info

Physical random access channel PRACH:
Initial access

Remark, no PHICH any longer, ACK/NACK sent asynchronously

Remark, no PCFICH any longer, PDCCH size by higher layer signaling

Reference signals in 5G NR – motivational aspects

Old style: one reference signal always on air and used for everything:
Channel estimation
Power detection
CQI evaluatoin etc.

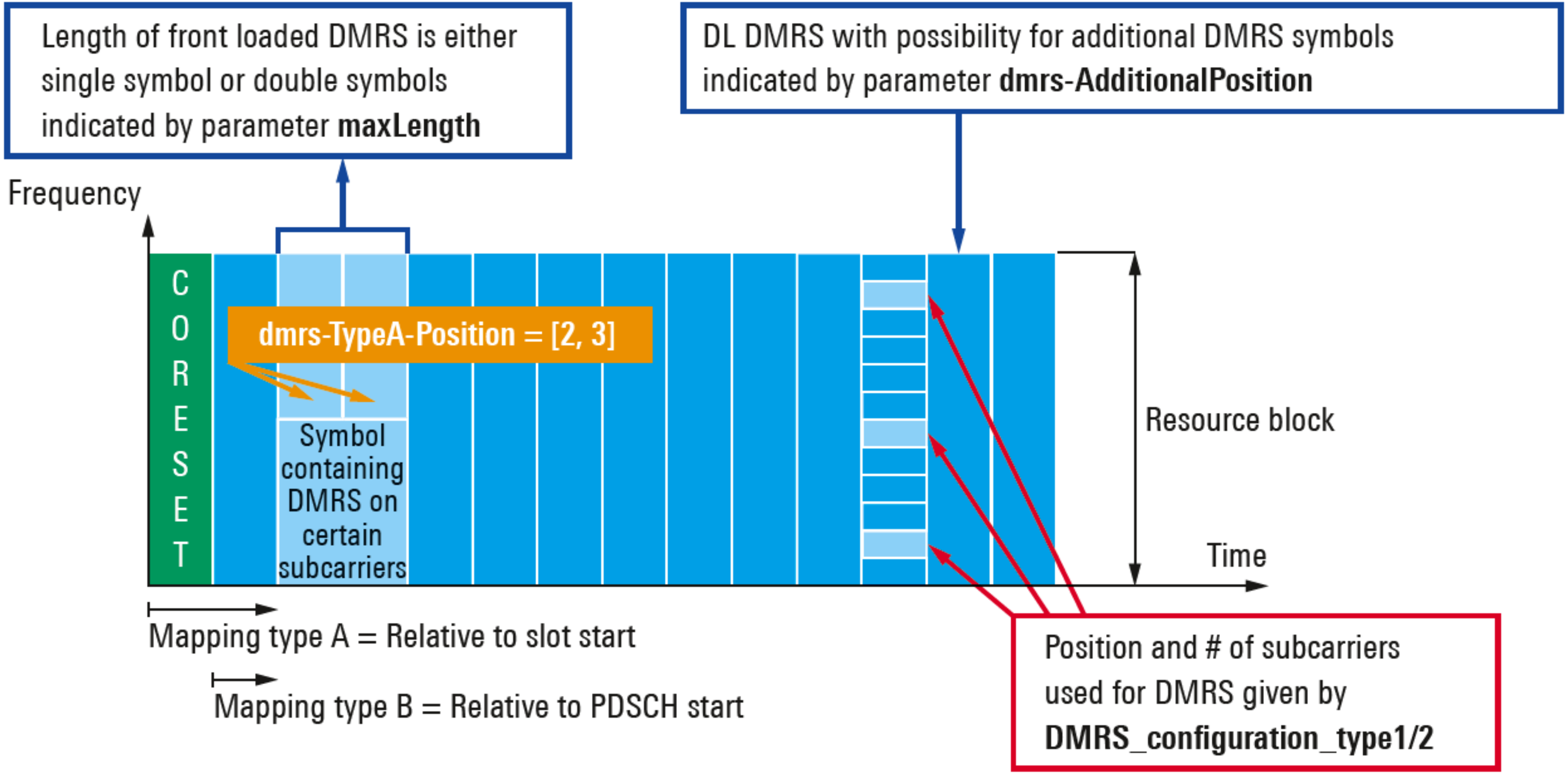
New style: repurposing of reference channels:
Specialist for various purpose:
Channel status estimation
Demodulation assistance
Position estimation etc.

5G NR – physical signals

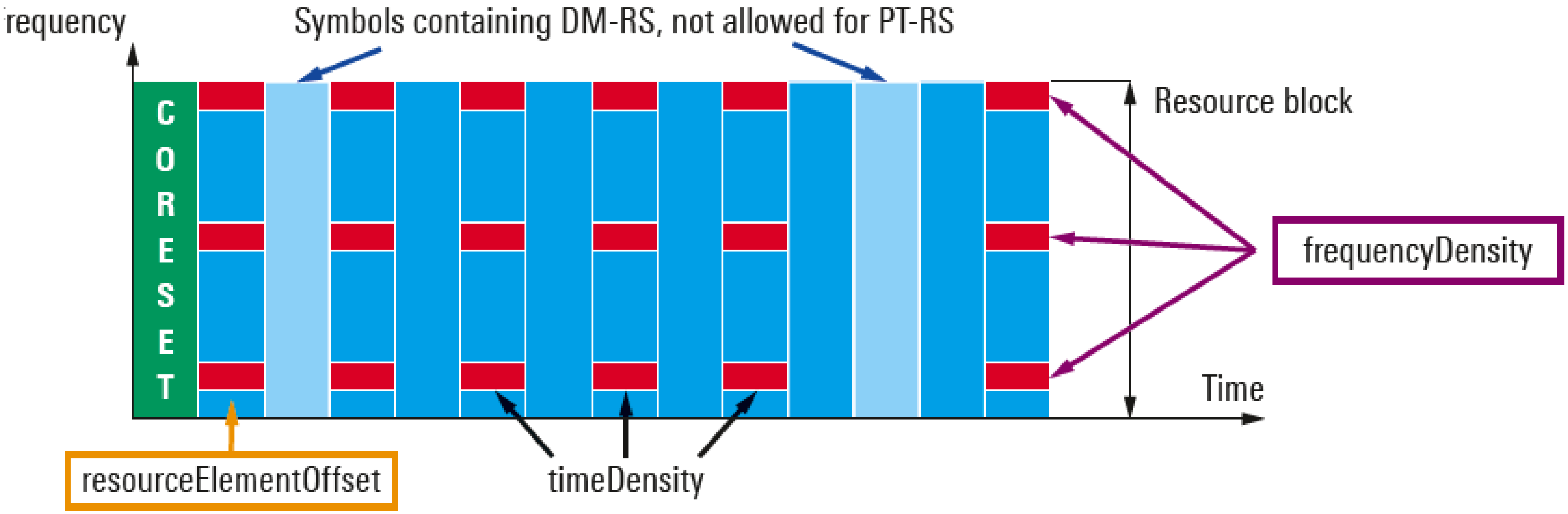
UL physical signals:
- Demodulation reference signals (**DMRS**) for PUSCH and PUCCH
- Phase-tracking reference signals (**PTRS**) for PUSCH
- Sounding reference signal (**SRS**)

DL physical signals:
- Demodulation reference signals (**DMRS**) for PDSCH, PDCCH and PBCH
- Phase-tracking reference signals (**PTRS**) for PDSCH
- Channel-state information reference signal (**CSI-RS**)
- Tracking reference signals (**TRS**)
- Primary synchronization signal (**PSS**)
- Secondary synchronization signal (**SSS**)

5G NR – physical signals. Demodulation reference signals (DMRS)



5G NR – physical signals. Phase tracking reference signals (PTRS)



CSI-RS for beamforming support

UE specific *scrambling ID*

$$c_{\text{init}} = \left(2^{10}\left(N_{\text{symb}}^{\text{slot}} n_{\text{s,f}}^{\mu} + l + 1\right)(2n_{\text{ID}} + 1) + n_{\text{ID}}\right) \bmod 2^{31}$$

Orthogonal sequences for CDM

$$r(m) = \frac{1}{\sqrt{2}}\left(1-2\cdot c(2m)\right) + j\frac{1}{\sqrt{2}}\left(1-2\cdot c(2m+1)\right)$$

$$a_{k,l}^{(p,\mu)} = \beta_{\text{CSIRS}} w_{\text{f}}(k')\cdot w_{\text{t}}(l')\cdot r_{l,n_{\text{s,f}}}(m')$$

$$m' = \lfloor n\alpha \rfloor + k' + \left\lfloor \frac{\bar{k}\rho}{N_{\text{sc}}^{\text{RB}}} \right\rfloor$$

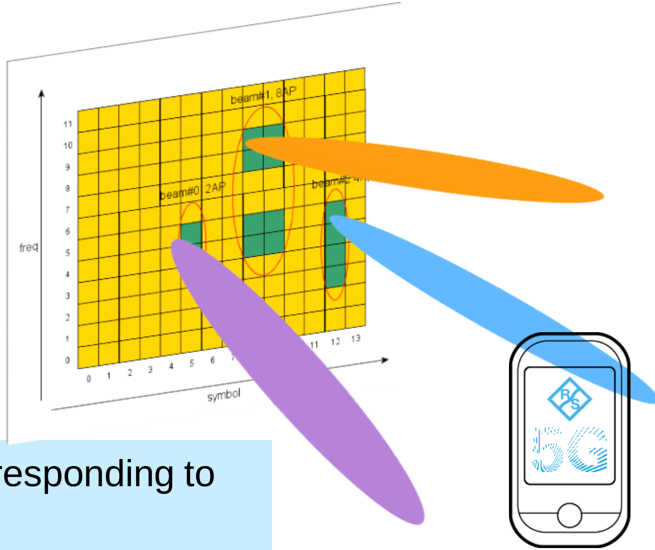
$$k = nN_{\text{sc}}^{\text{RB}} + \bar{k} + k'$$

$$l = \bar{l} + l'$$

density

$$\alpha = \begin{cases} \rho & \text{for } X = 1 \\ 2\rho & \text{for } X > 1 \end{cases}$$

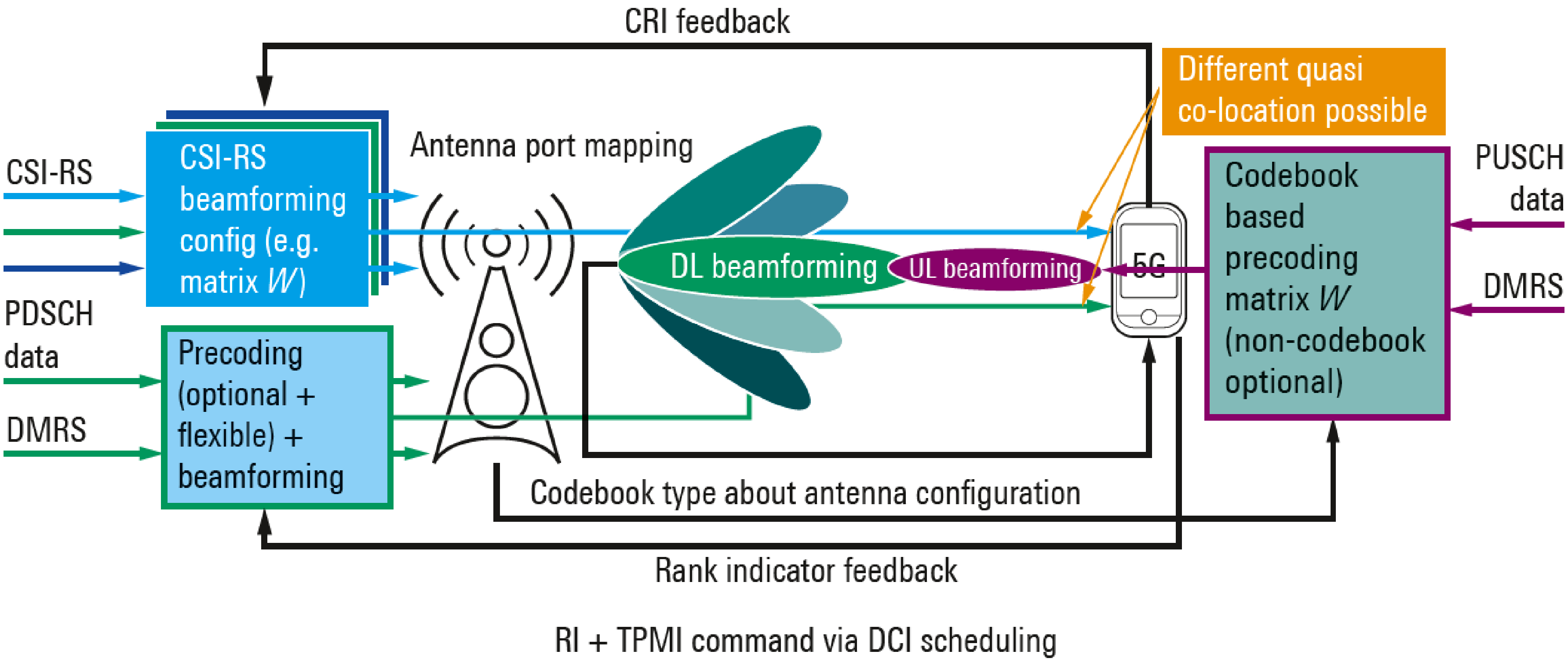
$$n = 0,1,\ldots$$



- Multiple CSI-RS-Resources corresponding to different beam direction
- UE measures different CSI-RS resources and selects the best beam
- **C**SI-RS **R**esources **I**ndicator (CRI) is reported corresponding to best beam + RI/PMI/CQI reports are conditioned on reported CRI

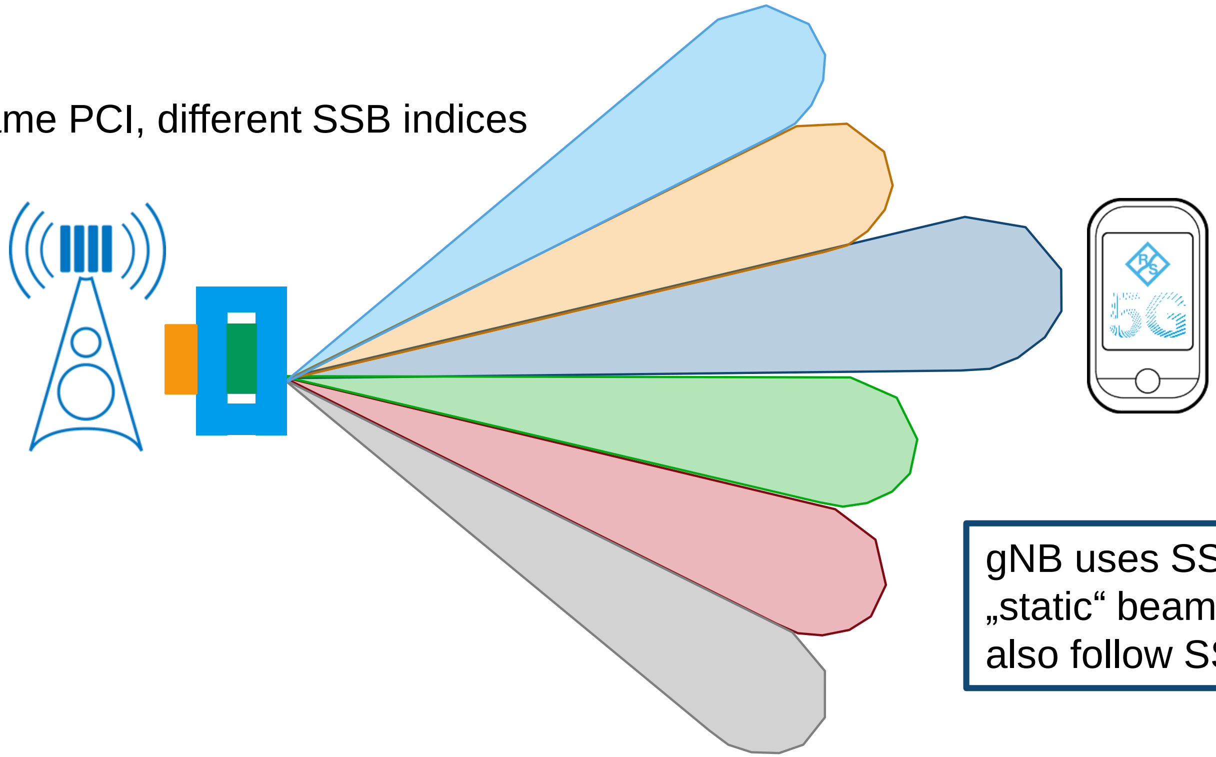
CSI can be non-zero power NZP or zero power ZP

5G NR – precoding, general model



5G NR beamforming aspects

Same PCI, different SSB indices



gNB uses SSBs to be mapped on „static“ beams. PDSCH & PUSCH will also follow SSB beam concept

CSI-RS for beamforming support

UE specific *scrambling ID*

$$c_{\text{init}} = \left(2^{10}\left(N_{\text{symb}}^{\text{slot}} n_{\text{s,f}}^{\mu} + l + 1\right)(2n_{\text{ID}} + 1) + n_{\text{ID}}\right) \bmod 2^{31}$$

Orthogonal sequences for CDM

$$r(m) = \frac{1}{\sqrt{2}}\left(1 - 2\cdot c(2m)\right) + j\frac{1}{\sqrt{2}}\left(1 - 2\cdot c(2m+1)\right)$$

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$$m' = \lfloor n\alpha \rfloor + k' + \left\lfloor \frac{\bar{k}\rho}{N_{\text{sc}}^{\text{RB}}} \right\rfloor$$

$$k = nN_{\text{sc}}^{\text{RB}} + \bar{k} + k'$$

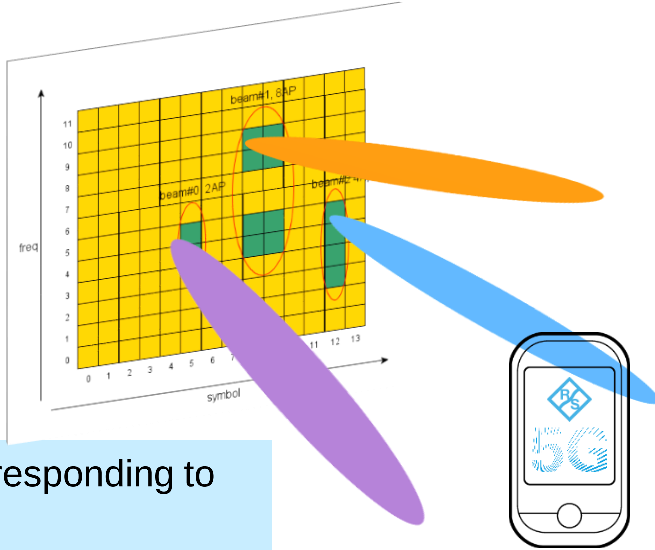
$$l = \bar{l} + l'$$

density

$$\alpha = \begin{cases} \rho & \text{for } X = 1 \\ 2\rho & \text{for } X > 1 \end{cases}$$

$$n = 0,1,\ldots$$

CSI can be non-zero power NZP or zero power ZP



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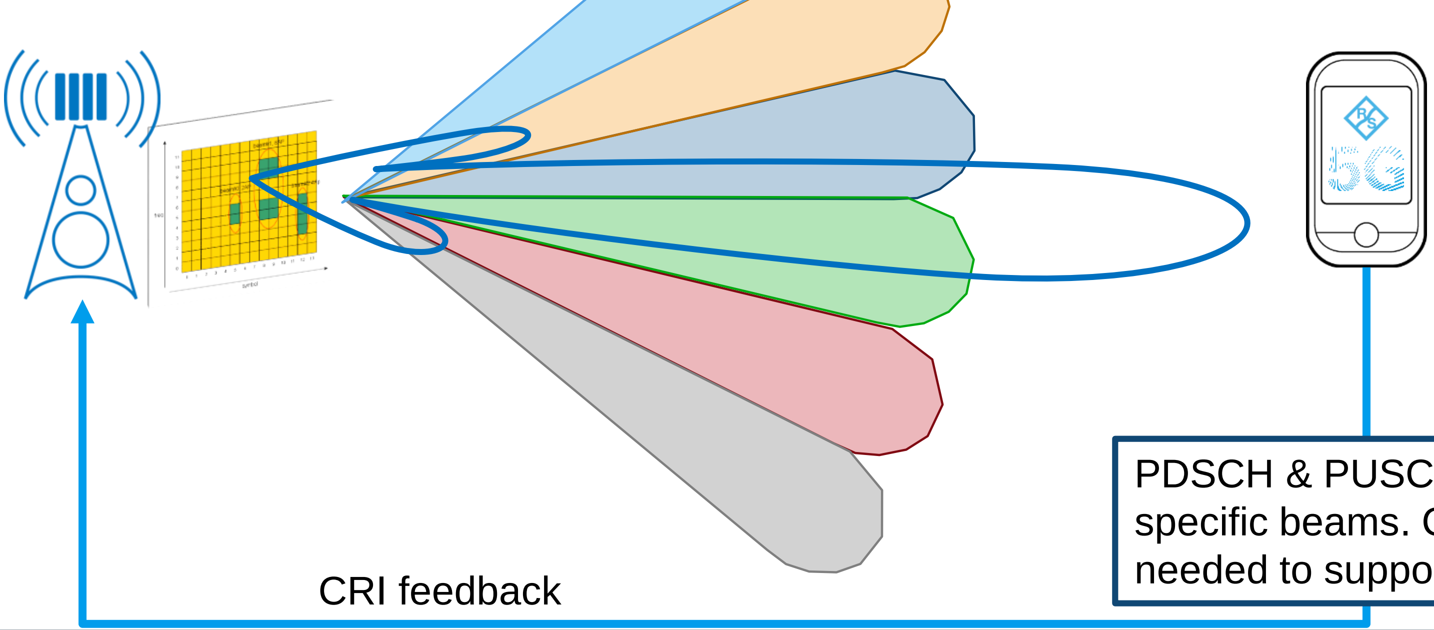
5G NR beamforming aspects

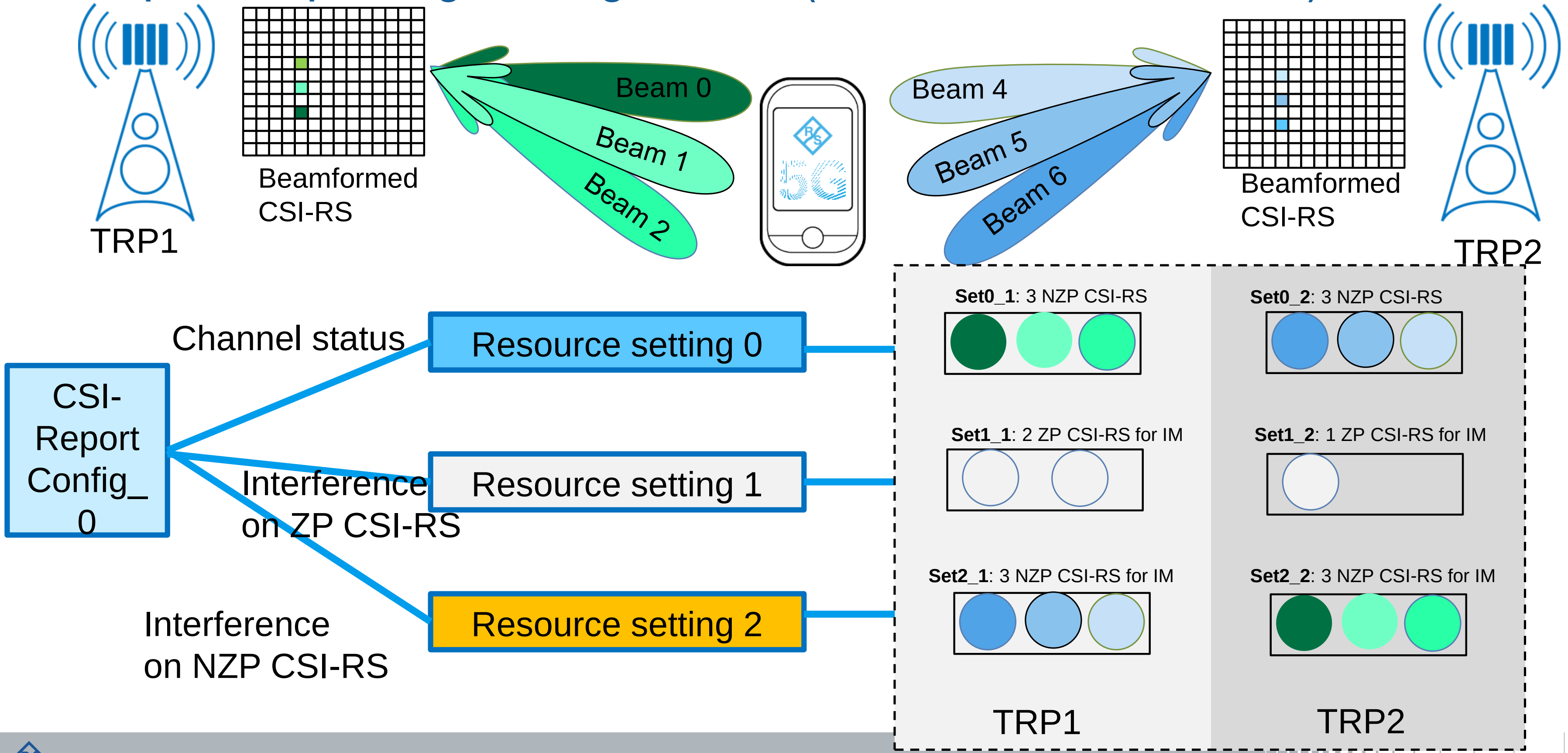
Same PCI, different SSB indices
+ UE specific CSI-RS for
beamforming support

gNB uses SSBs to be mapped on
„static“ beams.



PDSCH & PUSCH will be on UE
specific beams. CSI-RS and reporting
needed to support beam adjustment

Example: Reporting Configuration (2 TRPs and 3 Beams)



5G NR beamforming aspects

Same PCI, different SSB indices + UE specific CSI-RS & precoding for beamforming support

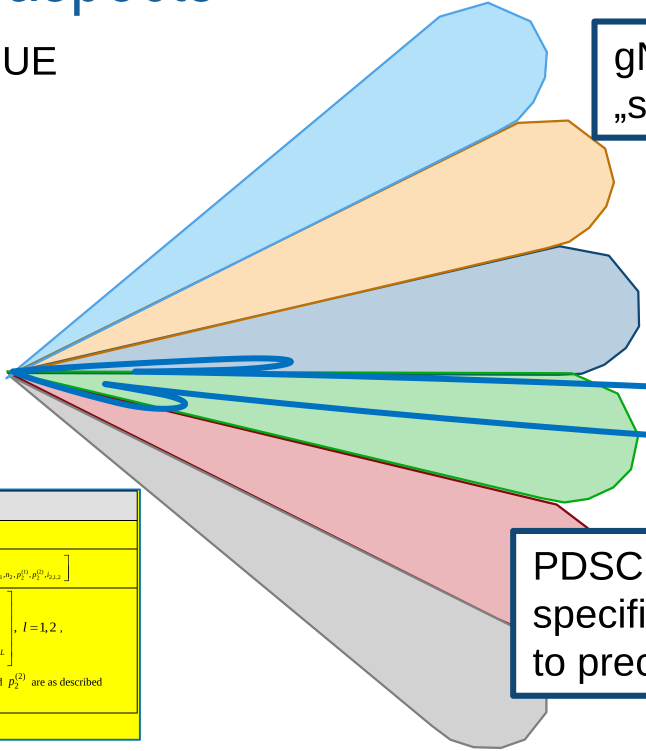
$$W^{1,2,1}_{l,m,p,n} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ \varphi_n \varphi_{p_1} v_{l,m} \end{bmatrix} \qquad W^{2,2,1}_{l,m,p,n} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ -\varphi_n \varphi_{p_1} v_{l,m} \end{bmatrix}$$

$$W^{1,4,1}_{l,m,p,n} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ \varphi_n \varphi_{p_1} v_{l,m} \\ \varphi_{p_2} v_{l,m} \\ \varphi_n \varphi_{p_2} v_{l,m} \\ \varphi_{p_3} v_{l,m} \\ \varphi_n \varphi_{p_3} v_{l,m} \end{bmatrix} \qquad W^{2,4,1}_{l,m,p,n} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ -\varphi_n \varphi_{p_1} v_{l,m} \\ \varphi_{p_2} v_{l,m} \\ -\varphi_n \varphi_{p_2} v_{l,m} \\ \varphi_{p_3} v_{l,m} \\ -\varphi_n \varphi_{p_3} v_{l,m} \end{bmatrix}$$

Layers	
$\upsilon = 1$	$W^{(1)}_{q_1,q_2,n_1,n_2,p_1^{(1)},p_1^{(2)},i_{2,1,1}} = W^1_{q_1,q_2,n_1,n_2,p_1^{(1)},p_1^{(2)},i_{2,1,1}}$
$\upsilon = 2$	$W^{(2)}_{q_1,q_2,n_1,n_2,p_1^{(1)},p_1^{(2)},i_{2,1,1},p_2^{(1)},p_2^{(2)},i_{2,1,2}} = \frac{1}{\sqrt{2}}\left[W^1_{q_1,q_2,n_1,n_2,p_1^{(1)},p_1^{(2)},i_{2,1,1}} \quad W^2_{q_1,q_2,n_1,n_2,p_2^{(1)},p_2^{(2)},i_{2,1,2}} \right]$

where $W^l_{q_1,q_2,n_1,n_2,p_l^{(1)},p_l^{(2)},c_l} = \frac{1}{\sqrt{N_1 N_2 \sum_{i=0}^{2L-1} \left(p_{l,i}^{(1)} p_{l,i}^{(2)} \right)^2}} \begin{bmatrix} \sum_{i=0}^{L-1} v_{m_1^{(i)},m_2^{(i)}} p_{l,i}^{(1)} p_{l,i}^{(2)} \varphi_{l,i} \\ \sum_{i=0}^{L-1} v_{m_1^{(i)},m_2^{(i)}} p_{l,i+L}^{(1)} p_{l,i+L}^{(2)} \varphi_{l,i+L} \end{bmatrix}$, $l = 1,2$,

and the mappings from i_1 to q_1, q_2, n_1, n_2, $p_1^{(1)}$, and $p_2^{(1)}$, and from i_2 to $i_{2,1,1}$, $i_{2,1,2}$, $p_1^{(2)}$ and $p_2^{(2)}$ are as described above, including the ranges of the constituent indices of i_1 and i_2.



gNB uses SSBs to be mapped on „static“ beams.

PDSCH & PUSCH will be on UE specific beams. Beam refinement due to precoding and PMI feedback

PMI & CRI feedback

3GPP RAN Rel-16 Study-Item / Work-Item Status (March 2019)

NR

NR Study-Item / Work-Item Description	Study-Item	Work-Item	Notes
NR Core and Performance part		Rel-15 WI	
NR MIMO enhancements	No Rel-16 SI	ongoing	
NR V2X	completed	ongoing	
NR in unlicensed band	completed	ongoing	
NR NOMA	completed		No Rel-16 work-item planned
2-step RACH for NR		ongoing	
NR over non-terrestrial networks	ongoing		No Rel-16 work-item planned
NR UE power savings	ongoing	planned	SI to be completed in June 2019
NR positioning	completed	ongoing	
NR eURLLC PHY enhancements	completed	ongoing	
NR mobility enhancements	No Rel-16 SI	ongoing	
Multi-RAT Dual Connectivity/Carrier Aggregation enh.	No Rel-16 SI	ongoing	
NR Remote interference management	completed	ongoing	

Source: RP-190750
Table lists important RAN1 and RAN2 led SI/WIs, does not include RAN4 band related SI/WIs, ITU related SI/WIs

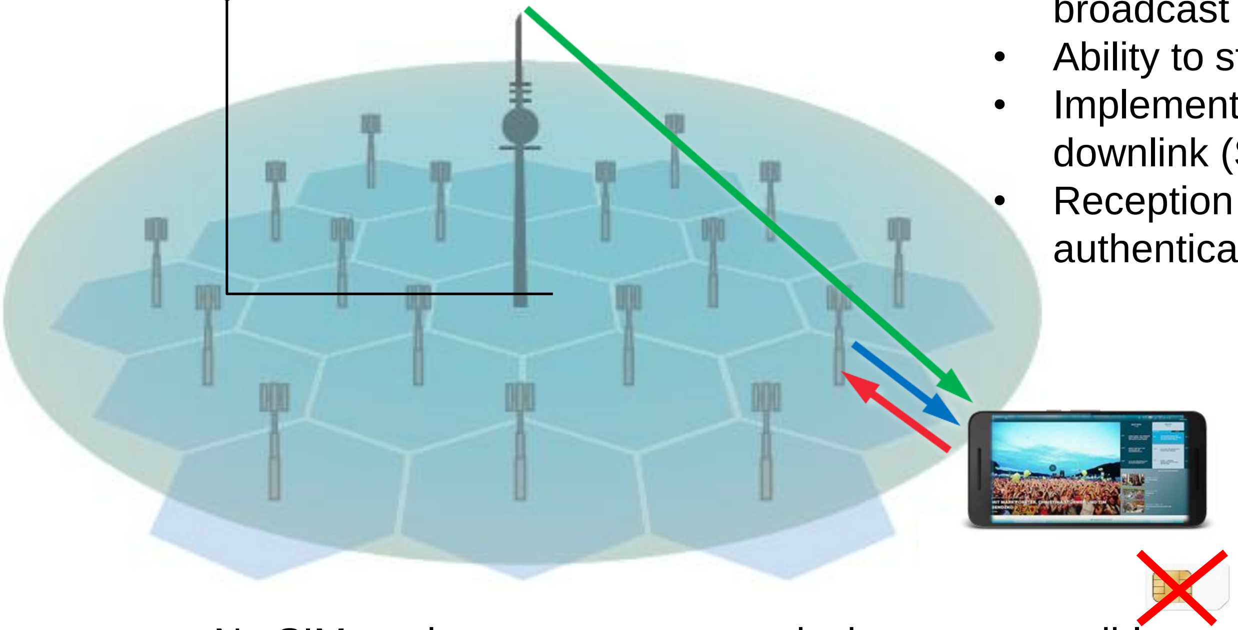
3GPP RAN Rel-16 Study-Item / Work-Item Status (March 2019)

NR Study-Item / Work-Item Description	Study-Item	Work-Item	Notes
NR Integrated Access and Backhaul	completed	ongoing	
Indoor channel model for Industrial IoT	ongoing		No follow-up work-item planned
NR Industrial IoT / Non-Public Networks (NPN)	completed	ongoing	
Optimisations on UE radio capability signaling	completed	ongoing	
SRVCC from 5G to 3G	completed	ongoing	
NR test methods	completed		
NR MIMO OTA test methods	ongoing		
2 RX antenna exception for vehicles	completed		
29 dBm UE power class for B41/n41		ongoing	to be completed in June 2109
NR in 7 – 24 GHz frequency range	ongoing		
NR design beyond 52.6 GHz	ongoing		
NR UE capability signaling	completed	ongoing	

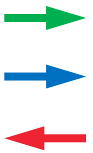
NR

Source: RP-190750
Table lists important RAN1/2/4 led SI/WIs, does not include RAN4 band related SI/WIs, ITU related SI/WIs

5G broadcast: FeMBMS – further enhanced MBMS, Rel. 14 feature

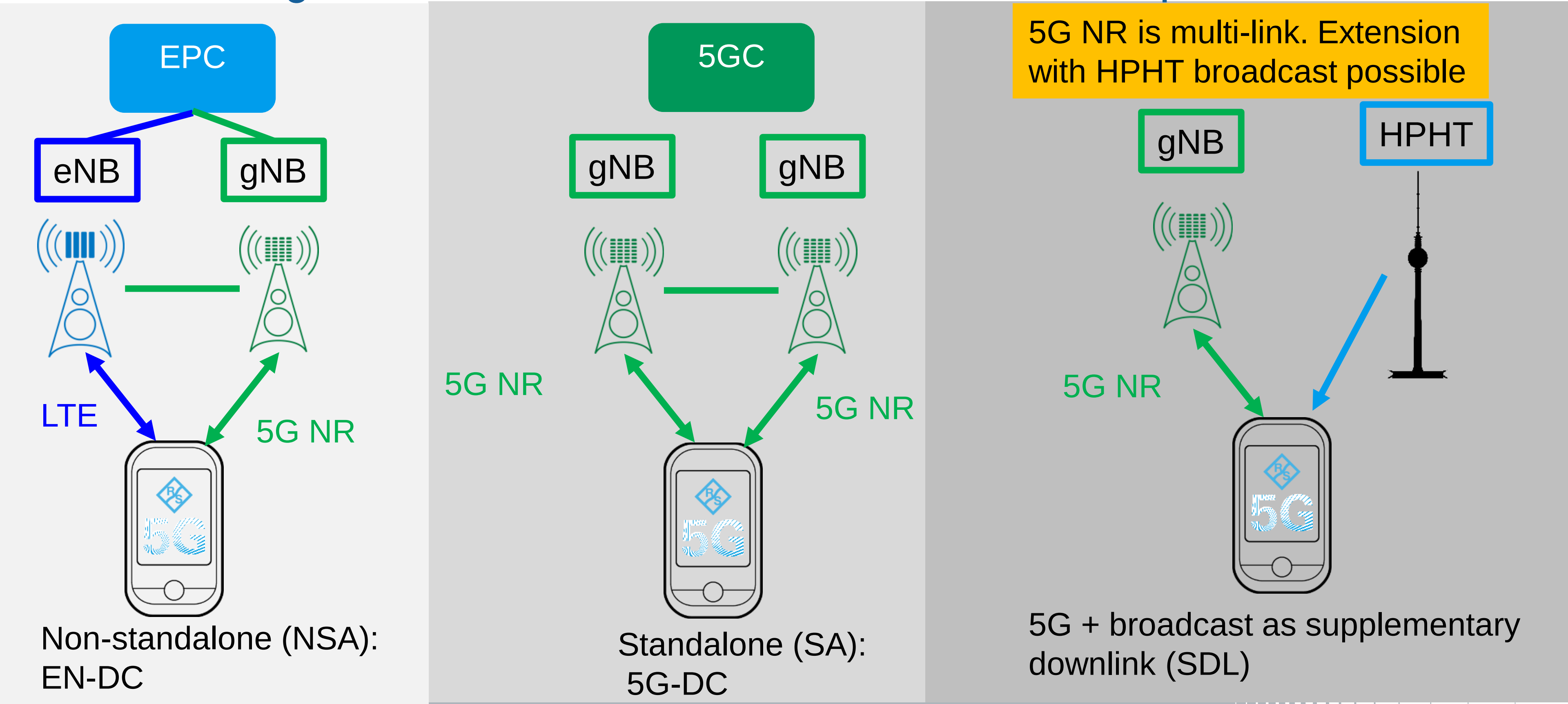


- High power high tower (HPHT) concept
- True broadcast, independent on PLMN
- Resolution + formats in line with conventional broadcast
- Ability to stream video over IP
- Implementation scenario using supplementary downlink (SDL) concept of cellular networks
- Reception possible without SIM & authentication

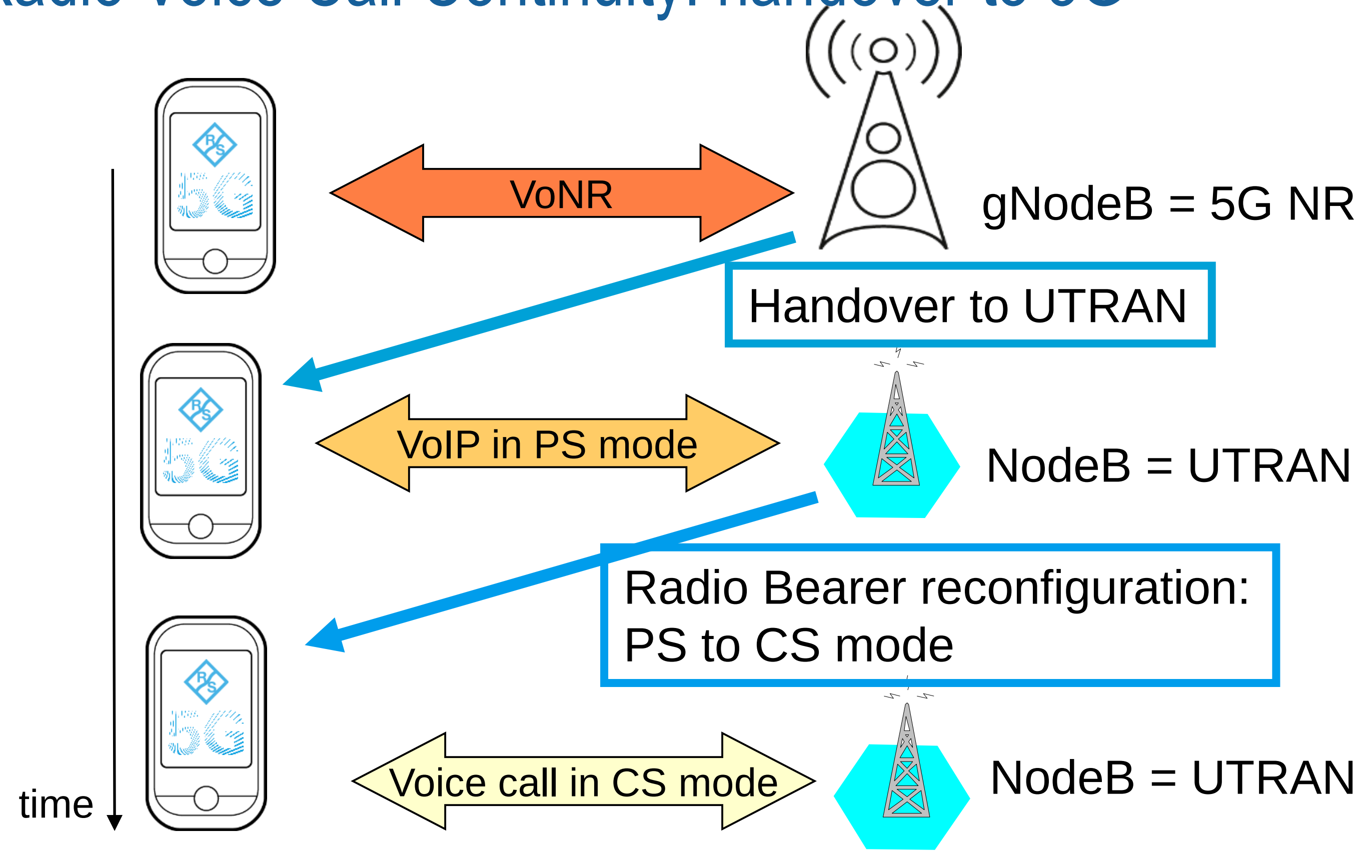


No SIM card necessary => new device types possible + true broadcast

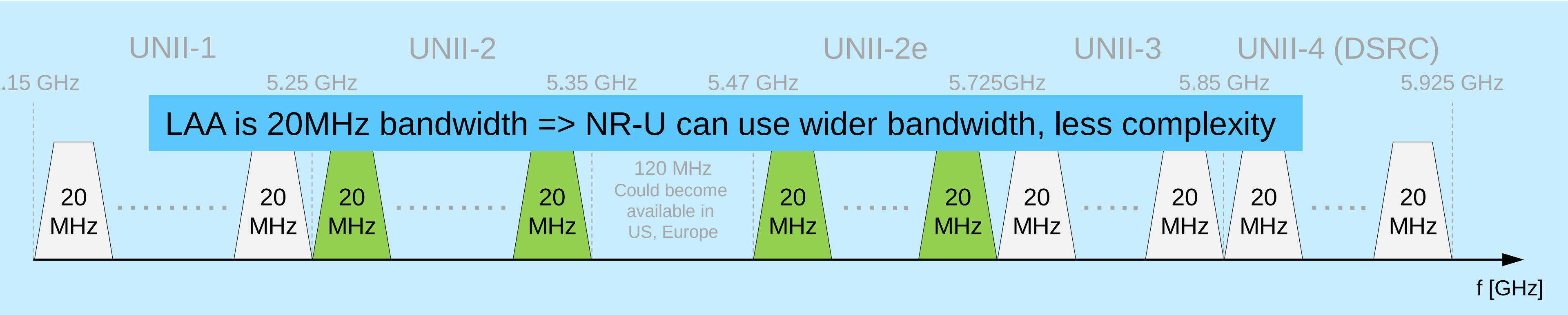
5G NR the right choice for broadcast: multi-link concept

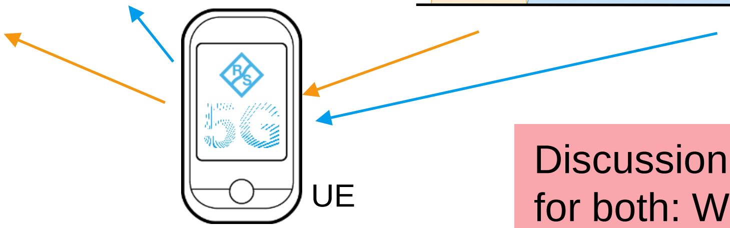


Single Radio Voice Call Continuity: handover to 3G



5G NR in Unlicensed Spectrum (NR-U)





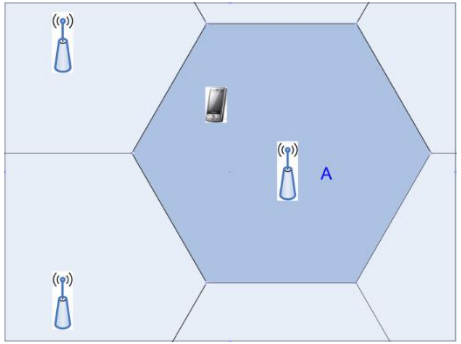
3 deployment scenarios.

- LTE licensed + NR-U
- 5G NR licensed + NR-U
- Standalone NR-U

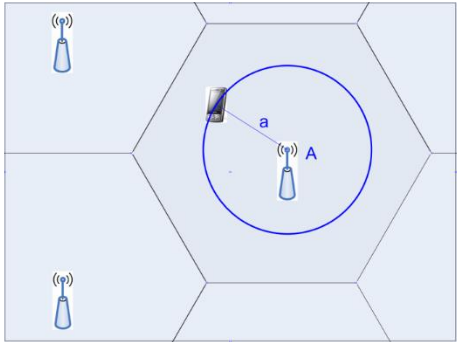
Discussion about common preamble for both: WLAN and 5G NR

5G NR positioning services

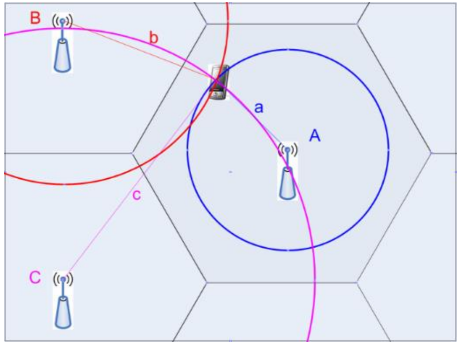
CID



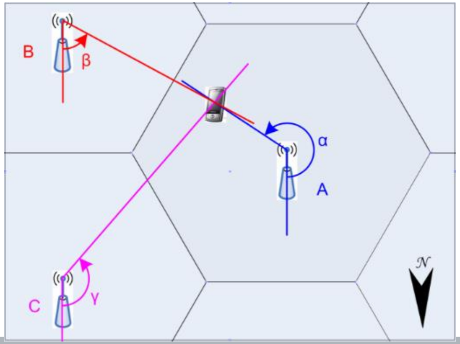
E-CID (RSRP/TOA/TADV)



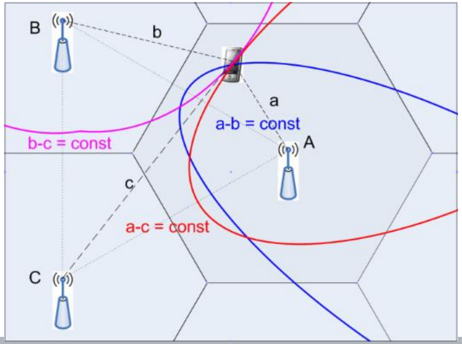
E-CID (RSRP/TOA/TADV) [Trilateration]



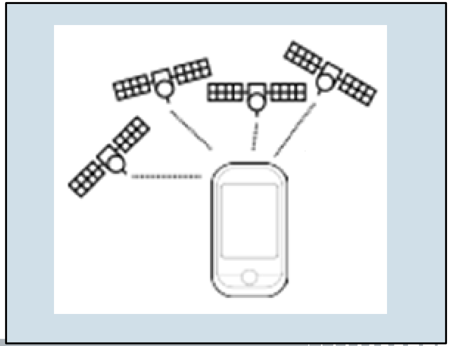
E-CID (AOA) [Triangulation]



Downlink / Uplink (O/U-TDOA) [Multilateration

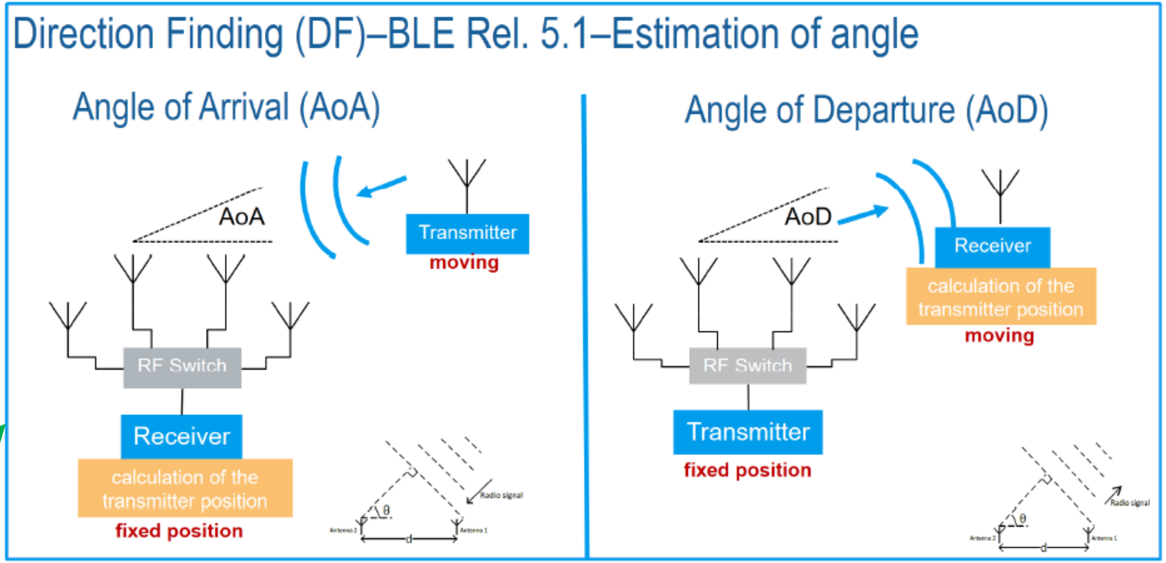


GNSS based



5G NR location based services – hybrid modes

5G NR link using OTDO/UTDOA for trilateration

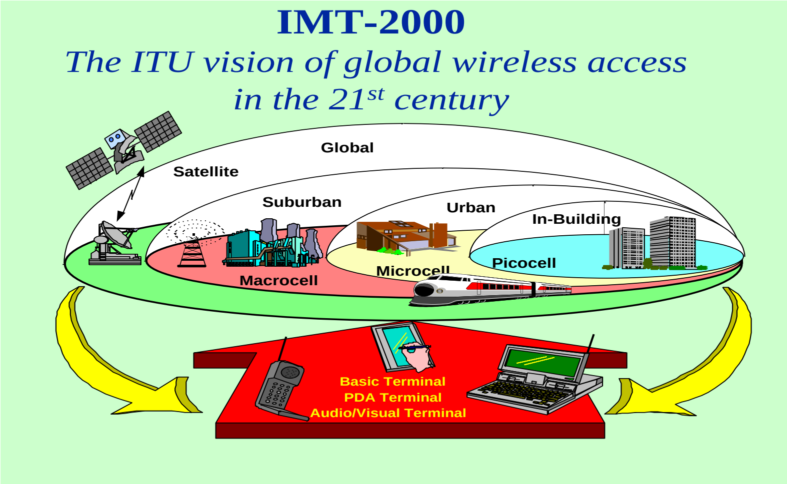


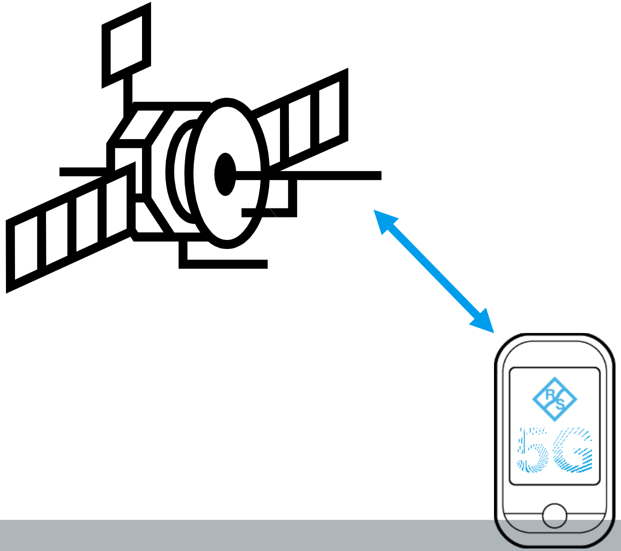
Bluetooth AoA for additional accuracy

5G NR over non-terrestrial networks

Déjá vu???

IMT2000 already defined the possibility of earth-to-satellite communcation. Never took off commercially



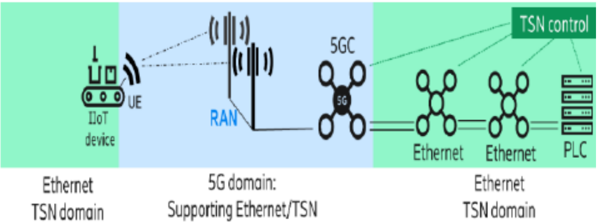


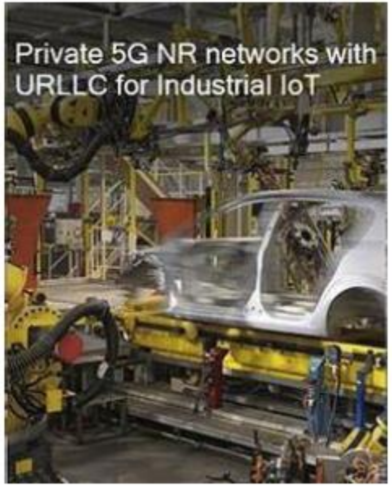
Rel. 16 work item for 5G NR over Non-terrestrial networks. E.g. UE to airborne or sattelite based gNBs.

5G NR industrial IoT

Industrial controller

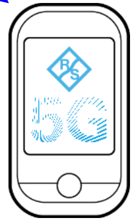
Support of time sensitive networks (TSN), i.e. common clock reference





Coordinated SIB / RRC broadcast

5GC



SDAP

PDCP

RLC

MAC

PHY

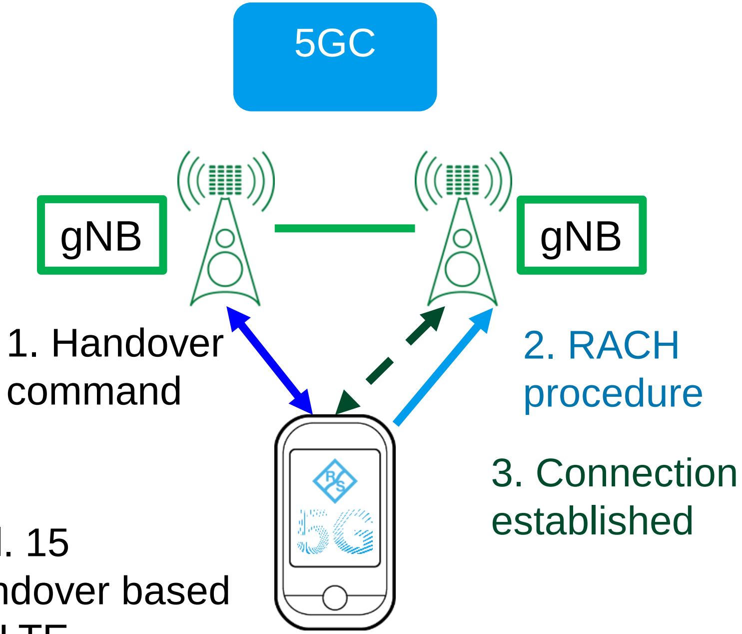
Ethernet RoHC or header removal

~~Ethernet header~~	Data

Intra-UE packet priorization, L2/L3

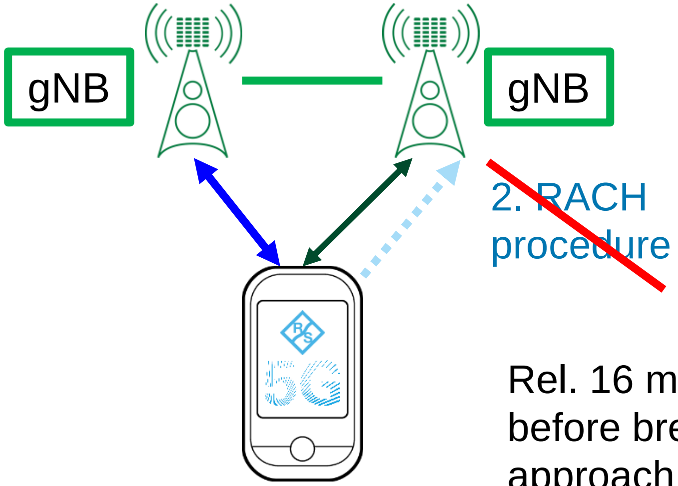
5G NR mobility enhancements

Rel. 15 mobility



Rel. 15 handover based on LTE approach

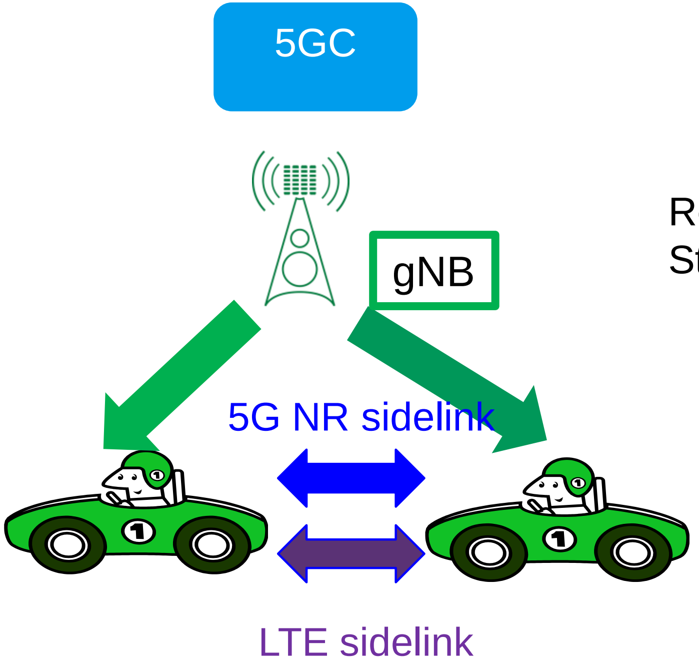
Rel. 16 mobility



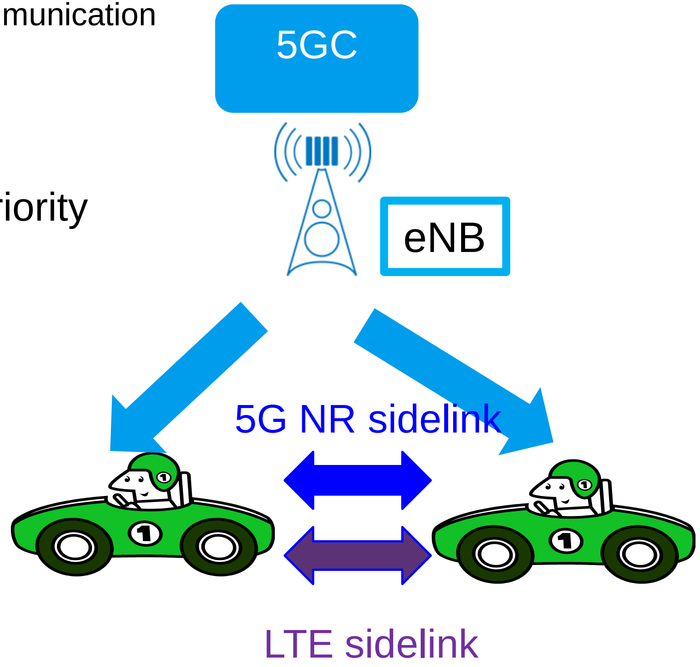
Rel. 16 make before break approach
+
RACH less handover procedure

5G NR C-V2X connection modes

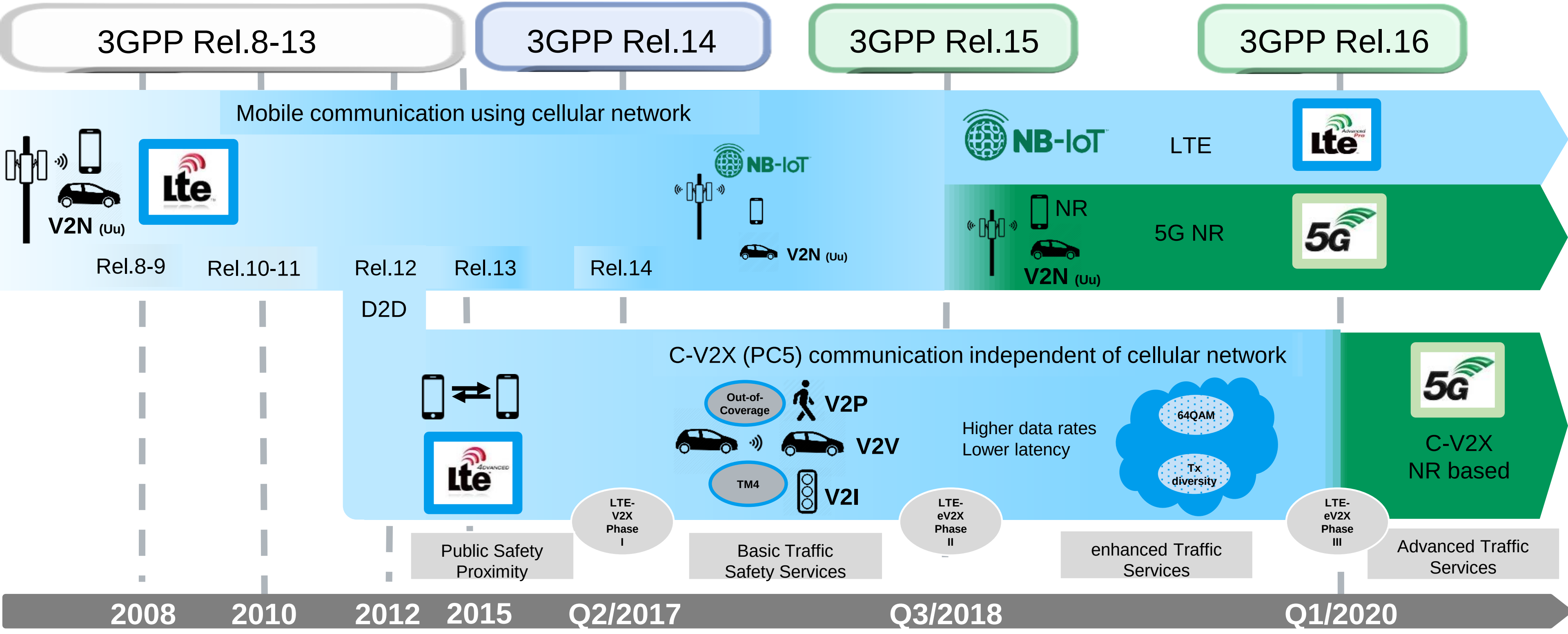
Enhancements of **LTE Uu and NR Uu** to control **NR sidelink** from the cellular network
Enhancements of **NR Uu** to control **LTE sidelink** from the cellular network
NR Sidelinkshall cover **Ultra Reliable** and **high Data** communication



Rel. 16 WI:
Standalone first priority



V2X - The road to 5G



Credits

Many graphics from this presentation were taken from:

Please use this link to get access to the online version of this technology book:

www.rohde-schwarz.com/5G-ebook/

“If you want to go fast, go alone.
If you want to go far, go together!”

African proverb