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5G : An Overview

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Overview and Requirements

RAN support for 5G use cases

eMBB, URLLC and mMTC

Capacity

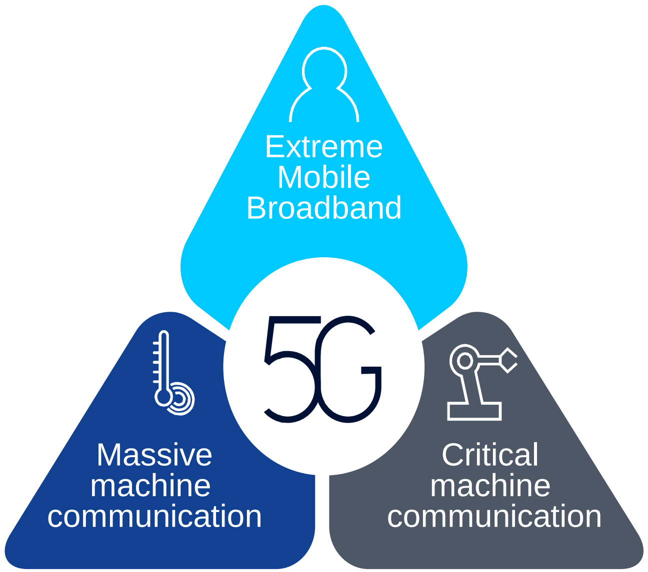
- Massive MIMO
- Wider carrier and transmit bandwidths
- cmWave and mmWave bands
- Shared uplink
- Multi-connectivity and NSA

Services

- Network slicing
- 5GC QoS

Connectivity

- NB-IoT and Cat M
- Signaling reduction (RRC Inactive)
- Contention access



Reliability

- Multi-connectivity
- Cloud native

Energy and operations

- Lean carrier
- Flexible numerology
- Machine learning

Latency

- Numerology support for shorter TTI
- Mini-slot overwriting
- Grant free UL
- RAN based QoS

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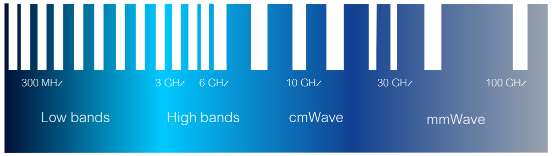
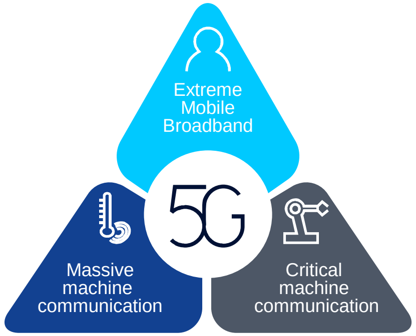
Technology enablers for 5G New Radio (NR) interface and RAN

New spectrum options

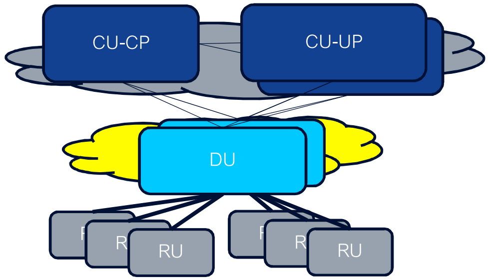
Massive capacity and throughput





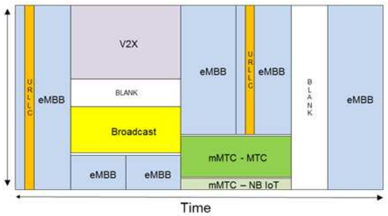
Cloud native

Flexible architecture



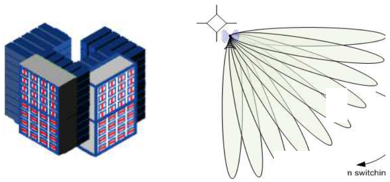
Flexible radio design

- *For all use cases – Lean design, high capacity, flexibility*



Massive MIMO

Massive capacity , improved end-user experience and coverage



Multi-connectivity and aggregation

End-user experience, extreme mobility, robustness and ultra reliability

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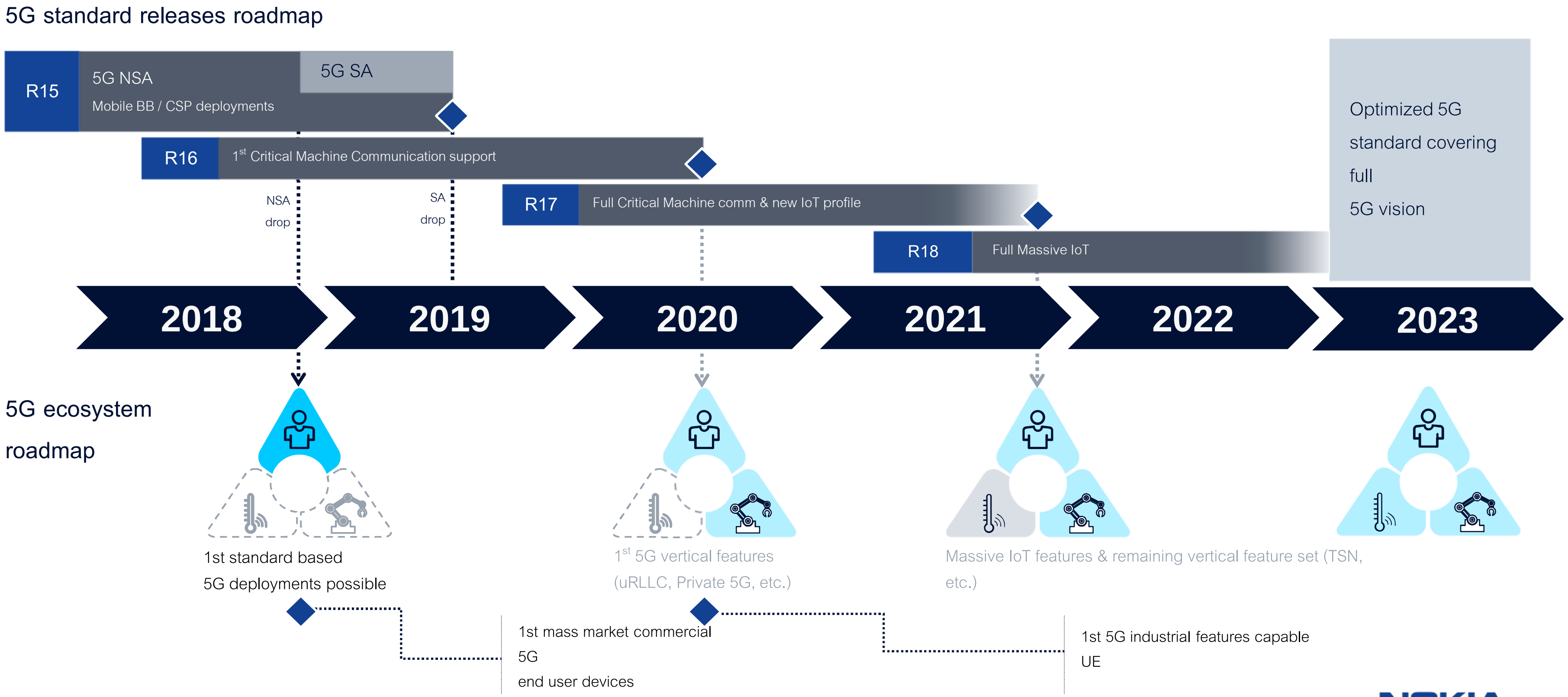
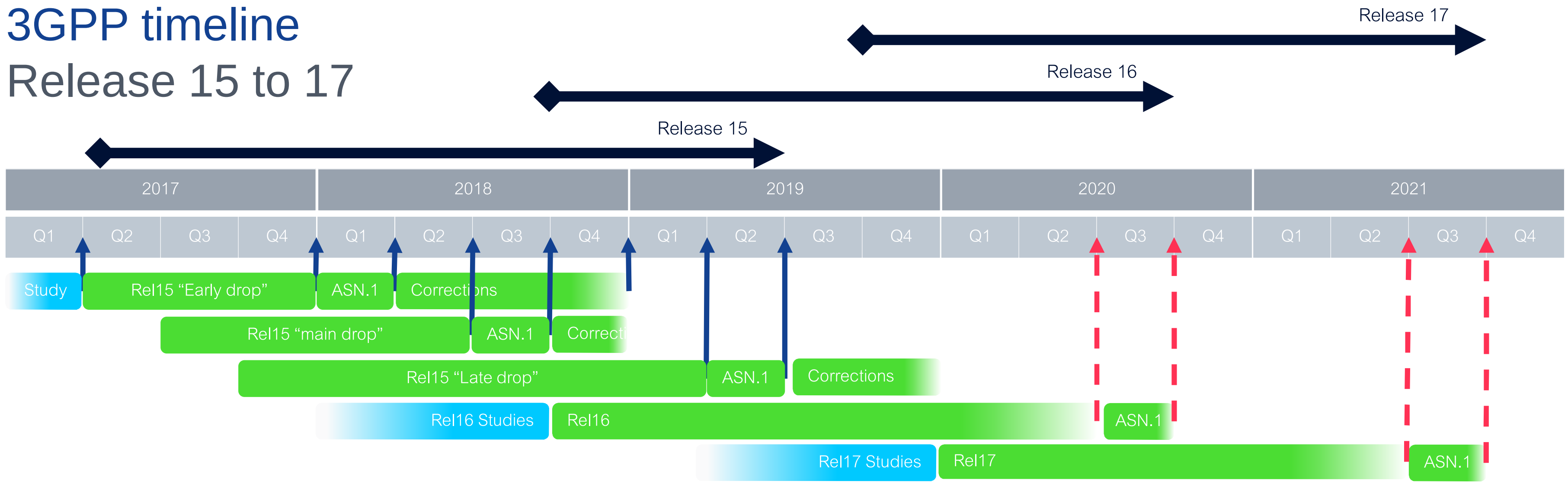
From 5G to Industrial 5G
Long term roadmap for Industrial applications



3GPP timeline
Release 15 to 17



Release 15: 5G First release focus on eMBB

- Split into three “drops”: “Early drop” 5G Non-Standalone (EN-DC NSA option 3) and 5G core (5GC); 5G Standalone (SA, option 2), eLTE (option 5); “Late Drop” for 5GC NSA solutions (NE-DC options 4& NG-EN-DC option 7) and NR-DC

Release 16: Industrial IoT (IIoT), Wireline convergence, Non-public networks, NR-unlicensed

- Studies completed in 2018, rel. 16 completion due March 2020 with ASN.1 due June 2020

Release17: NR-lite, IIoT enh, Beyond 52 GHz, Non-Terrestrial Networks

- Work started early 2020

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Requirements driven by use cases

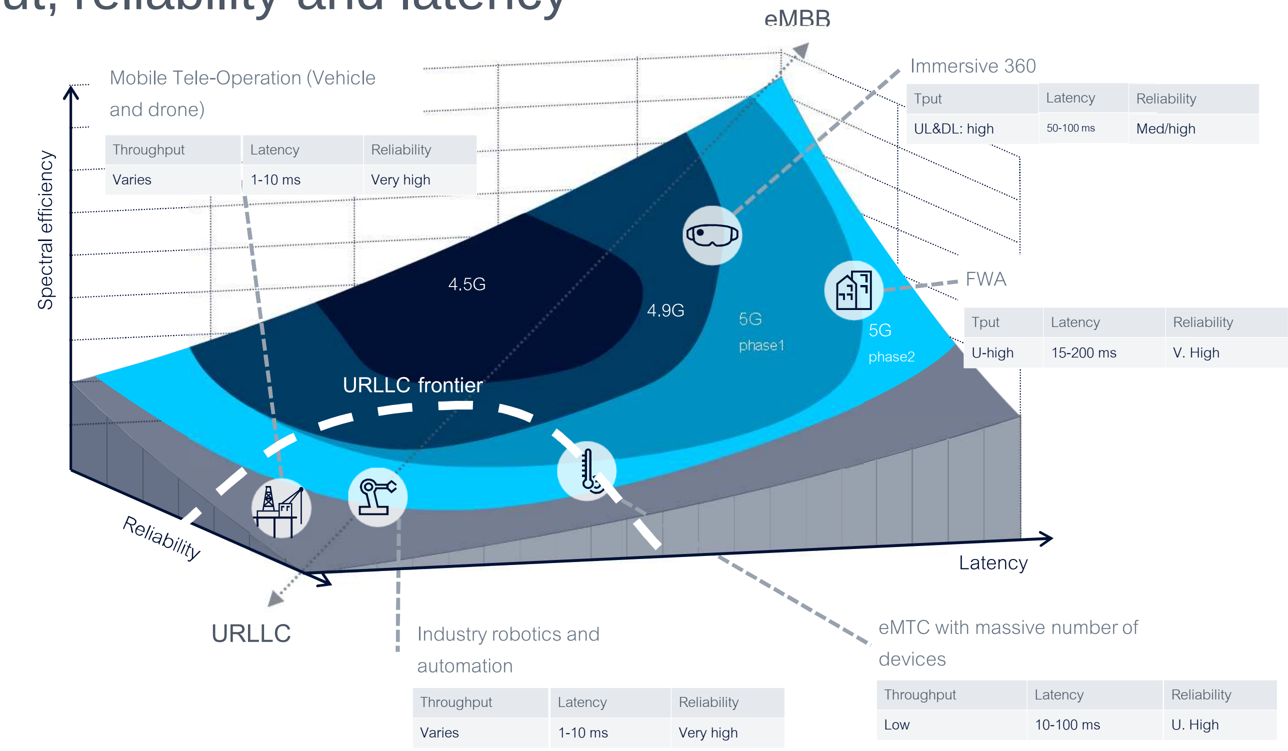
Evolution of throughput, reliability and latency

Requirement items

- Traffic profiles
- User density and service area
- Latency (1ms to 100x ms)
- Reliability & availability & survivability
- TSN requirements

Technical approaches

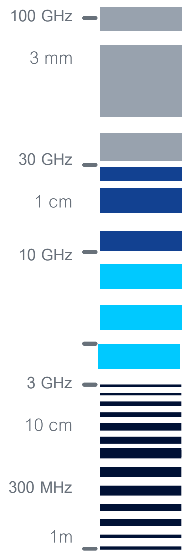
- Flexible function placement
- Flexible Radio design
- Multi-connectivity
- Disaggregated RAN
- RAN Slicing
- Transport FH & BH



Wide range of requirements and use cases and need to efficiently use the radio resource

Spectrum and Migration

Spectrum: 5G bands from 300 MHz to 100 GHz



		More spectrum ×	More beamforming ×	More cell sites =	A lot more capacity
		Bandwidth	Beam size	Cell density	Capacity
39 GHz	mm waves 30-100 GHz	Up to 2 GHz	Very small Very narrow beams	Very dense small cell	Ultra high capacity booster
26/28 GHz	cm waves 24-30 GHz	Up to 400 MHz	Small antenna Narrow beams	Dense small cell	Capacity booster
3.5 GHz	3-6 GHz	Up to 100 MHz	Medium antenna Medium beams	Urban Macro and small cell	Coverage and high capacity
600-900 MHz	<3 GHz	Up to 20 MHz	Large antenna Wide beams	All Macro and urban small cell	Coverage and new services

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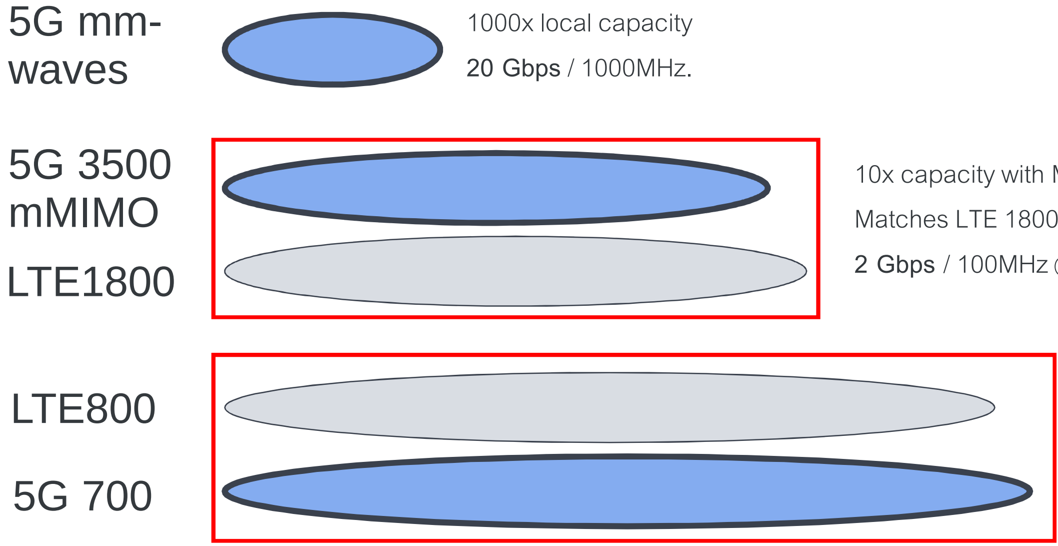
5G Spectrum and Coverage Footprint – combination of low and high bands



1000x local capacity

20 Gbps / 1000MHz.

10x capacity with Massive MIMO

Matches LTE 1800 coverage thanks to MMIMO

2 Gbps / 100MHz @3.5GHz

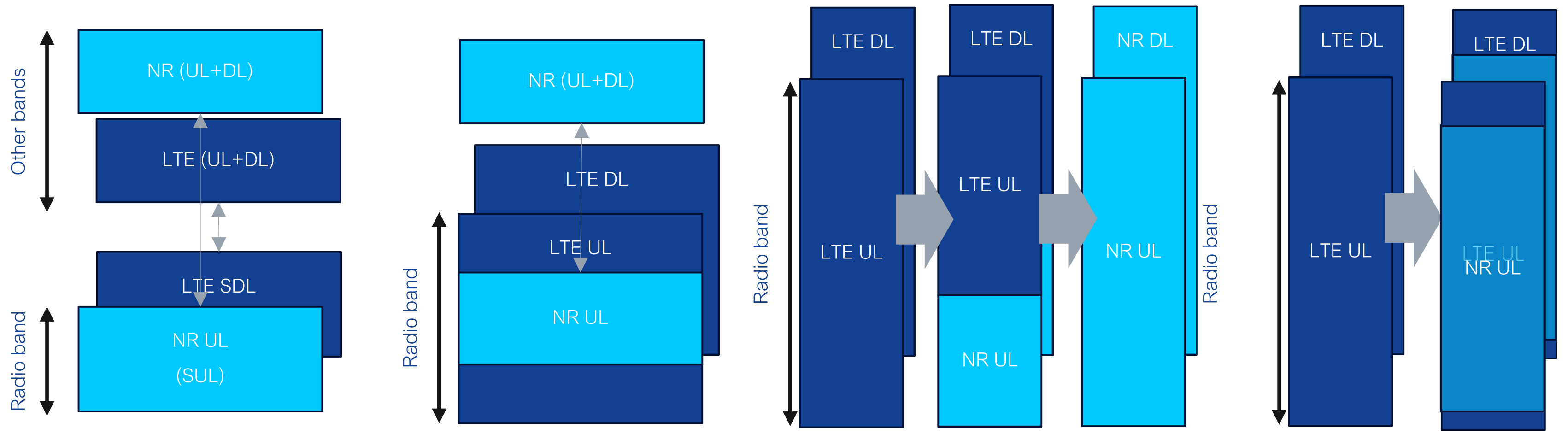
Large cells & Deep indoor

IoT and critical communications 200 Mbps /10MHz

The combination of different frequency bands fulfills diverse usage needs and coverage

New options for sharing LTE and NR spectrum

Supplemental UL, UL sharing, Spectrum refarming and DSS



Supplemental UL (SUL)	UL sharing	Spectrum refarming	Dynamic spectrum sharing (DSS)
Lower-frequency carrier for NR UL transmission in addition to NR's dedicated UL carrier.	NR UL resources overlap LTE UL band with UL schedulers managing split point	Longer term solution for legacy 2/3G and LTE bands	Transition solution mixing LTE and NR on same carrier

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Architecture

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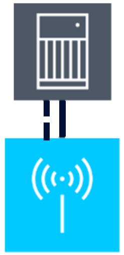
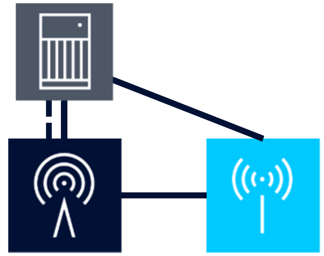
Stand-Alone (SA) and Non-Standalone (NSA)
3GPP background – New Radio (NR) functionality


NR (5G)


LTE/eLTE (4G) NR (5G)

Feature	Standalone (SA)	Non-standalone (NSA)
Master carrier	NR	LTE
Secondary carrier	-	NR
Core choice	5G core (5GC)	4G EPC
Operator perspective	Simple, high performance overlay	Leveraging existing 4G deployments
Vendor perspective	Independent RAN product	Requires tight interworking with LTE
End user experience	Peak bitrate set by NR Dedicated Low Latency transport	Peak bitrate is sum of LTE and NR Latency impacted if routed via LTE master

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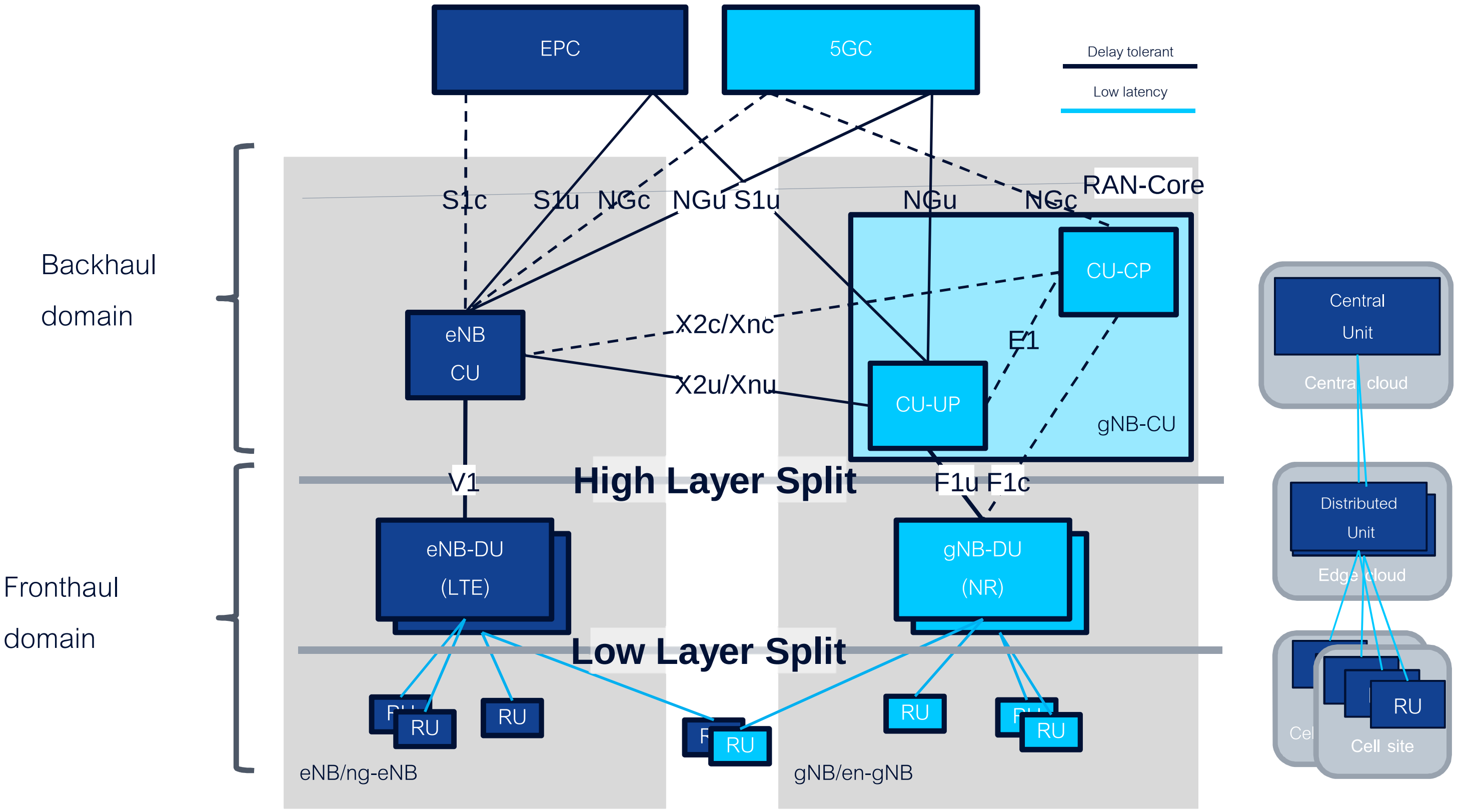
Functional RAN decomposition



Central Unit (CU)

- RRC, SDAP and PDCP
- User plane and control plane

Distributed Unit (DU)

- High-PHY layers, MAC and RLC

Radio unit (RU)

- Low-PHY layers

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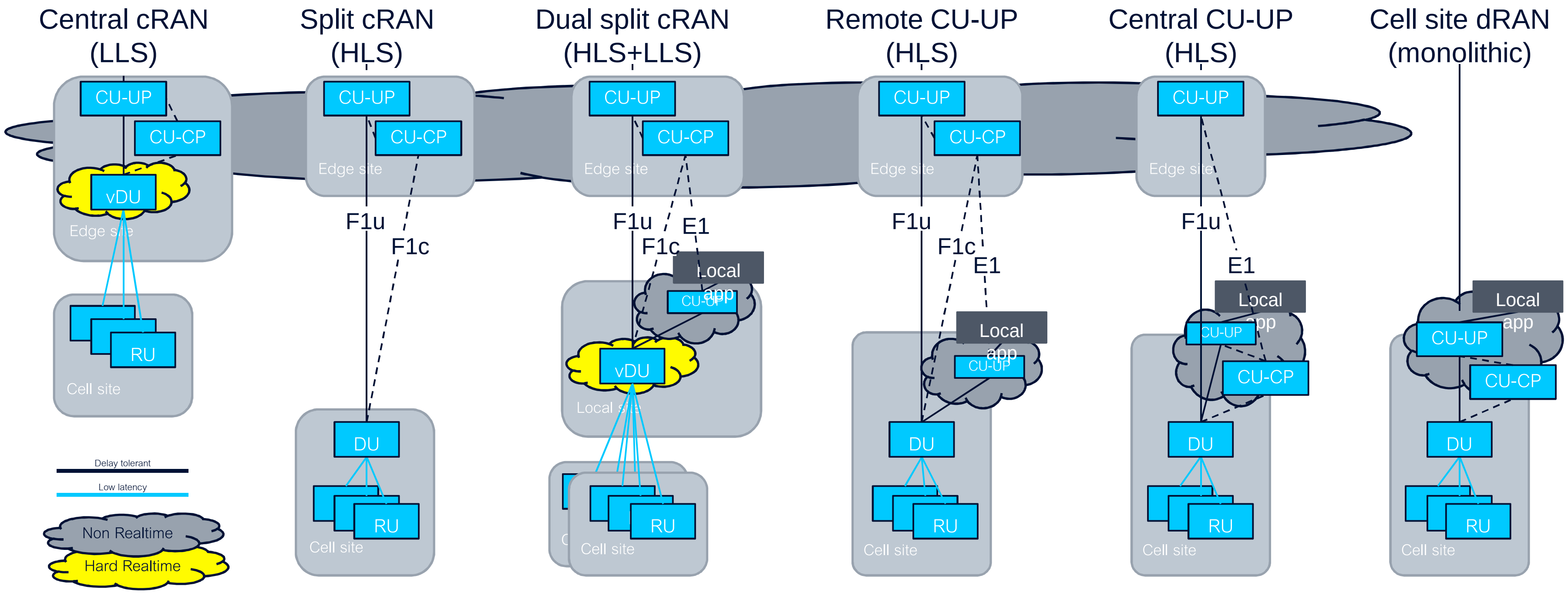
Flexible functions placement

Wide range of potential deployment use cases



DU: Digital Unit, CU: Central Unit, RU: Radio Unit. UP user plane, CP control Plane

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Radio interface

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Flexible radio design

“New Radio” (NR) numerology building on LTE

Radio	LTE	New Radio (NR)		
Bands	<4 GHz	< 3GHz	2-6 GHz	> 6 GHz
Multiple access	CP-OFDM / SC-OFDM	CP-OFDM / CP-OFDM (+ SC-OFDM)		
Duplex	FDD, TDD	FDD	TDD	
Sub-carrier (kHz)	15	15, 30, 60	15, 30, 60	60, 120
Carrier BW (MHz)	1.4 .. 20	5 .. 40	5 .. 100	50 .. 400
Carrier loading	90%	90 .. 97%	90 .. 98%	95%
Slot per 10ms frame	10	10-20	10-80	80
Channel codes	Turbo	LDPC (plus Polar for PBCH and PxCCH channels)		

NR radio interface: a more flexible OFDM than LTE

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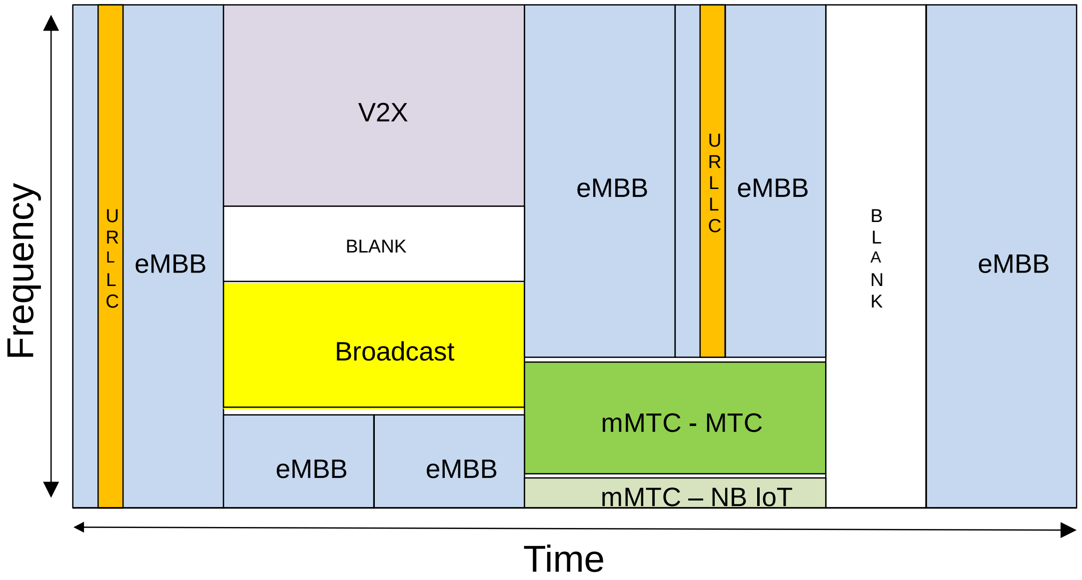
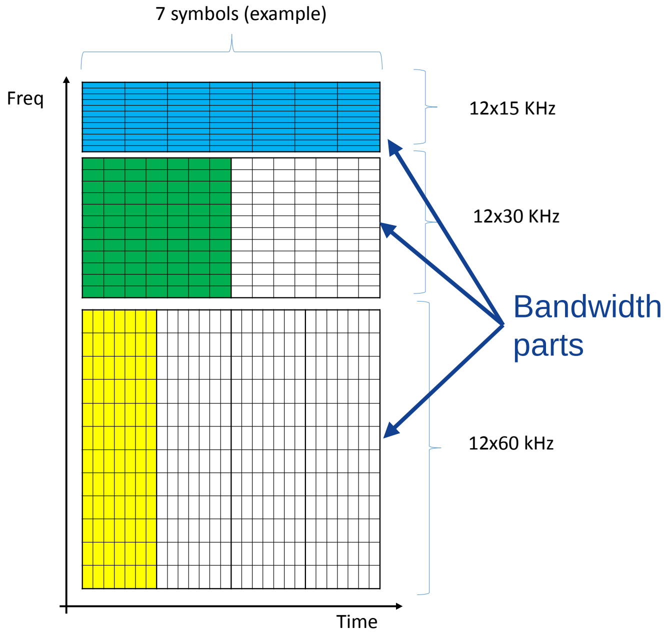
Flexible NR Framework





- NR provides flexible framework to support different services and QoS requirements
  - Scalable slot duration, mini-slot and slot aggregation
  - Self-contained slot structure
  - Traffic preemption for URLLC
  - Support for different numerologies for different services
  - Forward compatibility

- NR transmission is well-contained in time and frequency
  - Future features can be easily accommodated

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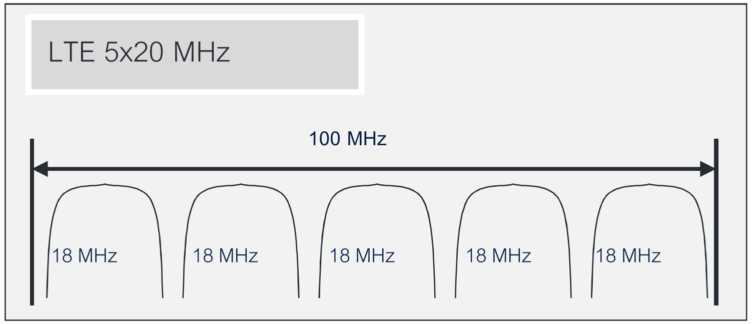
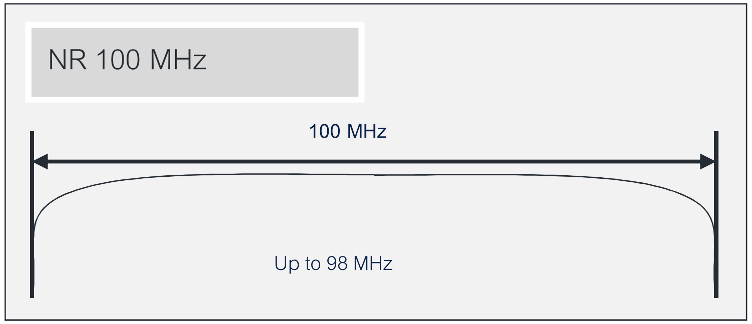
5G Enhances Spectral Utilization
Example: loading within 100 MHz spectrum allocation

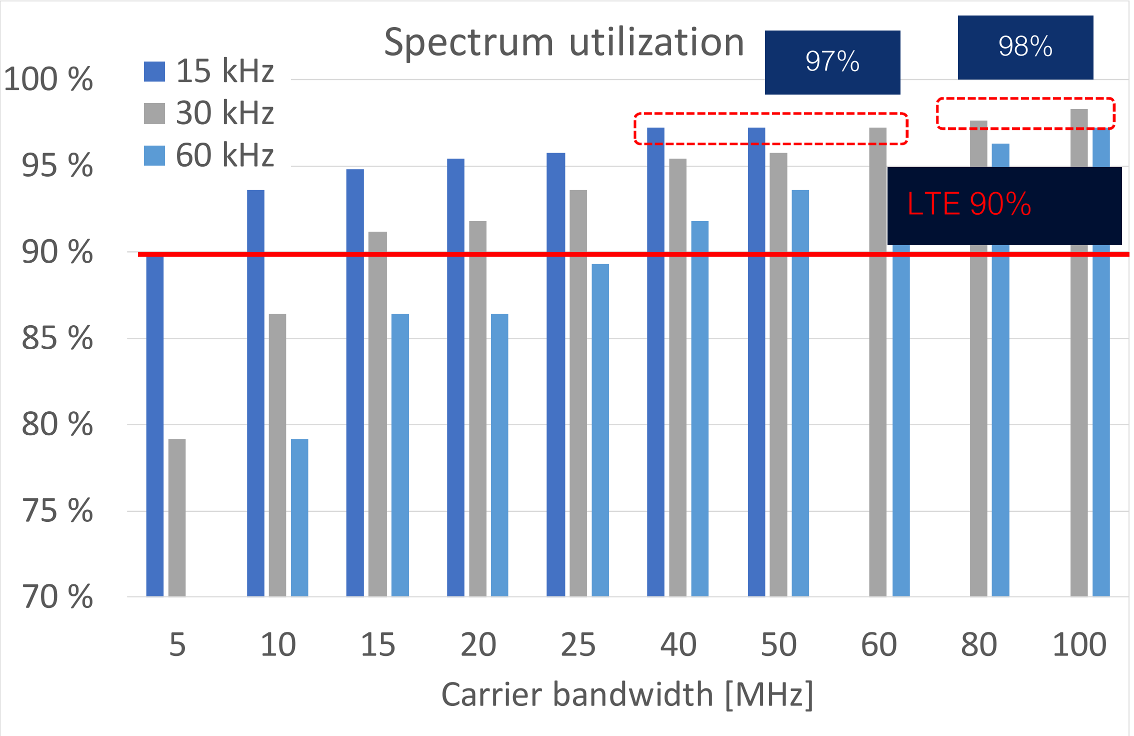




More efficient than multicarrier LTE

- LTE limited to 100 PRB per 20 MHz carrier (i.e. 90% of carrier bandwidth)
- NR supports wider carriers and larger transmit BW (up to 98% of carrier BW)
- No unnecessary guard bands between carriers

5G Spectrum Utilization up to 98%



5G spectrum utilization is up to 98% of carrier bandwidth with 40-100 MHz bandwidth

5G utilization is more than 95% with at least 20 MHz bandwidth with 15 kHz subcarrier spacing

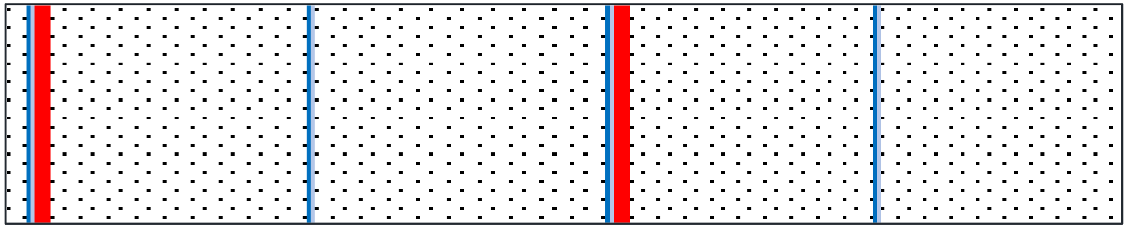
LTE utilization is 90%

Flexible radio design

Lean carrier also offers base station power savings

= Primary synchronization
= Secondary synchronization
= Broadcast channel
= LTE cell reference signals

LTE



Very limited capability for base station power savings due to continuous transmission of cell reference signals

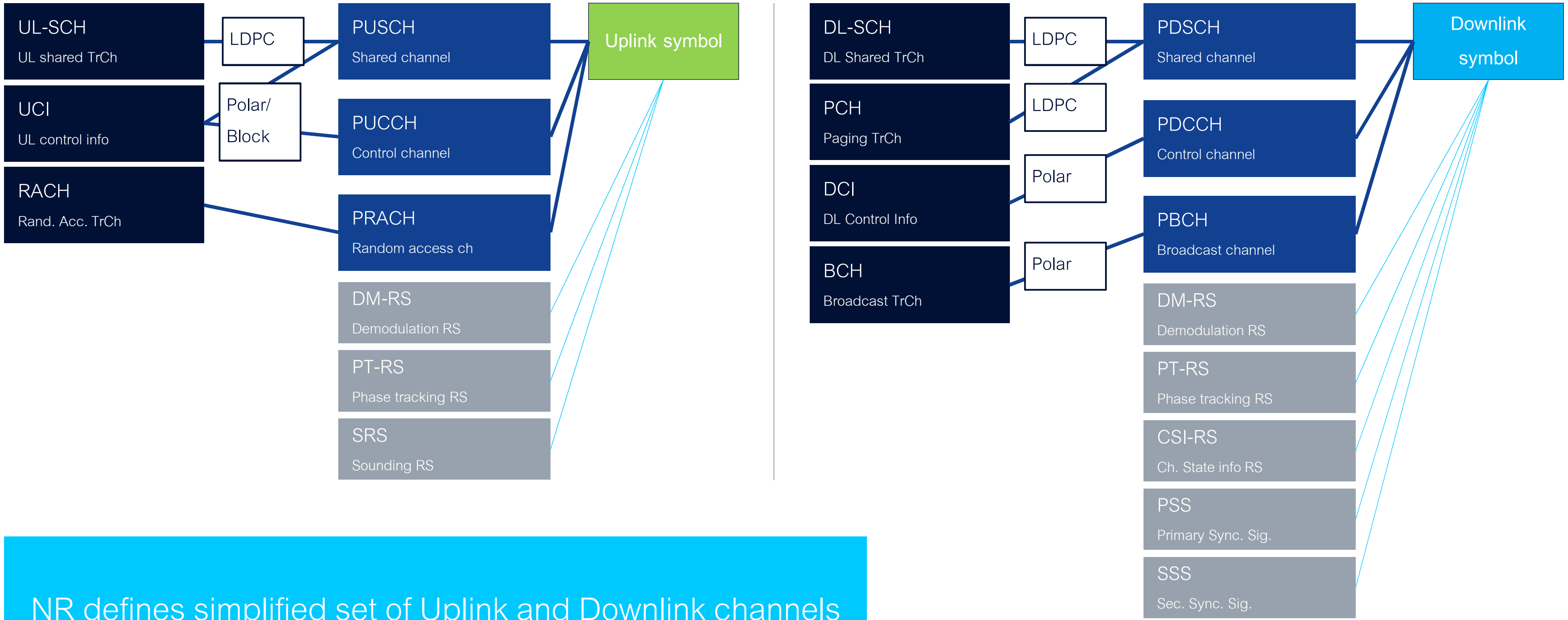
- Cell specific reference signal transmission 4x every millisecond
- Synchronization every 5 ms
- Broadcast every 10 ms

NR

5G enables advanced base station power savings

- No cell specific reference signals
- Synchronization every 20 ms
- Broadcast every 20 ms

Flexible radio design
Mapping and coding of Channels and Physical layer Signals to Symbols



NR defines simplified set of Uplink and Downlink channels

- RS: Reference signal
- CH: Channel
- SCH: shared Channel

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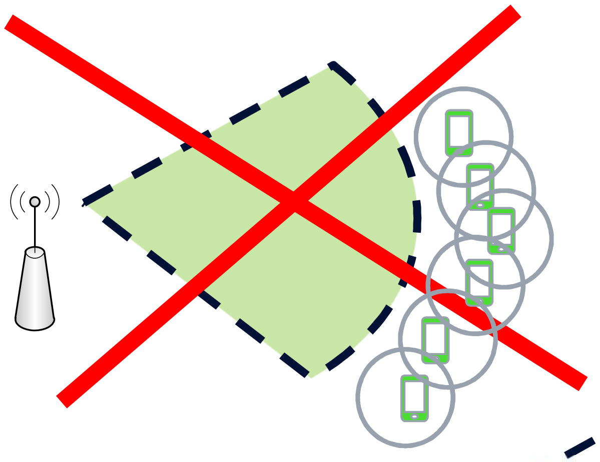
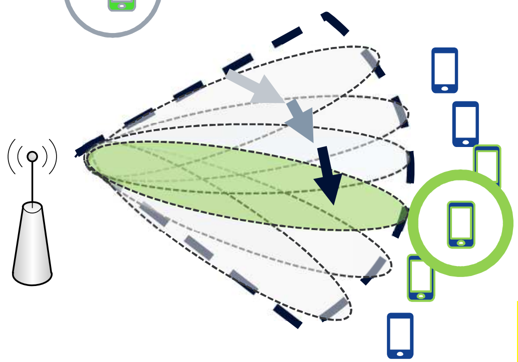
Beamforming – How to provide coverage for the common channels



The common channels need to be heard by all UEs.

But narrow beams, by definition, do not provide wide-area coverage.

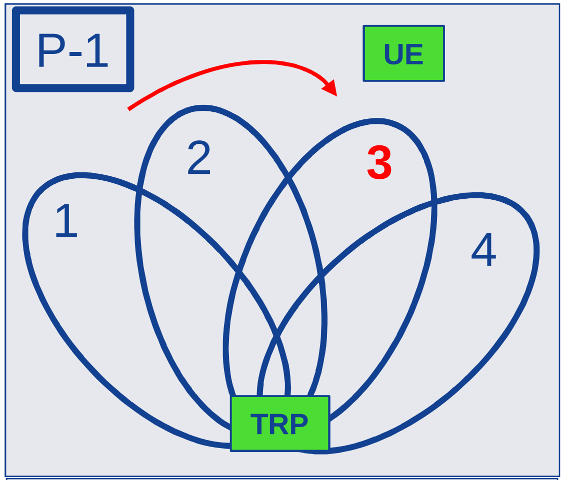


The solution is: **beam sweeping.**

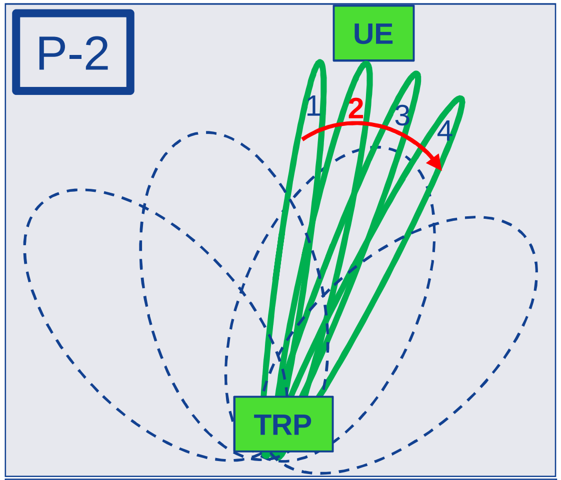
The common channels are transmitted in sequence across all beams, like a light-house.

*Common channels: Synch, PBCH, (minimum) system info, paging

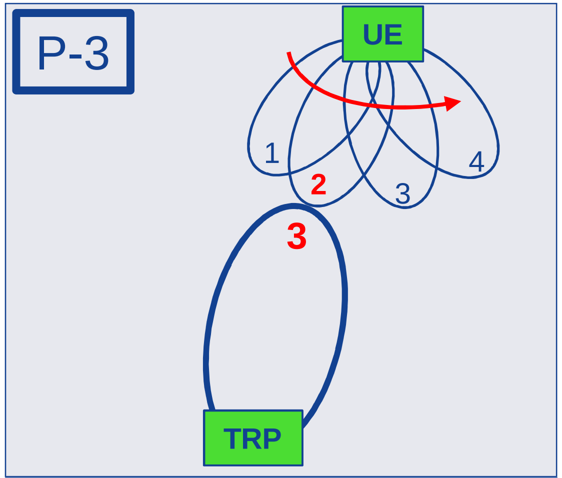
Downlink MIMO Framework: Beam Management



- Initial gNB Beam Acquisition
- SSB



- gNB Beam Refinement
  - CSI-RS (RSRP)
  - CSI-RS (CRI)
  - SRS



- UE Beam Refinement

Forming beam ports for MIMO transmission (TX and RX)

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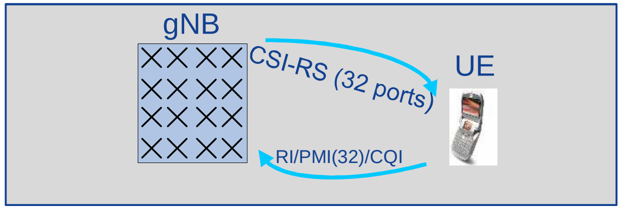
DL-MIMO Operation – Sub-6GHz

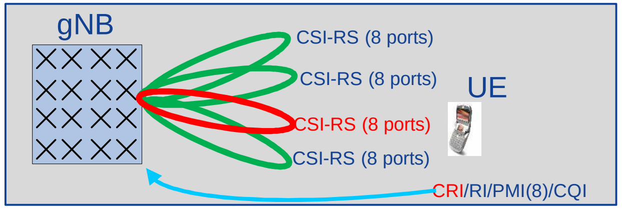
Single CSI-RS

- CSI-RS may or may not be beamformed
- Leverage codebook feedback
- Analogous to **LTE Class A**
- Process:
  - gNB transmit CSI-RS
  - UE computes RI/PMI/CQI
- Maximum of 32 ports in the CSI-RS (codebooks are defined for up to 32 ports)
- Typically intended for arrays having 32 TXRUs or less with no beam selection (no CRI)



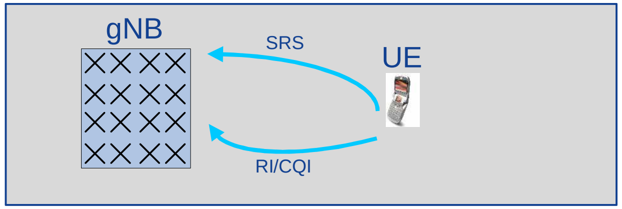
Multiple CSI-RS

- Combines beam selection with codebook feedback
- Analogous to **LTE Class B**
- Process:
  - gNB transmits one or more CSI-RS, each in different “directions”
  - UE computes CRI/PMI/CQI
- Supports arrays having arbitrary number of TXRUs
- Max 32 ports per CSI-RS



SRS-Based

- Exploits TDD reciprocity
- Similar to SRS operation in LTE
- Supports arrays having an arbitrary number of TXRUs.
- Process:
  - UE transmits SRS
  - Base computes TX weights

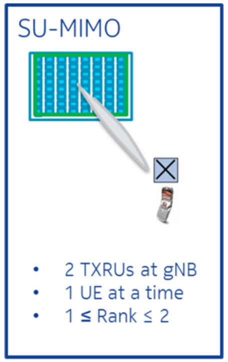


Disclaimer: NR-MIMO is flexible enough to support many variations on what is described on this slide

DL-MIMO Operation – Above 6GHz

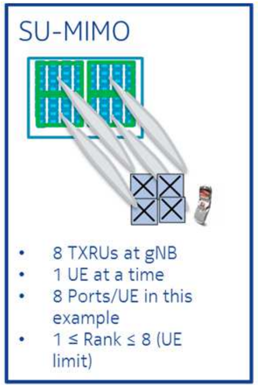
Single Panel Array

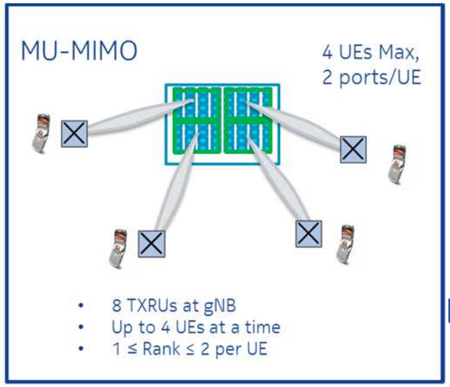
- Combination of RF Beamforming and digital precoding at baseband
- RF Beamforming is typically 1RF BF weight vector per polarization: a single “Cross-Pol Beam”
- 2 TXRUs, Single User MIMO only
- Baseband Precoding Options:
  - None (rank 2 all the time)
  - CSI-RS based (RI/PMI/CQI)
  - SRS-based (RI/CQI)



Multi-Panel Array

- Combination of RF beamforming and digital precoding at baseband
- RF Beamforming is typically 1RF BF weight vector per polarization per panel:
- One “Cross-Pol Beam” per sub-panel
- Number of TXRUs = 2 x # of panels
- Baseband Precoding Options:
  - CSI-RS based (RI/PMI/CQI)
  - SRS-based (RI/CQI)
- SU- and MU-MIMO (typically one UE per Cross-Pol Beam)





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Some radio performance trends

Downlink Massive MIMO: NR vs LTE: 16 and 32 TXRUs – Case Study

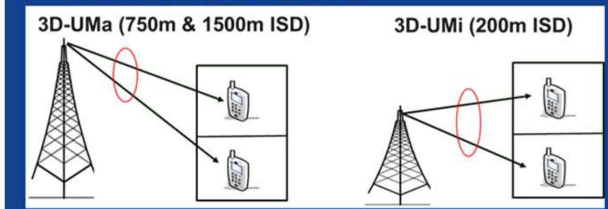
LTE:

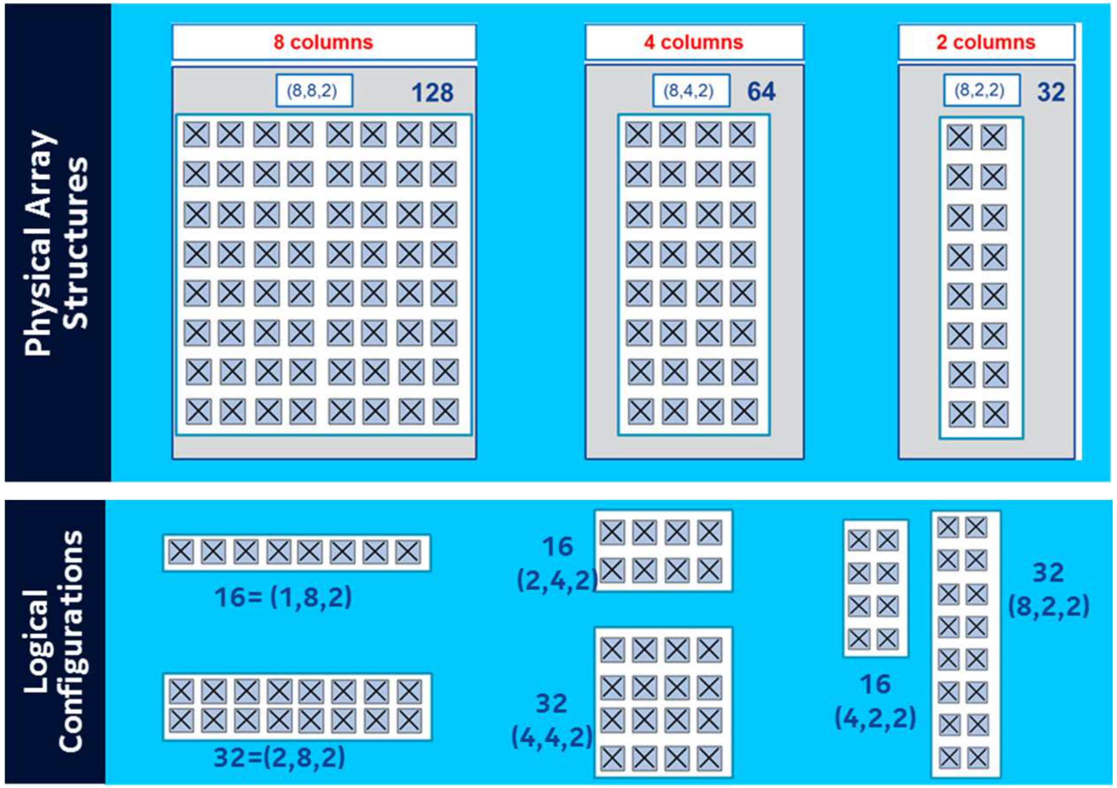
- **Rel-13 Codebook**
  - **16 Ports and 32 Ports, Maximum Rank = 8**
  - **(32 ports=Rel-13 extension CB approved in Rel-14)**
- **Rel-14 codebook (Advanced CSI CB)**
  - **16 Ports and 32 Ports, Maximum Rank = 2**

NR:

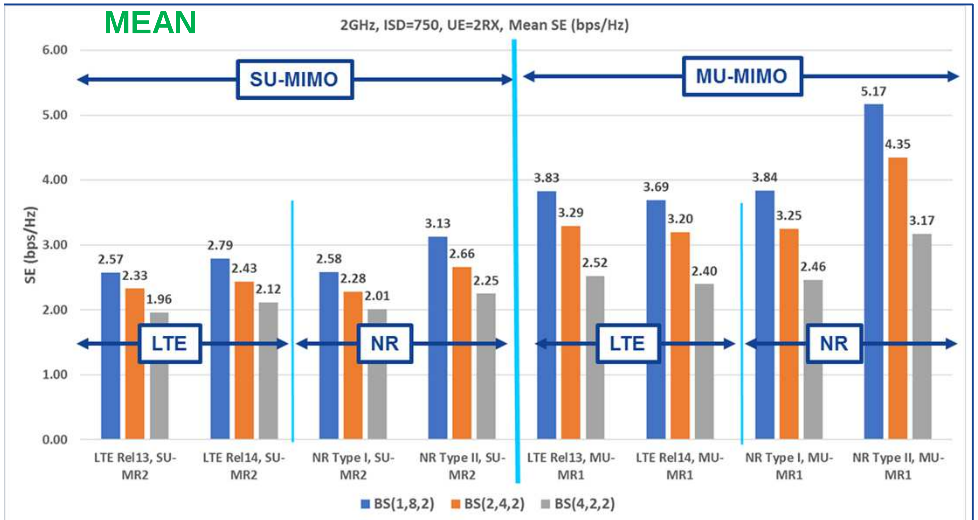
- **NR Codebook Type I**
  - **16 Ports and 32 Ports, Maximum Rank = 8**
- **NR Codebook Type II**
  - **16 Ports and 32 Ports, Maximum Rank = 2**

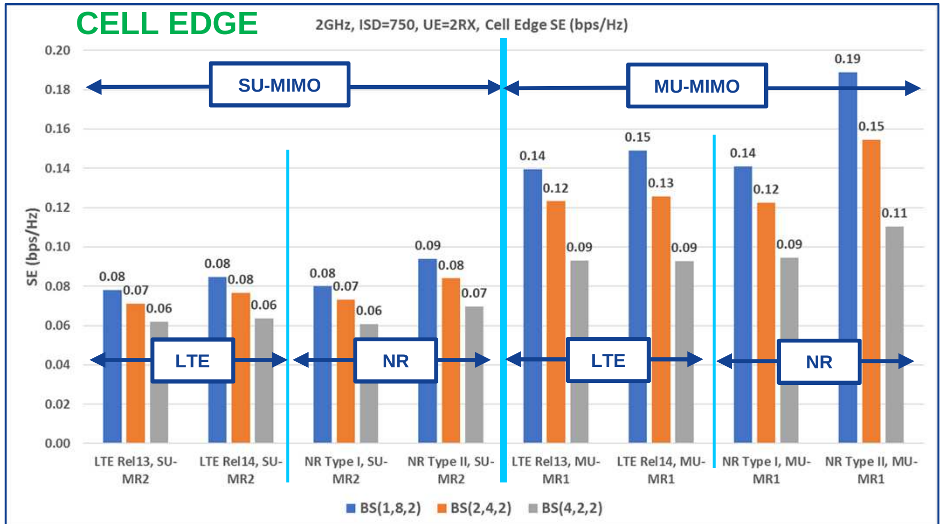
- **Scenarios at 2GHz**





LTE vs NR: DL Codebook Performance at 2GHz (full buffer traffic)





SU-MIMO:

- Slight gain from Rel-13 to Rel-14: 10%
- Bigger gain from NR Type I to NR Type II: 10-20%
- NR Type I CB performs similarly to LTE Rel-13 CB
- NR Type II CB outperforms LTE Rel-13, LTE Rel-14, NR Type I

MU-MIMO:

- Large gain over SU-MIMO for all codebooks
- LTE Rel-13 CB and Rel-14 CB and NR Type I CB all perform similarly
- NR Type II CB provides significant gain over other CBs

Array Configuration:

- The wide array significantly outperforms the other array configurations in mean and cell edge.

NR vs LTE:

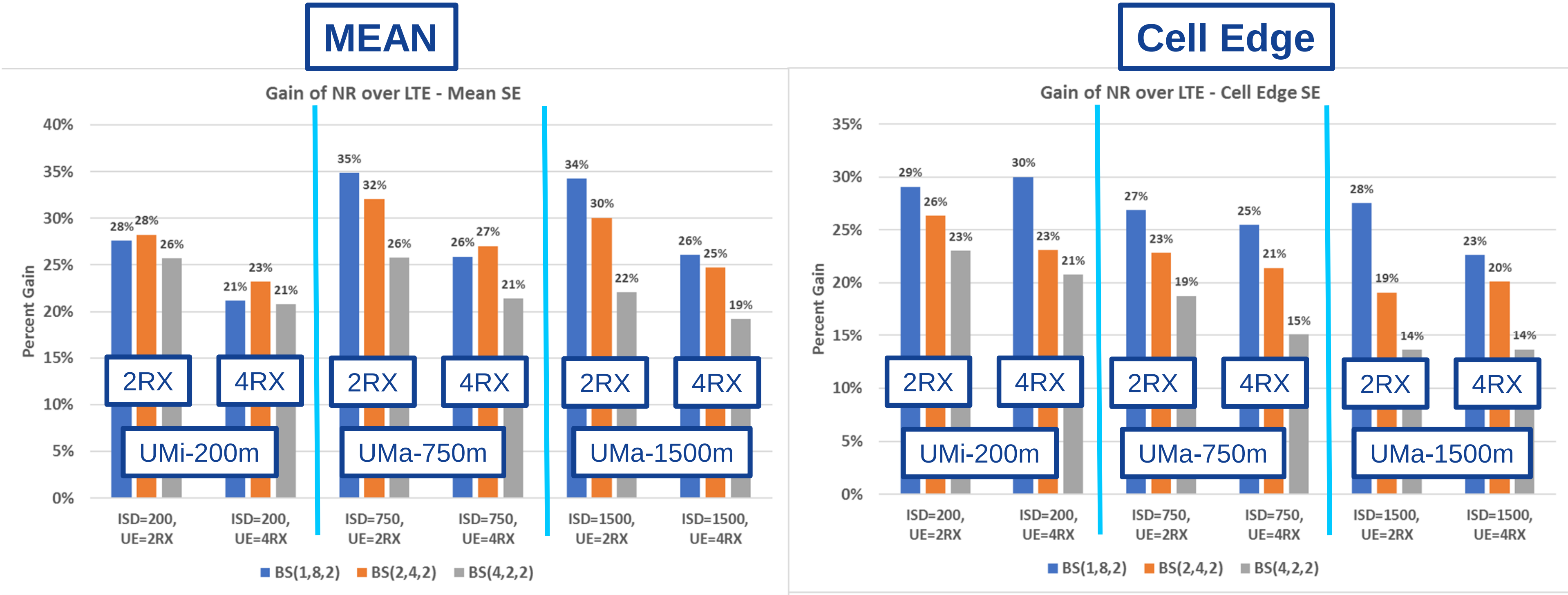
- NR Type II CB significantly outperforms LTE Rel-13, LTE Rel-14, NR Type I CBs with MU-MIMO
- Large gains with the NR Type II CB and MU-MIMO
- Mean and Cell Edge show similar trends

Summary

- NR-MIMO enables a beam-based air-interface for supporting both sub-6GHz and mmWave deployments with arbitrary array configurations
- NR-MIMO provides improvements in performance, efficiency, scalability, and flexibility over LTE-FD-MIMO
  - Beam Management – new feature over LTE
  - Type II CSI codebook – significant improvements over LTE codebooks
  - CSI acquisition framework for enhanced scalability and flexibility
  - Support for UE beamforming on UL
- Lots of evolutions planned in 3GPP R17 and R18, including:
  - Support of higher users mobility
  - UL overhead reduction
  - Improved support of multiple TRP & CoMP

Copyright and confidentiality

Gain of NR over LTE



- **Gain of NR over LTE is roughly 19-35% in Mean SE, 14%-30% in cell edge (Full Buffer)**

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