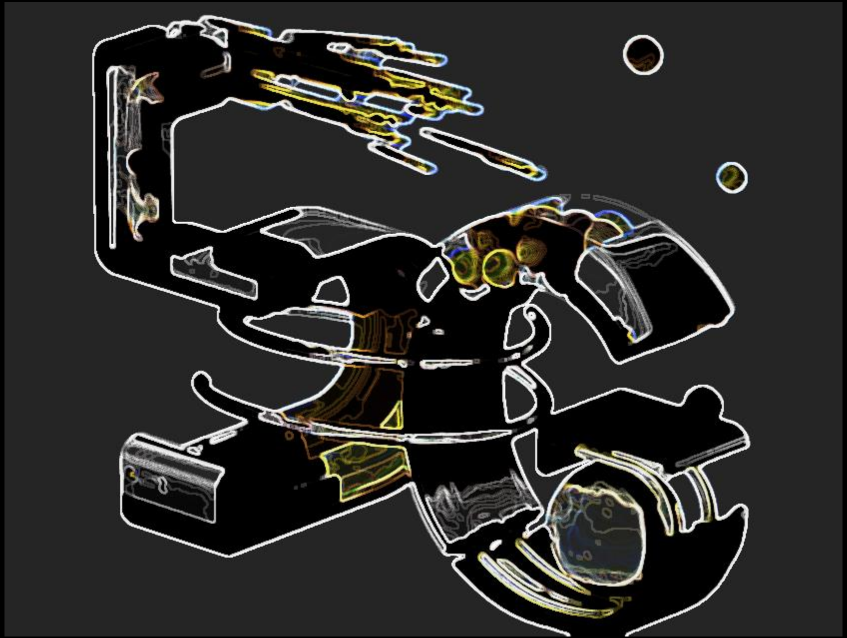


Sprint

Brighter Future For All

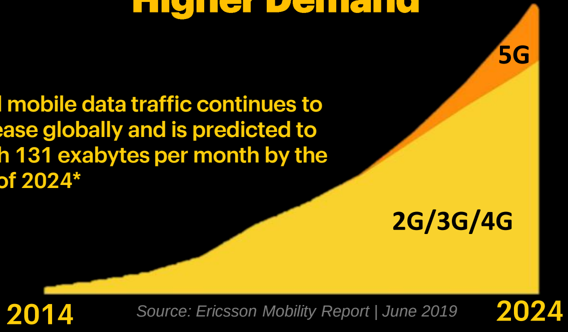
Why 5G?

Why 5G? More of everything is expected in the future

Sprint

Higher Demand

Total mobile data traffic continues to increase globally and is predicted to reach 131 exabytes per month by the end of 2024*

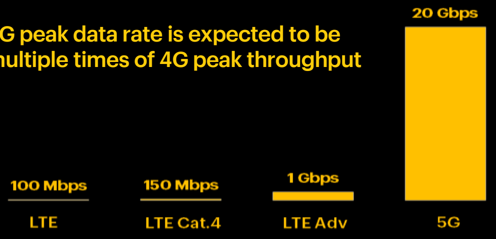


Source: Ericsson Mobility Report | June 2019

Higher Speeds

DL Peak Data Rate

5G peak data rate is expected to be multiple times of 4G peak throughput

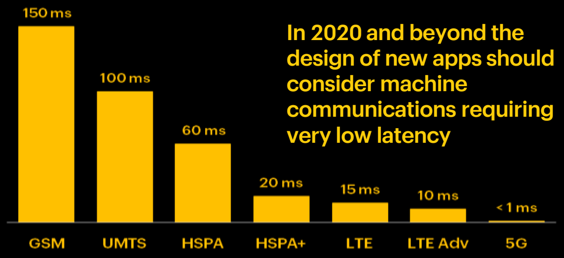


Source: Nokia

Lower Latency

Latency Per Technology

In 2020 and beyond the design of new apps should consider machine communications requiring very low latency



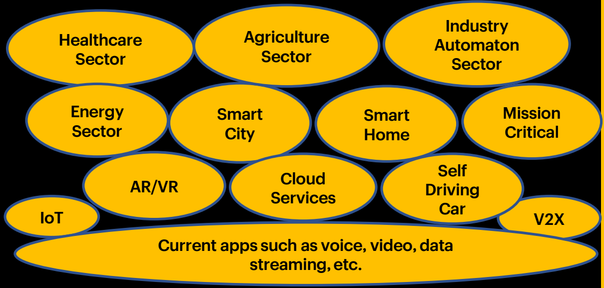
Source: Nokia

More Devices & Connections

There will be 11.5 billion mobile connected devices by 2019, exceeding the world's projected population at that time (7.6 billion).

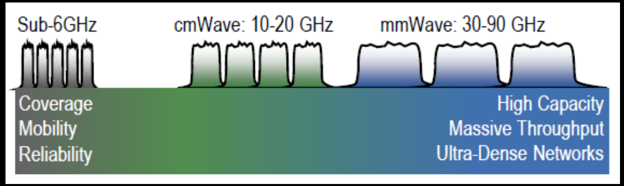
Source: GSMA

More Diverse Use Cases



5G can support very diverse use cases and applications with extreme range of requirements and at the same time it can create new opportunities

Higher Spectrums & Larger BWs



Sub-6GHz **cmWave** **mmWave**

Both sub-6GHz and beyond 6GHz spectrum bands will be needed and used on 5G. Use of much wider bandwidth, up to 400MHz, will also become available.

Source: 3GPP

5G Vision

5G Vision & Use Cases

eMBB
ENHANCED MOBILE BROADBAND

3D Video UHD Video | High Density Hot Spot | High user Mobility

- ✓High capacity
- ✓High speeds
- ✓ Low latency

Cloud Services | Seamless Browsing | AR/VR

- ✓Seamless user experience
- ✓Increased connection density
- ✓ Energy Efficient

mMTC/IoT
MASSIVE MACHINE TYPE COMMUNICATION

Smart City | Smart Home | E-Health

- ✓Low cost
- ✓ Low energy
- ✓ Wide-area coverage
- ✓ Small data volumes
- ✓ Massive # of devices
- ✓Long battery life

IoT | V2X | Utilities & Agriculture

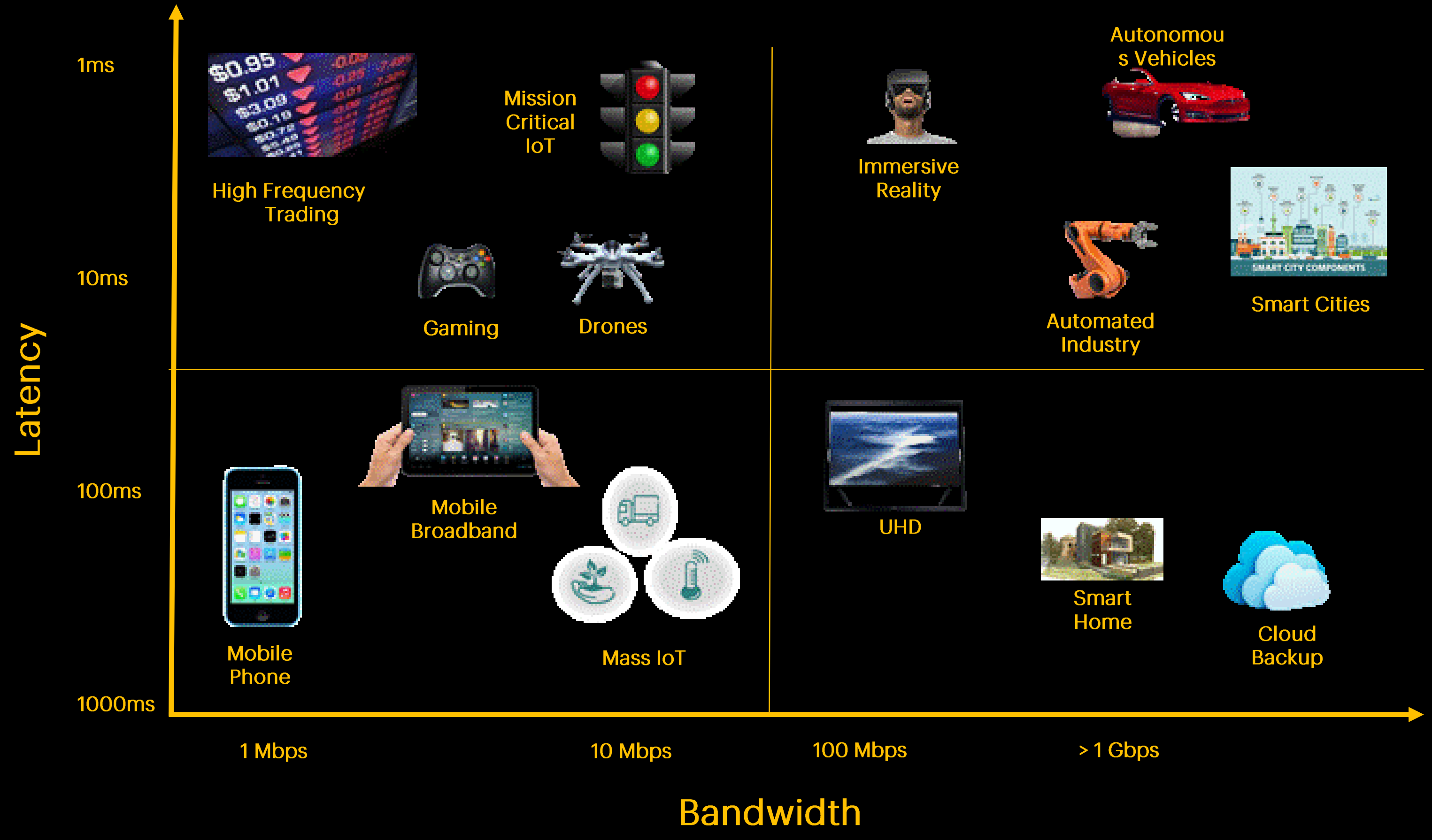
URLLC
ULTRA RELIABLE MACHINE TYPE COMMUNICATION

Mission Critical apps | Virtual Reality Service | Self Driving Cars

- ✓Ultra reliability
- ✓ Very low latency
- ✓ Very high availability
- ✓Mid range speeds

Online Gaming | Medical Surgery | Industry Automation & Robotics

Connectivity Paradigms



Waveform Evolution

2G
Modulation Waveform:
GMSK, QPSK, 16 QAM
Access: TDMA/FDMA
BW up to 200 kHz

4G
Modulation: Up to 256
QAM, DFT-S-OFDMA
Uplink and OFDMA
Downlink
Access: OFDMA/FDMA
BW up to 100 MHz

1G
Modulation: Analog
FM
Access: FDMA
BW up to 30 kHz

3G
Modulation: Up to 64
QAM Direct Sequence
Spread Spectrum
Access: CDMA/FDMA
BW up to 5 MHz

5G
Modulation: Up to
1024 QAM, OFDMA &
DFT-S-OFDM Uplink/
OFDMA Downlink
Access: OFDMA/FDMA
BW up to 800 MHz

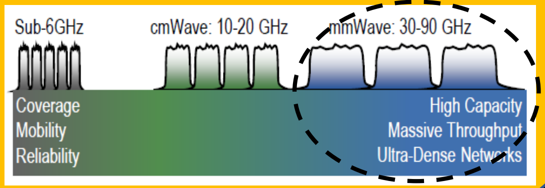
5G Key Technology Components

Main pillars of NR

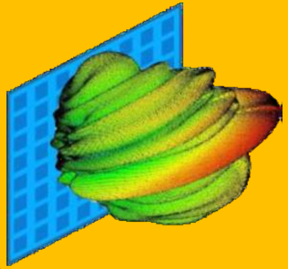
Sprint

New Spectrum

Use of wider frequency ranges



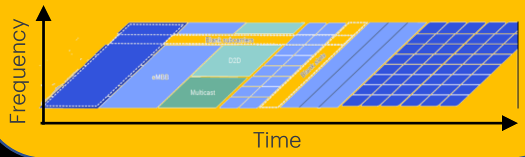
mMIMO & Beamforming



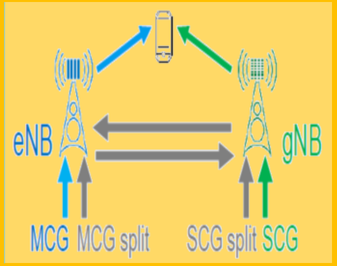
- Hybrid beamforming
- UE beam steering

Flexible Framework

- Scalable numerology and slot duration
- Nominal traffic puncturing

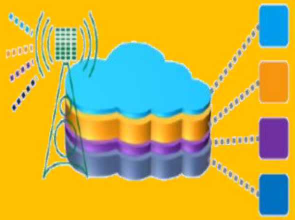


Multi-RAT Connectivity



Initially based on Dual Connectivity with E-UTRA as master

Network Flexibility



- Flexibility numerology
- Network Slicing
- NFV/SDN

Source: Rhode & Schwarz

4G vs. 5G Performance Comparisons

- In order for 5G use cases to become reality, a set of key 5G recommendations and requirements have been identified by 3GPP. As defined in LTE R12, 4G system falls short of meeting some of those requirements

Sprint

	Some Major Requirements Comparison	
	LTE in Practice (as of R12)	**5G Overall Requirements**
User experienced Data rate	-	100 Mbps
DL Peak Data Rate	1 Gbps	20 Gbps
UL Peak Data Rate	0.5 Gbps	10 Gbps
DL Spectral Efficiency	6.1 bps/Hz	30 bps/Hz
UL Spectral Efficiency	4.3 bps/Hz	15 bps/Hz
Latency	User: 10 ms Control: 50 ms	User (URLLC): 0.5 ms User (eMBB): 4 ms Control: 10 ms
Reliability	Not Specified	99.999%
Connection Density	Not Specified	1 million/km2
Mobility	350 km/h	500 km/h

Major gaps between 4G & 5G are in the areas of speeds and latency

In 5G, support for higher frequency ranges allows for larger capacity and throughput

In 5G, support for scalable numerologies and multiple sub-carrier spacing allows for ultra low latency and agile transmission

Source: Nokia

4G vs. 5G Major Radio Comparisons

Sprint

	4G	5G
Spectrum Support	Sub-6GHz	FR1 (Sub-6GHz) FR2 (mmWave)
Maximum Bandwidth Support	20MHz	• FR1: 50MHz (@15KHz SCS) 100MHz (@30 & 60KHz SCS) • FR2: 200MHz (@60KHz) 400MHz (@120KHz)
Maximum CCs	5 (Rel.10), 32 (Rel.12)	16
Spectrum Occupancy	90% of Channel BW	98% of Channel BW
Sub-Carrier Spacing (SCS)	Fixed SCS of 15KHz	Multiple SCS: 2^{μ} x 15 KHz
Waveform	DL: CP-OFDM UL: SC-FDMA	DL: CP-OFDM UL: CP-OFDM & DFT-s-OFDM
Maximum Number of Sub-carriers	1200	3300
Subframe Length	1ms	1ms
Latency (Air Interface)	10ms	<1ms
Channel Coding	Turbo Coding (data) TBCC (Control)	LDPC (data) Polar Coding (Control)

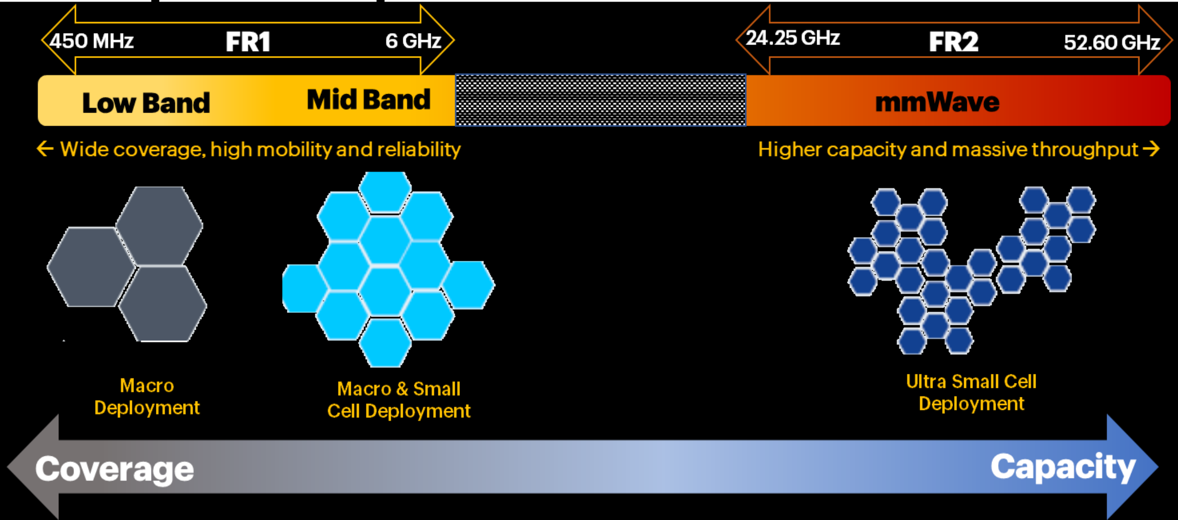
Source: Nokia

5G Spectrum Bands

5G wider spectrum range

Two types of frequency range are defined in 3GPP

	Type	Frequency Range	Band Type	5G Deployment Strategy
FR1	Sub-6 GHz	450 MHz - 6 GHz	Low Band < 1GHz	Frequencies < 1GHz performs well in applications requiring long range and low to medium data rates, mainly deployed in macro design. In 5G, they will be leveraged for lower data rate and narrow band applications and are looked at for the mMTC
			Mid Band 1 GHz - 6 GHz	Mid band is being looked at for use cases that need of the order of 100MHz of bandwidth, with the 2.5GHz Band 41 and 3.5GHz regarded as candidates for 5G eMBB applications, deployed in macro and small cell network design
FR2	mm-Wave	24.25 GHz - 52.60 GHz	High Band	The high end of the spectrum offers the most dramatic increase in available bandwidths, mostly deployed in ultra-small cell design within hotspot areas



Source: Nokia

5G NR Operating Bands

5G NR FDD Frequency Bands in FR1

FR1

5G NR Band	Uplink Frequency	Downlink Frequency	Bandwidth	Duplex
n1	1920 -1989 MHz	2110 - 2170 MHz	60 MHz	FDD
n2	1850 - 1910 MHz	1930 - 1990 MHz	60 MHz	
n3	1710 - 1785 MHz	1805 - 1880 MHz	75 MHz	
n5	824 - 849 MHz	869 - 894 MHz	25 MHz	
n7	2500 - 2670 MHz	2620 - 2690 MHz	70 MHz	
n8	880 - 915 MHz	925 - 960 MHz	35 MHz	
n12	699 – 716 MHz	729 – 746 MHz	17 MHz	
n14	788 – 798 MHz	758 – 768 MHz	10 MHz	
n18	815 – 830 MHz	860 – 875 MHz	15 MHz	
n20	832 - 862 MHz	791 - 821 MHz	30 MHz	
n25	1850 – 1915 MHz	1930 – 1995 MHz	65 MHz	
n28	703 - 748 MHz	758 - 803 MHz	45 MHz	
n30	2305 – 2315 MHz	2350 – 2360 MHz	10 MHz	
n65	1920 – 2010 MHz	2110 – 2200 MHz	90 MHz	
n66	1710 - 1780 MHz	2110 - 2200 MHz	90 MHz	
n70	1695 - 1710 MHz	1995 - 2020 MHz	15/25 MHz	
n71	663 - 698 MHz	617 - 652 MHz	35 MHz	
n74	1427 - 1470 MHz	1475 - 1518 MHz	43 MHz	

Source: 3GPP TS38.101-1 V16.0.0 (2019-07)

5G NR TDD Frequency Bands in FR1

FR1

5G NR Band	Uplink Frequency	Downlink Frequency	Bandwidth	Duplex
n34	2010 – 2025 MHz		15 MHz	TDD
n38	2570 - 2620 MHz		50 MHz	
n39	1880 – 1920 MHz		40 MHz	
n40	2300 – 2400 MHz		100 MHz	
n41	2496 - 2690 MHz		194 MHz	
n48	3550 – 3700 MHz		150 MHz	
n50	1431 - 1517 MHz		85 MHz	
n51	1427 - 1432 MHz		5 MHz	
n77	3300 - 4200 MHz		900 MHz	
n78	3300 - 3800 MHz		500 MHz	
n79	4400 - 5000 MHz		600 MHz	

5G NR Frequency Bands in FR2

FR2

5G NR Band	Uplink Frequency	Downlink Frequency	Bandwidth	Duplex
n257	26.5 - 29.5 GHz		3 GHz	TDD
n258	24.250 - 27.5 GHz		3.250 GHz	
n260	37 - 40 GHz		3 GHz	
n261	27.5 – 28.35 GHz		850 MHz	

ENDC Frequency Bands

Inter-band ENDC		LTE Frequency Bands																		
5G NR Frequency Band		B1	B3	B5	B7	B8	B11	B18	B19	B20	B21	B25	B26	B28	B38	B39	B41	B42	B66	B71
	n7		✓																	
	n28	✓	✓		✓					✓										
	n41											✓	✓				✓			
	n71																		✓	✓
	n77	✓	✓			✓	✓	✓	✓		✓		✓	✓			✓	✓		
	n78	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		
	n79	✓	✓			✓	✓	✓	✓		✓		✓	✓		✓	✓	✓		
	n257	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓			✓	✓	✓	
	n258		✓		✓	✓								✓		✓	✓			

Note: view is limited to major ENDC combos. Also, the view is limited to 2CC combos (3CC, 4CC, and 5CC views not shown)

Source: 3GPP TS38.101-3

5G Radio Frame

5G NR Frame Structure & Numerology

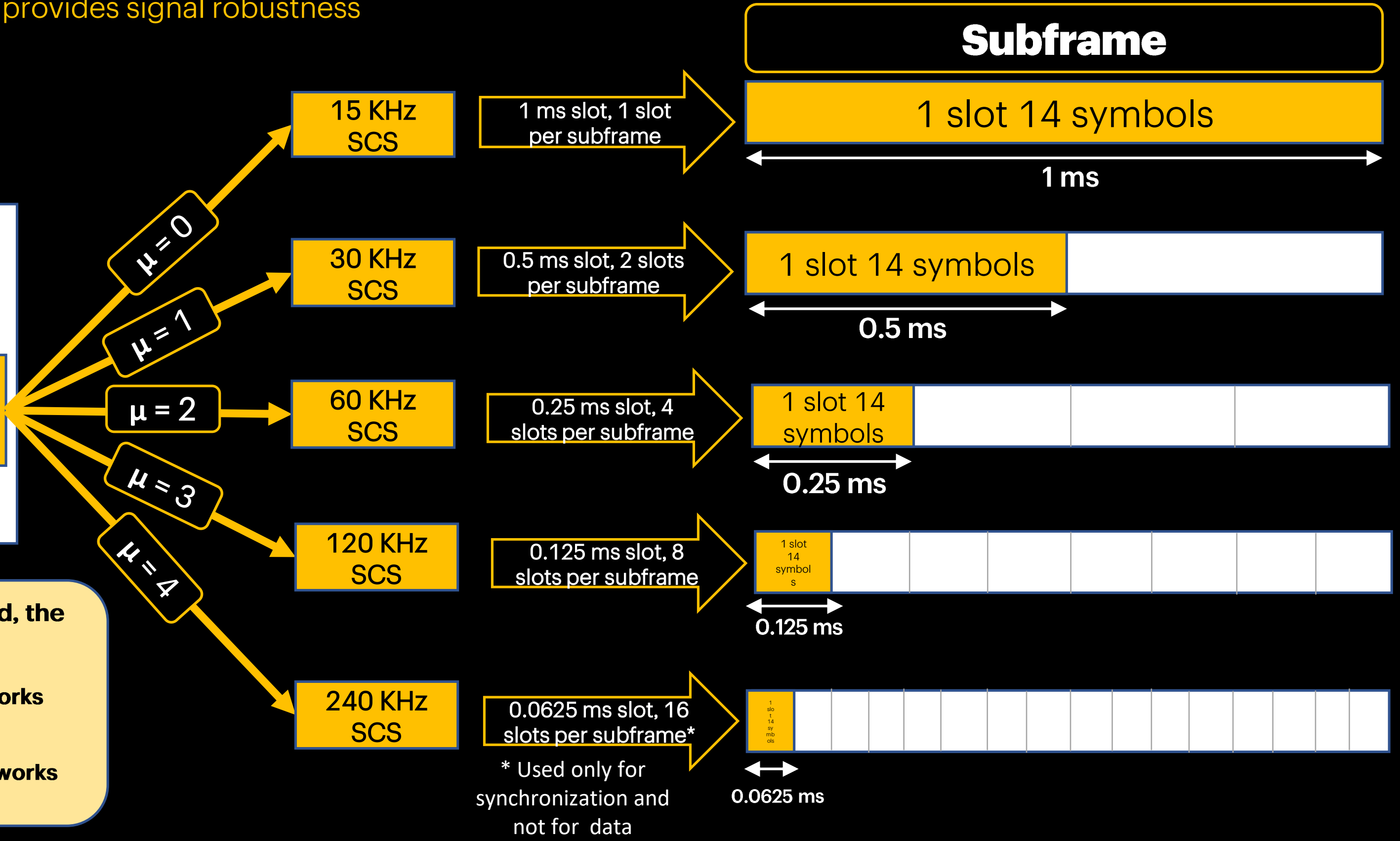
- When compared to LTE, the support of multiple numerologies and subcarrier spacing is the most outstanding NR feature presented in 5G
- Why multiple numerologies? 5G supports much wider frequency bands. At higher frequency, the phase noise increases. Numerologies with larger SCS provides signal robustness

Δf : Subcarrier Spacing (SCS)

μ: defines the numerology

$\Delta f = 2^{\mu} \times 15$KHz

Slot length = $1/2^{\mu}$



In 5G, the higher the frequency band, the lower symbol duration and higher subcarrier spacing

- **SCS 15 & 30 kHz are used for networks operating with sub-6GHz carrier frequencies**
- **SCS 60 & 120 kHz are used for networks operating with mmWave carriers**

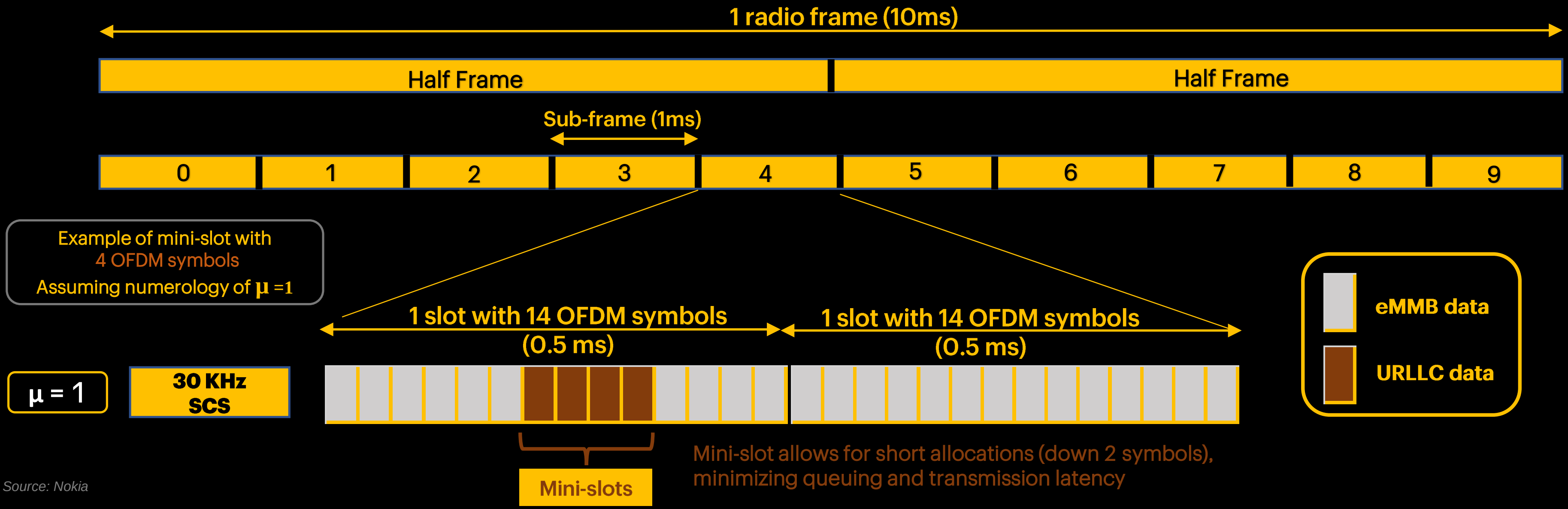
Mini-Slots

Types of 5G scheduling:

Slot-based scheduling (type A scheduling)	Non-slot based scheduling (type B scheduling)
• Where a slot with 14 OFDM symbols is the basic scheduling unit • Slot duration scales with subcarrier spacing ($1/2^{\mu}$)	• Where mini-slot with 2, 4, or 7 OFDM symbols is the minimum slot scheduling • A mini-slot can start at any OFDM symbol. This provides fast transmission opportunities (e.g. URLLC)

Mini-Slot Benefits:

- ✓ mini-slots provide a viable solution to low-latency transmissions irrespective of sub-carrier spacing
- ✓ mini-slots allows multiplexing of URLLC and MBB
- ✓ mini-slots can over-write a longer allocation (punctured scheduling)



Source: Nokia

5G Supported Bandwidths

Sprint

- In FR1: One component carrier supports a scalable bandwidth, 5, 10, 15, 20, 25, 40, 50, 60, 80 and 100MHz

FR1

Supported NR Carrier Bandwidths & Transmission Bandwidth Configuration
(Number of Resource Blocks)

SCS (KHz)	5MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz	40 MHz	50 MHz	60 MHz	80 MHz	100 MHz
15KHz	25	52	79	106	133	160	216	270	-	-	-
30KHz	11	24	38	51	65	78	106	133	162	217	273
60KHz	-	11	18	24	31	38	51	65	79	107	135

Size of SCS

Number of Resource Blocks (RBs)

Size of Bandwidth

- In FR2: One component carrier supports a scalable bandwidth, 50, 100, 200, and 400MHz

FR2

Supported NR Carrier Bandwidths & Transmission Bandwidth Configuration
(Number of Resource Blocks)

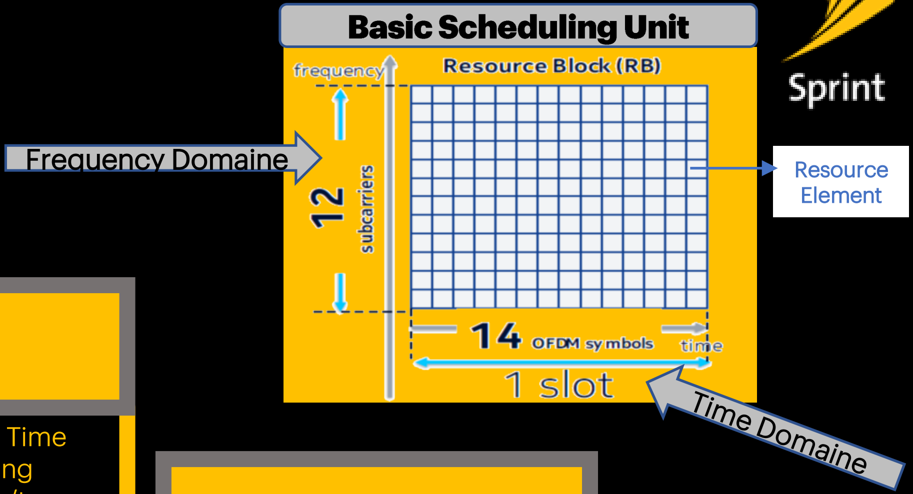
SCS (KHz)	50 MHz	100 MHz	200 MHz	400 MHz
60KHz	66	132	264	-
120KHz	32	66	132	264

5G Multiple Access Technology

Sprint

Multiple Access in 5G

- Orthogonal Frequency Division Multiple Access (OFDMA)
- Time Division Multiple Access (TDMA)
- Space Division Multiple Access (SDMA)



OFDMA

- OFDMA is based on Orthogonal Frequency Division Multiplexing (OFDM) with a cyclic prefix (CP)
- Transmission from/to different UEs Uses mutually orthogonal frequency assignments
- Granularity in frequency domain is equal to one resource block consisting of 12 subcarriers
- Multiple sub-carrier spacings are supported including 15kHz, 30kHz, 60kHz and 120kHz for data
- CP-OFDM applied for DL
- CP-OFDM and DFT-spread OFDM can be applied for UL

TDMA

- TDMA is based on Time Division Multiplexing
- Transmission from/to different UEs is based on separation in time
- Granularity in the time domain is equal to one slot consisting of 14 OFDM symbols
  - (or 2, 4, 7 OFDM symbols within one mini-slot)
- Depending on the sub-carrier spacing, the physical length of one slot ranges from 0.125ms to 1ms

SDMA

- SDMA is also known as multi-user MIMO
- Transmission from/to multiple UEs using the same time-frequency resources as part of the advanced antenna capabilities

Note: *Any duplexing mode (FDD or TDD) can be selected regardless of the multiple access scheme*

Source: Nokia

5G Massive MIMO & Beamforming

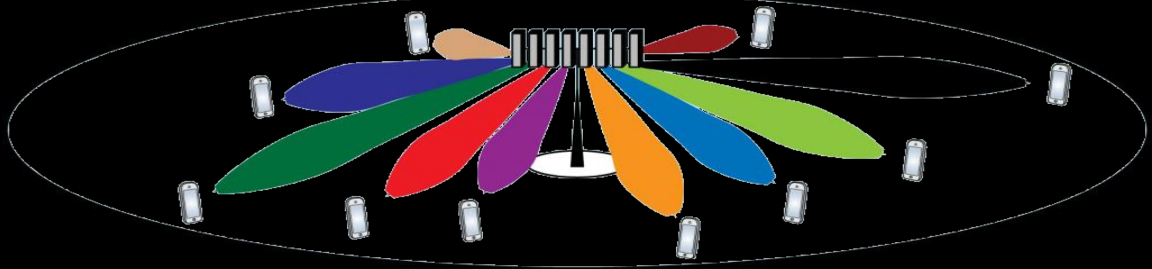
5G Massive MIMO & Beamforming

- Massive MIMO is the extension of traditional MIMO technology but using large number of controllable antennas (>8) .
  - It allows for simultaneously serving many UEs in the same time-frequency resources
    - Higher network capacity
    - Higher spectral efficiency
  - It allows for beamforming of large number of small RF units inside the antenna
    - Better signal strength
    - Coverage enhancement

Multi-antenna technology use in NR has 2 main objectives

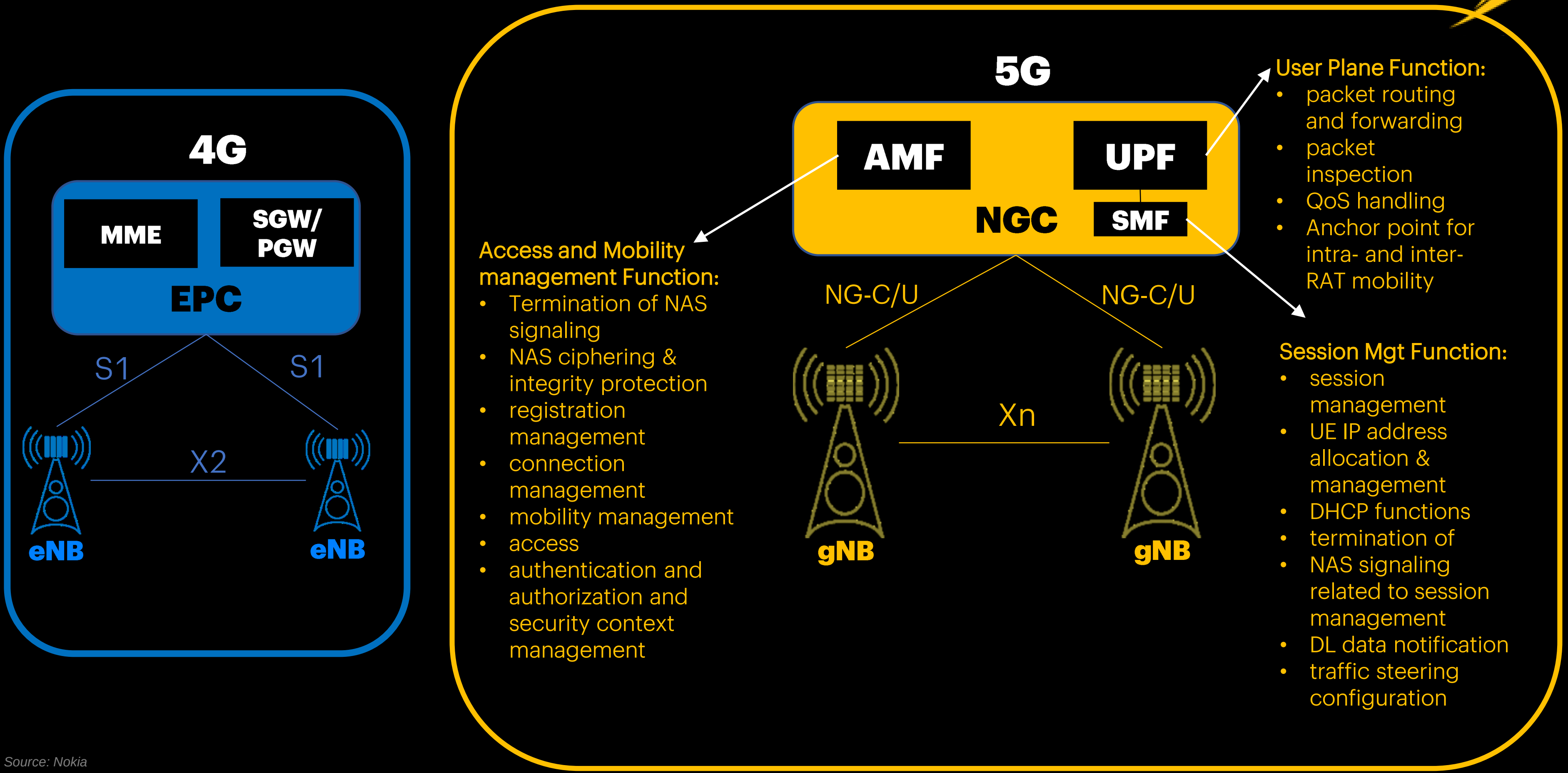
In case of sub-6GHz spectrum:
Improve Capacity & Spectral Efficiency

In case of mmWave spectrum:
Improve Signal Strength & Coverage



5G Network Architecture

5G Network Architecture



Source: Nokia

Q&A

Sources

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