CHALLENGES AND ISSUES OF FUTURE 5G MOBILE NETWORKS

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Dr. Evaldas Stankevičius, Regulatory and Security Expert

Email: evaldas.stankevicius@tele2.com

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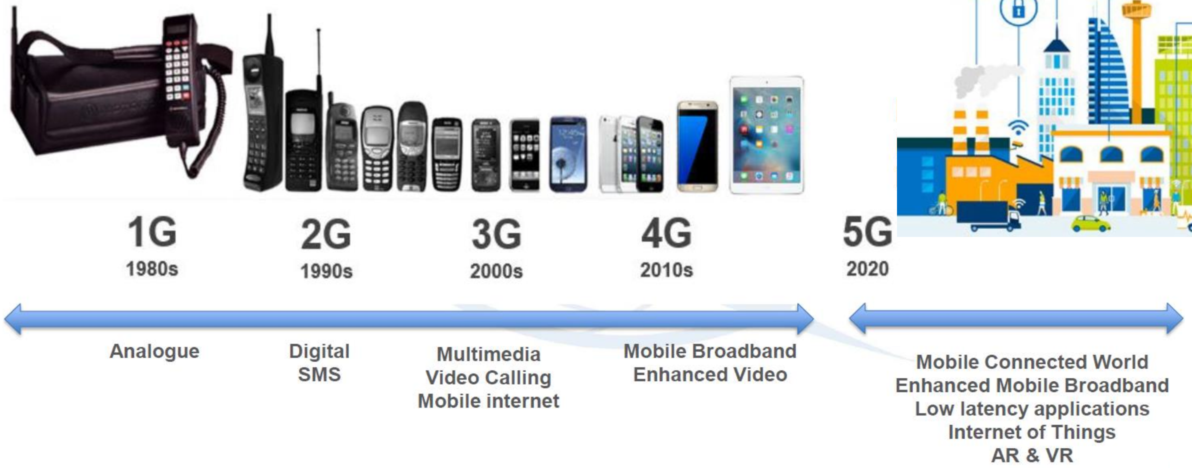
What is 5G?

5G is the 5th generation of mobile networks



1G: purely analog system.
2G: voice and SMS.
3G: packet switching communication.
4G: enhanced mobile broadband with rich content.
5G: not only mobile broadband, but also practice in various scope.

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5G Technical Specification

Peak Data Rate	1 - 20 Gbps
User Experienced Data Rate	10 - 100 Mbps
Spectral Efficiency	×1 - ×3
Mobility	350 - 500 km/h
Latency	1 - 10 ms
Connection Density	10k – 1M devices / km²
Network Energy Efficiency	×1 - ×100
Area Traffic Capacity	0.1 - 10 Mbps / m²
Availability	99.999% (of time)
Battery life	10 years*
Reliability	99.999% (of packets)
Position accuracy	10m - <1m
Security	Strong subscriber authentication, user privacy and network security

*For low-power IoT devices

Source: ITU-R, NGMN, 3GPP

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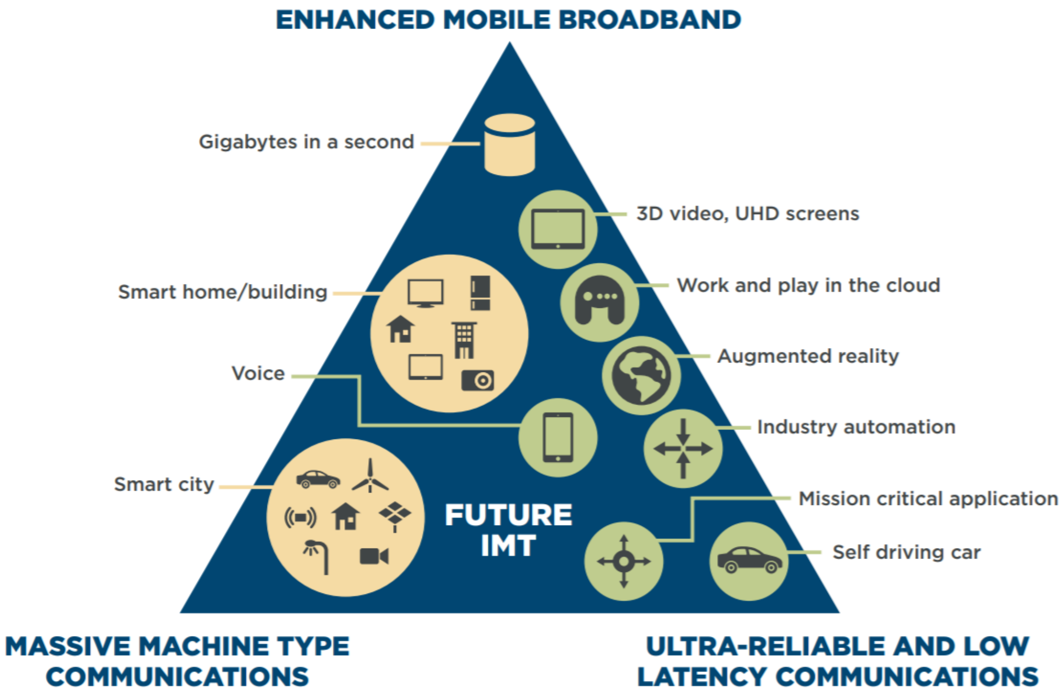
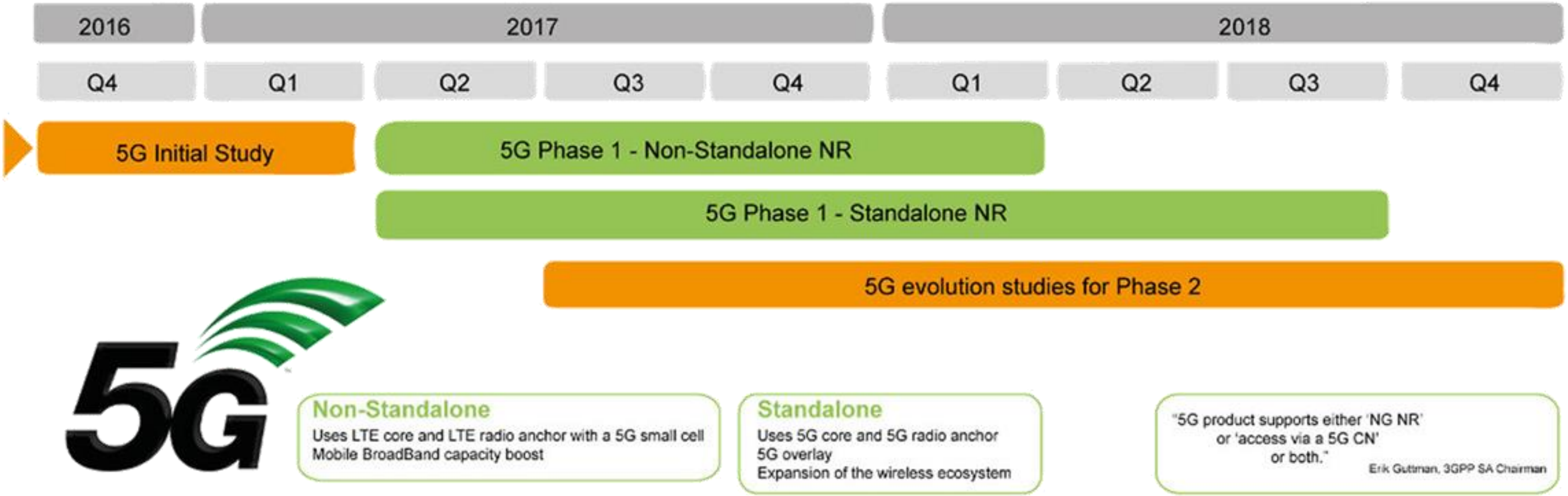
5G General Use Cases



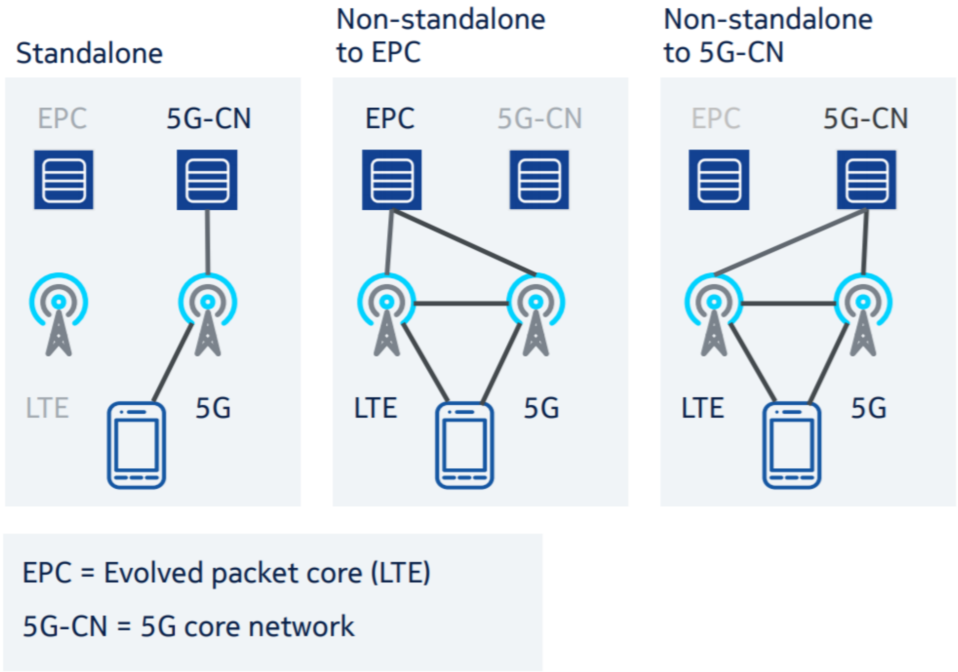
Source: ITU-R, NGMN, 3GPP

5G Standardization Process



Source: https://www.etsi.org/technologies-clusters/technologies/5g

5G architecture options in 3GPP Release 15/16

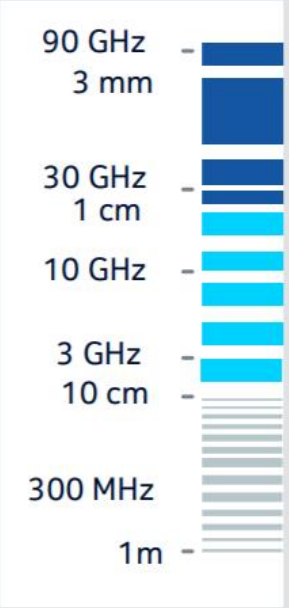


- 5G can be deployed as a **standalone** solution without LTE. It can also use a **non-standalone** solution with dual connectivity to LTE where the device has two parallel radio connections: one to 5G and one to LTE.
- The first dual connectivity solution is based on the existing **Evolved Packet Core (EPC)**. Both 5G base stations (gNodeB) and LTE base stations (eNodeB) are connected to the EPC. The control plane goes via LTE.
- It is also possible to subsequently have non-standalone architecture with both 5G and LTE nodes connected to the new **5G core network (5G-CN)**. The control plane can go via LTE or via 5G.

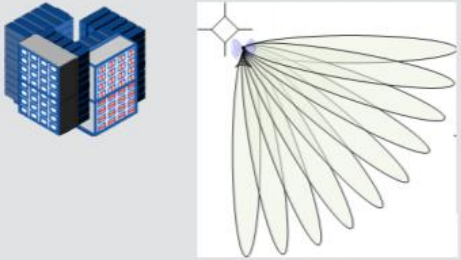
Source: Nokia White Paper „5G Technology Components. Building blocks of 5G networks“

Key 5G Technology Components

#1 New spectrum

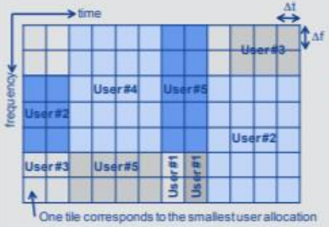


#2 Massive MIMO



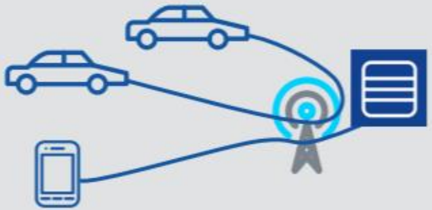
#4 Multi-connectivity

#3 Network slicing



- Service slices
- Flexi radio design and QoS

#5 Cloud and distributed architecture



Source: Nokia White Paper „5G Technology Components. Building blocks of 5G networks“

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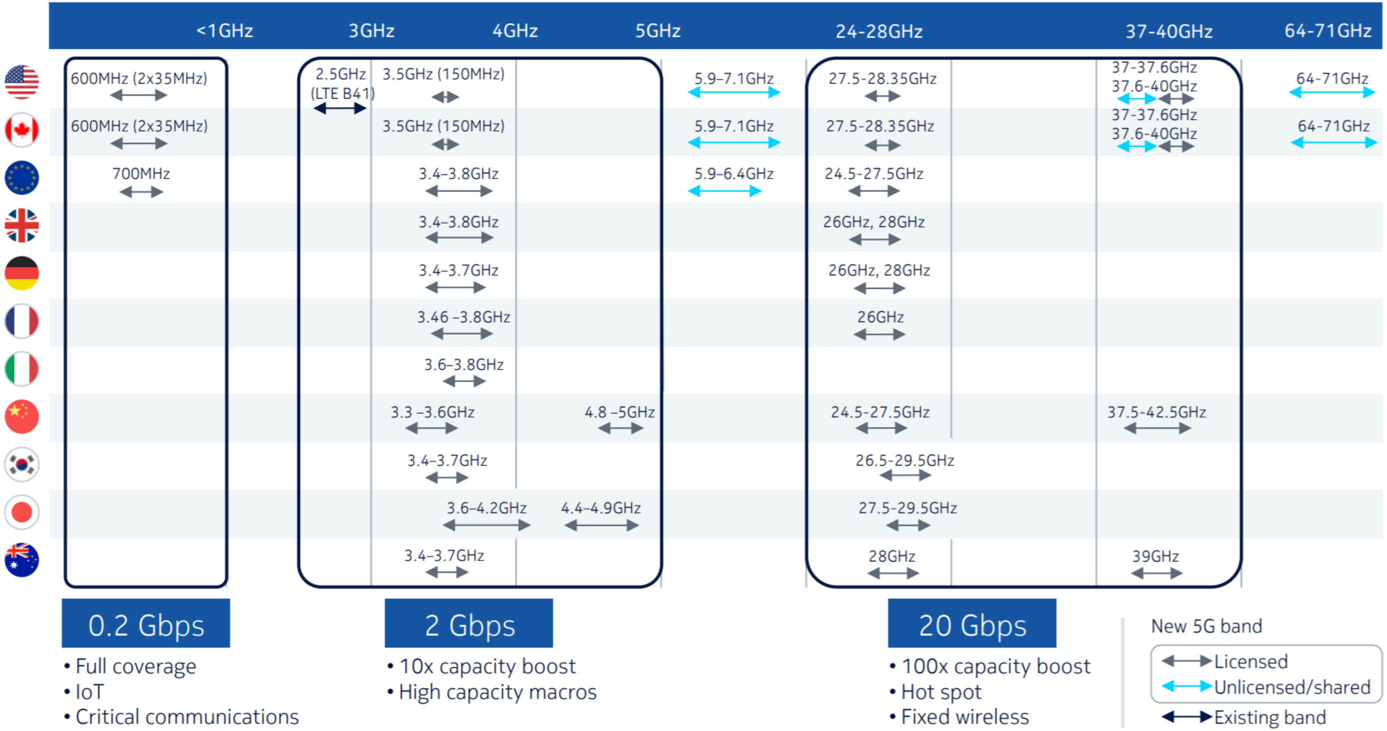
#1 New Spectrum

Main 5G spectrum options in different markets globally

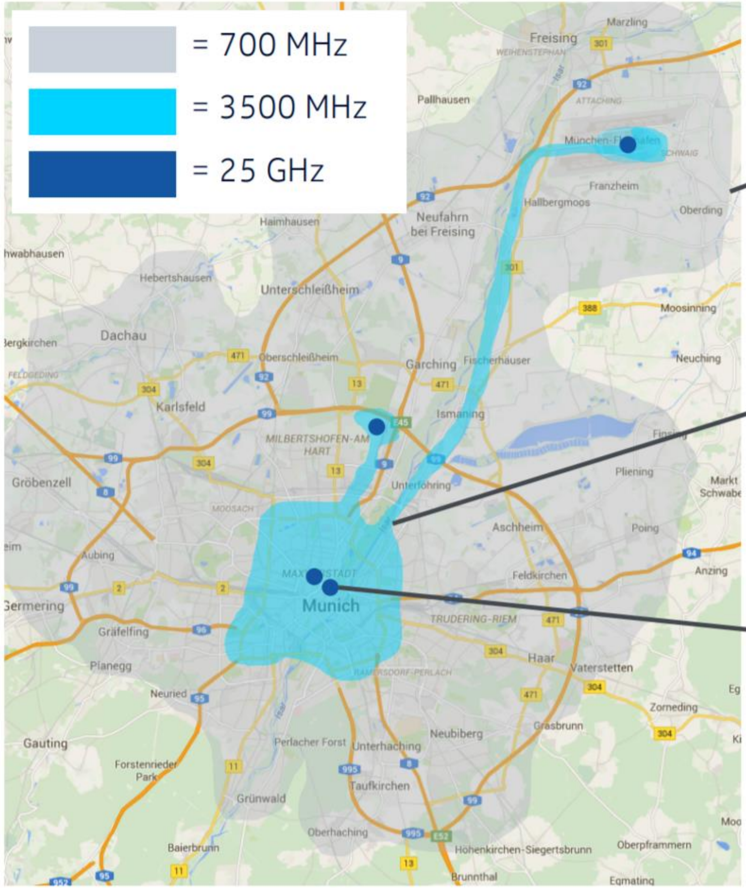


5G is the first radio system designed to support any spectrum between 400 MHz and 90 GHz. This wide range of spectrum options is needed to provide the combination of high capacity, high data rates, ubiquitous coverage and ultra-high reliability.

Low bands below 6 GHz are useful for wide area coverage and data rates up to a few Gbps. Reliable coverage is an important factor in providing connectivity for IoT devices and for critical communication such as remote control or automotive communication.

Source: Nokia White Paper „5G Technology Components. Building blocks of 5G networks“

Example early phase 5G deployment in a European city.



700 MHz layer

- Wide coverage with indoor penetration
- Massive IoT and ultra reliable low latency
- Reusing existing sites for 800/900 MHz

3.5 GHz layer

- Dense urban coverage
- Supports enhanced mobile broadband
- Reusing existing sites for 2 GHz

25 GHz layer

- Hot spots like airports and stadiums
- Supports full enhanced mobile broadband
- Data rates exceed 10 Gbps

Source: Nokia White Paper „5G deployment below 6 GHz. Ubiquitous coverage for critical communication and massive IoT“

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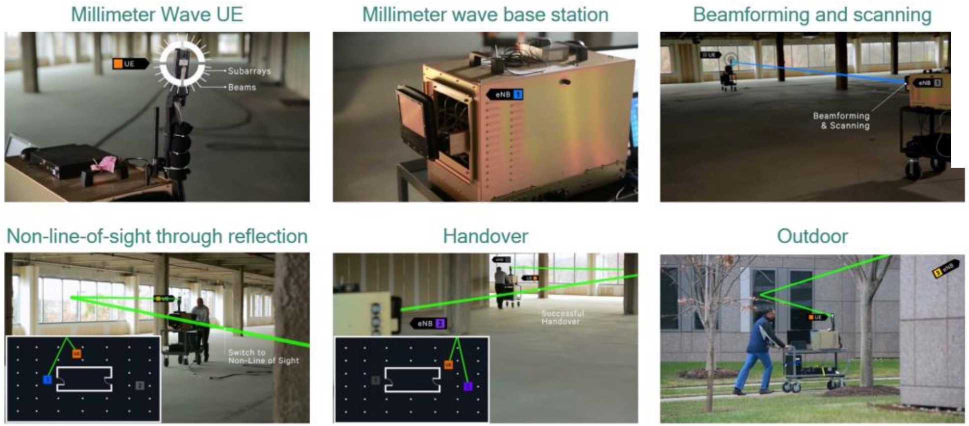
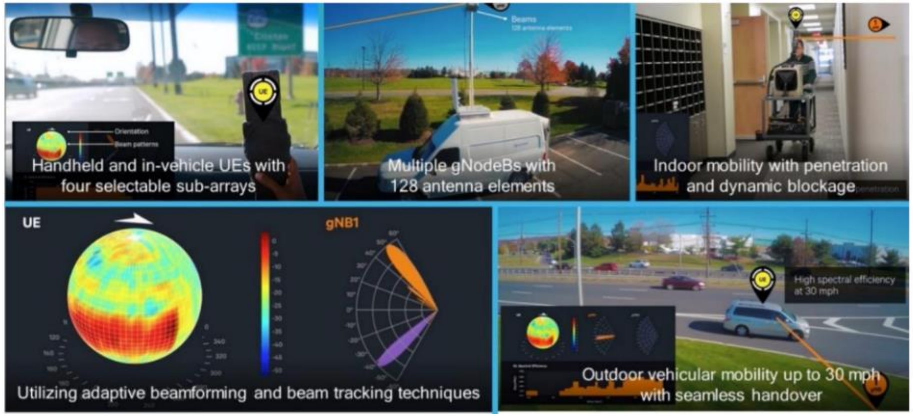
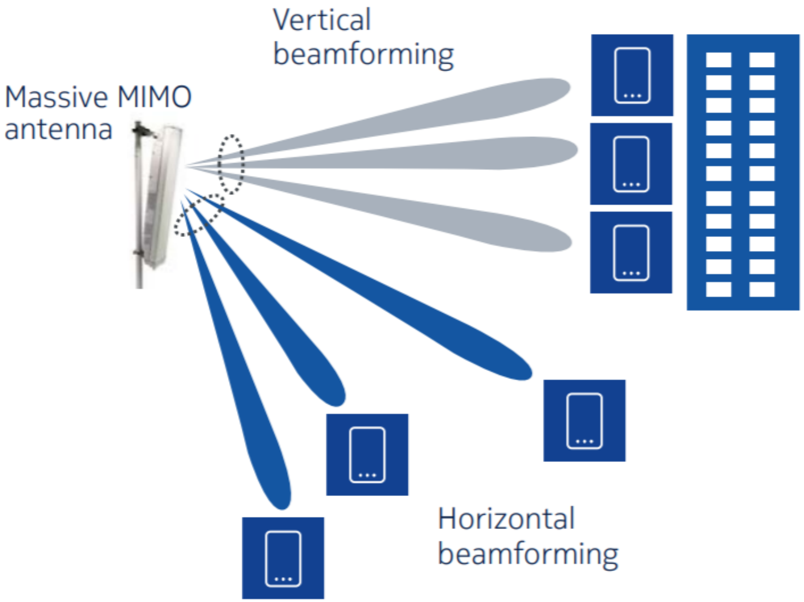
700 MHz + 3.5 GHz + 26 GHz in one device?





Source: Qualcomm and Nokia White Paper „Making 5G a reality: Addressing the strong mobile broadband demand in 2019 & beyond“

#2 Massive MIMO + Beamforming



Massive MIMO beamforming is an attractive solution for boosting mobile network capacity and coverage.

Massive MIMO has become an important technology because higher spectral efficiency is required, active antenna implementation has become practical, the latest 3GPP specifications support beamforming and higher frequencies allow massive MIMO antennas in a small enough form factor.

Massive MIMO can increase coverage by 6-9 dB with higher antenna gain. It can also increase spectral efficiency fourfold beyond 10 bps/Hz/cell with beamforming and peak cell throughput even up to 80 bps/ Hz.

The exact gain depends on the antenna configuration: the number of antenna elements, number of transceivers and output power.

Source: Nokia White Paper „5G Technology Components. Building blocks of 5G networks"

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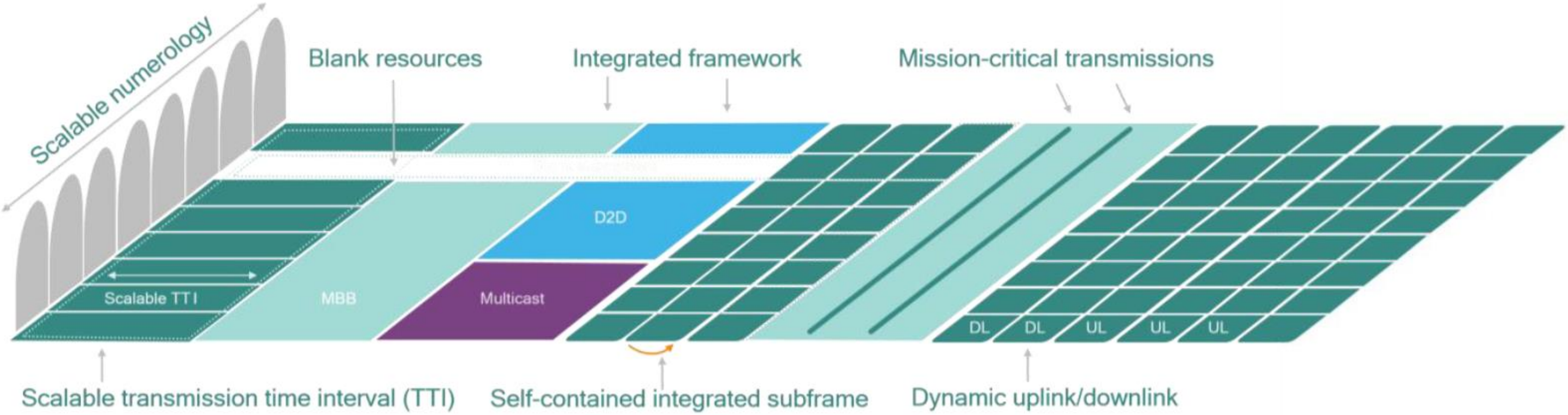
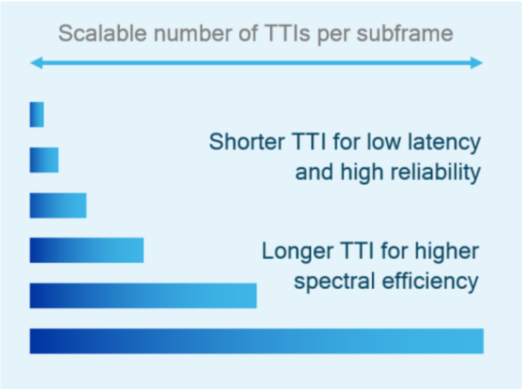
#3 Network slicing





A 5G network is designed to support diverse and extreme requirements for latency, throughput, capacity and availability. Network slicing offers a solution to meet the requirements of all use cases in a common network infrastructure. The same network infrastructure can support, for example, smartphones, tablets, virtual reality connections, personal health devices, critical remote control or automotive connectivity.

Source: Qualcomm report „Making 5G NR a reality. Leading the technology inventions for a unified, more capable 5G air interface“

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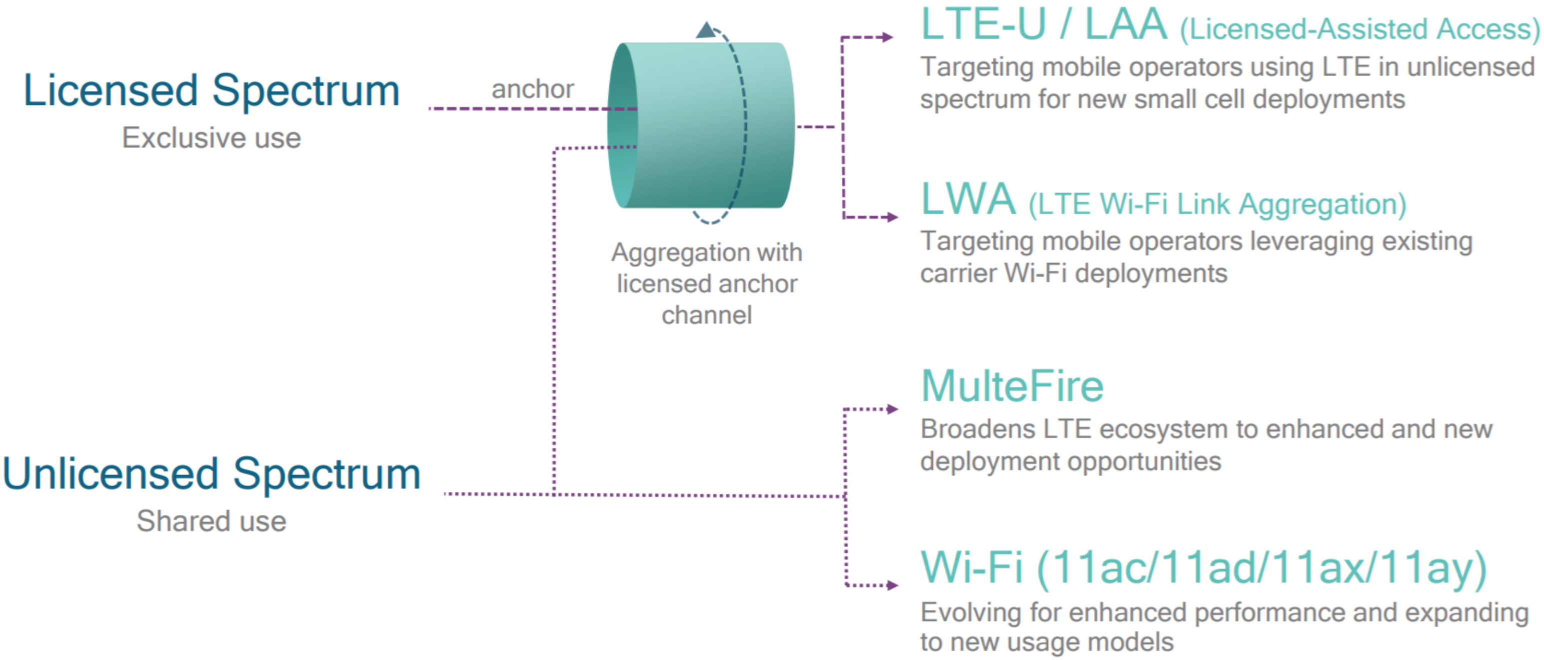
#4 Multi-connectivity



Licensed Assisted Access (LAA) is a key milestone on the road to 5G, delivering speeds of above 1 Gbps. LAA is an LTE feature that leverages the free 5 GHz unlicensed band in combination with licensed spectrum to deliver a performance boost for mobile users.

Source: Qualcomm report „Making 5G NR a reality. Leading the technology inventions for a unified, more capable 5G air interface"

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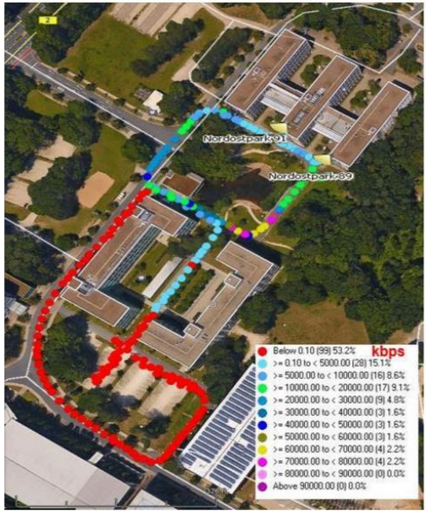
#4 Multi-connectivity

~2X coverage improvement outdoors

Downlink throughput in unlicensed spectrum for each location on test route[1]

LWA (Wi-Fi)



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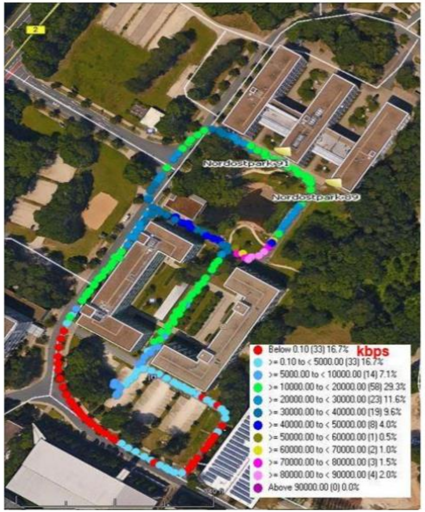
LAA



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Coverage[2] in unlicensed

Mbps	Wi-Fi	LAA
	x2.5	
>10	24% of route	60% of route
	x1.8	
>1	39% of route	71% of route
	X1.7	
>0	47% of route	82% of route

[1] Single small cell, LAA based on 3GPP release 13; LWA using 802.11ac; LTE on 10 MHz channel in 2600 MHz licensed spectrum with 4W transmit power; the following conditions are identical for LAA and Wi-Fi: 2x2 downlink MIMO, same 20 MHz channel in 5 GHz unlicensed spectrum with 1W transmit power. terminal transmit power 0.2W, mobility speed 6-8 mph; [2] Based on geo-binned measurements over test route

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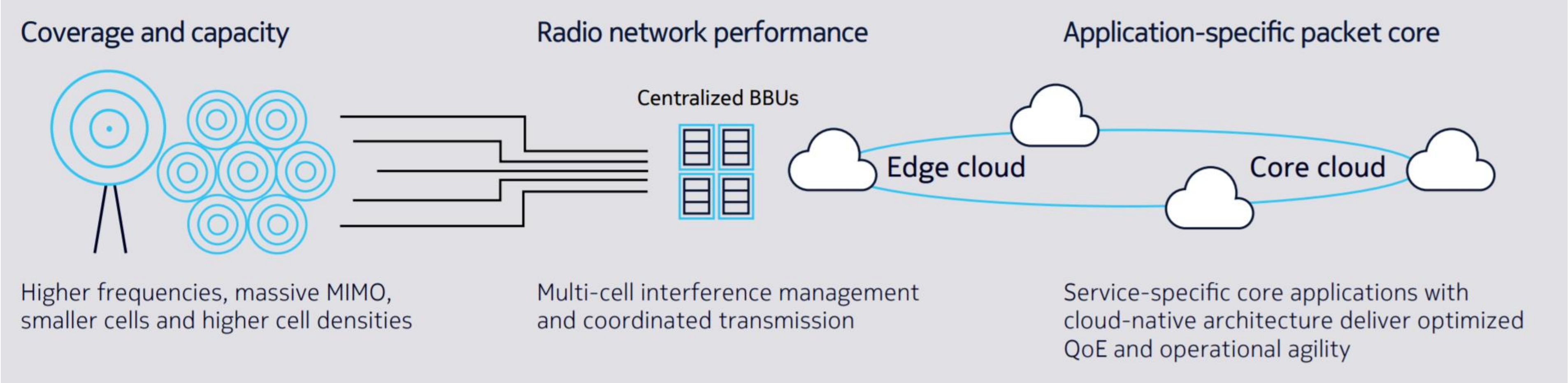
Source: Qualcomm report „Progress on LAA and its relationship to LTE-U and MulteFire“

#5 Cloud and distributed architecture



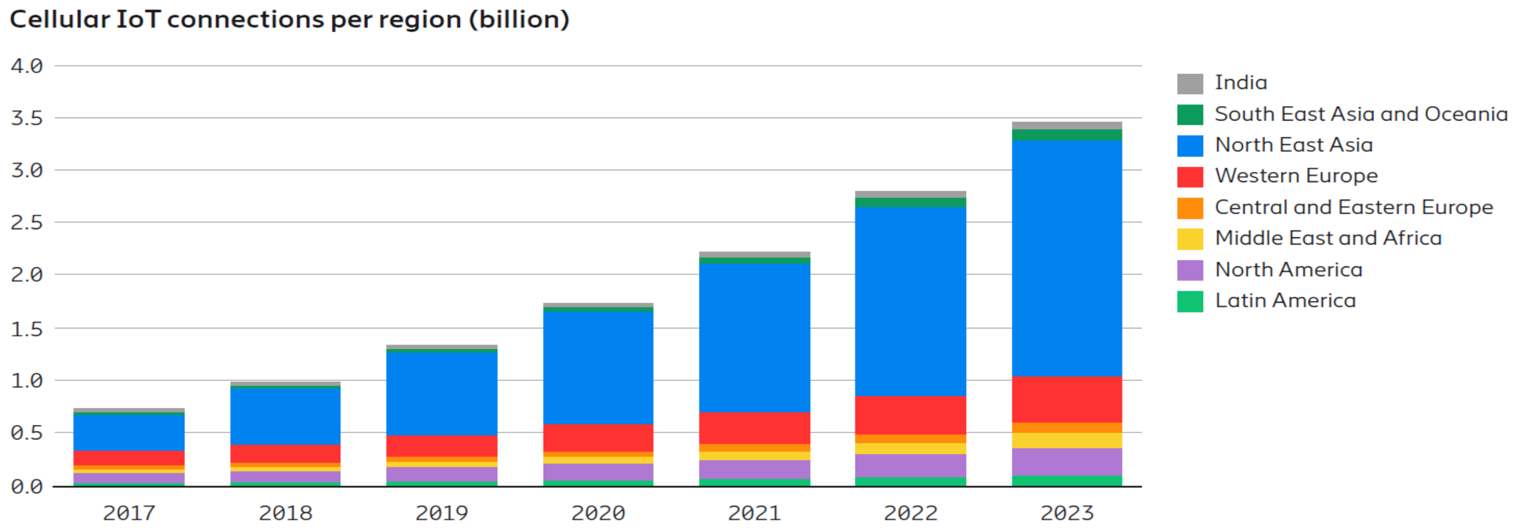
At the center of every mobile and wireless service is spectrum, and there are only three ways to get more of it: add more, get more out of it, and re-use it more effectively.

An issue with denser, smaller cells is an increase in cell edge interference. This must be managed or it will detract from the spectrum's abilities. This is a big driver for C-RAN architectures where baseband processing is centralized. The concept of pooling processing functions in hubs is an effective way to improve multi-cell interference management, thereby ensuring the most spectrum is available for payable traffic.

Source: Nokia White Paper „Mobile anyhaul“

5G Challenges for Engineers to Overcome

1- IoT and number of connections



The IoT is predicted to create a massive increase in the number of devices and connections across wireless networks. Some are predicting that billions of devices will be connected to the networks.

Although many of these will only be sending and receiving relatively small amounts of data, they will create new demands in the total volume of data and managing the physical number of connections.

Hence new scheduling and access control mechanisms will be required, as well as reducing the amount of control plane signaling for IoT users.

Source: Ericsson report „Ericsson Mobility Report “

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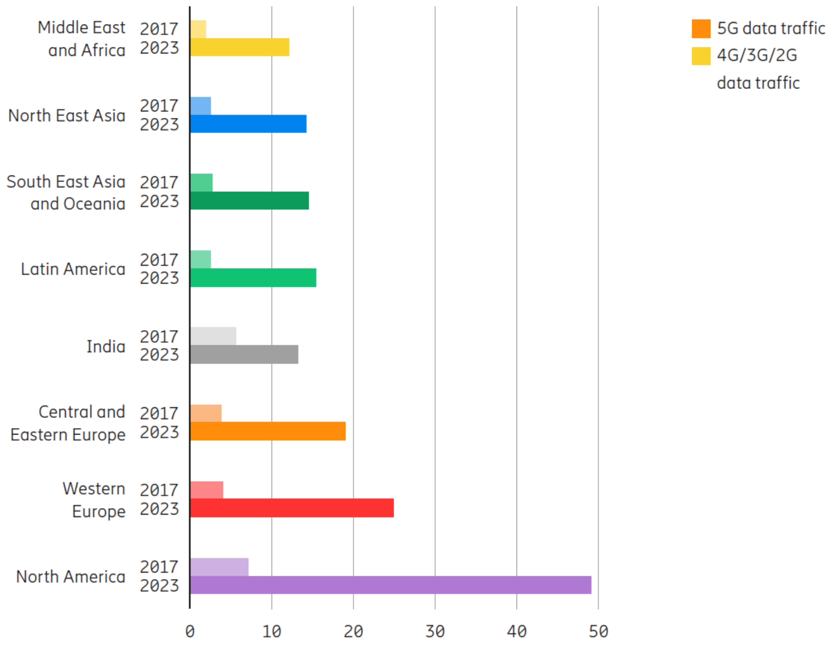
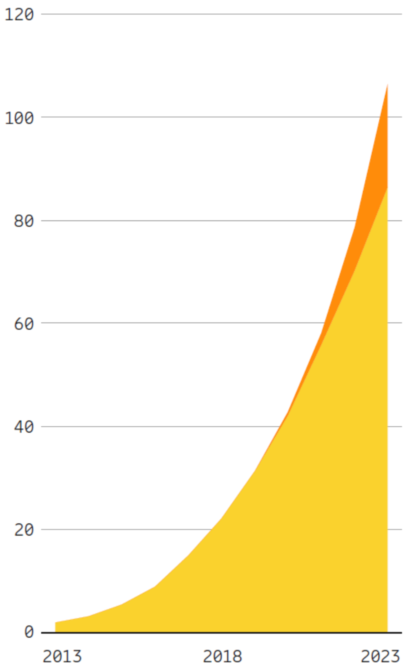
2 - Data volumes

Mobile data traffic per active smartphone (gigabytes per month)



Global mobile data traffic (exabytes per month)



Monthly mobile data traffic per smartphone continues to increase in all regions.

North America has the highest usage, reaching 7.2 gigabytes (GB) at the end of 2017. This figure is expected to rise to 49GB by the end of 2023.

Western Europe has the second highest mobile data usage. At the end of 2017, 4GB per month per smartphone was consumed, and this figure is forecast to reach 25GB by the end of 2023.

Source: Ericsson report „Ericsson Mobility Report “

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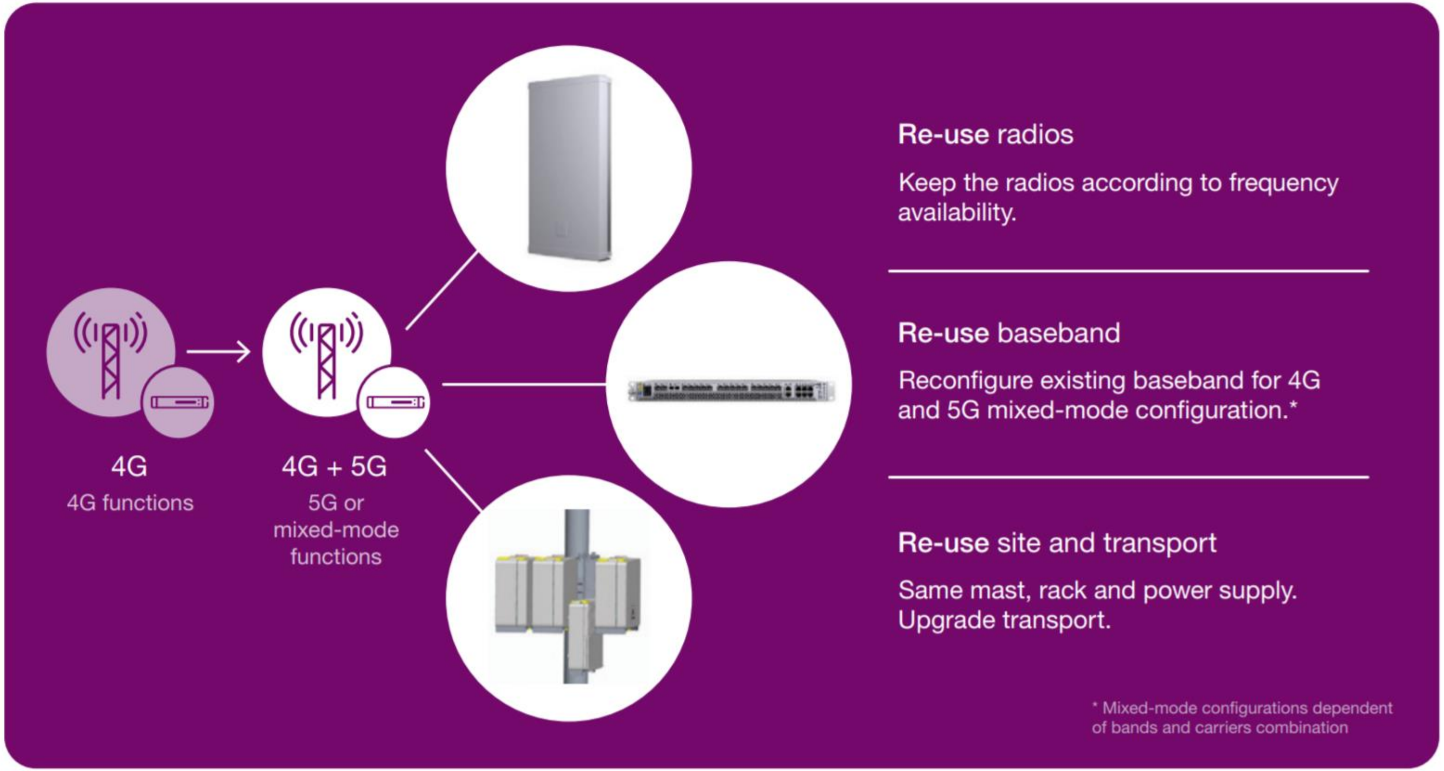
3 - Fast and flexible deployment architecture.

Increasing capacity without increasing cost



Source: Ericsson report „5G deployment considerations“

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4 - Real-time information for critical services

CRITICAL SERVICES AND INFRASTRUCTURE CONTROL

Opportunity areas

- Public Safety
- Mission critical utilities – Energy active grid
- Mission critical utilities – Water active grid

Benefits

- Manage **massive number of connections**
- Energy and water utilities connecting to **millions of networked devices,** enabling **real-time intelligent** and **autonomous** decisions

5G technology brings

- Security
- Enable real-time, intelligent and autonomous decisions
- Robust coverage
- Reliability
- Sustainability

Target Users

- Police and security services
- Health care
- Agriculture
- Energy utilities
- Water utilities

Source: Ericsson report „5G Use Cases"

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5 - Coping with augmented reality

As augmented reality becomes deployed on portable and personal devices, so the demand on network performance is dramatically increased. A key aspect is that the latency or delay must be very small to enable true interaction between the real and virtual environments. The human brain is very sensitive to time delays when processing visual data thus, unless the delay is small enough, true virtual reality services cannot be delivered.

Source: http://fortune.com/2016/09/20/t-mobile-5g-vr-rock-concert/

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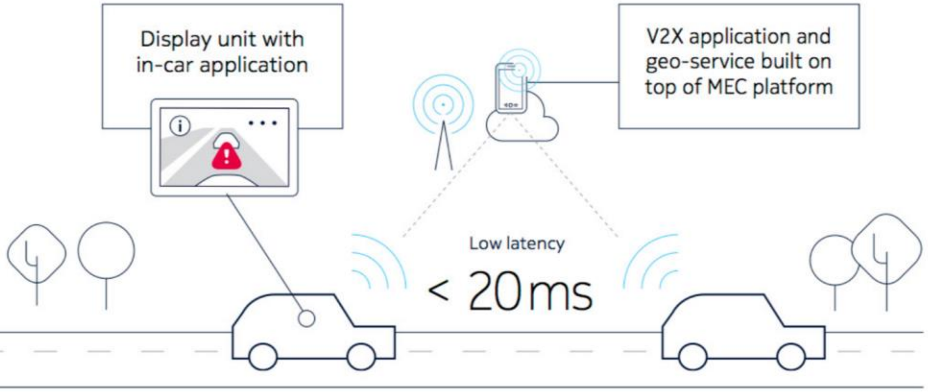
6 - M2M and automotive

90% of fatal car accidents are caused by human error. Connected cars and automated driving can increase driving comfort and reduce accidents significantly.

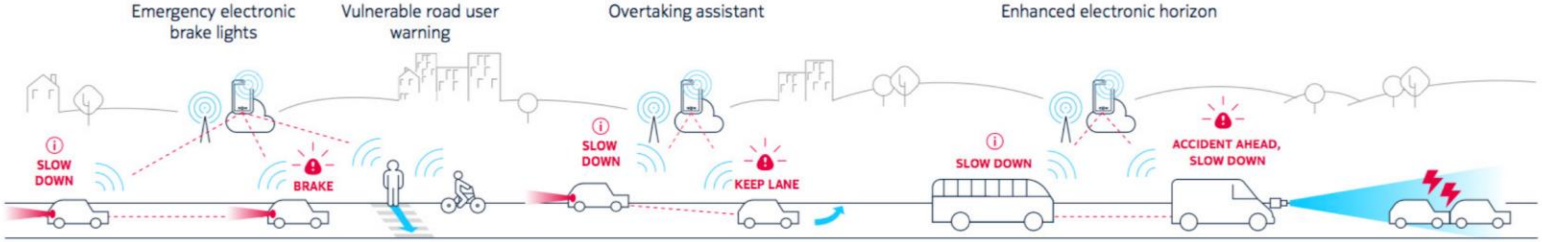
Reliable and secure vehicle-to-everything (V2X) communication over the network enables vehicles to interact with other vehicles, infrastructure, pedestrians and the network with low investments.



V2X example use cases - steps towards automated driving

- Intersection collision warning
- Traffic condition warning

- Co-operative merging assistance
- Overtaking vehicle warning



Source: https://networks.nokia.com/products/vehicle-to-everything

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7 - Device-to-device

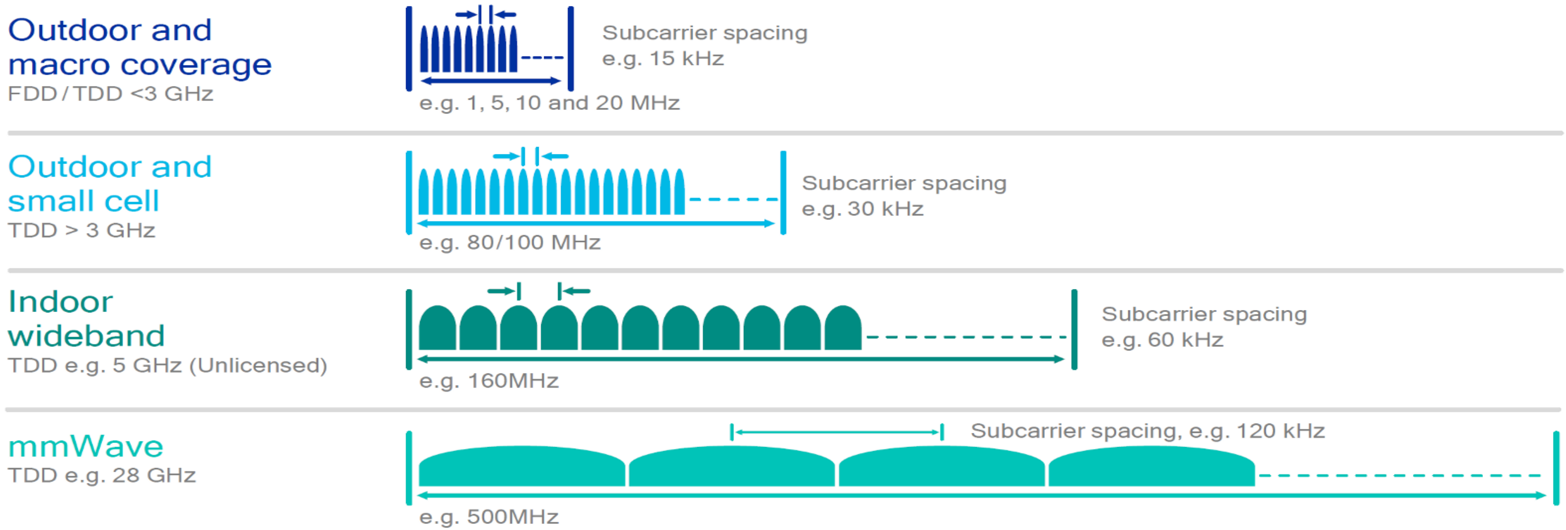
Device-to-device communications have traditionally been outside the realm of cellular networks.

These are direct links that do not relay information through the base station or over the network.

Such walkie-talkie type devices have been available for a long time but with only narrow spectrum bandwidth and hence limited capacity to transmit data.

Source: https://www.indiegogo.com/projects/linc-the-smart-walkie-talkie#/

8 - Air interface



One thing that is clear is that a new air interface will be needed. Current research even suggests that several types of air interface will coexist in the same network. From a theoretical perspective, this is ideal but from an operational and economical viewpoint, this would mean significant development costs and deployment effort.

As MIMO has been successfully deployed into 4G networks, it is expected that 5G will continue to support 5G and also expand further the MIMO capabilities using higher order MIMO and advanced beam-forming. In addition, the current static time/frequency resource allocation blocks must be revised, as more flexible methods of allocating and controlling resource allocations are required.

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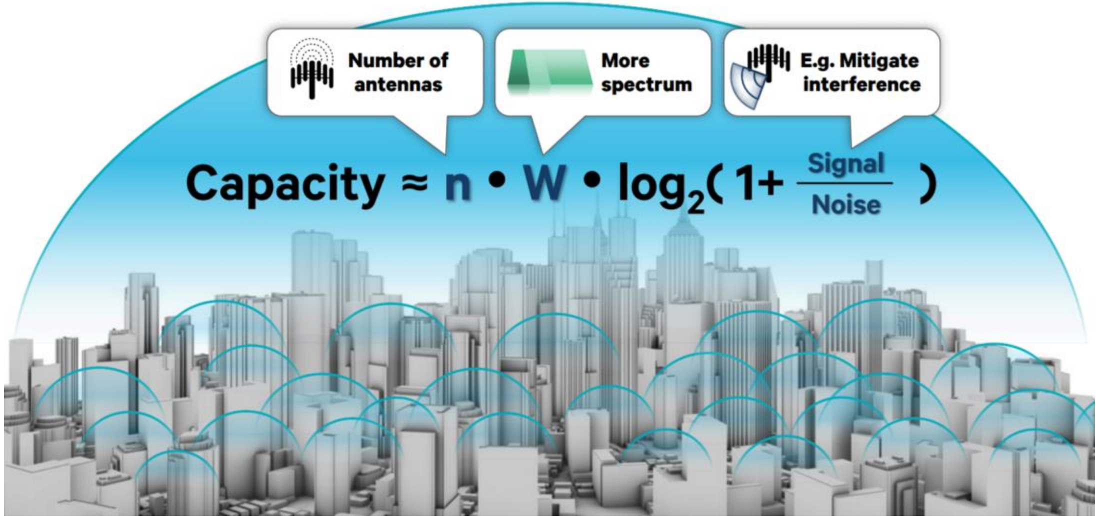
Source: https://www.qualcomm.com/invention/5g/5g-nr

9 - Network densification

The biggest gain—re-use Shannon's Law everywhere!

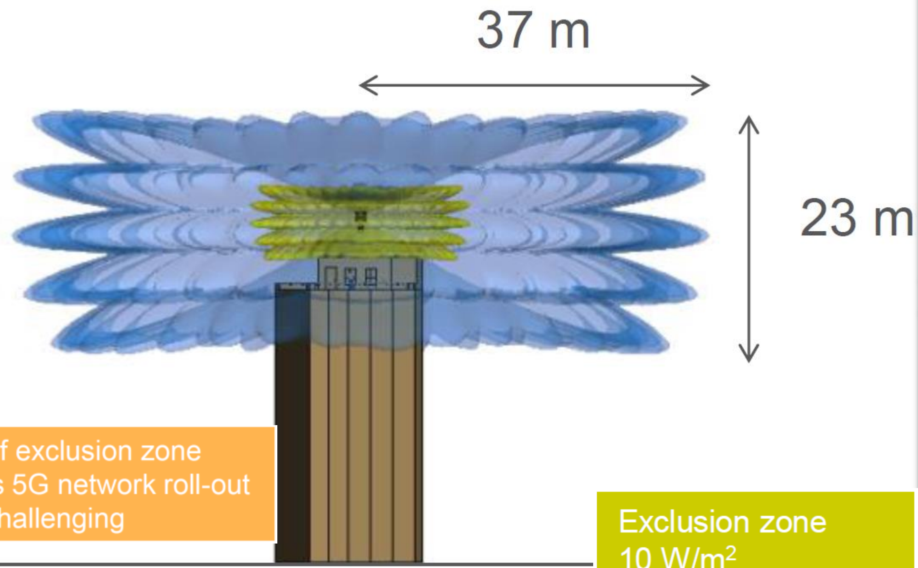


With 5G, the networks are likely to consist of several layers of connectivity from a wide area macro layer for lower data speed connectivity, through various other layers, to a localized layer for very high data speeds. Network deployment and coordination are major challenges here that need to be addressed as they increase exponentially with the number of network layers.

Source: https://www.qualcomm.com/media/documents/files/1000x-more-small-cells-.pdf

More sites, frequencies, power?

What about the maximum exposure limits of electromagnetic fields?



Size of exclusion zone makes 5G network roll-out very challenging

5G site

3.5 GHz, three sectors
28 GHz, one sector
Actual maximum power

Exclusion zone
10 W/m²

ICNIRP limit

Exclusion zone
1 W/m²

1/10 of ICNIRP limit

Countries	900 MHz Equivalent plain wave power density (W/m2)	1800 MHz Equivalent plain wave power density (W/m2)	2100 MHz Equivalent plain wave power density (W/m2)	Comment
ICNRP 1999/519/EC	4.5	9	10	
Estonia	4.5	9	10	
Latvia	—	—	—	Electric field strength (V/m) and Magnetic flux density(μT) according to ICNRP 1999/519/EC
Lithuania	0.45	0.9	1	
Poland	0.1	0.1	0.1	

Influence to health?

Source: Ericsson report „Impact of EMF limits on 5G network roll-out“

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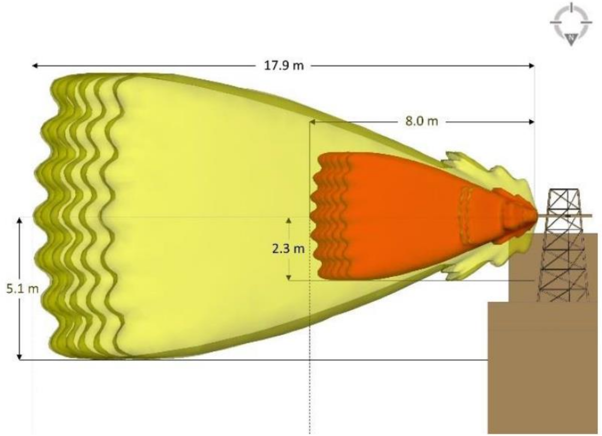
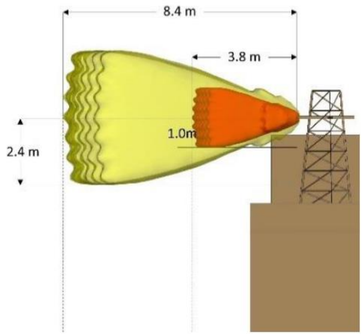
Maximum exposure limits of electromagnetic fields

Rationale for actual maximum power use



- Not all power will be focused in the same direction for several minutes
- 100% utilization is very unlikely
- TDD will limit transmit time



3.5 GHz 5G base station compliance boundary determined using **theoretical maximum** transmitted power (200 W)

3.5 GHz 5G base station compliance boundary determined using **actual maximum** transmitted power (44 W)

Source: Ericsson report „Impact of EMF limits on 5G network roll-out“

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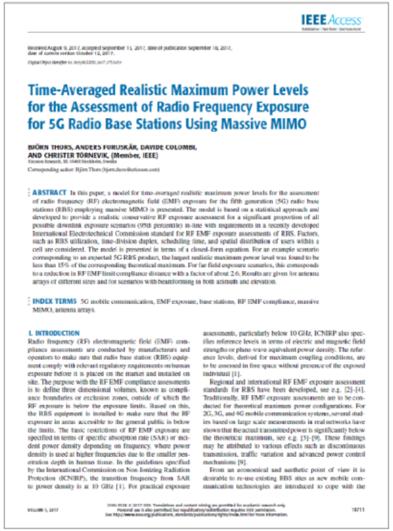
Actual maximum power of 5G massive MIMO antennas

Statistical model developed that takes into account base station utilization, scheduling time, distribution of user equipment, and time-division duplexing to determine actual power



IEEE Access

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Time-Averaged Realistic Maximum Power Levels for the Assessment of Radio Frequency Exposure for 5G Radio Base Stations Using Massive MIMO

BJÖRN THORS, ANDERS FURUSKÄR, DAVIDE COLOMBI, AND CHRISTER TÖRNEVIK, (Member, IEEE)

ABSTRACT In this paper, a model for time-averaged realistic maximum power levels for the assessment of radio frequency (RF) electromagnetic field (EMF) exposure for the fifth generation (5G) radio base stations (RBS) employing massive MIMO is presented. The model is based on a statistical approach and developed to provide a realistic conservative RF exposure assessment for a significant proportion of all possible downlink exposure scenarios (95th percentile) in-line with requirements in a recently developed International Electrotechnical Commission standard for RF EMF exposure assessments of RBS. Factors, such as RBS utilization, time-division duplex, scheduling time, and spatial distribution of users within a cell are considered. The model is presented in terms of a closed-form equation. For an example scenario corresponding to an expected 5G RBS product, the largest realistic maximum power level was found to be less than 15% of the corresponding theoretical maximum. For far-field exposure scenarios, this corresponds to a reduction in RF EMF limit compliance distance with a factor of about 2.6. Results are given for antenna arrays of different sizes and for scenarios with beamforming in both azimuth and elevation.

INDEX TERMS 5G mobile communication, EMF exposure, base stations, RF EMF compliance, massive MIMO, antenna arrays.

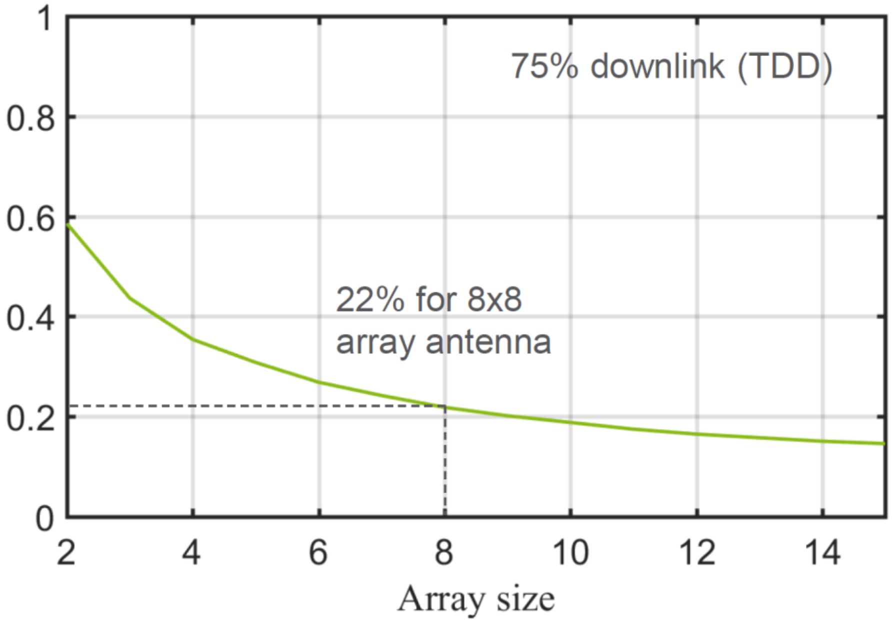
I. INTRODUCTION

Radio frequency (RF) electromagnetic field (EMF) compliance assessments are conducted by manufacturers and operators to make sure that radio base station (RBS) equipment comply with relevant regulatory requirements on human exposure before it is placed on the market and installed on site. The purpose with the RF EMF compliance assessments is to define three dimensional volumes, known as compliance boundaries or exclusion zones, outside of which the RF exposure is below the exposure limits. Based on this, the RBS equipment is installed to make sure that the RF exposure in areas accessible to the general public is below the limits. The basic restrictions of RF EMF exposure are specified in terms of specific absorption rate (SAR) or incident power density depending on frequency, where power density is used at higher frequencies due to the smaller penetration depth in human tissue. In the guidelines specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the transition frequency from SAR to power density is at 10 GHz [1]. For practical exposure assessments, particularly below 10 GHz, ICNIRP also specifies reference levels in terms of electric and magnetic field strengths or plane-wave equivalent power density. The reference levels, derived for maximum coupling conditions, are to be assessed in free space without presence of the exposed individual [1].

Regional and international RF EMF exposure assessment standards for RBS have been developed, see e.g. [2]-[4]. Traditionally, RF EMF exposure assessments are to be conducted for theoretical maximum power configurations. For 2G, 3G, and 4G mobile communication systems, several studies based on large scale measurements in real networks have shown that the actual transmitted power is significantly below the theoretical maximum, see e.g. [3]-[9]. These findings may be attributed to various effects such as discontinuous transmission, traffic variation and advanced power control mechanisms [9].

From an economical and aesthetic point of view it is desirable to re-use existing RBS sites as new mobile communication technologies are introduced to cope with the

Fraction of total power contributing to the EMF exposure as function of antenna array size (95th percentile)



Source: Ericsson report „Impact of EMF limits on 5G network roll-out“

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