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Networks and Services Section

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5G fact sheet

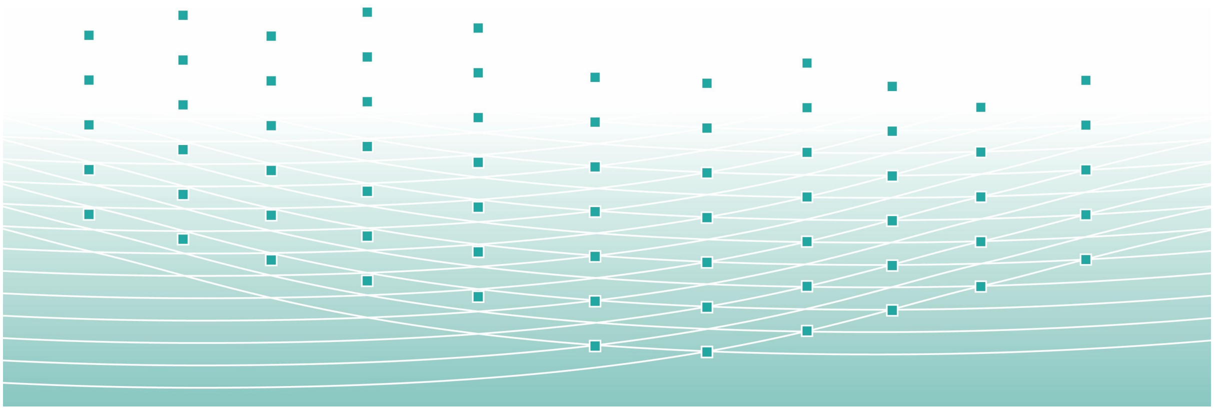
An introductory overview

Summary

Every year sees a doubling of the amount of data we transmit over the mobile network. The introduction of the third generation of mobile telephony (3G, UMTS) in the mid-2000s and the fourth generation (4G, LTE) from 2012 onwards have enabled us to meet the demand so far, but these technologies are now reaching their limits. One effect of the introduction of 5G will be an increase in the number of active connections and a significant increase in data transmission capacities.

5G networks represent an important evolutionary step in the field of mobile communications, opening the door to new application scenarios, in particular the Internet of Things (IoT), machine-to-machine communication (M2M), ultra-broadband and real-time applications.

This fact sheet identifies the background, properties, application scenario and innovations that the new 5G mobile communications standard offers.



Content

1 Introductory remarks

1.1 What is 5G and what does it offer?

5G is the next generation of mobile communication systems. It is the logical continuation of the previous mobile telephony systems and is to a large degree based on 4G LTE. In essence, the 5G technology consists of a new air interface (radio access network (RAN)) and a new core network architecture (further information on this topic in section 3.2). The 5G system's new air interface is known as "5G New Radio" (5G NR), while the new core network is referred to as the "5G Core Network" (5G CN or 5GC).

The performance characteristics of 5G compared to 4G are as follows:

- data rates up to 100 times higher to cope with the rapidly growing volume of mobile data and therefore a greater system capacity (1000 times higher data transmission capacity/km^2)
- shorter time lag (latency) for data transmissions within the 5G system and thus a shorter response time for end-user telecommunications services
- higher number of simultaneously connected terminal devices (up to 1 million per km^2) with regard to the Internet of Things (IoT)
- Support for frequencies above 6 GHz for the future expansion of mobile networks

These significant advancements justify its designation as a new mobile telephony generation. In contrast to previous systems, 5G enables connections with guaranteed transmission speeds and lower, guaranteed latency times, in addition to more reliable connections, longer battery life for terminal devices and application-related network segmentation (network slicing, parallel virtual mobile networks; see Chapter 3.5).

These characteristics create new opportunities for innovation in mobile telecommunications services (see section 2). The 5G technology is therefore considered to have great potential benefits.

1.2 Expanding data volumes

The volume of mobile data traffic is constantly expanding. In 2017, approximately 56 percent of the data volume was generated by video (audiovisual transmissions in fields such as entertainment, production, education, video conferencing, surveillance, medicine, virtual and augmented reality). This share is likely to rise to around 73 per cent in 2023 (Illustration 1). Representatives of the mobile telephony industry expect mobile broadband to remain an important component of mobile telephony in the future.

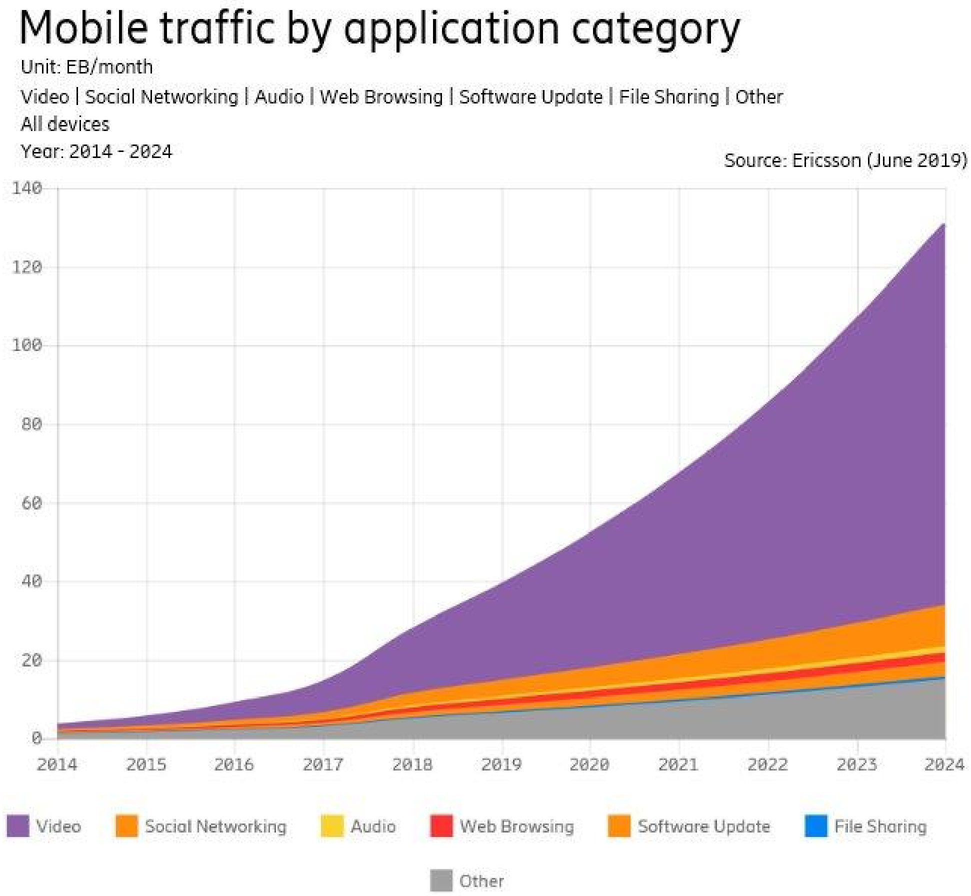


Illustration 1: Mobile traffic volume by application category (in exabytes = 1 billion gigabytes, 10^{18}) (source: Ericsson) [1]

1.3 Worldwide number of mobile subscribers

Illustration 2 shows the development in the number of subscribers to the main mobile technologies and the projected number of subscribers up to 2024. By the end of 2024, it is estimated that there will be 1.8 billion 5G Enhanced Mobile Broadband (eMBB) subscriptions worldwide, although LTE subscriptions will continue to account for the largest share (approximately 5 billion). In Western Europe, it is estimated that there will be 220 million 5G subscriptions and 300 million LTE subscriptions by the end of 2024.

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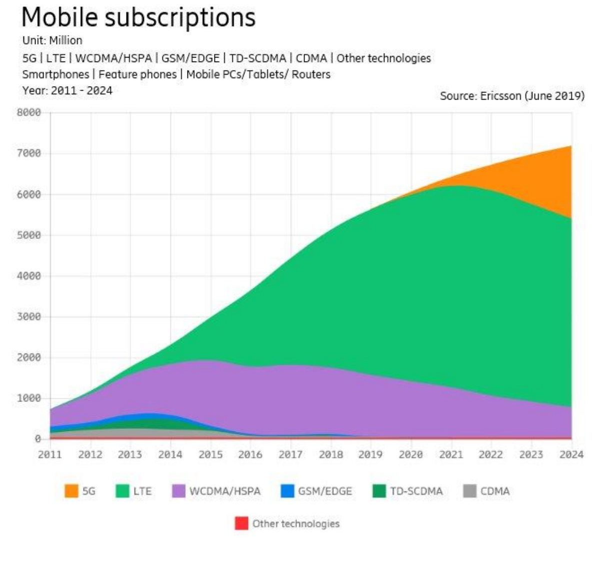
<tr><th>Worldwide</th><th>Western Europe</th></tr>
<tr><td>
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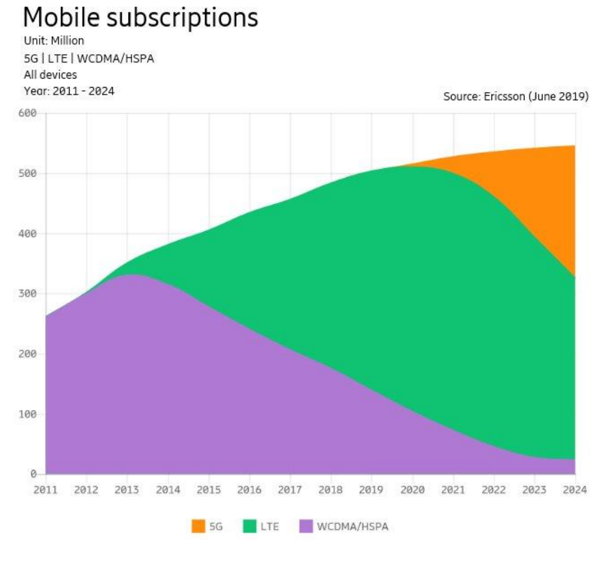
<td>
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Illustration 2: Number of mobile phone subscriptions worldwide and in Western Europe by mobile phone technology (in millions) (source: Ericsson) [1]

1.4 Which countries use 5G?

The number of countries investing in 5G technologies or performing laboratory testing, pilot projects and field trials is increasing significantly (Illustration 3). According to the Global Supplier Association (GSA), the association of suppliers of components for mobile networks, in July 2019 a total of 293 operators in 98 countries were working on introducing 5G services.

The European Commission has set up a 5G Observatory to monitor developments in the implementation of 5G in the EU and the rest of the world. [2]

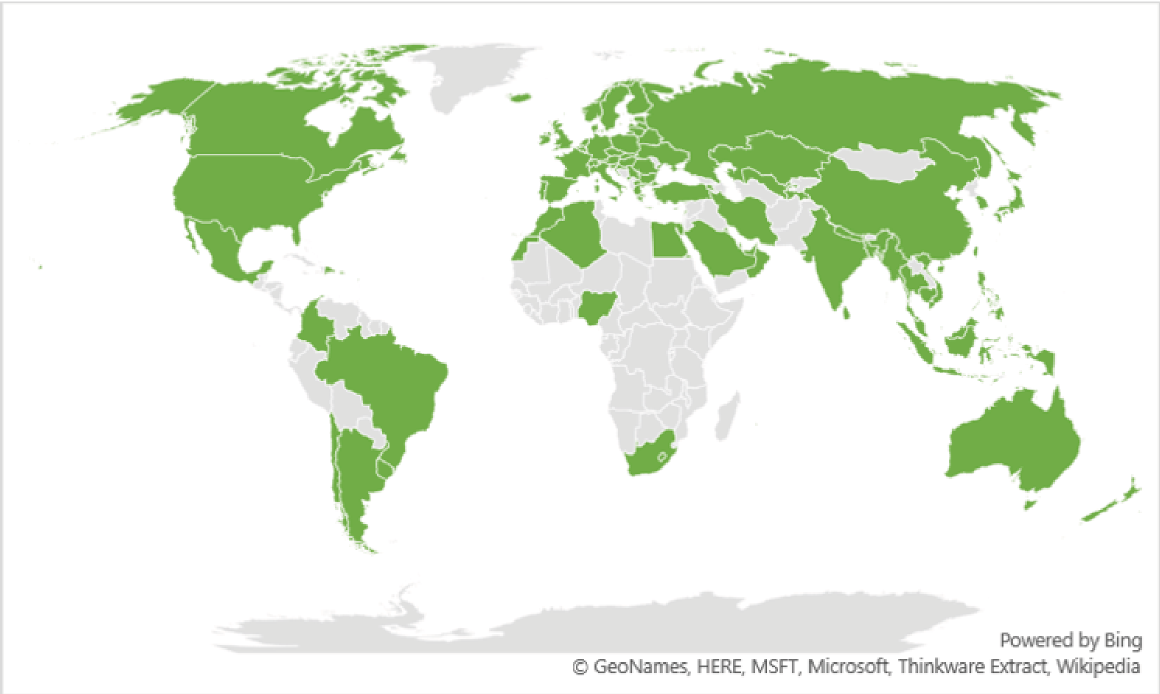


Illustration 3: Countries with network operators investing in 5G (source: GSA) [3]

2 5G application scenarios

The International Telecommunication Union (ITU) envisages three application scenarios for 5G: Enhanced Mobile Broadband (eMBB),Ultra-Reliable Low Latency Communication (URLLC) and Massive Machine-Type Communication (mMTC) (see Illustration 4). The main features of the application scenarios are described in Table 1.

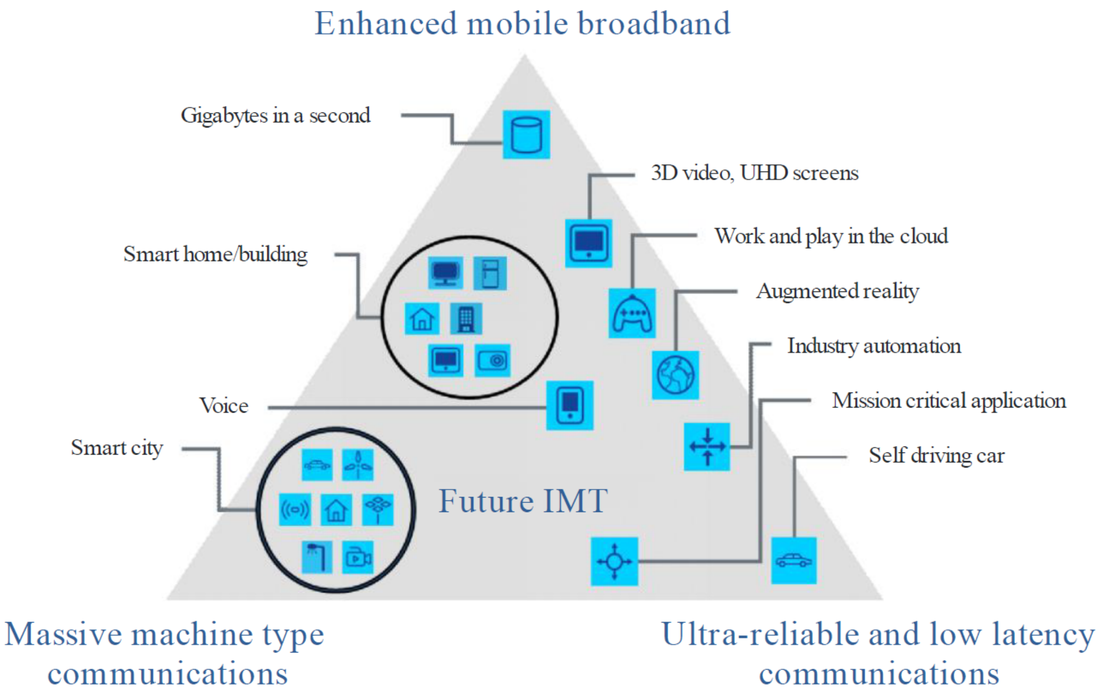


Illustration 4: Division of the 5G applications into three application scenarios (source: ITU) [4]

Enhanced Mobile Broadband (eMBB)	Massive Machine-Type Communication (mMTC)	Ultra-Reliable and Low Latency Communication (URLLC)
The primary characteristics of this application scenario are high and variable data rates (up to 20 Gbps) and high mobility (e.g. in high-speed trains) and density of subscribers. Improved mobile broadband access allows the transition between fixed and mobile networks to become increasingly seamless.	This application scenario is characterised by a very large number of networked devices (Internet of Things, IoT) that typically transmit small volumes (a few bytes) of non-critical data (e.g. water meters). The devices must be inexpensive and have an extremely lengthy autonomy (battery life up to 10 years).	This application scenario is characterised by reliable and/or time-critical connections with guaranteed transmission speeds, assured latency times of a few milliseconds and a defined probability of failure. Examples include remote control of machines, energy management in smart grids or vehicle control systems.

Table 1: Main features of 5G application scenarios

The new scenarios and applications place very different technical demands on the networks. For example, a fast response time (short time lag, latency) is key for automated vehicles, while latency is less important for other applications, but a high data rate (e.g. for streaming services) or a defined probability of failure (e.g. for alarm systems and production monitoring) are vital.

3 5G technology

3.1 Standardisation

The 3GPP (3rd Generation Partnership Project) standardisation committee develops the specifications and standards for the 5G system. 3GPP is a collaboration between standardisation organisations and representatives from industry and forms part of the European Telecommunications Standards Institute (ETSI) based in the South of France.

In contrast to previous mobile telephony systems, 5G was standardised on the basis of previously defined application scenarios. This standardisation resulted in flexible communication parameters (section 3.3) that enable the provision of different data services for the three application scenarios described in Table 1.

In June 2018, 3GPP published the 5G NR specification for standalone operation (see section 3.2) as Release 15 (Illustration 5). This is the first 5G specification. Releases 16 and 17 are currently being prepared (as at December 2019).

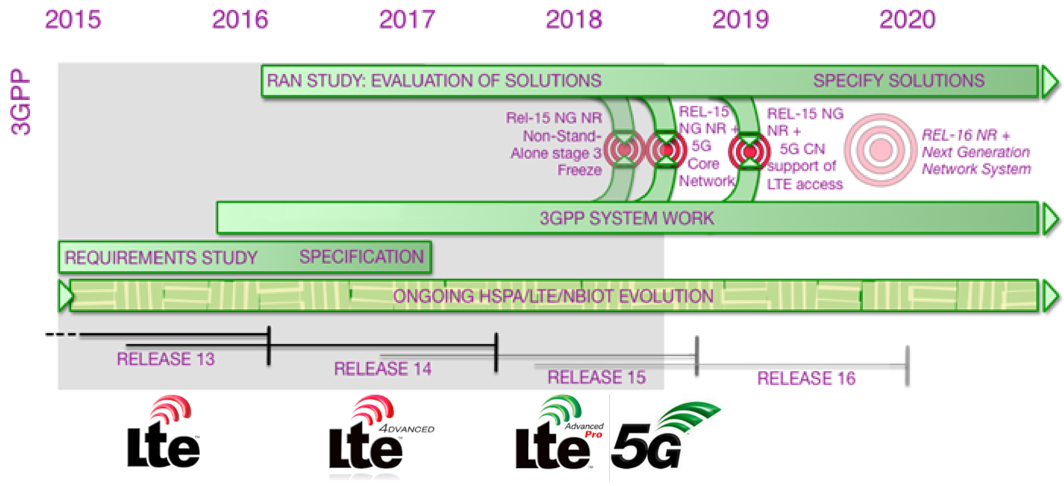


Illustration 5: 5G standardisation schedule (source: ETSI/3GPP)

3.2 5G system architecture

The principle elements of a mobile telephony system are the core network (transport and control network) and the radio access network (RAN) (Illustration 6). The core network connects the transmitter sites and transports the user data and control signals between the transmitter sites and other telecommunications networks (other telephone networks, the Internet, etc.). The 4G core network is known as the “Evolved Packet Core” (EPC), while the 5G core network is called the “5G Core Network” (5G CN). The RAN consists of the transmitter sites (base stations) and is the interface to the terminal devices.

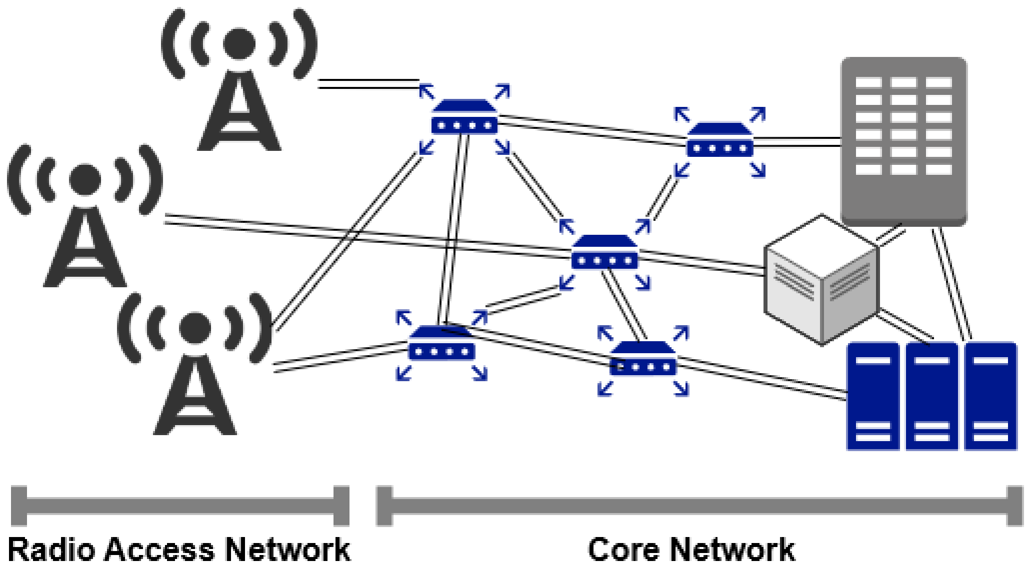
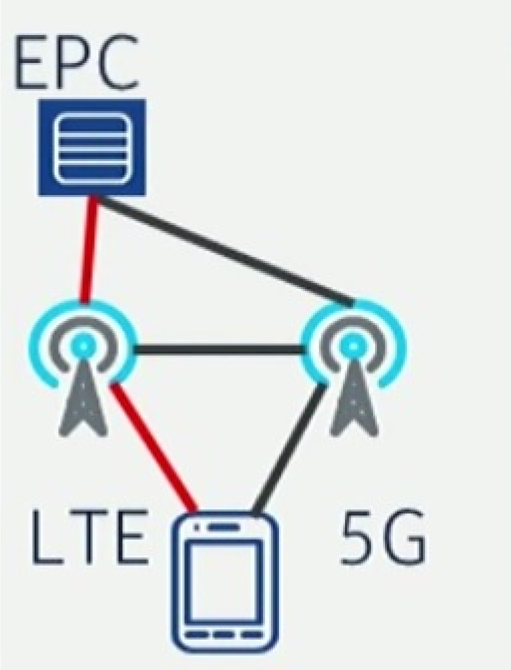


Illustration 6: 5G system architecture (source: OFCOM)

The 5G standard offers network operators the following options for connecting 5G base stations (Illustration 7):

a) The non-standalone architecture (NSA) uses the existing 4G wireless and core network. It is the first step toward full 5G implementation, but requires a simultaneous 4G connection (Dual Connectivity, DC).
b) In the stand-alone implementation option (SA), the 5G system consists of the new 5G core network (5GC or 5G CN) and the 5G RAN (NR). The LTE nodes will continue to be used for the purposes of 4G network access.

a) Non-standalone



b) Standalone

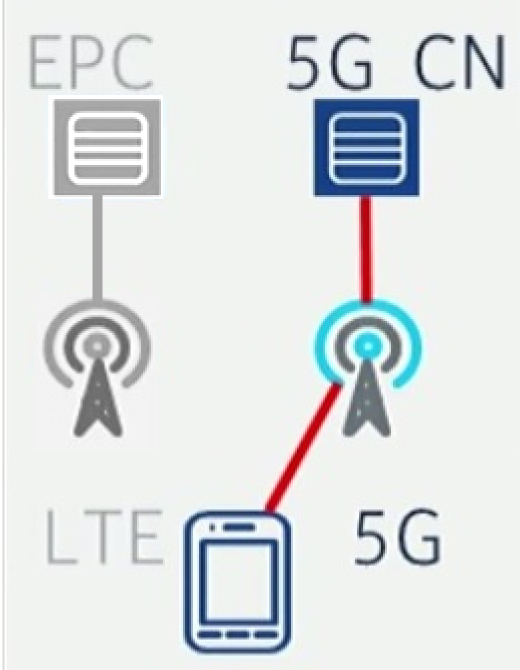


Illustration 7: The 5G architecture implementation options (source: 3GPP, OFCOM)

3.3 The radio access network (RAN)

The RAN provides the connection between the core network (5G CN) and the terminal devices via the air interface (5G NR).
The main features of the 5G-NR air interface compared to the LTE air interface are the following [5]:

- orthogonal frequency division multiplexing *(*OFDM) as a modulation type in the uplink[1] (as per the downlink[2])
- flexible modulation parameters (OFDM) for new application scenarios (see section 2) and for the use of future frequency ranges above 6 GHz
- Quadrature amplitude modulation with 1024 symbols (1024-QAM) for broadband communication with line of sight between the transmitting and receiving antennas
- Adaptation of the time frame structure of the wireless protocol to reduce latency, save energy and ensure more flexible and faster availability of radio resources for network access
- Use of extended multi-antenna technologies (MIMO) to compensate for the propagation loss of the transmitted signal, particularly but not exclusively, at higher frequencies (from 3.6 GHz); 5G NR supports up to 32 transmitting antennas in the base station and four receiving antennas in the terminal device (depending on the frequency band; see section 3.3.1)
- extended aggregation of frequency carriers to a single user (carrier aggregation, CA; see section 3.3.3)

3.3.1 MIMO

The Multiple Input Multiple Output (MIMO) multi-antenna system formed part of the previous generations of mobile telephony systems and will play an even more important role in 5G.

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[1] Terminal device transmits, base station receives.

[2] Base station transmits, terminal device receives.

In comparison to the first LTE release, in which up to four transmitting antennas could be used in the base station and two receiving antennas in the terminal device, NR supports up to 32 transmitting antennas in the base station and four receiving antennas in the terminal device (depending on the frequency band; see section 4). Where possible, the data to be transmitted is divided among all the transmitting antennas and transmitted in parallel to the receiving antennas. The data streams received in parallel are aggregated to form the transmitted information in the terminal device.

The use of MIMO increases the spectral efficiency (bit rate per channel bandwidth, Mbps/Hz). In addition, NR uses MIMO in each phase of the wireless transmission: searching for a network, setting up a connection, transmitting signalling and data, etc.

3.3.2 Beamforming

The frequency-dependent transmission signal attenuation can be partially compensated by beamforming, i.e. the targeted focussing of the transmitting antenna to the individual terminal devices.

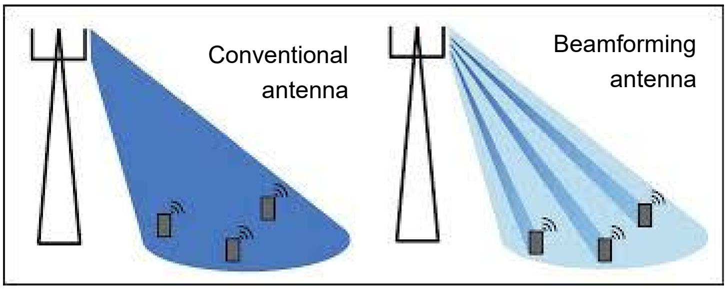

Illustration 8: Radio field with and without beamforming focussing (source: Cerclair)

This makes it possible for a stronger receiving signal to be generated in the terminal device, despite the base station having the same transmitting power, which allows a higher data rate to be achieved.

3.3.3 Carrier aggregation

Carrier aggregation (CA) bundles two or more single channels (component carriers, CCs) to achieve larger transmission bandwidths. CA is not new to 5G NR and has formed part of the LTE technical specifications since Release 10. Unlike earlier generations, it was however extended to 5G NR in Release 15. The aggregated single channels can be contiguous in the same frequency band (intra-band contiguous configuration), in the same frequency band with a frequency gap or gaps (intra-band non-contiguous configuration) or in different frequency bands (inter-band configuration) (Illustration 9).

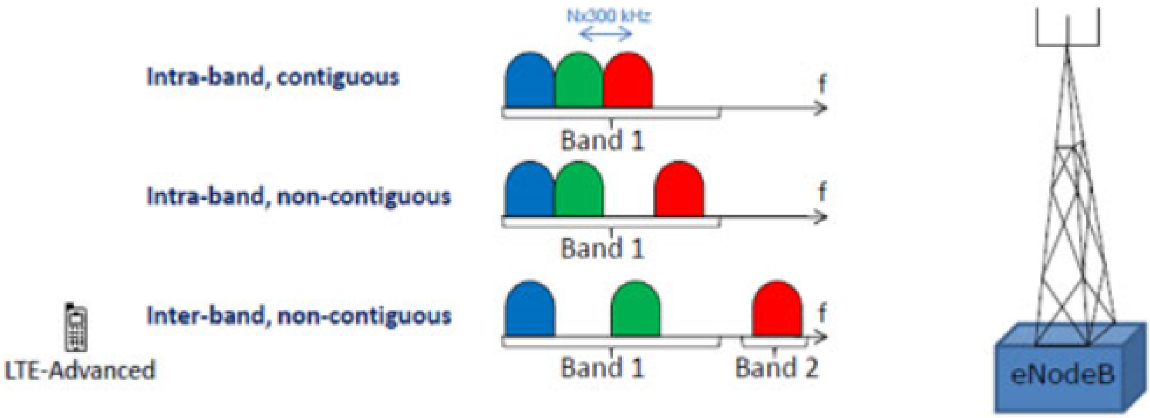

Illustration 9: Aggregation of single and adjacent channels between the base station (eNodeB) and the terminal device using LTE Advanced as an example (source: 3GPP)

In addition, 5G NR enables the bundled use of carriers with different combinations of modulation parameters. Release 15 allows up to 16 5G NR carriers to be aggregated to form a connection. The number of aggregated 5G NR single channels can be independently configured for the downlink and uplink.

The technical specifications TS 38.101 of the 3GPP list the possible band combinations for the CA in tables [6].

3.3.4 Data rates

The peak data rate is the highest data rate (in bps) that can be achieved under ideal conditions, i.e. the largest amount of data bits per unit of time that can be received by a single terminal device assuming error-free transmission if all radio resources allocable to a connection are used for the corresponding transmission direction.
In addition to the peak data rate, the data rate experienced by users is defined as the minimum data rate necessary to achieve an adequate user experience in terms of quality.

The data rate requirements depend on the 5G system’s application scenario: e.g. in urban and rural areas, in offices and apartments, in high-speed trains or at major events. The data rates experienced for certain scenarios are summarised in Table 2.

	Scenario	Experienced data rate (DL)	Experienced data rate (UL)	Area traffic capacity (DL)	Area traffic capacity (UL)	Total user density	Activity factor	Speed of movement of the user device	Coverage
1	Urban macrocells	50 Mbps	25 Mbps	100 Gbps/km^2 (Note 4)	50 Gbps/km^2 (Note 4)	10,000/km^2	20%	Pedestrians and users in vehicles (up to 120 km/h)	Complete network (Note 1)
2	Rural macrocells	50 Mbps	25 Mbps	1 Gbps/km^2 (Note 4)	500 Mbps/km^2 (Note 4)	100/km^2	20%	Pedestrians and users in vehicles (up to 120 km/h)	Complete network (Note 1)
3	Indoor hotspot	1 Gbps	500 Mbps	15 Tbps/km^2	2 Tbps/km^2	250,000/km^2	Note 2	Pedestrians	Offices and housing (Note 2) (Note 3)
4	Broadband access for user aggregations	25 Mbps	50 Mbps	3.75 Tbps/km^2	7.5 Tbps/km^2	500,000/km^2	30%	Pedestrians	Restricted area
5	Dense urban area	300 Mbps	50 Mbps	750 Gbps/km^2 (Note 4)	125 Gbps/km^2 (Note 4)	25,000/km^2	10%	Pedestrians and users in vehicles (up to 60 km/h)	City centre (Note 1)
6	Services comparable to broadcasting	Maximum 200 Mbps (per TV channel)	Not perceivable or modest (e.g. 500 kbps per user)	N/A	N/A	TV transmitter with 20 Mbps on a single carrier	N/A	Stationary users, pedestrians and users in vehicles (up to 500 km/h)	Complete network (Note 1)
7	High-speed train	50 Mbps	25 Mbps	15 Gbps/train	7.5 Gbps/train	1,000/train	30%	Users in trains (up to 500 km/h)	Along the track (Note 1)
8	High-speed vehicle	50 Mbps	25 Mbps	100 Gbps/km^2	50 Gbps/km^2	4,000/km^2	50%	Users in vehicles (up to 250 km/h)	Along the roads (Note 1)
9	Provision to aircraft	15 Mbps	7.5 Mbps	1.2 Gbps/aircraft	600 Mbps/aircraft	400/aircraft	20%	Users in aircraft (up to 1,000 km/h)	(Note 1)

The values in this table are guide values, not strict requirements.

NOTE 1: For users in vehicles, the user device may be connected to the network directly or via a wireless router in the vehicle.
NOTE 2: It is assumed that there will be some mixture of traffic. Only a few users use services that require the highest data rates.
NOTE 3: For interactive audio and video services, such as virtual meetings, the required end-to-end latency (UL and DL) is 2-4 ms, while the corresponding experienced data rate for 3D videos up to 8K must be around 300 Mbps in the uplink and downlink.
NOTE 4: These values are derived on the basis of the total user density. Detailed information can be found in the reference document.

Table 2: Performance requirements for high data rate and traffic density scenarios [7]

3.3.5 Latency

Latency is the time taken to transmit data from one point to another within a network. In a mobile network, it is the time that is needed to transmit user data, network control commands, etc., between the base station and the terminal device.

The total latency of a transmission is dependent on the delay in the air interface, its transmission within the core network, its transmission to a server that may be outside the 5G system and the processing time of the request on the server. Each leg of the route and each element of the network involved therefore contributes to the overall delay. Some of these factors depend directly on the 5G system itself, while others do not (see section 3.6).

Even where the possible data rate is high, high latency will cause the transmission of data to stall and give the impression of a “long haul interconnection”. An example of this is the interval between clicking a mouse on a web page (request) and the requested web page being loaded.

5G has also been referred to as “real-time data transmission”, since very short response times can be achieved with telecommunications services. With 5G NR, the shortest latency between the transmitter site and the terminal device is 1 millisecond for URLLC applications and 4 milliseconds for eMMB applications. By way of comparison: The blink of a human eye takes about 100 milliseconds. The short latency in the air interface allows applications to run simultaneously with reality, such as augmented reality, virtual reality, automation, remote control, immediate tactile feedback, etc.

3.4 The 5G CN core network

The new requirements of the applications require a new core network (see section 2). A core network transports user data and encompasses network functions that control the network. While the network functions were built into the core network in 4G, in 5G they are now decoupled from one another and from the core network (e.g. separated control and user plane, stand-alone authentication function, detached mobility management). The decoupling of the network functions allows them to be virtualised. In other words, these functions are no longer performed by a specialised core network infrastructure (hardware), but instead from any location using software in a data centre (in the Cloud). Virtualisation will be one of the key technologies to deliver highly managed, secure and reliable services at a reduced cost and to respond with agility to customer requirements. **Network slicing**

The wide range of 5G application scenarios and applications means that 5G has to be able to meet several requirements simultaneously. Instead of creating a dedicated network for each application specifically tailored to the needs of each (business) customer, such as a network purely for the emergency services, the mobile network is divided into segments (network slicing). Each of these segments can be regarded as an independent network with its own characteristics and functions. This allows multiple dedicated virtual mobile networks to be deployed simultaneously, all of which are based on a common physical infrastructure. Depending on the telecommunications service requested, the terminal devices are then “connected” to the corresponding segments. For example, a mobile phone requesting an HD streaming service uses the multimedia segment (Illustration 10).

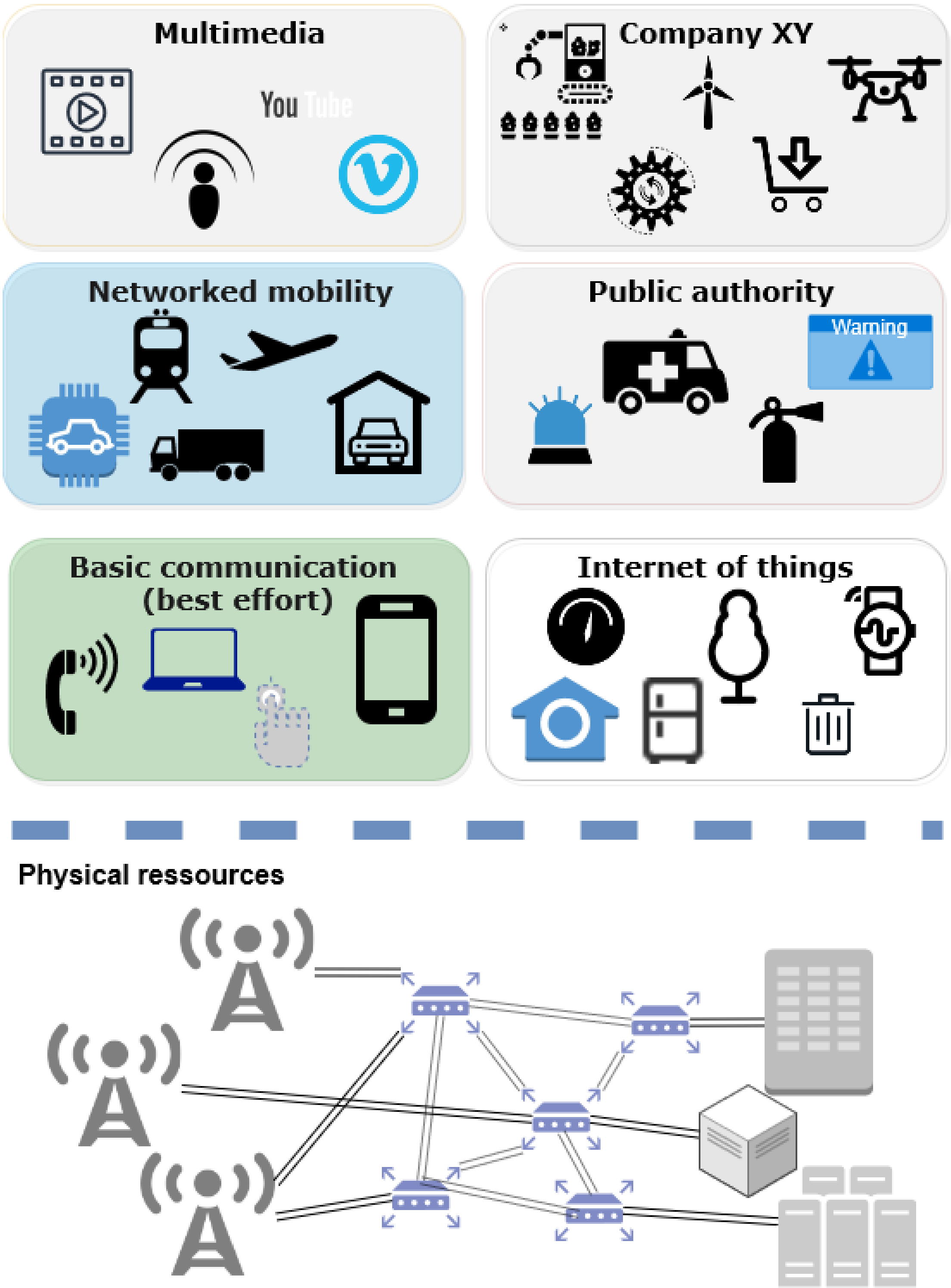

Illustration 10: Concept of network slicing with parallel virtual mobile telephony networks for different applications (source: OFCOM)

3.6 Local hosting of Services and edge computing

"Local hosting" and "edge computing", i.e. decentralised data processing in the periphery of the network allows a significant reduction in the latency of a service to be achieved.

In 5G networks, the platform for local hosting is called the "5G service hosting environment". This allows the software that provides the respective end-user service to be hosted in the vicinity of the terminal device. The shortened transmission paths eliminate data transmissions that are susceptible to delays and relieve the core network.

4 Frequencies

At the World Radiocommunication Conference 2019 (WRC-19), the frequency ranges 24.25–27.5 GHz, 37–43.5 GHz, 45.5–47 GHz, 47.2–48.2 GHz and 66–71 GHz were identified for mobile networks for most countries. Each country is free to decide how it wishes to use these frequency ranges.

Of the frequencies newly identified at WRC-19, the ranges 24.25–27.5 GHz, 40.5–43.5 GHz and 66–71 GHz are the most relevant for Switzerland. When and how these frequency bands can be used in the future is currently an open question.
In Switzerland, the mobile telephony frequencies 800 MHz, 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz were auctioned off in 2012 and the frequencies 700 MHz, 1400 MHz and 3500–3800 MHz in 2019. The licences are designed to be technology-neutral, allowing the licensed operators the freedom to choose the technology that provides mobile telecommunications services (2G, 3G, 4G and 5G) (see Table 3).

Pursuant to the 3GPP specification (Release 15), 5G NR can basically be operated in two frequency ranges: 450–6000 MHz (FR1) and 24,250–52,600 MHz (FR2) [6]
At European level, various pioneer frequency bands have been identified as suitable for the introduction of 5G, including frequencies with different characteristics to meet the many requirements of 5G:

- Frequencies below 1 GHz, in particular the 700 MHz band: Their superior operating distance (e.g. deep-indoor penetration) make these frequency ranges suitable for area coverage. [8]
- Frequencies between 1 GHz and 6 GHz, in particular the 3.5 GHz band: These frequency ranges are essential for the introduction of 5G in Europe because of the larger amount of available frequencies they offer and their suitability for macro and small cells due to their limited operating distance [9]
- New and wider frequency bands above 6 GHz, in particular the 26 GHz band [10]: These frequency ranges have an even greater amount of available frequencies compared to those below 6 GHz, although their operating distance is more limited. They are therefore best suited for the expansion of local capacity in the form of small and micro cells in railway stations, stadiums, at major events, etc.

NR operating band	Uplink (UL) operating band (base station receiving/user device transmitting)	Downlink (DL) operating band (base station receiving/user device transmitting)	Duplex process
n1	1920 MHz-1980 MHz	2110 MHz-2170 MHz	FDD
n3	1710 MHz-1785 MHz	1805 MHz-1880 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-733 MHz	758 MHz-788 MHz	FDD
n38	2570 MHz-2620 MHz	2570 MHz-2620 MHz	TDD
n75	unavailable	1432 MHz-1517 MHz	SDL (1)
n76	unavailable	1427 MHz-1432 MHz	SDL (2)
n78	3500 MHz-3800 MHz	3500 MHz-3800 MHz	TDD
FDD: Frequency duplex SDL (1): supplementary downlink to NR operating bands n8, n28 and n78 SDL (2): supplementary downlink to NR operating band n78 TDD: Time duplex			

Table 3: Frequencies currently usable in Switzerland with 5G NR

5 Abbreviations

3GPP	Third Partnership Project
CA	Carrier aggregation
CC	Component carrier
DC	Dual connectivity
DL	Downlink
eMBB	Enhanced Mobile Broadband
EPC	Evolved Packet Core
FDD	Frequency Division Duplex
FR	Frequency range
GHz	Gigahertz (10^9 Hertz)
IMT	International Mobile Telecommunications
IoT	Internet of Things
ITU	International Telecommunication Union
IP	Internet Protocol
LTE	Long-Term Evolution
M2M	Machine-to-Machine Communication
MHz	Megahertz (10^6 Hertz)
MIMO	Multiple Input Multiple Output
mMTC	Massive Machine-Type Communication
MTC	Machine-Type Communication
NR	New Radio
NSA	Non-standalone
OFDM	Orthogonal Frequency Division Multiplexing
RAN	Radio Access Network
SA	Standalone
SDL	Supplemental Downlink
TDD	Time Division Duplex
UL	Uplink
URLLC	Ultra-Reliable Low Latency Communication
UMTS	Universal Mobile Telecommunications System
WRC	World Radio Conference

6 References

[1] Ericsson Mobility Visualizer https://www.ericsson.com/en/mobility-report/mobility-visualizer

[2] EU 5G Observatory https://5gobservatory.eu/

[3] GSA report – Evolution of LTE to 5G, August 2019 update

[4] ITU-R Recommendation M.2083, IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond, September 2015

[5] 3GPP TS 38.211; NR Physical Channels and Modulation (Release 15)

[6] 3GPP TS 38.101; NR User Equipment (UE) radio transmission and reception

[7] 3GPP TS 22.261; Service requirements for the 5G system; Stage 1 (Release 15)

[8] Decision (EU) 2017/899 of the European Parliament and of the Council of 17 May 2017 on the use of the 470-790 MHz frequency band in the Union
EN: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32017D0899

[9] Decision (EU) 2019/235 of 24 January 2019 on amending Decision 2008/411/EC as regards an update of relevant technical conditions applicable to the 3400-3800 MHz frequency band
EN: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008D0411

[10] Commission Implementing Decision (EU) 2019/784 of 14 May 2019 on harmonisation of the 24,25-27,5 GHz frequency band for terrestrial systems capable of providing wireless broadband electronic communications services in the Union
EN: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32019D0784