UNIVERSITÀ DELLA CALABRIA

Master Degree in Telecommunications Engineering

"Mobile Networks" Class

9 - 5G : introduction and overview

Antonio Iera
DIMES Department - University of Calabria
Arcavacata di Rende, ITALY
antonio.iera@dimes.unical.it

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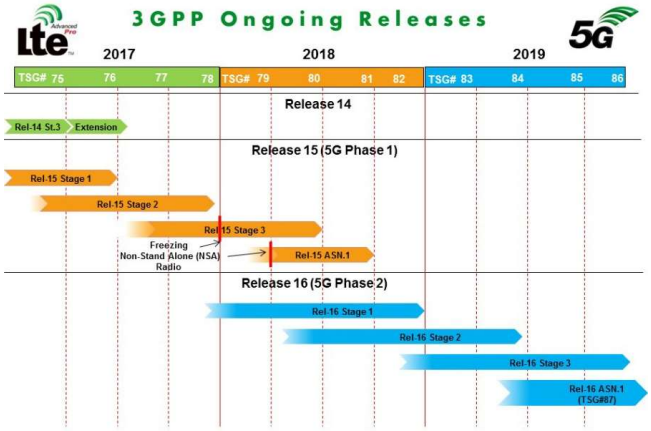
How 3GPP works?

- 3GPP uses a system of parallel "**Releases**" which provide developers with a stable platform for the implementation of features at a given point and then allow for the addition of new functionality in subsequent Releases.



http://www.3gpp.org/specifications/67-releases

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Cellular systems evolution

Generation	Primary services	Key differentiator	Weakness (addressed by subsequent generation)
1G	Analogue phone calls	Mobility	Poor spectral efficiency, major security issues
2G	Digital phone calls and messaging	Secure, mass adoption	Limited data rates – difficult to support demand for internet/e-mail
3G	Phone calls, messaging, data	Better internet experience	Real performance failed to match hype, failure of WAP for internet access
3.5G	Phone calls, messaging, broadband data	Broadband internet, applications	Tied to legacy, mobile specific architecture and protocols
4G	All-IP services (including voice, messaging)	Faster broadband internet, lower latency	?

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Cellular systems evolution

- Mobile technologies have a lifetime of 10 years
- 4G first deployments in 2009-2010

1G	2G	3G	4G	5G
1981	1992	2001	2010	2020(?)
2 Kbps	64 Kbps	2 Mbps	100 Mbps	10 Gbps
Basic voice service using analog protocols	Designed primarily for voice using the digital standards (GSM/CDMA)	First mobile broadband utilizing IP protocols (WCDMA / CDMA2000)	True mobile broadband on a unified standard (LTE)	'Tactile Internet' with service-aware devices and fiber-like speeds
				?

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Towards 5G

- By 2022: the society should be connected and mobile through 5G

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5G: definitions

- **View 1 – The hyper-connected vision***:* In this view of 5G, mobile operators would create a **blend of pre-existing technologies covering 2G, 3G, 4G, Wi-Fi** and others to allow higher coverage and availability, and higher network density in terms of cells and devices, **with the key differentiator being greater connectivity as an enabler for M2M services and IoT**. This vision may include a new radio technology to enable low power, low throughput field devices with long duty cycles of ten years or more.
- **View 2 – Next-generation radio access technology***:* This is more of **the traditional 'generation-defining' view**, with specific targets for data rates and latency being identified, such that **new radio interfaces** can be assessed against such criteria. This in turn makes for a clear demarcation between a technology that meets the criteria for 5G, and another which does not."

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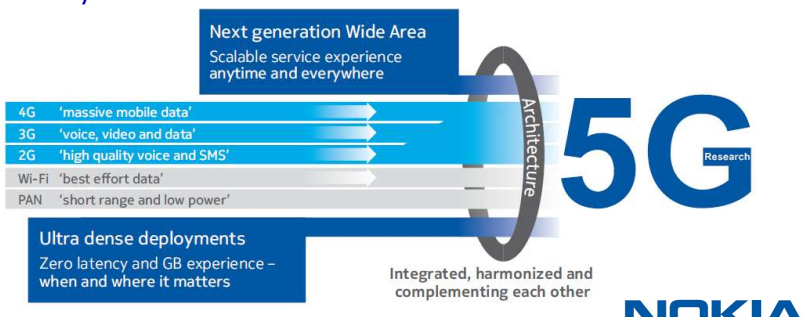
5G: definitions

- "Communications and control beyond 2020 will involve a combination of **existing** (LTE-A, Wi-Fi) and **evolving systems** (e.g., **new revolutionary technologies** to meet new requirements, such as **virtually zero latency** to support **tactile Internet**, machine control or augmented reality). 5G will be the set of technical components and systems needed to handle these requirements and overcome the limits of current systems."



Nokia, 5G use cases and requirements

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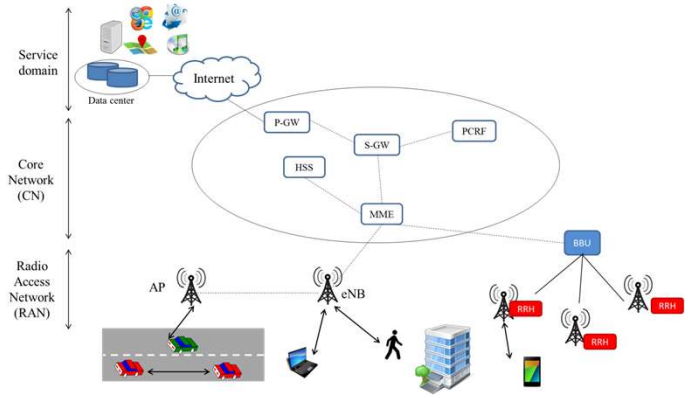
5G: definitions

- 5G is **not only a new radio interface**
- 5G affects **both the RAN and the CN design**
- 5G is **not only a communication infrastructure**



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5G: definitions

Through its enabling technologies

Akyildiz, Ian F., et al. "5G roadmap: 10 key enabling technologies." Computer Networks 106 (2016): 17-48.

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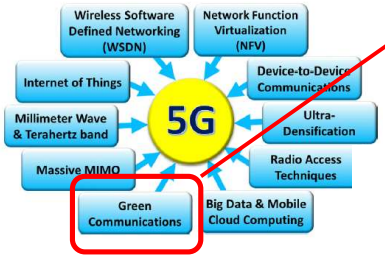
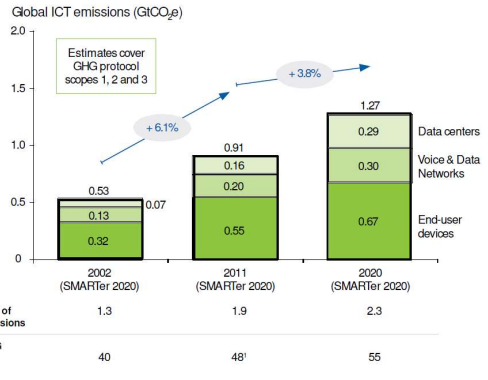
5G: definitions



Why green communications?
ITU-T estimates ICT to cause the 2-2.5% of global greenhouse gas emissions



http://gesi.org/SMARTer2020
ITU-T, ICTs and Energy Efficiency, URL:
http://www.itu.int/en/action/climate/Pages/energy_efficiency.aspx

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Evolution to 5G

Releases 8, 9 — LTE

Releases 10, 11, 12 — LTE-Advanced

Releases 13, 14, … — LTE-Advanced Pro

5G

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5G: motivations

Avalanche of
Traffic Volume

Further expansion of mobile broadband

Additional traffic due to communicating machines

"1000x in ten years"

Massive growth in
Connected Devices
"Communicating machines"

"50 billion devices in 2020"

Large diversity of
Use cases & Requirements

Device-to-Device Communications

Car-to-Car Comm.

New requirements and characteristics due to communicating machines

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5G: motivations

- Support for **latency below 10 ms**
- Support for **data rates up to 10 Gbps**
  - in densely connected areas
  - in high-speed trains
- Support for **billions of connected sensors** (resource-constrained) limited in terms of data rate requirements and latency, but with demands in terms of **scalability and battery lifetime**
- Support for **mission-critical operations**
- Main peculiarity: not the capability to provide high speeds (~ Gbps) but its capability to **adapt over time and space** to the needs of the provided service

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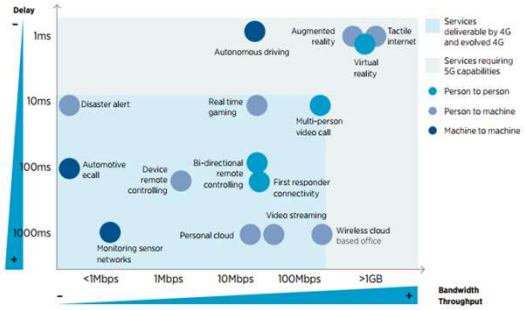
New requirements for the 5G

- 5G is not only targeting higher data rates.
- New applications are arising in plethora of vertical markets:
  - Industry 4.0
  - E-Health
  - Automotive
  - Smart Cities
  - Smart Electrical Grids
  - Public Safety
  - Multimedia and Entertainment
  - …



Source: GSMA

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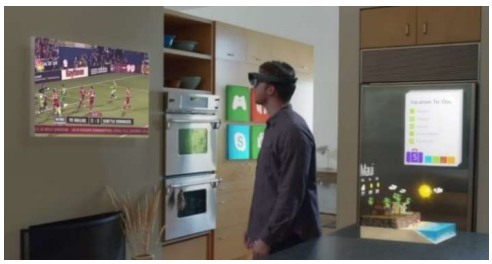
5G: new use cases



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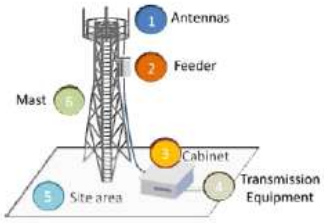
5G: operators' requirements

- Mobile Network Operators (MNOs) are facing many challenges
- The seemingly insatiable **traffic demands** of subscribers (e.g., IoT, social networks and other apps for mobile UEs) **require physical network expansions** (increased Capital Expenditure, **CAPEX**, and Operational Expenditure, **OPEX**)
- It is **difficult to upgrade and maintain** network infrastructure
- Networks are designed to handle the **peak traffic (overprovisioning)** and they are poorly flexible to manage varying traffic loads



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5G: operators' requirements

- MNOs are experiencing unceasing reductions in revenue
  - ✓ **Competition both among themselves and from Over-The-Top (OTT) service providers** means that MNOs cannot respond to the increased costs with increased subscriber fees

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5G: main players

- Multiple forums and standardization bodies produced so far recommendations, guidelines for 5G systems (e.g., through ***white papers***)
  - 3GPP
  - Next Generation Mobile Networks (NGMN)
  - ITU
  - IEEE
  - GSMA Alliance
  - ETSI
  - 4G Americas, Chinese IMT-2020 (5G) Promotion Association, ITU-R WP5Ds, Korea's 5G Forum
  - 5GPP in Horizon 2020 https://5g-ppp.eu/

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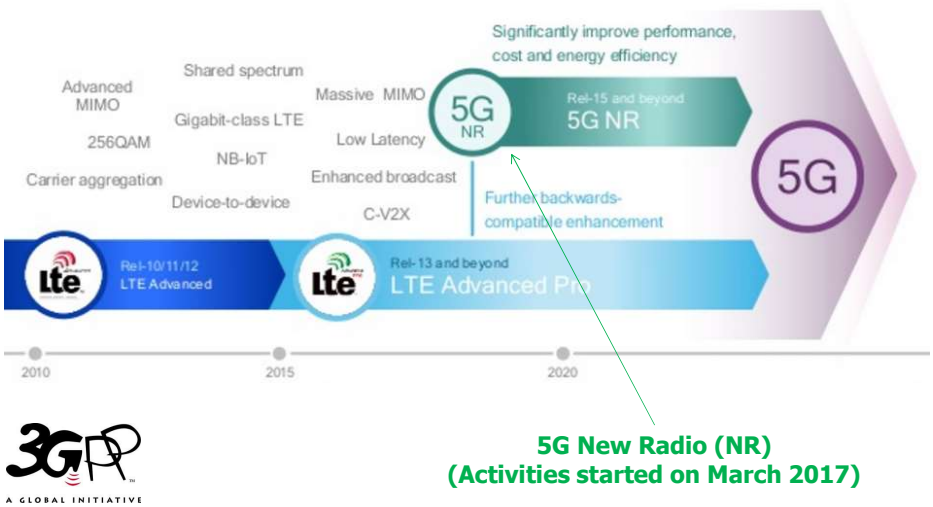
5G: standardization



5G New Radio (NR)
(Activities started on March 2017)

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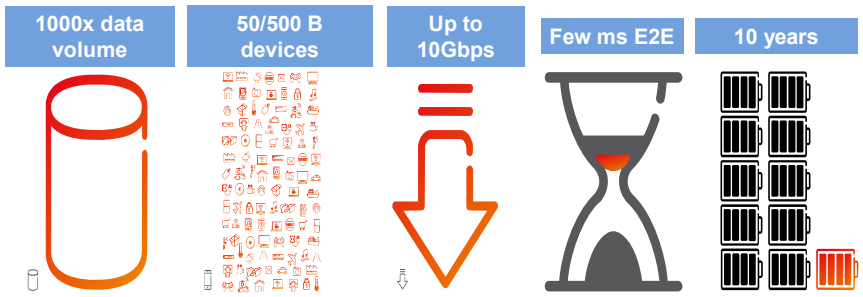
5G: objectives

@METIS: https://www.metis2020.com/

Mobile and wireless communications Enablers for the Twenty-twenty Information Society



1000x	10-100x	10-100x	5x	10x
higher mobile data volumes	higher number of connected devices	typical end-user data rates	lower latency	longer battery life for low-power devices

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5G: objectives

- 1-10Gbps connections to end points in the field (i.e. not theoretical maximum)
- 1 millisecond end-to-end round trip delay (latency)
- 1000x bandwidth per unit area
- 10-100x number of connected devices
- (Perception of) 99.999% availability
- (Perception of) 100% **coverage**
- 90% reduction in **network energy** usage
- Up to ten year **battery life** for low power, machine-type **devices**

No use case exists that requires all of these 8 requirements to be supported simultaneously

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5G: objectives

- A subset of the identified requirements will be supported when and where it matters
- **Not all of them are service requirements**
- Some of them are **contradicting each other**: how a new generation of network with **higher bandwidths** being deployed mainly on top of the pre-existing network equipment could result in **lower energy consumption?**

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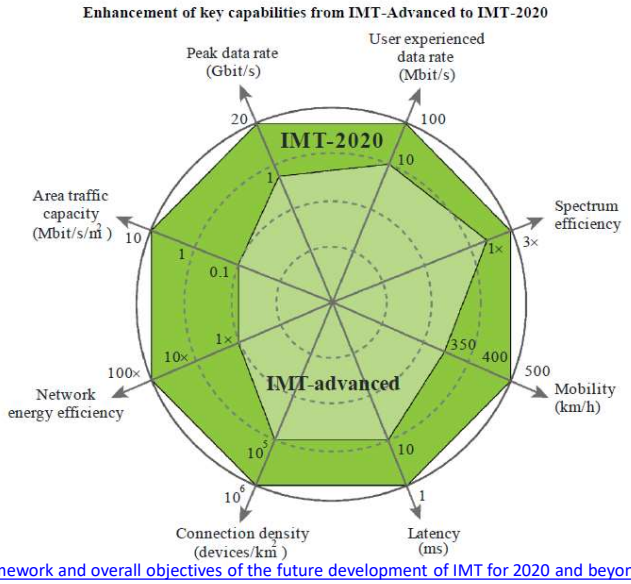
5G:New requirements for the 5G



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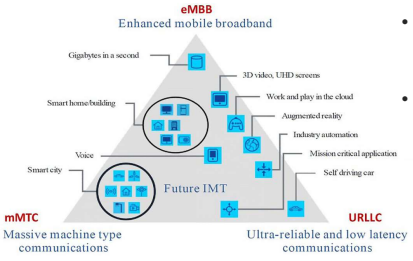
The 5G Network Service Categories



Source: ITU-R M.2083-0

- The variety of applications that has to be supported is commonly called the "triangle of applications."
- The requirements of such applications can be classified into three main network service categories:
  - **Enhanced Mobile Broadband (eMBB)**;
  - **Massive Machine-type Communication (mMTC)**;
  - **Ultra-reliable low latency communications (URLLC)**.
- This provides a challenge, as these different requirements and priorities have to be addressed simultaneously with a "**one-fits-all**" technology like LTE.

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5G: use cases

Why are they important?

As with each preceding generation, the rate of adoption of 5G and the ability of operators to monetise it will be a direct function of the new and unique use cases it unlocks.

ITU

- ❑ **Enhanced mobile broadband (eMBB)**
- ❑ **Massive machine-type communications (MMTC)**
- ❑ **Ultra-reliable and low-latency communications (URLLC)** (a.k.a Critical MTC)

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5G: use cases

Enhanced mobile broadband (eMBB): Mobile broadband addresses the **human-centric use cases for access to multimedia content, services and data**.

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5G: use cases

- eMBB **beyond basic mobile Internet access** and covers rich interactive work, media, and entertainment apps in the cloud or reality augmentations
- Increase in the size of contents and number of apps. requiring high data rates
- Increase in camera resolution, screen resolution (4K or UHD), developments in 3D video
- Cloud storage and apps rapidly increasing for both work and entertainment and driving growth of uplink data rates

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5G: use cases

The enhanced mobile broadband usage scenario will come with new application areas and requirements in addition to existing mobile broadband applications for improved performance and an increasingly **seamless user experience**.

This scenario covers a range of cases, including **wide-area coverage** and **hot spots**, which have different requirements.

- **For areas with high user density,** very high capacity is needed, while the requirement **for mobility is low** and user data rate is higher than that of wide area coverage.
- For the **wide area coverage** case, seamless coverage and medium to **high mobility** are desired, with much improved user data rate compared to existing data rates.

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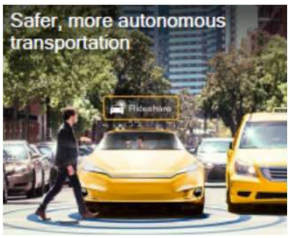
5G: use cases

Ultra-reliable and low-latency communications (URLLC): Requirements for capabilities such as **throughput, latency and availability** use cases include wireless control of industrial manufacturing or production processes, remote medical surgery, distribution automation in a smart grid, transportation safety, etc.



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5G: use cases

Massive machine-type communications (MMTC):

Very large number of connected devices typically transmitting a **relatively low volume of non-delay sensitive data**. Devices are required to be **low cost** and have a **long battery life**.

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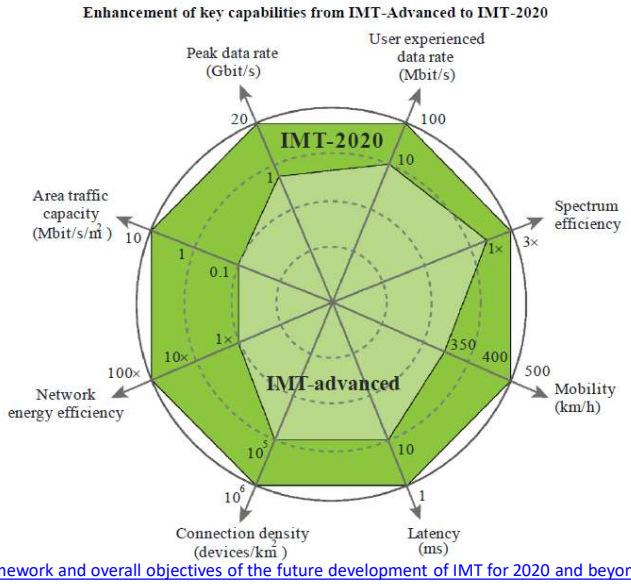
5G:New requirements for the 5G



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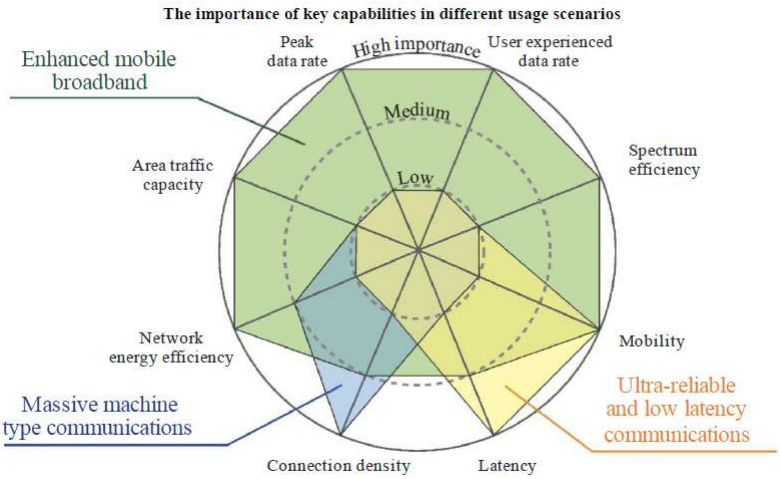
5G: use cases and objectives



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5G: use cases

Multi-layer frequency approach for 5G usage scenarios

HUAWEI

http://www-file.huawei.com/-/media/CORPORATE/PDF/public-policy/public_policy_position_5g_spectrum.pdf?la=en

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5G: peculiarities

"Virtually zero latency"

- Devices will not only be remotely controlled and managed, but will also communicate with one another
- IoT and M2M require more reliable communication links but also lower transmission delays (latency): **machines can process information much faster than people**

- Human interactions more demanding in the future
  - 2G: for voice latency requirements ~ 100 ms driven by the human audible delay constraint
  - Multimedia apps: human eye more sensitive (10 ms < delay < 100 ms)
  - Tactile interactions related to the increasing use of touch interfaces (delay ~ 1 ms)

Nokia, 5G use cases and requirements

NOKIA

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5G: peculiarities

Despite the advances in processor speeds and network latency, the speeds at which signals can travel through the air and light can travel along a fibre are governed by **fundamental laws of physics**.

- **Communication delay due to the speed of light** (300 km in 1 ms means that max distance for a steering & control server from the point of tactile interaction of the users is 150 km)
- With signal processing, protocol handling, switching delays the **max distance becomes 15 km (or even lower)**

Services requiring a delay < 1 ms must have all of their content served from a position **very close to the user's device, i.e., at the base stations/APs**.

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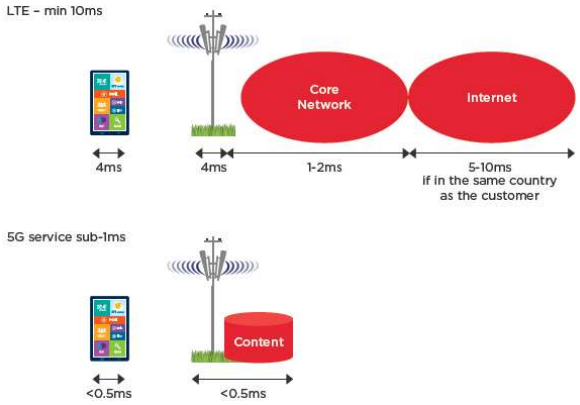
5G: peculiarities

"Virtually zero latency"

Solution: Fog computing/Mobile Edge Computing (MEC)



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5G: peculiarities

"Gigabit experience"

- High-capacity networks **not everywhere** but e.g., at the city centers
- **Peak data rates of Gbps** and **cell-edge data rate of 100 Mbps** (mobile Internet as a reliable replacement for cable)
- Better capacity, higher densification, broader carriers in new spectrum

Nokia, 5G use cases and requirements

NOKIA

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To summarize

5G:

- has to be a **future-proof technology** and last at least until **2030**
- needs to be **FLEXIBLE**: we cannot predict all future use cases
- should be conceived according to a **service-driven** technology design
- has to support **any-to-any** communication
- needs to be **programmable** and **software-driven**

- ❑ Many use cases do not strictly require 5G
- ❑ They can be supported by existing systems
- ❑ They could offer an enhanced user experience of a 5G network

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The 5G System

- The 5G System (5GS) has been specifically designed to go **beyond the «one-fits-all» paradigm** of previous mobile network technologies.
  - Mobile Networks <5G has a monolithic architecture designed to support the most extreme requirements 24/7 and for all applications.
- Compared to previous generations the 5GS architecture is **service-based**, that means:
  - Architecture elements are defined as Network Functions;
  - Network Functions offer their services via interfaces of a common framework ;
  - Other Network Functions can consume such services if authorized.

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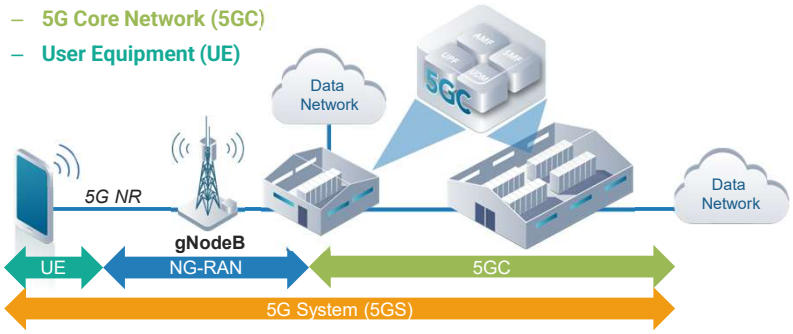
The 5G System

- Similarly to previous generations, the 5GS will have three main components:
  - **5G Access Network (5G-AN)**
  - **5G Core Network (5GC)**
  - **User Equipment (UE)**



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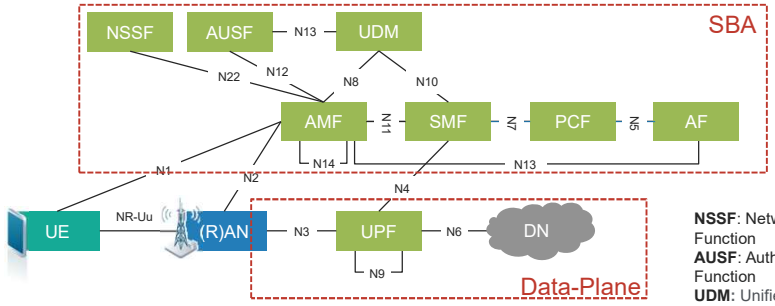
The 5G System

- Main Functions and Reference Points in the Service Based Architecture (SBA):



NSSF: Network Slice Selection Function
AUSF: Authentication Server Function
UDM: Unified Data Management
AMF: Access and Mobility Management
SMF: Session Management Function
PCF: Policy Control Function
AF: Application Function
UPF: User Plane Function

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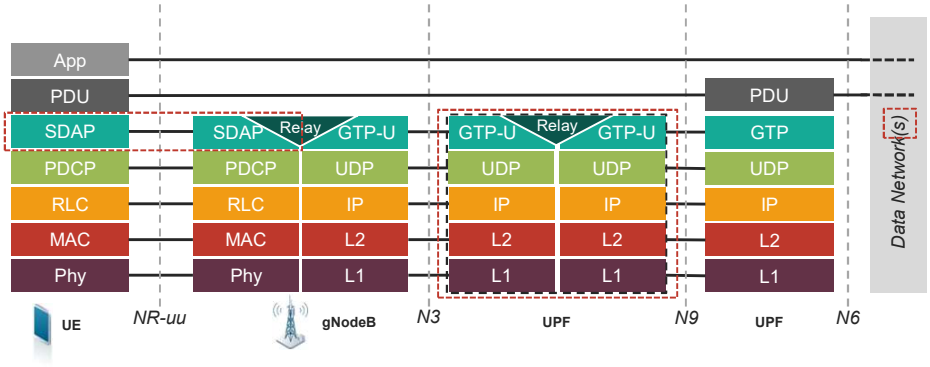
5G User-Plane Protocol Stack

- Similar to the protocol stack used by LTE.
- Data-/User-plane:



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PDU Sessions

- In 5G, the LTE EPS bearer (for end-to-end connectivity) has been replaced with the more flexible concept of **PDU session**.
- The PDU Session represents an end-to-end connectivity service between one UE and one Data Network.
- It can be composed of:
  - Multiple (parallel) Data Radio Bearers in the Access Network.
  - Multiple tunnels in the Core Network.
- A PDU Session can be configured to carry:
  - IP traffic.
  - Non-IP traffic.
  - Ethernet traffic.
- Traffic flows of a same PDU Session can be bound to a different QoS level.

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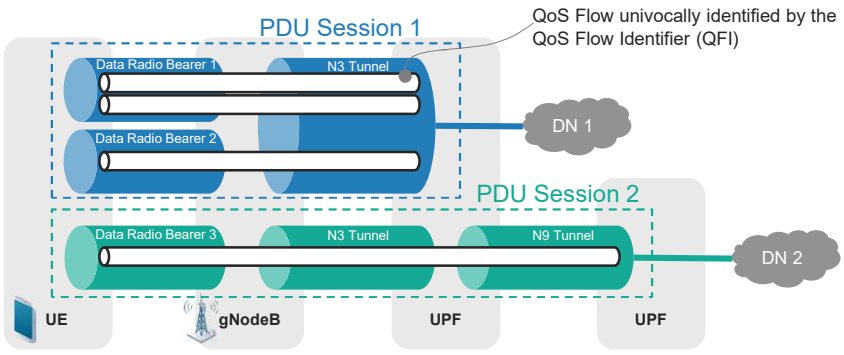
PDU Sessions



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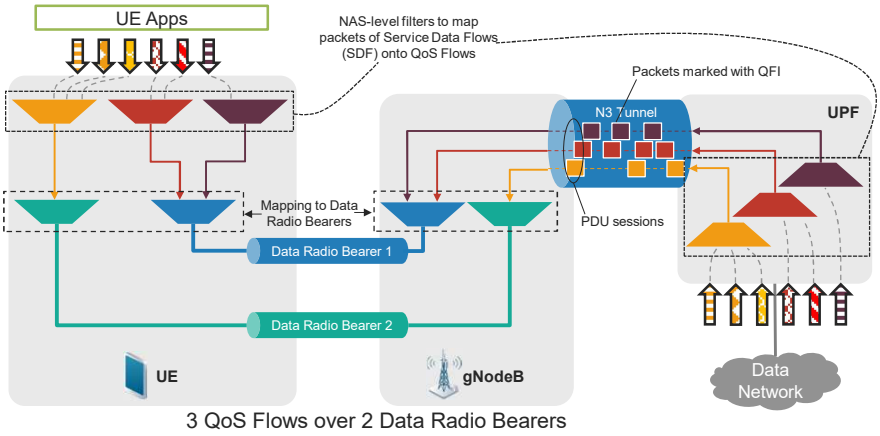
PDU Sessions and QoS



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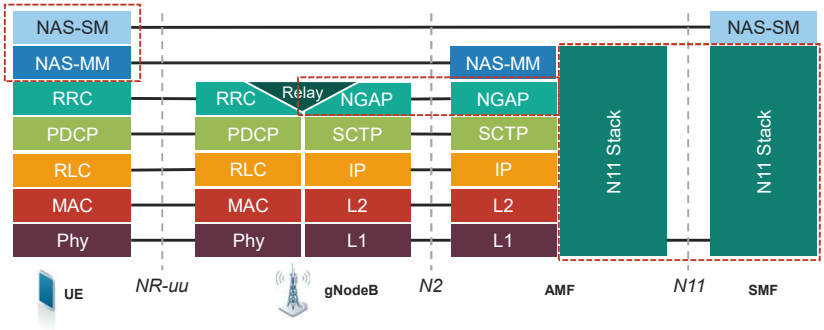
5G Control-Plane Protocol Stack

- Control Plane:



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