



# 5G Mobile Communication System

# <https://www.upvx.es/courses/course-v1:TecnologiasAvanzadasDeComunicaciones+5g-tech-business+2023-01/about>



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## 5G and Beyond Technology & Business Innovation Potential

ΕΓΓΡΑΦΗ



DURATION

WHAT YOU WILL LEARN:

PREREQUISITES

LECTURERS

### Duration

### About this course

5G is a highly disruptive technology that is transforming our world. 5G opens up possibilities for disruptive innovation in any sector, as well as innumerable opportunities for the creation of new business models or the critical enhancement of existing ones. With the emergence of B5G, the upcoming Mobile Wireless Generations, this vast innovation potential will be dramatically multiplied.

This course aims to prepare Higher Education Institution students for this cutting-edge new technologies, by providing a comprehensive background on the essentials of 5G & B5G technologies, their immense potential for innovation, and by encouraging to leverage it for the creation of new services and businesses, fostering entrepreneurship on these emerging opportunities.



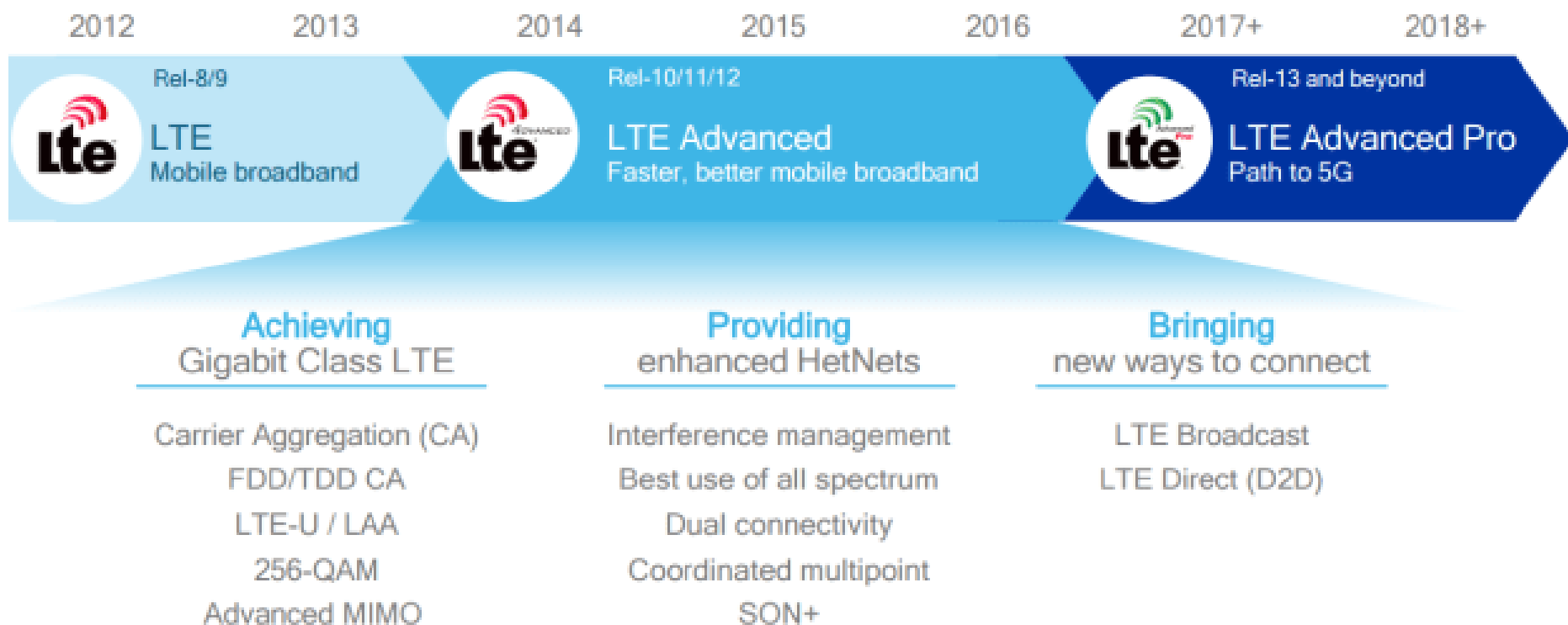
Κωδικός Μαθήματος

5g-tech-business

Έναρξη Μαθήματος

Nov 17, 2023

# LTE Advanced: part of a rich roadmap of LTE technologies



# 3GPP Releases

- ❑ **Rel. 8-9**: LTE
- ❑ **Rel. 10-12**: LTE-Advanced (4G)
- ❑ **Rel. 13-14**: LTE Advanced-Pro (**4.5G**)
- ❑ **Rel. 15-16**: LTE NR (5G)

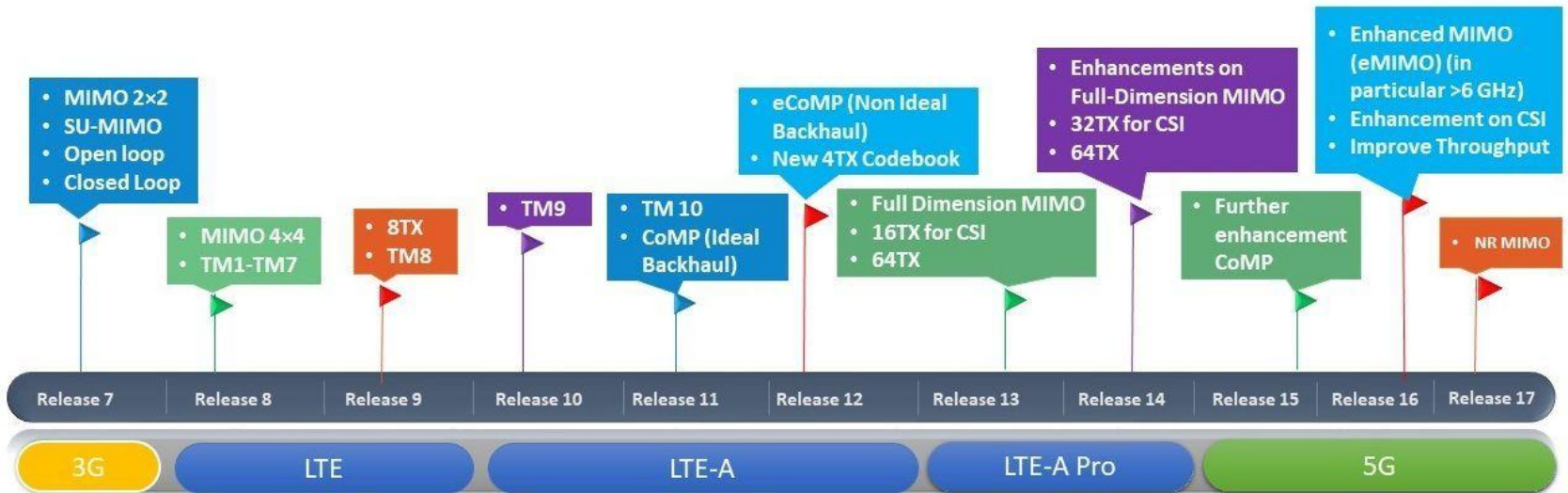
# Release 13 Features

1. Active Antenna Systems (AAS)
2. Self-Organizing Networks (SON)
3. Elevation Beamforming
4. Inter-eNB CoMP
5. Indoor Positioning
6. Carrier Aggregation Enhancements
7. License Assisted Access (LAA)
8. LTE-WLAN Aggregation Enhancements
9. Wi-Fi with IP Flow Mobility
10. RAN Sharing
11. Enhanced D2D Proximity Services (PROSE)
12. Dual Connectivity Enhancements
13. MTC Enhancements
14. Single-Cell Point-to-Multipoint (SC-PTM)

# Release 14 Features

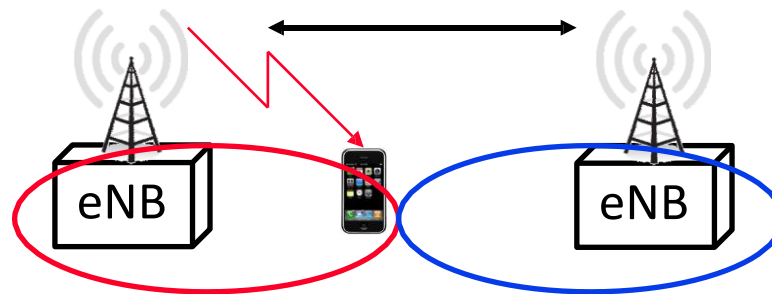
1. Enhanced Narrowband IoT (eNB-IoT)
2. Enhanced Machine Type Communications (eMTC)
3. Enhanced LWIP (eLWIP)
4. Enhanced LTE-WLAN Aggregation (eLWA)
5. Enhanced License Assisted Access (eLAA)
6. Enhanced Full-Dimension (eFD) MIMO
7. Enhanced Multimedia Broadcast Multicast Service (eMBMS)
8. Multiuser Superposition Transmission (MUST)
9. Layer 2 (L2) Latency Reduction
10. Vehicle to Vehicle (V2X) Based on Sidelink
11. Uplink (UL) Capacity Enhancements
12. Light Connection

# 5G specifications



# Inter-eNB CoMP

- ❑ Coordinated Multipoint Operation (CoMP) in Release 11 was restricted to eNBs connected **via ideal backhaul**
  - No need for network interfaces
- ❑ In Release 12, a signaling interface has been added which allows eNBs to interchange measurement and resource allocation information
- ❑ In Release 13, new signaling elements were added





# Indoor Positioning

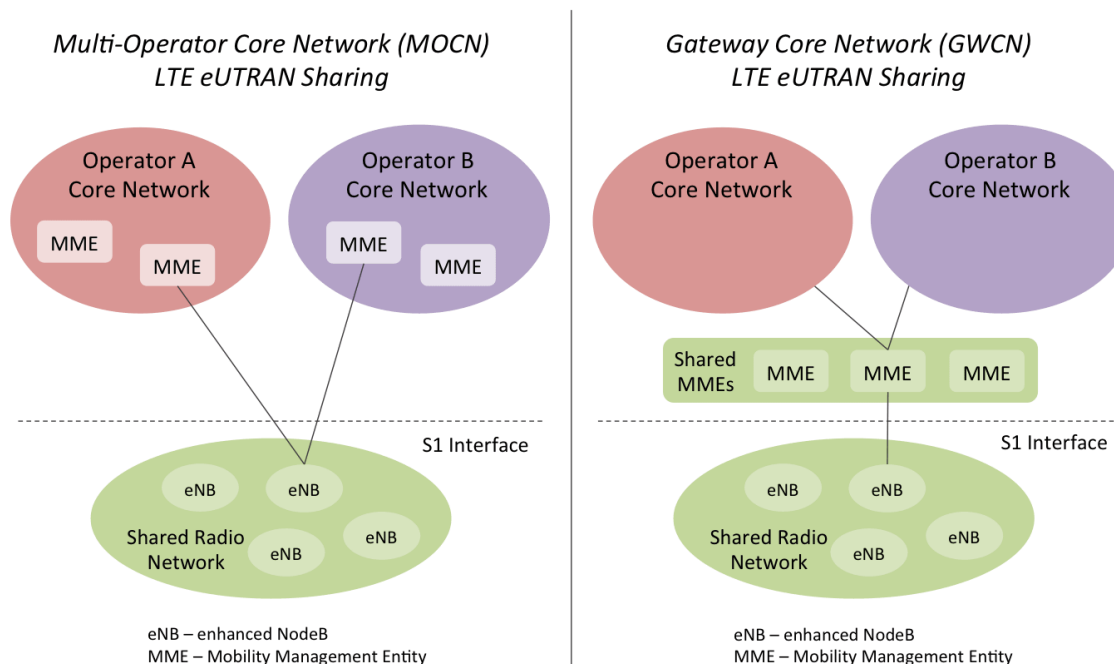
- ❑ Position can be determined by:
  - ❑ Barometric sensors
  - ❑ Wireless LANs
  - ❑ Bluetooth beacons
  - ❑ Terrestrial beacon system broadcasting signals for positioning, e.g., Metropolitan Beacon Systems (MBS)
- ❑ R13 supports only standalone mode without network assistance
- ❑ R14 introduced advanced techniques

# Carrier Aggregation Enhancements

- CA was introduced in R12
- R12 limited to 5 carriers -> 100 MHz
- R13 extended to 32 carriers -> 640 MHz
  - Inter-band and Intra-band
  - Licensed and Unlicensed

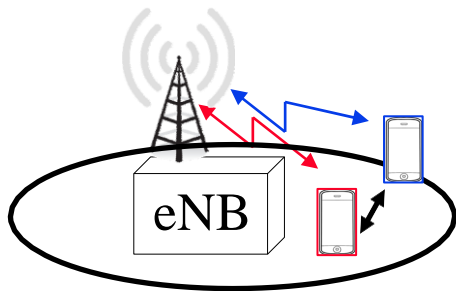
# RAN Sharing

- Multiple operators can share a radio access network (RAN)
- Owner operator can put limits on total UL/DL load of sharing
- QoS profile can also be limited as agreed

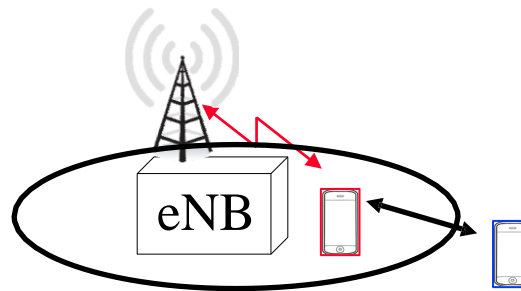


# Enhanced D2D Proximity Services (PROSE)

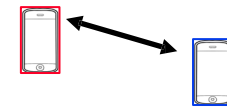
- ❑ Device-to-Device (D2D) was introduced in R12
- ❑ In R13:
  - ❑ UEs can search multiple networks for “side-link”
  - ❑ Support for relaying using D2D
  - ❑ Out-of-coverage D2D discovery



(a)

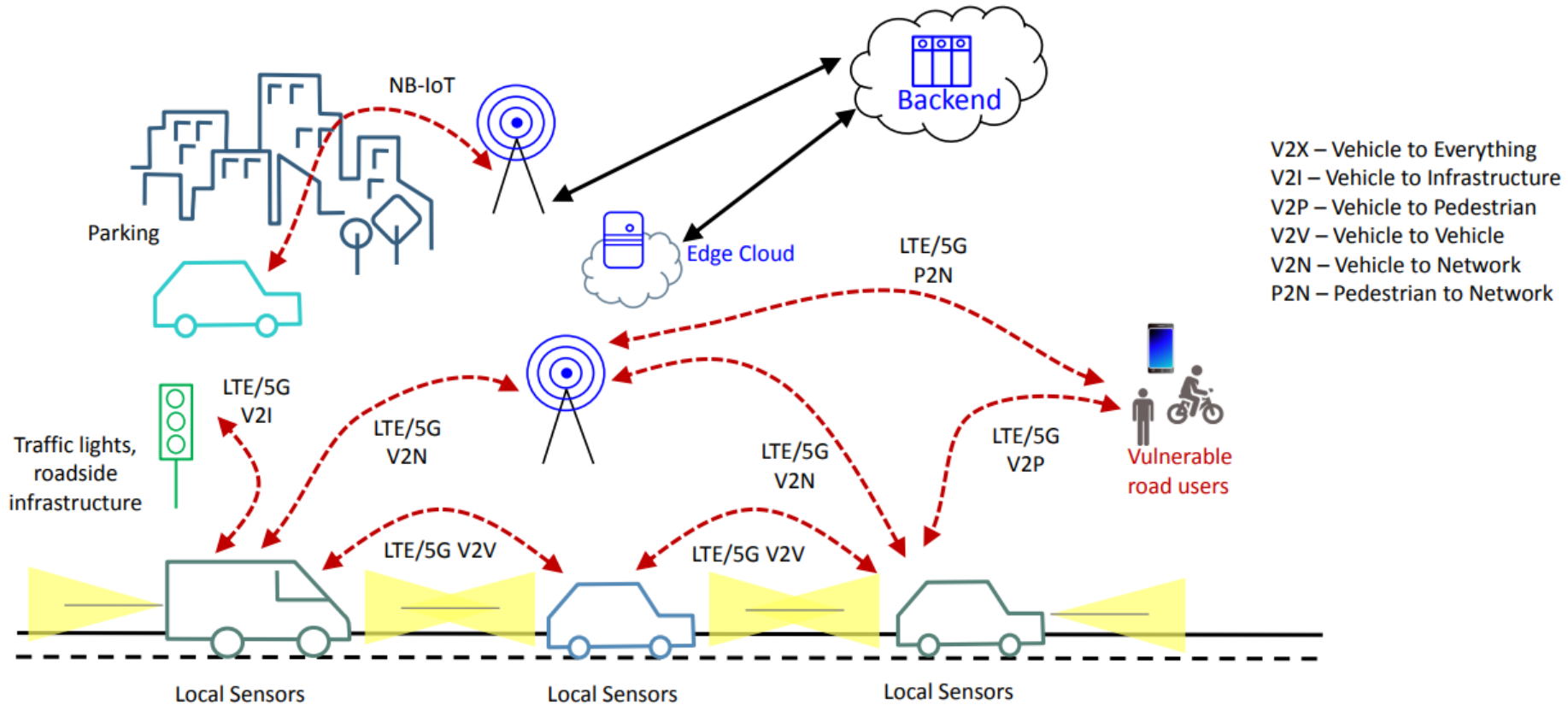


(b)



(c)

# Cellular Vehicle-to-X (C-V2X)



# 4G Evolution



3.9G? 4G?

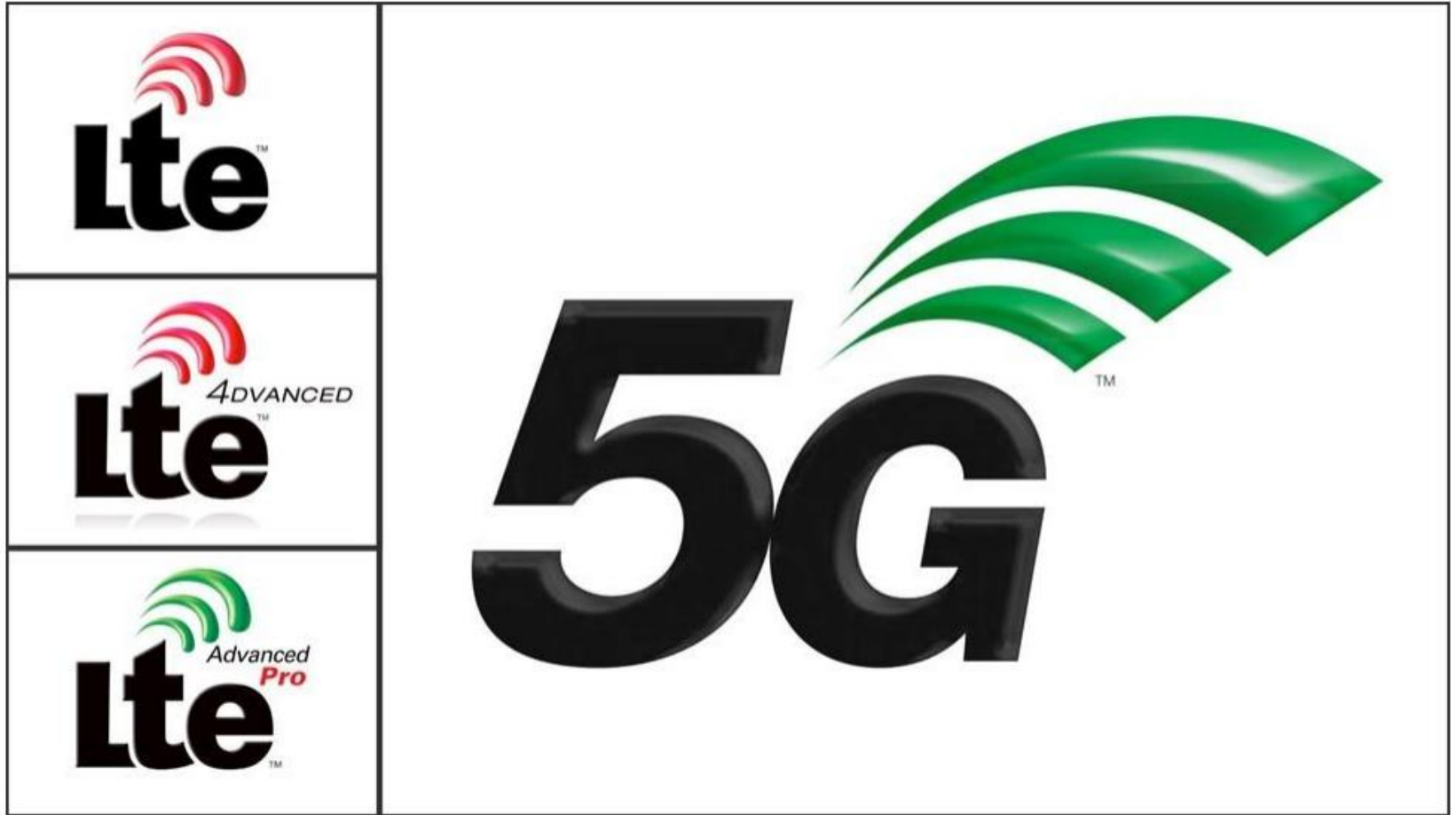


4G? 4G+? Advanced 4G?  
4.5G?

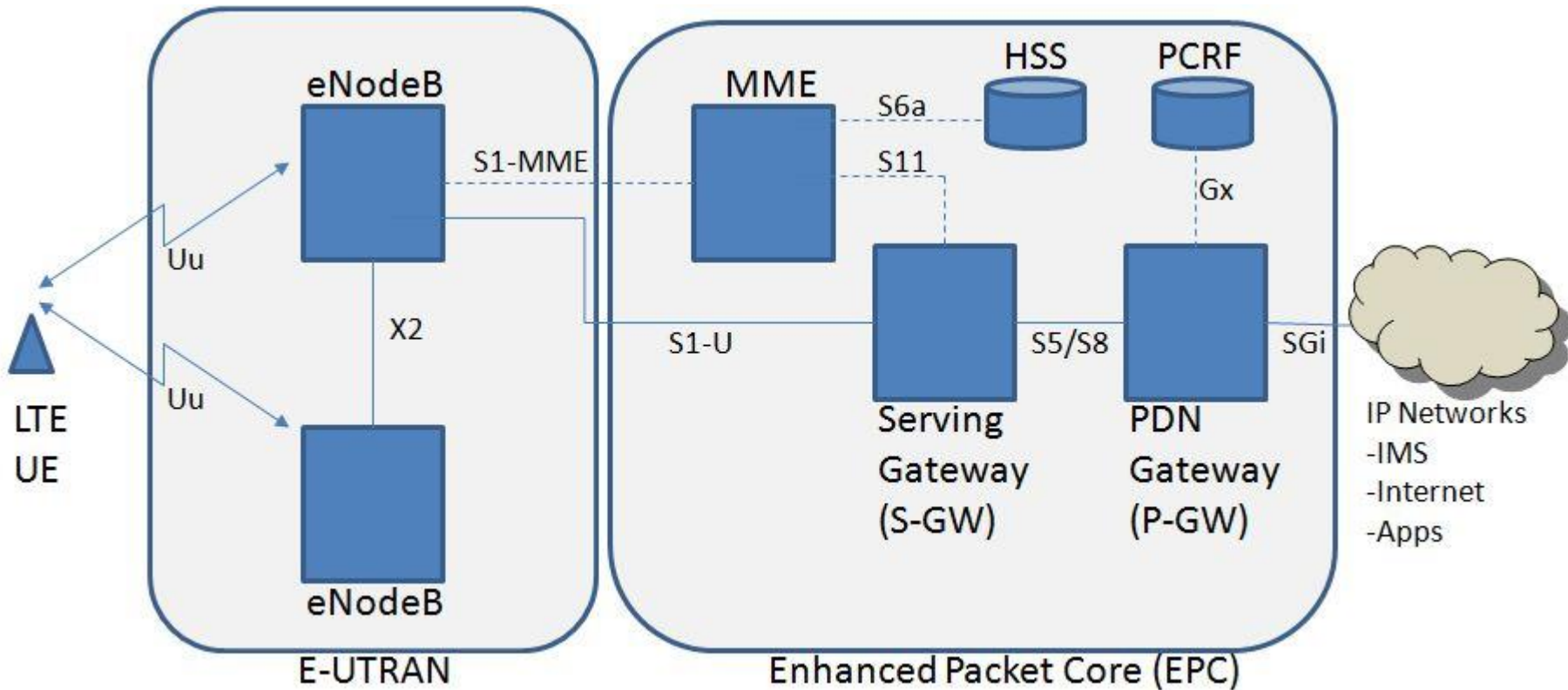


4.5G? 4.9G? 5G?

5G → IMT-2020



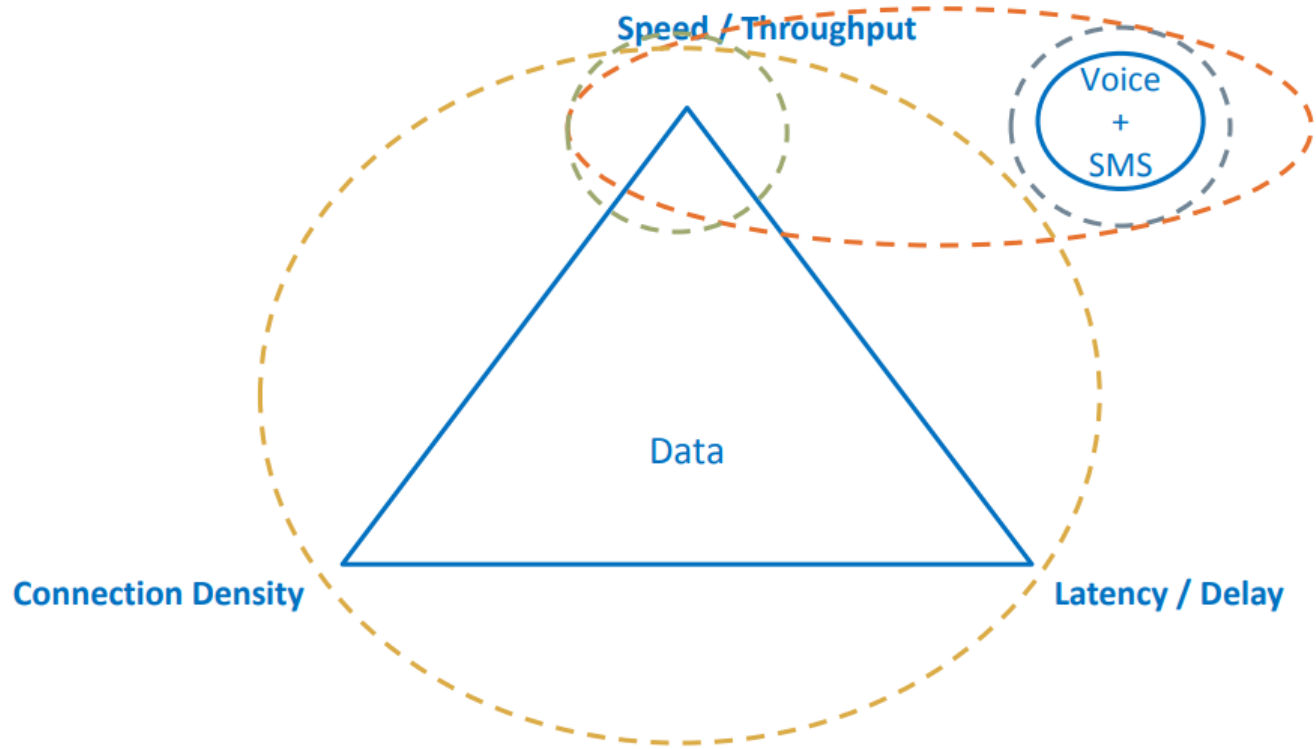
# LTE Architecture



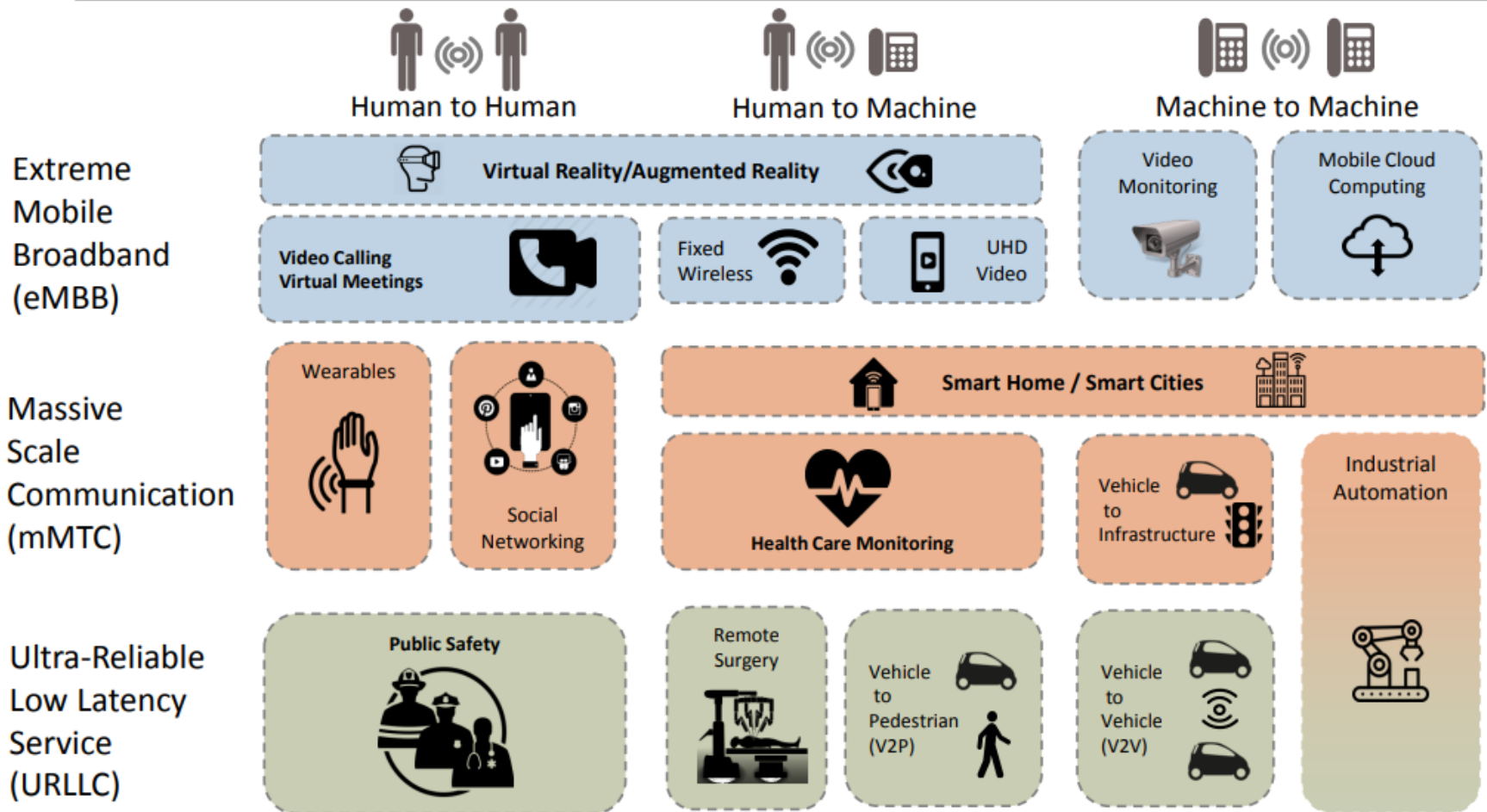


# Focus area for different technology generations

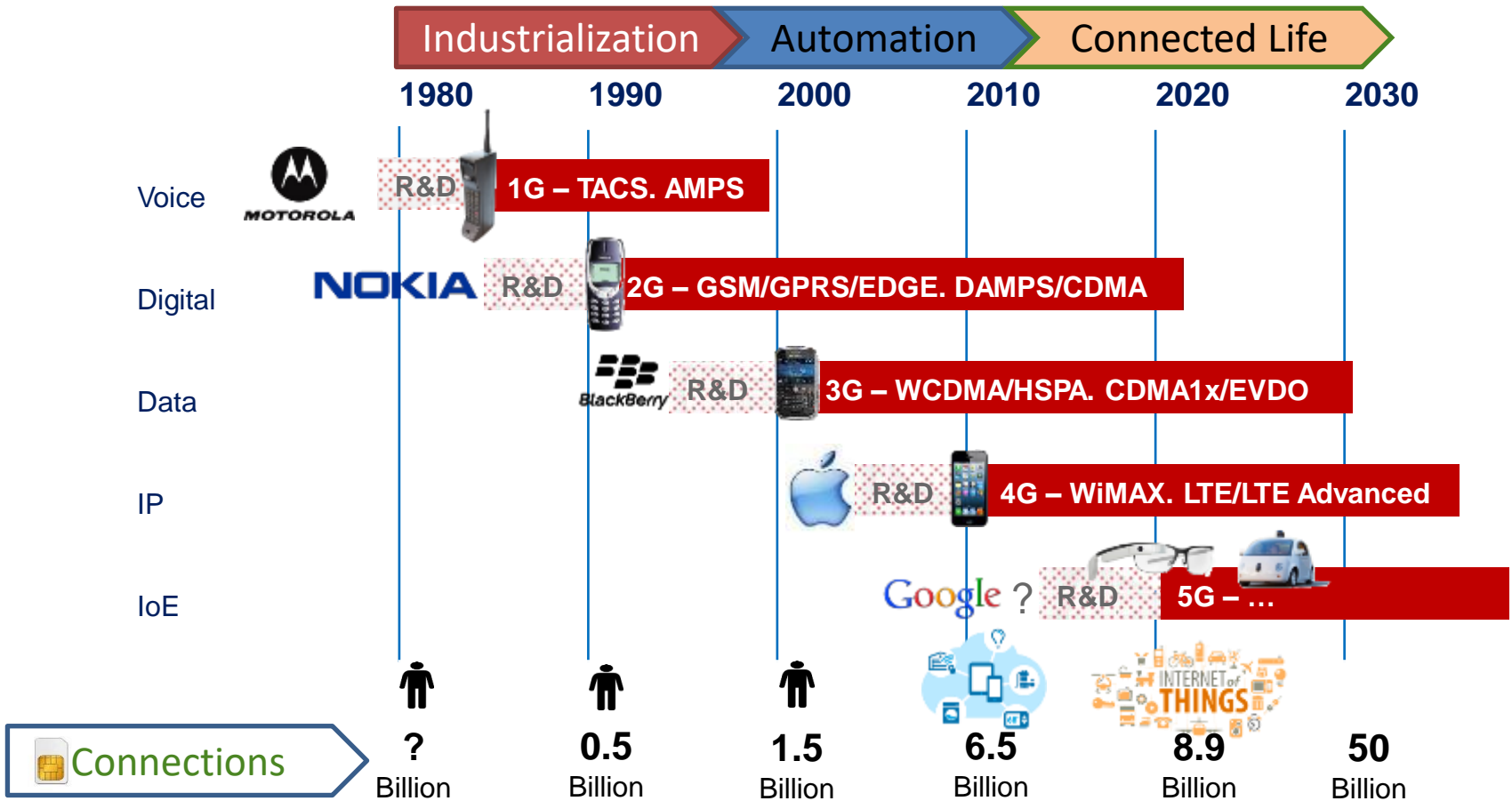
- 2G Focus area
- 3G Focus area
- 4G Focus area
- 5G Focus area



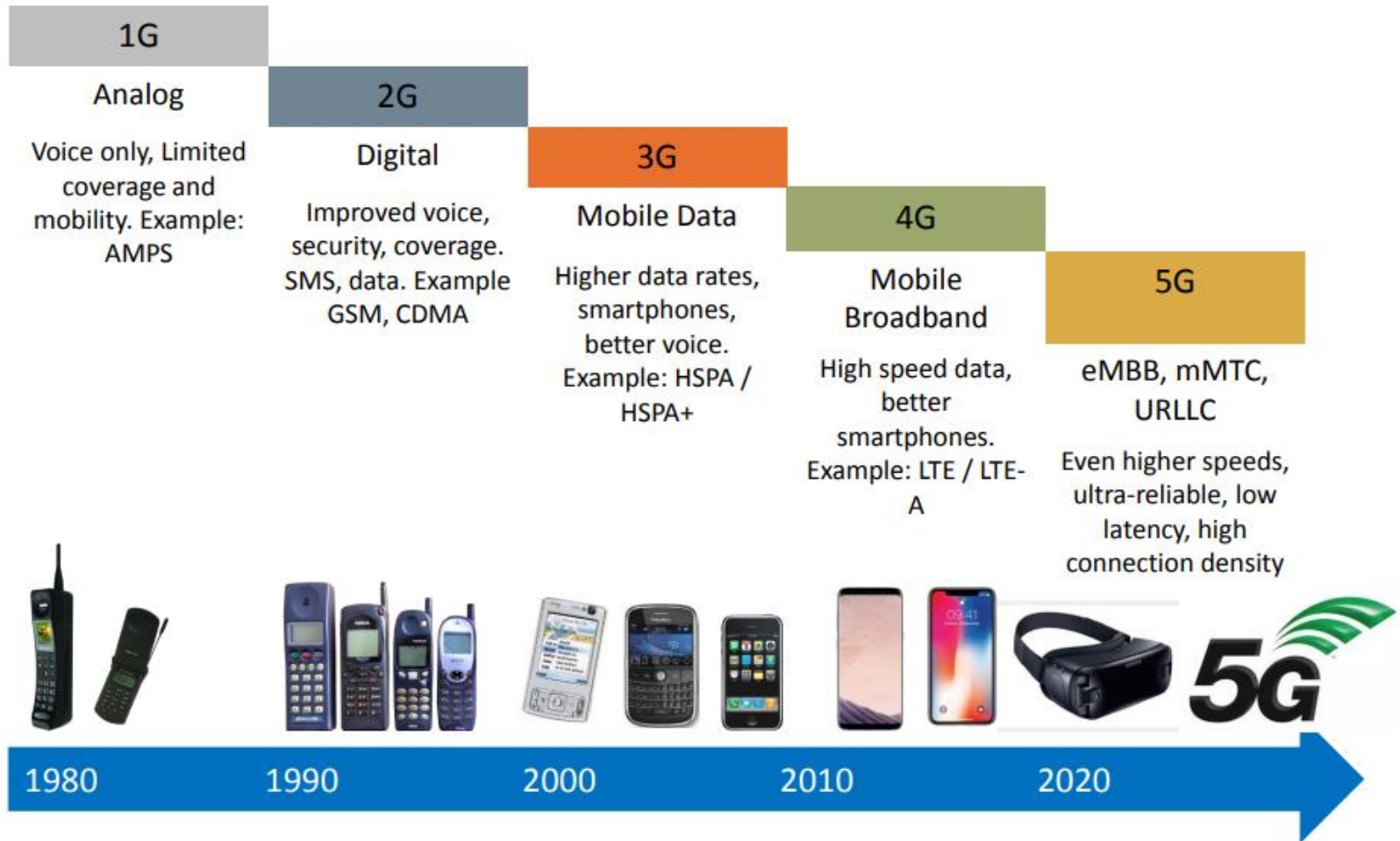
# Summary of 5G Use Cases



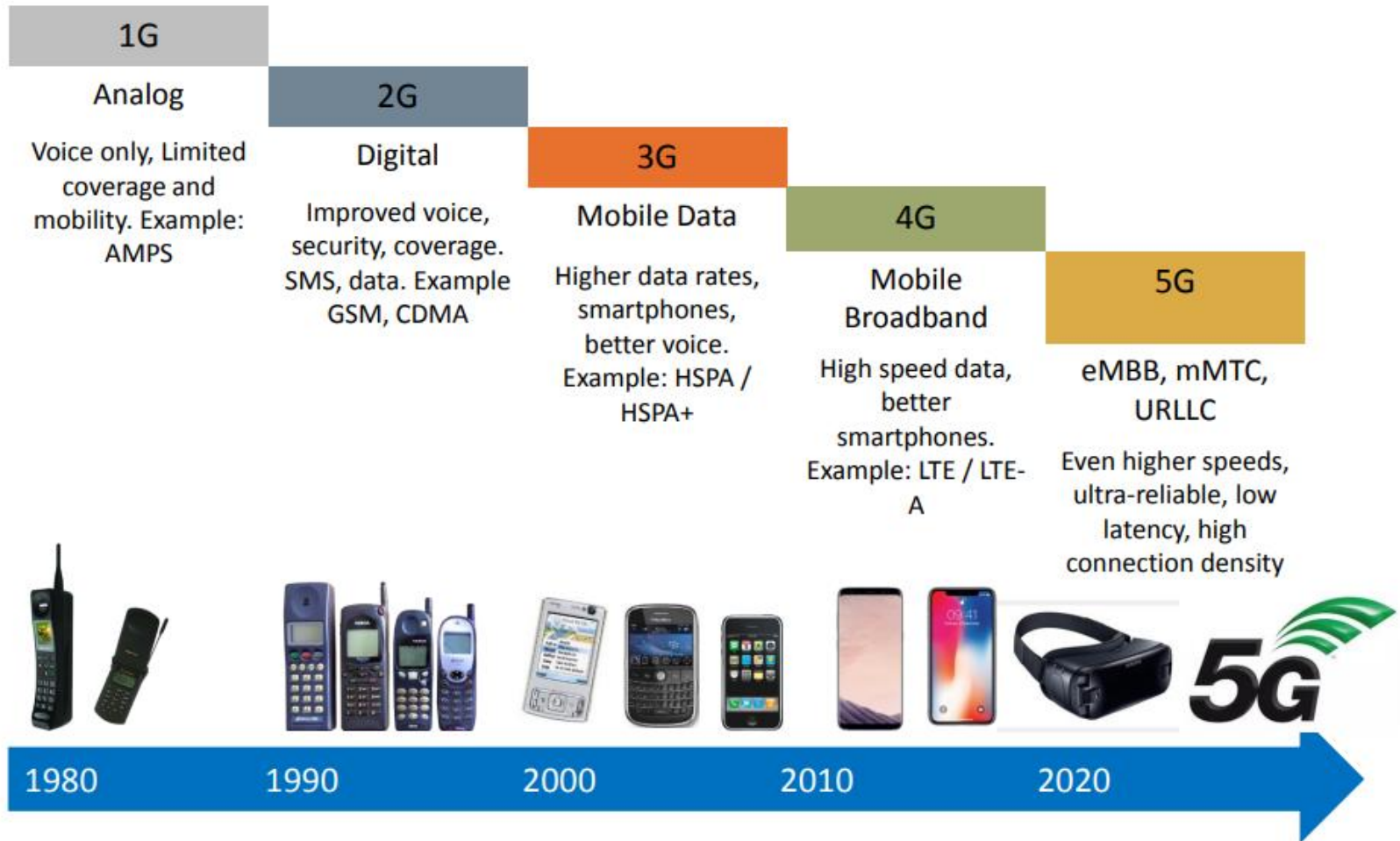
# Evolution of mobile communications



# Evolution of mobile communications



# Evolution of mobile communications



# 5G Spectrum

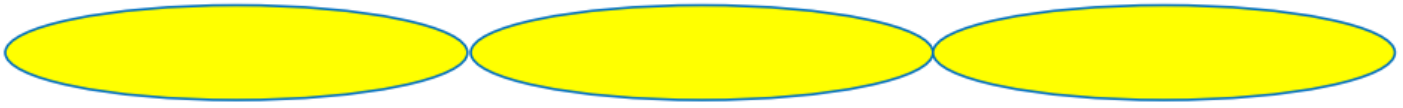


# Multiple layer for multiple needs

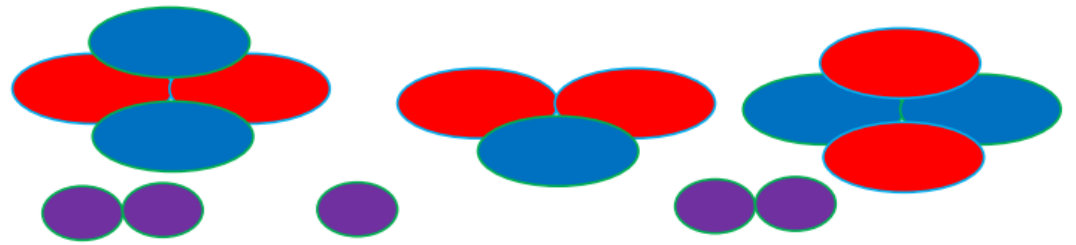
Coverage Layer  
Sub-1GHz



Capacity Layer  
1GHz – 6GHz



High Throughput Layers  
6GHz – 100GHz



# Latency requirements

## NGMN 5G Requirements

- 5G E2E Latency (eMBB) = **10ms** (i.e. RTT from UE-Application-UE)
  - 5G E2E Latency (URLLC) = **1ms** (i.e. RTT from UE-Application-UE – or just UE-UE)
- In both cases, the values are defined as capabilities that should be supported by the 5G System.

## GSMA 5G Requirements

- 5G E2E Latency = **1ms** (again, defined as a capability target, not as a universal requirement)

## ITU-R IMT-2020 Requirements

- eMBB User Plane Latency (one-way) = **4ms** [radio network contribution]
- URLLC User Plane Latency (one-way) = **1ms** [radio network contribution]
- Control Plane Latency = **20ms (10ms target)** [UE transition from Idle to Active via network]

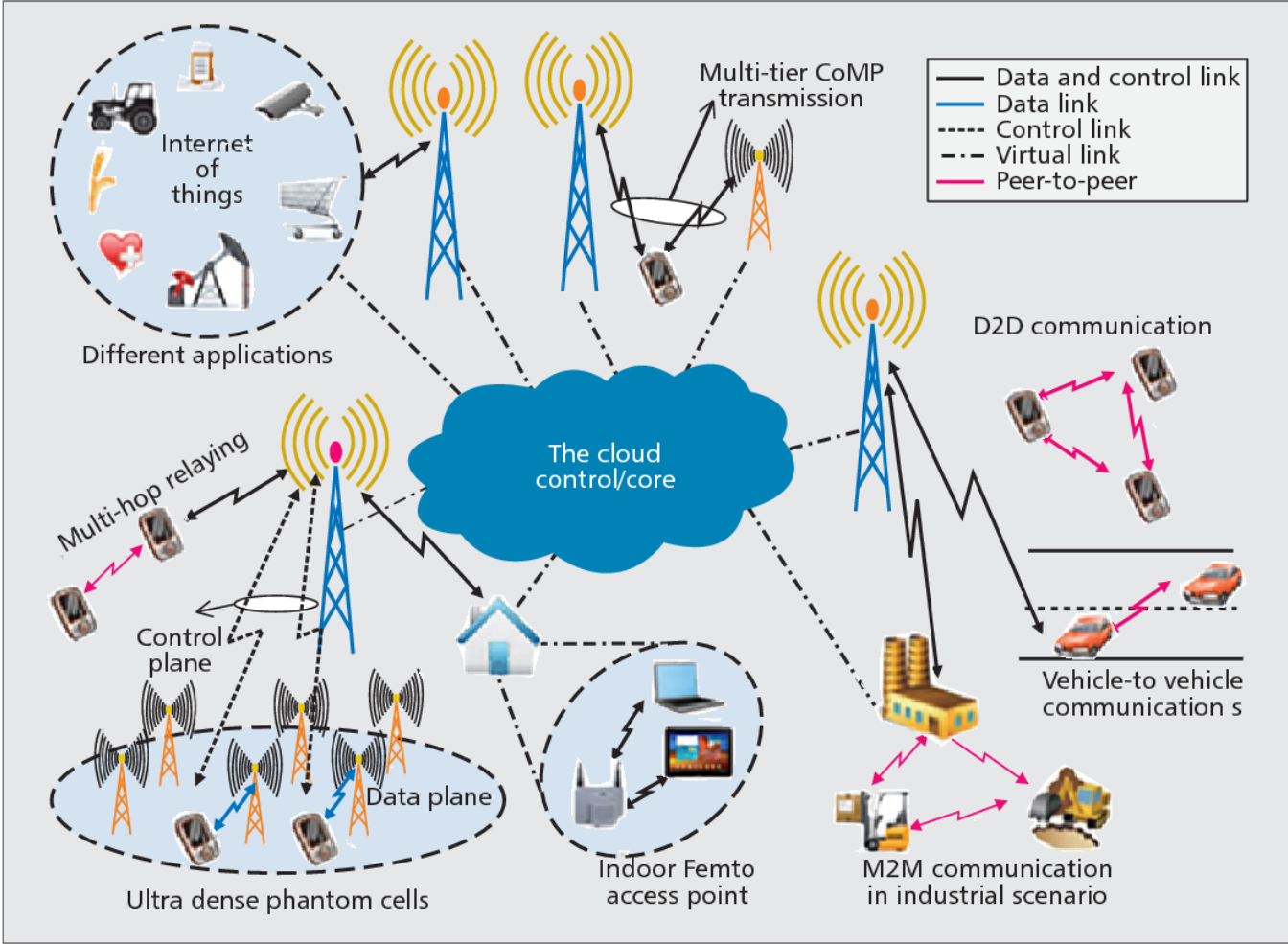
## Low Latency Use Case Requirements (various sources)

- Virtual Reality & Augmented Reality: **7-12ms**
- Tactile Internet (e.g. Remote Surgery, Remote Diagnosis, Remote Sales): **< 10ms**
- Vehicle-to-Vehicle (Co-operative Driving, Platooning, Collision Avoidance): **< 10ms**
- Manufacturing & Robotic Control / Safety Systems: **1-10ms**



# An illustration of a 5G network

## Infrastructure/functions/technologies



# ITU IMT-2020 Requirements

## **About the ITU** - International Telecommunications Union

- Specialized UN agency responsible for issues that concern ICTs
- Coordinates global use of the radio spectrum
- Assists in the development of worldwide ICT technical standards

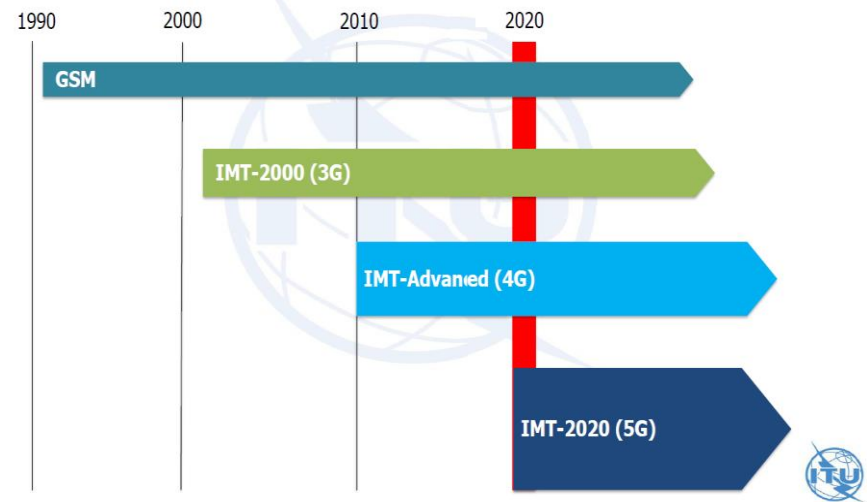
## **Technologies include:**

- broadband internet, latest-generation wireless technology, internet access, data, voice, TV broadcasting, next-Generation networks, ...

# ITU IMT-2020 requirements

- **About the IMT**
- IMT = International Mobile Telecommunications
- **IMT-2000 requirements (Marketed as 3G)**
  - 3GPP Family: UMTS WCDMA (GSM Evolution)
  - 3GPP2 Family: CDMA2000 (1xEV DO Rev A, EV DO Rev B)
- **IMT-Advanced requirements (Marketed as 4G)**
  - 3GPP Family: LTE Advanced (E UTRA)
  - IEEE Family: WiMAX (802.16m)
- **IMT-2020 (Marketed as 5G)**

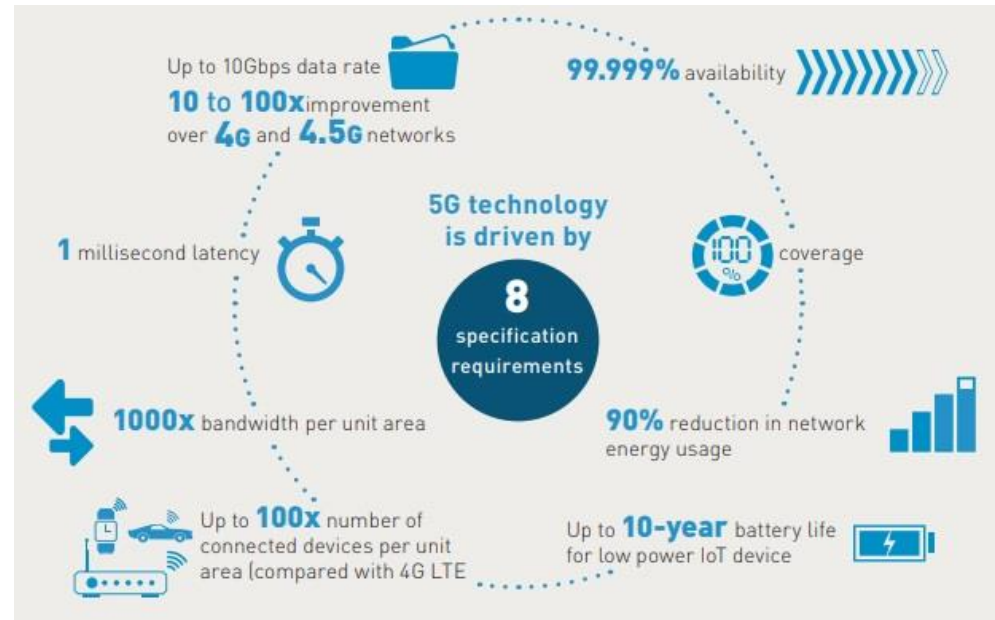
## IMT Standards Evolution towards 5G



# ITU IMT-2020 vision

## • Services

- Ubiquitous bandwidth (no more cell edge)
- HD video everywhere (up and down)
- Internet of Everything (M2M, M2P & P2P)
- Sensing, Presence and Ad-hoc networking
- Web eco-system of Apps and Services



## • Technical Requirements



1. Higher System Capacity

2. High Data Rates

3. Lower Latency

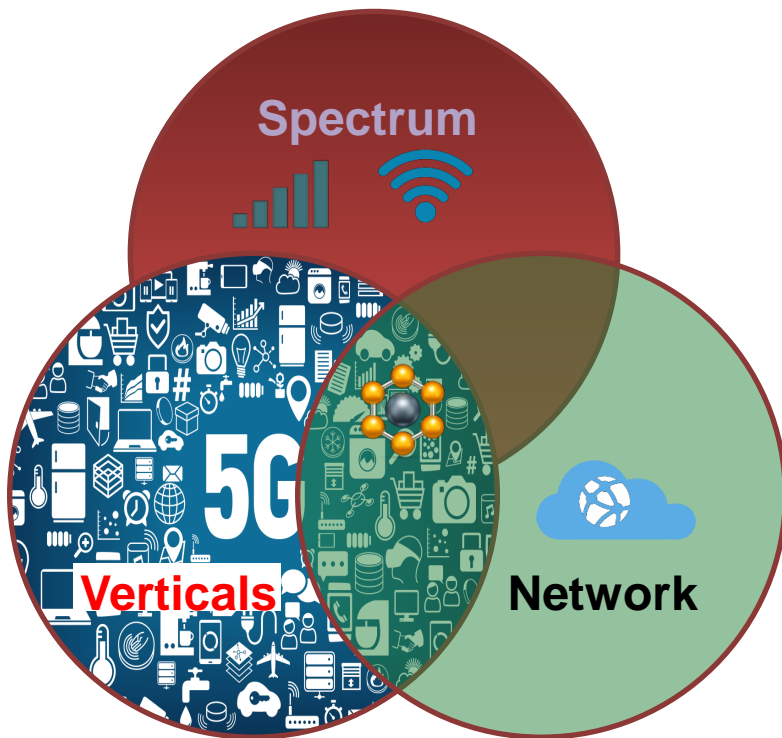
4. Mass Connectivity

5. Energy Efficiency

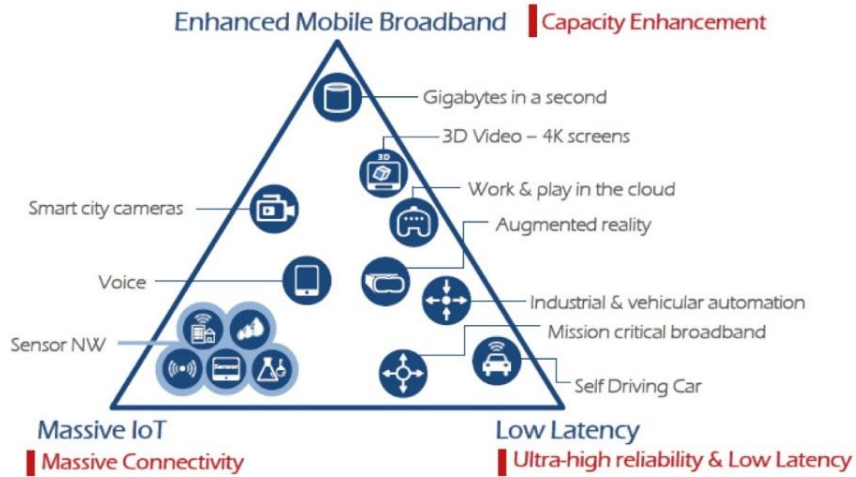
6. More Agile

- 10-100x current 4G rates
- Below 1ms latency
- 100x connected devices
- 10x network and device power savings
- 10x faster time-to-market

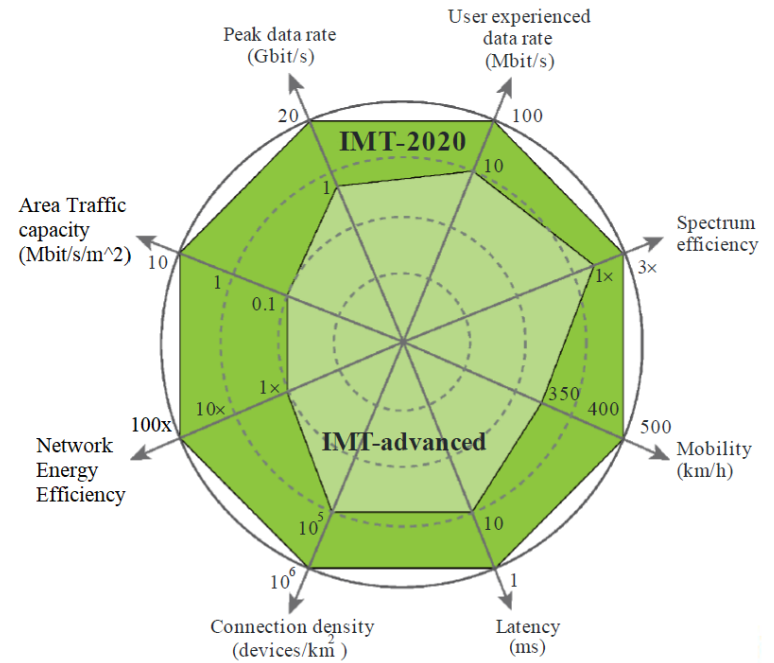
# ITU IMT-2020 vision



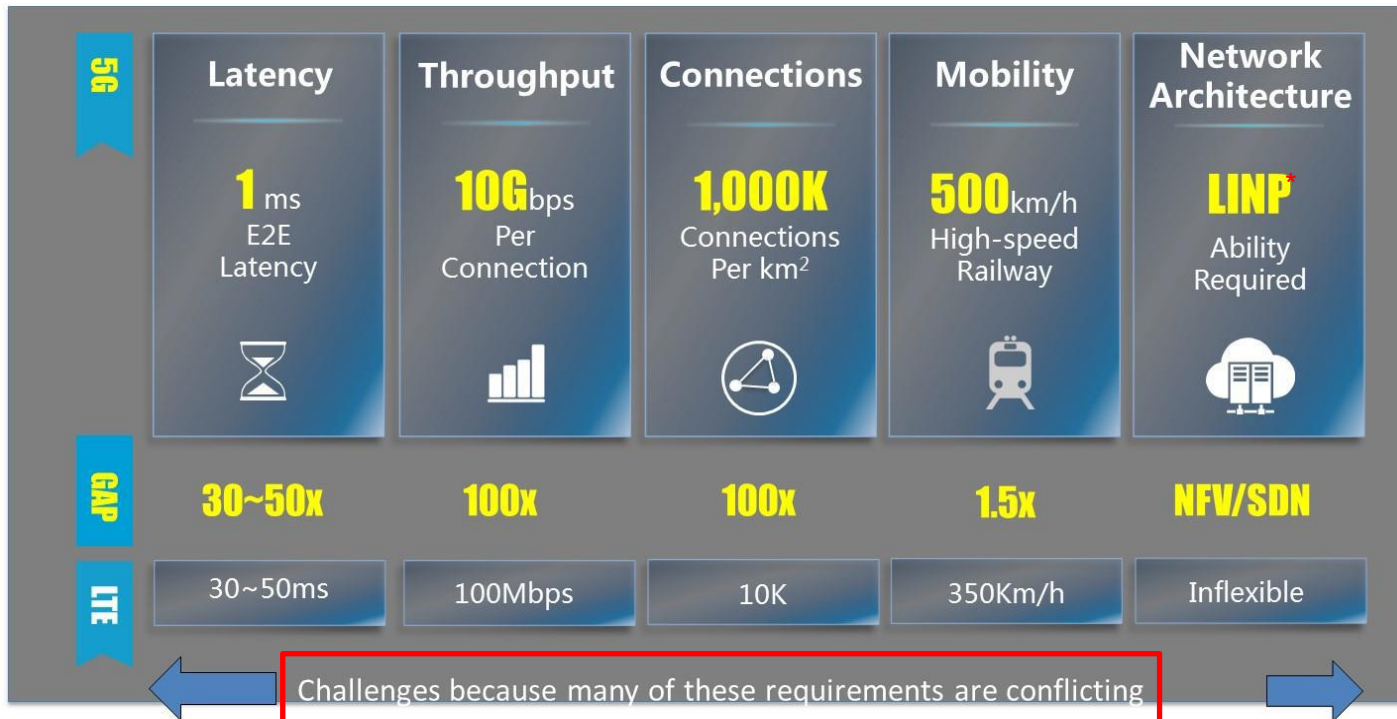
# 5G Performance



(Source: ETRI graphic, from ITU-R IMT 2020 requirements)

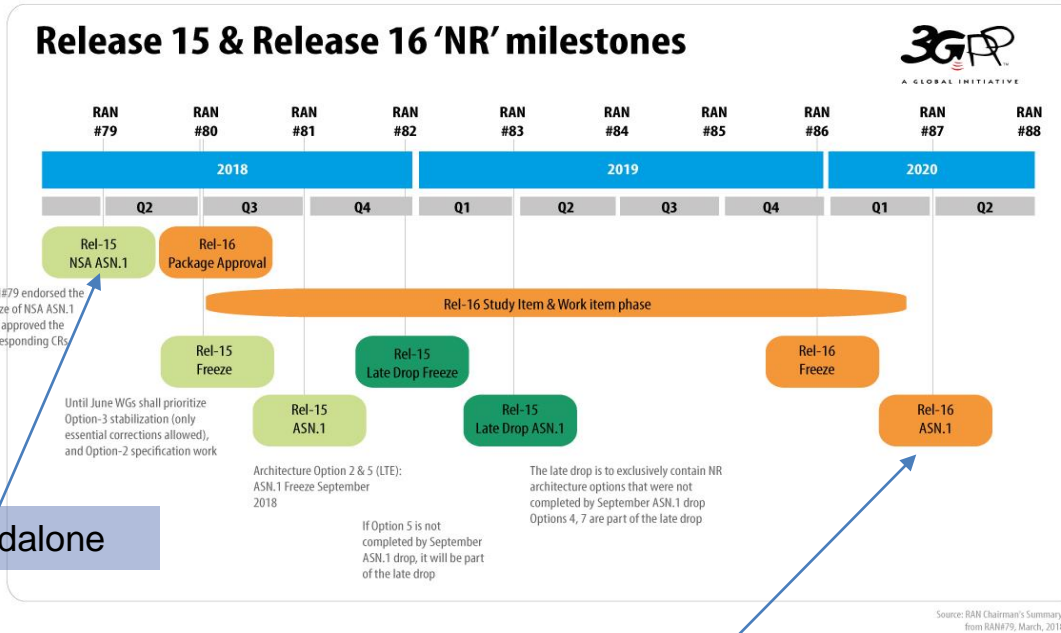


# 5G Performance (compared to LTE)



\*LINP-Locally Isolated Network Partitions

# 5G Standardization: 3GPP Rel.15/16

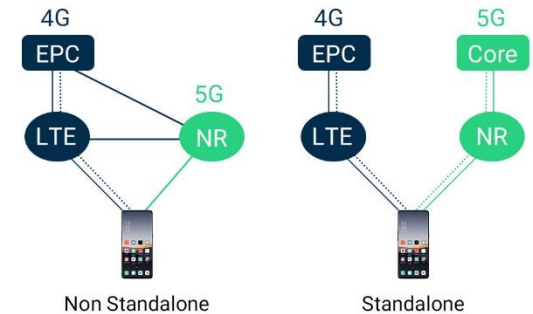


non-standalone

standalone

3GPP Release 15 = 5G Phase 1 – Non standalone

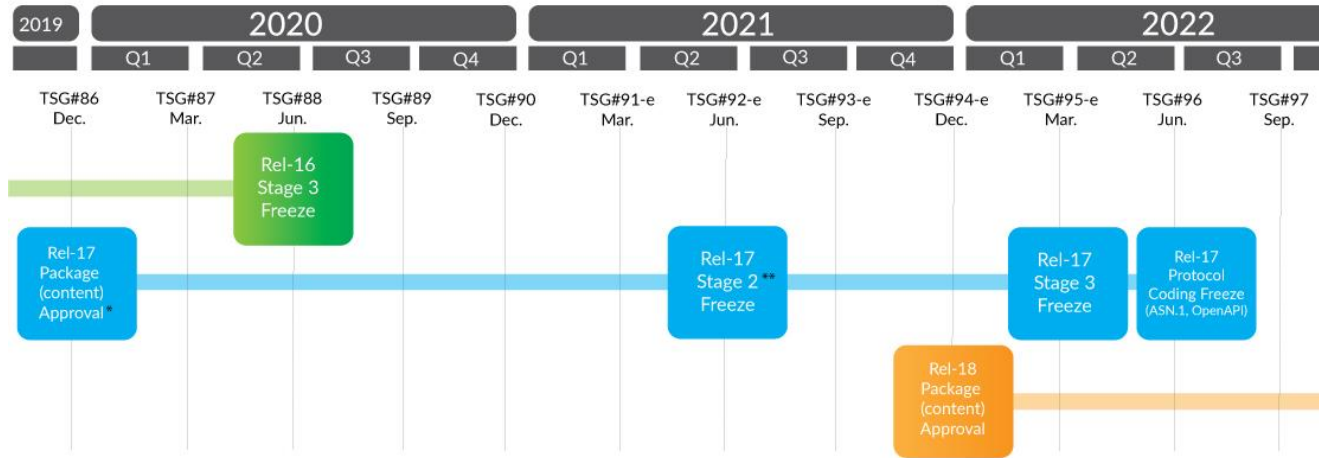
3GPP Release 16 = 5G Phase 2 – Standalone



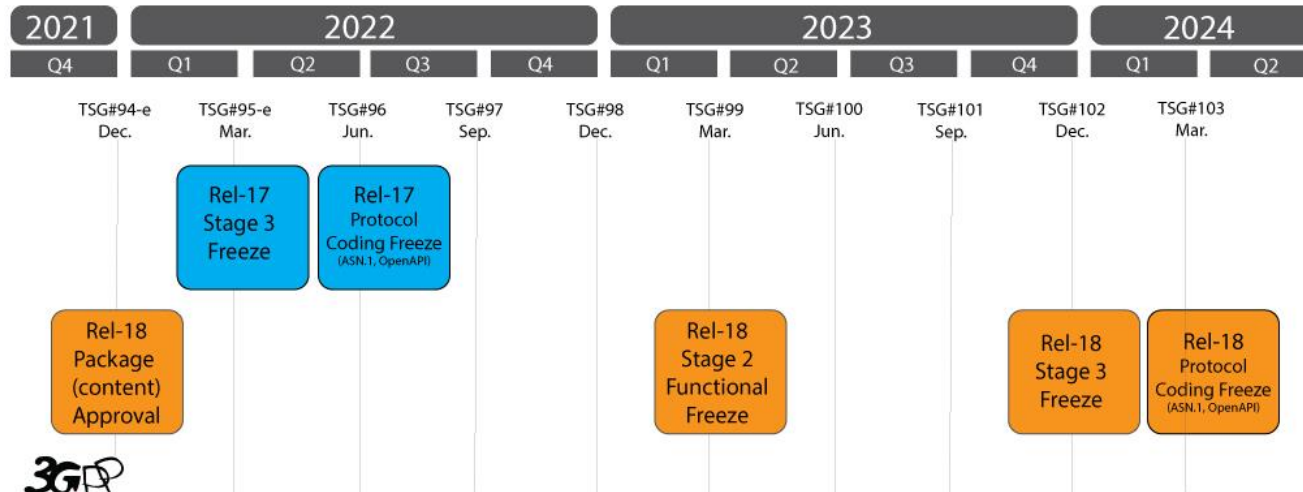
..... Control Plane      ——— Data Plane



# Standardization beyond 5G: 3GPP Rel.17/18

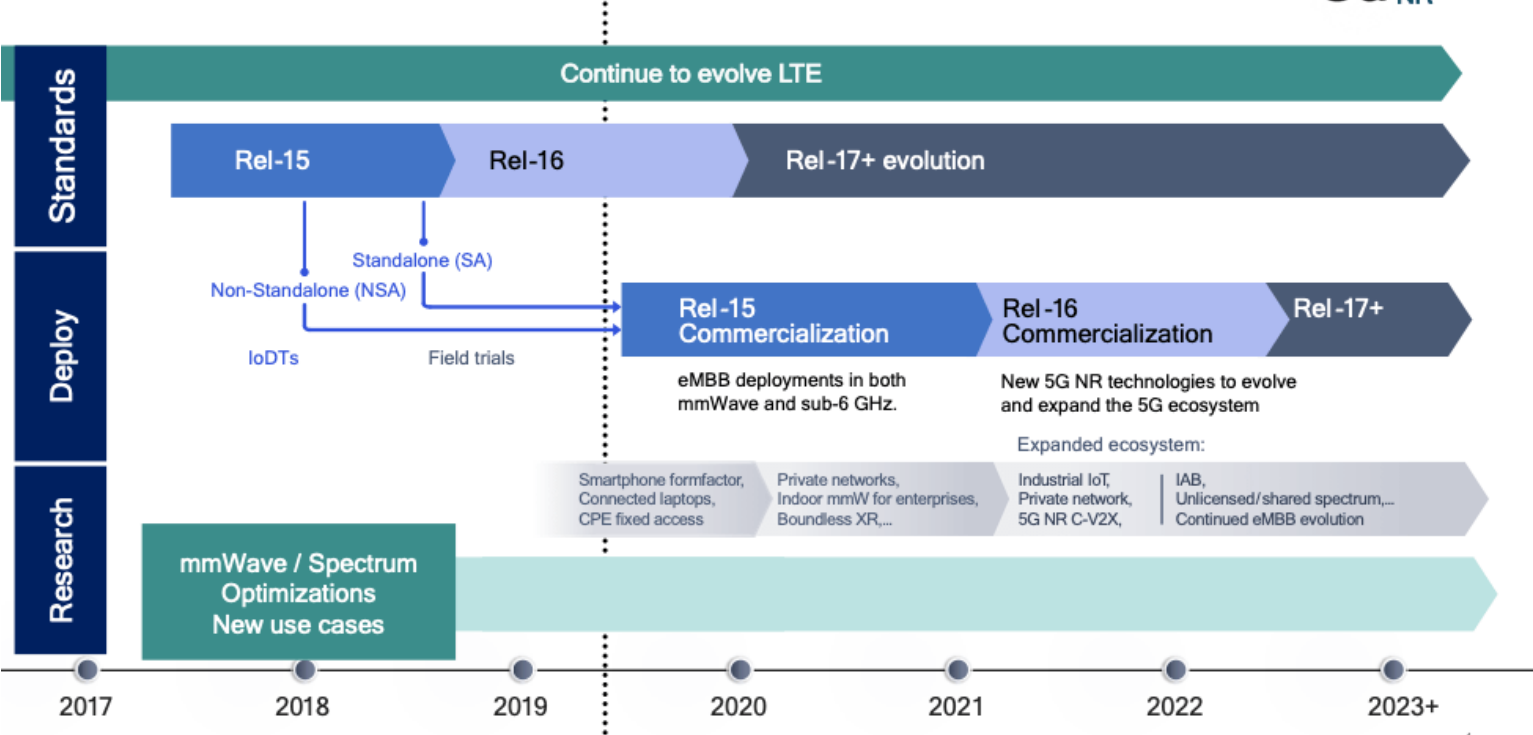


\* Stage 1: WG SA1 work and "RAN content definition" completed TSG#86.  
 \*\* Stage 2: Studies completed TSG#90, Stage 2 Normative work completed TSG#92, Stage 2 exceptions completed TSG#93



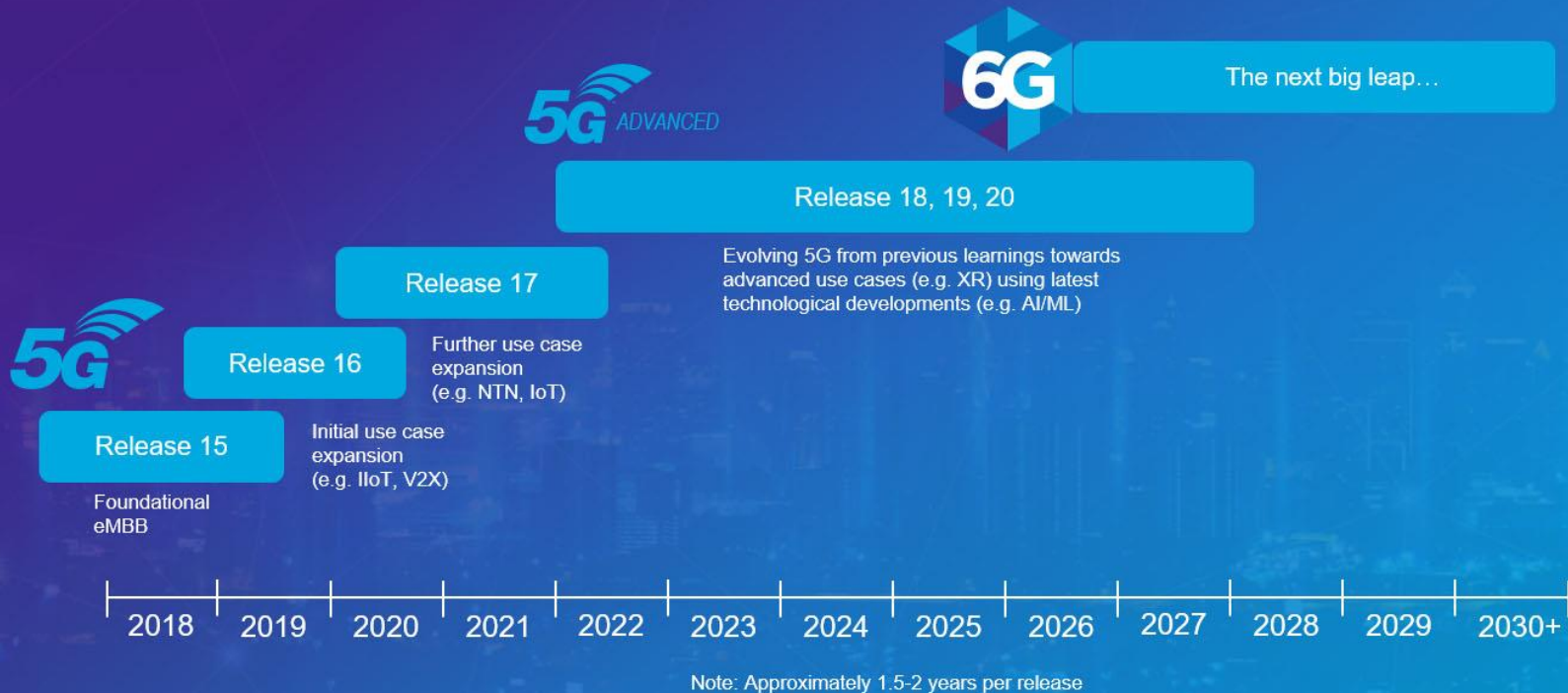
# Standardization beyond 5G: 3GPP Rel.17/18

## 3GPP 5G Timeline



# Standardization towards 6G

## 3GPP Evolution from 5G and Beyond



# 5G IA – 5GPPP

- 5G-PPP = European Commission + 5G Infrastructure Association (IA)
  - *The 5G Infrastructure Public Private Partnership (5G PPP) is a joint initiative between the European Commission and European ICT industry (ICT manufacturers, telecommunications operators, service providers, SMEs and researcher Institutions).*
  - <https://5g-ppp.eu/>

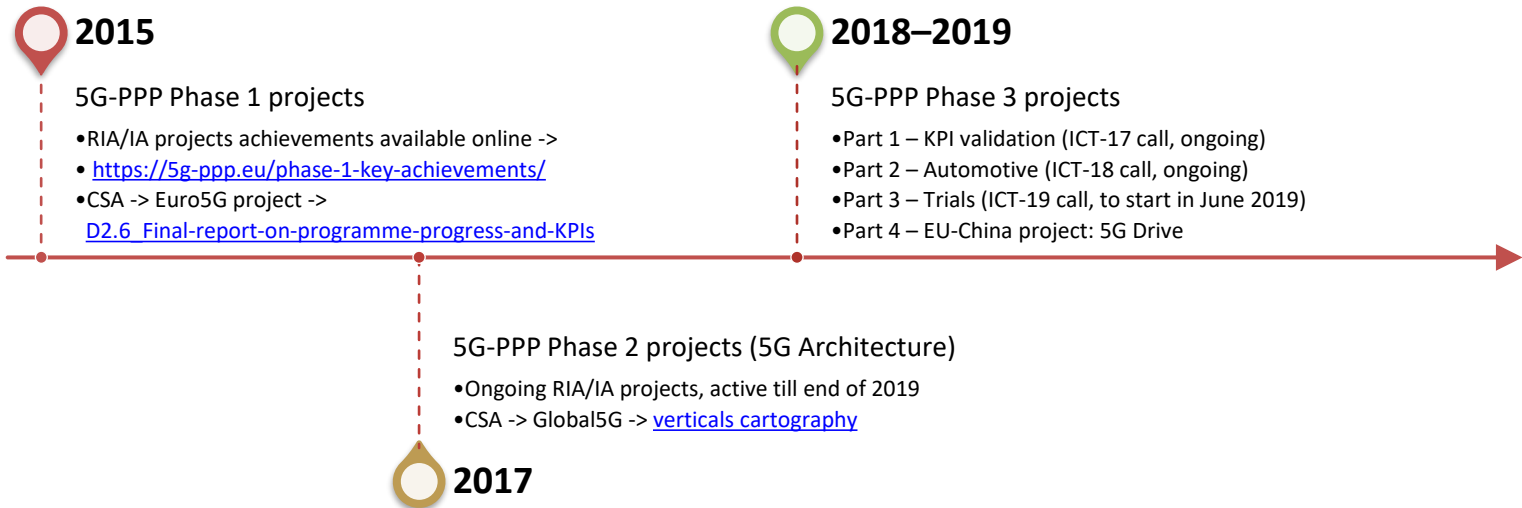


## *Other 5G associations*

- *The **5G Automotive Association (5GAA)** is a global, cross-industry organisation of companies from the automotive, technology, and telecommunications industries (ICT), working together to develop end-to-end solutions for future mobility and transportation services.*



# 5G-PPP Research Projects



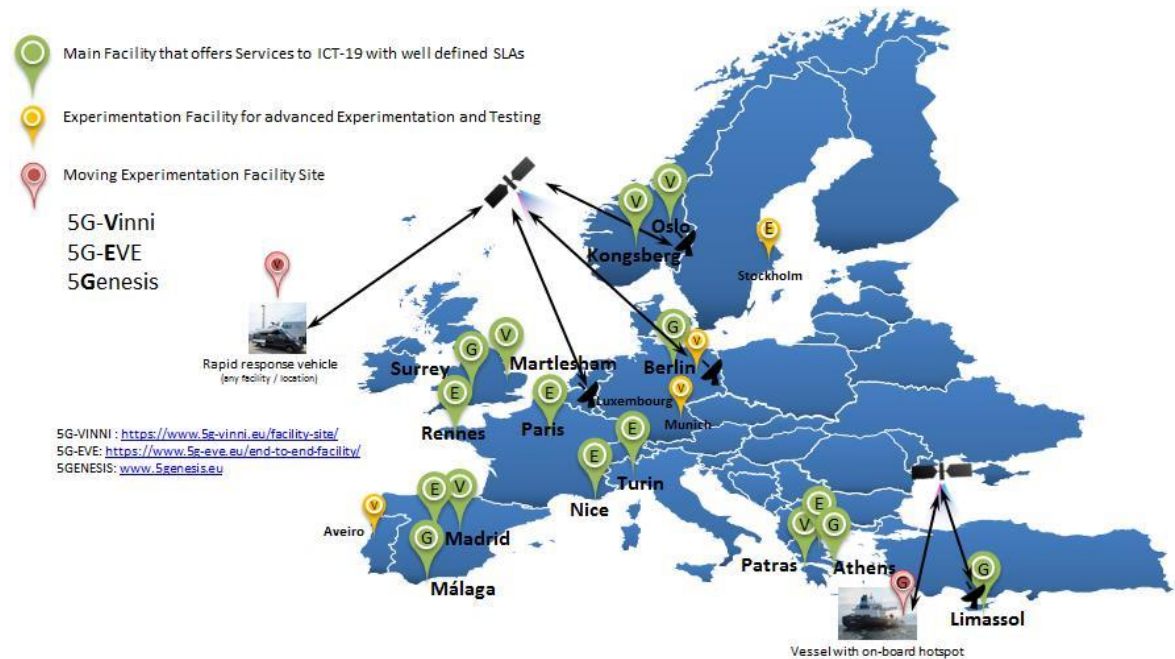
# 5G-PPP working groups

- 5G-PPP Working Groups (WGs)
  - Originated by 5G IA (6):
    - Pre-Standardization -> Alignment with ETSI, 3GPP, IEEE, ITU-R
    - Security
    - Vision & societal challenges
    - Spectrum
    - IMT-2020 Evaluation Group -> one of the 11 independent 5G Evaluation Groups from ITU-R
    - Trials -> [European Trial Roadmap v0.4](#)
  - Originated by 5G-PPP projects (4):
    - Automotive
    - Software
    - Architecture
    - Network Management & QoS (closed 2019)
    - Test, measurements and KPIs validation (TMV) WG (launched Nov2018)

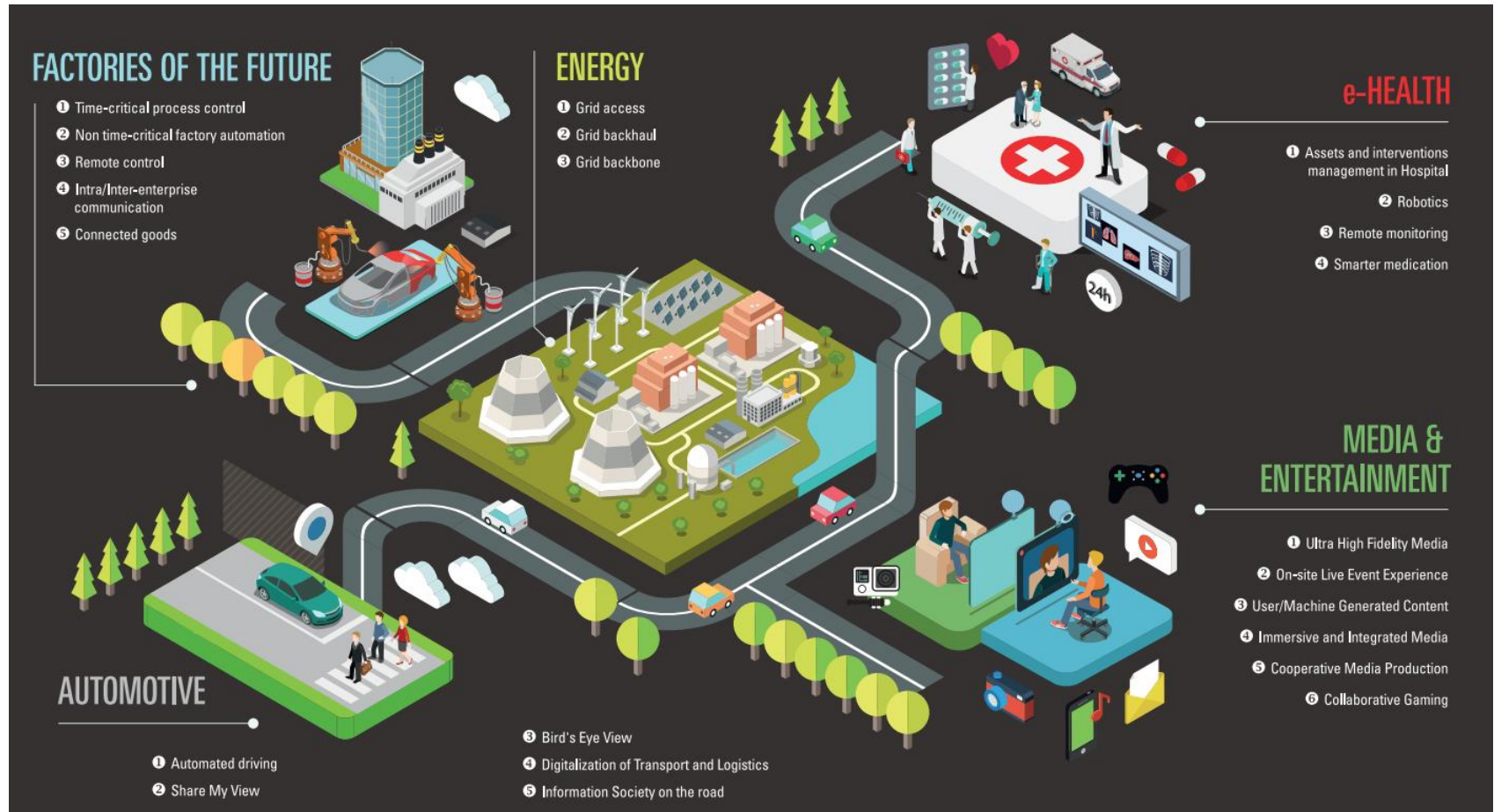
# 5G experimentation platforms/ testbeds

<https://5g-ppp.eu/5g-ppp-platforms-cartography/>

<https://www.ip45g.de/en/5g-testbeds/>



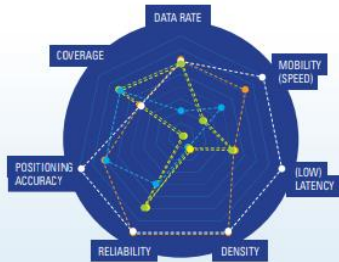
# 5G Verticals





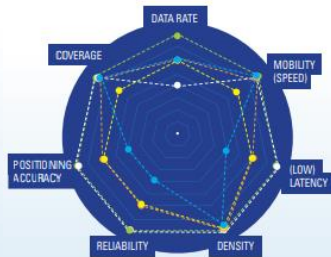
# 5G Verticals

## FACTORIES



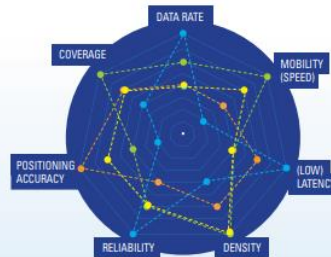
- Time-critical process control
- Non time-critical factory automation
- Remote control
- Intra/Inter-enterprise communication
- Connected goods

## AUTOMOTIVE



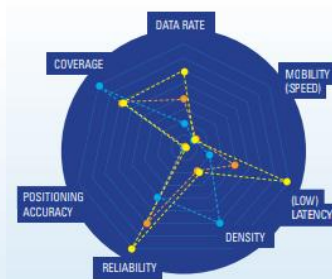
- Automated driving
- Share my view
- Bird's eye view
- Digitalization of transport and logistics
- Information society on the road

## e-HEALTH



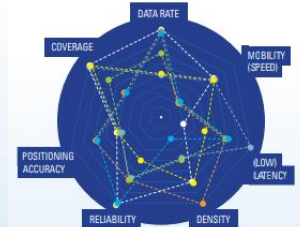
- Assets and interventions management in Hospital
- Robotics
- Remote monitoring
- Smarter medication

## ENERGY



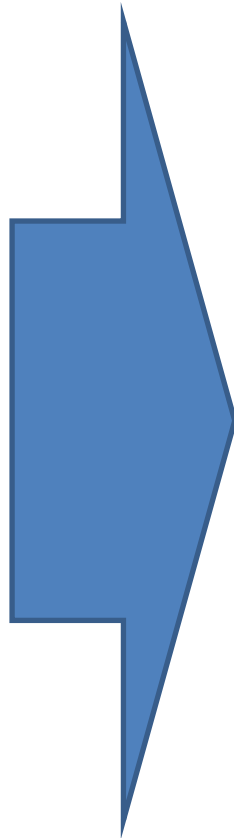
- Grid access
- Grid backhaul
- Grid backbone

## MEDIA & ENTERTAINMENT



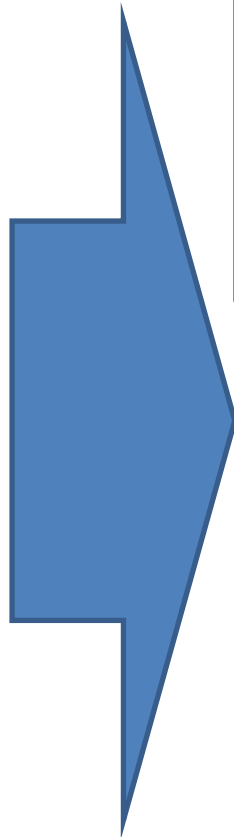
- Ultra high fidelity media
- On-site Live Event Experience
- User/Machine generated content
- Immersive and integrated media
- Cooperative media production
- Collaborative gaming

# 5G Advancements



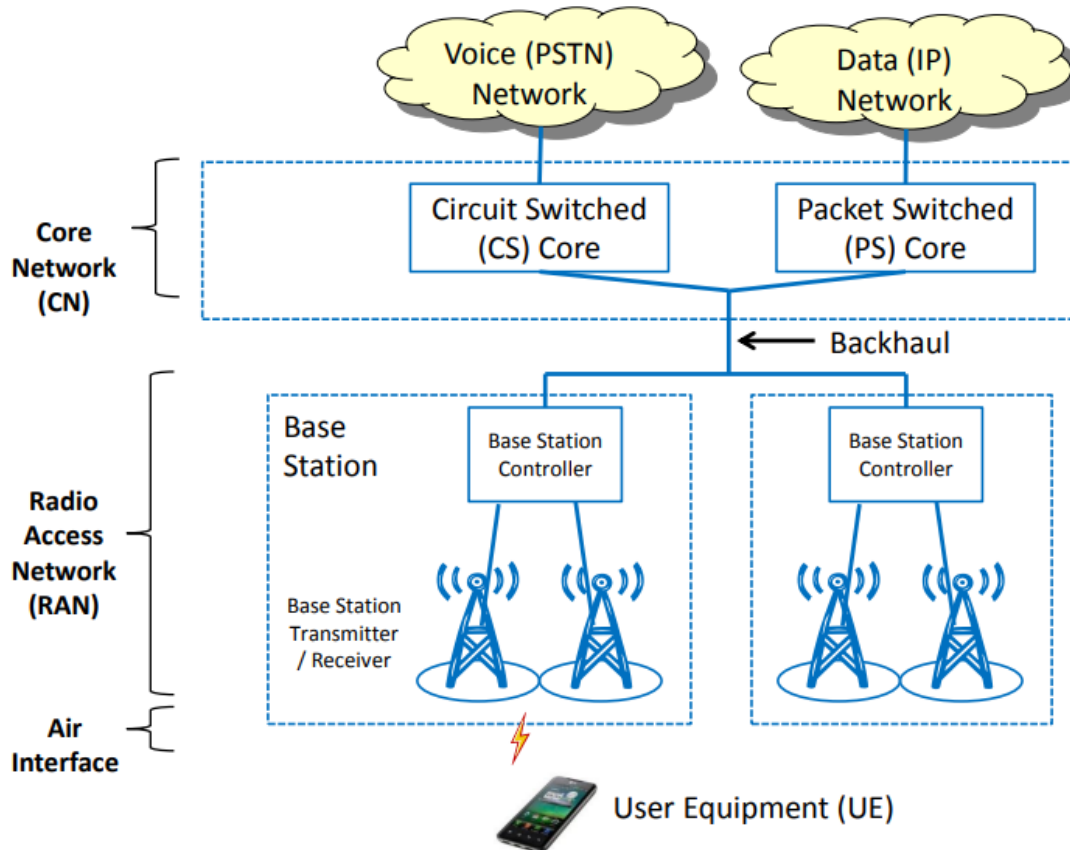
- ▶ **New Architecture**
  - ▶ Advanced core network functions / NG RAN
  - ▶ Incorporate SDN/NFV (NFV MANO)
    - ▶ Decoupling of control and data plane
    - ▶ Decoupling of functions from the hardware
- ▶ **Network Slicing**
  - ▶ eMBB, URLLC, mMTC | 8 subclasses per slice type
- ▶ **New Radio (NR)**
  - ▶ RAN protocol stack (+SDAP)
  - ▶ New numerology for the PHY compared to LTE
- ▶ **Functional Split**
  - ▶ gNodeB Fronthaul Central, Distributed and Radio Units (CU, DU and RU)
- ▶ **Device-to-Device**
  - ▶ Allow direct communications (Public safety)

# 5G Advancements



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# 2G / 3G Mobile Network Architecture



## Core Network

- Connects to voice and data networks
- Provides Security and Authentication
- Billing / Charging
- Roaming

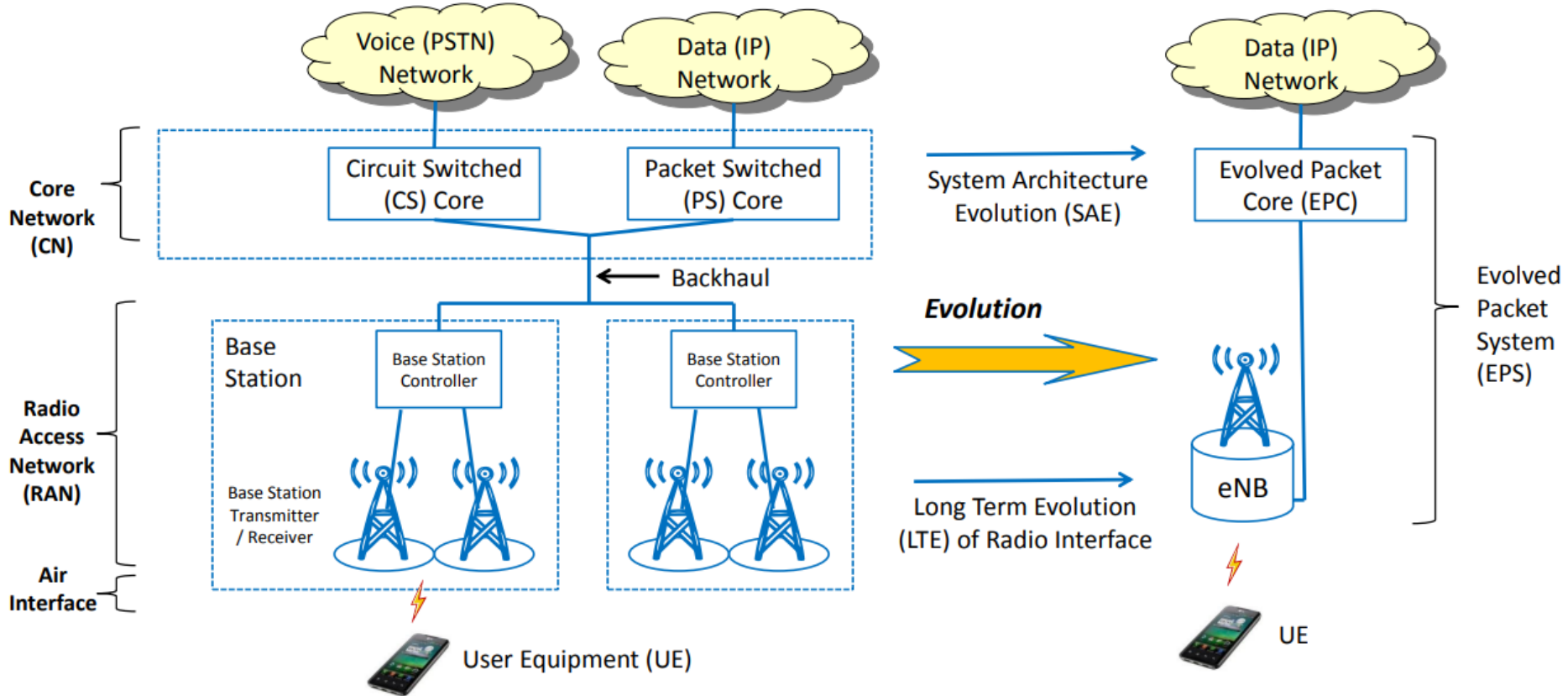
## Backhaul

- Connects access network with core network
- Example: Fiber, microwave, satellite, mesh, etc.

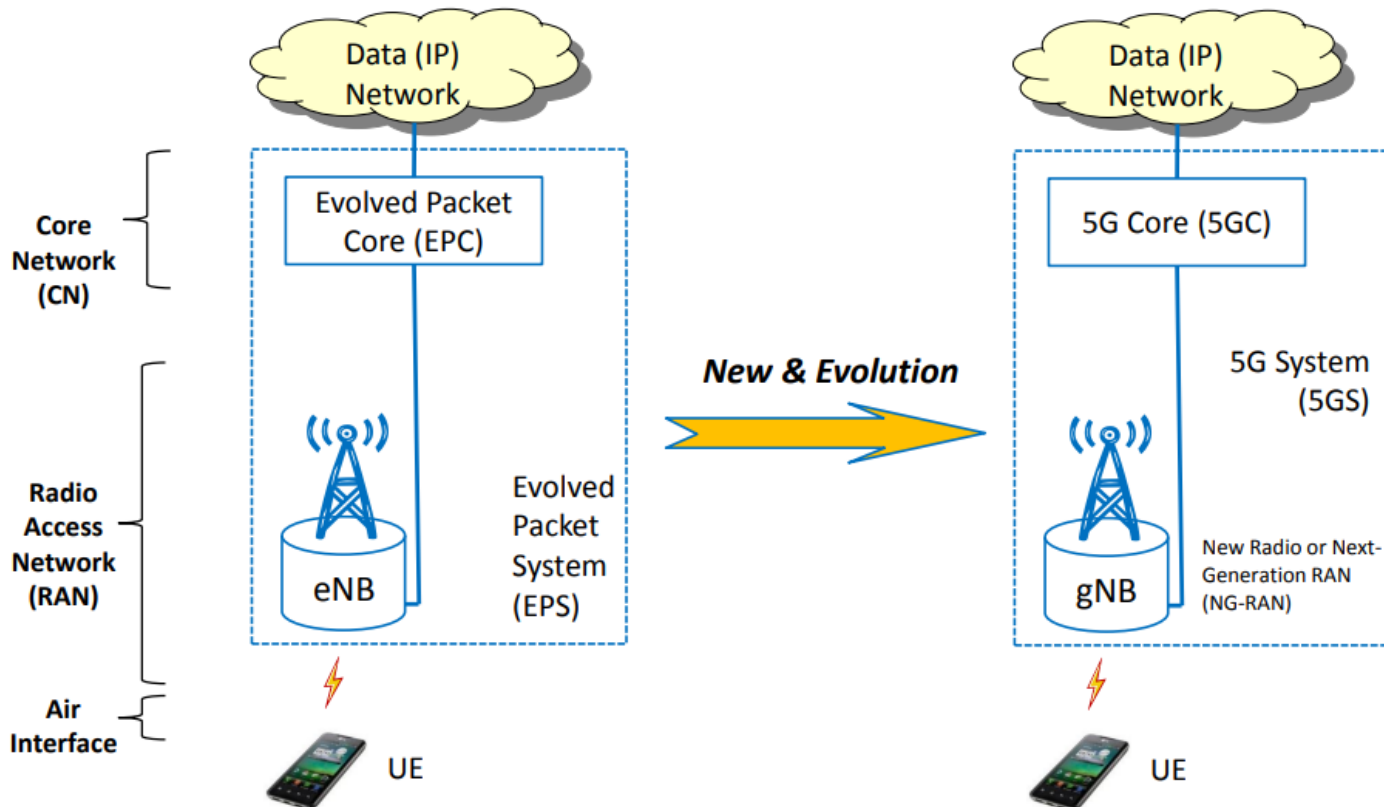
## Access Network

- Connects devices over the air
- Allows mobility and handovers

# 4G Mobile Network Architecture



# 5G Mobile Network Architecture

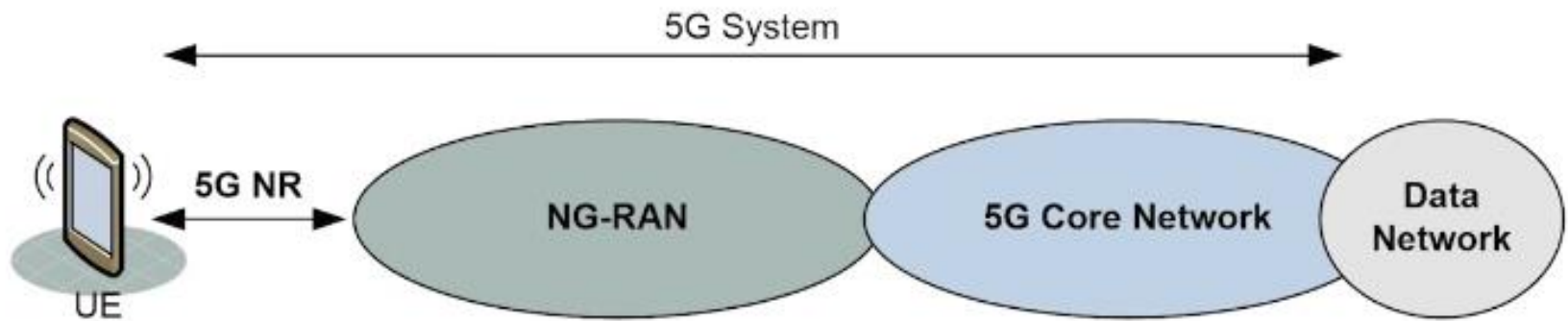


5G System is defined as 3GPP system consisting of 5G Access Network (AN), 5G Core Network and UE. The 5G System provides data connectivity and services.

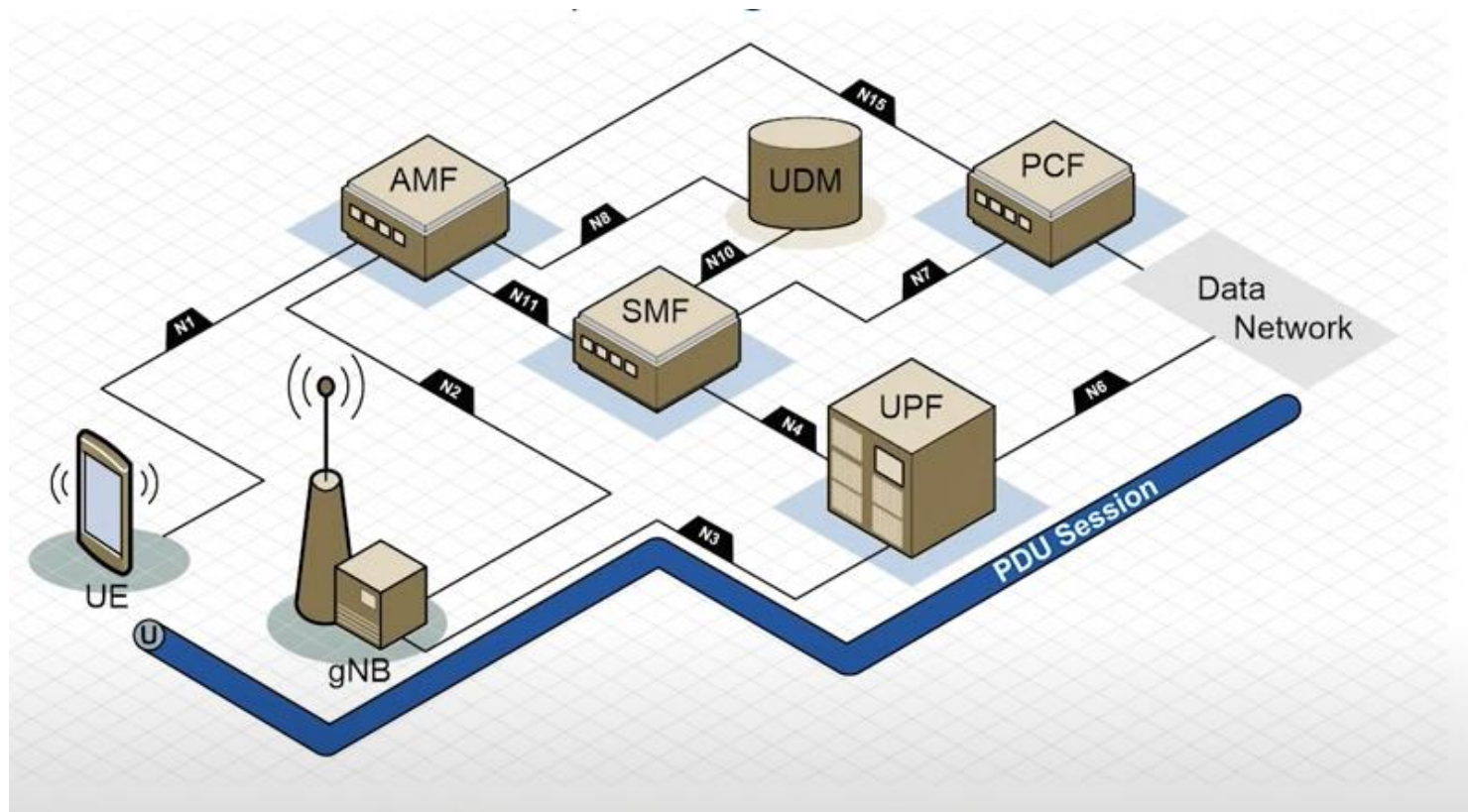
3GPP TS 23.501: System Architecture for the 5G System; Stage 2

3GPP TS 23.502: Procedures for the 5G System; Stage 2

# Access and Core Network



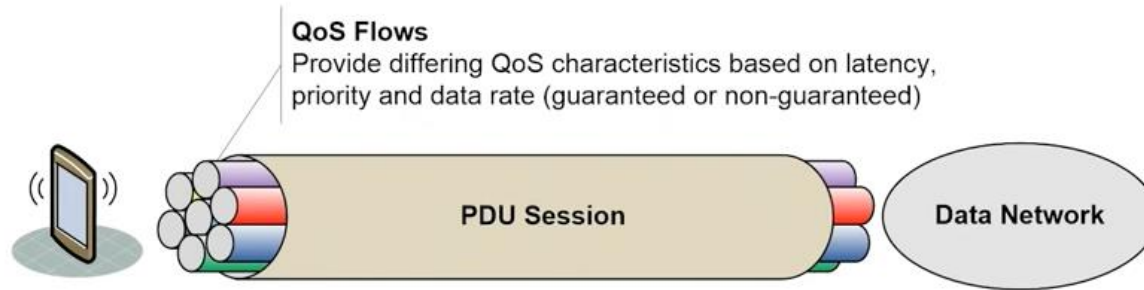
# General 5G architecture



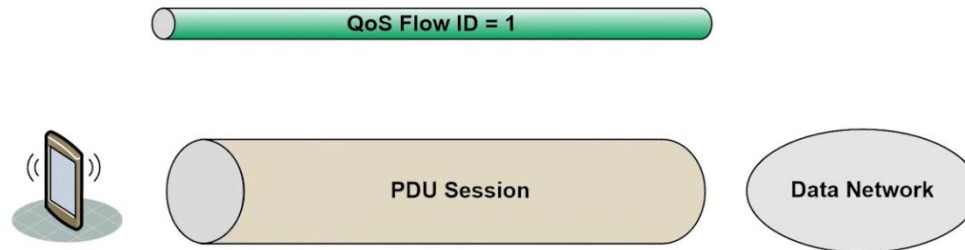


# Data flow

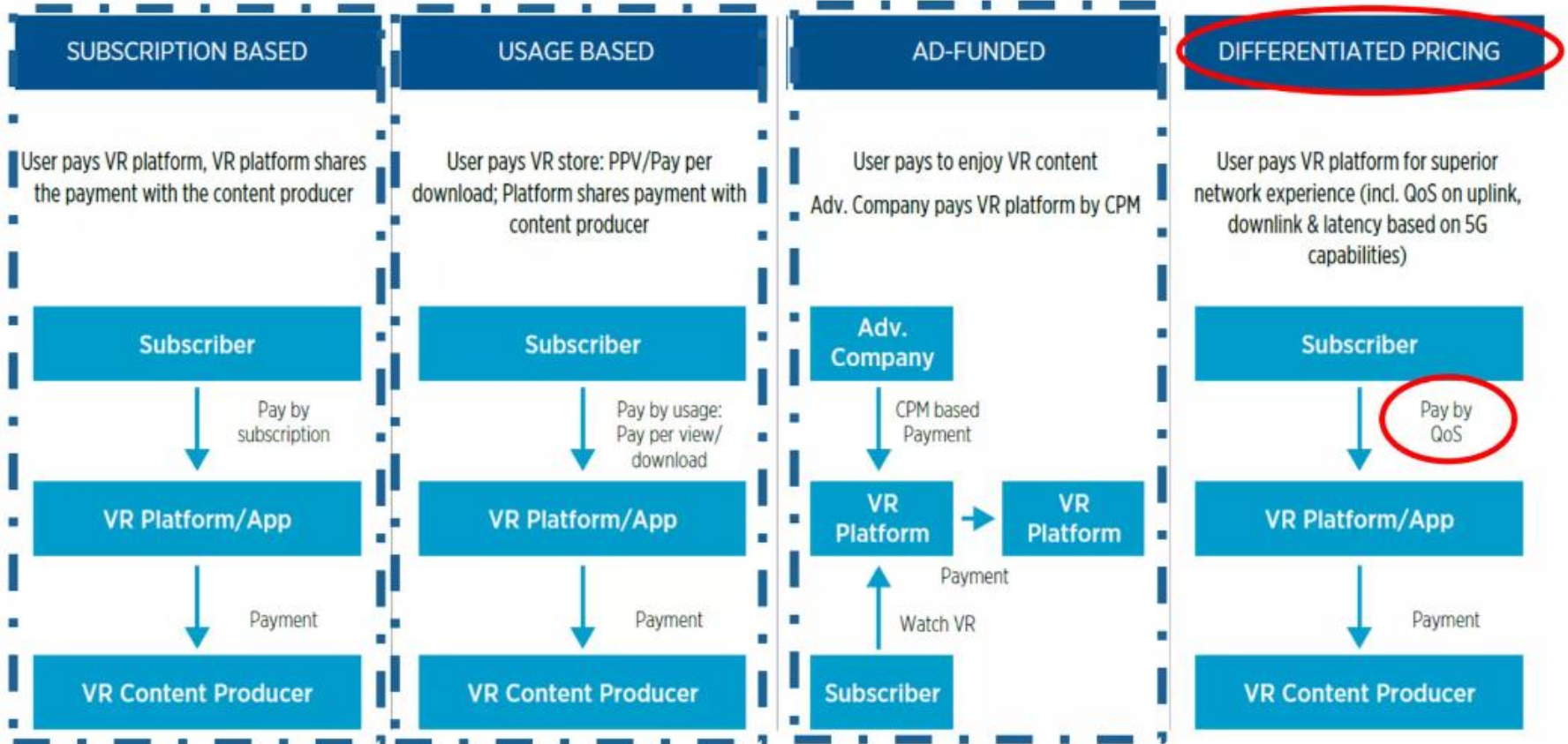
## PDU Sessions and QoS Flows



QoS Flows can be established and removed on the basis of the QoS requirements of the User Plane traffic



# Business model options for cloud AR/VR in the 5G era



The factors that affect the network service quality need to be learned to improve network quality:

Bandwidth

Delay

Jitter

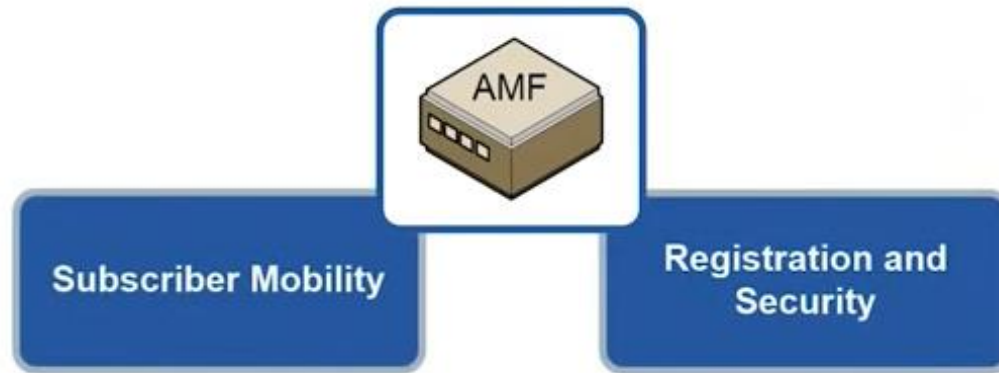
Packet Loss rate

The acceptable E2E delay for VOIP is 150 to 200 ms

- increase link bandwidth
- prioritizing
- layer 2 payload compression
- RTP header compression

QoS indicators

# Access and Mobility-Management Function



Similar to MME in 4G  
Location  
Paging  
Handover

Authentication  
Temporary ID

# International Mobile Subscriber Identifier

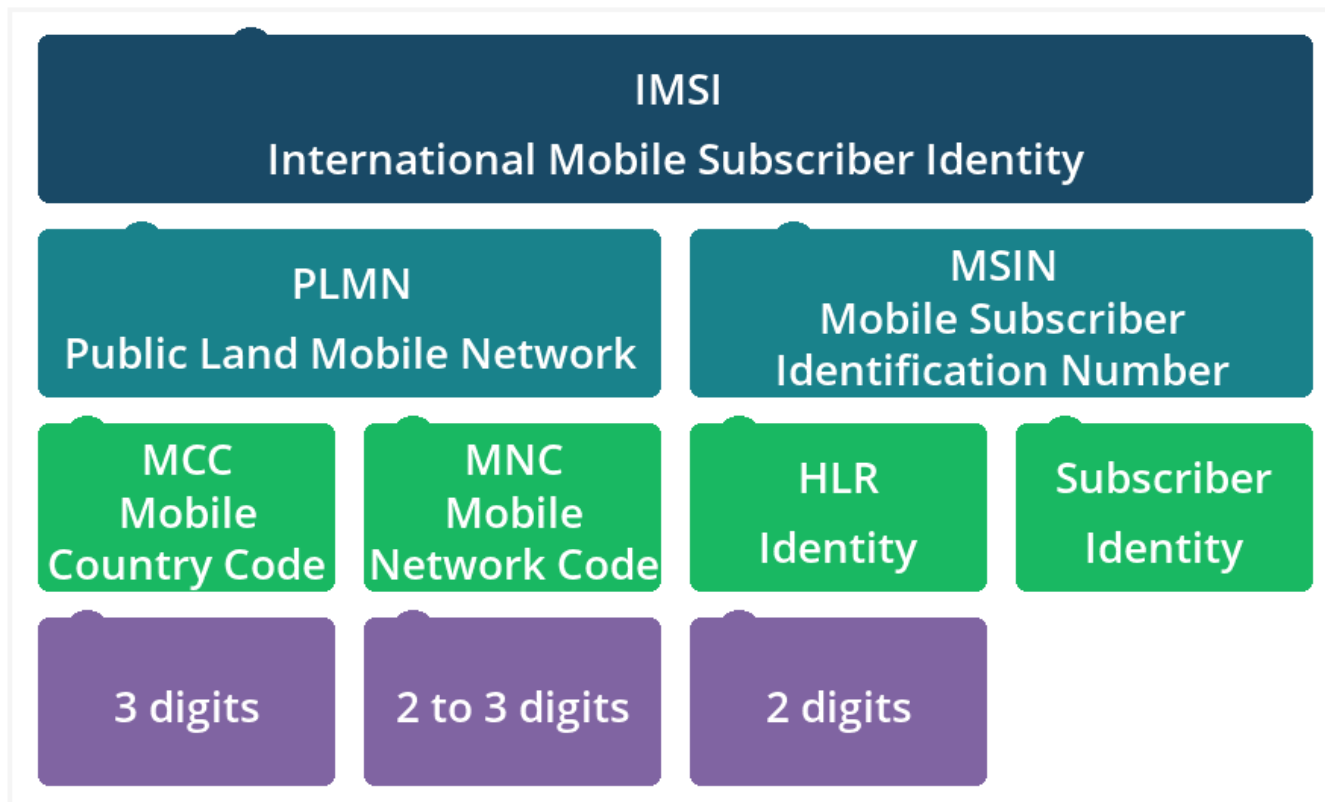
3GPP identifiers [23.003](#)

## IMSI

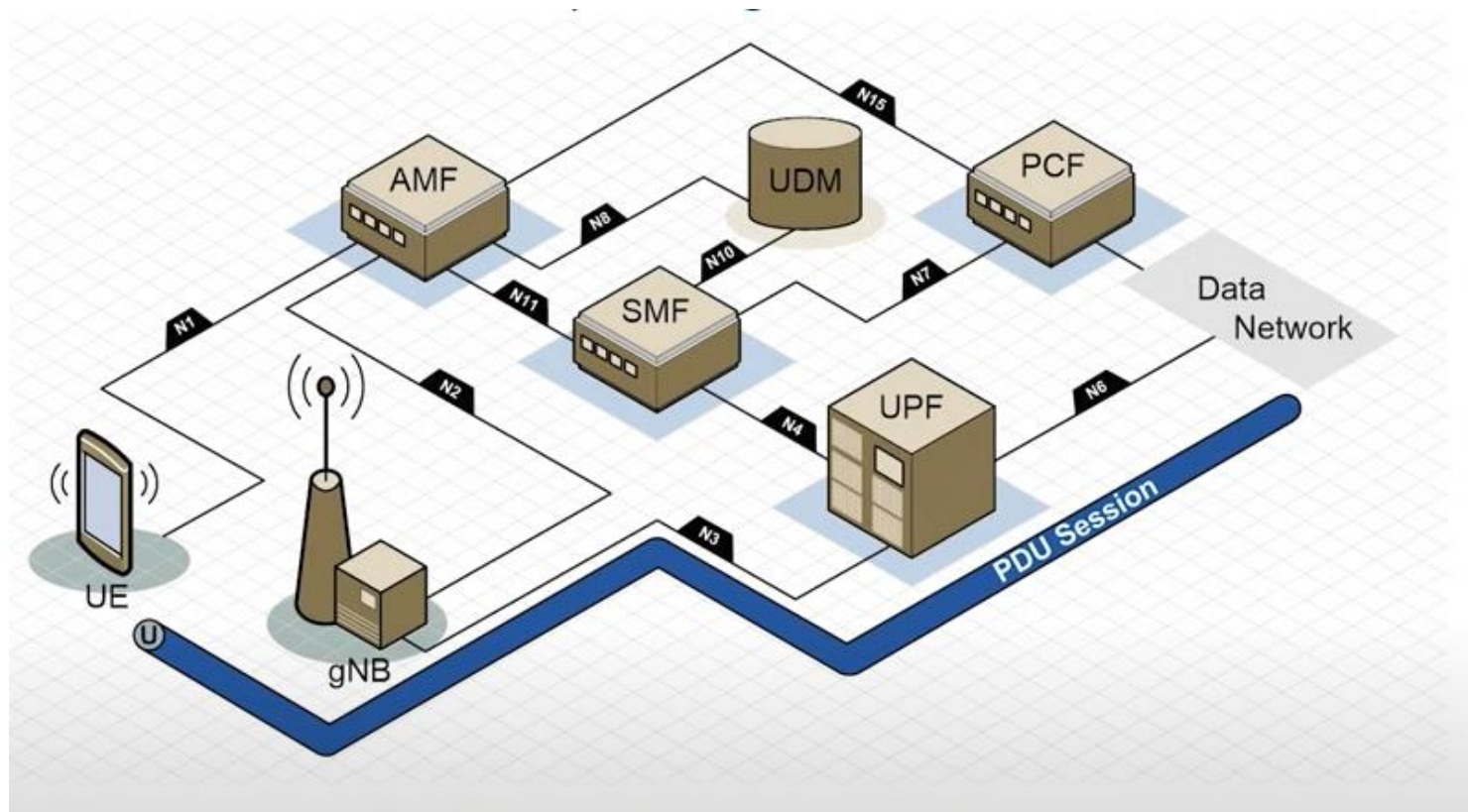
*Identifies the SIM. It includes the Home PLMN*

*IMSI is flashed in the SIM card and stored in the HLR (Home Location Register)*

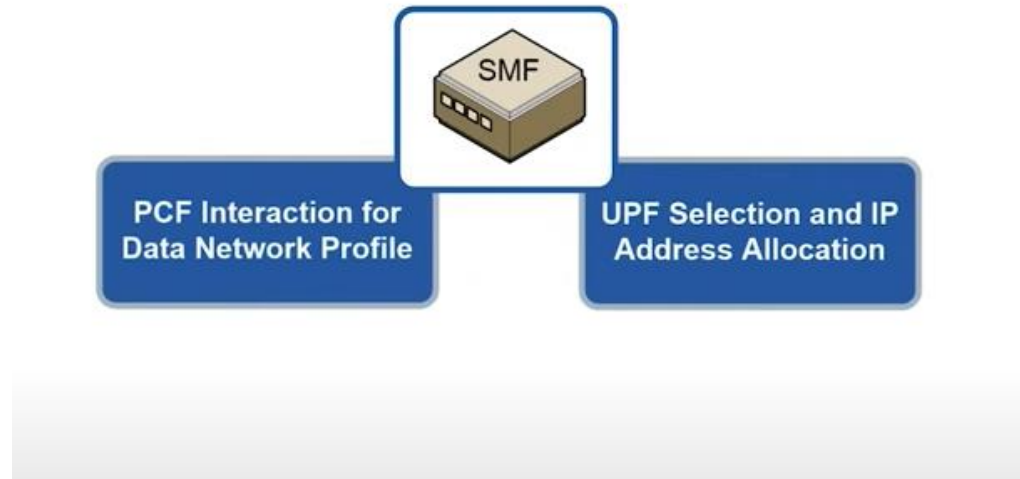
*Length : 15 digits or less*



# General 5G architecture



# Session Management Function

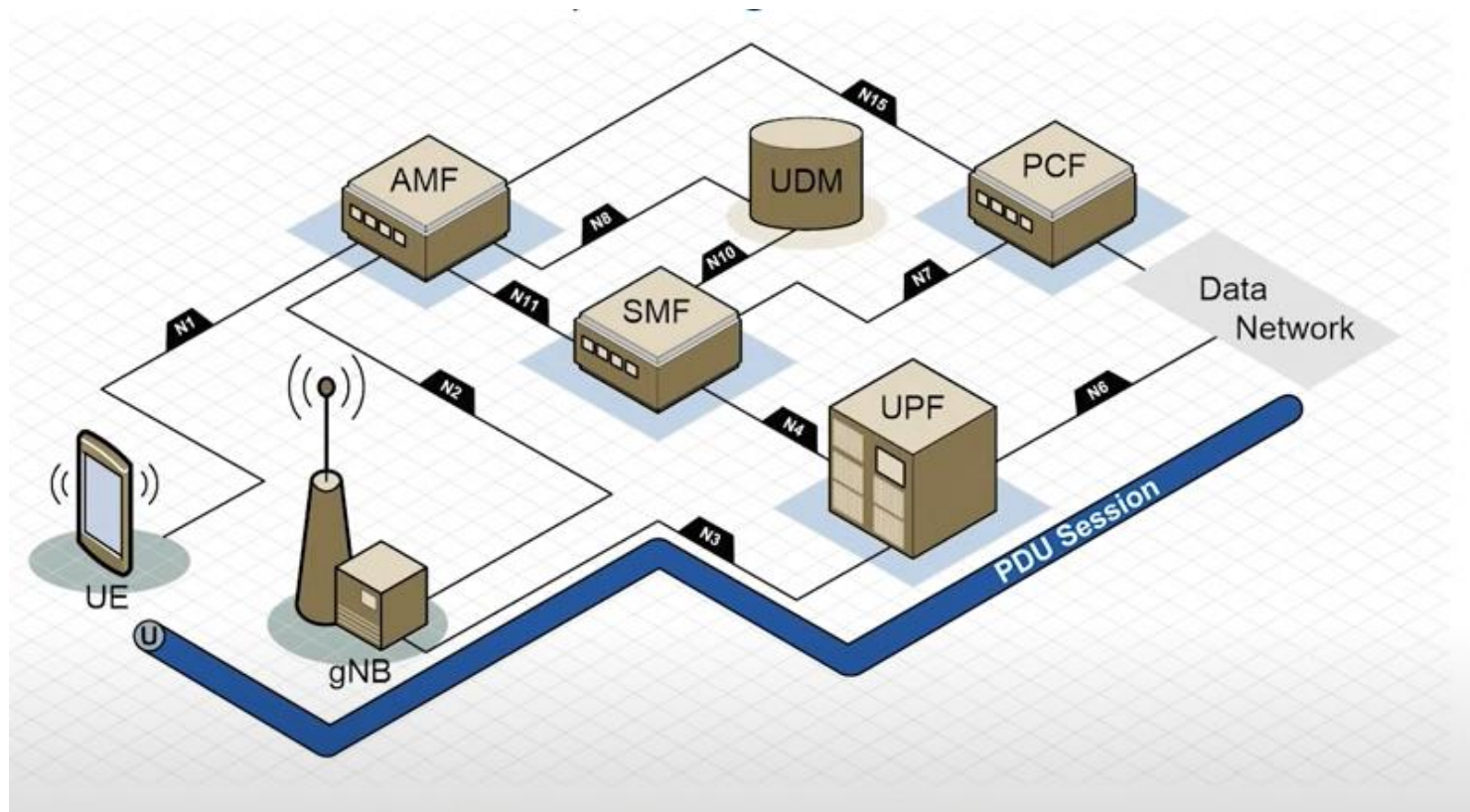


In 4G mobility and session functionality were both in one entity: MME – In 5G this is split to AMF and SMF respectively.

Establishment, modification, termination of PDU sessions

- Interact with Policy Control Function to check the user subscription status
- Interact with User Plane Function to setup the PDU session

# General 5G architecture





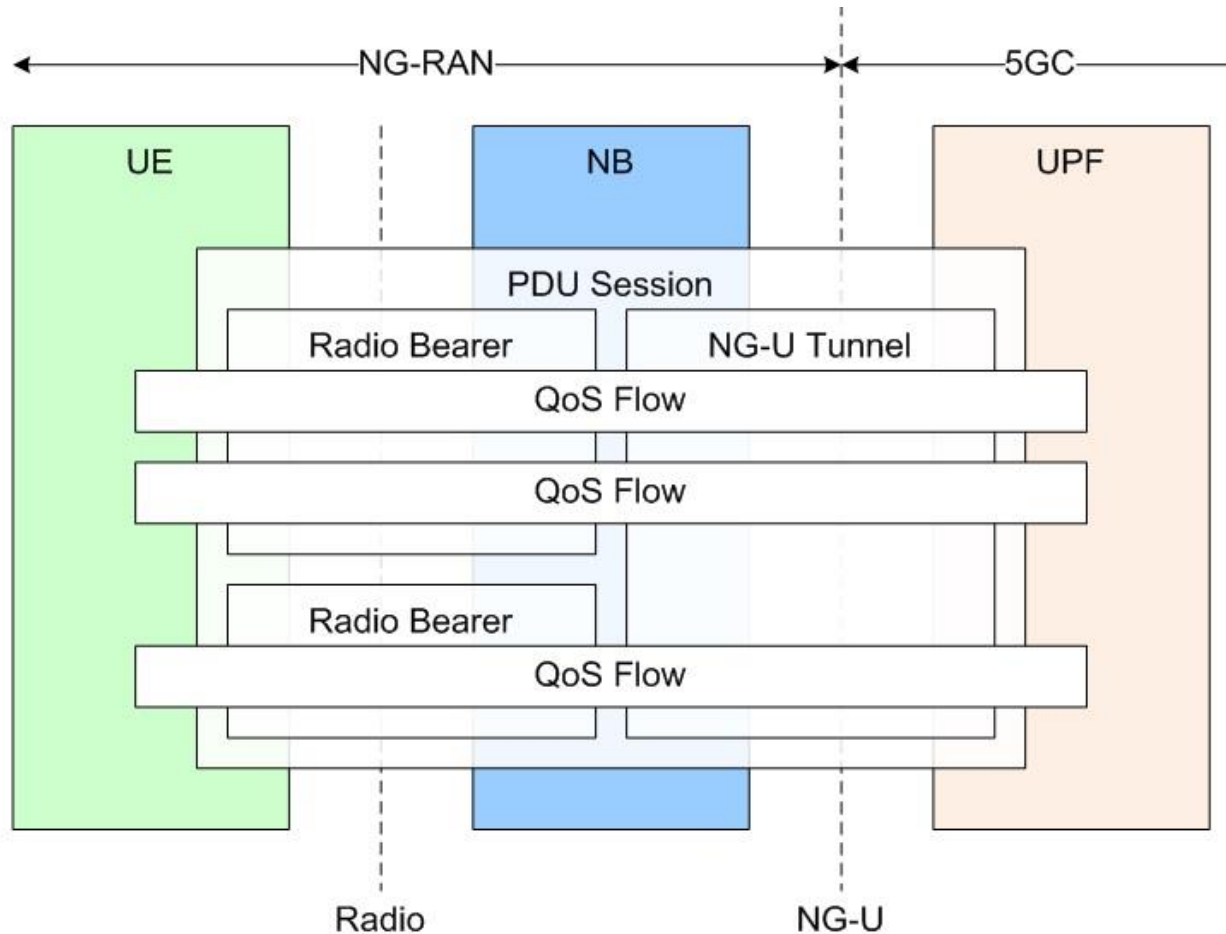
# User Plane Function



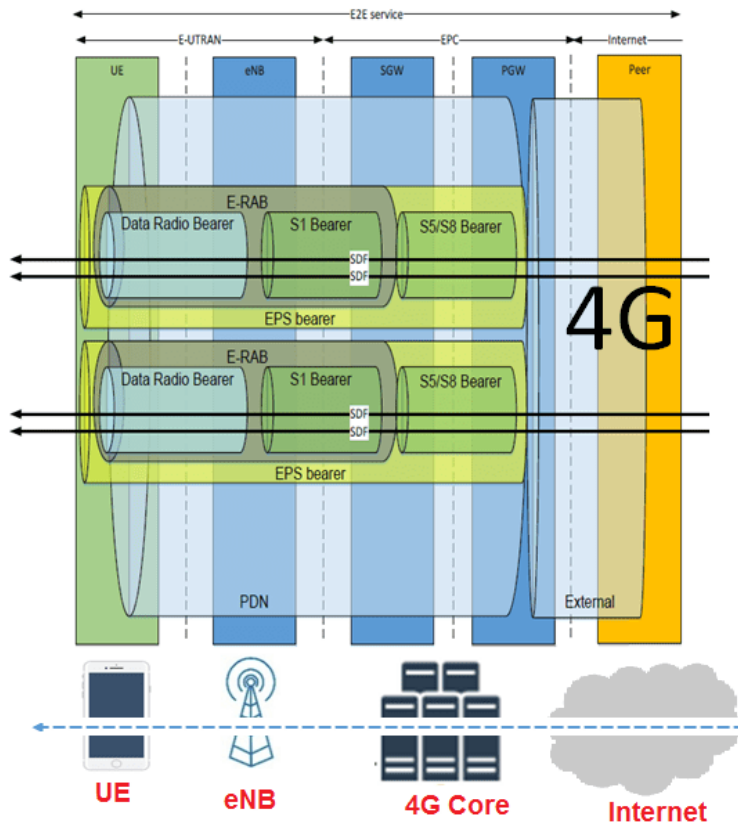
Remains the same for a PDU session

Enforces QoS and data forwarding from/to the UE to/from the data network

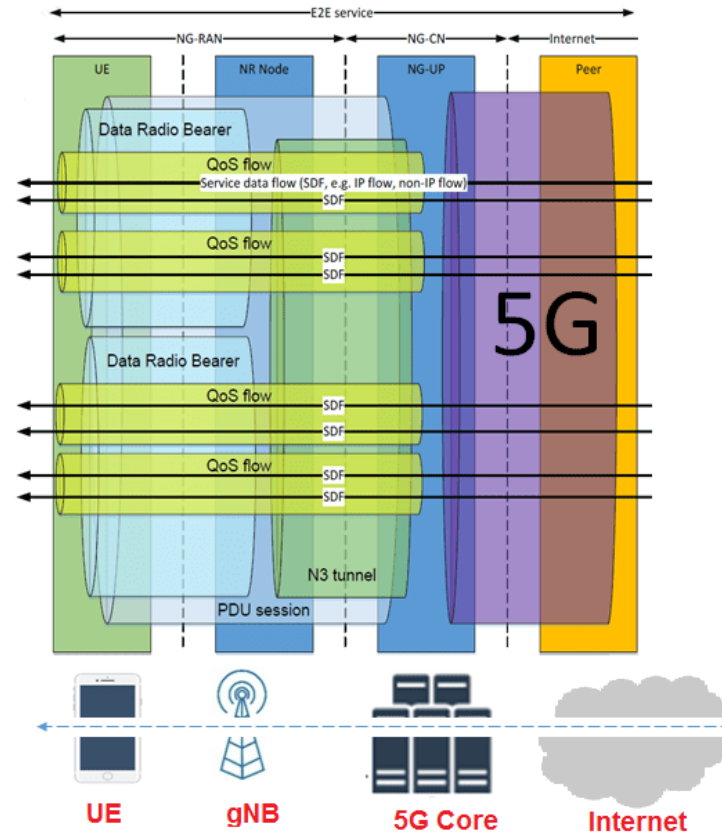
# User Plane Function



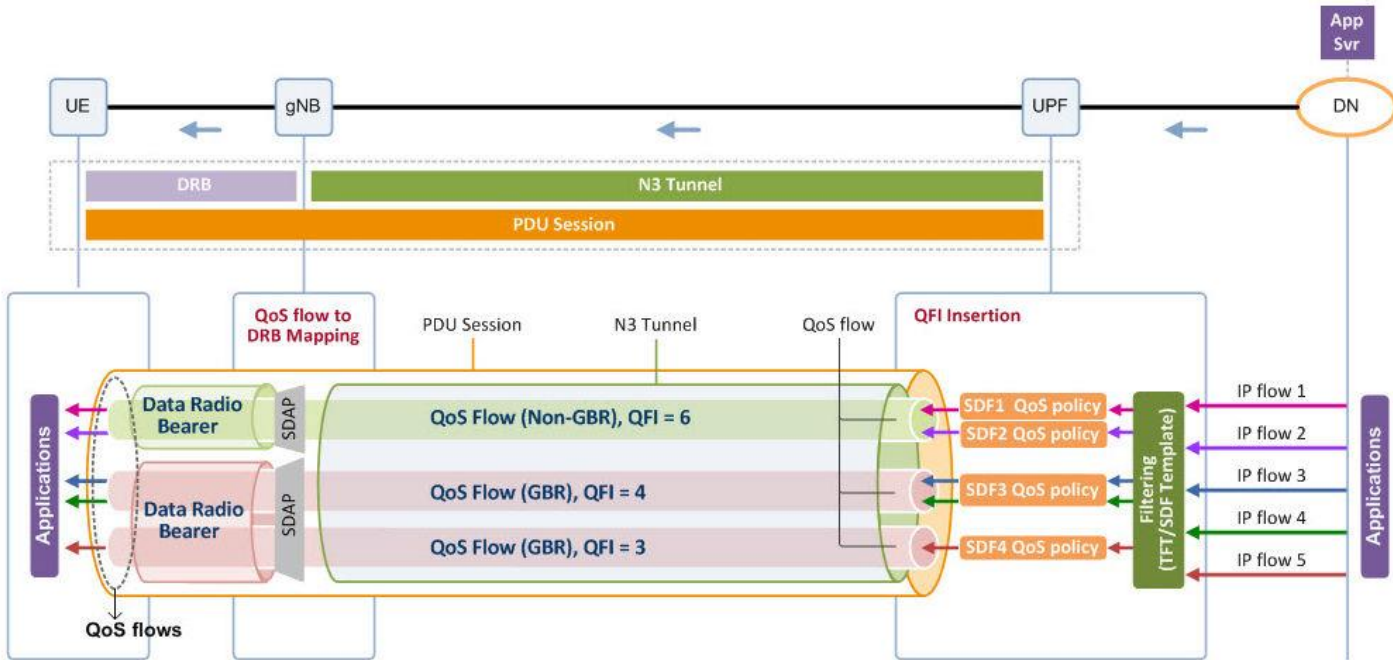
# User Plane Function



**Vs**



# User Plane Function



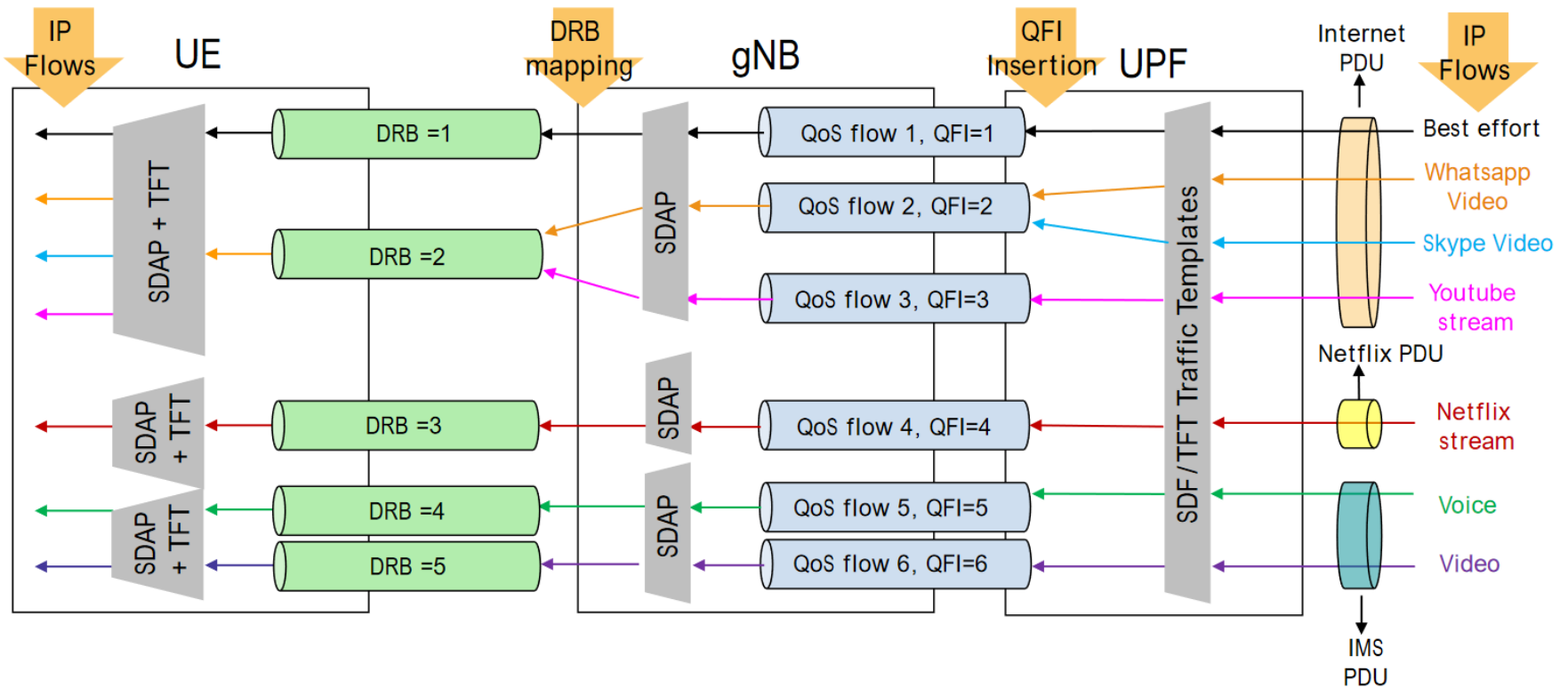
- 5QI : 5G QoS Identifier
- ARP : Allocation and Retention Priority
- GFBR : Guaranteed Flow Bit Rate
- MFBR : Maximum Flow Bit Rate
- PDB : Packet Delay Budget
- PER : Packet Error Rate
- QFI : QoS Flow Identifier
- RQA : Reflective QoS Attribute

QoS Flow type	QoS Flow parameters
GBR flow	Non-GBR flow
	5QI
	ARP
	RQA
	GFBR
	MFBR
	Notification Control
Maximum Packet Loss Rate	

- 5QI
- Resource Type\*
- Default Priority Level
- PDB
- PER
- Default Maximum Data Burst Volume
- Default Averaging Window

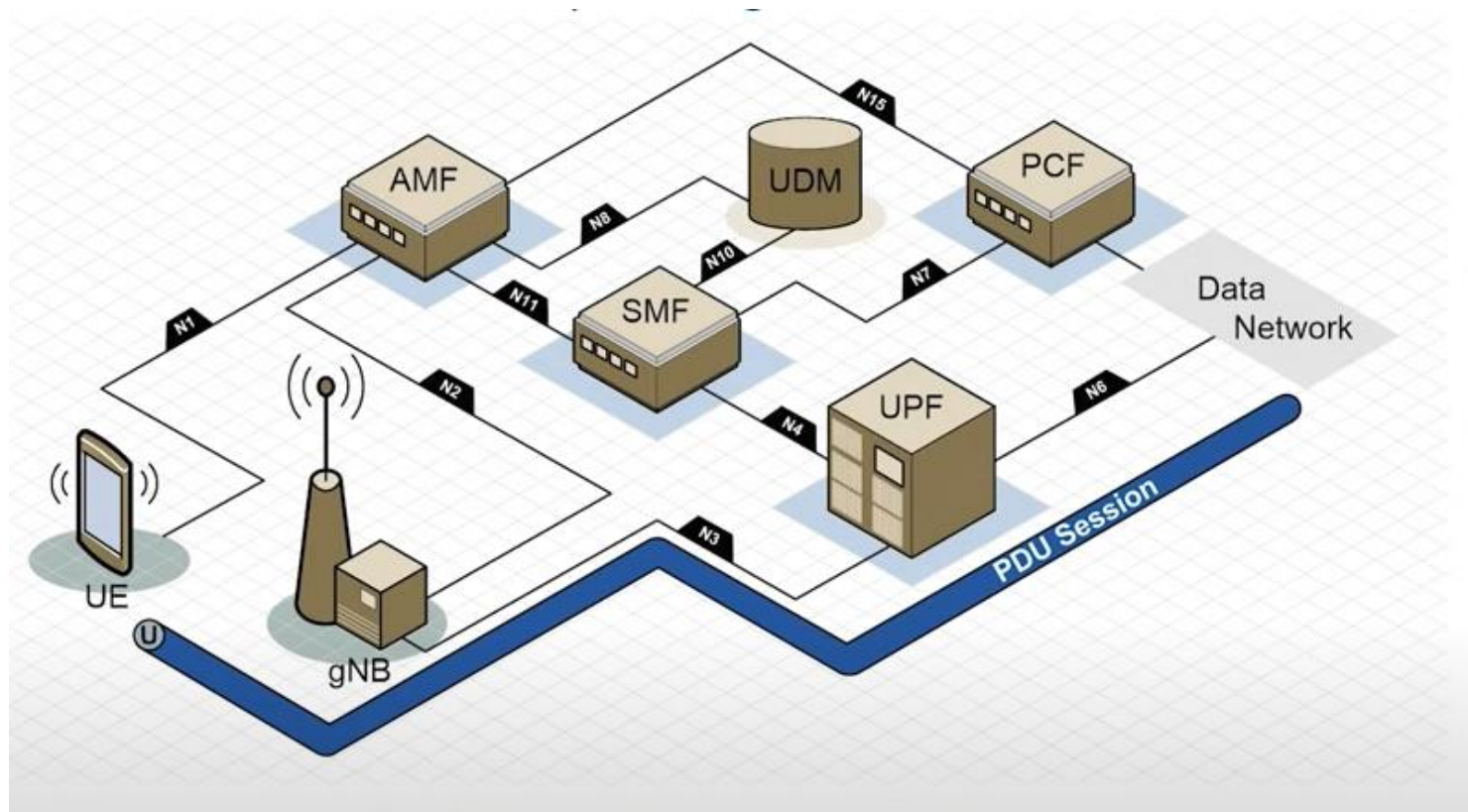
\* GBR, non-GBR or delay critical GBR.

# User Plane Function

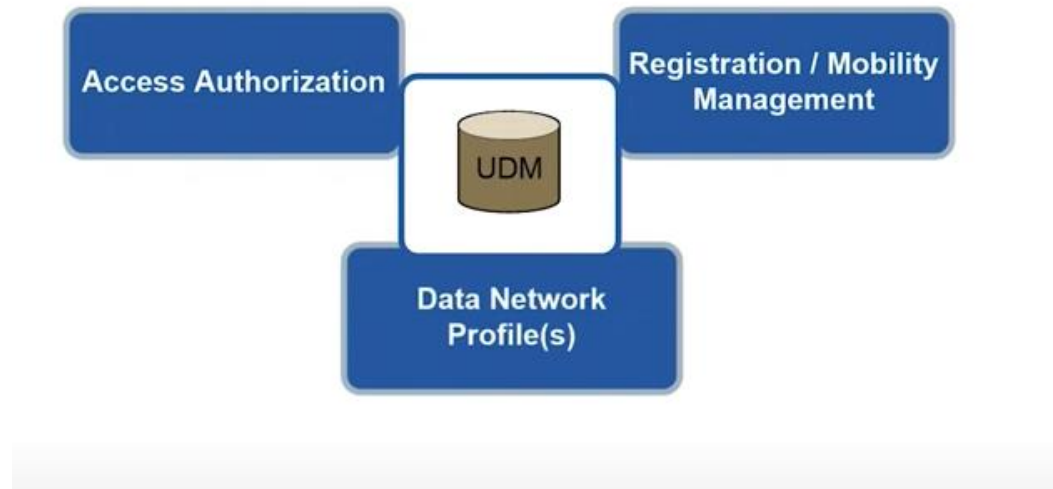




# General 5G architecture



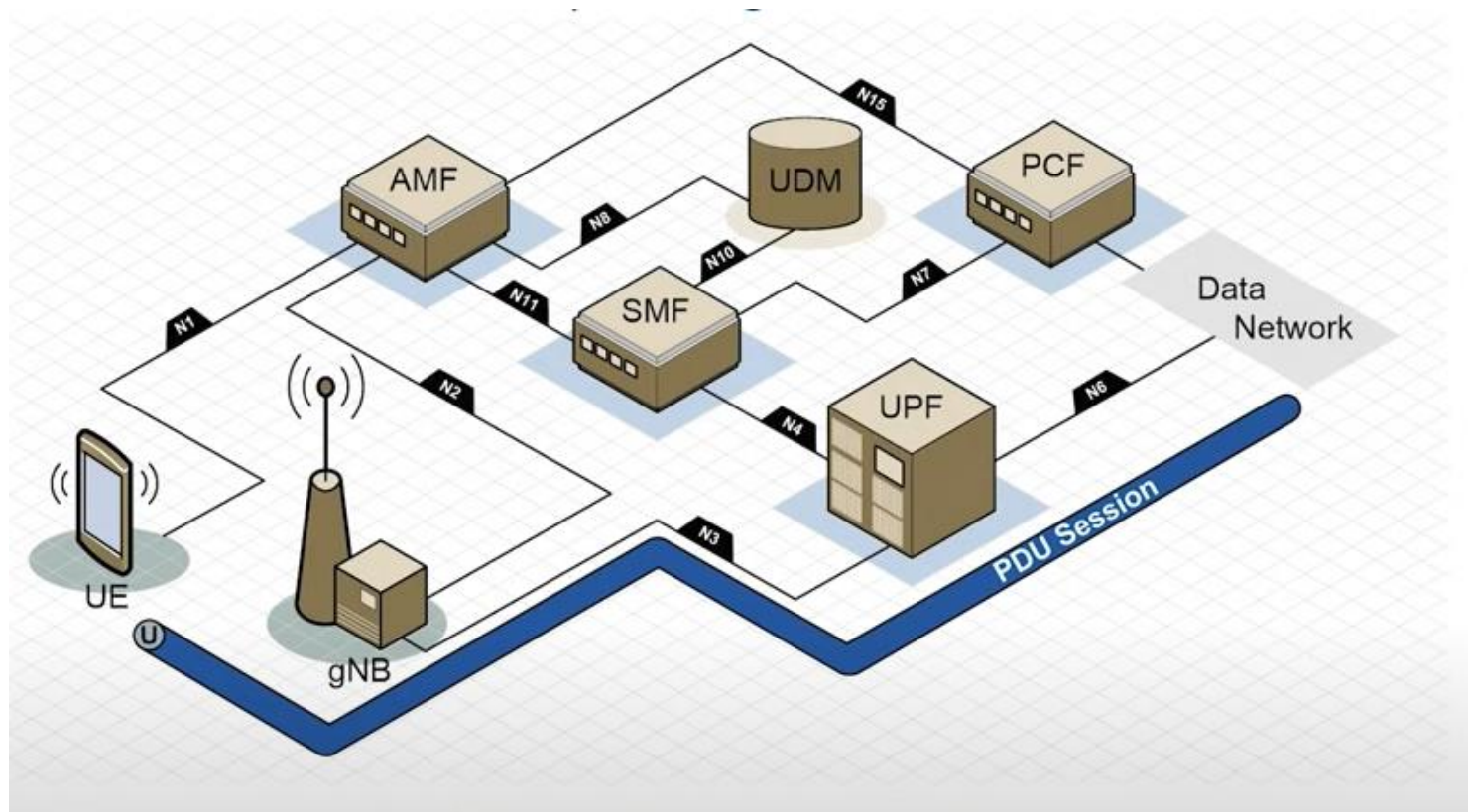
# Unified Data Management



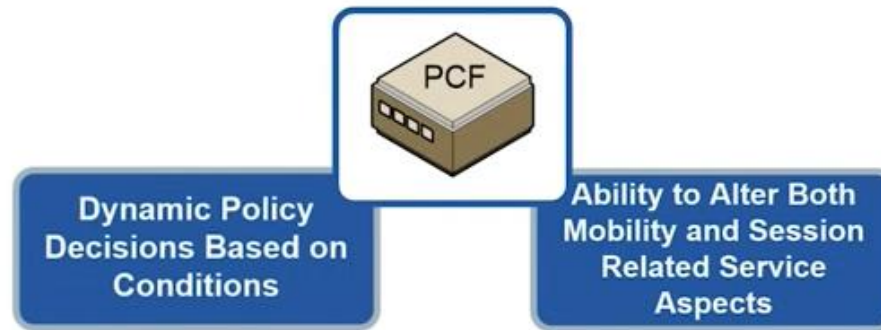
- Central repository of subscriber information
- Access authorization
- Tracking information
- Data network profile (what the user can and cannot do)



# General 5G architecture



# Policy Control Function



- Knowledge of network conditions
- Real time decisions based on these conditions
- May deny or alter service if conditions do not allow
- Information from the Data Network (external) as well