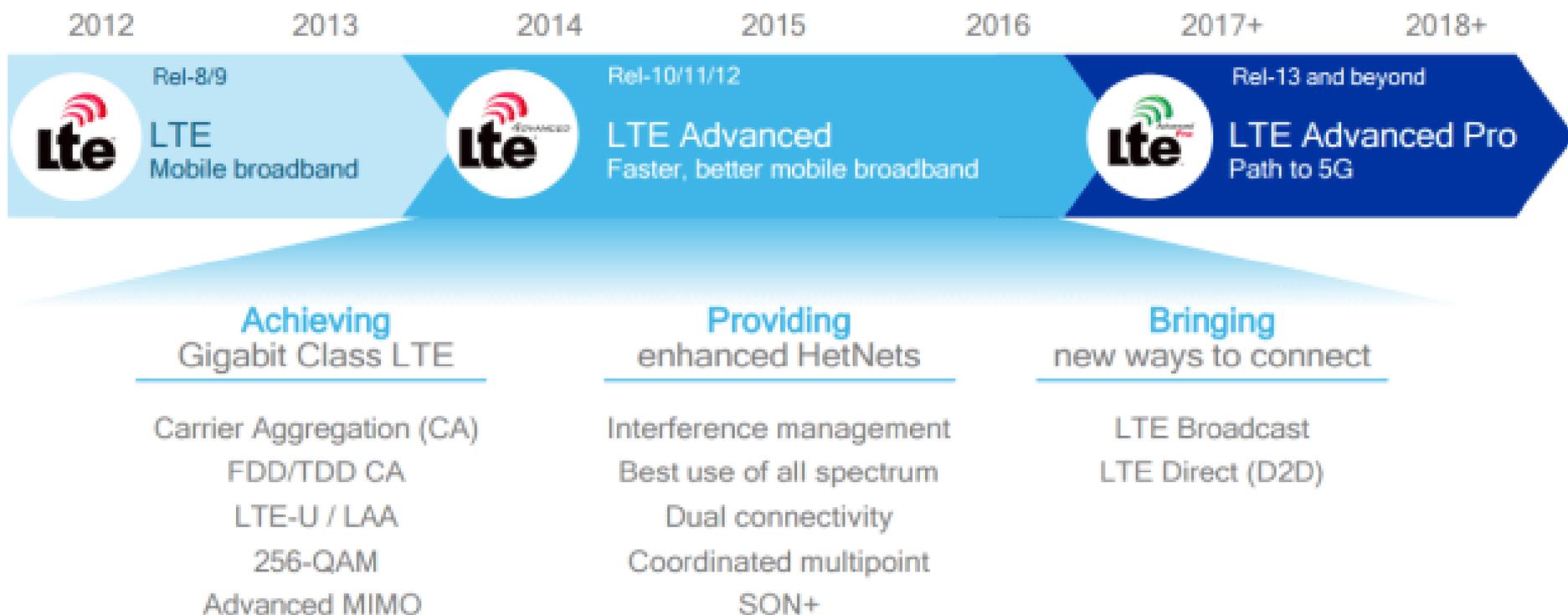




5G Mobile Communication System

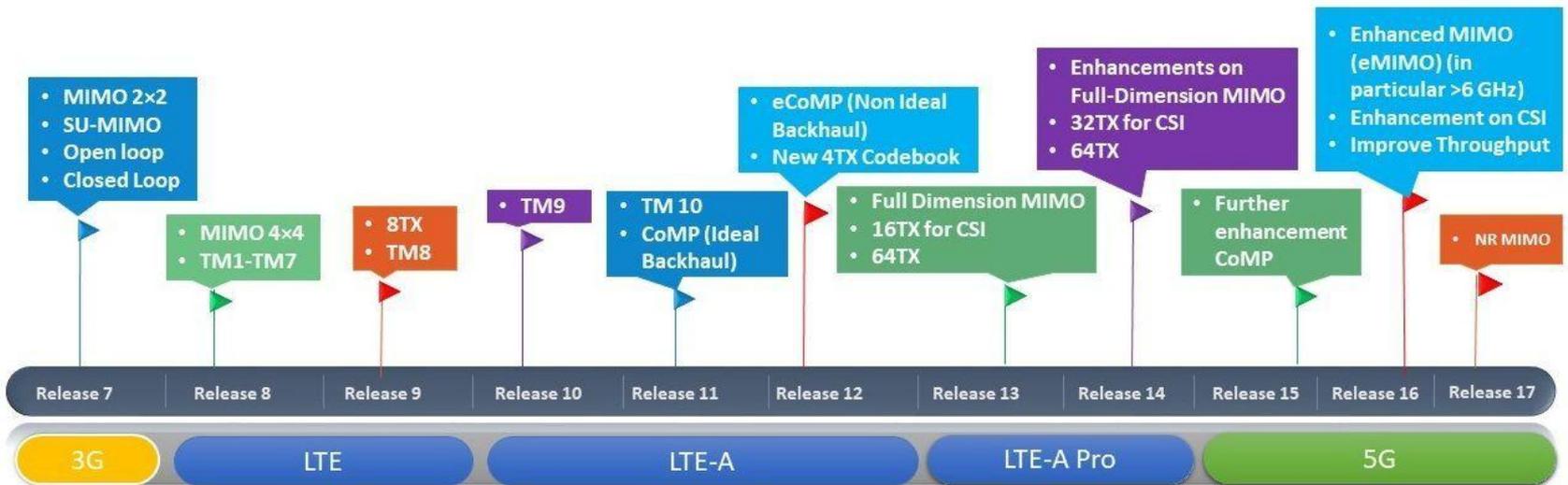
LTE Advanced: part of a rich roadmap of LTE technologies



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)

5G specifications



Release 13 Features

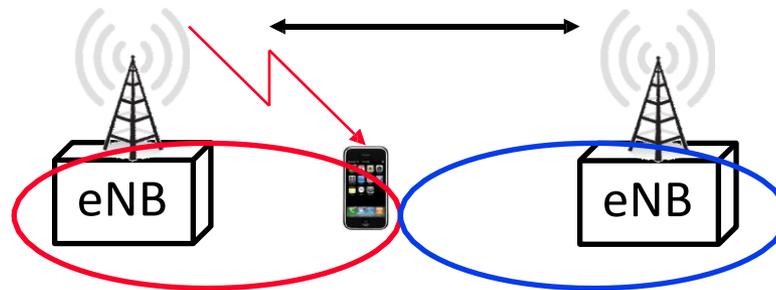
1. Active Antenna Systems (AAS)
2. Self-Organizing Networks (SON)
3. Elevation Beamforming
4. Inter-eNB CoMP
5. Indoor Positioning
6. Carrier Aggregation Enhancements
7. License Assisted Access (LAA)
8. LTE-WLAN Aggregation Enhancements
9. Wi-Fi with IP Flow Mobility
10. RAN Sharing
11. Enhanced D2D 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

Inter-eNB CoMP

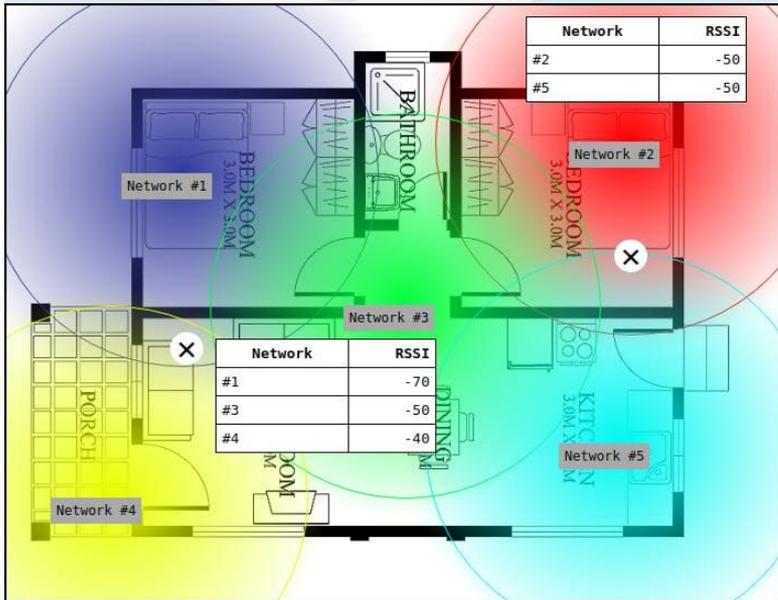
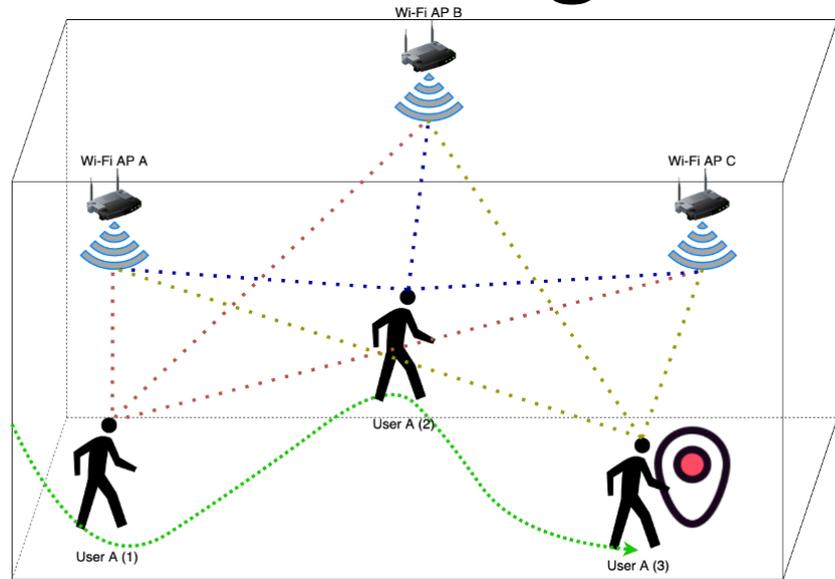
- ❑ Coordinated Multipoint Operation (CoMP) in Release 11 was restricted to eNBs connected **via ideal backhaul**
 - No need for network interfaces
- ❑ In Release 12, a signaling interface has been added which allows eNBs to interchange measurement and resource allocation information
- ❑ In Release 13,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

Indoor Positioning



Received Signal Strength Indicator (RSSI): This method calculates distances between the device and access points according to received signal strength.

Fingerprinting: Collects data about the signal's characteristics (RSSI values from multiple access points) at known reference points during a calibration phase.

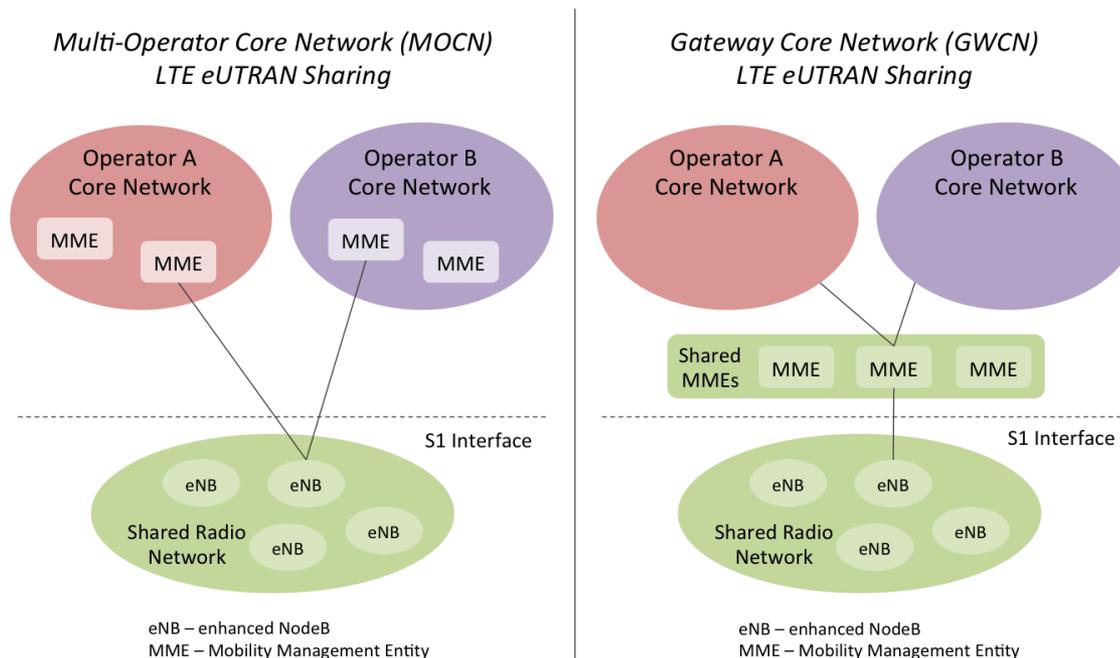
Time of Flight (ToF) and Round Trip Time (RTT): More advanced systems measure the time it takes for Wi-Fi signals to travel from the device to the access point and back.

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

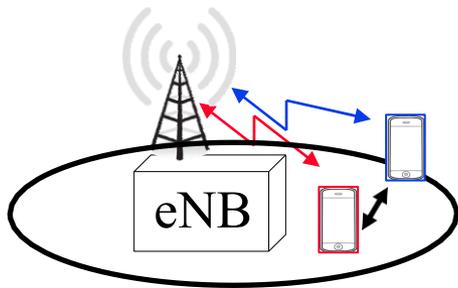
RAN Sharing

- 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

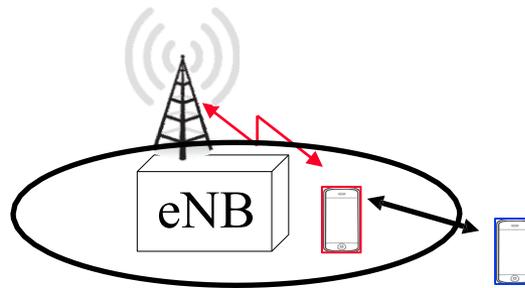


Enhanced D2D Proximity Services (PROSE)

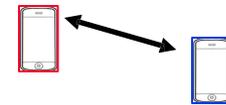
- ❑ Device-to-Device (D2D) was introduced in R12
- ❑ In R13:
 - ❑ UEs can communicate directly coordinated by eNB
 - ❑ Support for relaying using D2D
 - ❑ Out-of-coverage D2D discovery



(a)

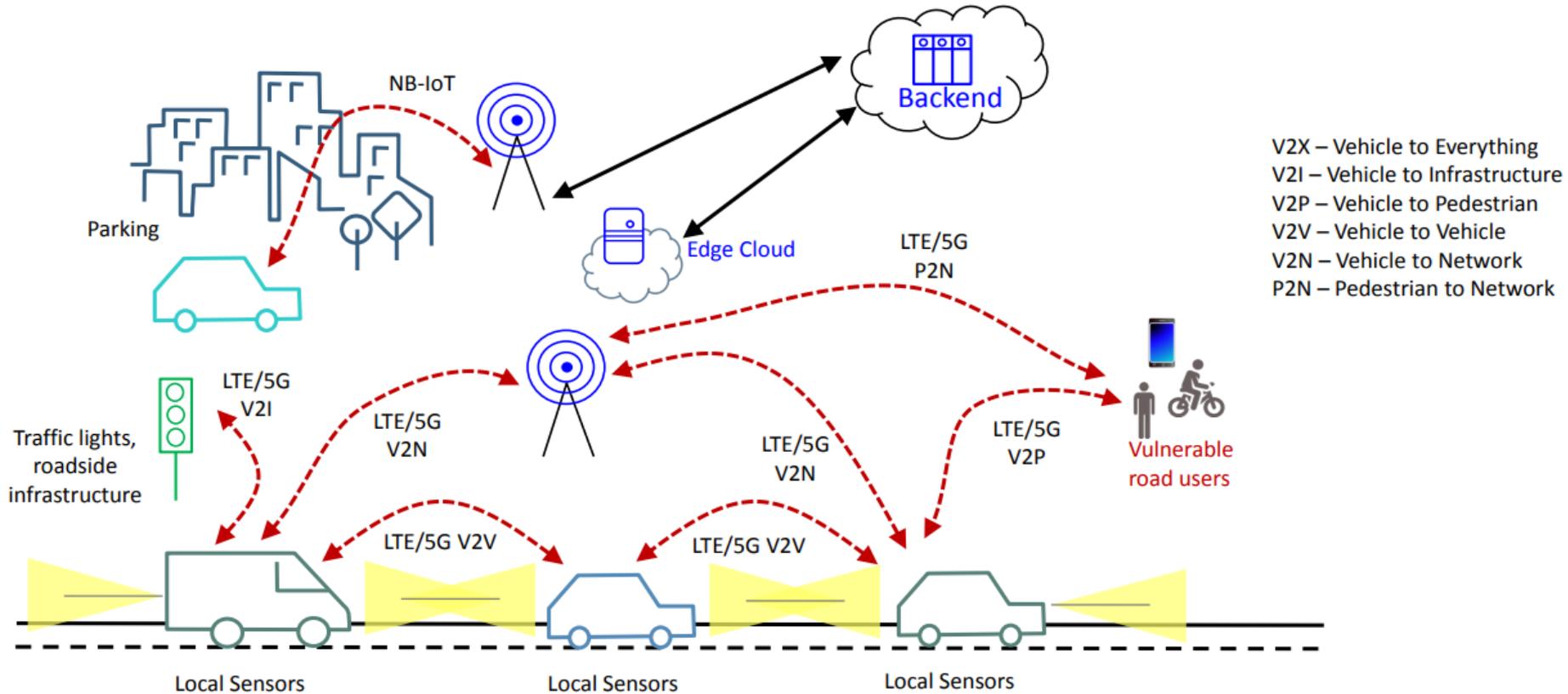


(b)



(c)

Cellular Vehicle-to-X (C-V2X)



4G Evolution



3.9G? 4G?

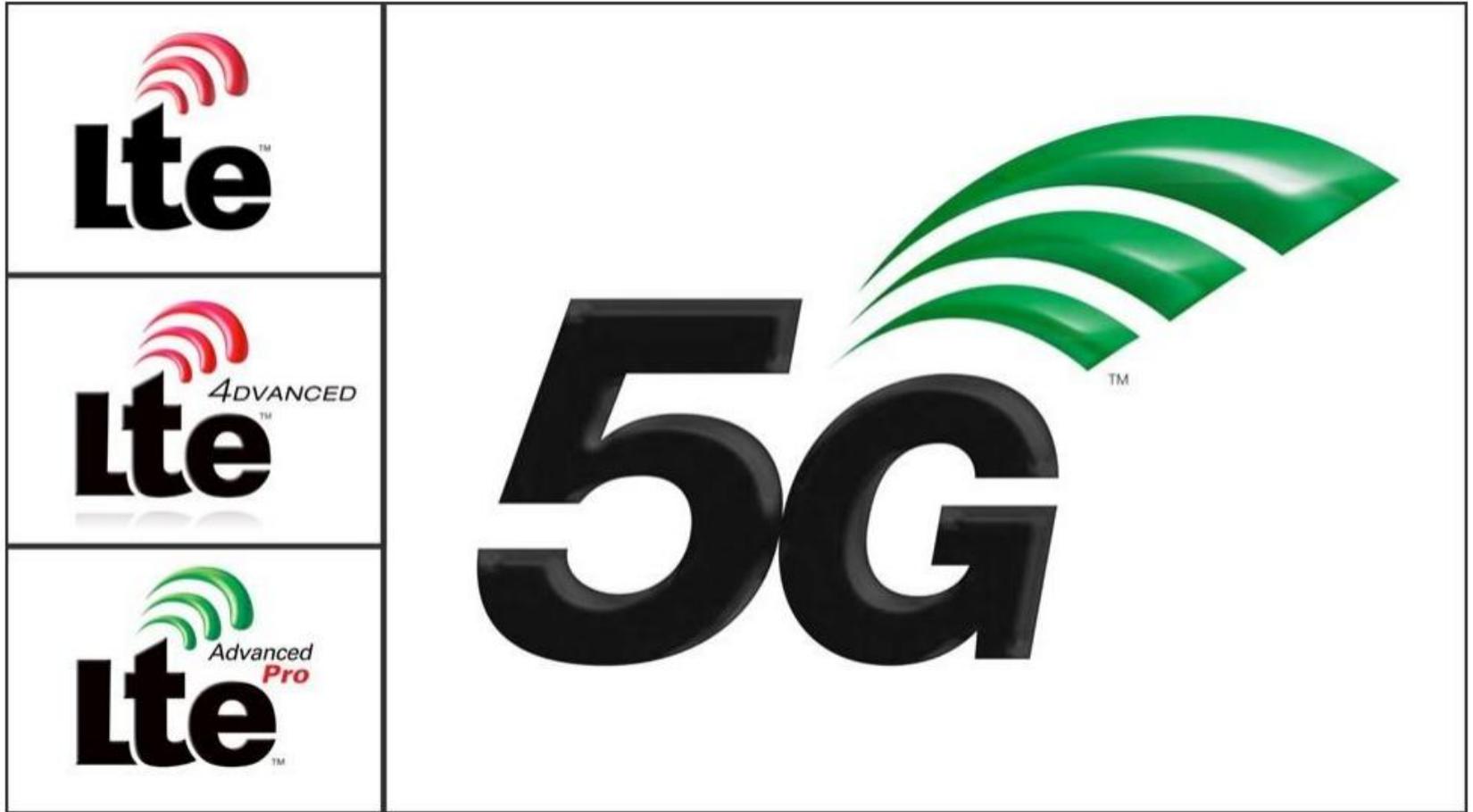


4G? 4G+? Advanced 4G?
4.5G?



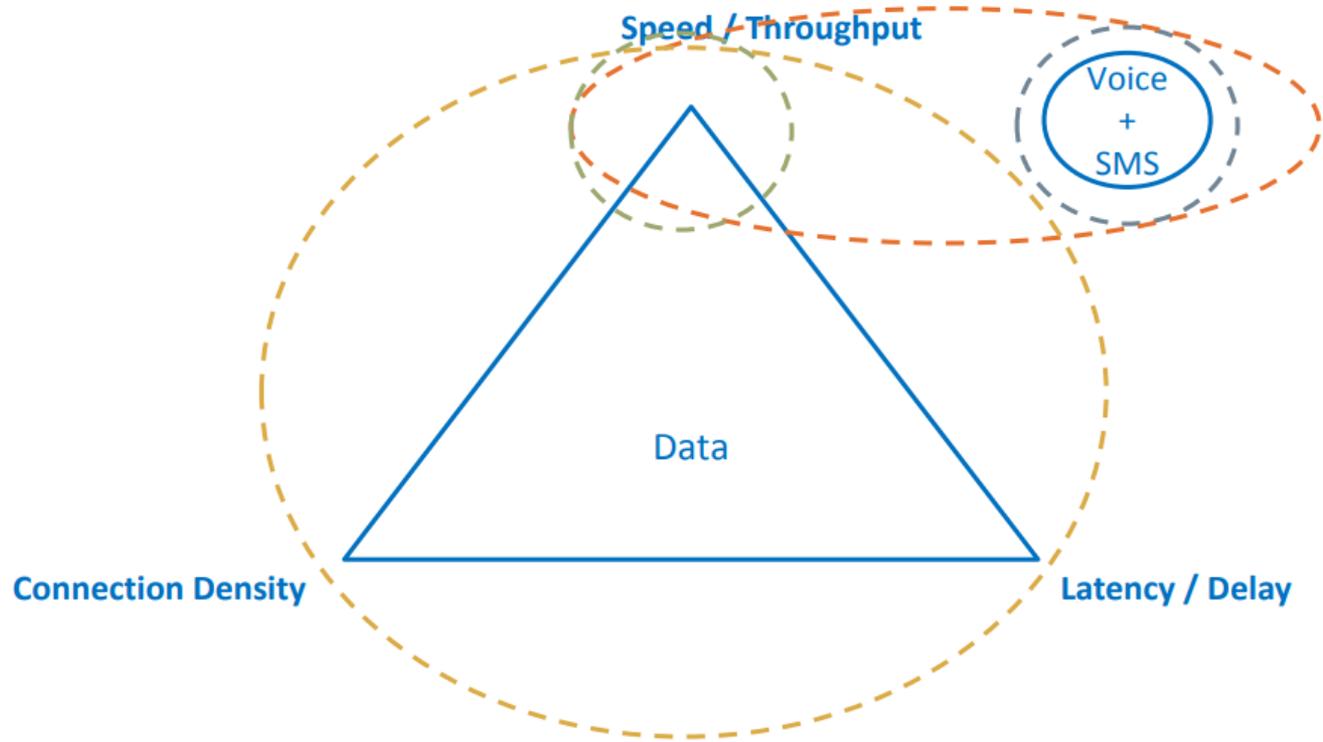
4.5G? 4.9G? 5G?

5G → IMT-2020

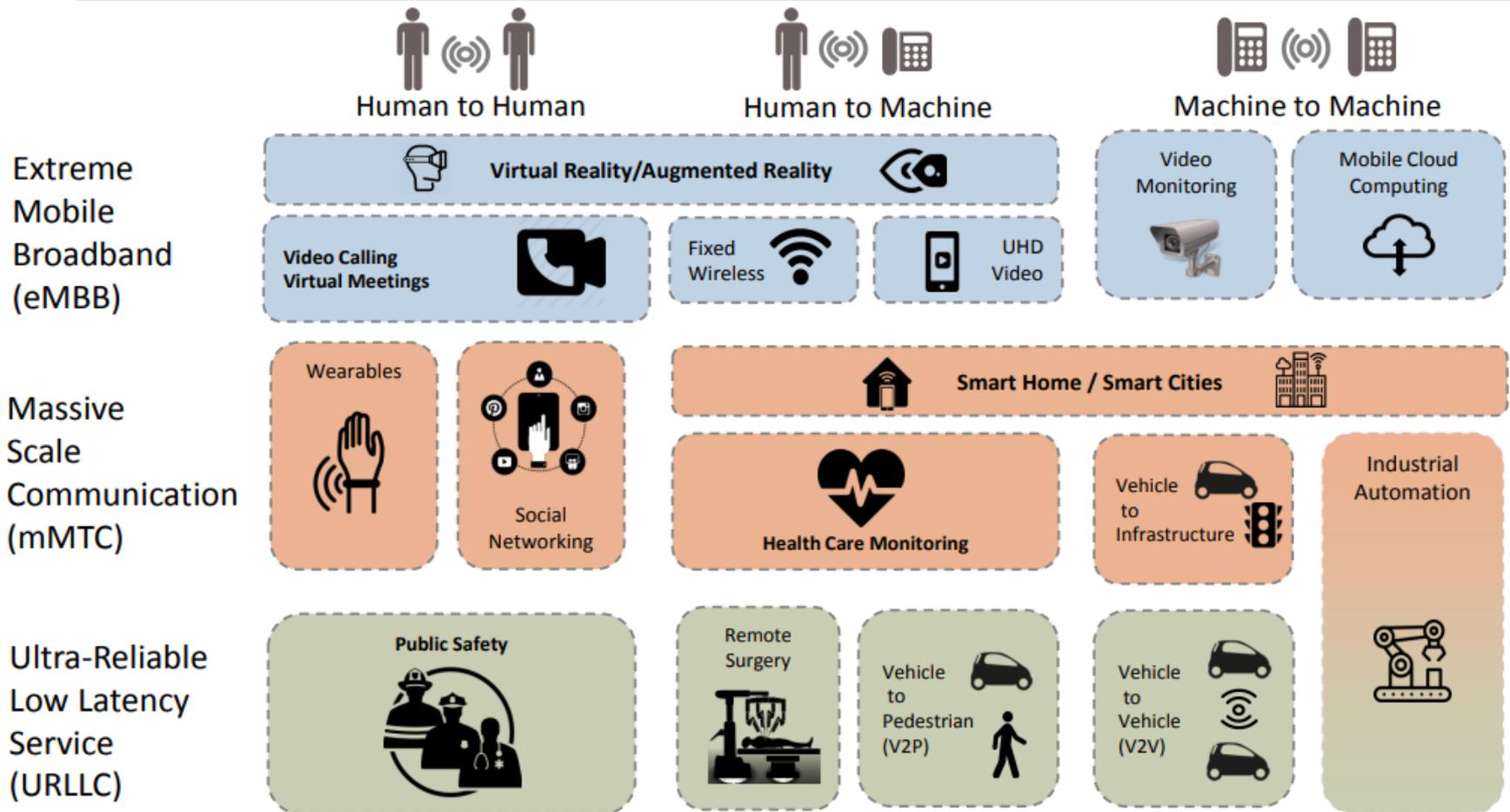


Focus area for different technology generations

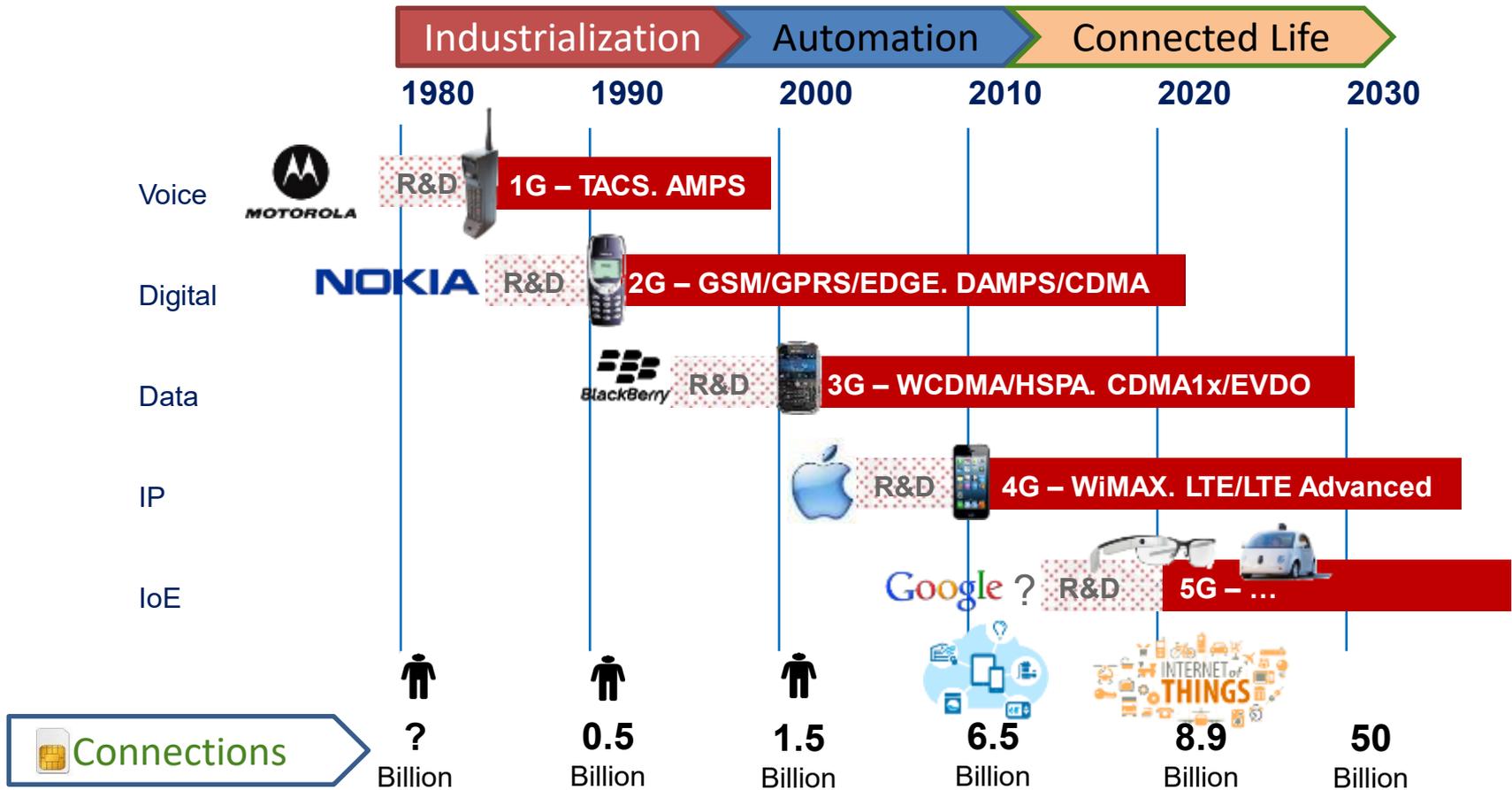
- 2G Focus area
- 3G Focus area
- 4G Focus area
- 5G Focus area



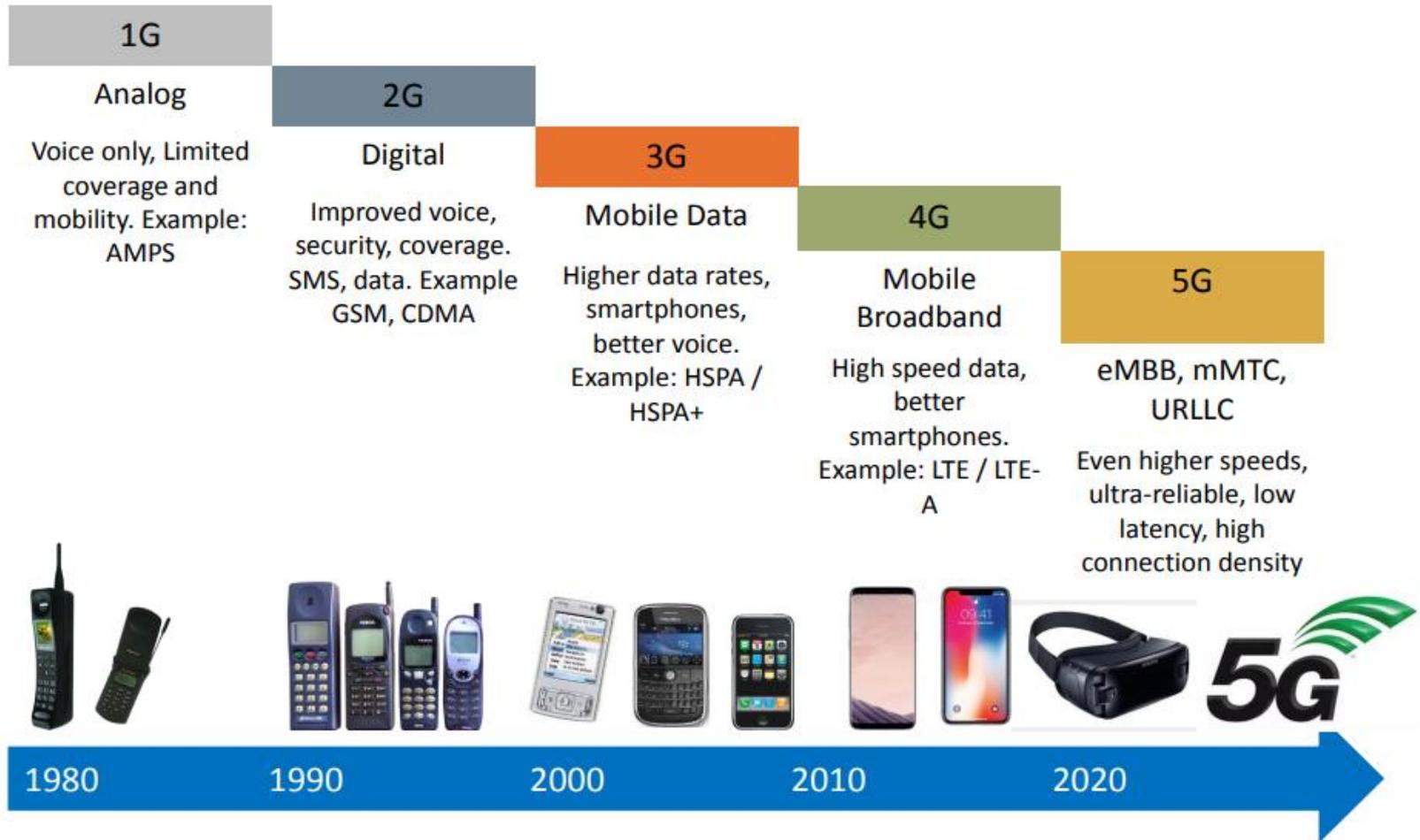
Summary of 5G Use Cases



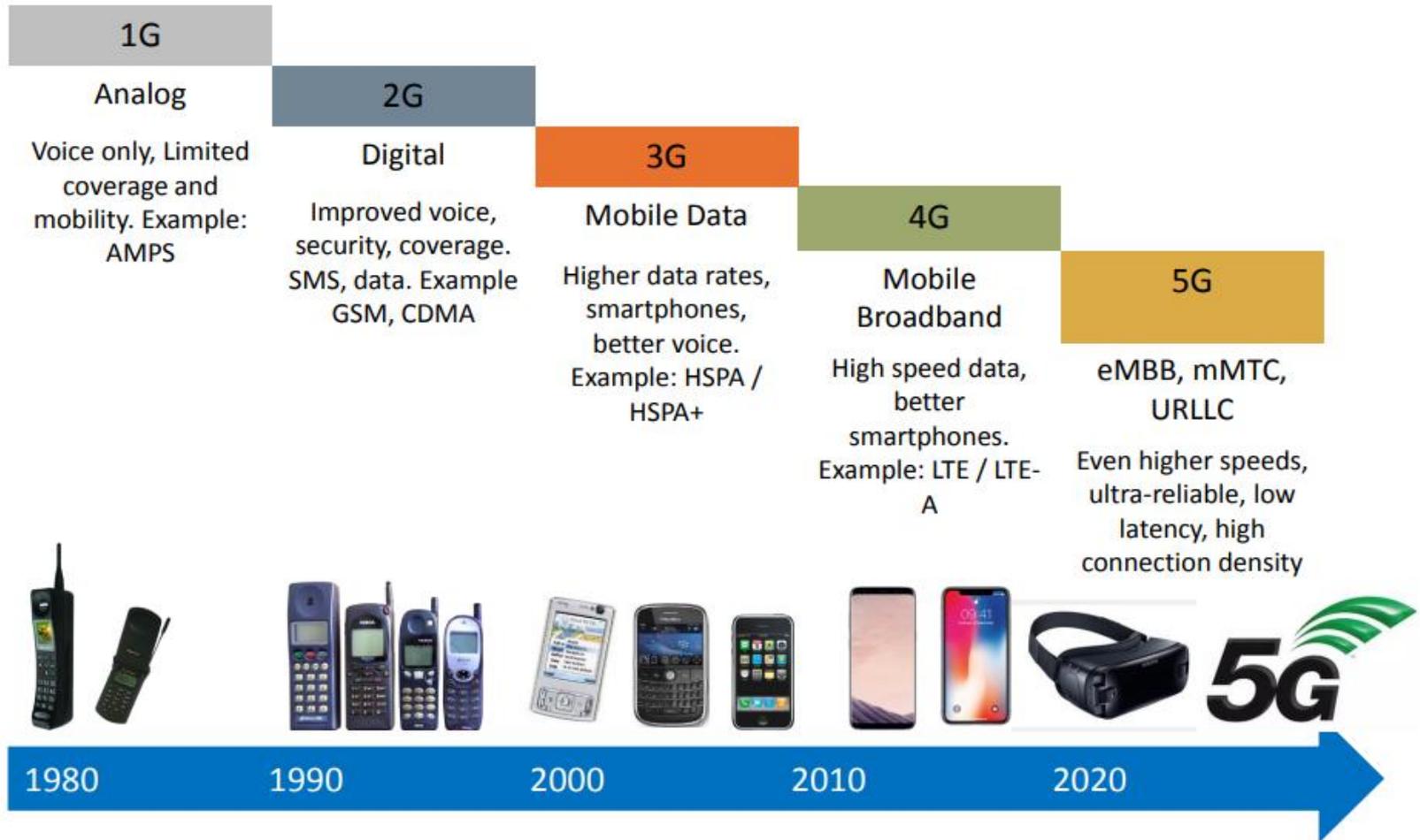
Evolution of mobile communications



Evolution of mobile communications



Evolution of mobile communications



5G Spectrum



Multiple layer for multiple needs

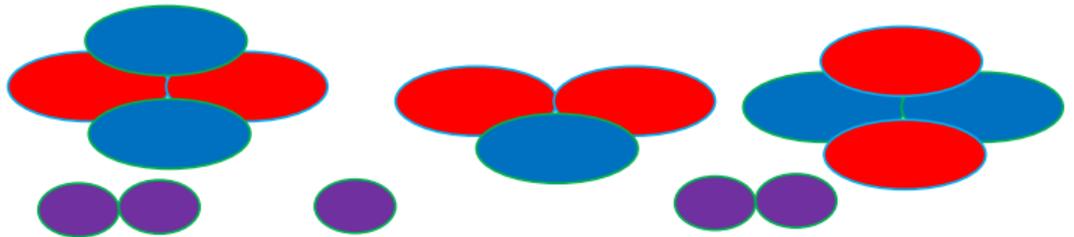
Coverage Layer
Sub-1GHz



Capacity Layer
1GHz – 6GHz

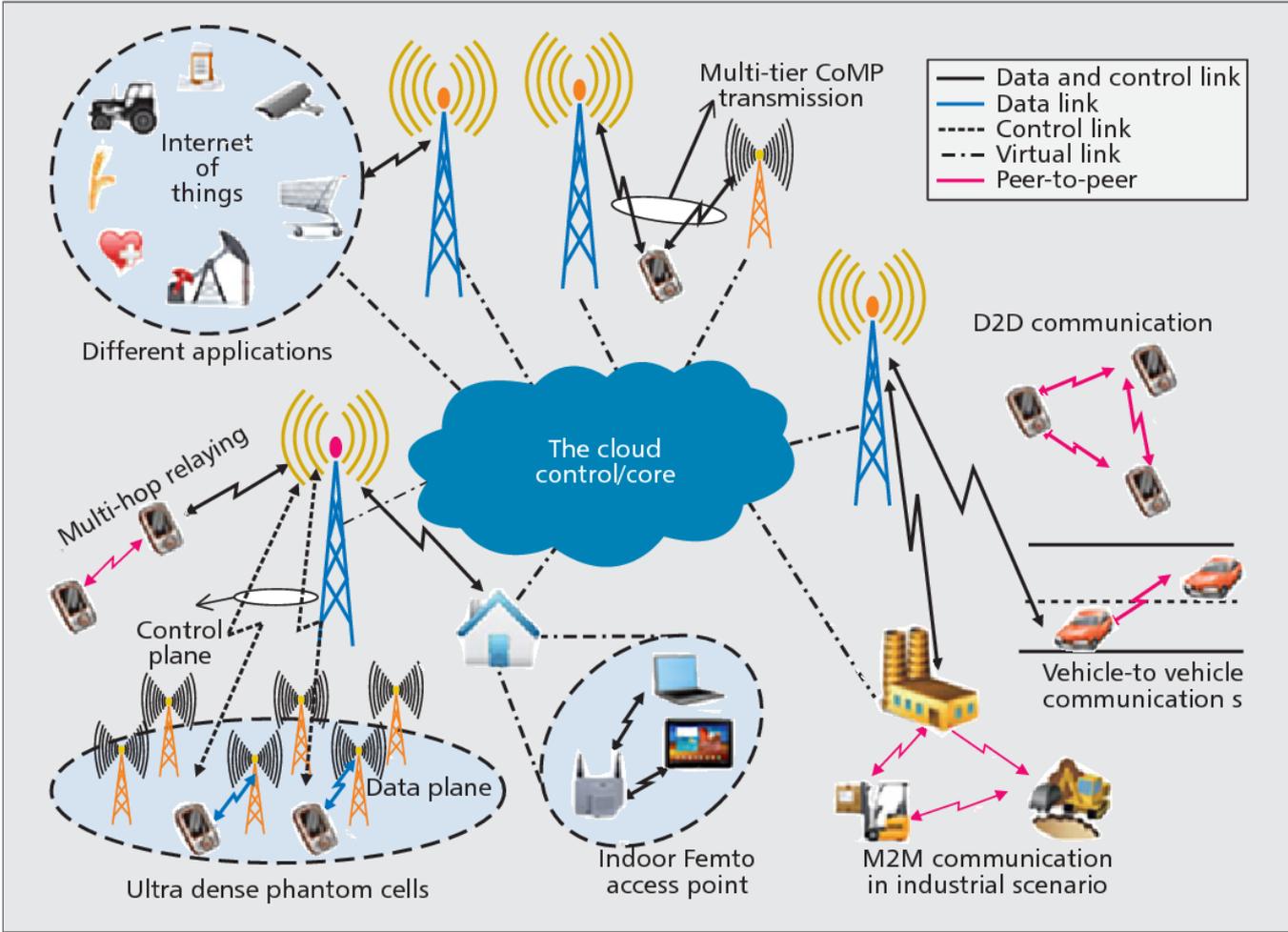


High Throughput Layers
6GHz – 100GHz



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

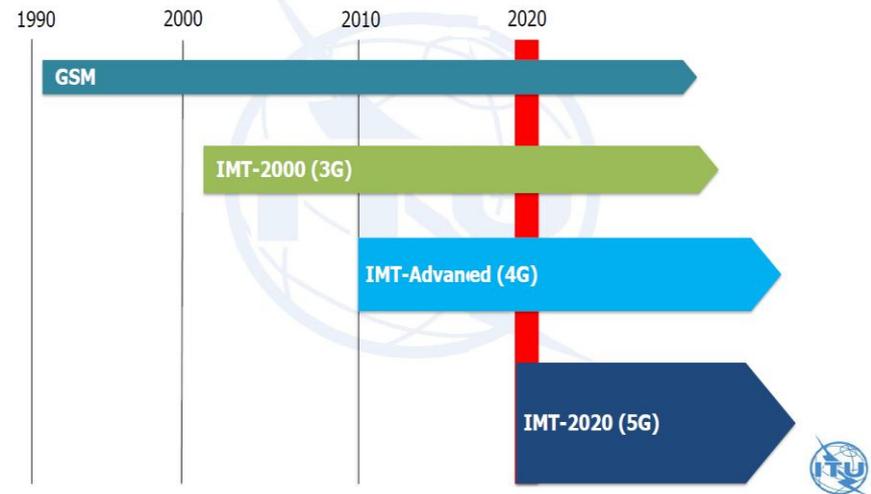
Technologies include:

- 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



IMT requirements comparison

	Rec. ITU-R M.1645 (IMT-2000/IMT-Advanced)	Rep. ITU-R M.2134 (IMT-Advanced)	Rec. on Vision (IMT-2020)
Year of approval	2003	2008	2015
Mobile terminal mobility	250 km/h	350 km/h	500 km/h
Peak transmission rate	0.1–1 Gbit/s	1 Gbit/s	20 Gbit/s
User throughput	–	10 Mbit/s	0.1–1 Gbit/s
Mobile terminal density	–	$10^5/\text{km}^2$	$10^6/\text{km}^2$
Radio link latency	–	10 ms	1 ms
Power efficiency (/bit)	–	–	100 times that of IMT-Advanced
Spectrum use efficiency	–	–	2–5 times that of IMT-Advanced
Area traffic capacity	–	0.1 Mbit/s/m ²	10 Mbit/s/m ²

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]

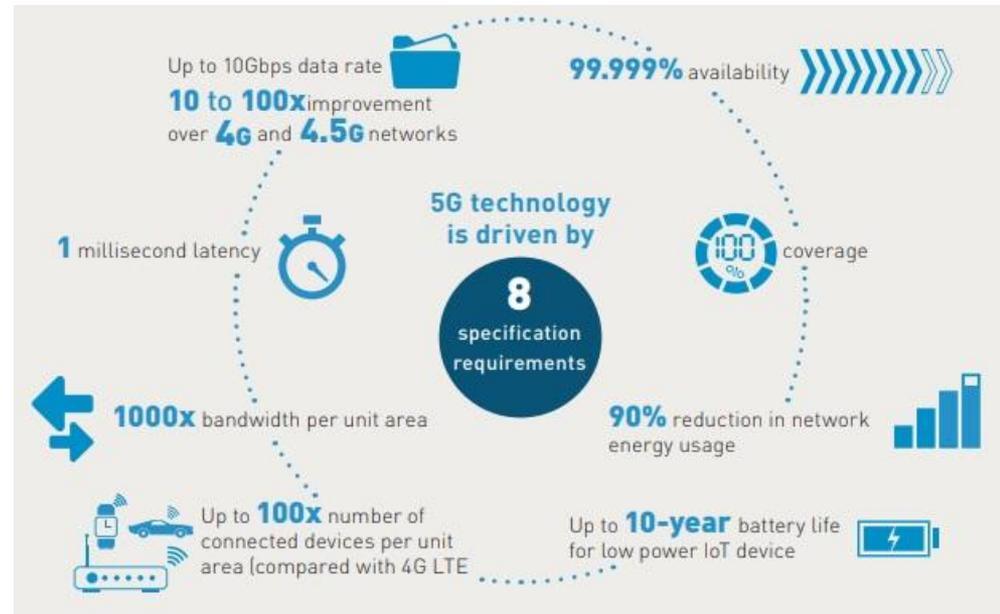
Low Latency Use Case Requirements (various sources)

- 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**

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

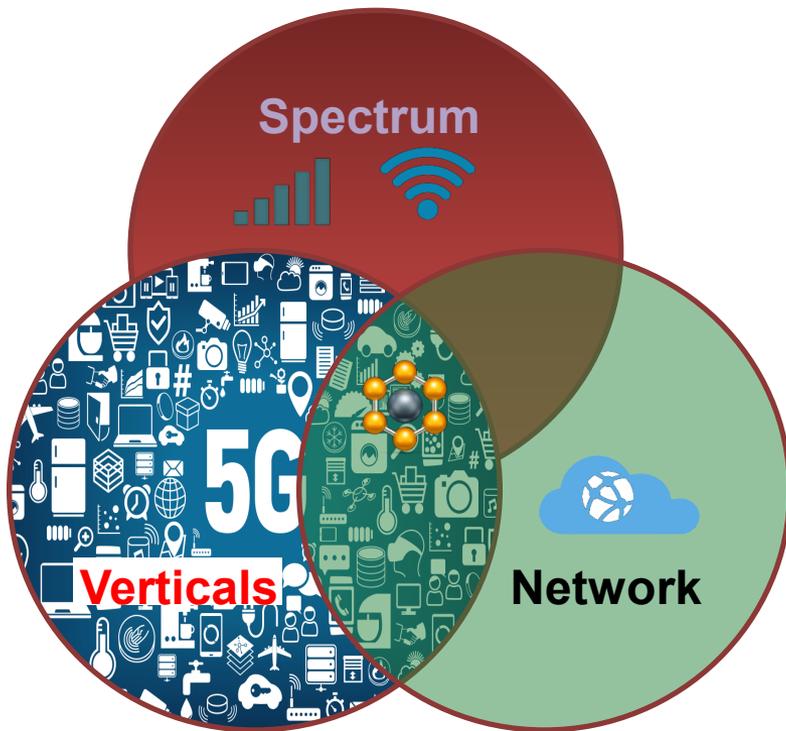
4. Mass Connectivity

5. Energy Efficiency

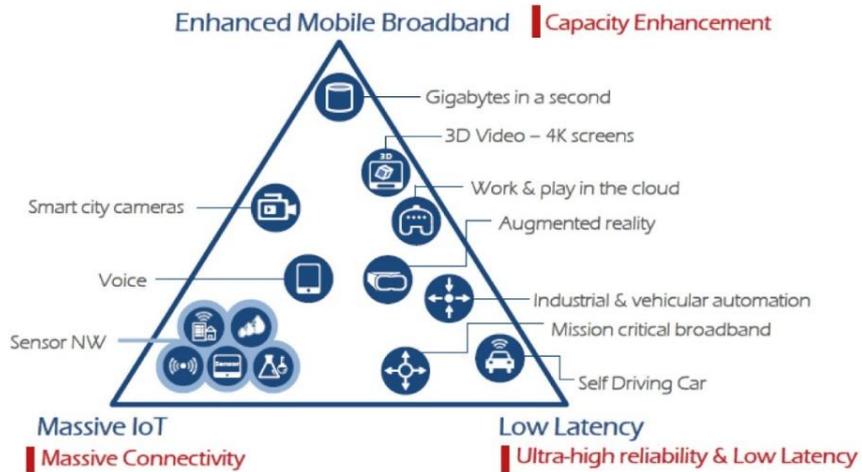
6. More Agile

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

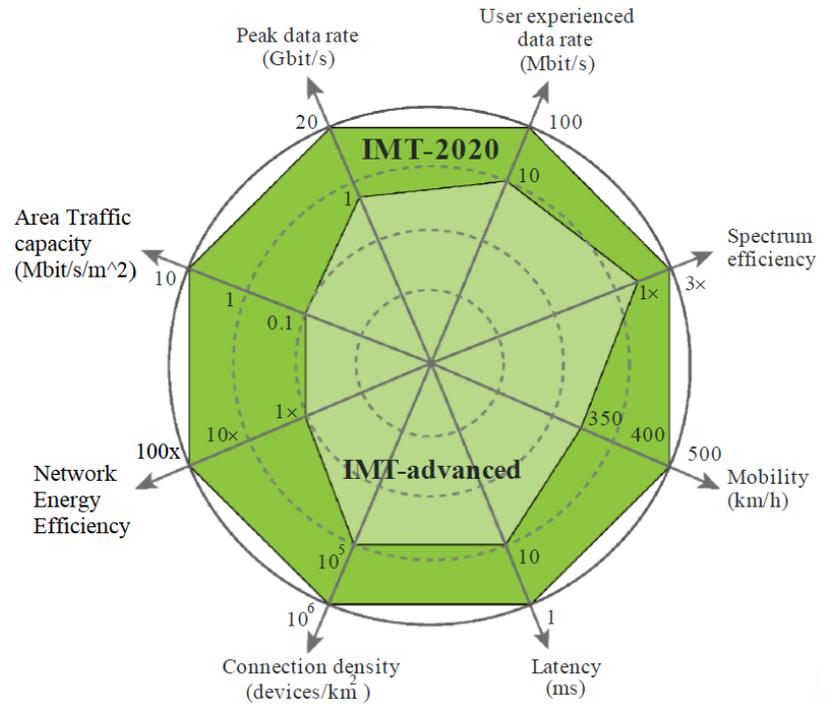
ITU IMT-2020 vision



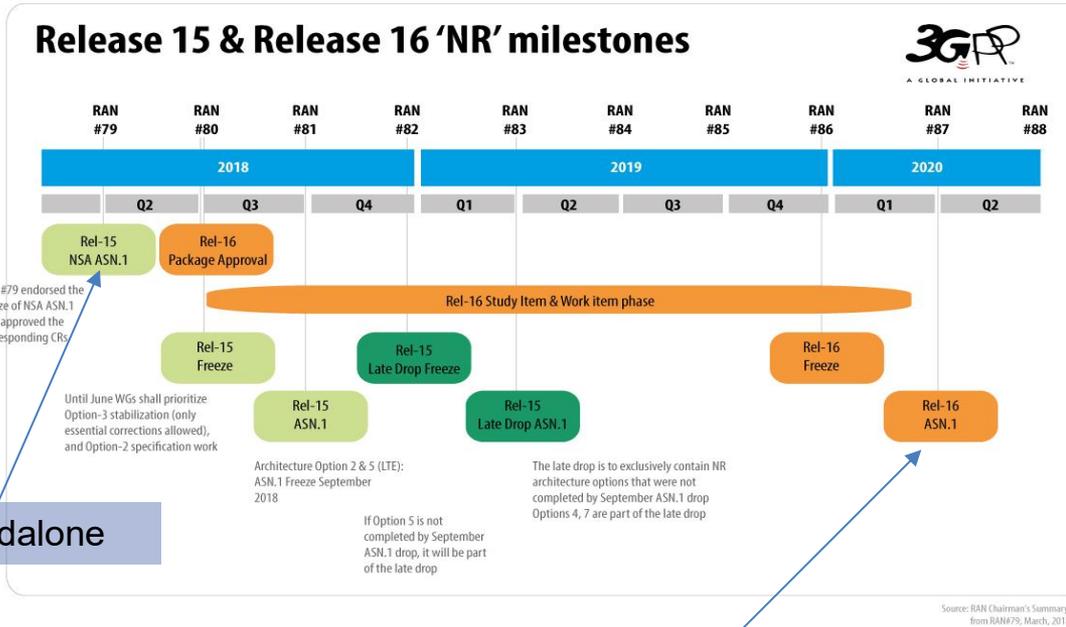
5G Performance



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



5G Standardization: 3GPP Rel.15/16

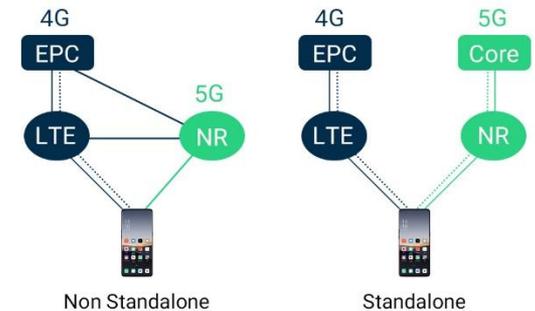


non-standalone

standalone

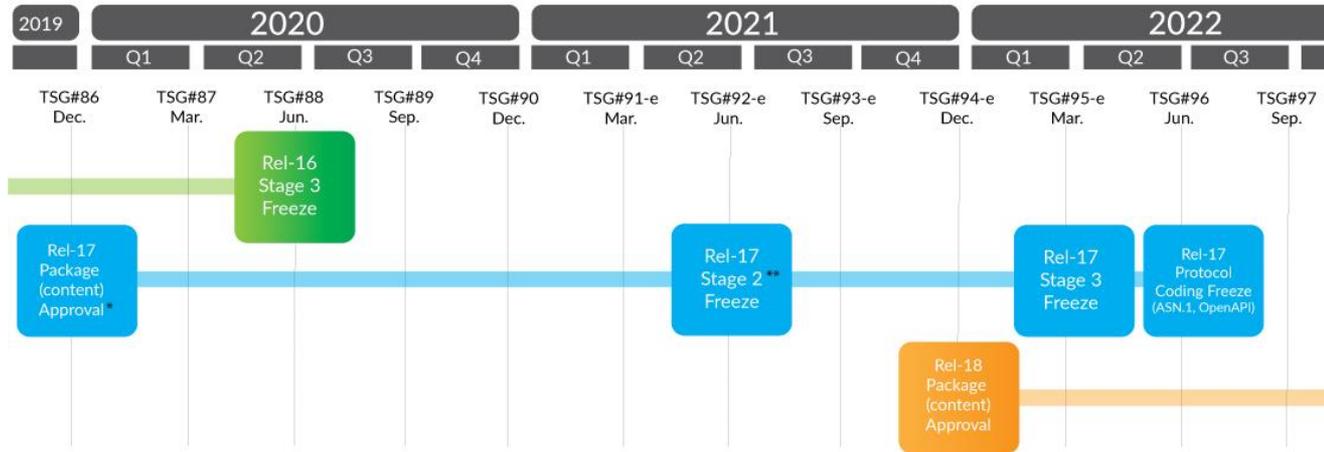
3GPP Release 15 = 5G Phase 1 – Non standalone

3GPP Release 16 = 5G Phase 2 – Standalone

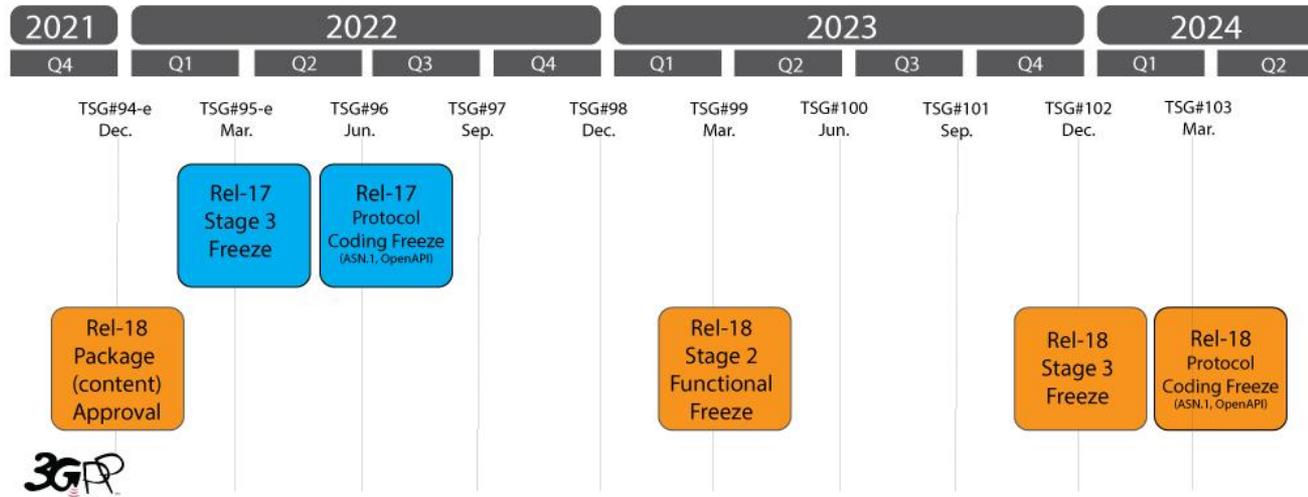


..... Control Plane ——— Data Plane

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

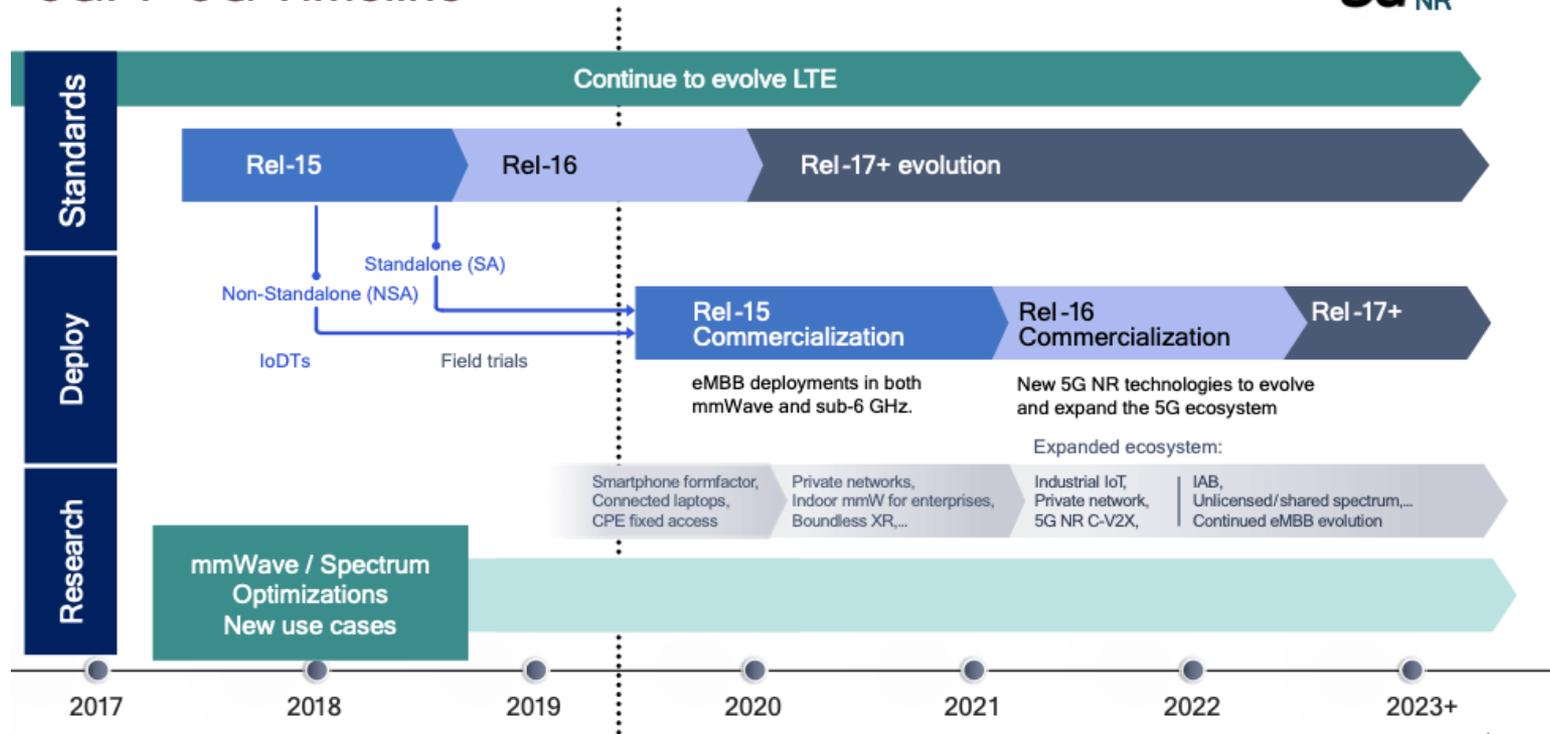


* Stage 1: WG SA1 work and "RAN content definition" completed TSG#86.
 ** Stage 2: Studies completed TSG#90, Stage 2 Normative work completed TSG#92, Stage 2 exceptions completed TSG#93



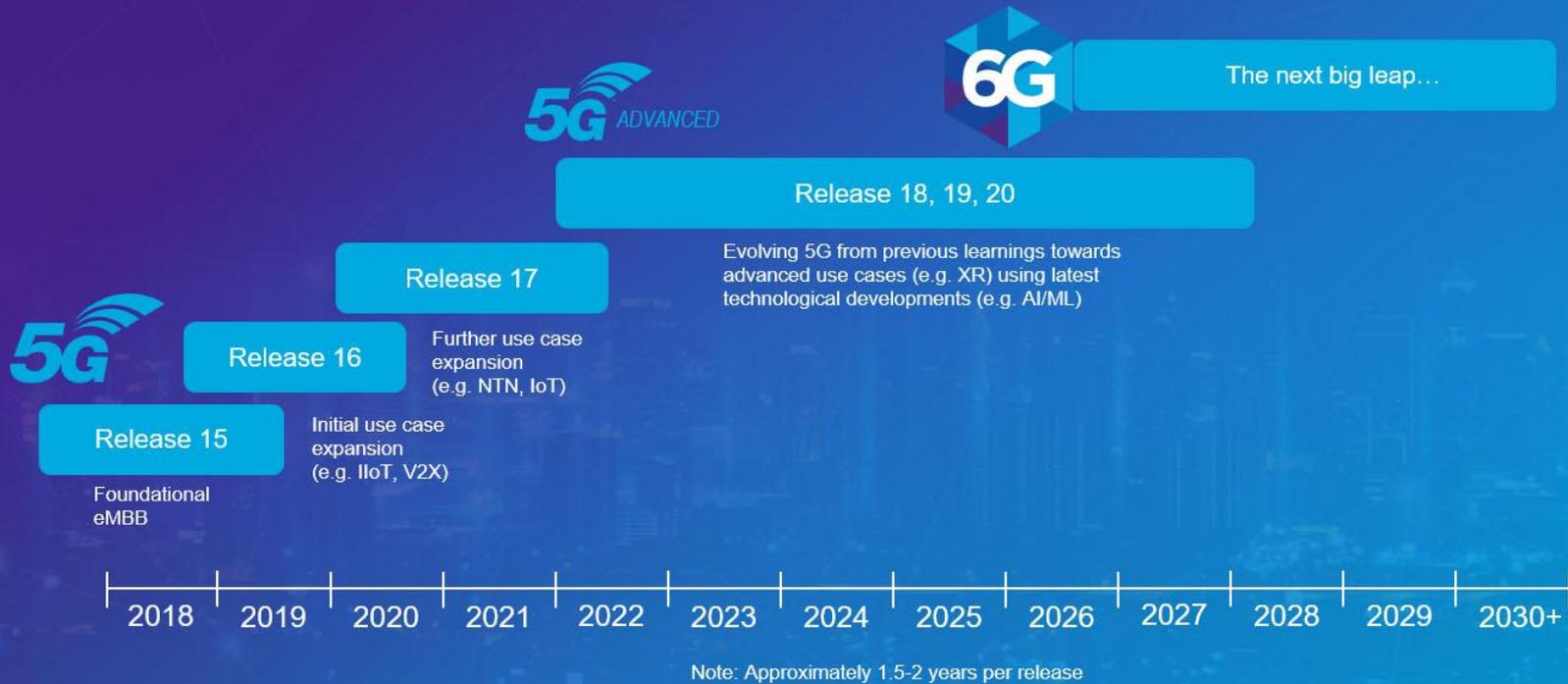
Standardization beyond 5G: 3GPP Rel.17/18

3GPP 5G Timeline



Standardization towards 6G

3GPP Evolution from 5G and Beyond



5G Verticals

FACTORIES OF THE FUTURE

- 1 Time-critical process control
- 2 Non time-critical factory automation
- 3 Remote control
- 4 Intra/Inter-enterprise communication
- 5 Connected goods

ENERGY

- 1 Grid access
- 2 Grid backhaul
- 3 Grid backbone

e-HEALTH

- 1 Assets and interventions management in Hospital
- 2 Robotics
- 3 Remote monitoring
- 4 Smarter medication

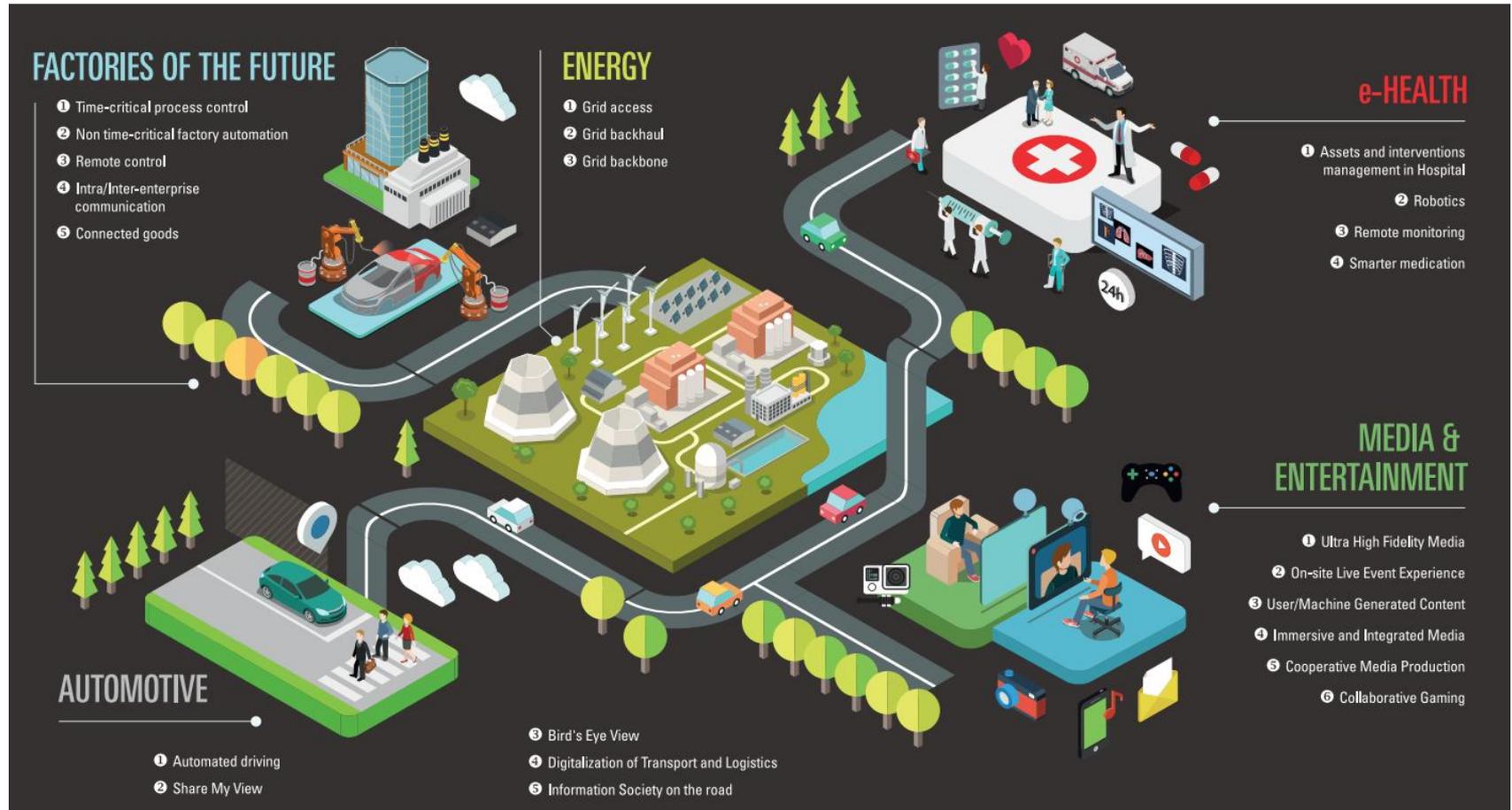
MEDIA & ENTERTAINMENT

- 1 Ultra High Fidelity Media
- 2 On-site Live Event Experience
- 3 User/Machine Generated Content
- 4 Immersive and Integrated Media
- 5 Cooperative Media Production
- 6 Collaborative Gaming

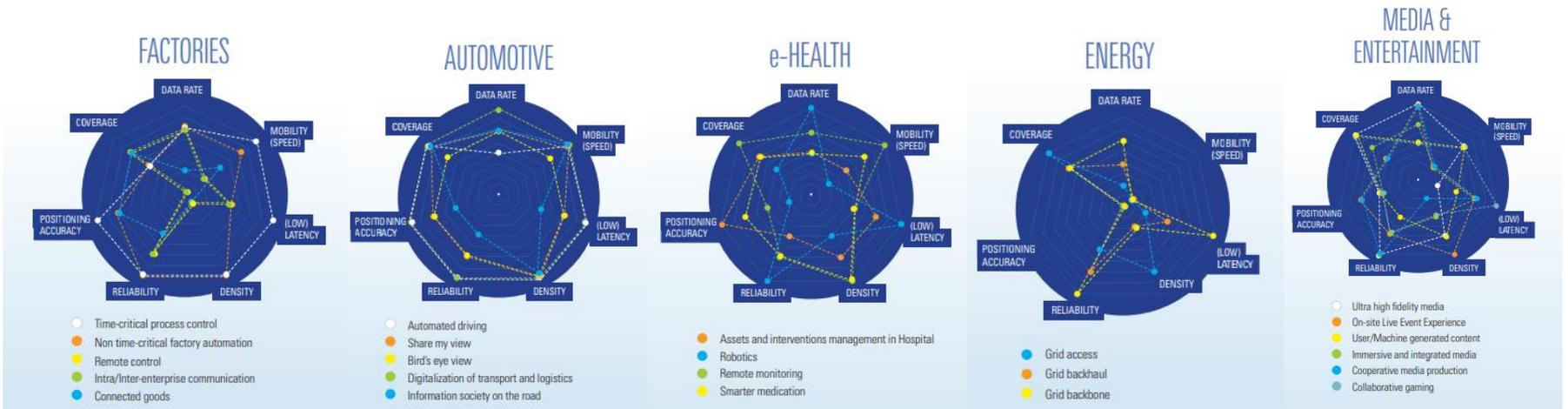
AUTOMOTIVE

- 1 Automated driving
- 2 Share My View

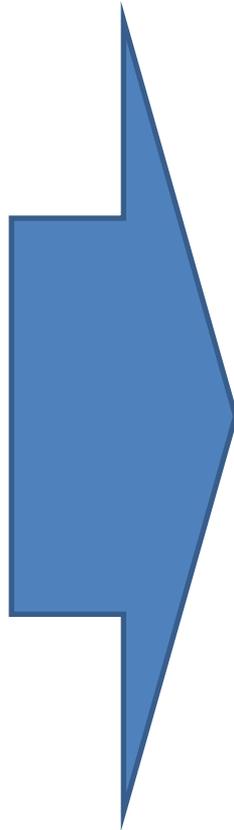
- 3 Bird's Eye View
- 4 Digitalization of Transport and Logistics
- 5 Information Society on the road



5G Verticals

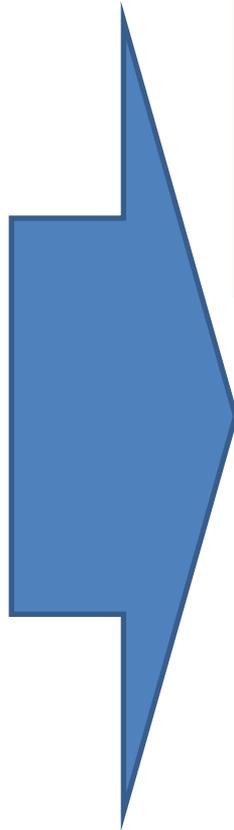


5G Advancements



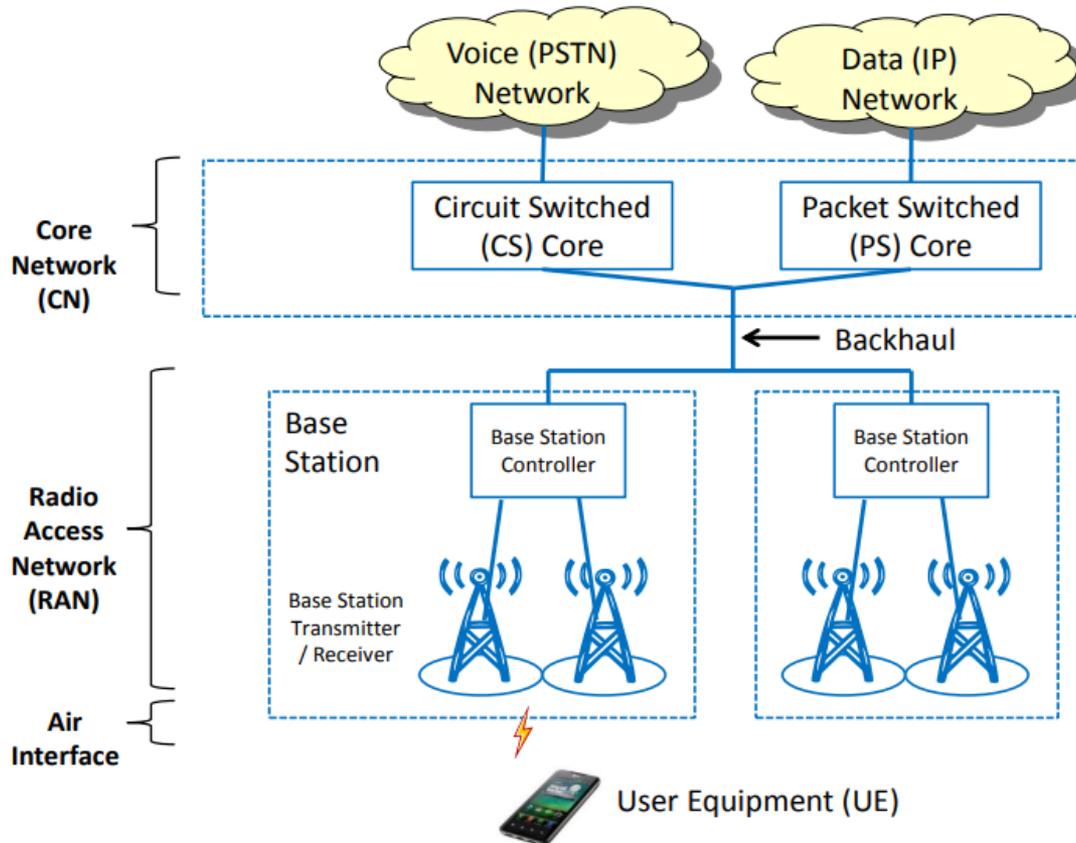
- ▶ **New Architecture**
 - ▶ Advanced core network functions / NG RAN
 - ▶ Incorporate SDN/NFV (NFV MANO)
 - ▶ Decoupling of control and data plane
 - ▶ Decoupling of functions from the hardware
- ▶ **Network Slicing**
 - ▶ eMBB, URLLC, mMTC | 8 subclasses per slice type
- ▶ **New Radio (NR)**
 - ▶ 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



- ▶ **New Architecture**
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- ▶ **Device-to-Device**
 - ▶ Allow direct communications (Public safety)

2G / 3G Mobile Network Architecture



Core Network

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

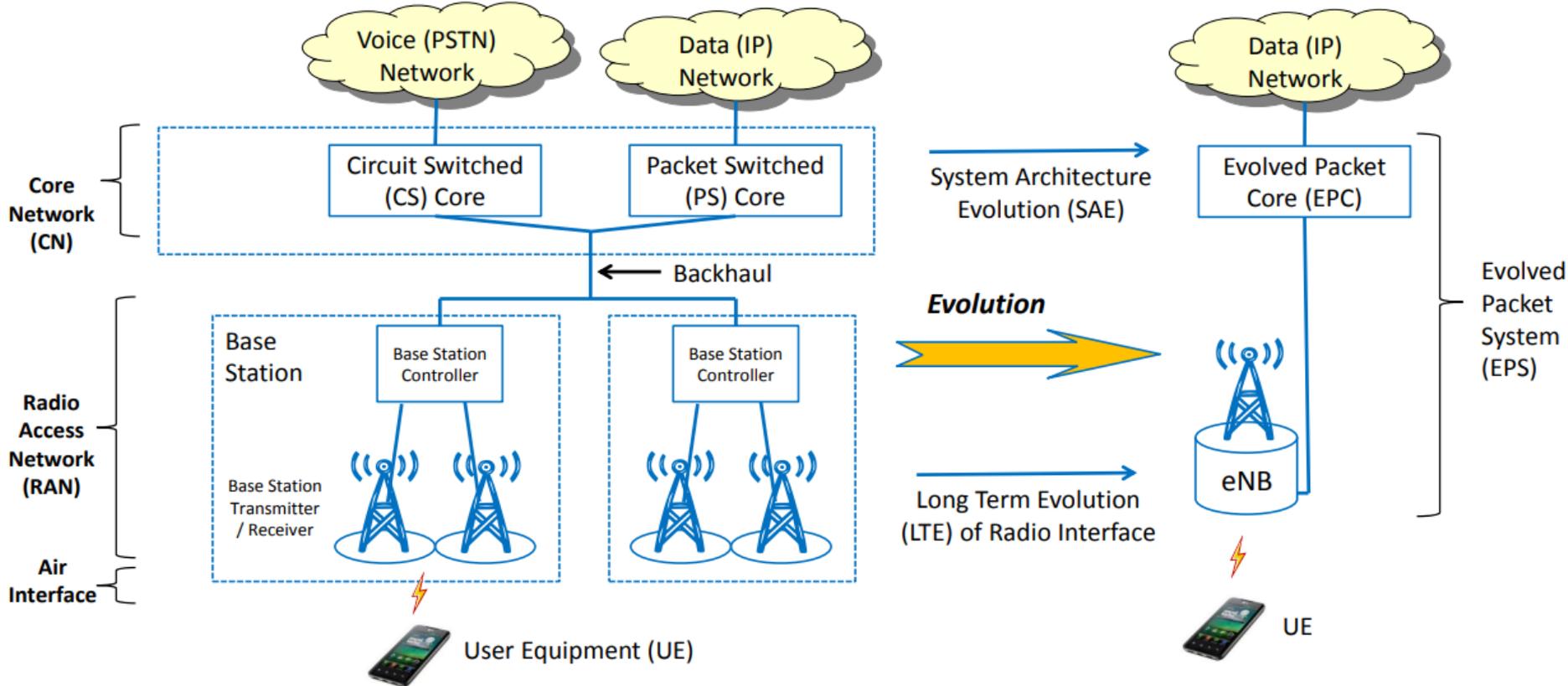
Backhaul

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

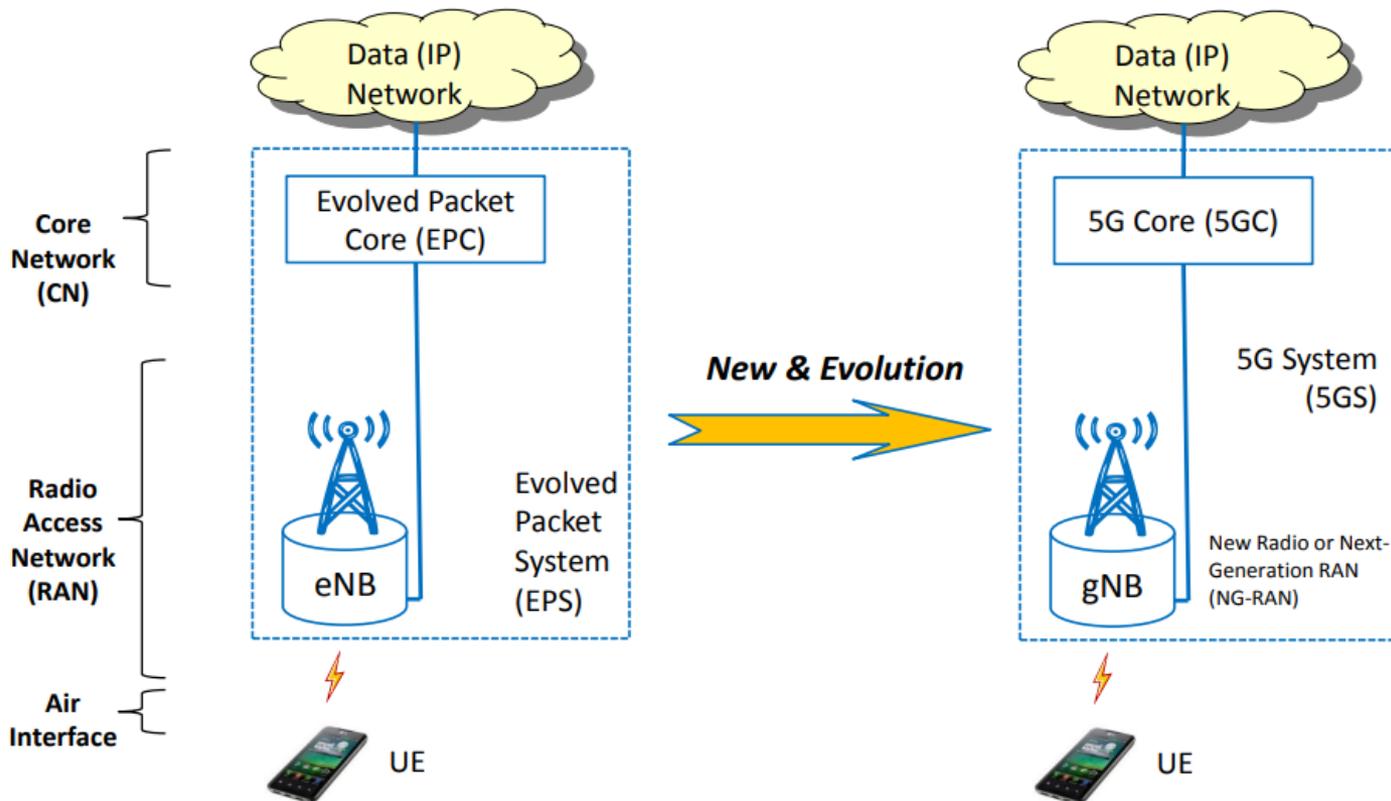
Access Network

- Connects devices over the air
- Allows mobility and handovers

4G Mobile Network Architecture



5G Mobile Network Architecture

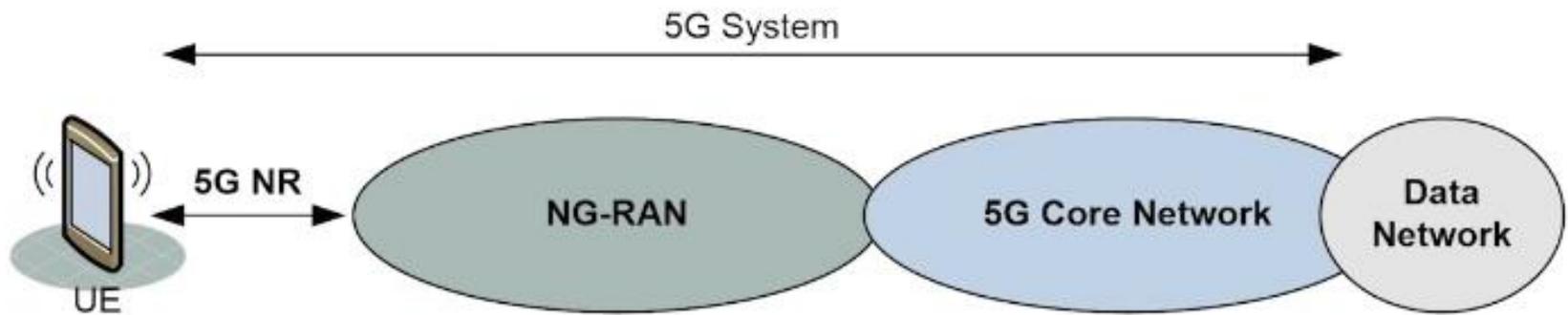


5G System is defined as 3GPP system consisting of 5G Access Network (AN), 5G Core Network and UE. The 5G System provides data connectivity and services.

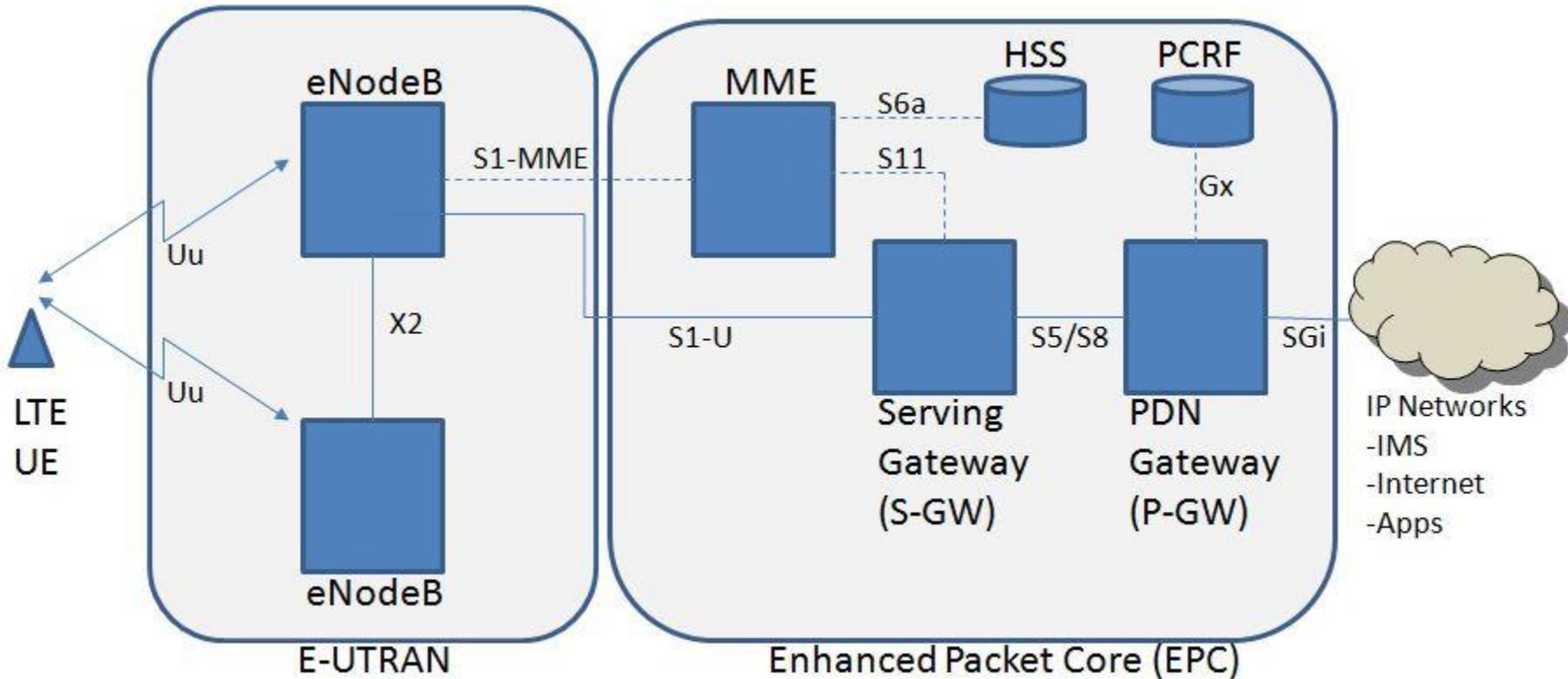
3GPP TS 23.501: System Architecture for the 5G System; Stage 2

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

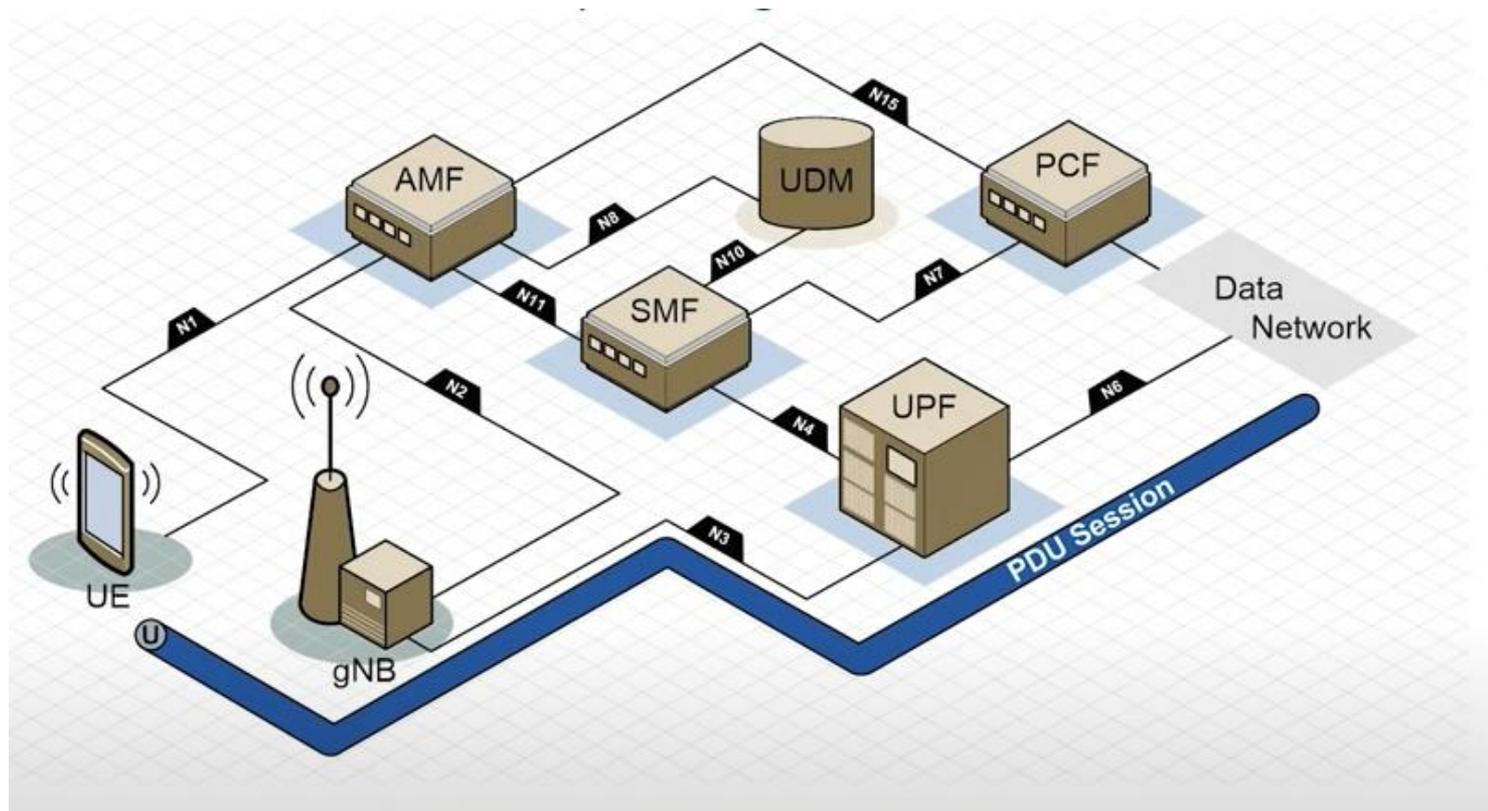
Access and Core Network



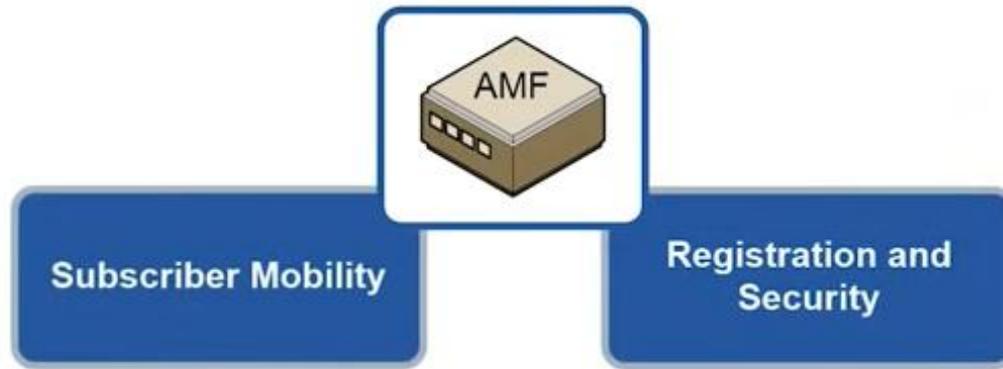
LTE Architecture



General 5G architecture



Access and Mobility-Management Function



Similar to MME in 4G
Location
Paging
Handover

Authentication
Temporary ID

International Mobile Subscriber Identifier

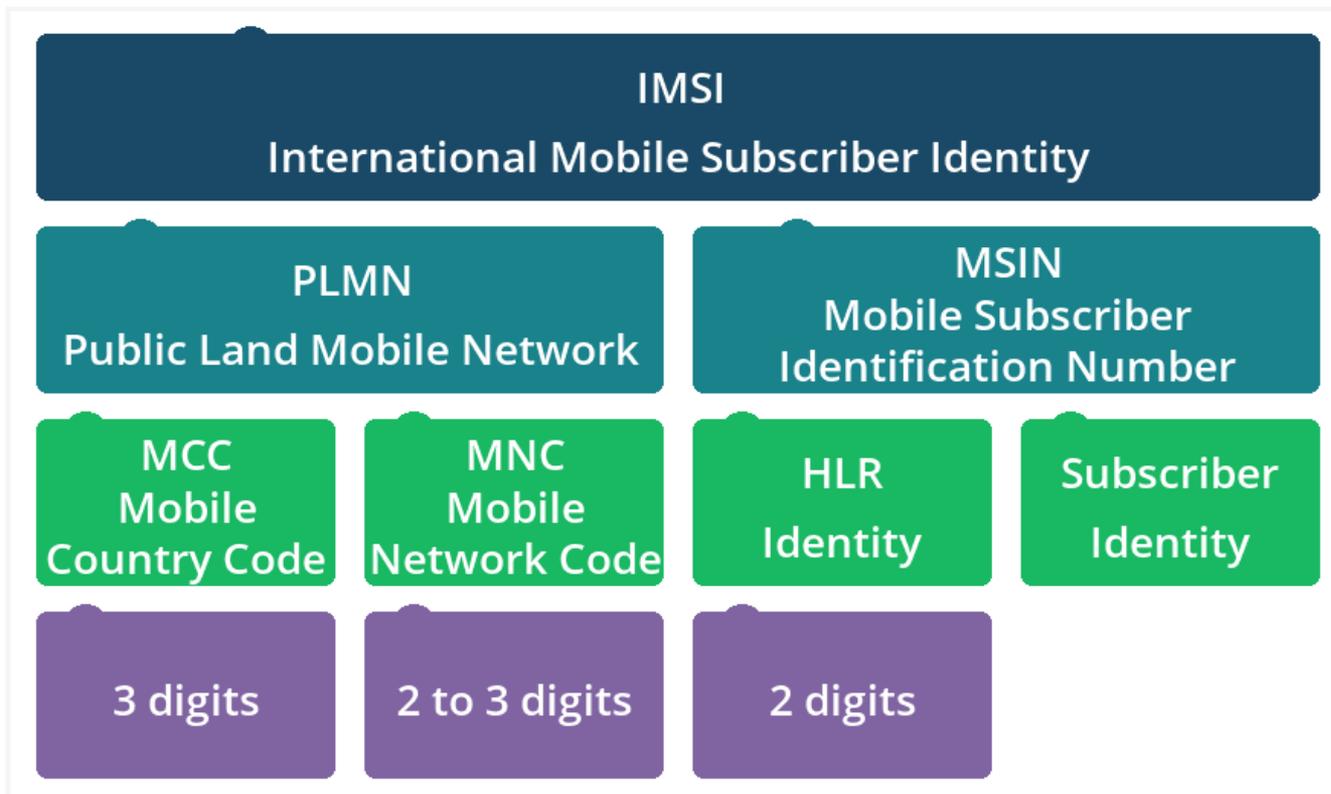
3GPP identifiers [23.003](#)

IMSI

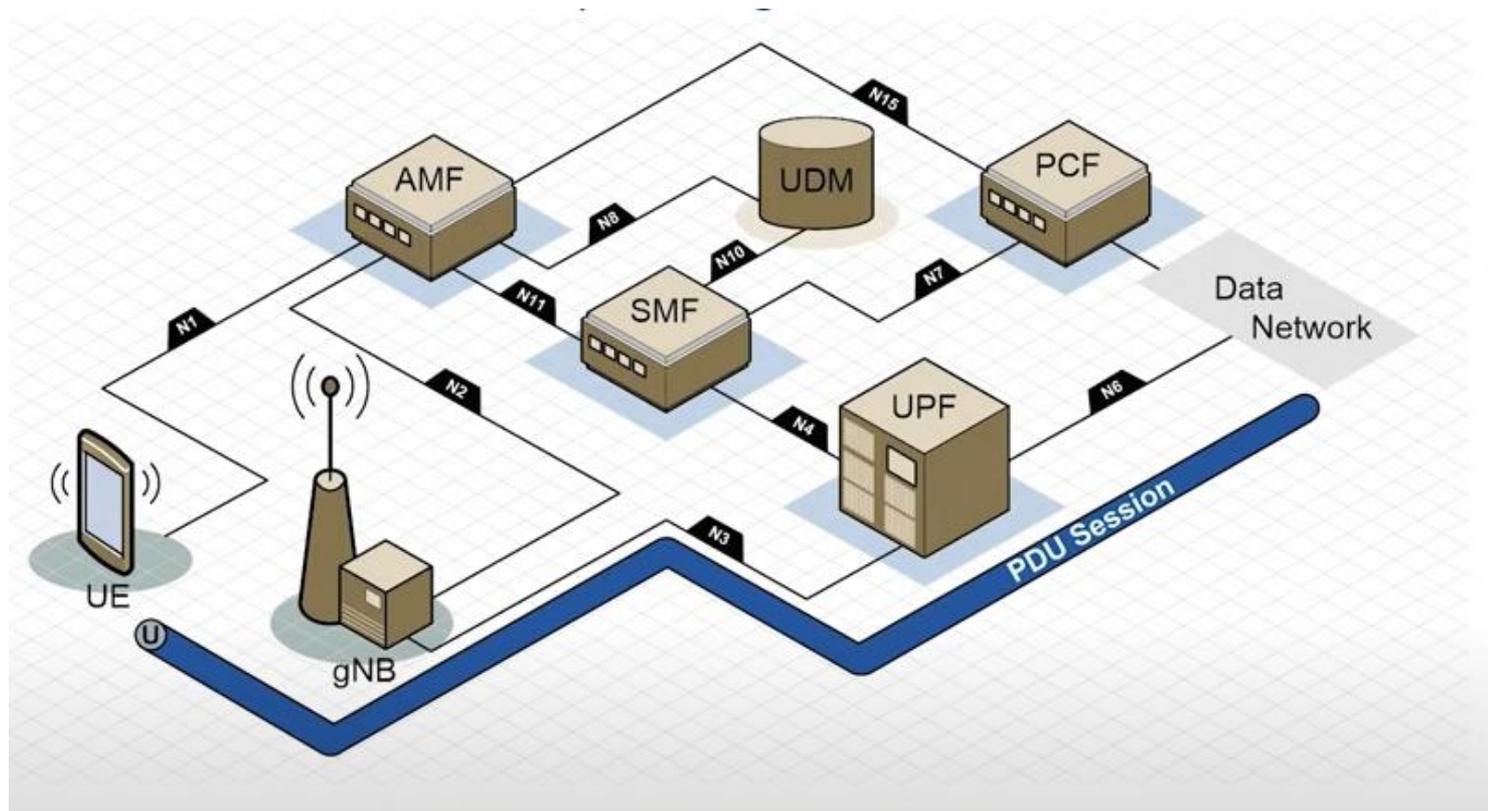
Identifies the SIM. It includes the Home PLMN

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

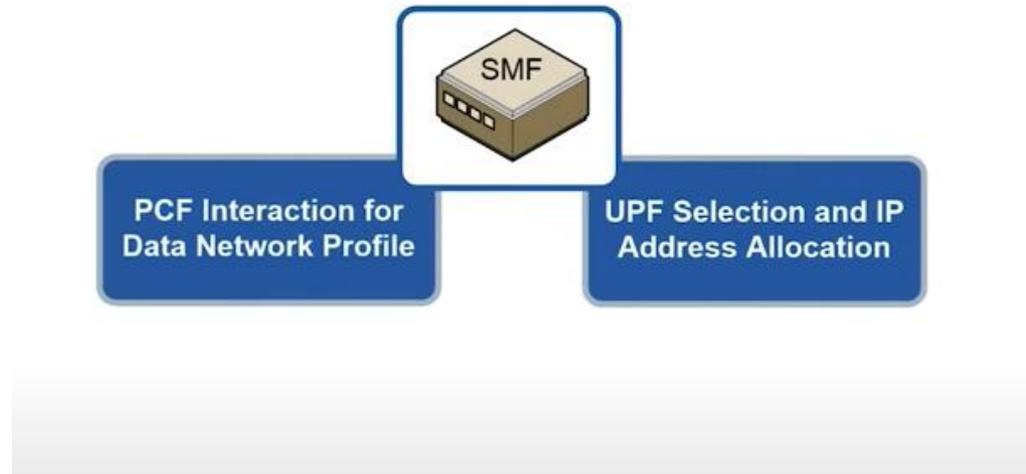
Length : 15 digits or less



General 5G architecture



Session Management Function

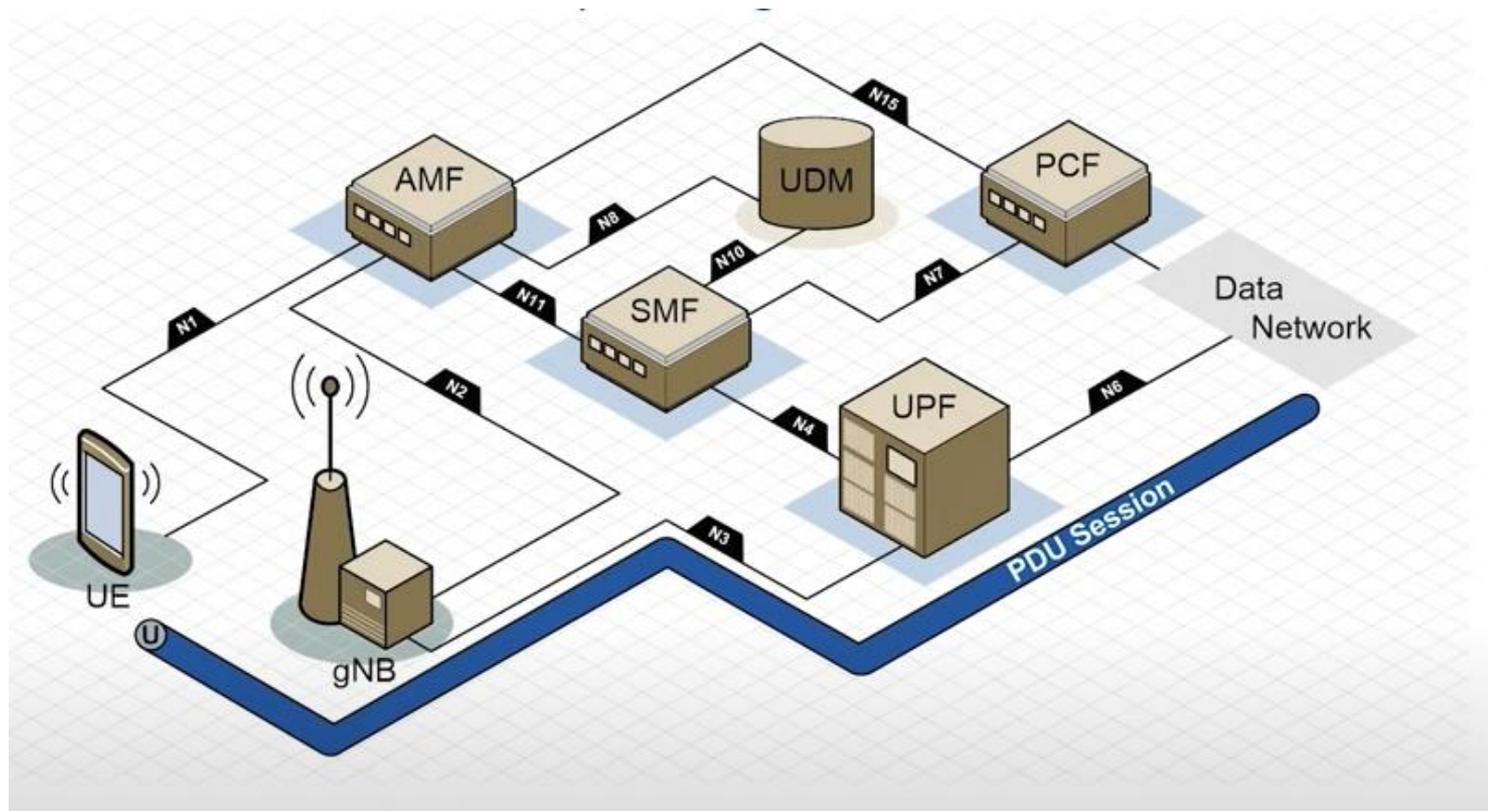


In 4G mobility and session functionality were both in one entity: MME – In 5G this is split to AMF and SMF respectively.

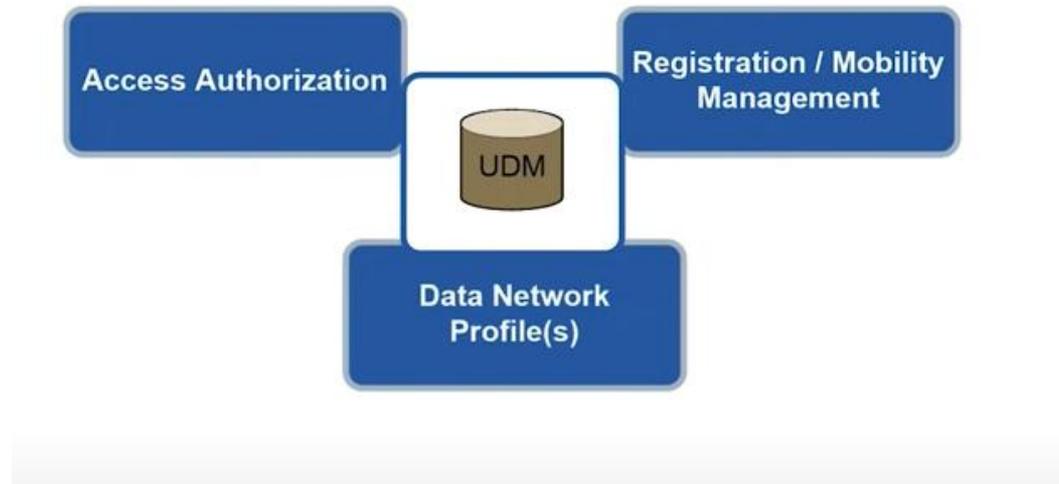
Establishment, modification, termination of PDU sessions

- Interact with Policy Control Function to check the policies affecting the session
- Interact with User Plane Function to setup the PDU session

General 5G architecture

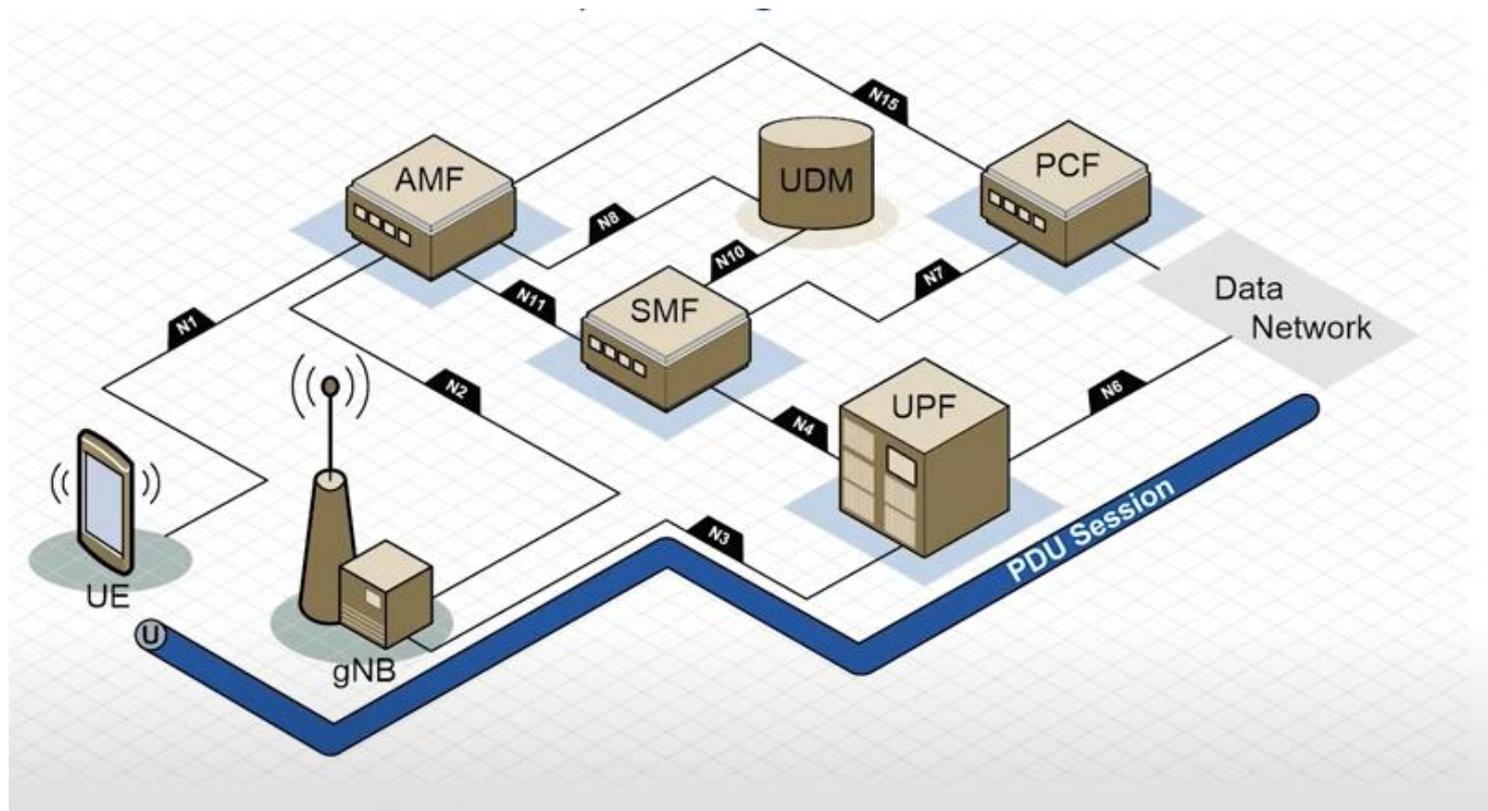


Unified Data Management

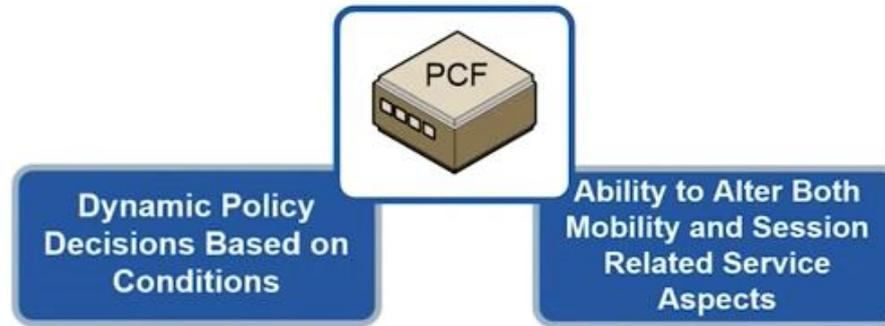


- Central repository of subscriber information
- Access authorization
- Tracking information
- Data network profile (what the user can and cannot do)

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

PCF examples

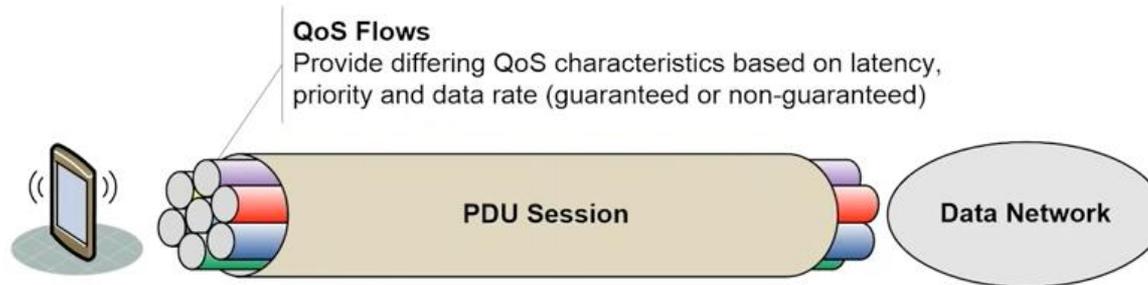
Quality of Service (QoS) for Video: When a user starts an 8K video stream, the PCF can detect the application type and issue a policy to allocate higher bandwidth (e.g., 50 Mbps) and prioritized traffic flow to ensure a buffer-free experience.

Low Latency for Gaming/IoT: For a cloud gaming service or critical IoT sensor, the PCF can set policies that minimize latency and ensure high reliability, even if the rest of the network is congested.

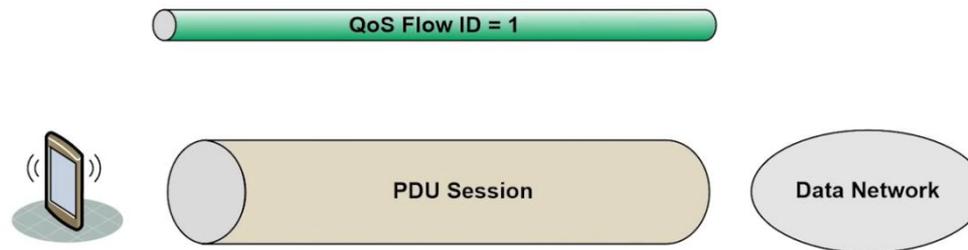
Spending Limit Reached: If a user reaches their pre-set data or financial limit, the PCF can trigger a session release or refuse new session establishment to prevent further charges.

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



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

Bandwidth

Delay

Jitter

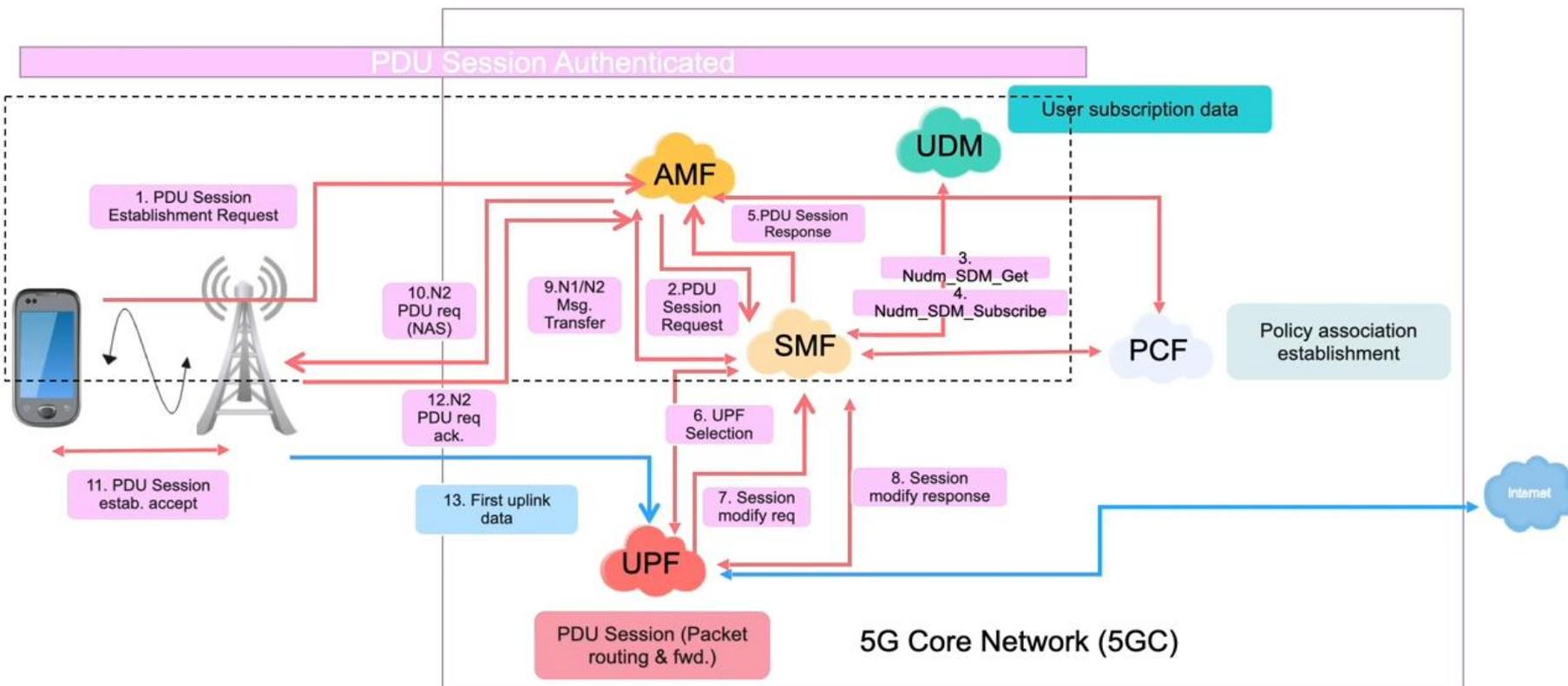
Packet Loss rate

The acceptable E2E delay for VOIP is 150 to 200 ms

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

QoS indicators

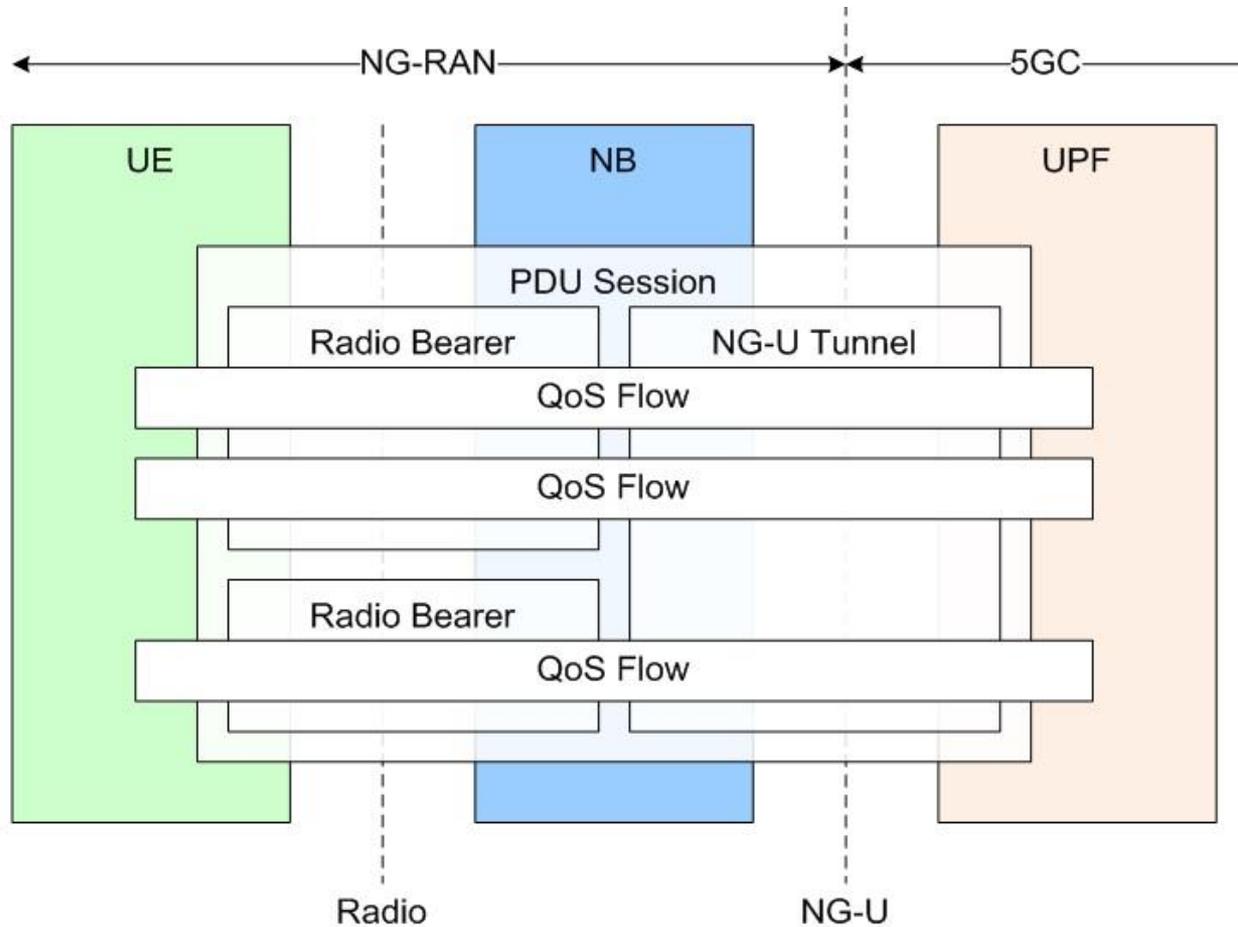
PDU Session Establishment



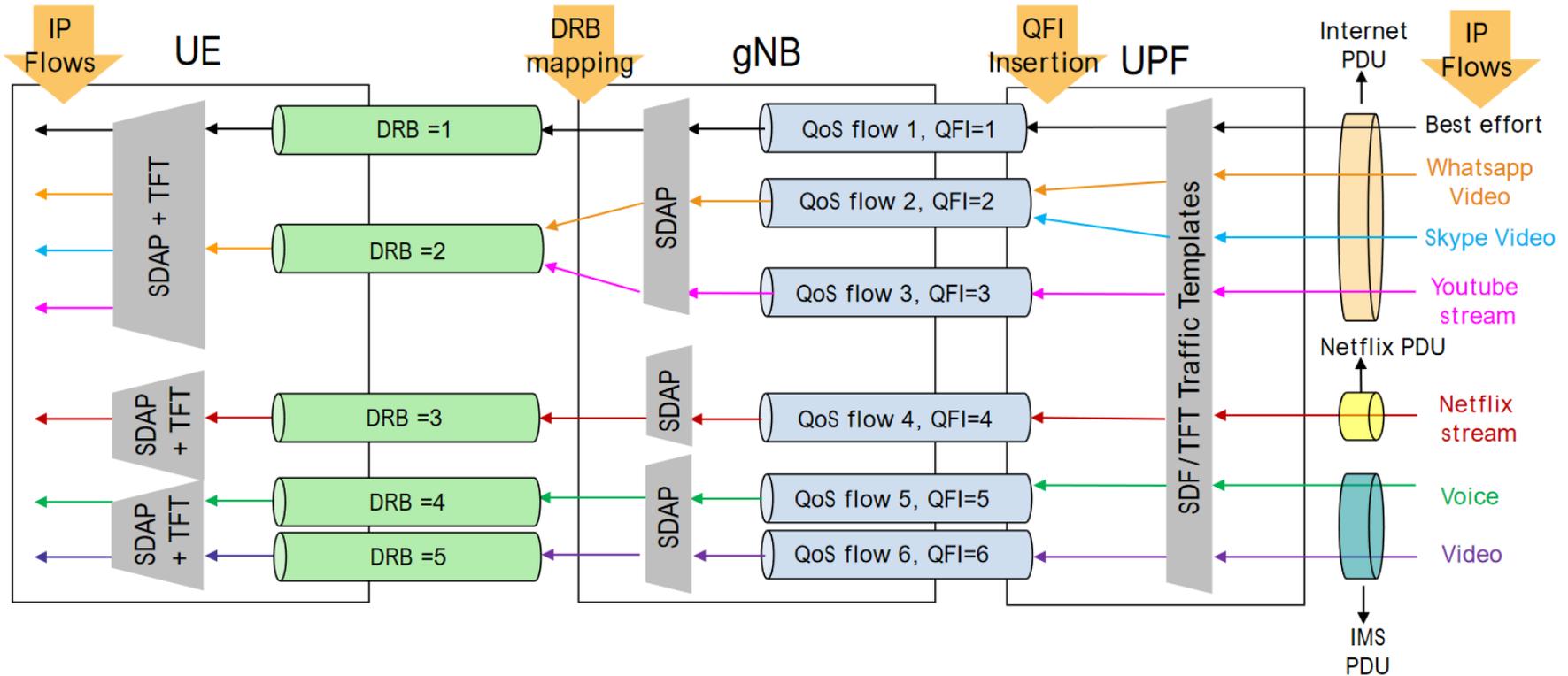
↔ Control Plane

↔ User Plane

User Plane Function



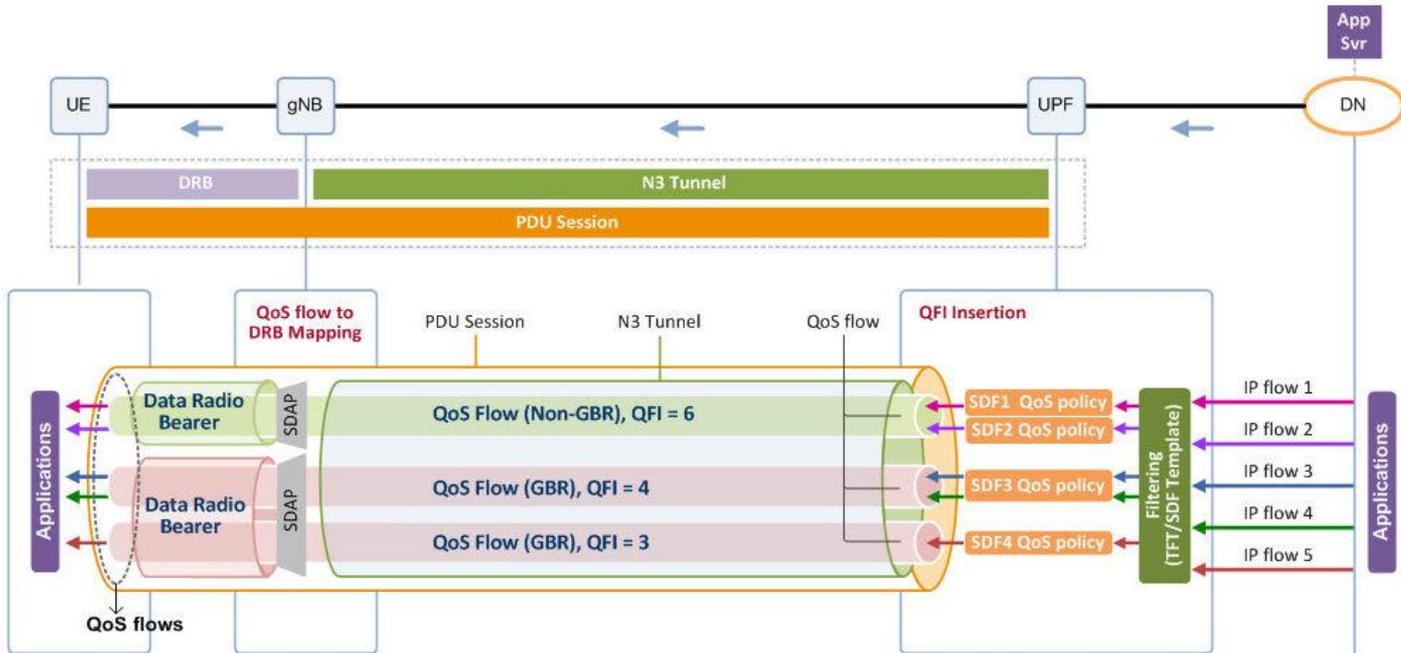
User Plane Function



SDAP: Service Data Adaptation Protocol

SDF/TFT: Service Data Flow / Traffic Flow Template

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.