5G Mobile Communication System

Wireless Networks

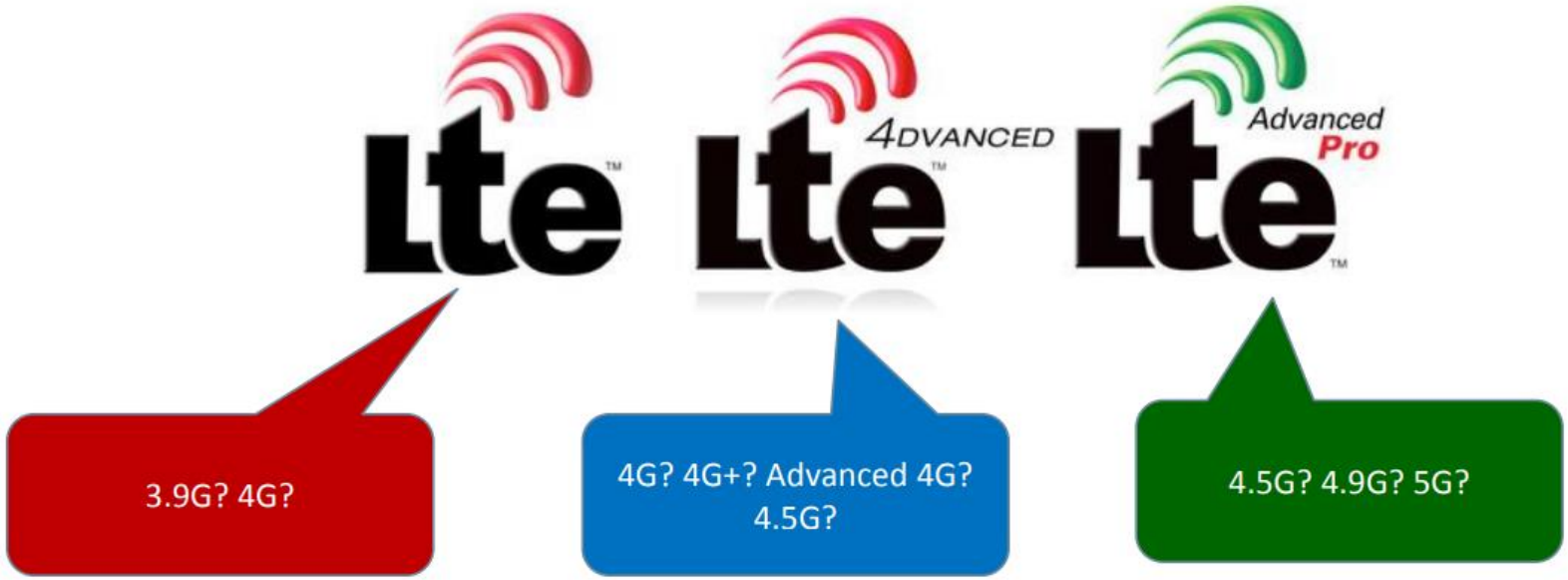
Overview

- **Wireless Mobile/Cellular Networks**: Licensed spectrum, reliability
- **Wireless Local Area Networks (WLANs)**: internet access, local area
- **Mobile/Vehicular Ad-hoc NETwork (MANET/VANET)**: self-configuring, independent movement
- **Wireless Sensor Network (WSN)**: spatially distributed sensors, monitoring purposes
- **Wireless Mesh Network (WMN)**: more planned ad-hoc network
- **Wireless Person Area Networks (WPAN):** data transmission among devices /personal digital assistants.
- **Professional/private Mobile Radio networks (PMR)**: Push-to-talk, release to listen - VHF or UHF frequency bands

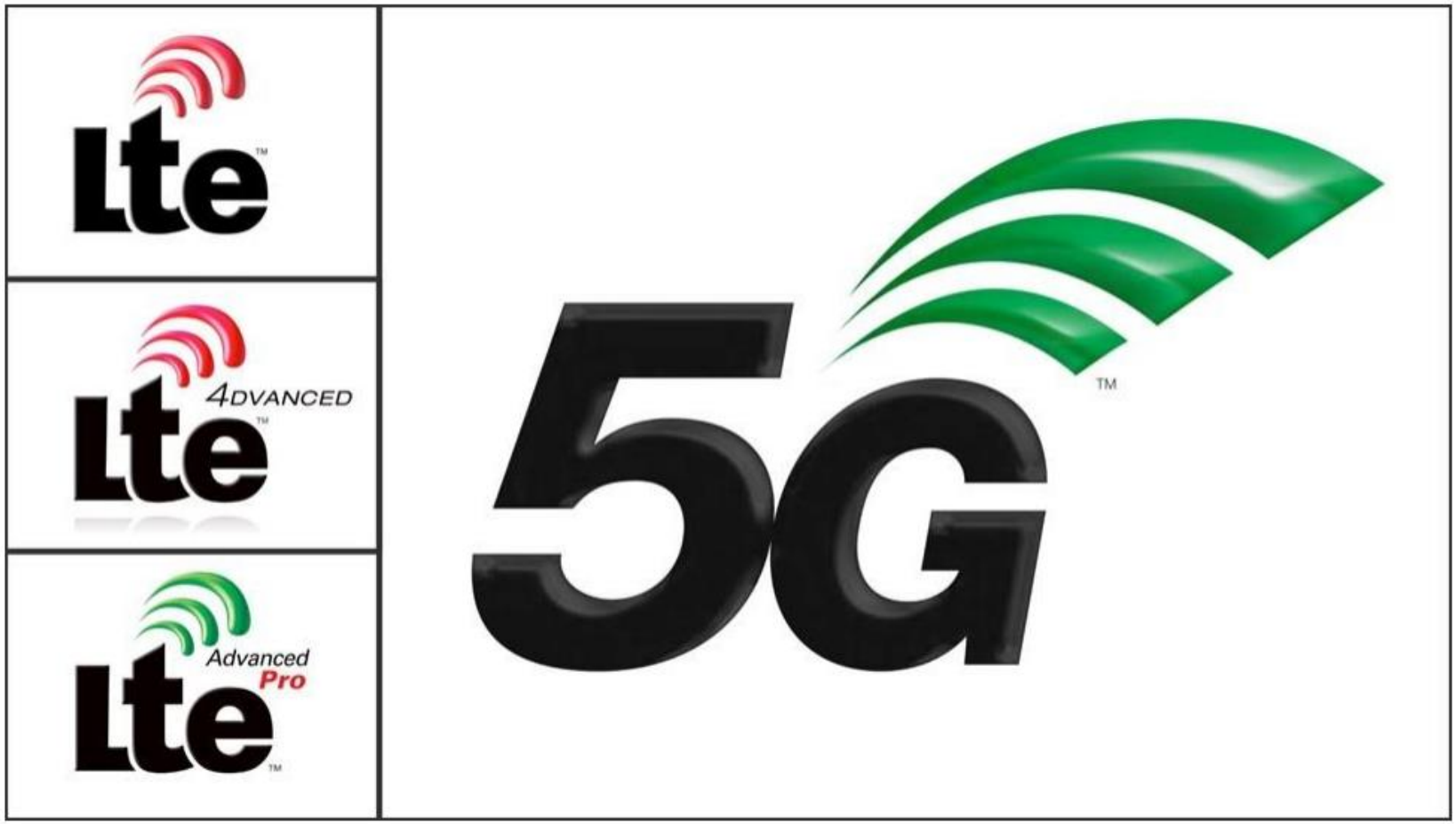
Wireless Networks
Related Technologies /Systems

- **Wireless Mobile/Cellular Networks**: GSM, UMTS, LTE, LTE-A, **5G**..
- WLANs: WiFi, WiFi direct
- WSN: Zegbee, WiFi, Bluetooth, LoRa/LoraWAN
- WPAN: Radio-Frequency IDentification (RFID): Identify tags attached to objects, one-direction
- Near Field Communication (NFC): Few centimeters range, 2-way communication
- Ultra-wideband (UWB): very low energy level for short range, high bandwidth
- Infrared (IR): short range, line of sight, bidirectional
- Bluetooth: short distances, unlicensed ISM band
- PMR: TETRA, TETRAPOL

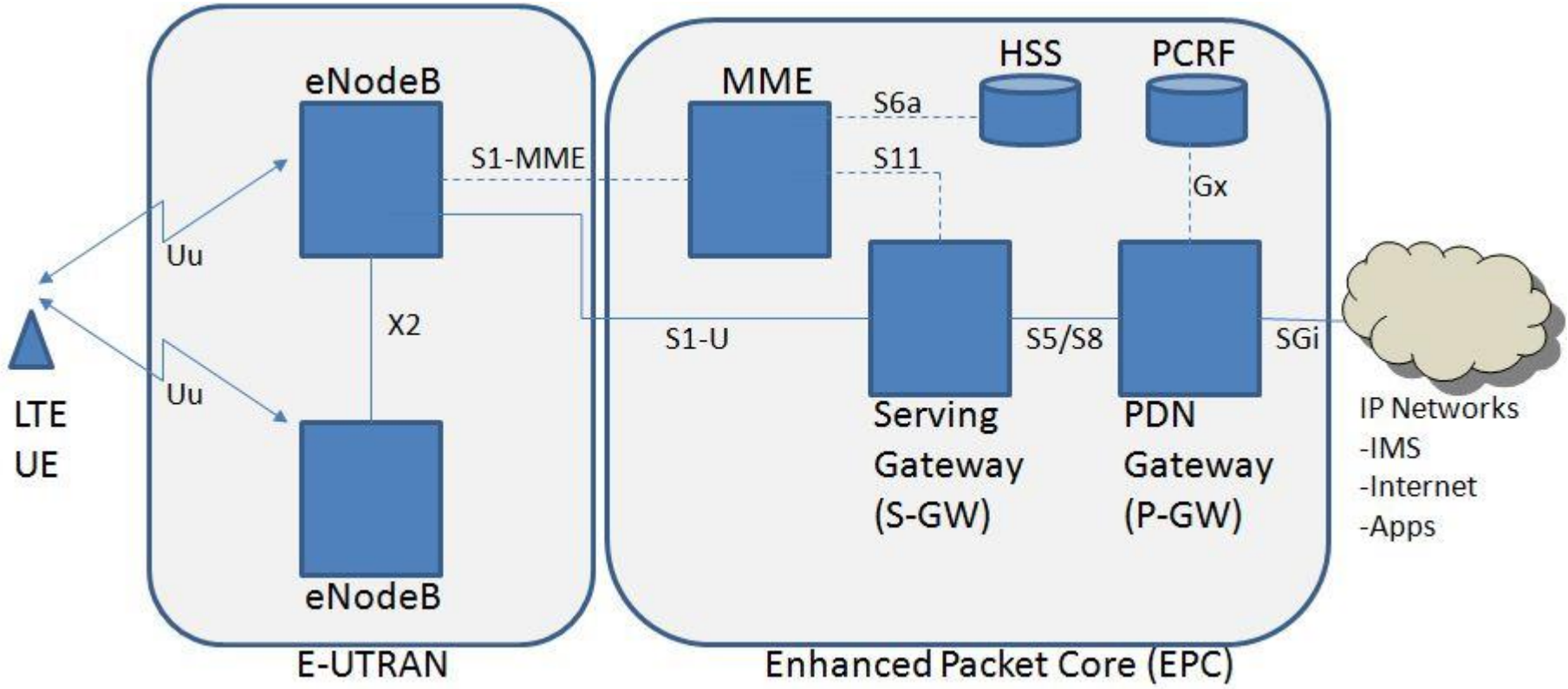
4G Evolution



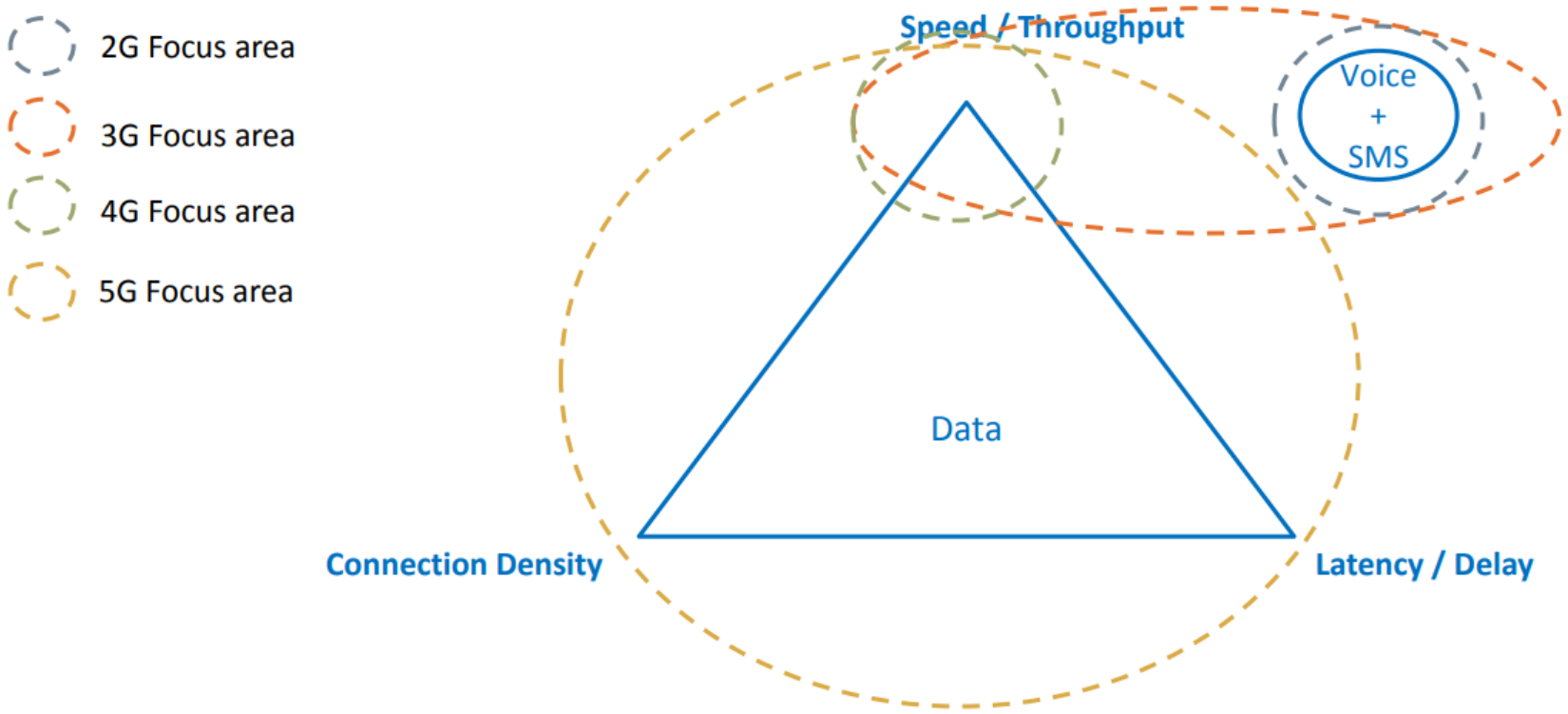
5G → IMT-2020



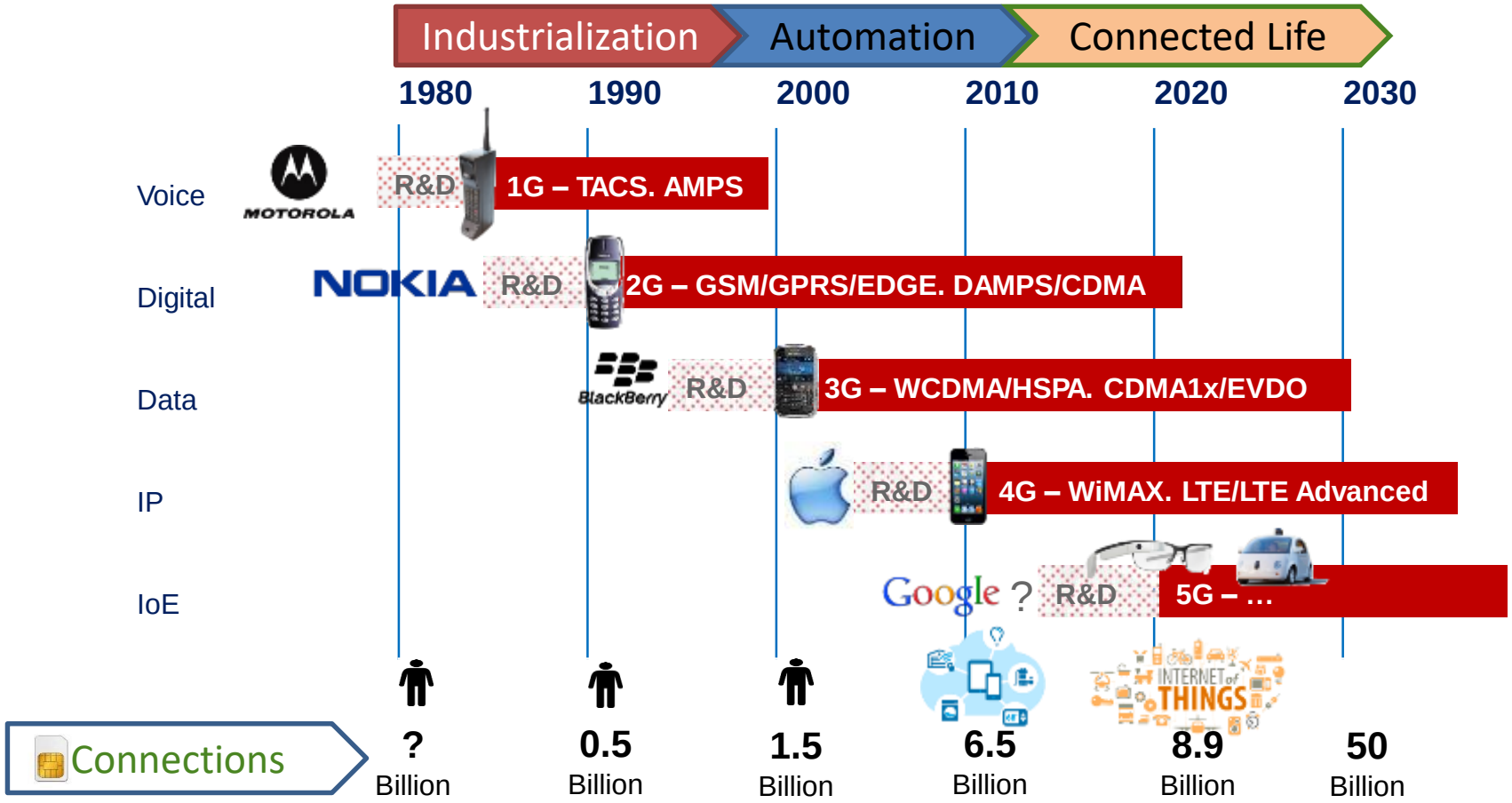
LTE Architecture



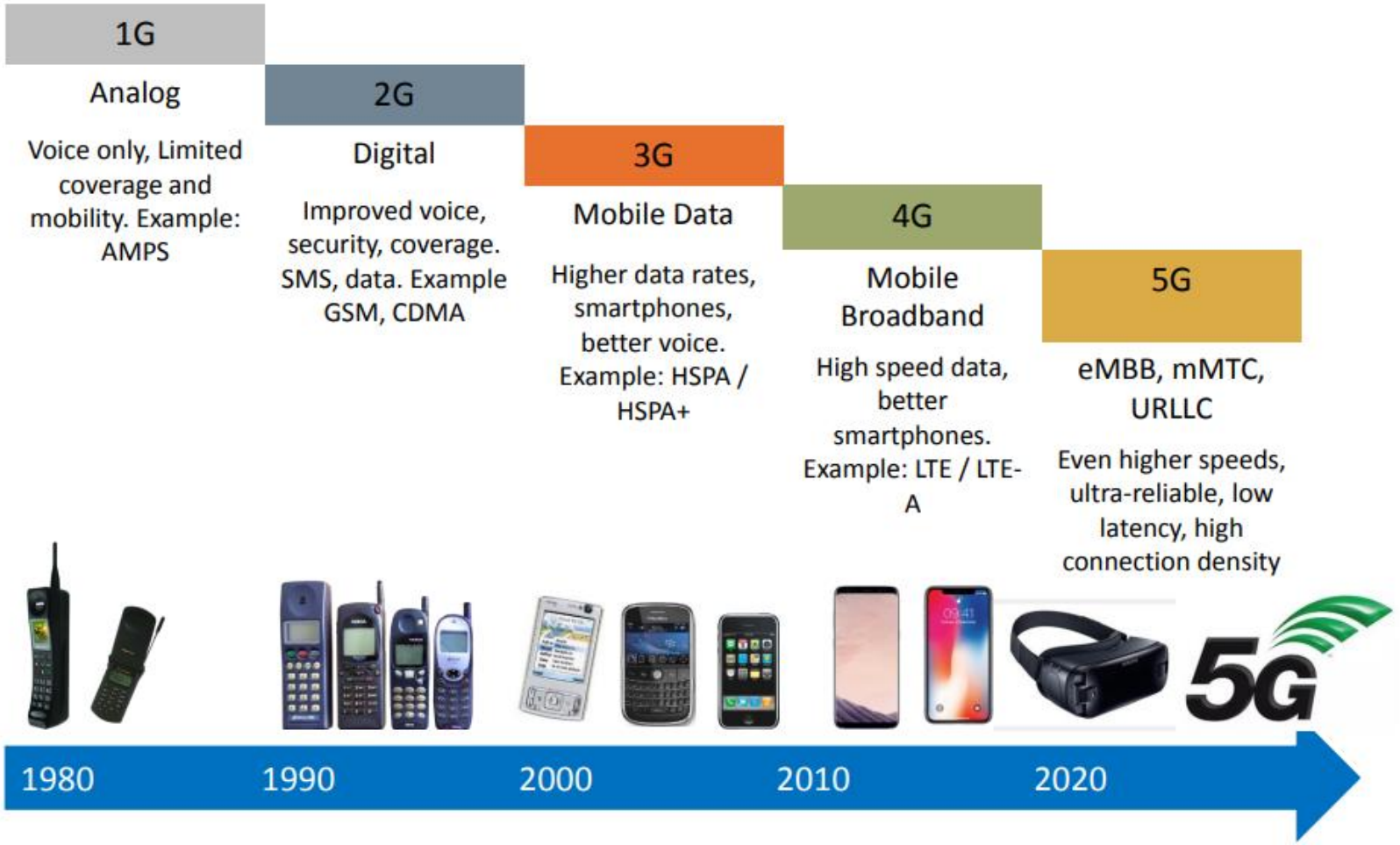
Focus area for different technology generations



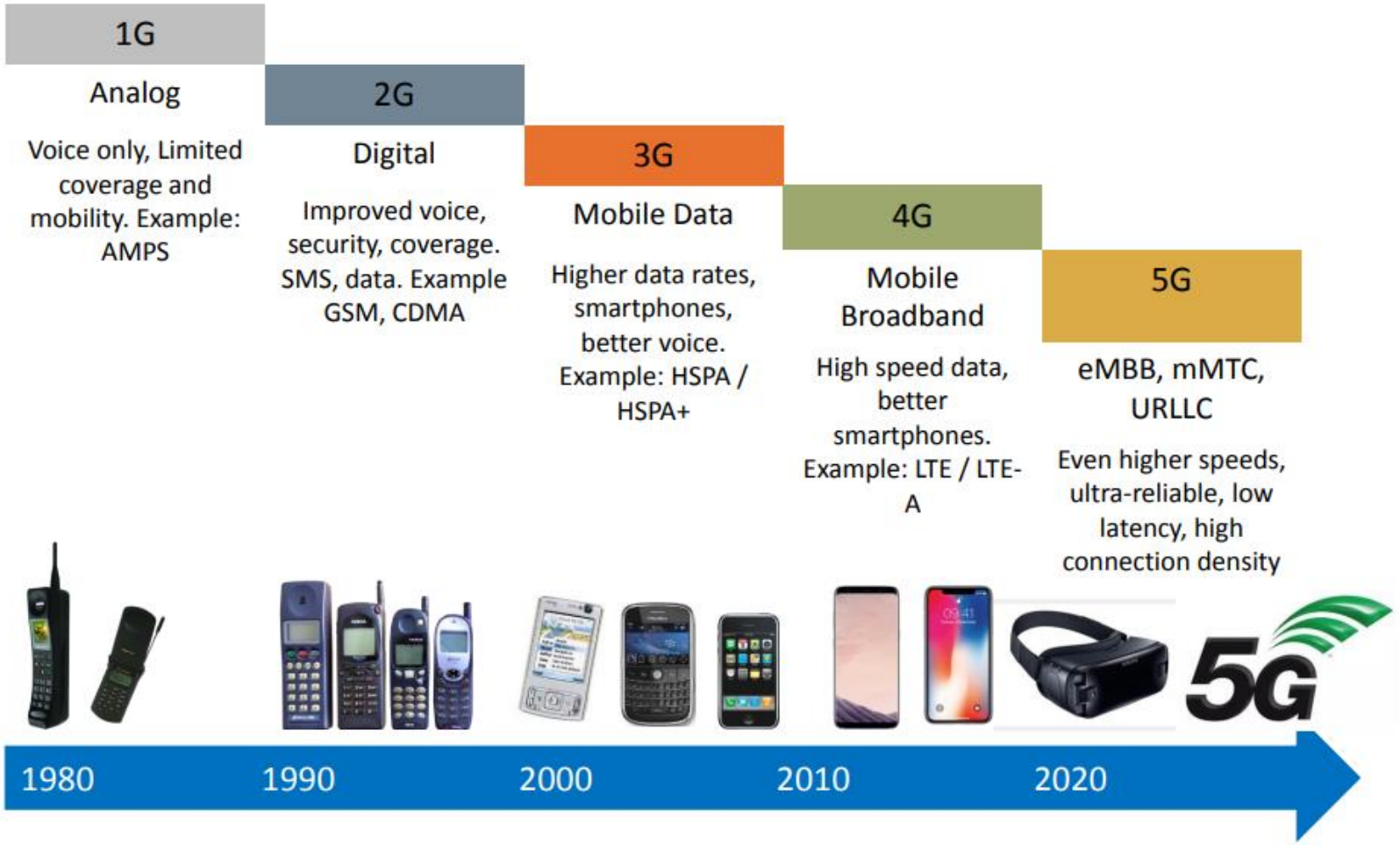
Evolution of mobile communications



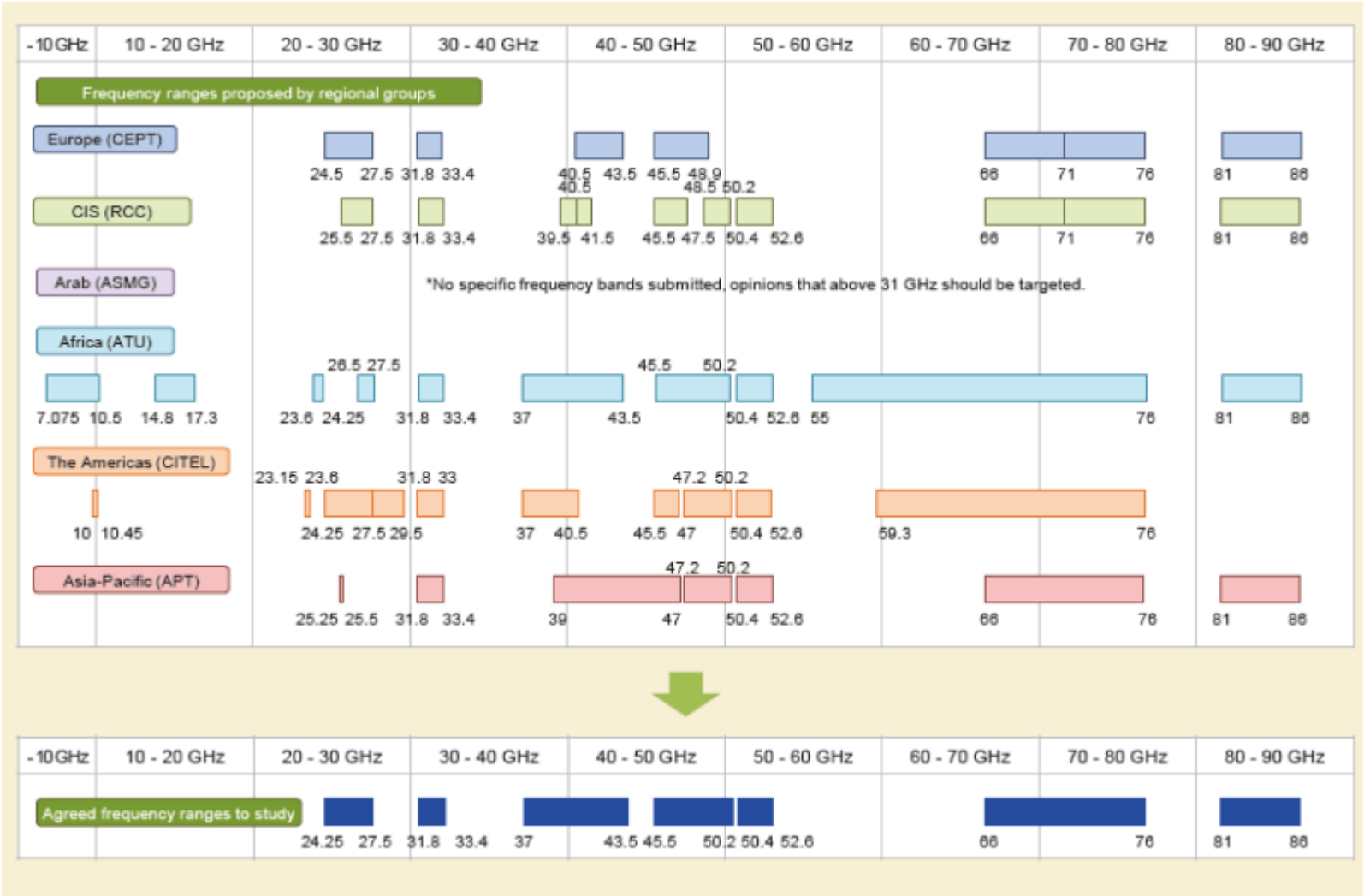
Evolution of mobile communications



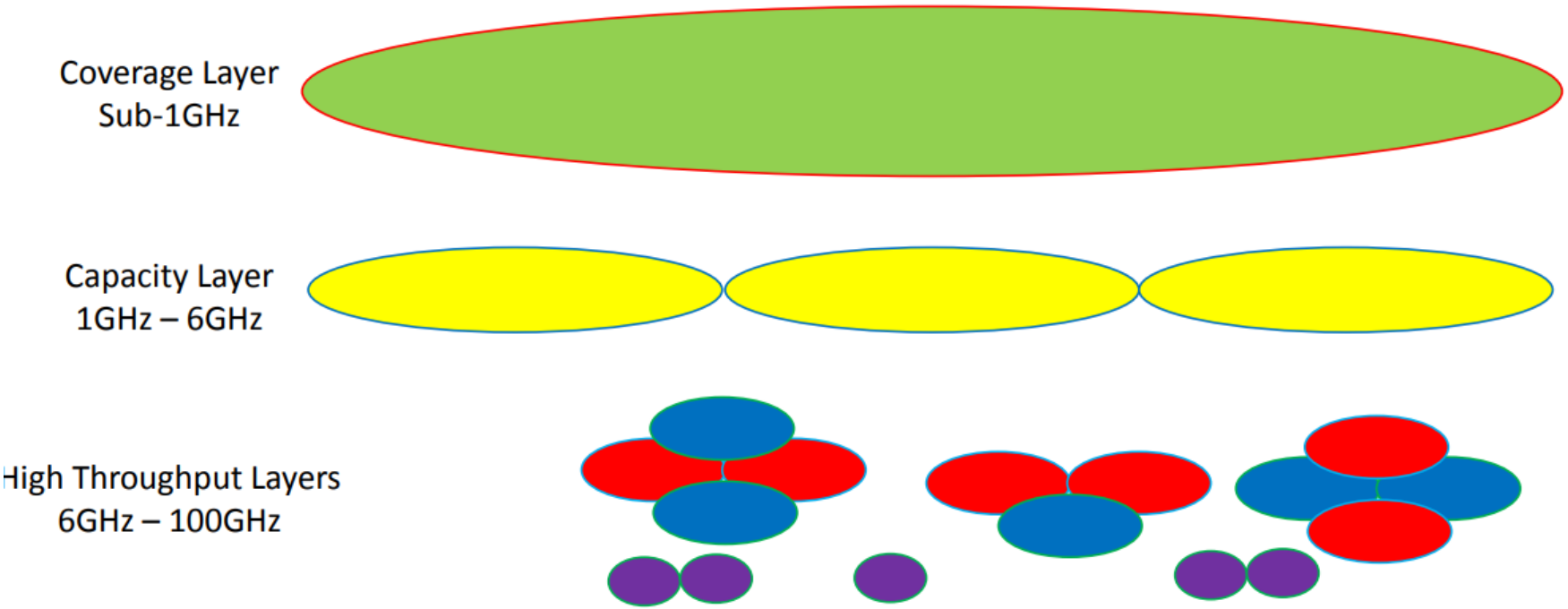
Evolution of mobile communications



5G Spectrum


-10GHz
10 - 20 GHz
20 - 30 GHz
30 - 40 GHz
40 - 50 GHz
50 - 60 GHz
60 - 70 GHz
70 - 80 GHz
80 - 90 GHz
Frequency ranges proposed by regional groups
Europe (CEPT)
24.5 27.5 31.8 33.4
40.5 43.5 45.5 48.9
66 71 76
81 86
CIS (RCC)
25.5 27.5 31.8 33.4
40.5
39.5 41.5
48.5 50.2
45.5 47.5 50.4 52.6
66 71 76
81 86
Arab (ASMG)
*No specific frequency bands submitted, opinions that above 31 GHz should be targeted.
Africa (ATU)
7.075 10.5 14.8 17.3
23.6 24.25 26.5 27.5 31.8 33.4
37 43.5
45.5 50.2
50.4 52.6 55 76
81 86
The Americas (CITEL)
10 10.45
23.15 23.6 24.25 27.5 29.5 31.8 33
37 40.5
45.5 47 47.2 50.2 50.4 52.6
59.3 76
Asia-Pacific (APT)
25.25 25.5 31.8 33.4
39 47 47.2 50.2 50.4 52.6
66 76
81 86
-10GHz
10 - 20 GHz
20 - 30 GHz
30 - 40 GHz
40 - 50 GHz
50 - 60 GHz
60 - 70 GHz
70 - 80 GHz
80 - 90 GHz
Agreed frequency ranges to study
24.25 27.5 31.8 33.4 37
43.5 45.5 50.2 50.4 52.6
66 76
81 86

Multiple layer for multiple needs



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

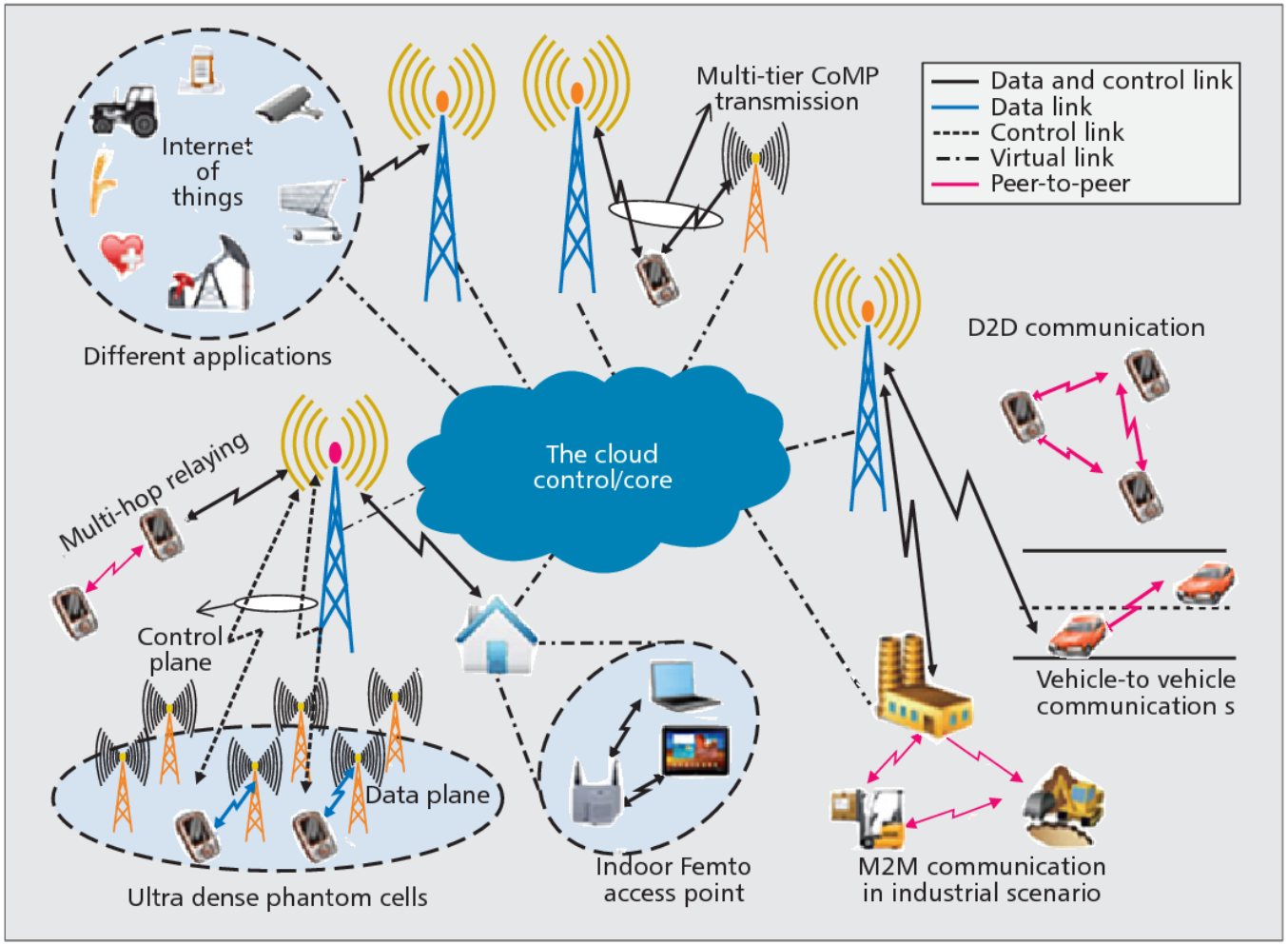
- eMBB User Plane Latency (one-way) = **4ms** [radio network contribution]
- URLLC User Plane Latency (one-way) = **1ms** [radio network contribution]
- Control Plane Latency = **20ms (10ms target)** [UE transition from Idle to Active via network]

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

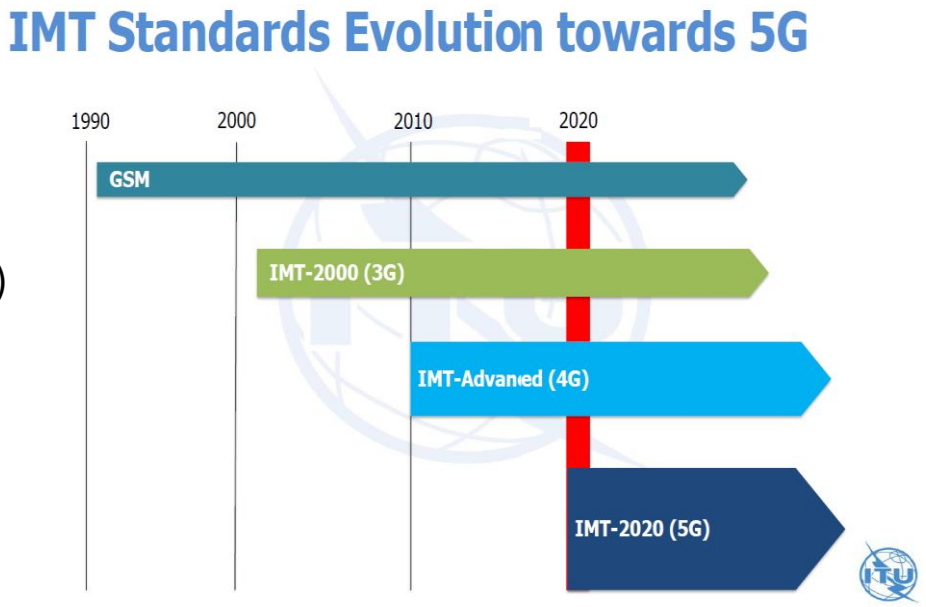
Technologies include:

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

ITU IMT-2020 requirements

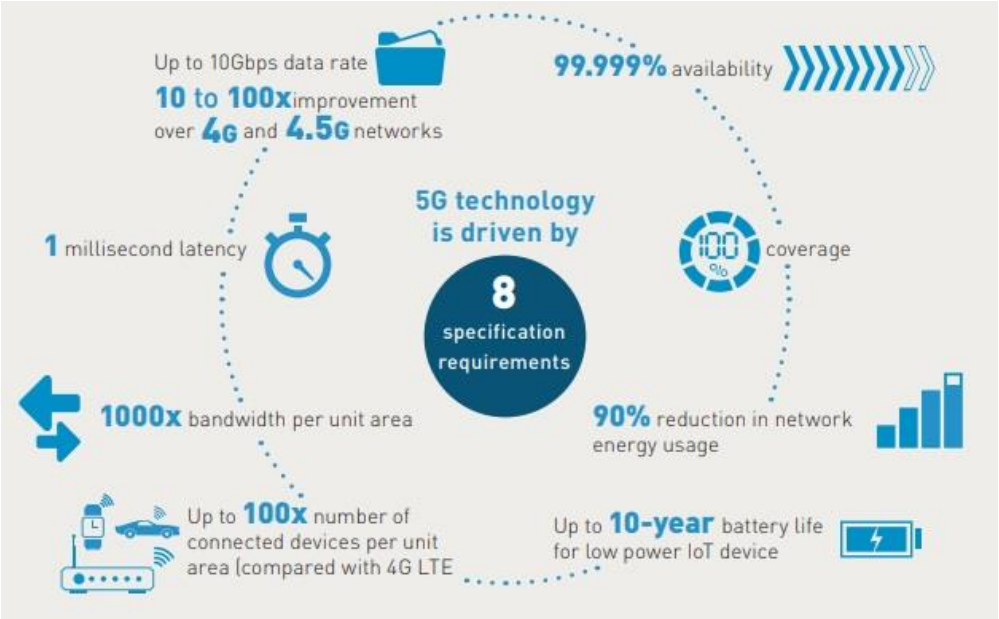
- **About the IMT**
- IMT = International Mobile Telecommunications
- **IMT-2000 requirements** (Marketed as 3G)
  - 3GPP Family: UMTS WCDMA (GSM Evolution)
  - 3GPP2 Family: CDMA2000 (1xEV DO Rev A, EV DO Rev B)
- **IMT-Advanced requirements** (Marketed as 4G)
  - 3GPP Family: LTE Advanced (E UTRA)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

- **IMT-2020 (Marketed as 5G)**



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

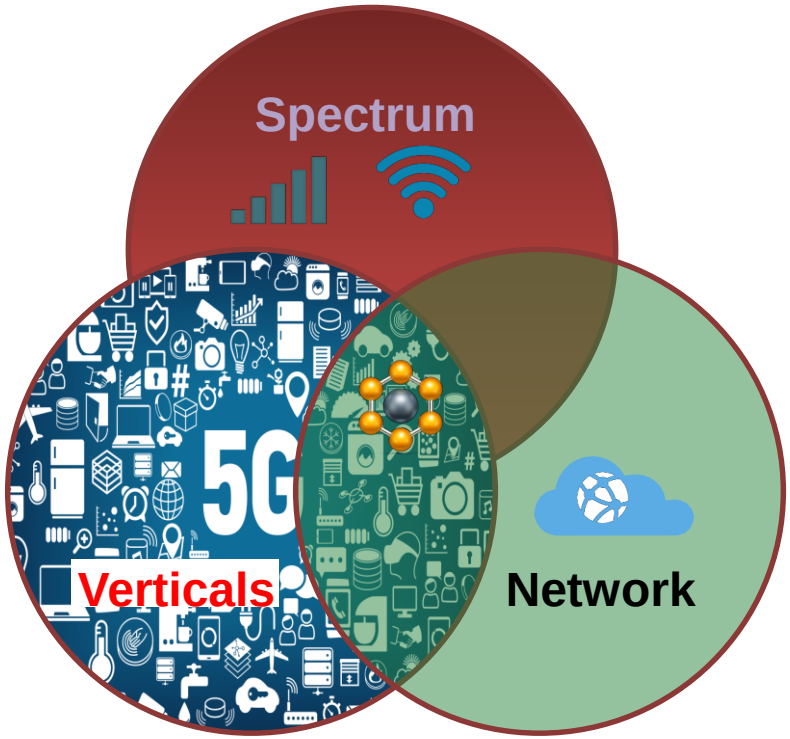


- Technical Requirements

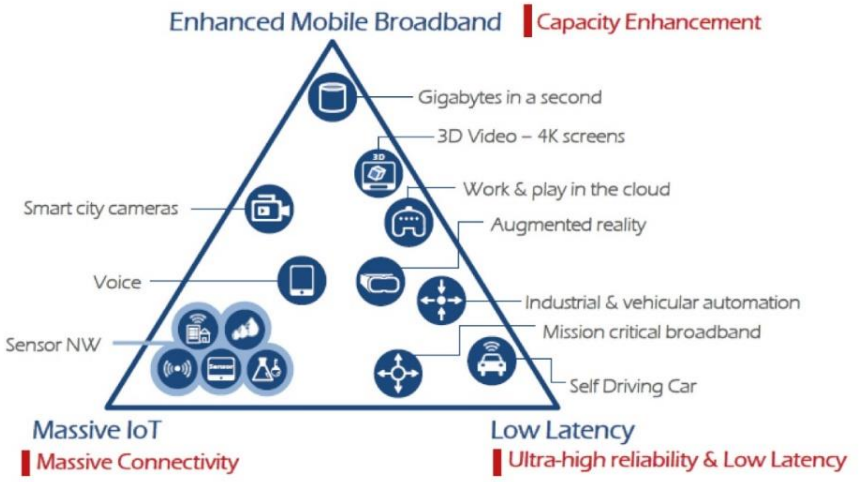
1. Higher System Capacity
2. High Data Rates
3. Lower Latency
4. Mass Connectivity
5. Energy Efficiency
6. More Agile

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

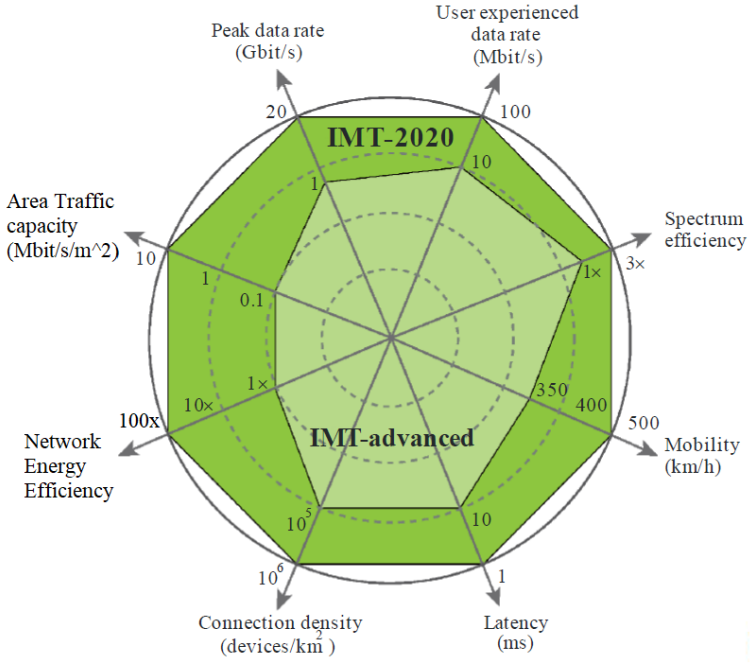
ITU IMT-2020 vision



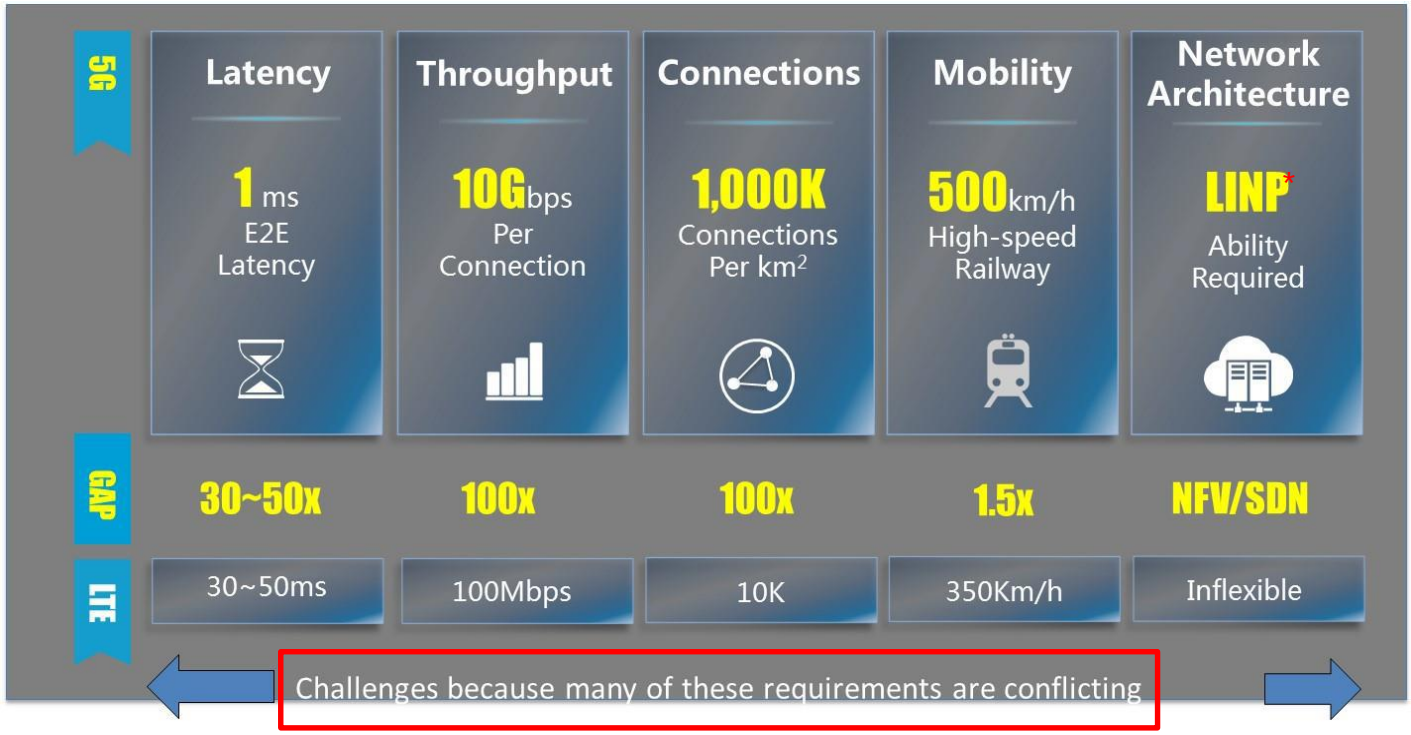
5G Performance



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

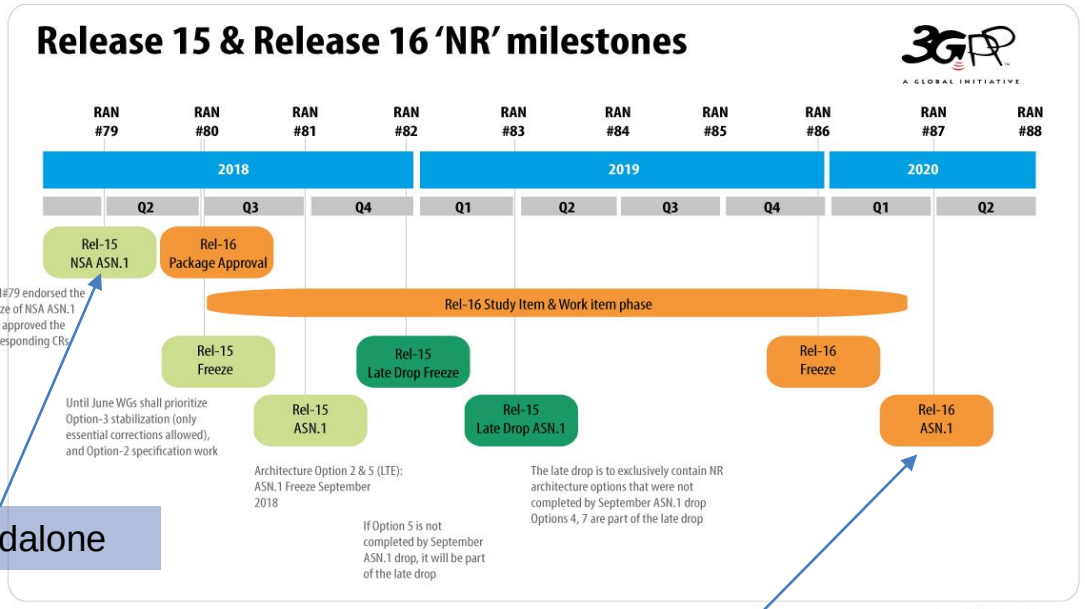


5G Performance (compared to LTE)



*LINP-Locally Isolated Network Partitions

5G Standardization: 3GPP Rel.15/16

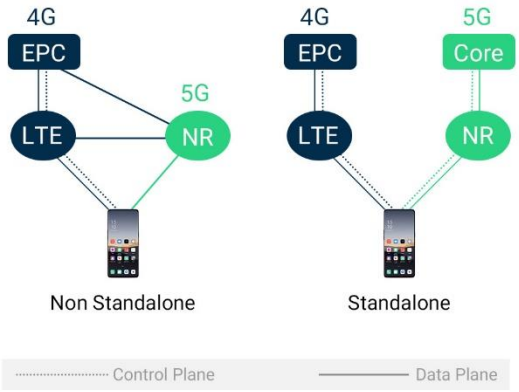


non-standalone

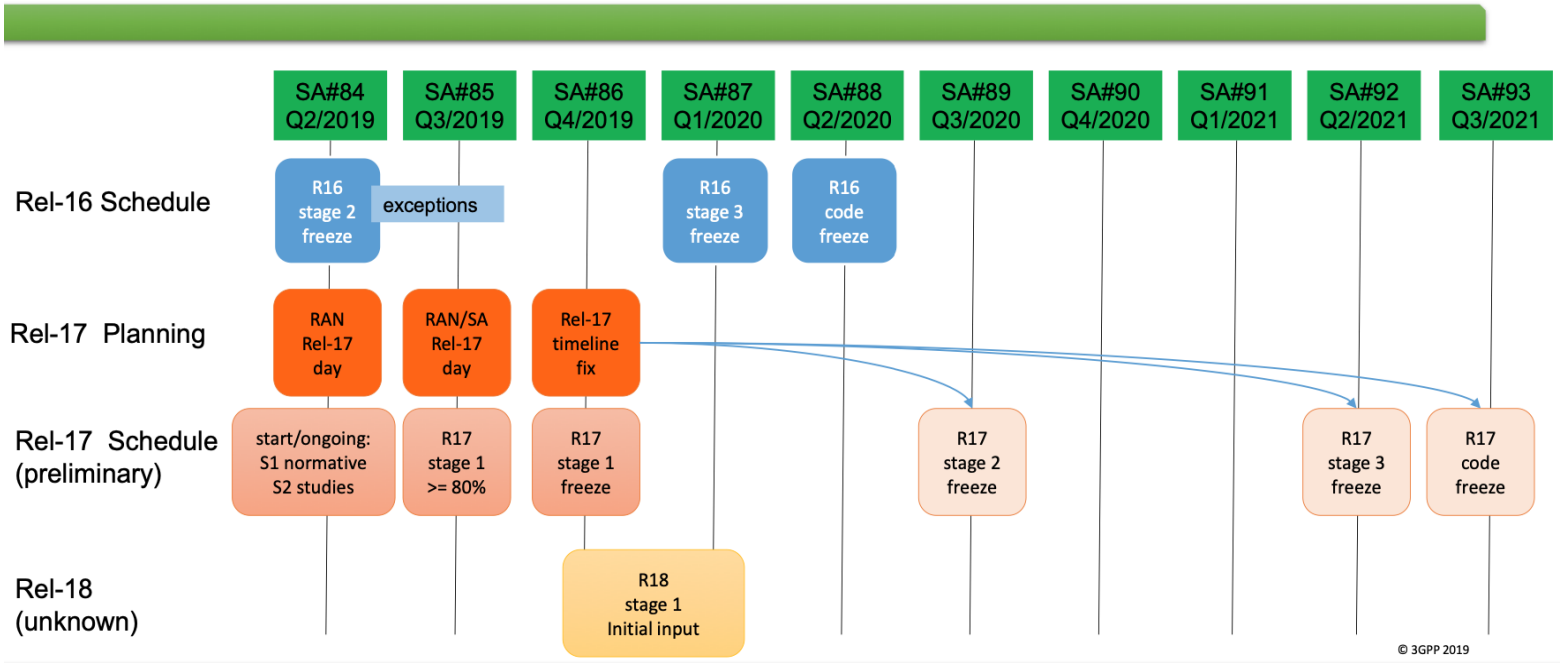
standalone

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

3GPP Release 16 = 5G Phase 2 – Standalone



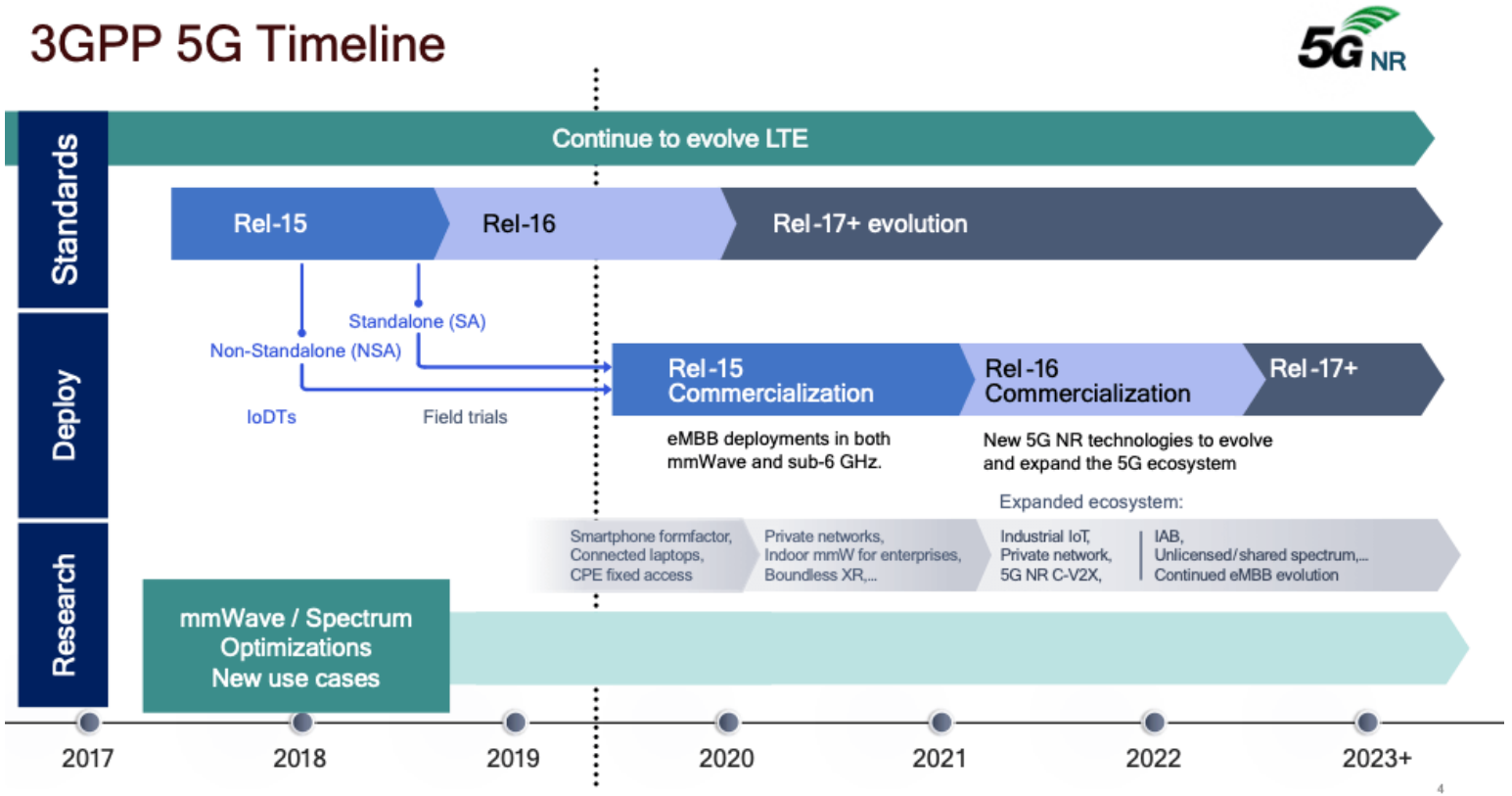
Standardization beyond 5G: 3GPP Rel.17/18



Stage 1 Service requirement level -> Stage 2 Functions to be supported by the system -> Stage 3 Implementation aspects

System Aspects (SA)
Radio Access Network (RAN)
Core network and Terminals (CT)

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



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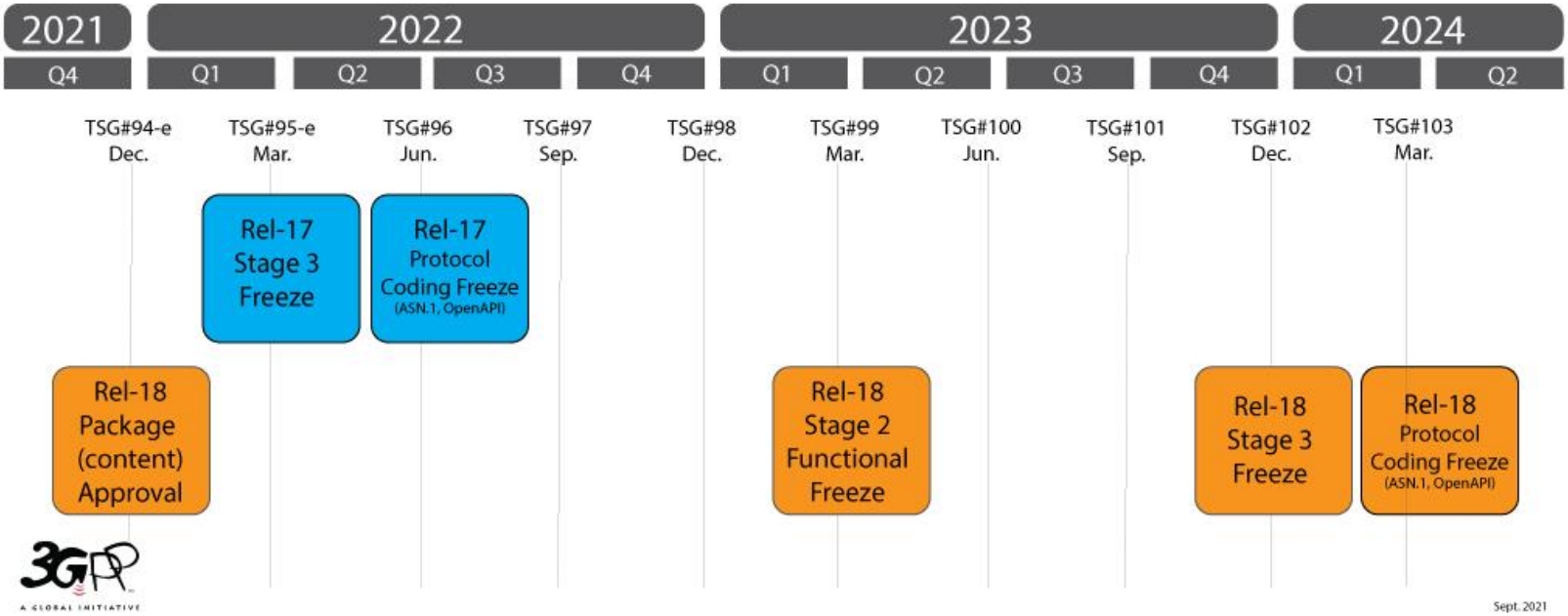
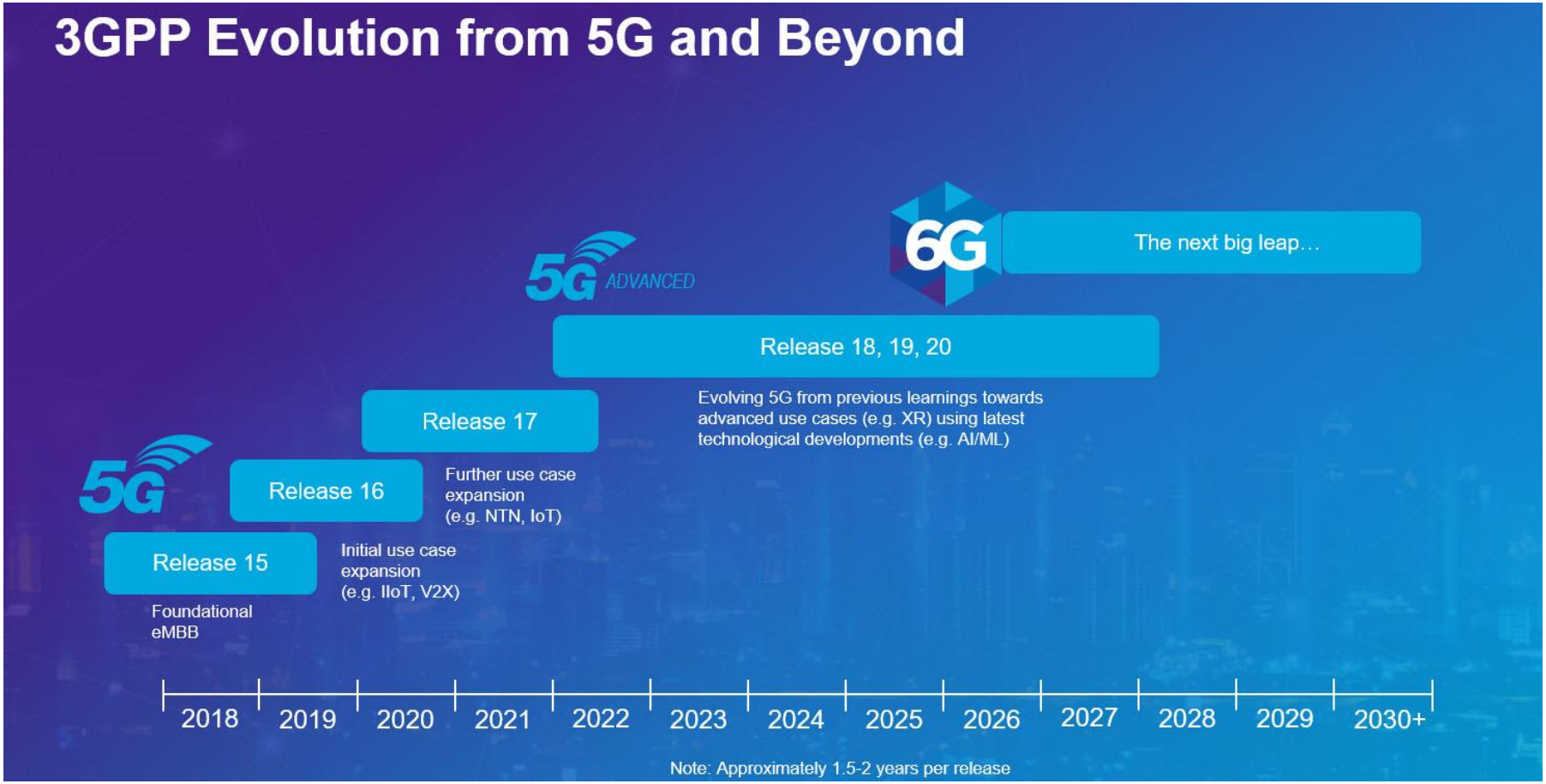


Standardization towards 6G



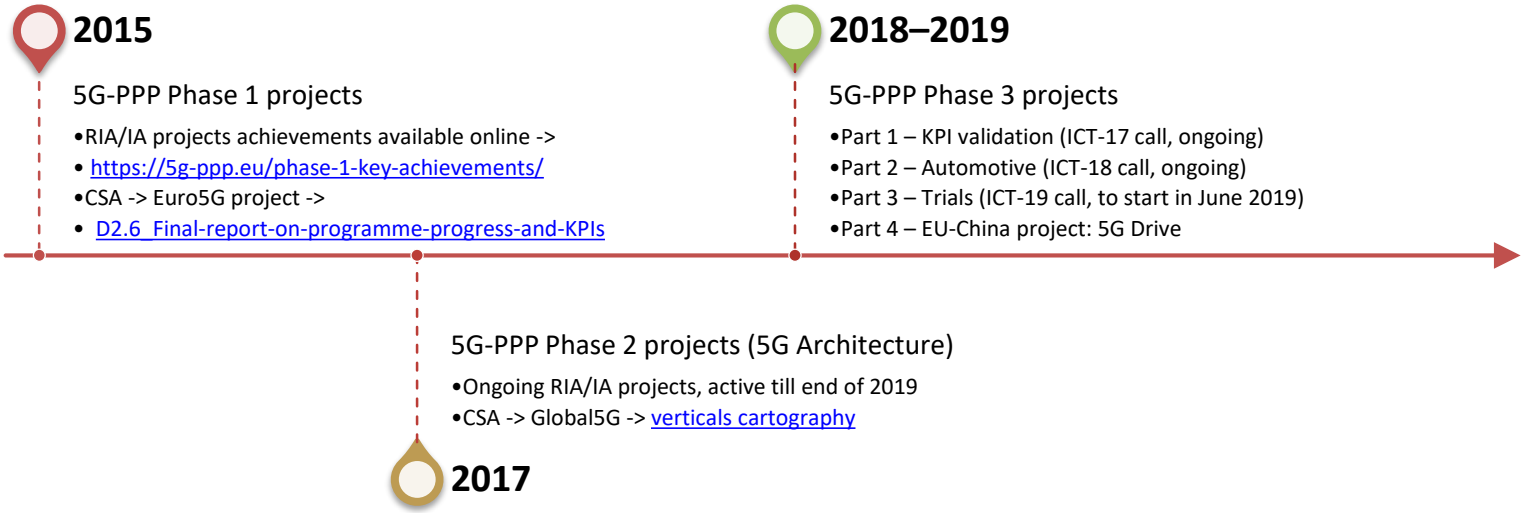
5G IA – 5GPPP

- 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

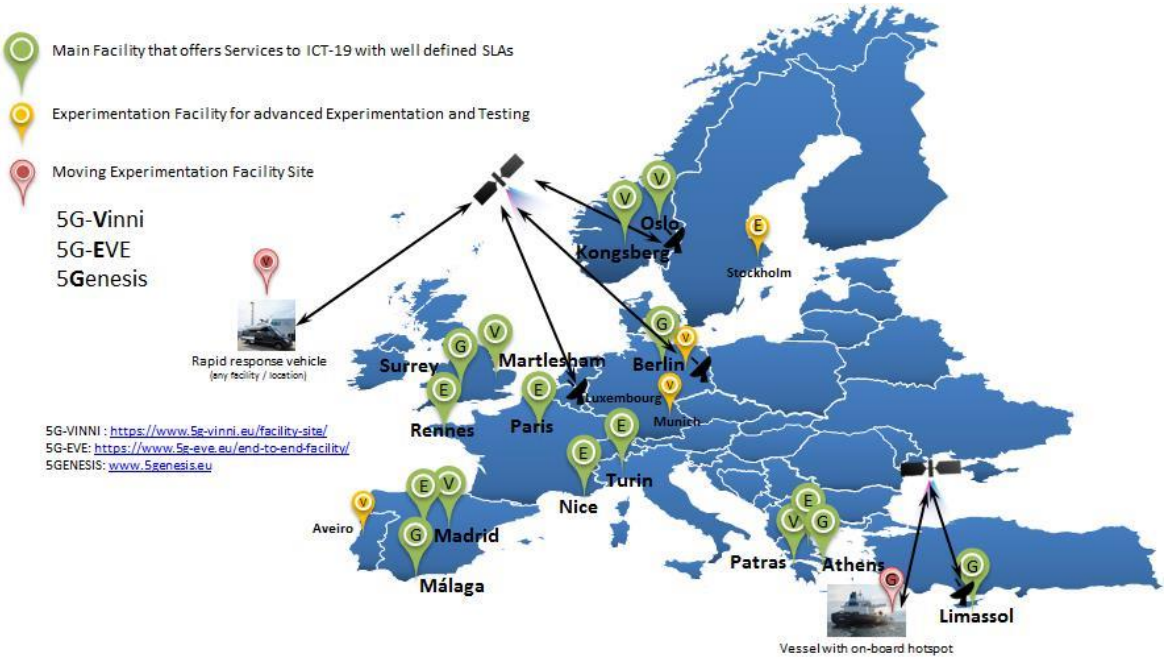


5G-PPP working groups

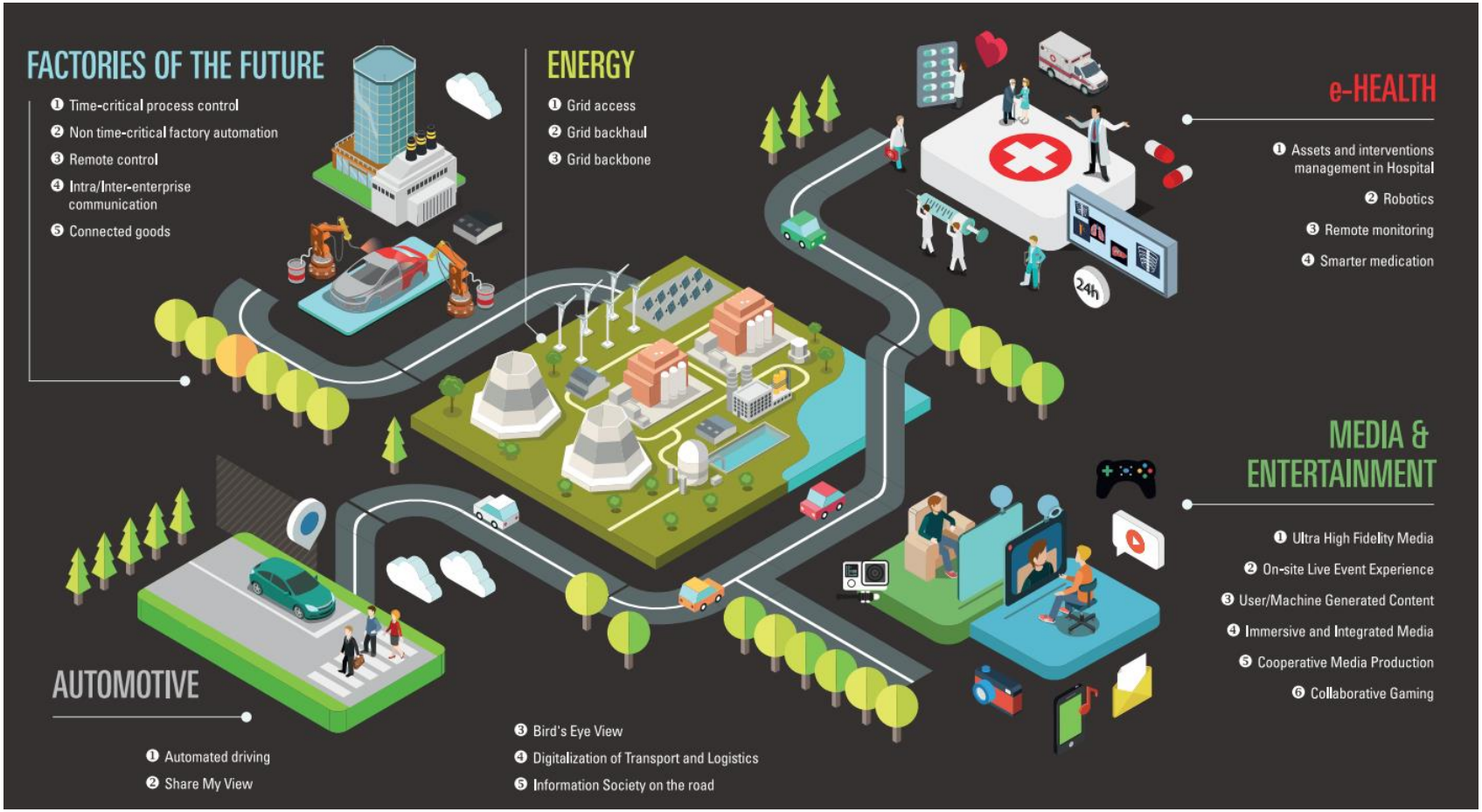
- 5G-PPP Working Groups (WGs)
  - Originated by 5G IA (6):
    - Pre-Standardization -> Alignment with ETSI, 3GPP, IEEE, ITU-R
    - Security
    - Vision & societal challenges
    - Spectrum
    - IMT-2020 Evaluation Group -> one of the 11 independent 5G Evaluation Groups from ITU-R
    - Trials -> 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



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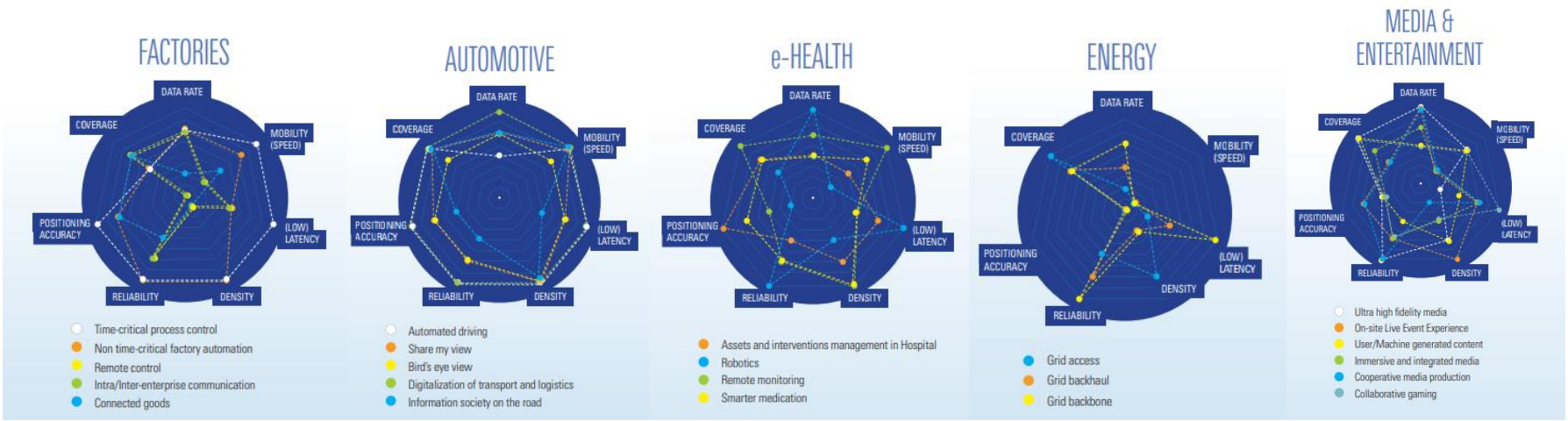
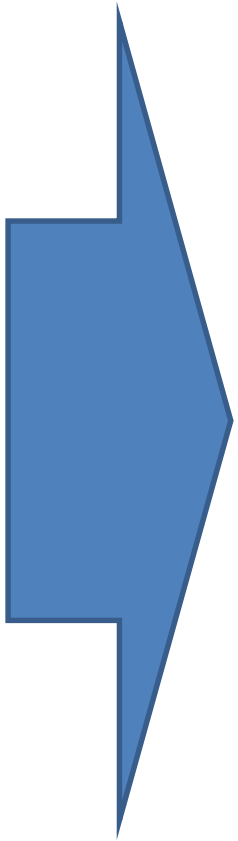
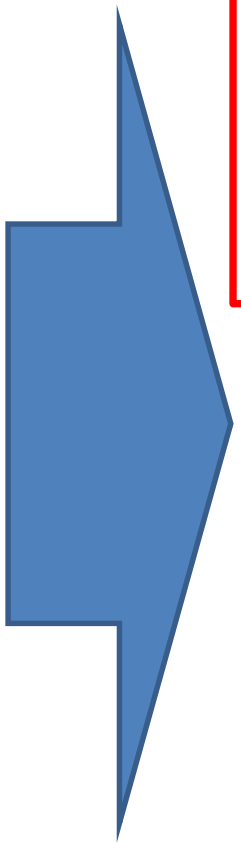


5G Advancements



- **New Architecture**
  - Advanced core network functions / NG RAN
  - Incorporate SDN/NFV (NFV MANO)
    - Decupling of control and data plane
    - Decupling of functions from the hardware
- **Network Slicing**
  - eMBB, URLLC, mMTC | 8 subclasses pes 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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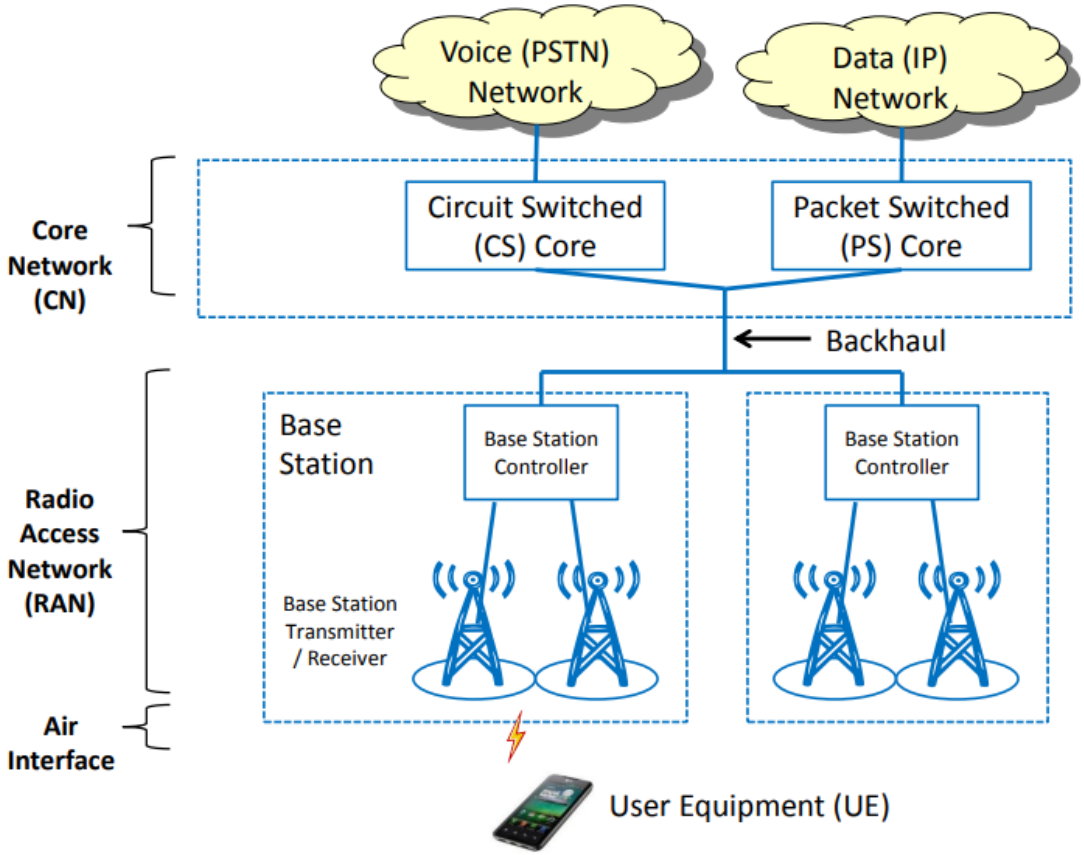
2G / 3G Mobile Network Architecture



Core Network

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

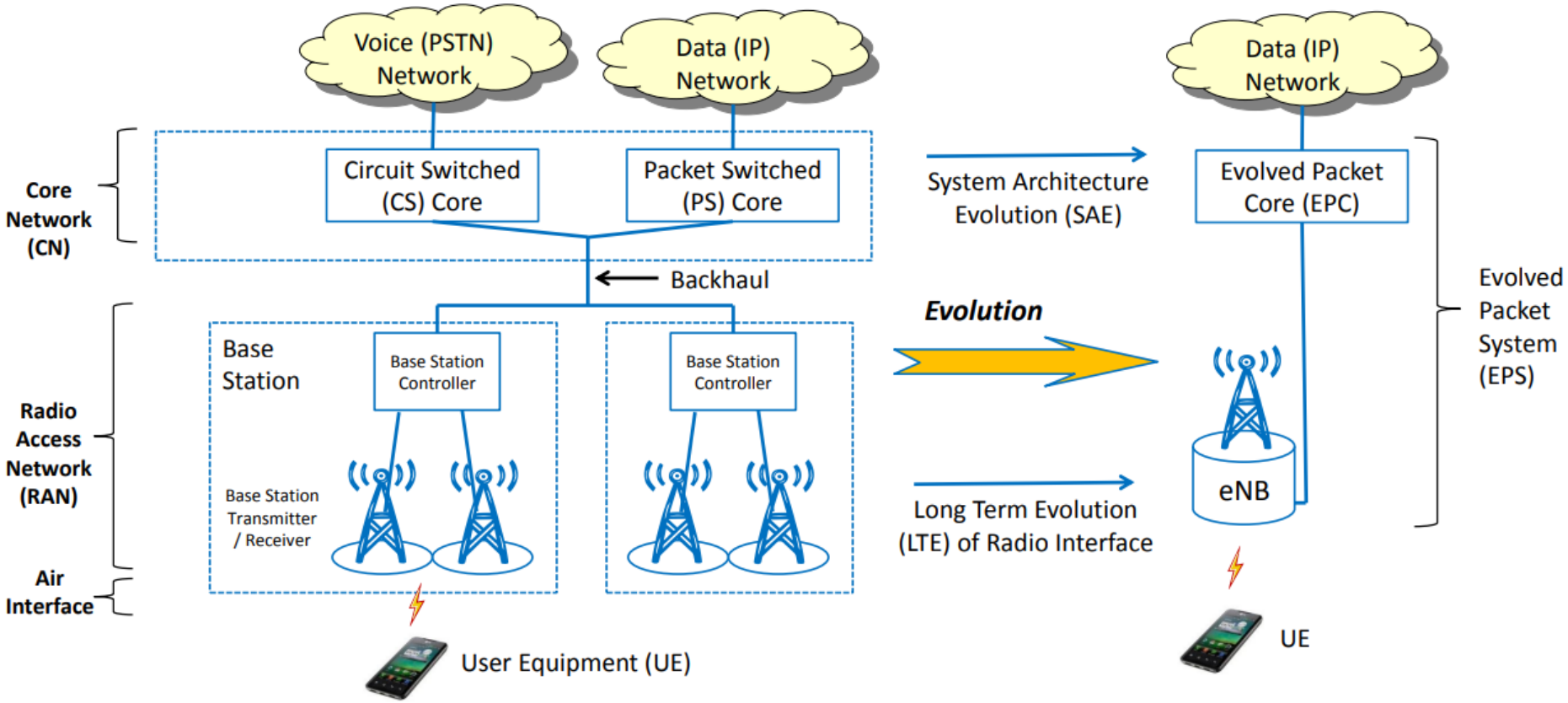
Backhaul

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

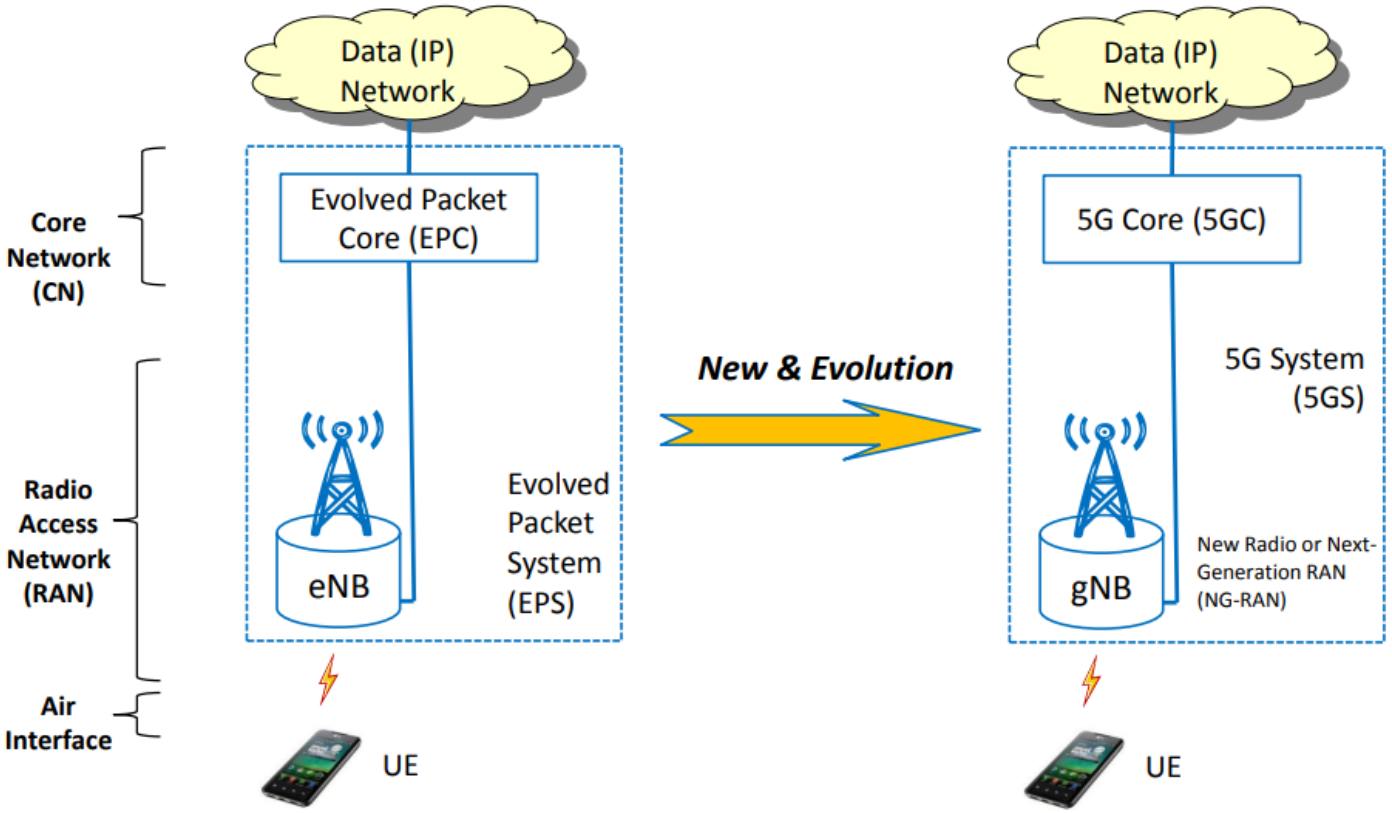
Access Network

- Connects devices over the air
- Allows mobility and handovers

4G Mobile Network Architecture



5G Mobile Network Architecture

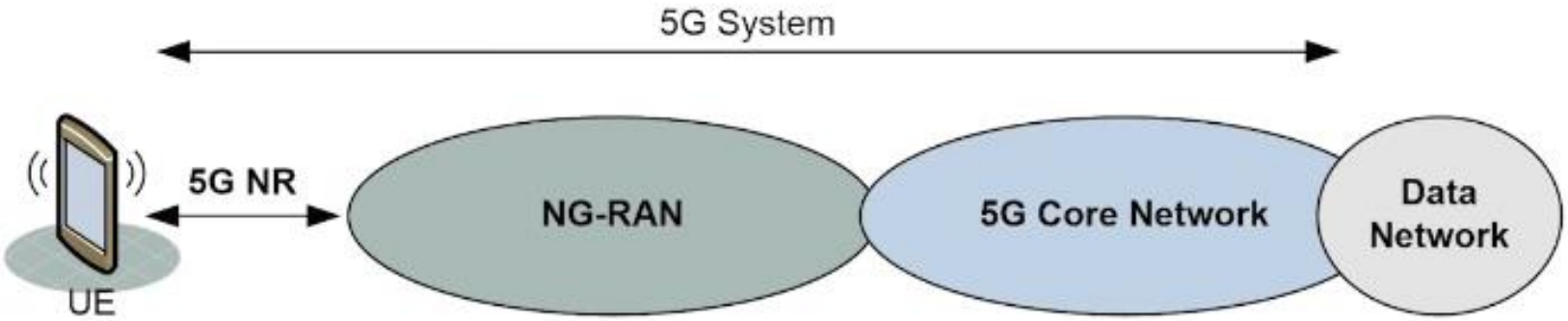


5G System is defined as 3GPP system consisting of 5G Access Network (AN), 5G Core Network and UE. The 5G System provides data connectivity and services.

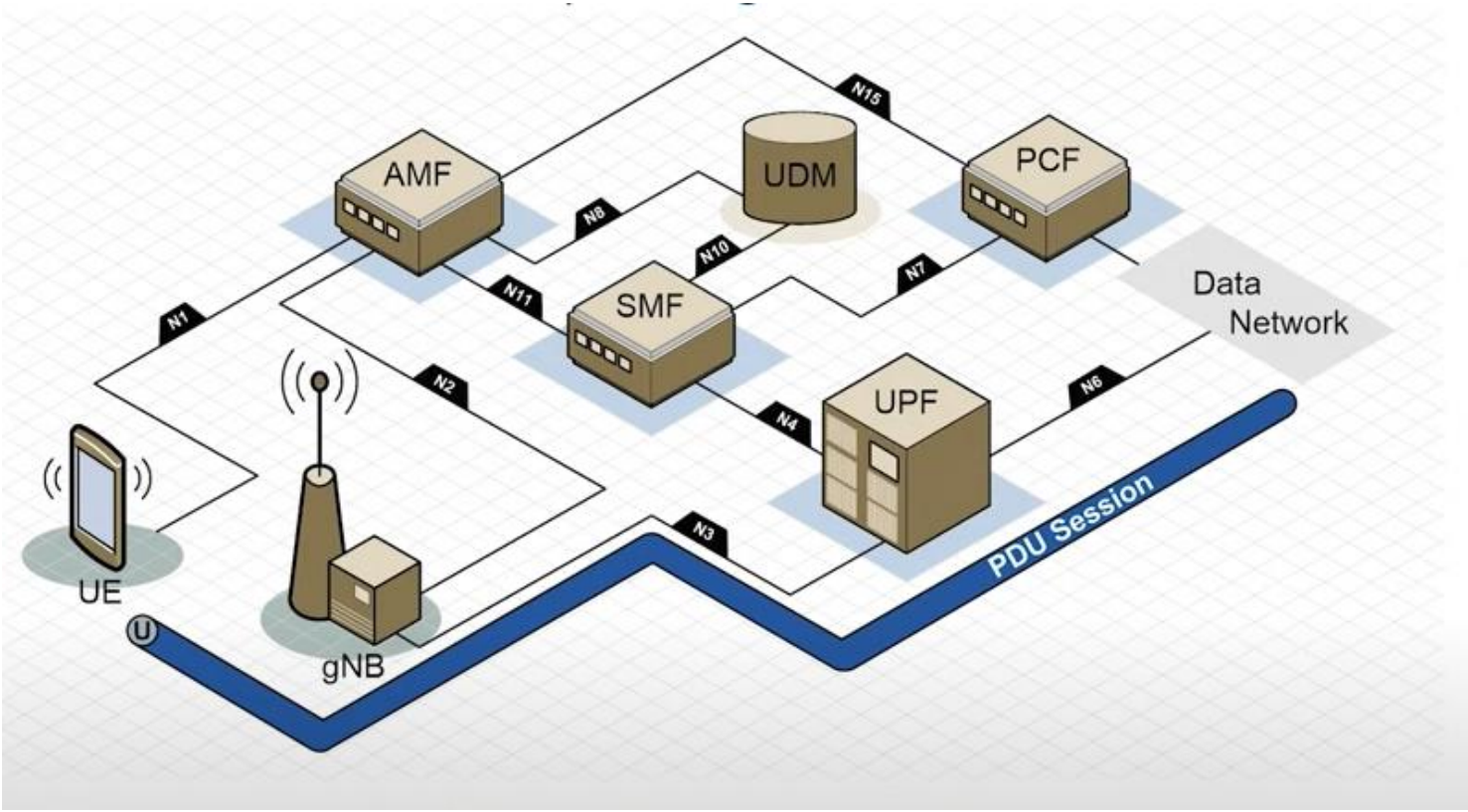
3GPP TS 23.501: System Architecture for the 5G System; Stage 2

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

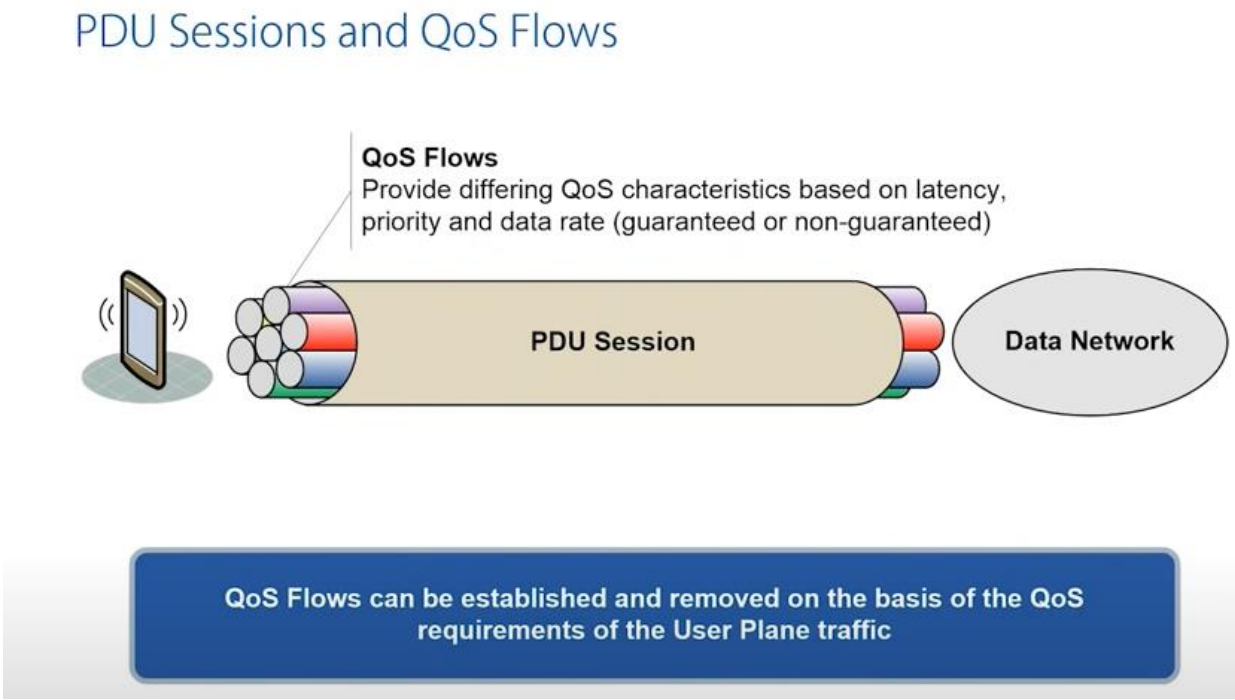
Access and Core Network

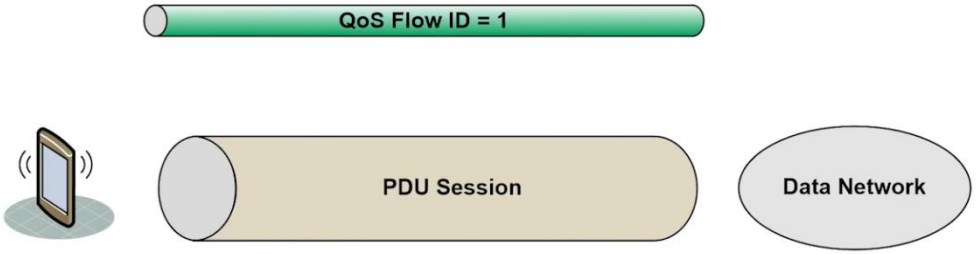


General 5G architecture



Data flow


PDU Sessions and QoS Flows
QoS Flows
Provide differing QoS characteristics based on latency, priority and data rate (guaranteed or non-guaranteed)
PDU Session
Data Network
QoS Flows can be established and removed on the basis of the QoS requirements of the User Plane traffic


QoS Flow ID = 1
PDU Session
Data Network

Access and Mobility-Management Function

Similar to MME in 4G
Location
Paging
Handover

Authentication
Temporary ID

International Mobile Subscriber Indentifier

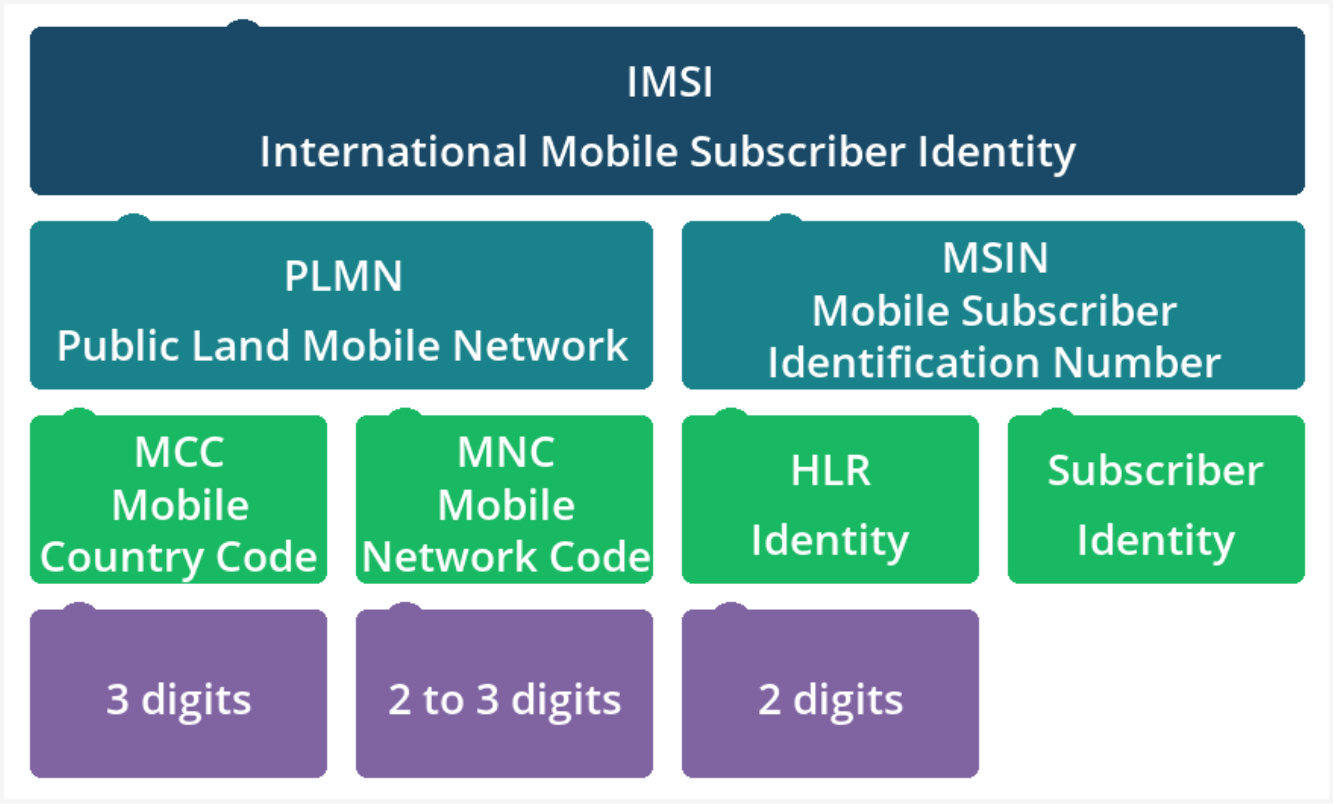
3GPP identifiers 23.003

IMSI

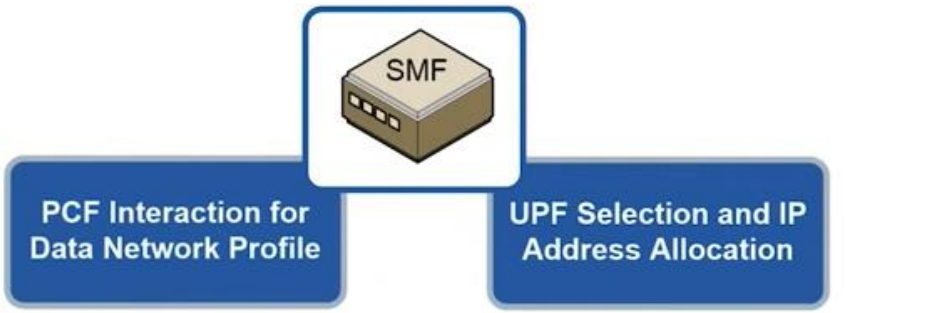
Identifies the SIM. It includes the Home PLMN

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

Length : 15 digits or less



Session Management Function

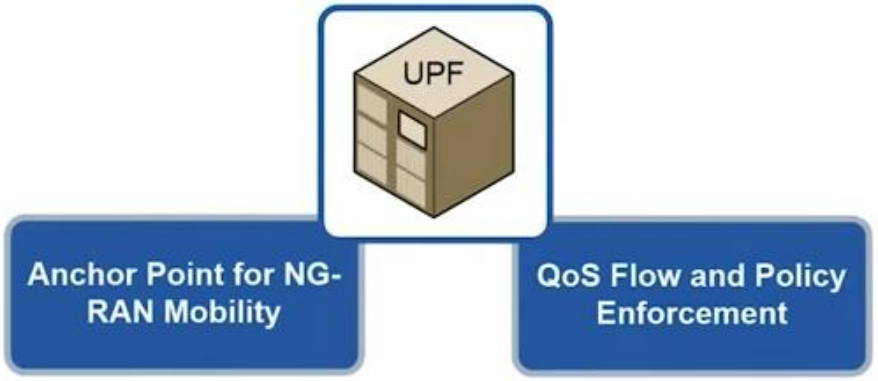


In 4G mobility and session functionality were both in one entity:
MME – In 5G this is split to AMF and SMF respectively.

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

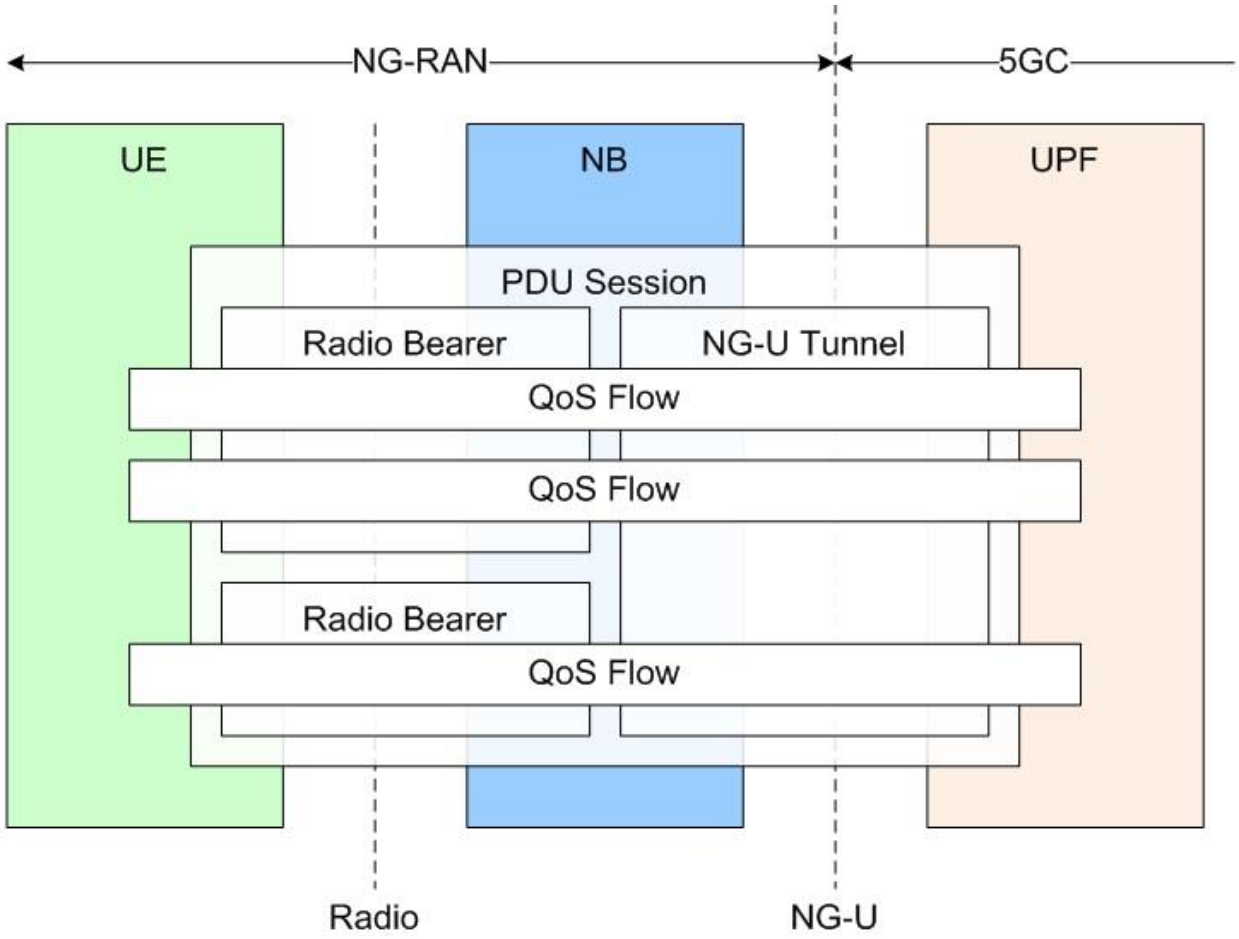
User Plane Function



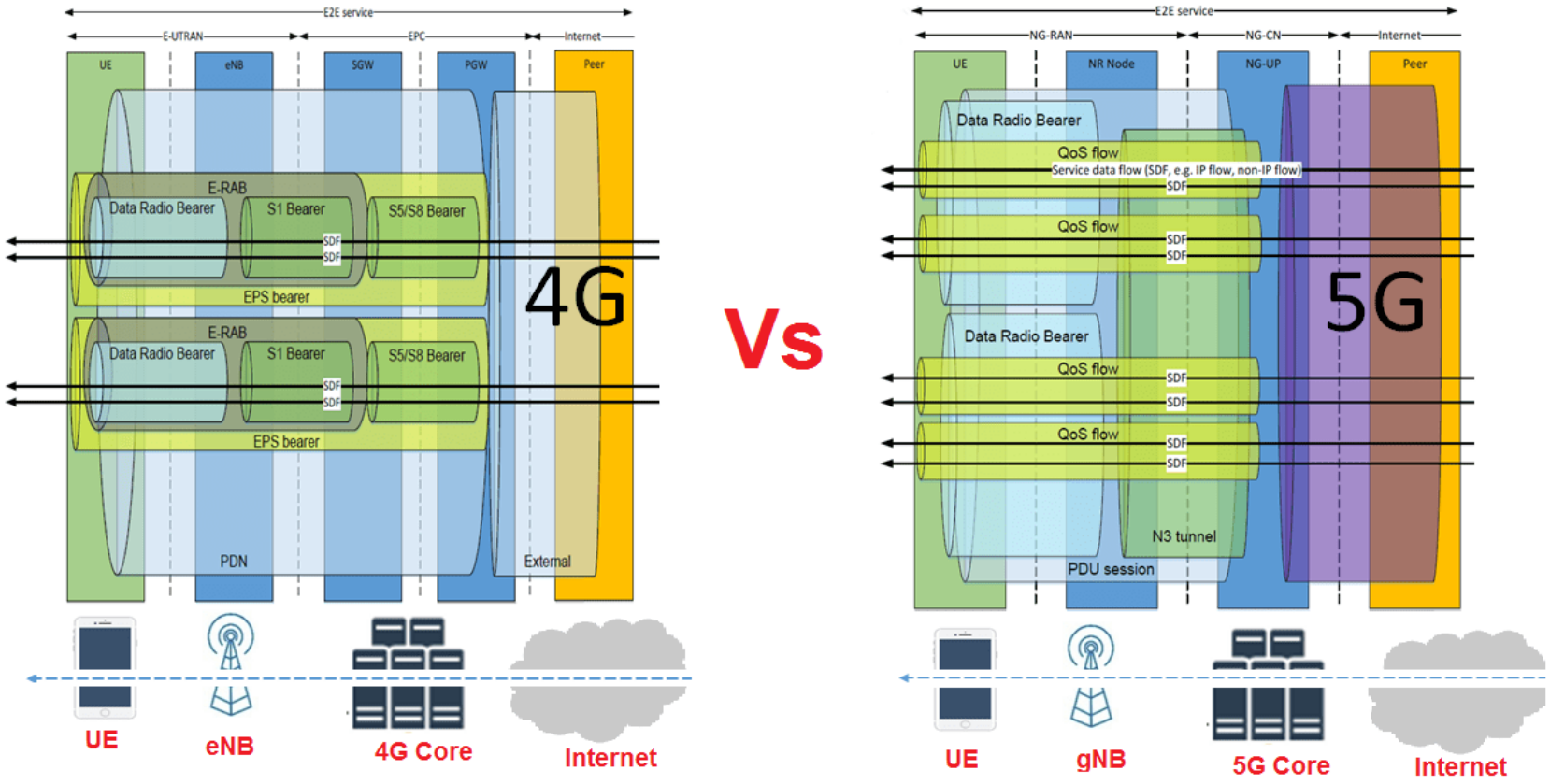
Remains the same for a PDU session

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

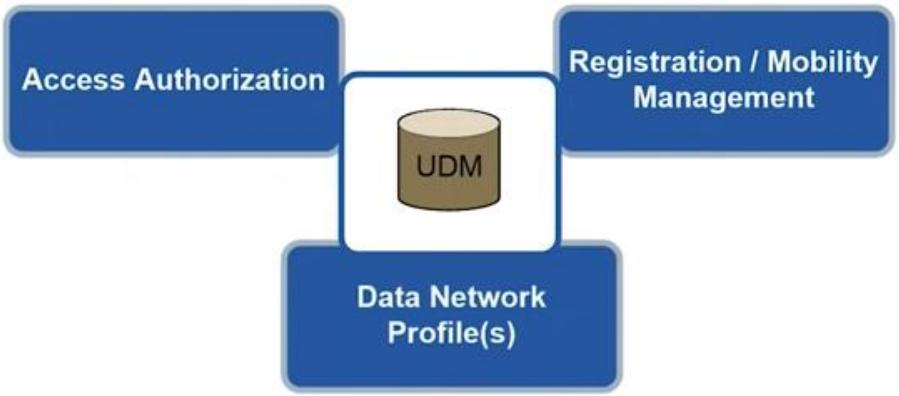
User Plane Function



User Plane Function

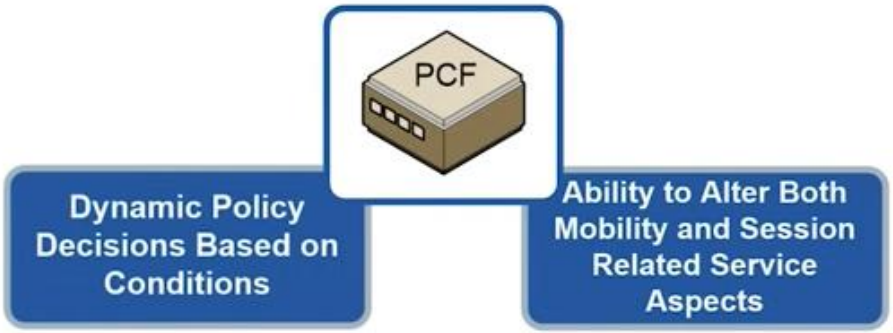


Unified Data Management



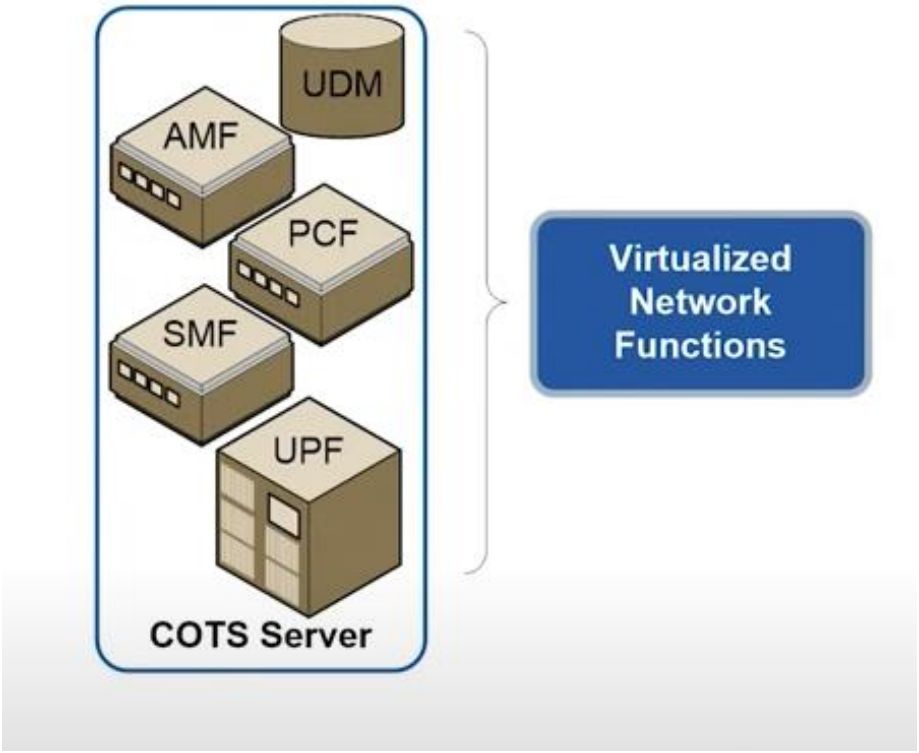
- Central repository of subscriber information
- Access authorization
- Tracking information
- Data network profile (what the user can and cannot do)

Policy Control Function



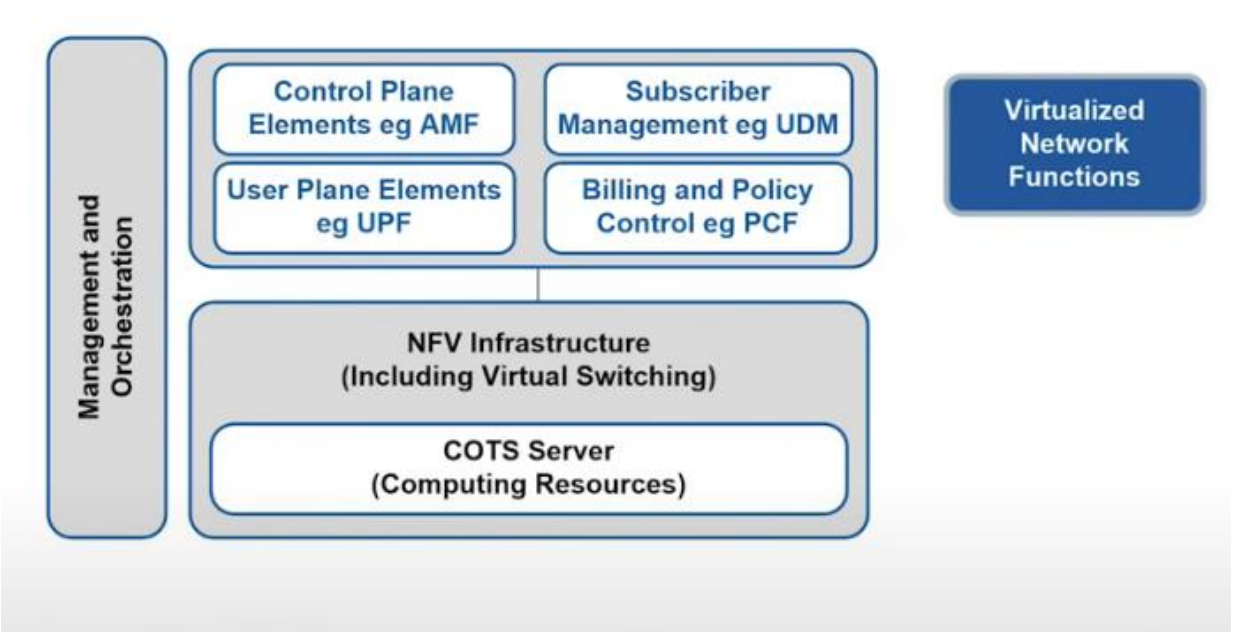
- Knowledge of network conditions
- Real time decisions based on these conditions
- May deny or alter service if conditions do not allow
- Information from the Data Network (external) as well

Network Function Virtualization



- Most of NFV nodes may be virtualized (software processes)
- Running in Commercial Off The Self (COTS) Servers

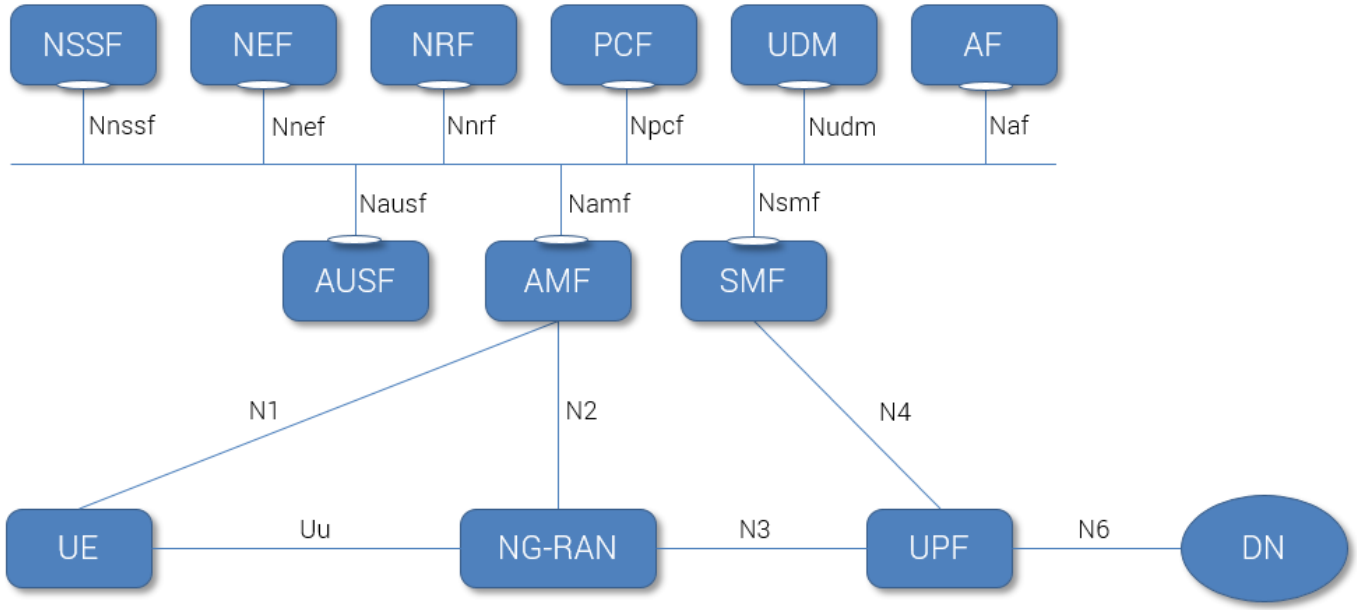
Network Function Virtualization



- Flexibility
- Scaling through software
- MANO in needed
- 5G is a series of virtualized processes
- API driven

5G Architecture Virtualization

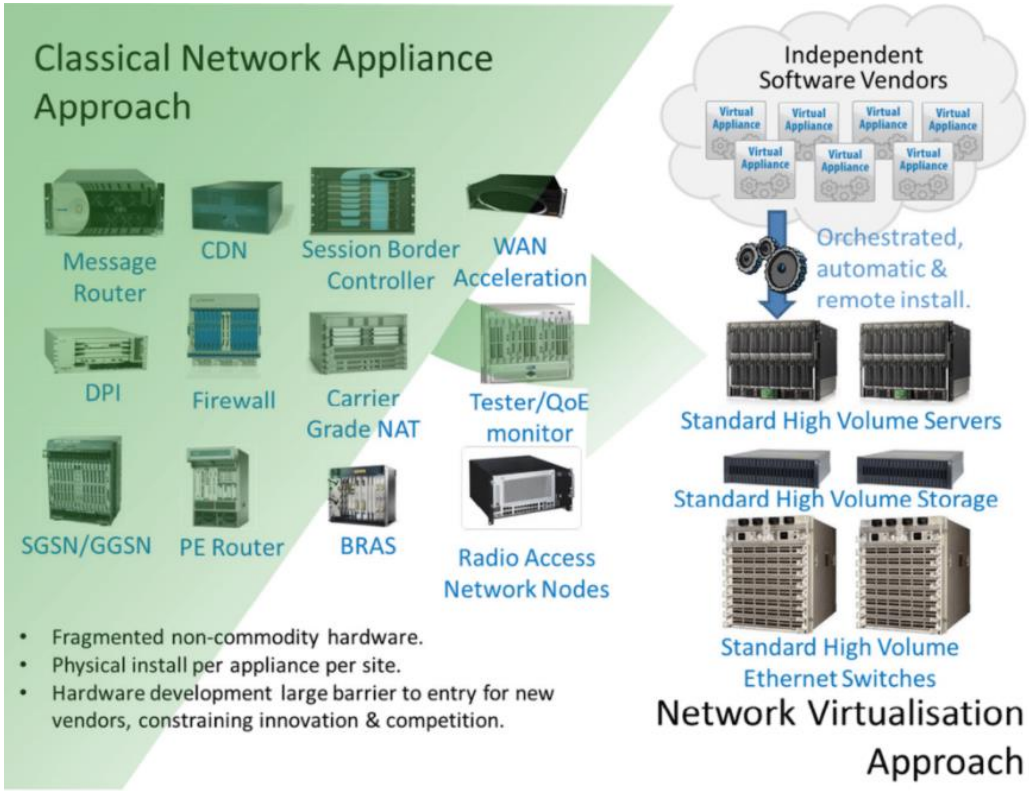
Service-Based Architecture (SBA)



5G Architecture Virtualization

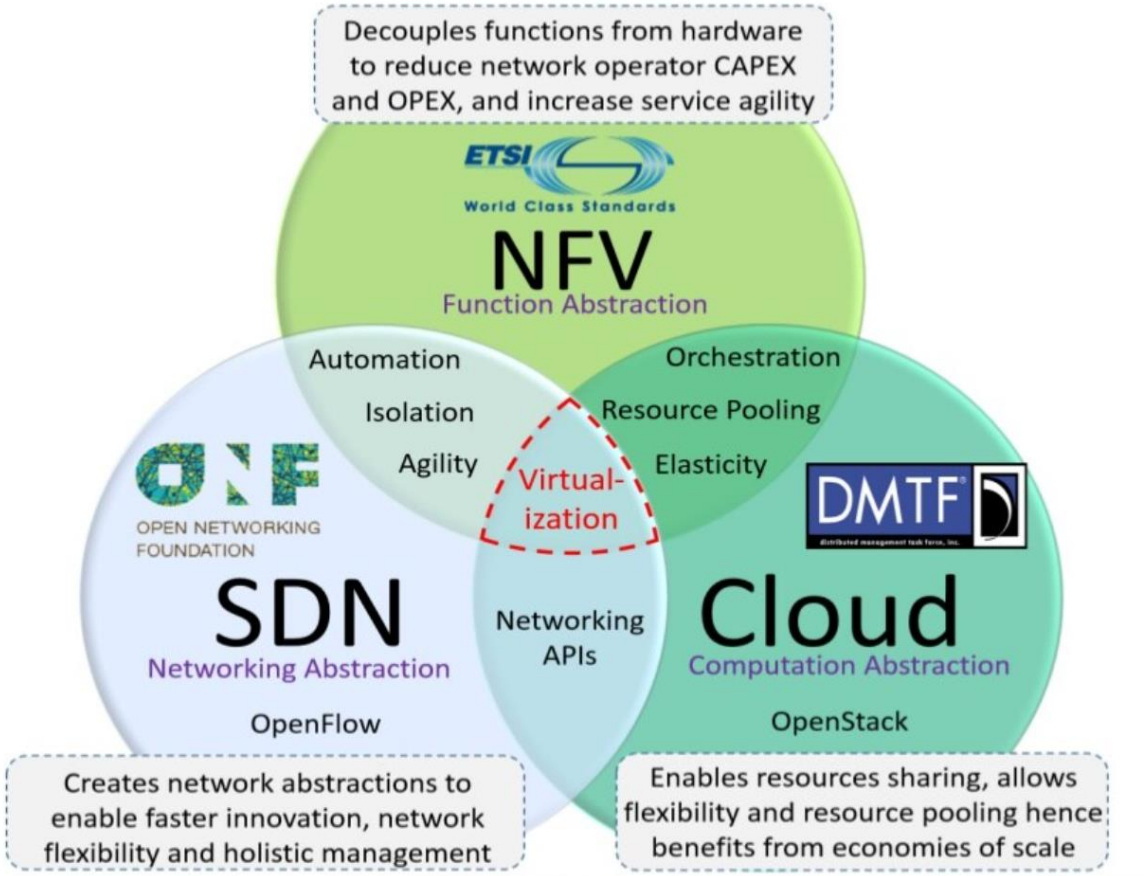
- **Authentication Server Function (AUSF):** supports the Authentication Server Function (AUSF)
- **Policy Control function (PCF):** supports unified policy framework to govern network behaviour, provides policy rules to control plane functions
- **Core Access and Mobility Management Function (AMF):** supports mobility management, access authentication and authorization, security anchor functions and context management
- **Session Management Function (SMF).** Supports session management, selection and control of UP functions, downlink data notification and roaming
- **User Plane Function (UPF):** is the anchor point for inter/intra RAT mobility and the external PDU session point of interconnection, supports packet routing and forwarding, QoS handling for user plane, packet inspection and policy rule enforcement
- **Network Exposure Function (NEF):** provides a means to securely expose the services and capabilities provided by 3GPP NFs.
- **NF Repository Function (NRF):** maintains the deployed NF Instance information when deploying/ updating/removing NF instances
- **Slice Selection Function (SSF):** supports the functionality to bind a UE with a specific slice

Network Function Virtualization

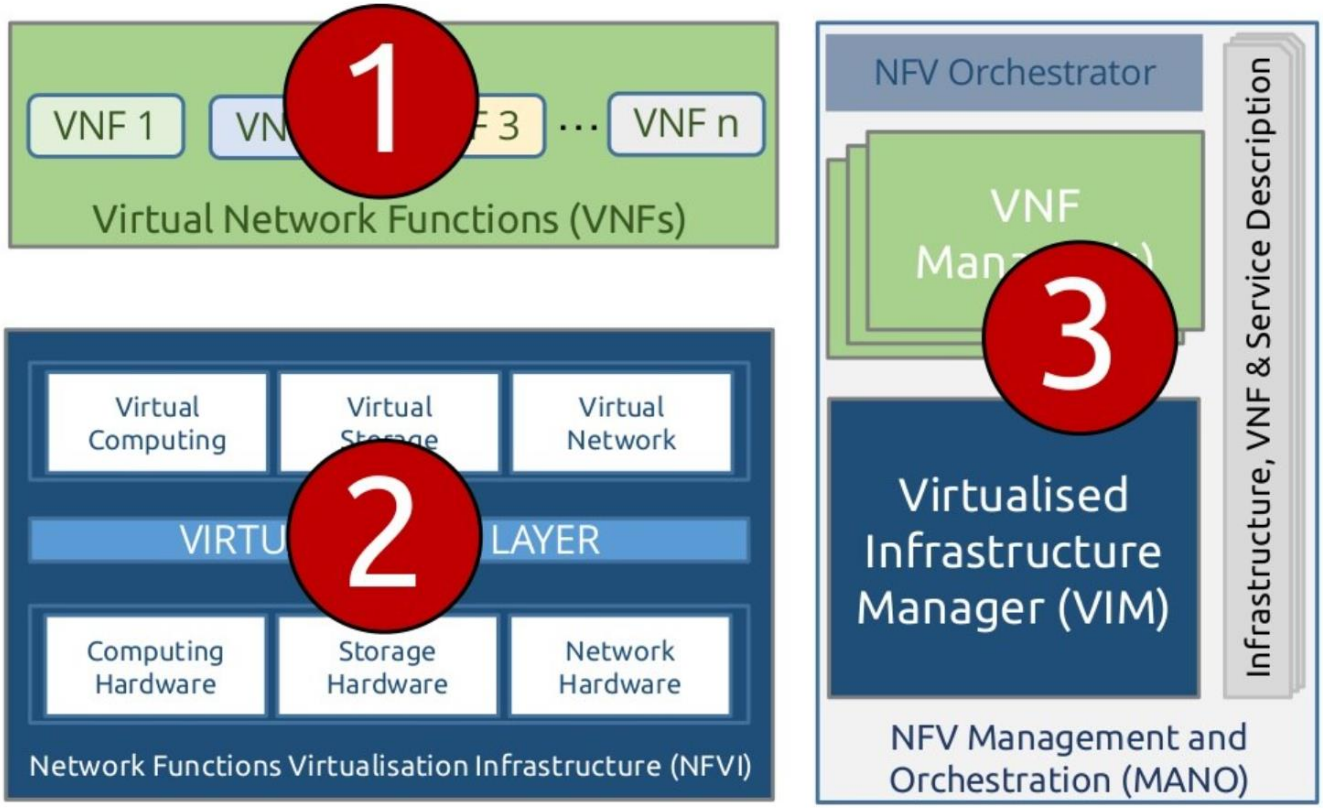


- Fewer platforms
- More flexibility
- More efficient use of resources
- Use less power
- SLAs needed

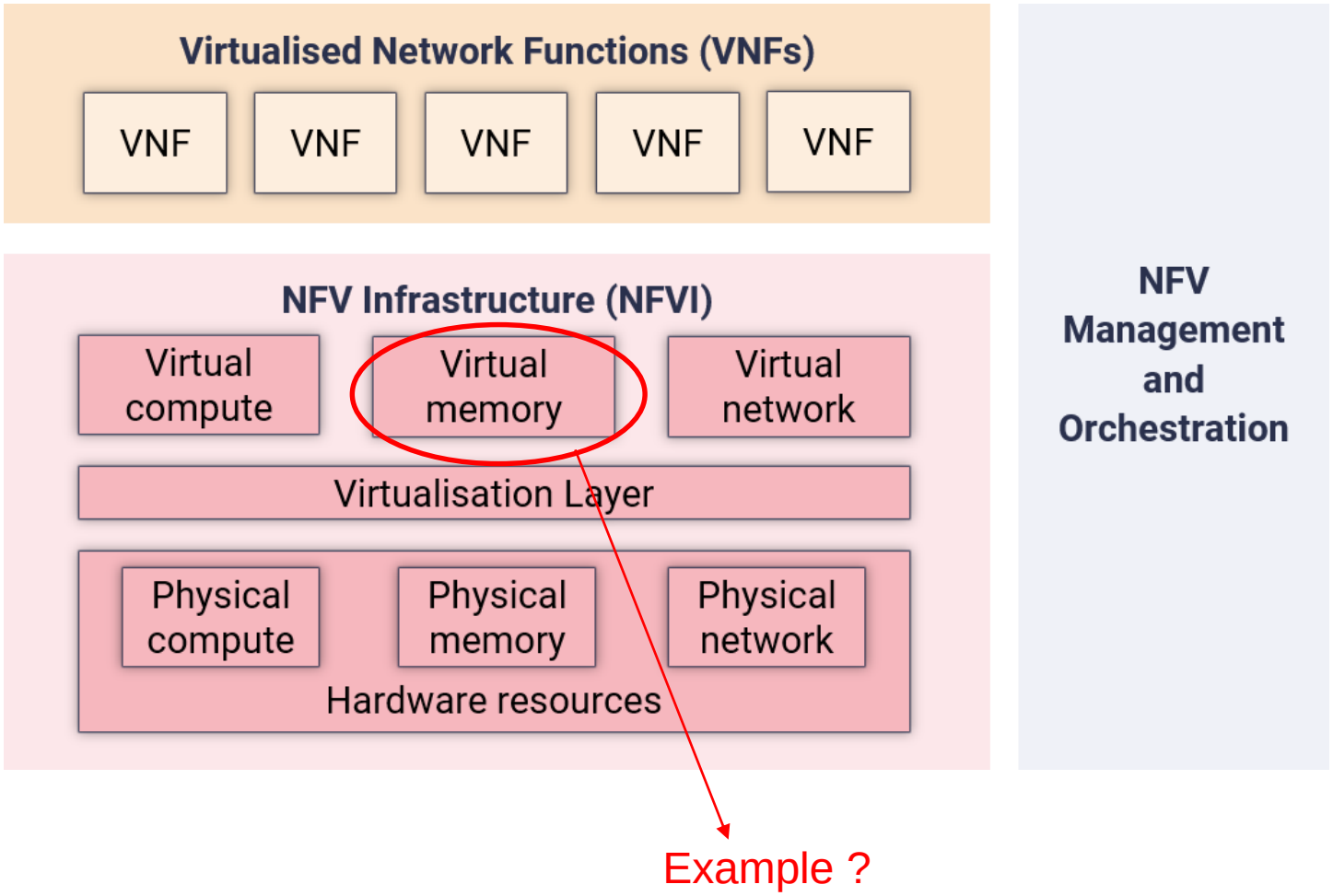
Network Function Virtualization



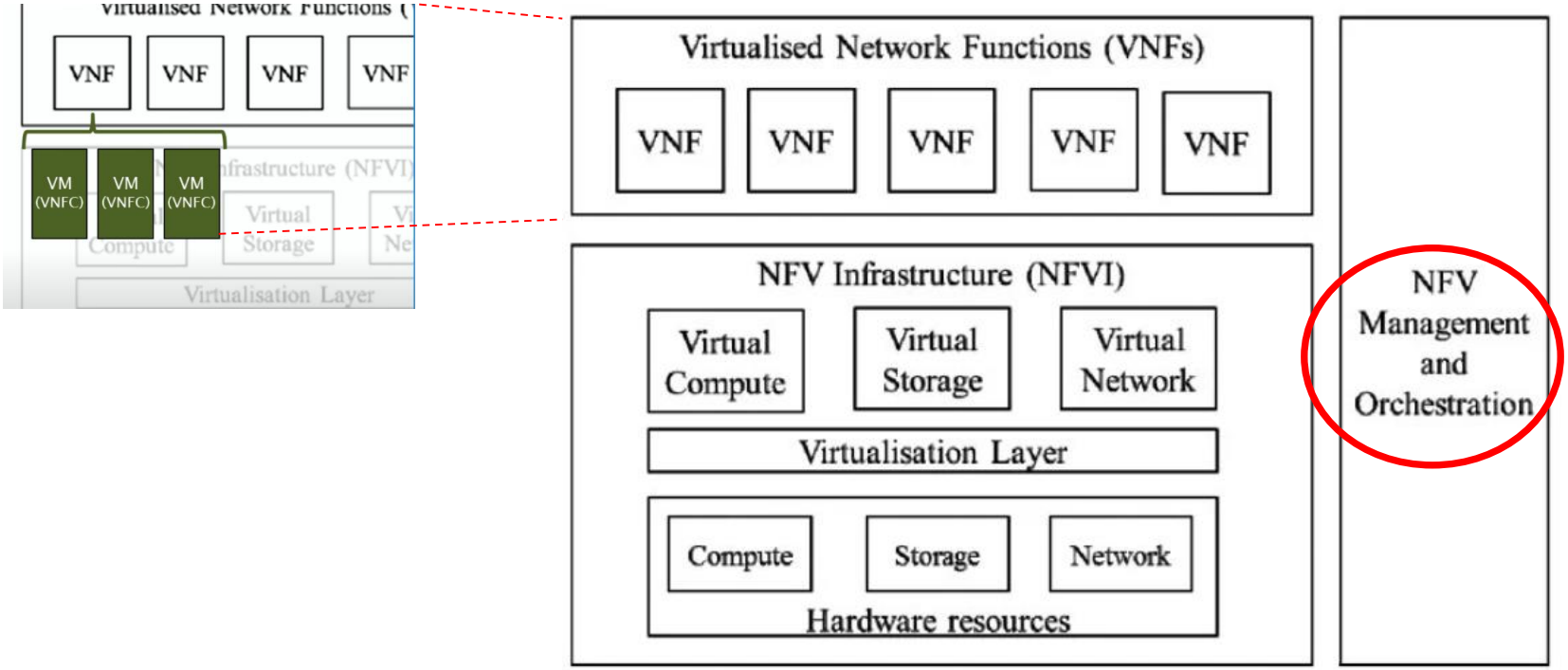
Network Function Virtualization



Network Function Virtualization



Network Function Virtualization



What a MANO should do

- **Implementable as software only (even virtualized)**
- **Distributed across NFVI**
- **Support full automation without human intervention**
- **Avoid single-point-of-failure**
- **Use standards or “de-facto” standards**
- **Support munti-ventor environment**

What a MANO actually does

- **Initiate**
- **Scale**
- **Update/upgrade**
- **Terminate**

VNFs