Wide Area Wireless Networks- from 3G to 6G: evolution, integration, challenges

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- **Acknowledgement**

- This overview text and analysis is compiled and structured, based on several public documents, conferences material, studies, research papers, standards, projects, surveys, tutorials, etc. (see specific references in the text and Reference list).
  - The selection and structuring of the material belong to the author.
  - **Given the extension of the topics, this presentation is limited to a high- level view only.** The list of topics selected to be discussed is also limited.

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Wide Area Wireless Networks- from 4G to 6G: evolution, integration, challenges

- **Motivation of this talk**
  - Last decade: increased set of capabilities required for the current and future networks and services, especially related to mobile communications
  - Complex sets of **requirements**
    - **Communication infrastructure**: bandwidth, flexibility, capacity, mobility, geographic coverage, large communities of users, response time, number of user terminals, energy saving, space communications, etc.
    - **User applications and services**: flexibility, integration, intelligent behavior, large set of service types, security and privacy, etc.
    - **Need of novel technologies integration**: **Software defined Networking (SDN), Network Function Virtualization (NFV), Cloud/Edge computing, Artificial Intelligence/Machine Learning (AI/ML)**
    - **Objective**: Internet of Everything
  - Driving forces for novel generation communication technologies 5G, 6G,..development: IoT, smart cities, industry, governance, IoV/automotive, safety/emergency, entertainment apps., environment, etc.
  - Significant field/commercial deployment of 5G, in many countries
  - Research, prototypes, trials in progress for 6G
  - Standardization/fora organizations –involved
    - **3GPP, 5GPP, ETSI, ITU-T, GSMA, ONF, NGNM, IETF, IEEE, etc.**

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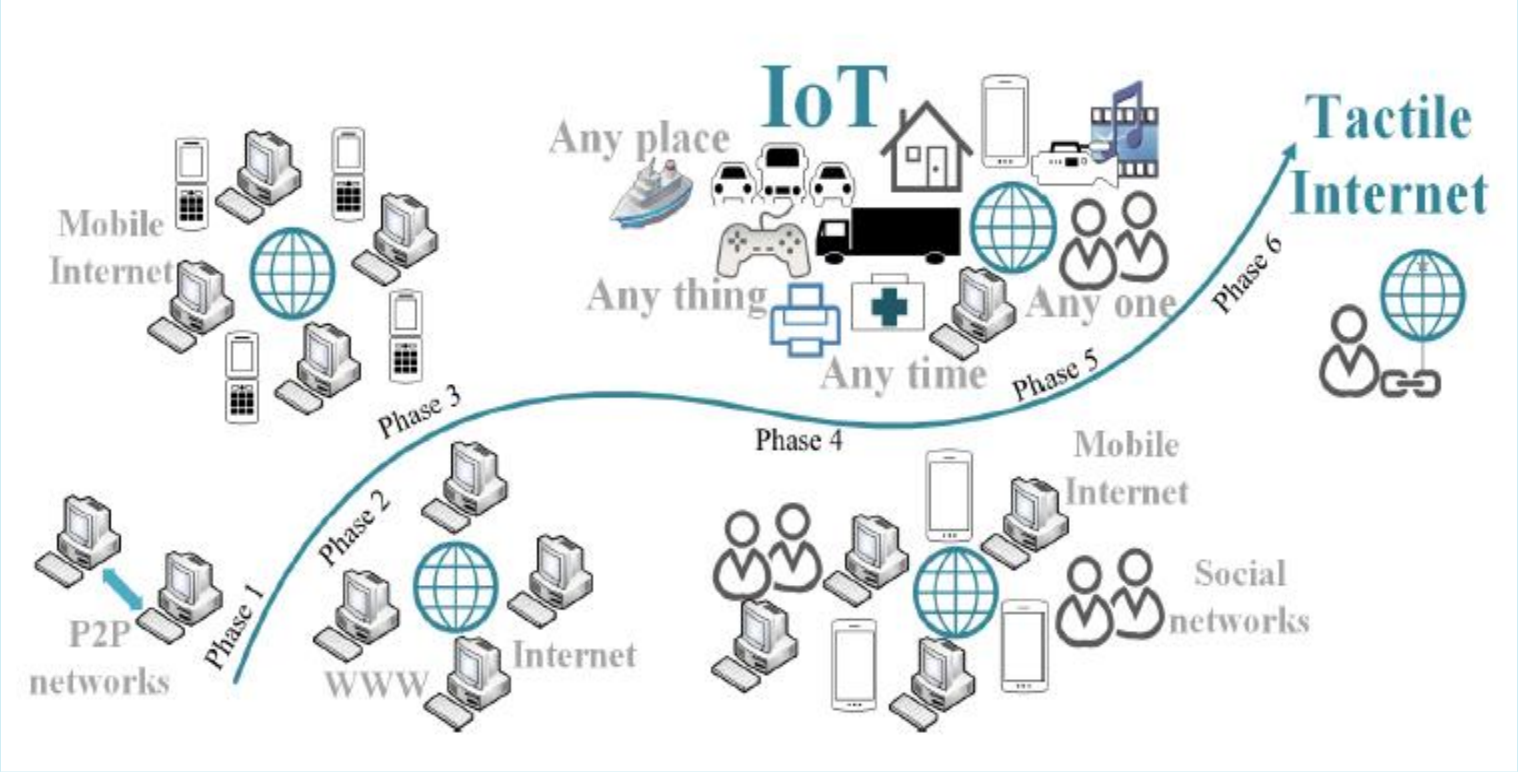
1. Introduction

1.1 Internet evolution

- Several phases: P2P, WWW, Mobile Internet, Social networks, IoT, Tactile Internet, ….
- Today: strong trend to develop and deploy IoT in many domains

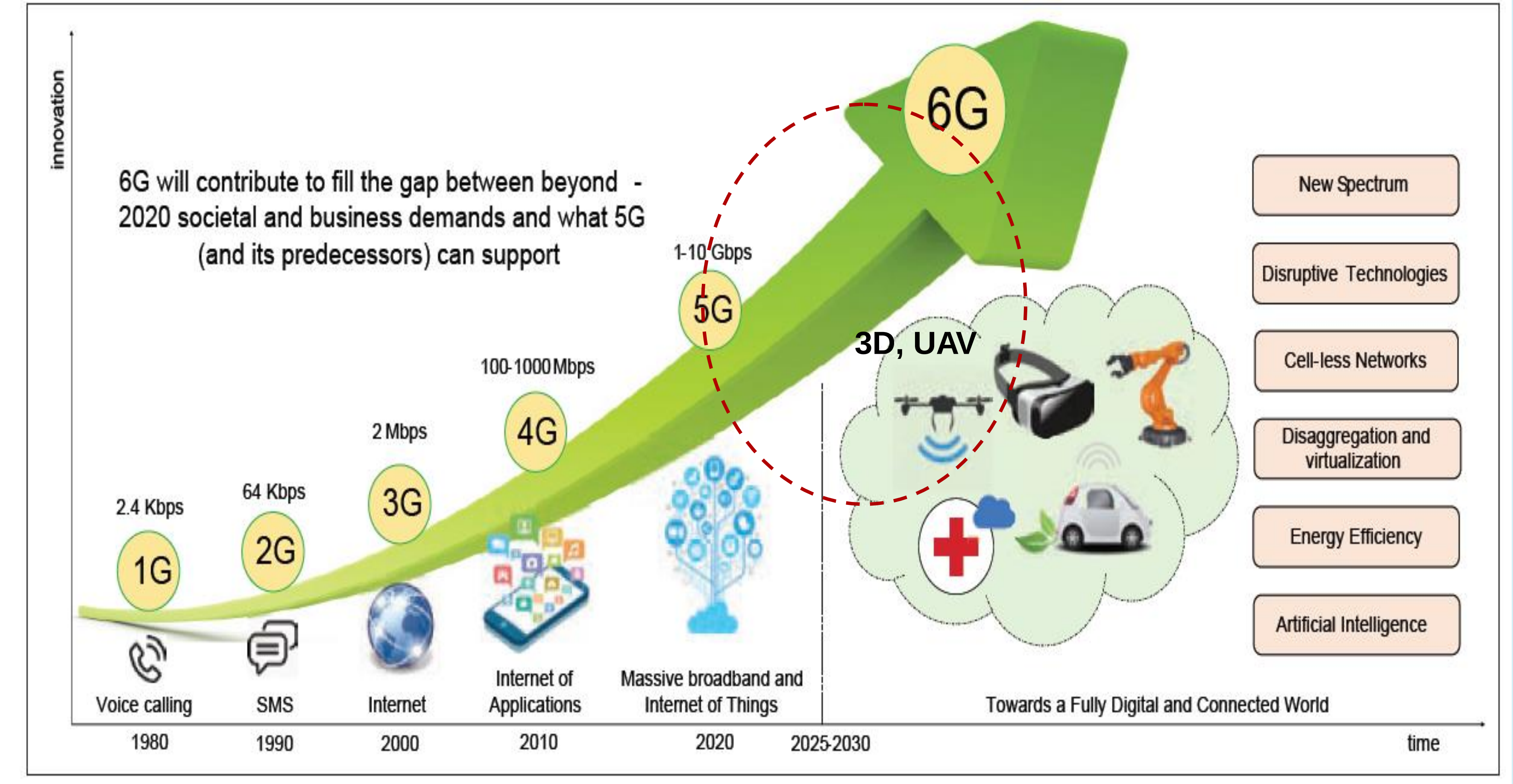


Source: P.Porambage,et.al., "Survey on Multi-Access Edge Computing for IoT Realization", arXiv:1805.06695v1 [cs.NI] May 2018

1. Introduction

1.2 Mobile communications evolution

- **Historical and estimated 1G ..6G evolution**

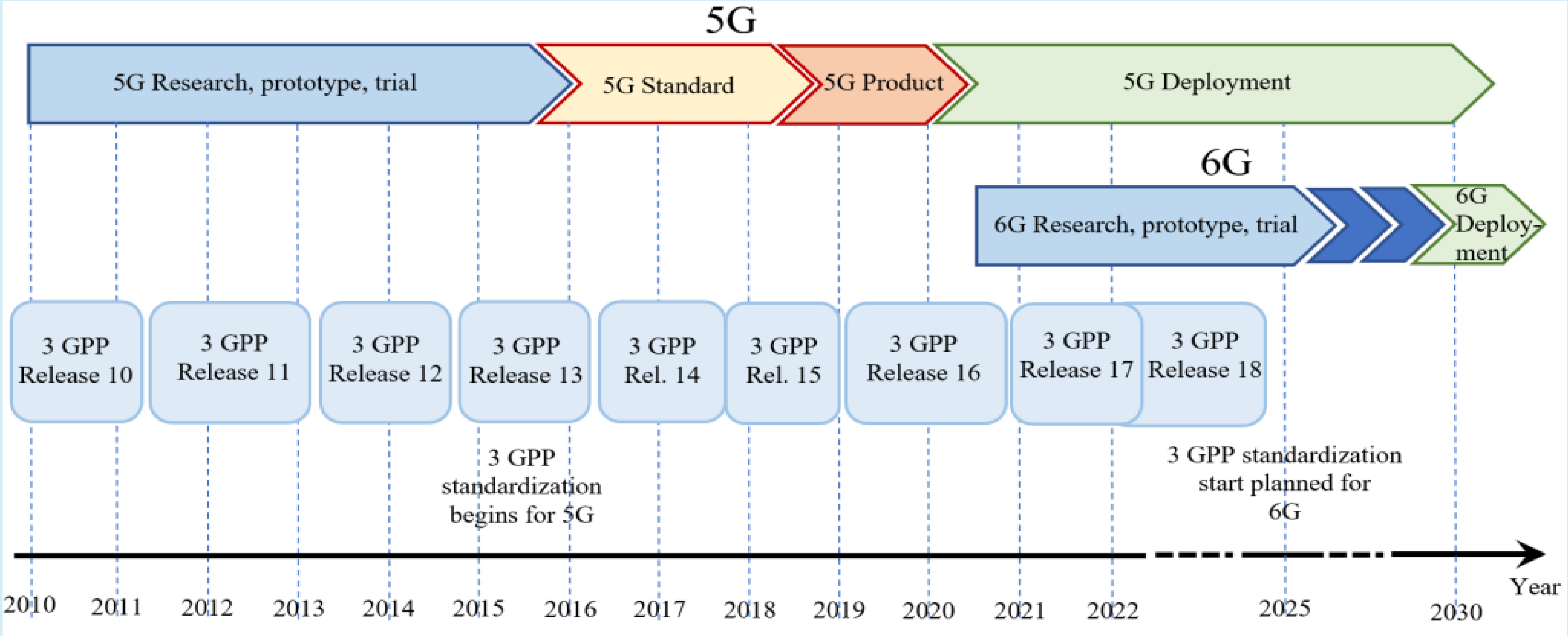


Source: M. Giordani, et al., "Toward 6G Networks:Use Cases and Technologies", IEEE Communications Magazine , March 2020

1. Introduction

1.3 Standardization phases

- 5G, 6G, and 3GPP standard versions- roadmap
  - ***3rd Generation Partnership Project (3GPP)*** **: umbrella term for a number of standards organizations which develop technologies and protocols for mobile communications**



Sources: C. Schroeder, "Early indications of 6G," Microwave Journal, vol. 64, pp. 5–9, 2021.
International Telecommunication Union, IoT Standards Part II: 3GPP Standards. Training on Planning Internet of Things (IoTs) Networks. U.S.: ITU Report, 2018.

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2. 3G, 4G-LTE Networks

2.1 Main actors involved in standardization – under 3GPP

- **3rd Generation Partnership Project (3GPP)** (>1998) - umbrella term for a number of standardization organizations developing specifications for protocols, development and maintenance in mobile telecommunications

Organization	Country/region
Association of Radio Industries and Businesses (ARIB)	Japan
Alliance for Telecommunications Industry Solutions (ATIS)	USA
China Communications Standards Association (CCSA)	China
European Telecommunications Standards Institute (ETSI)	Europe
Telecommunications Standards Development Society (TSDSI)	India
Telecommunications Technology Association (TTA)	South Korea
Telecommunication Technology Committee (TTC)	Japan

2. 3G, 4G-LTE Networks

2.1 Main actors involved in standardization – 3GPP

- **Target technologies of the 3GPP**
  - **GSM** and related **2G, 2.5G, GPRS and EDGE**
  - UMTS and related **3G, 3.5G** standards including HSPA and HSPA+
  - **LTE** and related **4G** standards, **LTE Advanced** and LTE Advanced Pro
  - **5G** and related 5G standards, 5G-Advanced
  - Evolved IP Multimedia Subsystem (**IMS**)
  - **6G**
  - ….
- **3GPP Work domains**
  - Radio Access Networks
  - Services and Systems Aspects
  - Core Network and Terminals

Acronyms
GSM-Global System for Mobile Communications
GPRS/2.5G- General Packet Radio Service
EDGE Enhanced Data rates for GSM Evolution
HSPA – High Speed Packet Access
UMTS-Universal Mobile Telecommunications System
LTE- Long Term Evolution

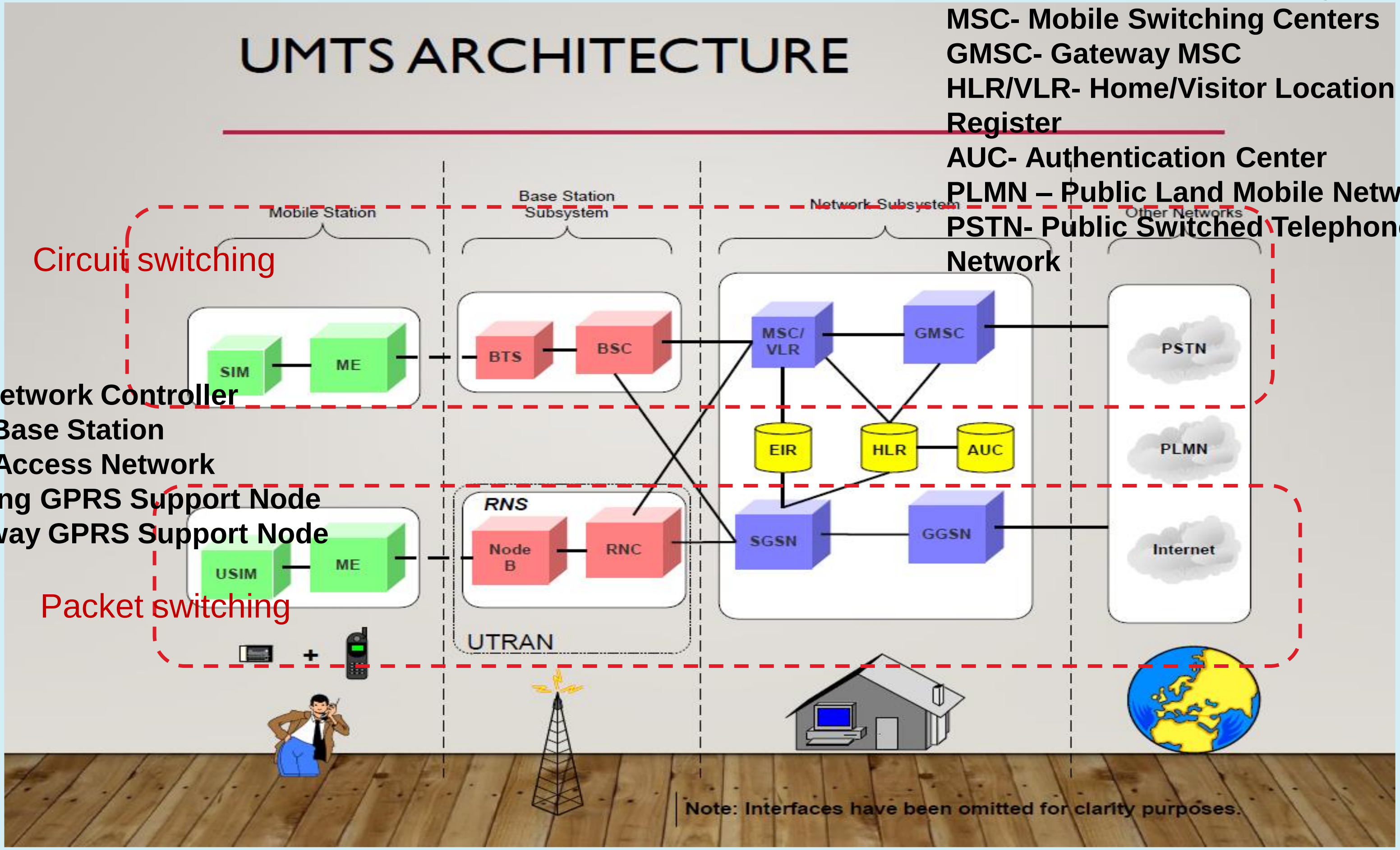
- **UMTS/3G** **-** upgrade from GSM via GPRS or EDGE
  - Data rates :144 kbps for rural; 384 kbps for urban outdoor; 2 Mbps for indoor and low range outdoor
  - Virtual Home Environment (VHE)
- **3.5G** - new features for UMTS, e.g.: -*Adaptive Modulation* and *Coding,* Fast Scheduling Backward compatibility with 3G, Enhanced Air Interface

2. 3G, 4G-LTE Networks

ME- Mobile Equipment
SIM – Subscriber Identity Module
BTS – Base Transceiver Station
BSC- Base Station Controller
RNC- Radio Network Controller
EIR- Equipment Identity Register
MSC- Mobile Switching Centers
GMSC- Gateway MSC
HLR/VLR- Home/Visitor Location Register
AUC- Authentication Center
PLMN – Public Land Mobile Network
PSTN- Public Switched Telephone Network

2.2 UMTS Architecture

- Main actors involved in standardization – 3GPP



RNC- Radio Network Controller
Node B – 3G Base Station
RAN – Radio Access Network
SGSN - Serving GPRS Support Node
GGSN- Gateway GPRS Support Node

Source: http://www.cse.unt.edu/~rdantu/FALL_2018_WIRELESS_NETWORKS/2G_3G_4G_Tutorial.ppt

2. 3G, 4G-LTE Networks

2.3 4G

- **Ultra-mobile broadband access**
  - For a variety of mobile devices
- **International Telecommunication Union (ITU) - 4G definition**
  - directives for IMT-Advanced
    - **All-IP packet switched network**
    - Peak data rates
      - Up to 100 Mbps for high-mobility mobile access
      - Up to 1 Gbps for low-mobility access
    - Dynamically share and use network resources
    - Smooth handovers across heterogeneous networks, including 2G and 3G networks, small cells- such as picocells, femtocells, and relays, WLANs
    - High QoS for multimedia-oriented applications
    - Circuit-switched voice- replaced with Voice over LTE (VoLTE)
    - Replace spread spectrum with *Orthogonal Frequency Division Multiplexing -OFDM*

- **Two candidates for 4G**
  - **IEEE 802.16 WiMax** - Enhancement of previous fixed wireless standard- for mobility
  - **3GPP Long Term Evolution (LTE)**

  - Both are similar in use of OFDM and OFDMA
  - **LTE has become the universal standard for 4G- adopted by all major carriers**

Source- 4G TECHNOLOGY : LTE (LONG TERM EVOLUTION) CS-1699 Wireless Networks, 2018

2. 3G, 4G-LTE Networks

2.4 LTE Overview

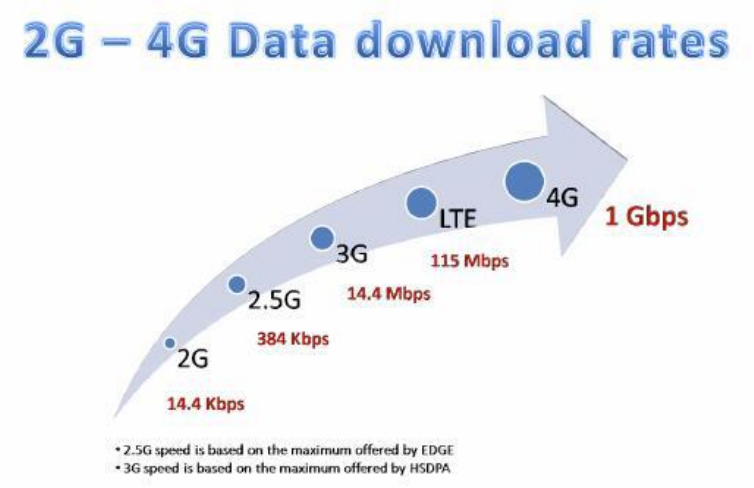
- Evolution**: GSM -> UMTS -> Long Term Evolution (LTE)**
  - Why LTE?? : A rapid increase of mobile data usage; new applications such as mobile TV, Web 2.0,MMOG (*Multimedia Online Gaming*), streaming contents
  - LT E started as a project in 2004 by (3GPP)
  - **LTE = subset of 4G (4G is the ITU-T definition)**
  - SAE (System Architecture Evolution) is the corresponding evolution of the GPRS/3G packet core network evolution.
    - The term LTE is typically used to represent both LTE itself and SAE
  - The specs are also known as evolved UMTS terrestrial radio access (E-UTRA)
  - **First version of LTE : Release 8 of the 3GPP specs. (2010)**

- High network throughput
- Low latency
- Plug & Play architecture
- Low Operating Costs
- All-IP network
- Simplified upgrade path from 3G networks

for Network Operators

- Faster data downloads/uploads
- Improved response for applications
- Improved end-user experience

for End Users



Source: http://www.cse.unt.edu/~rdantu/FALL_2018_WIRELESS_NETWORKS/2G_3G_4G_Tutorial.ppt

2. 3G, 4G-LTE Networks

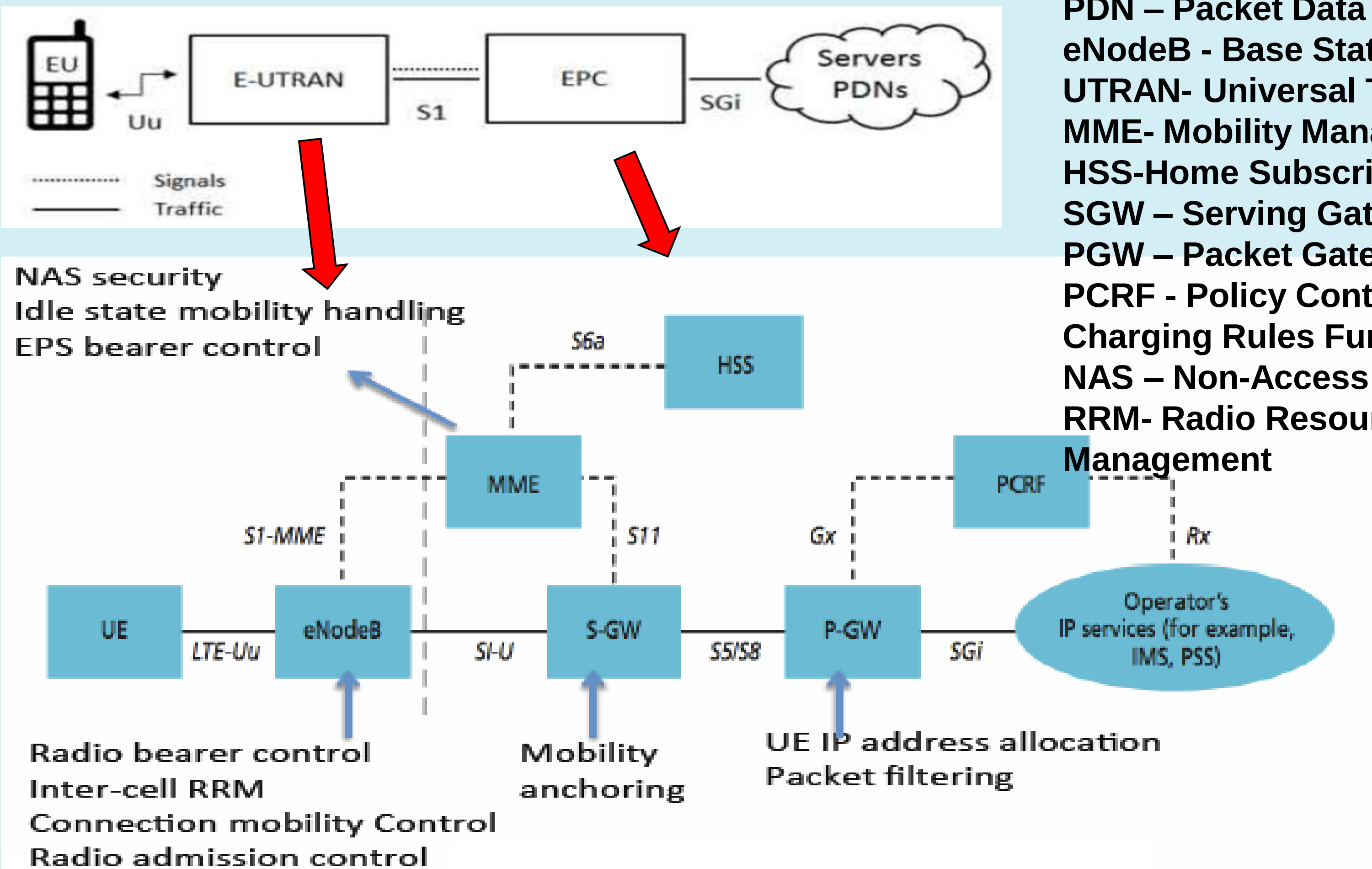
2.4 LTE Overview - Characteristics

- **All IP (flat) architecture**: I/Fs between network nodes in LTE are IP based
  - Simplified architecture (packet based) vs. previous generations
- **Support for all high-level services**: VOIP, streaming multimedia, videoconference, high-speed data, broadcast, etc.
- Enhanced security
- **Physical layer -**higher performance vs. 3G
  - **Better spectral efficiency**
    - DL: 3-4 times HSDPA for MIMO (2,2); UL: 2-3 times HSUPA for MIMO(1,2)
  - **High data rates: 300 Mbps peak DL and 75 Mbps peak UL**
    - data rates > 300Mbps in a 20 MHz carrier, under very good signal conditions
  - **Duplex modes:** both *Time Division (TDD)* and *Frequency Division (FDD)*
  - **Flexible/scalable carrier** bandwidths, from **1.4 - 20 MHz for FDD and TDD**
  - All LTE devices have to support **MIMO** transmissions
    - BS can transmit/receive several data streams over the same carrier simultaneously
  - **Layer 2 QoS assurance mechanisms** - satisfies the needs (bandwidth, delay, jitter, loss) for media-oriented apps (voice, video, MM)
  - **Orthogonal Frequency Division Multiplexing (OFDM)** for DL and **Single Carrier Frequency Division Multiple Access (SCFDMA)** for UL
- Backward compatibility for GSM/EDGE/UMTS systems

2. 3G, 4G-LTE Networks

2.5 LTE Architecture

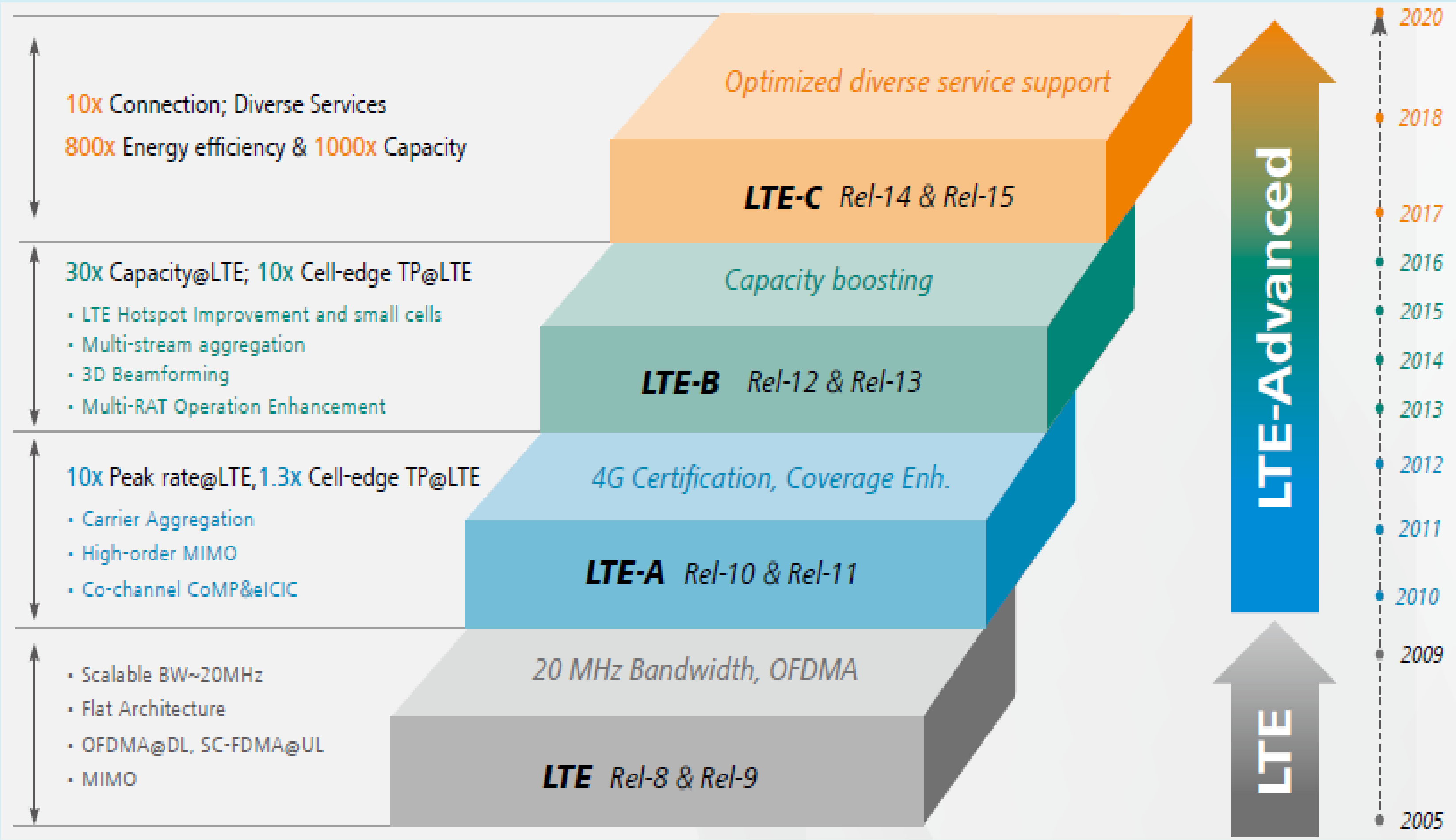
- All IP architecture



UE- User Equipment
EU- End User
EPC-Evolved Packet Core
PDN – Packet Data Network
eNodeB - Base Station
UTRAN- Universal Terrestrial RAN
MME- Mobility Management Entity
HSS-Home Subscriber System
SGW – Serving Gateway (router)
PGW – Packet Gateway (router)
PCRF - Policy Control and Charging Rules Function
NAS – Non-Access Stratum
RRM- Radio Resource Management

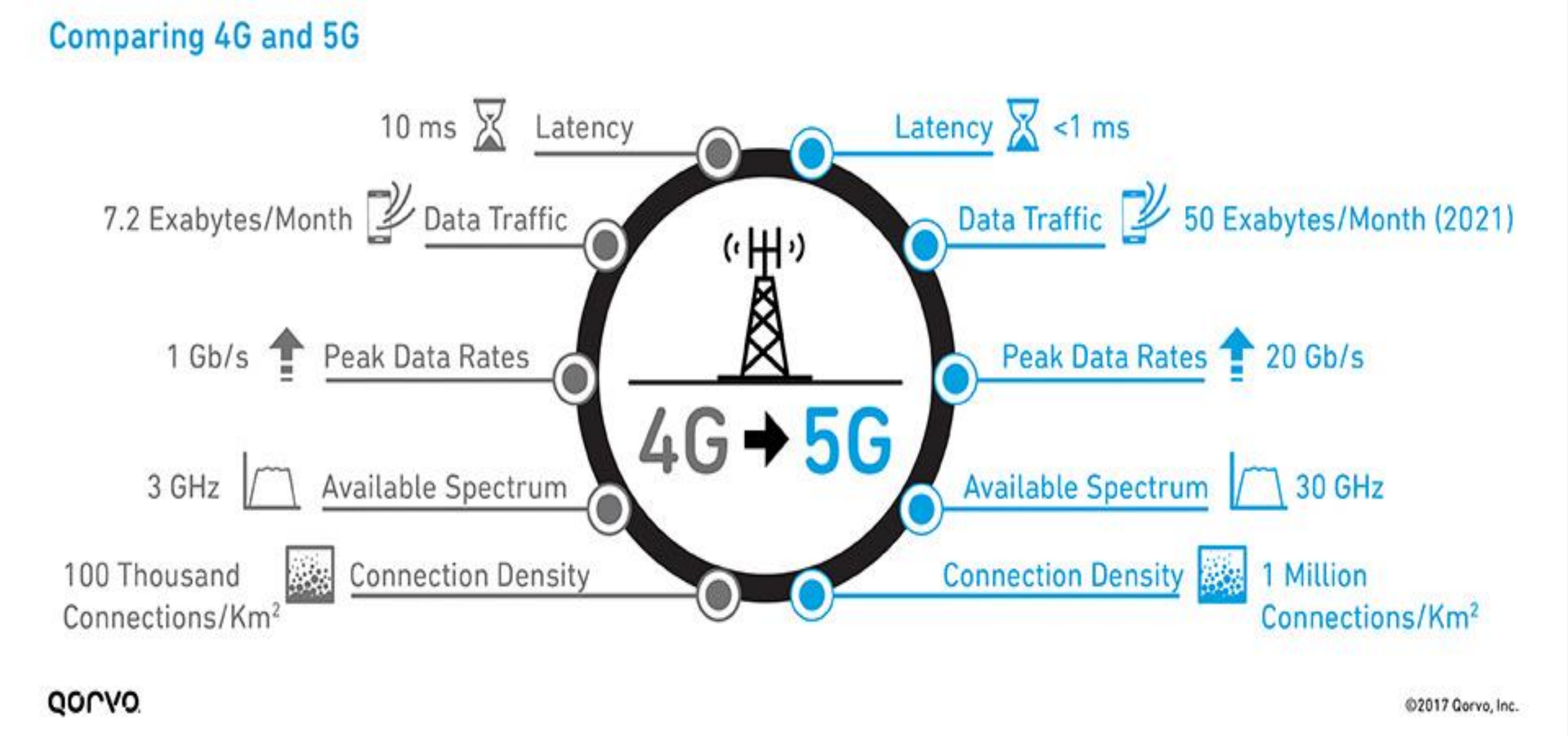
Source: http://www.cse.unt.edu/~rdantu/FALL_2018_WIRELESS_NETWORKS/2G_3G_4G_Tutorial.ppt

2.6 LTE evolution to LTE Advanced



Source: 4G to 5G networks and standard releases, ITU PITA WS on Mobile network planning and security Sami TABBANE, 2019

2.7 4G evolution towards 5G



Source: Qorvo(2015-American semiconductor company

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3. 5G Networks

3.1 5G Key concepts (summary)

- **Significant advances w.r.t. 4G**

- **Three main 5G features**
  - ***Ubiquitous connectivity for large sets of users*** *:* devices connected ubiquitously; uninterrupted user experience
  - ***Very low latency*** (~ few ms): useful for life-critical systems, real-time applications, services with zero delay tolerance
  - ***High-speed Gigabit connection***

- **5G: evolution of mobile *broadband networks* + *new unique network and service capabilities*:**
  - It will ensure *user experience continuity* in various situations
    - high mobility (e.g. in trains)
    - very dense or sparsely populated areas
    - regions covered by heterogeneous technologies (including the traditional ones)

- **5G- universal support for a large set of applications and services**
  - Industry, health, governance, education, environment, commerce, etc.
  - 5G - key enabler for the Internet of Things, M2M

3. 5G Networks

3.2 5G Key characteristics

- Heterogeneous set of integrated air interfaces
- **Cellular and satellite solutions**
- Simultaneous use of different **Radio Access Technologies (RAT)**
  - **Seamless handover** between heterogeneous RATs
- **Ultra-dense networks** with numerous small cells
  - Need new interference mitigation, backhauling and installation techniques
- 5G frequency spectrum - three sections: low-band (<1 GHz), mid-band(1-6 GHz) and high-band (>24 GHz-called millimeter waves band).

- **Driven by SW**
  - unified OS in a number of PoPs, especially at the network edge

- **Support technologies**
  - Software Defined Networking (SDN)
  - Network Functions Virtualization (NFV)
  - Cloud/Mobile Edge Computing (MEC) /Fog Computing (FC)
  - Artificial Intelligence/ Machine Learning

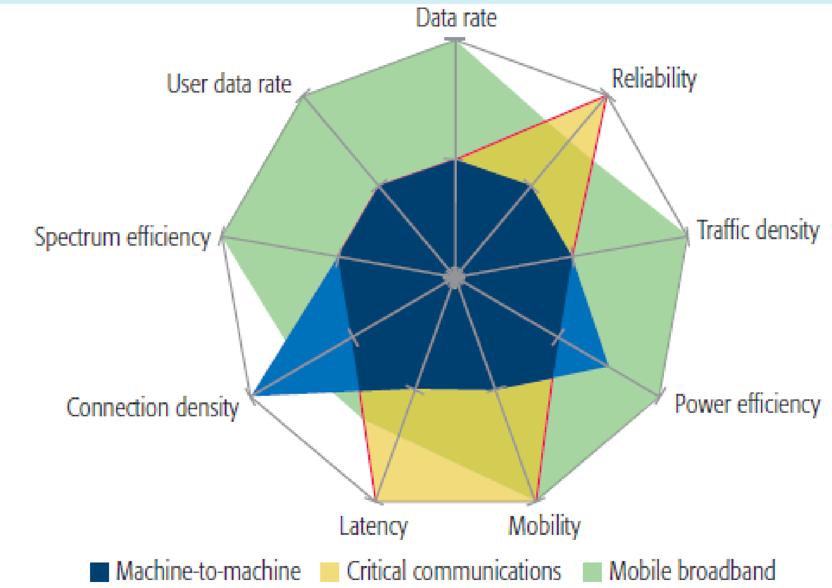
- **Optimized network management** operations, through
  - **cognitive features and AI/ML-embedded capabilities**
  - advanced **automation** of operation through proper algorithms
  - **Data Analytics** and **Big Data** techniques -> monitor the users' QoE

3. 5G Networks

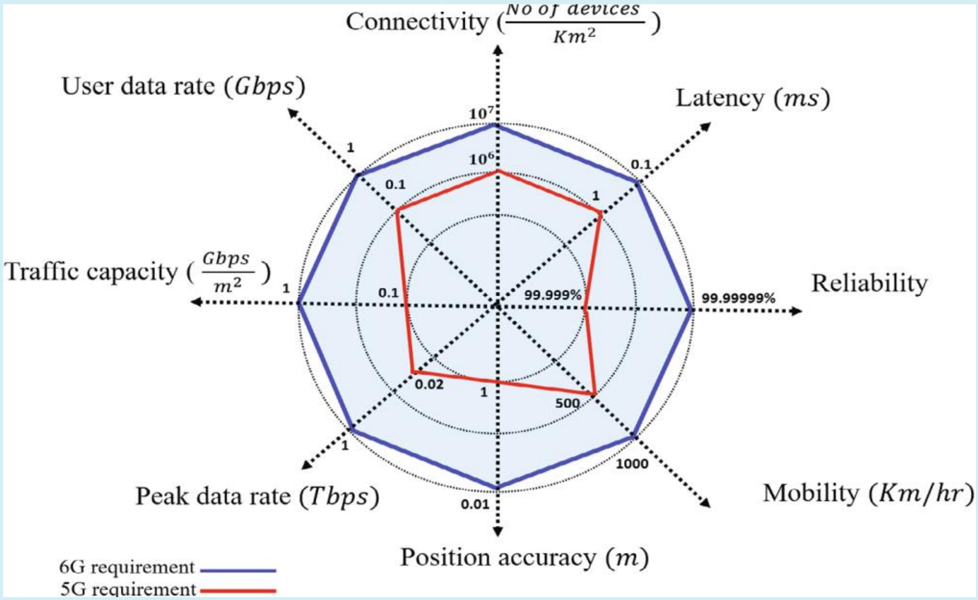
3.3 5G capabilities

- **General requirements**
  - **x 10 improvement in performance (versus 4G)** : capacity, latency, mobility, accuracy of terminal location, reliability and availability
  - **simultaneous connection of many devices +** improvement of the terminal battery capacity life
  - **lower energy consumption** w.r.t. today 4G networks; energy harvesting
  - **better spectral efficiency than** in 3G, 4G
  - **citizens may manage their personal data**, tune their exposure over the Internet and protect their privacy
  - **reduce service creation time** and facilitate integration of various players delivering parts of a service
  - built on **more efficient hardware**
  - **flexible and interworking in heterogeneous** environments

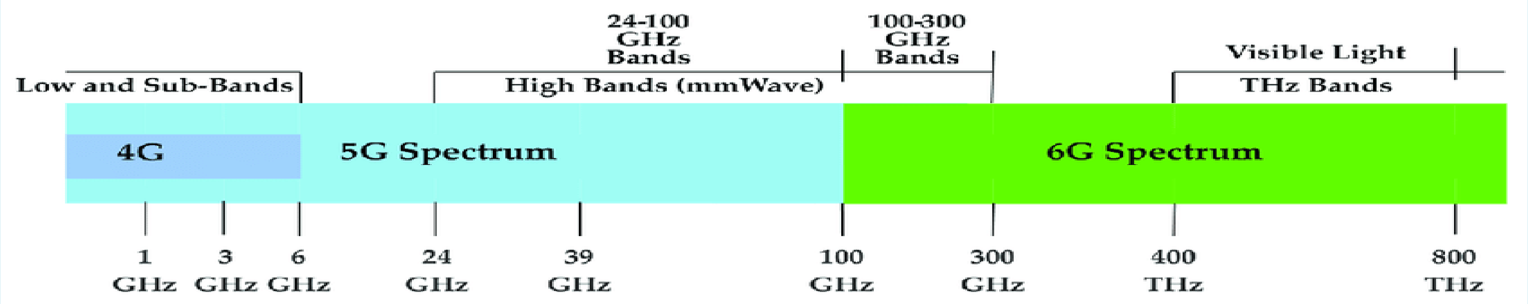
3.4 5G and 6G connectivity capabilities; 5G service categories; Spectrum allocation



Source: X. Foukas, G. Patounas, A.Elmokashfi, and M.K. Marina, Network Slicing in 5G: Survey and Challenges, IEEE Communications Magazine, May 2017, pp.94-100

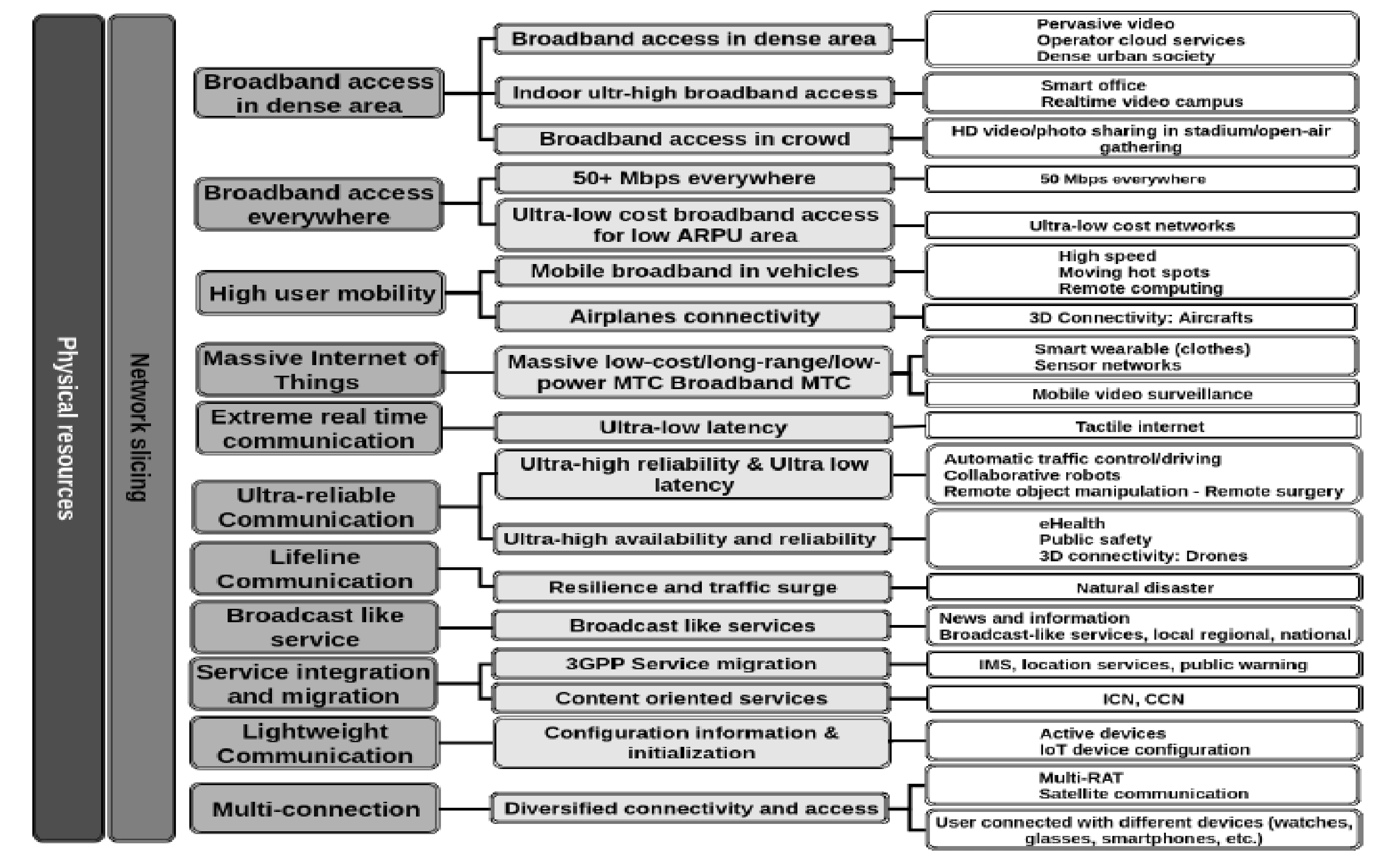


Source: S.A. Abdel Hakeem, H.H. Hussein, H.Kim, Vision and research directions of 6G technologies and applications, Computer and Information Sciences 34 (2022) 2419–2442



3. 5G Networks

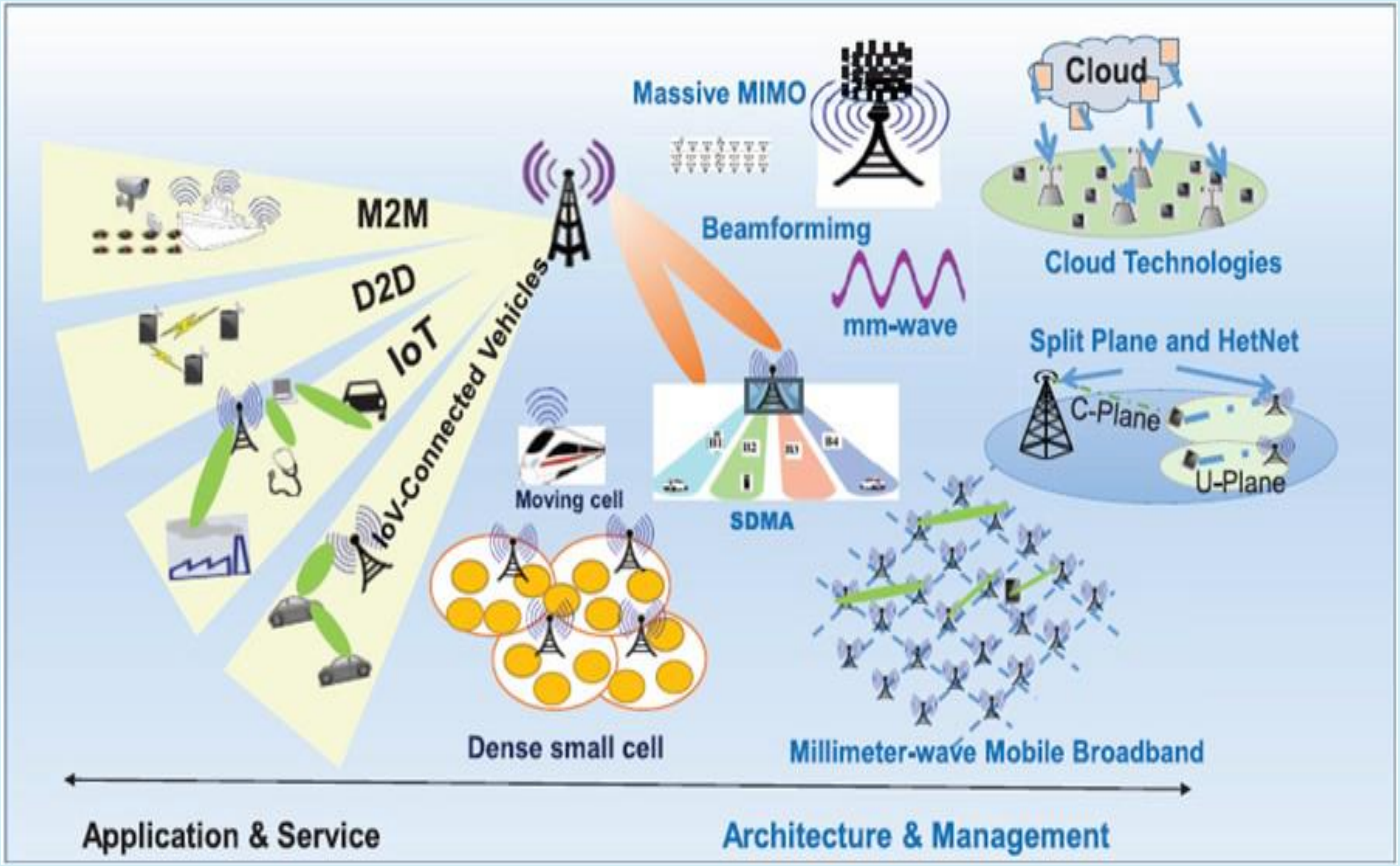
3.5 5G Applications and use cases
Use-cases family and category per 3GPP and NGMN



Source: MGMN 5G WHITE PAPER, NGMN Alliance, white paper, https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf, Feb. 2015.

3. 5G Networks

3.6 5G architectural objectives



M2M- Machine to Machine
D2D- Device to Device
IoT - Internet of Things
IoV- Internet of Vehicles
MIMO- Multiple Inputs Multiple Outputs

Arhitectural functional planes
C-Plane Control Plane
U-Plane- User Plane

Source: Agiwal, M.; Roy, A.; Saxena, N. Next generation 5G wireless networks: A comprehensive survey. IEEE Commun. Surv. Tutorials 2016.

3. 5G Networks

3.7 Categories of 5G main scenarios

- **Enhanced mobile broadband (eMBB)**
- **Ultra reliability low latency communication (URLLC)**
- **Massive machine type communication (mMTC)**

- **Enhanced Mobile Broadband (eMBB)**
  - **Objectives:** High data rate, large data applications, high capacity
  - **Features:** Transfer high volume of data, millions of users, support for social media, 500 km/h mobility, peak data rate: 20 Gbps for downlink & 10 Gbps for uplink
  - **Main applications**: Fixed wireless, Ultra high definition (UHD) video, Video call, Mobile cloud computing, Virtual reality (VR) /Augmented reality (AR)
- **Ultra-Reliable, Low Latency Communications (uRLLC)**
  - **Objectives:** Fast and highly reliable, perfect coverage and uptime, strong security
  - **Features:** Ultra-high reliability (99.9999 %),Ultra-responsive, Data rate: 50 kbps .. 10 Mbps, Low latency: < 1 ms air interface and 5 ms E2E latency
  - **Main Applications:** Vehicular networks, Industrial automation, Public safety, Health systems
- **Massive Machine Type Communications (mMTC)**
  - **Objectives**: Massive connection density, energy efficiency, reduced cost per device
  - **Features:** Cover 30 billion ‘things’ connected, Low cost and low energy consumption, Density of up to 10^6 devices/km^2, 1 to 100 kbps/device, 10 years battery life
  - **Main Applications:** IoT, Wearables, Health care monitoring, Smart home/city, Smart sensors

3.7 Categories of 5G main scenarios

- **Specific requirements for 5G categories:**
  - **functional** (e.g. priority, charging, policies, security, and mobility)
  - **performance** (e.g. data rates, latency, mobility, availability, reliability, no. of users)
  - **Solution: dedicated parallel virtual networks (slices) on the same physical infrastructure**

Characteristics	mMTC	URLLC	eMBB
Availability	Regular	Very High	Regular (baseline)
E2E latency	Not highly sensitive	Extremely sensitive	Not highly sensitive
Throughput type	Low	Low/med/high	Medium
Frequency of Xfers	Low	High	High
Density	High	Medium	High
Network coverage	Full	Localized	Full

Source: End to End Network Slicing – White paper 3 Outlook 21, Wireless World , Nov 2017

3.8 Network slicing

General concepts (summary)

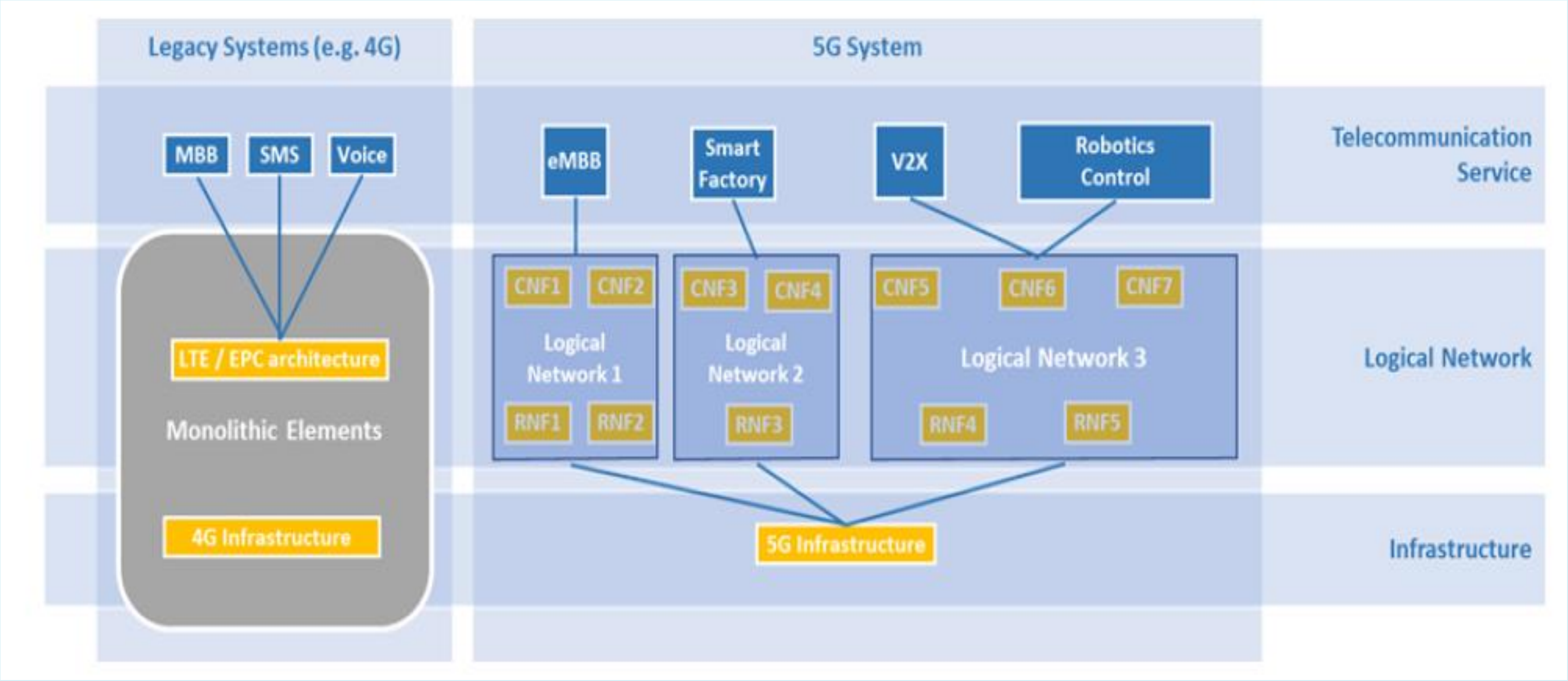
- **End to End (E2E) :** covers all network segments : radio, wire access, edge networks, transport and core (central) network
- **concurrent deployment of multiple E2E logical, self-contained and independent shared** or **partitioned networks** on a **common infrastructure platform**

    - **Network Slices (NSL)**
        - created by **provisioning**, or **on demand**, each tailored for a given use case, mutually isolated with independent OM&C,
        - **composition** of adequately configured NFs, network apps. and the underlying cloud infrastructure (PHY/virtual/ emulated resources, etc.)
        - **resources are bundled together** to meet specific Use cases requirements (e.g., bandwidth, latency, processing, resiliency) coupled with a business purpose
        - **Slice life cycle:** *Preparation, Instantiation, Configuration and activation, Run-time, Decommissioning* - phases

- **Software Defined Networking (SDN) and Network Function Virtualization (NFV) –** support technologies provide virtualization, programmability, flexibility, and modularity to create **multiple network slices**

3.8 Network Slicing

- **4G versus 5G slicing concepts**

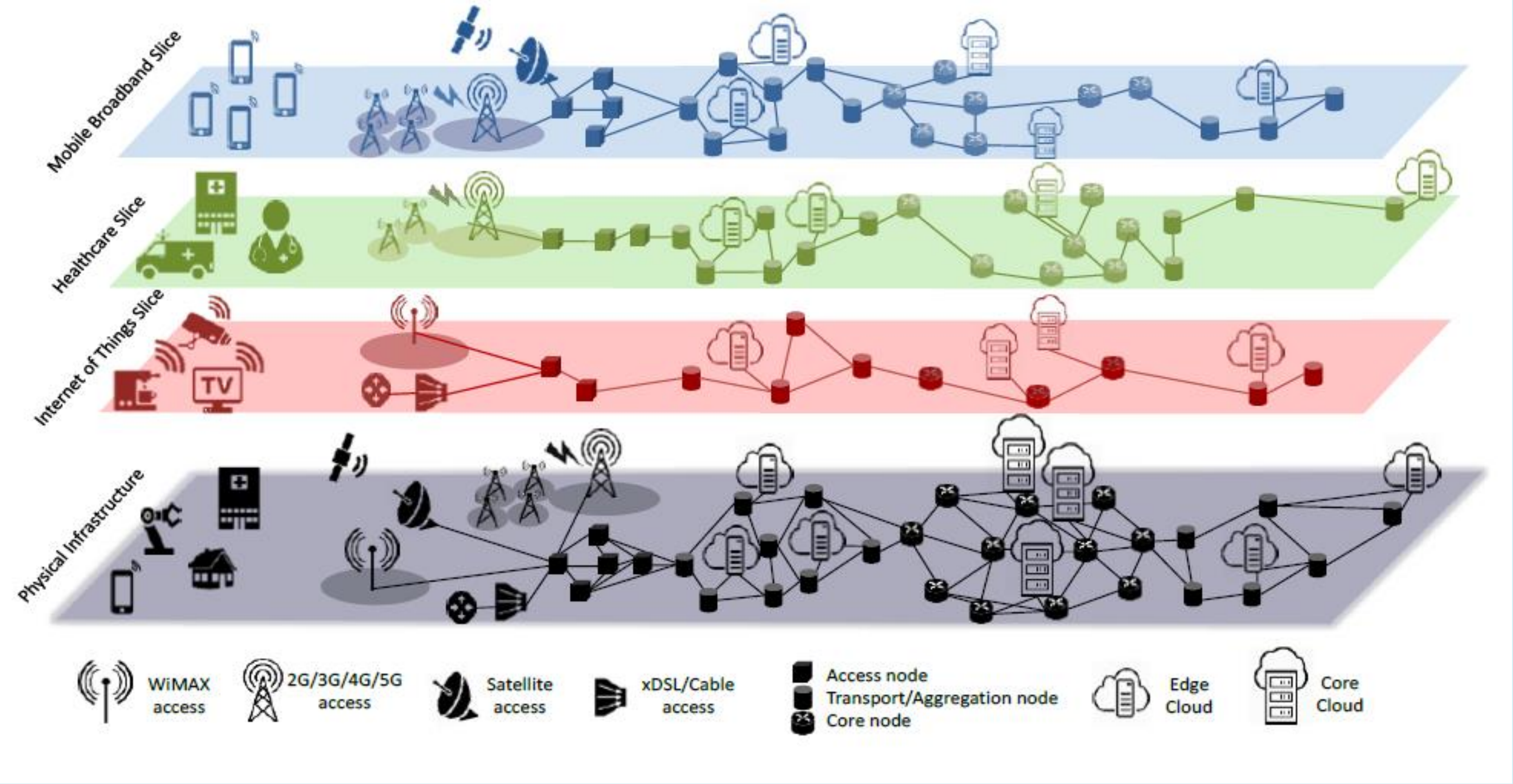


MBB - Mobile Broadband;
LTE - Long Term Evolution (4G) ;
V2X - vehicle to X ; **CNF**- Core Network Functions;

SMS - Short Messages service;
EPC- Evolved Packet Core
RNF- RAN network Functions

3.8 Network slicing

- **Network slicing generic example**

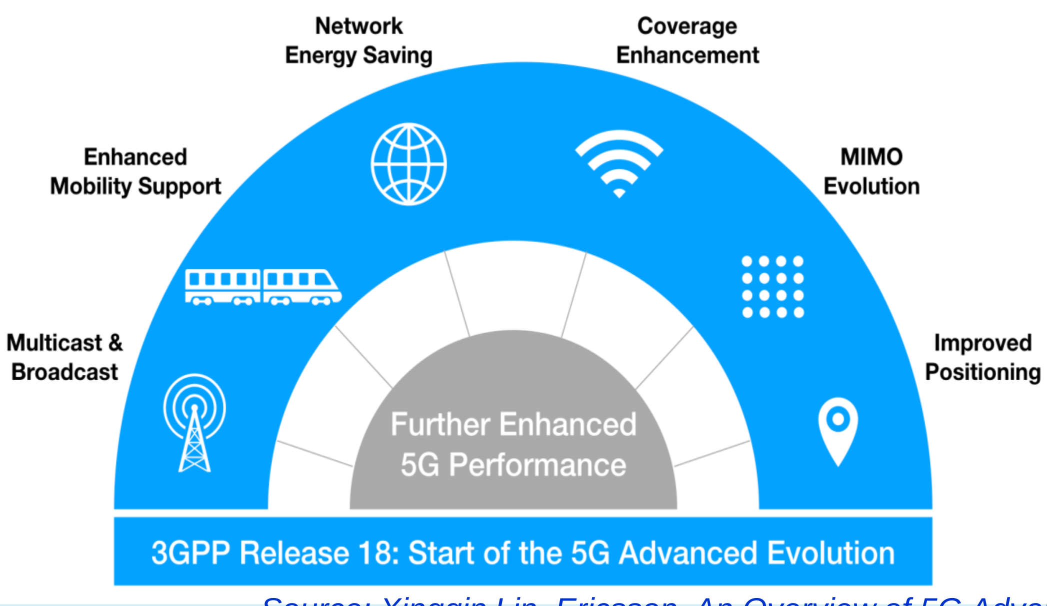


Source: J. Ordonez-Lucena, P. Ameigeiras, D. Lopez, J.J. Ramos-Munoz, J. Lorca, J. Folgueira, Network "Slicing for 5G with SDN/NFV: Concepts, Architectures and Challenges" , IEEE Communications Magazine, 2017, Citation information: DOI 10.1109/MCOM.2017.1600935

3. 5G Networks

3.9 5G Advanced- Second phase of 5G standardization

- Built on the 5G previous 3GPP Releases 15, 16, and 17
  - **bridge 5G - 6G** ; new features previously not standardised in 3GPP
  - **3GPP Release 18, 2022-** start of 5G-Advanced
    - expand 5G capabilities
      - device, network(layer 1, 2, 3), balanced mobile broadband evolution
      - vertical domain expansion, new use cases
      - accommodating immediate and long-term commercial needs, etc.
    - **early 5G-Advanced commercial deployment will begin in 2024/25**



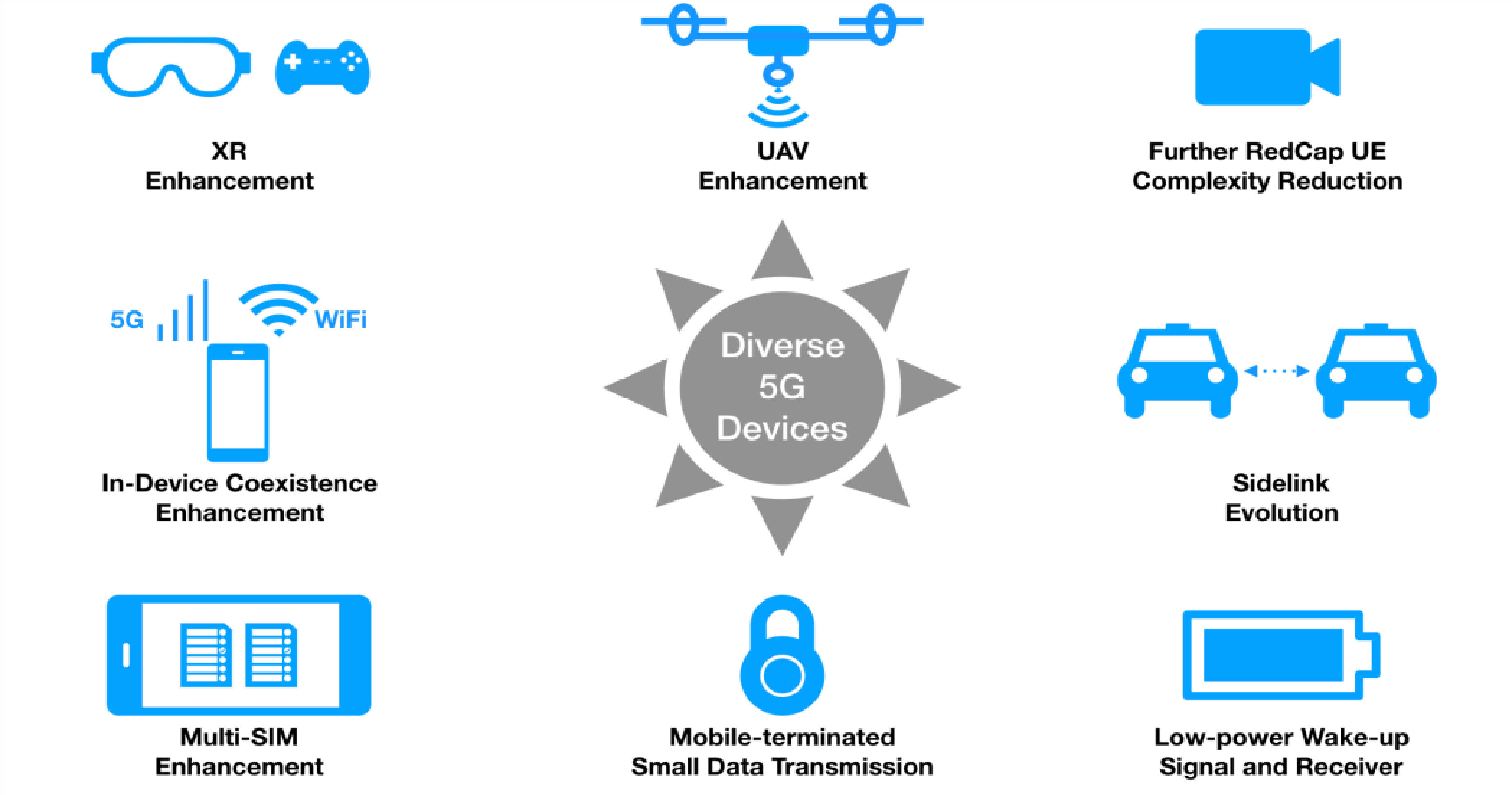
5G Advanced Feature Categories

- **Performance enhancements vs. 5G**
- **Flexible Spectrum Applications**
- **Diverse Devices**
- **Evolved Network**
- **Data and AI/ML driven 5G**

Source: Xingqin Lin, Ericsson, An Overview of 5G Advanced Evolution in 3GPP Release 18, 2022

3.9 5G Advanced

- **3GPP Release-18 expanding 5G capability for diverse devices**



Source: Xingqin Lin, Ericsson, An Overview of 5G Advanced Evolution in 3GPP Release 18, 2022

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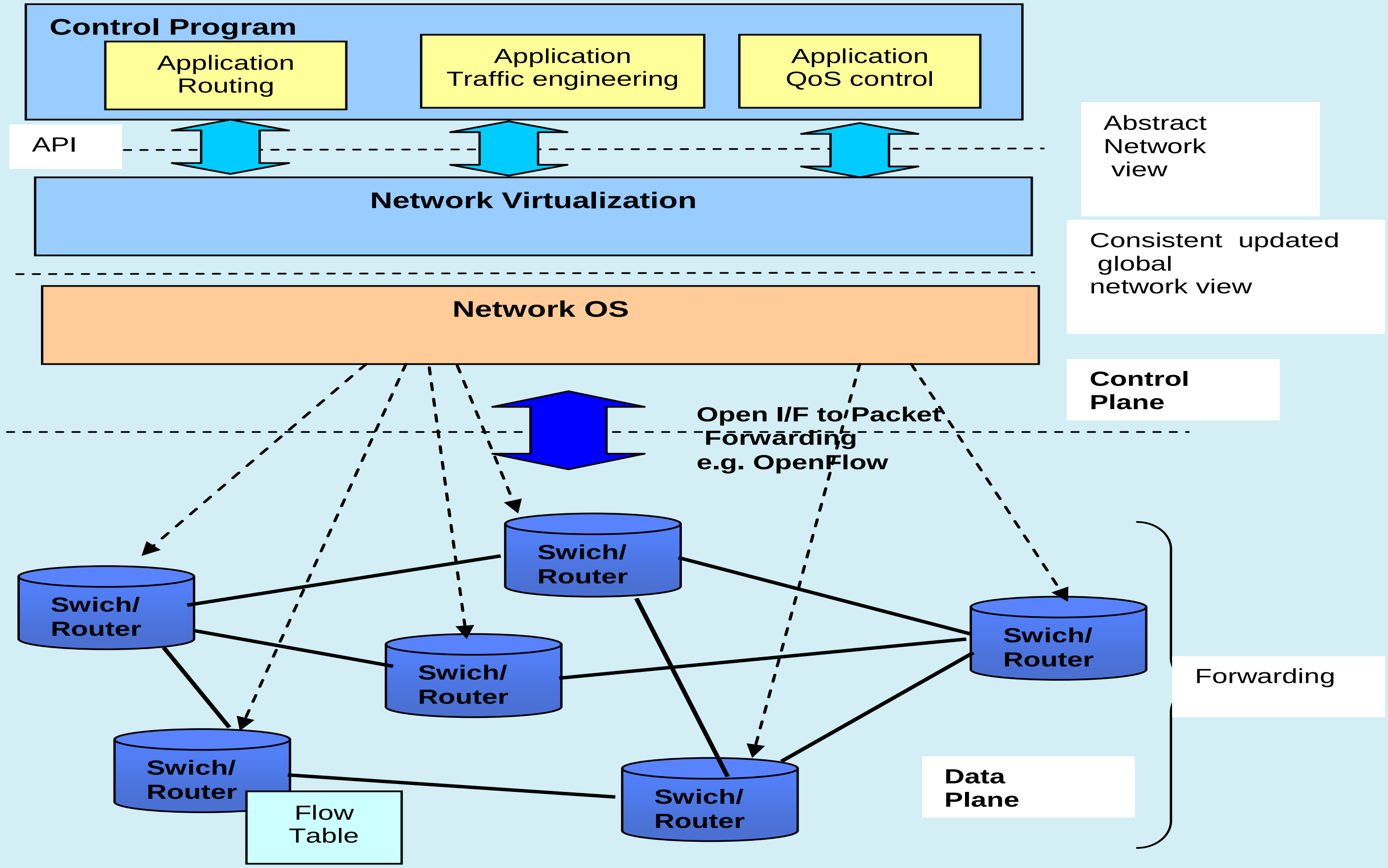
4. Support Technologies, Integration

4.1 Software Defined Networking (SDN)- summary

- **SDN main concepts**
  - Architectural: ***Control Plane(CPl)*** (and ***Management Plane-MPl***) - separated from the ***Data Plane (DPl)*** (even physically)
  - Network intelligence (CPl/MPl) is (logically) centralized in SW-based **SDN controller(s),** which maintain a global view of the network.
  - Execute CPl /MPl SW on general purpose HW (commodity servers)
    - **CPl software and apps are independent from specific networking HW**
  - **DPl** (Forwarding plane) **behaviour is programmable**
  - The architecture defines the control for a whole network (and not for an individual network device)
  - **Flow concept** – used in Data /Forwarding Plane
    - *Flow* = a sequence of packets having a least common characteristic (e.g., one or more header fields with the same value); the network is programmed on a per-flow basis
  - **Network OS**:
    - Distributed system that creates a consistent, updated network view
    - Executed on servers (controllers) in the network
      - Controller examples: NOX, ONIX, ONOS, RYU, HyperFlow, Floodlight, Trema, Kandoo, Beacon, Maestro,..
    - Communicates with Forwarding Elements FE-switches) (via vertical protocol, e.g. OpenFlow),
  - **SDN still open issues**: centralization native problems, H/V scalability, real–time capabilities, security, integration with traditional networking distributed technologies

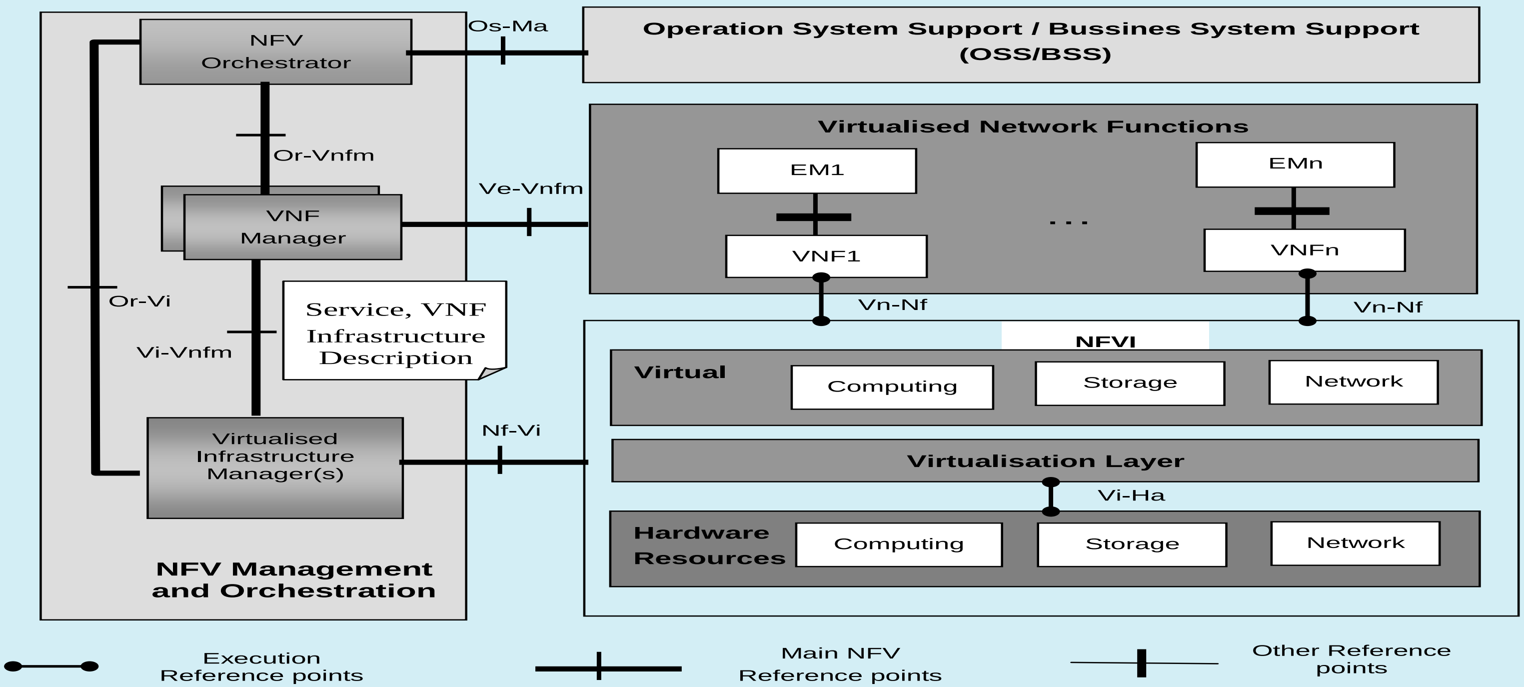
4.1 Software Defined Networking (SDN)- summary

- **SDN basic architecture**



4.2 Network Function Virtualization (NFV) -summary

- **NFV – architectural development** (> 2014)
  - **Objectives**- efficiency improvement vs. traditional dedicated HW-SW implementation
  - **NFV - implements NFs through SW** by using **virtualization** and off-the-shelf (COTS) programmable HW (general-purpose servers, storage, software switches)
  - **Network-related functions**, e.g., load balancing, network address translation (NAT), firewalling, intrusion detection, domain name service, caching, etc. – are SW implemented
- **ETSI NFV Framework and Reference Architecture**



Source: ETSI GS NFV 002 v1.2.1 2014-12, "NFV Architectural Framework"

4. Support Technologies, Integration

4.2 Network Function Virtualization (NFV) -summary

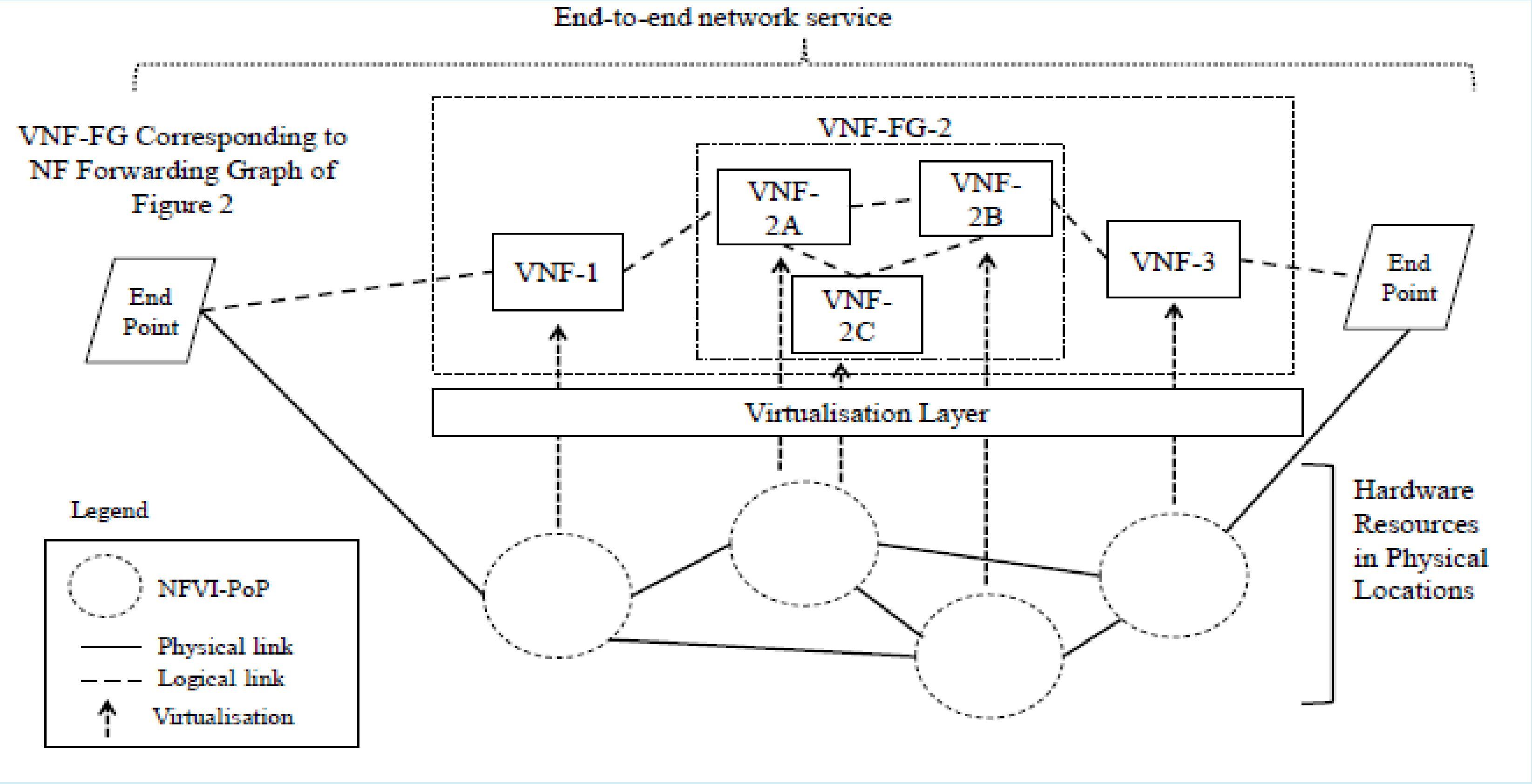
- **NFV Framework and Reference Architecture**
  - **Operations and Business Support Systems** (OSS/BSS);
  - **Virtualized Network Functions (VNF)** -SW implementations
  - **Element Management** entities exist for VNFs
  - **NFV Infrastructure (NFVI) -** all HW and SW components building up the environment in which VNFs are deployed
    - **Virtualized Resources, Virtualization Layer (VL). HW Resources**
  - **NFV Management and Orchestration (NFV-MANO) -** orchestration and lifecycle management (LCM) of HW/SW resources that support the infrastructure virtualization
    - NFV MANO -**virtualization-specific management tasks** and includes the partial managers for the Data Plane layers:
      - **NFV Orchestrator (NFVO)-** higher layer- orchestrates the resource allocation
      - **Virtualized Network Function Manager (VNFM)**
      - **Virtualized Infrastructure Manager (VIM)**

  - **Network Service (NS) -** composition of NFs (functional and behavioral specs)
    - The NSes contributes to the behavior of the higher layer service specifications (performance, dependability, security, etc.)
    - The individual NF behaviors plus a network infrastructure composition mechanism determines the End to End (E2E) NS behavior

Source: ETSI GS NFV 002 v1.2.1 2014-12, "NFV Architectural Framework"

4.2 Network Function Virtualization (NFV) -summary

- NFV Framework and Reference Architecture
- VNF Graph example – to construct a network service

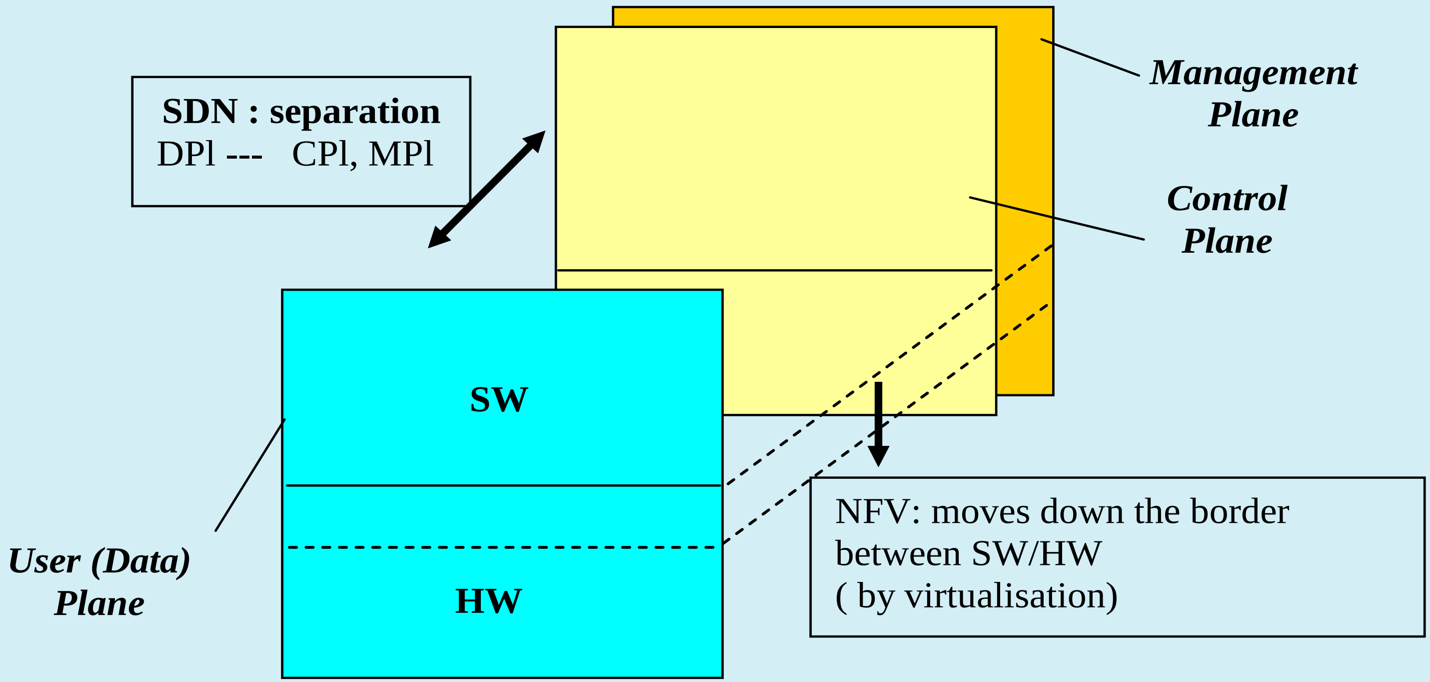


Source: ETSI GS NFV 002 v1.2.1 2014-12, "NFV Architectural Framework"

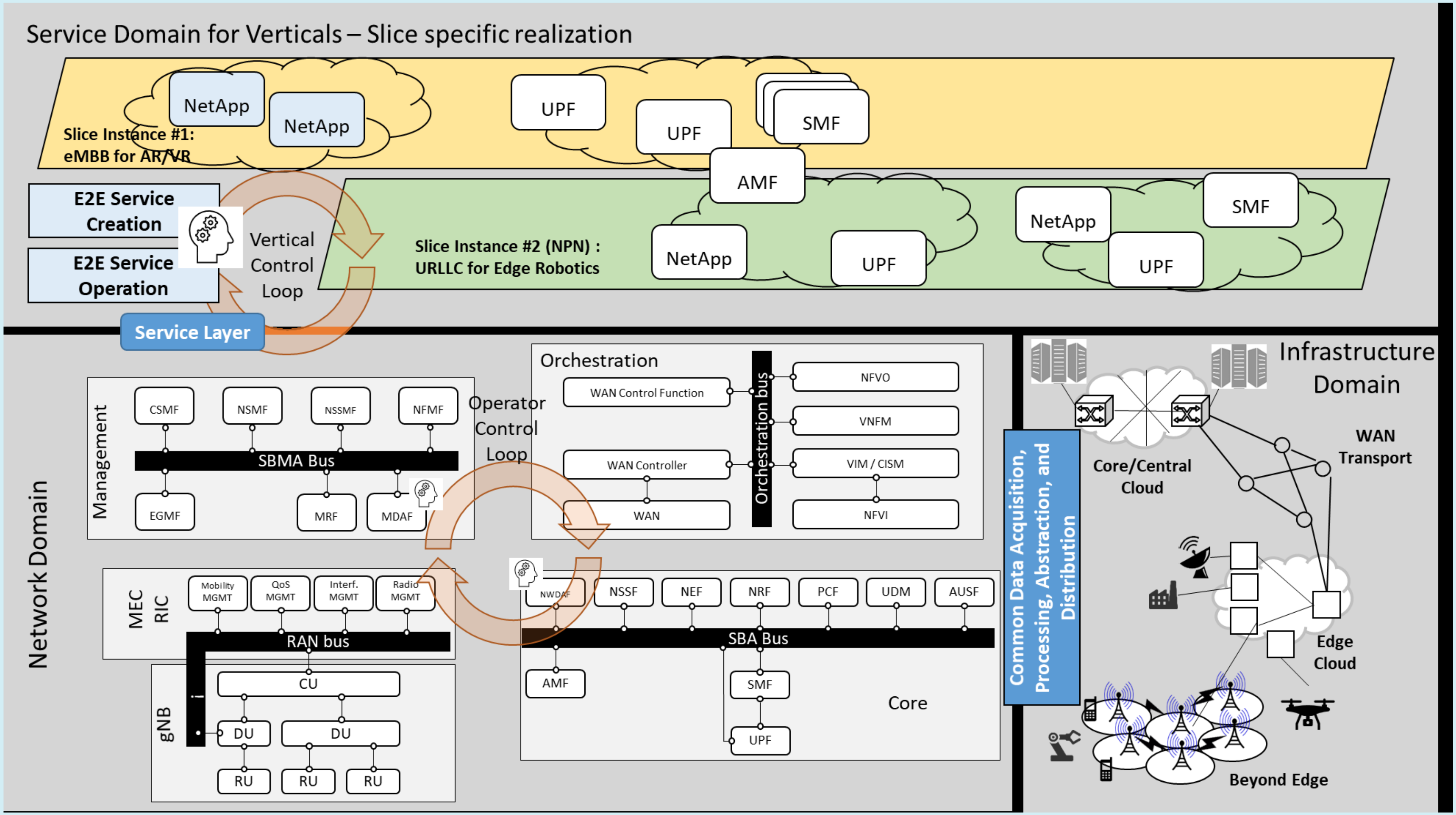
4. Support Technologies, Integration

4.3 Network SDN – NFV cooperation

- **SDN and NFV are complementary technologies**
  - They **can be used independently or in cooperation**
  - SDN acts horizontally by separating architectural planes (DPl --- CPl+MPl)
  - NFV acts vertically – by realizing through SW many functions that traditionally are implemented through dedicated HW +SW



4.5 Network slicing – architecture- based on NFV- 5GPPP vision *(see abbreviation list)*



Source: 5GPPP Architecture Working Group , View on 5G Architecture, Version 4.0, October 2021

4. Support Technologies, Integration

4.5 Network slicing – architecture- based on NFV- 5GPPP vision *(abbreviation list)*

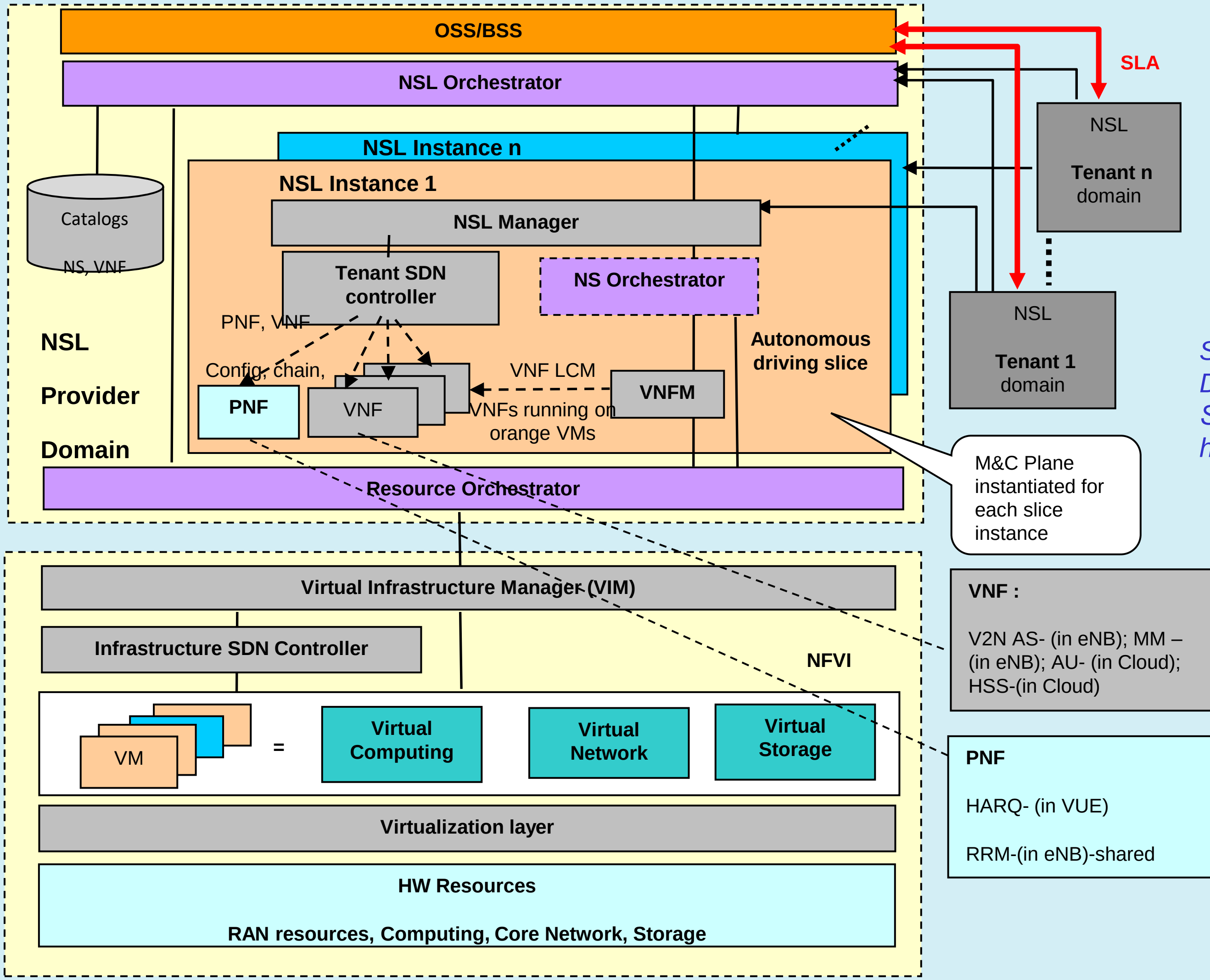
AF	Application Function
AUSF	Authentication Server Function
AMF	Access and Mobility Management Function
CHF	Charging Function
CISM	Container Infrastructure Service Management
CSMF	Communication Service Management Function
CU	Centralized Unit
DN	Data Network
DU	Distributed Unit
E2E	End-to-End
EGMF	Exposure Governance Management Function
eMBB	**Enhanced Mobile Broadband**
EMS	**Element Management System**
mMTC	**Massive machine type communication**
MANO	**Management and Orchestration**
MCC	Mobile Cloud Computing
MDAF	Management Data Analytics Function
MEC	Multi-access (Mobile) Edge Computing
MGMT	Management
MRF	Multi-Radio Function
NetApp	Network Application
NF	Network Function
NFV	**Network Function Virtualization**

NFVI	**Network Function Virtualization Infrastructure**
NFVO	**NFV Orchestrator**
NSMF	Network Slice Management Function
NSI	Network Slice Instance
NSSMF	Network Sub Slice Management Function
NFMF	Netwrk Function Management Function
NSSF	Network Slice Selection Function
NWDAF	Network Data Analytics Function
PCF	Policy Control Function
RAN	Radio Access Network
RIC	RAN Itelligent Control
RU	Radio Unit
SBA	Service Based Architecture
SMF	Session Management Function
UCMF	UE radio Capability Management Function
UDSF	Unstructured Data Storage Function
UDM	Unified Data Management
UDR	Unified Data Repository
UE	User Equipment
UPF	User Plane Function
URLLC	**Ultra-Reliable Low Latency Cellular Networks**
VIM	**Virtual Infrastructure Manager**
WAN	Wide Area Network

Source: 5GPPP Architecture Working Group , View on 5G Architecture, Version 4.0, October 2021

4. Support Technologies, Integration

4.6 Example of a 5G layered architecture- based on SDN-NFV



High level functional architecture – for V2X slicing- single domain (run-time view)

Source:Solid B5G-Project D2.4 - Deliverable "Final System Architecture" V1.0 https://solid-b5g.upb.ro/

4. Support Technologies, Integration

4.6 Example of a 5G layered architecture- based on SDN-NFV (cont’d)

- **High level functional architecture – for V2X slicing- single domain (run-time view)** (cont’d)
- **Notations**
- **General (5G slicing, NFV)**
- SDN Software Defined Networking; SLA – Service Level Agreement; MANO- Management and Orchestration; NS – Network Service; NSO- Network Service Orchestrator; NSL - Network Slice; NSLO - Network Slice Orchestrator; RO- Resource Orchestrator; VNF – Virtualized Network Function; PNF- Physical Network Function; VNFM – VNF Manager; LCM – Life Cycle Management; VIM – Virtual Infrastructure Manager; IC- Infrastructure SDN Controller

- **V2X –dedicated entities**
- AS- Application Server; AU- Authentication and Authorization Management; MM Mobility Management ; V2N – Vehicle to Network; RRM – Radio Resource Management; HARQ- Hybrid Automatic Repeat Request

Source:Solid B5G-Project D2.4 - Deliverable “Final System Architecture” V1.0, https://solid-b5g.upb.ro/

4. Support Technologies, Integration

4.7 Evolution towards Cloud-based implementations

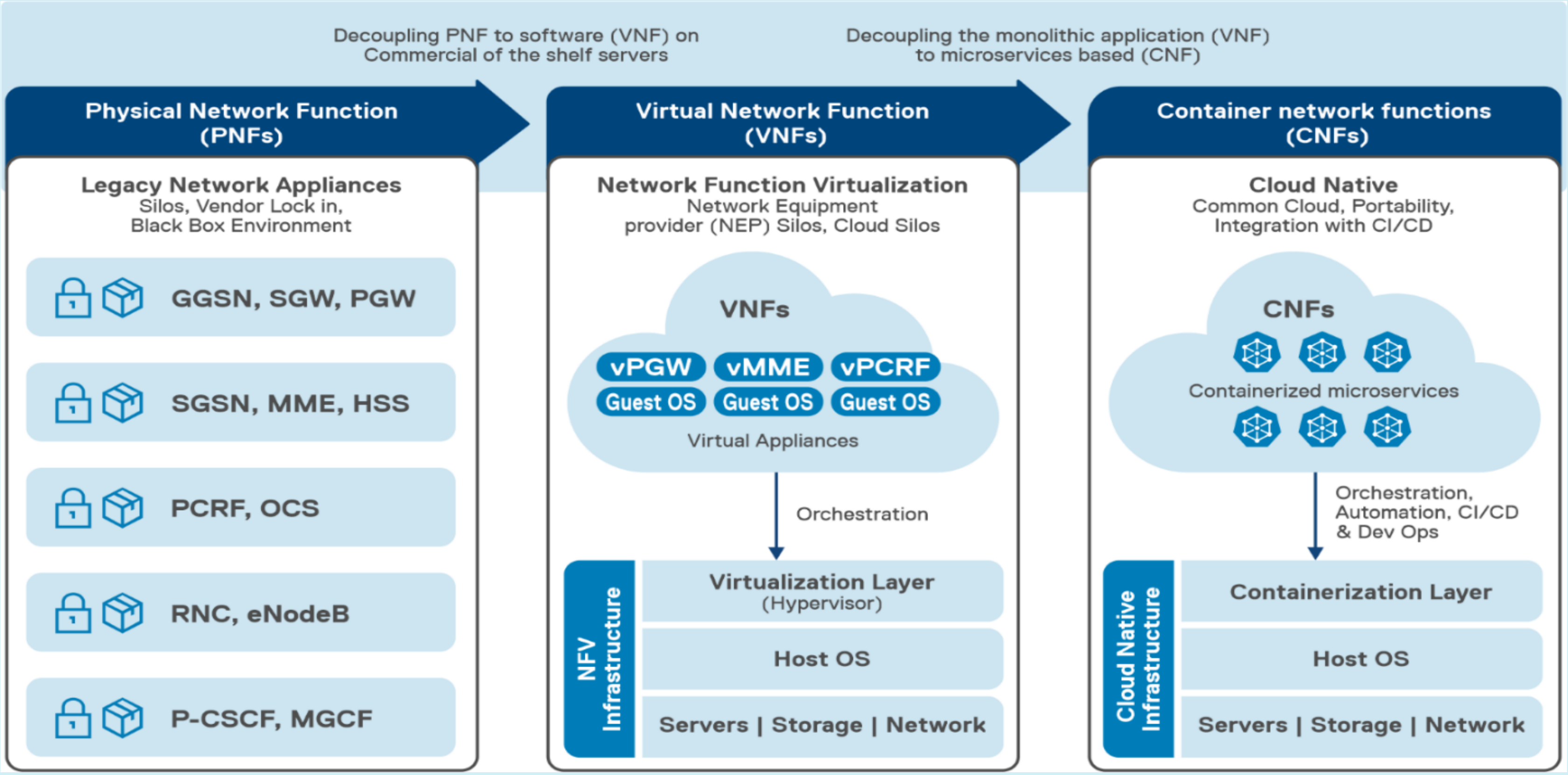
- **Trend: many PNFs and VNFs will become *CNFs (Cloud Native Network Function)***
- The enterprises are moving their monoliths to Kubernetes and then refactoring them into **microservices**
- The architectural distinction 4G vs. 5G Core
  - 5G Core makes use of the *Service-Based Architecture (SBA)* with **cloud-native flexible configurations** of loosely coupled and independent NFs deployed as containerized microservices
  - This provides the ability for NFs to scale and upgrade independently of each other which is significant benefit to CSPs
- **5G Core has a cloud-native architecture**
  - It can be built with microservices that can be reused for supporting different NFs
  - The 5G core leverages technologies like microservices, containers, orchestration, CI/CD pipelines, APIs, and service meshes, making it more agile and flexible
  - *Continuous Integration/ Continuous Deployment (CI/CD)* describes the key stages in an automated software development and deployment flow
    - This flow typically includes *design, coding, testing, integration, delivery, validation and phased deployment* activities before operation in a target environment.

4. Support Technologies, Integration

4.7 Evolution towards Cloud based implementations

Cloud technologies can support implementation of the 5G, 6G systems

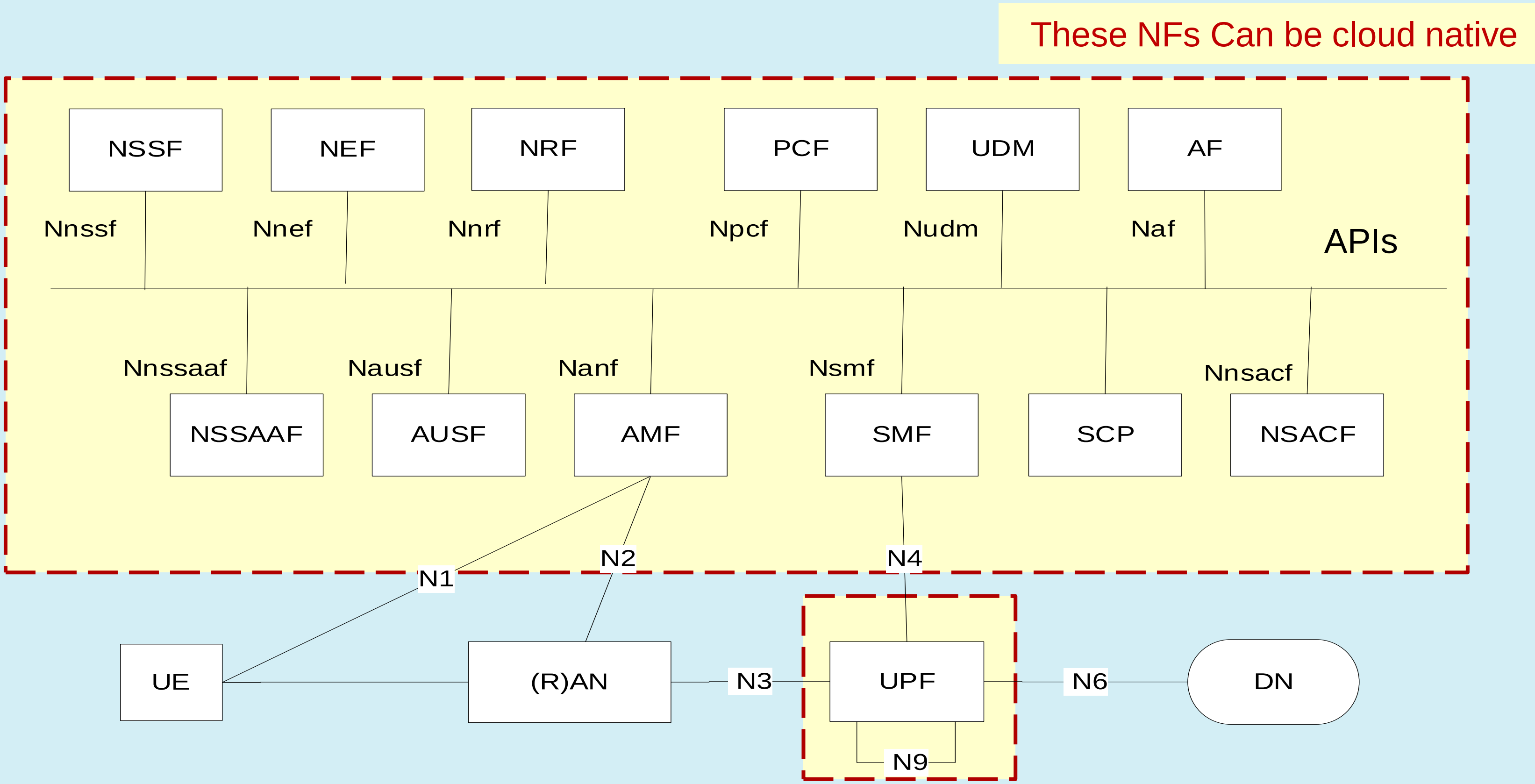
- From Physical Network Functions -> Container Network Functions



Source: The 5G Core Network Demystified
https://infohub.delltechnologies.com/en-US/p/the-5g-core-network-demystified/ 2023

4.7 Evolution towards Cloud based implementations

- **5G System architecture (non-roaming) [3GPP-2021-TS 23.501 R.17]**



4. Support Technologies, Integration

4.7 Evolution towards Cloud based implementations

- **5G System architecture [3GPP-2021-TS 23.501 R.17]**
- **Acronyms for previous slide**
- Access and Mobility Management Function (AMF).
- Data Network (DN), e.g. operator services, Internet access or 3rd party services.
- Network Exposure Function (NEF).
- Network Repository Function (NRF).
- Network Slice Admission Control Function (NSACF).
- Network Slice-specific and SNPN Authentication and Authorization Function (NSSAAF).
- Network Slice Selection Function (NSSF).
- Policy Control Function (PCF).
- Session Management Function (SMF).
- Unified Data Management (UDM).
- Unified Data Repository (UDR).
- User Plane Function (UPF).
- UE radio Capability Management Function (UCMF).
- Application Function (AF).
- User Equipment (UE).
- (Radio) Access Network ((R)AN).
- Network Data Analytics Function (NWDAF).
- Charging Function (CHF).
- Data Collection Coordination Function (DCCF).
- Analytics Data Repository Function (ADRF).
- Messaging Framework Adaptor Function (MFAF).

4.8 Edge computing

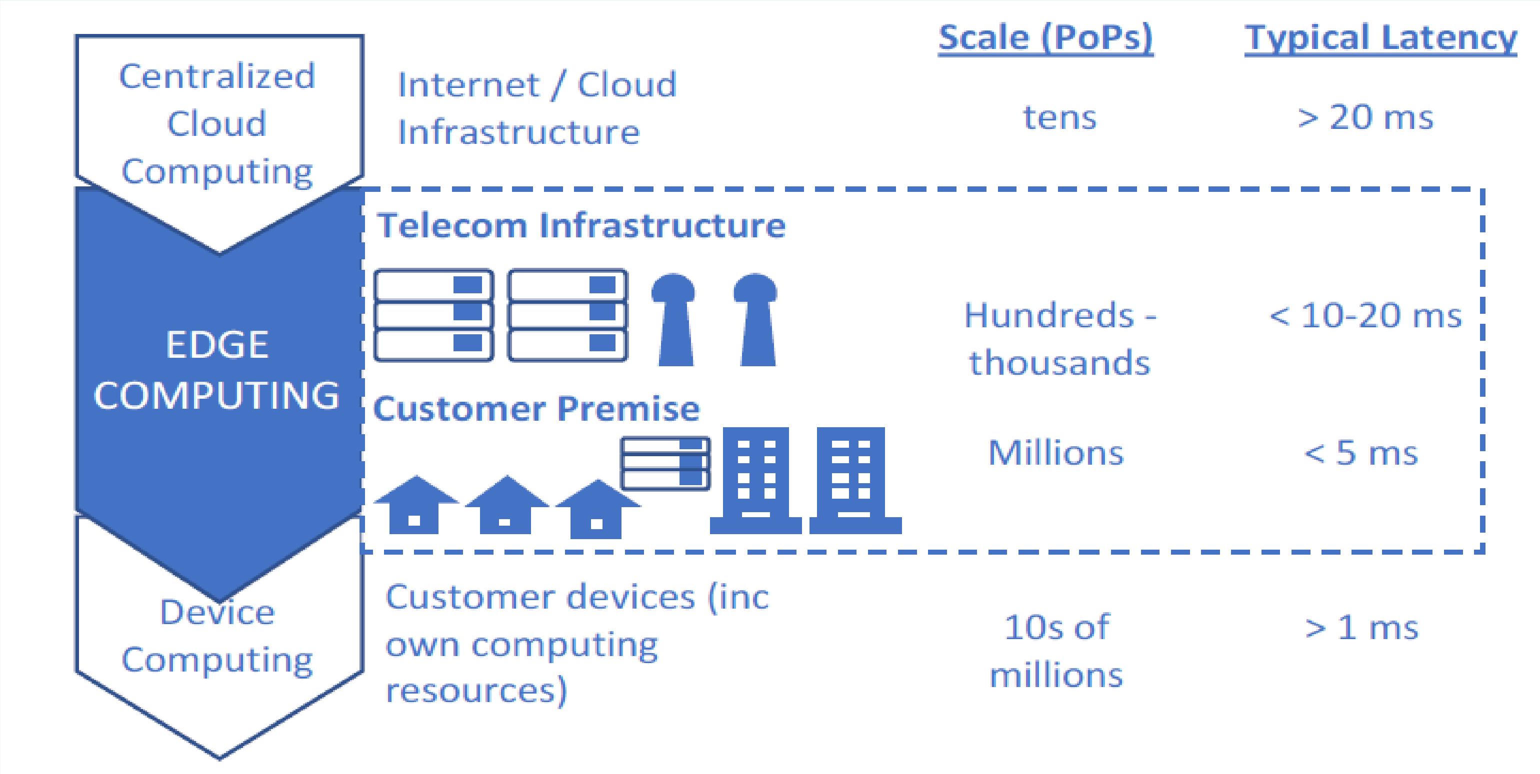
Edge computing in 5G architecture

- **Edge computing (EC) – generic definition**
  - **EC- autonomous computing model -** many distributed heterogeneous devices at the network edge performing computing tasks (storage, processing)
  - Part of CC capabilities and operations are offloaded from **centralized CC Data Center (CCDC)** to the **network, edge and/or terminal devices**
  - EC
    - provides context aware storage and distributed computing at the network edge
    - takes benefit from processing power of edge devices and provide faster response to mission critical tasks
    - will not replace centralized CC; they are complementary

- **Several solutions for EC**
  - **Multi-access Edge Computing (MEC)**
  - **Fog computing**
  - **Cloudlets, ..**

4. Support Technologies, Integration

4.8 Edge computing
Edge computing in 5G architecture

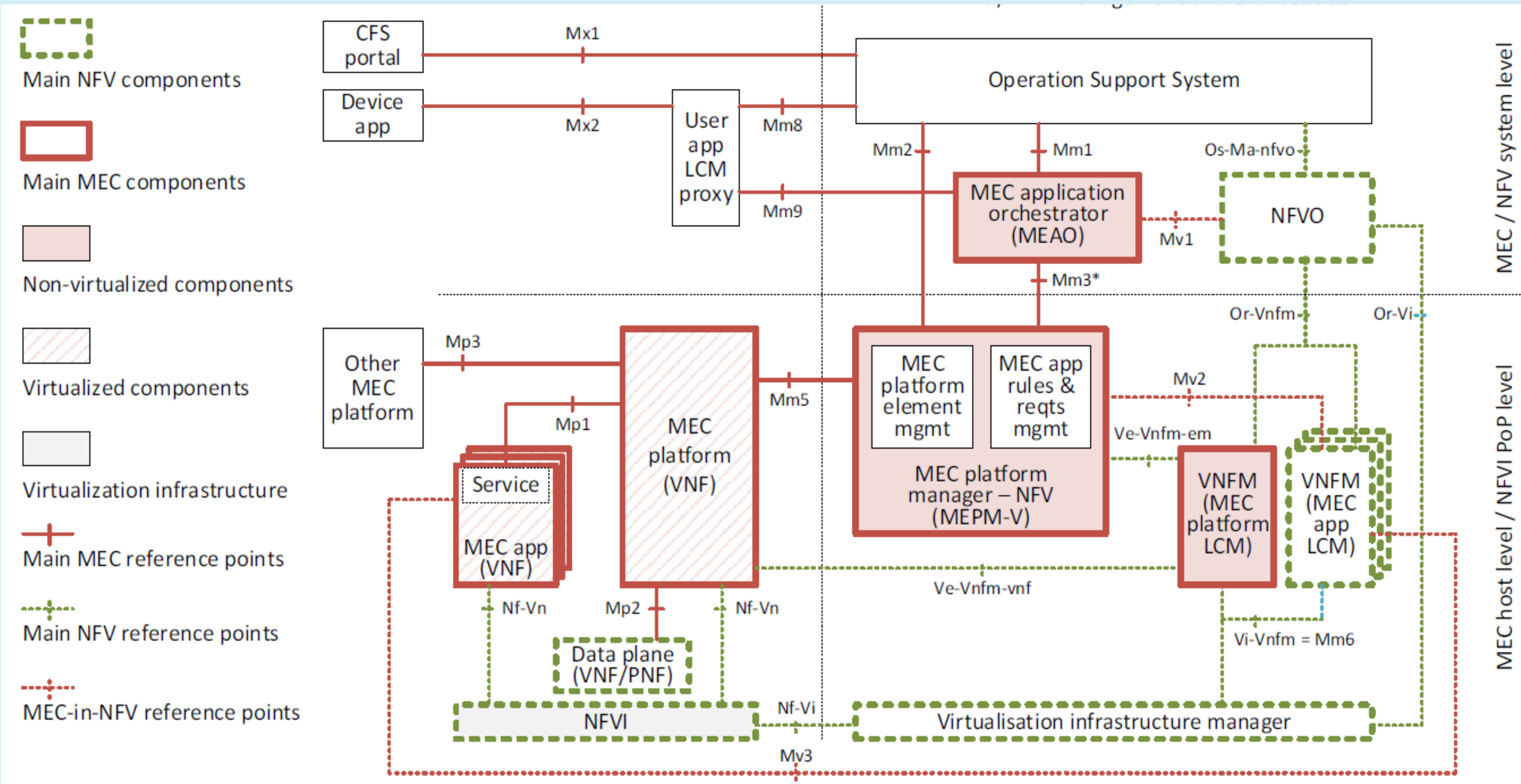


Source: 5GPPP Technology Board Working Group, 5G-IA's Trials Working Group Edge Computing for 5G Networks, 2021

4. Support Technologies, Integration

4.8 Edge computing

Mobile Access Computing (MEC) for 5G architecture in NFV environment

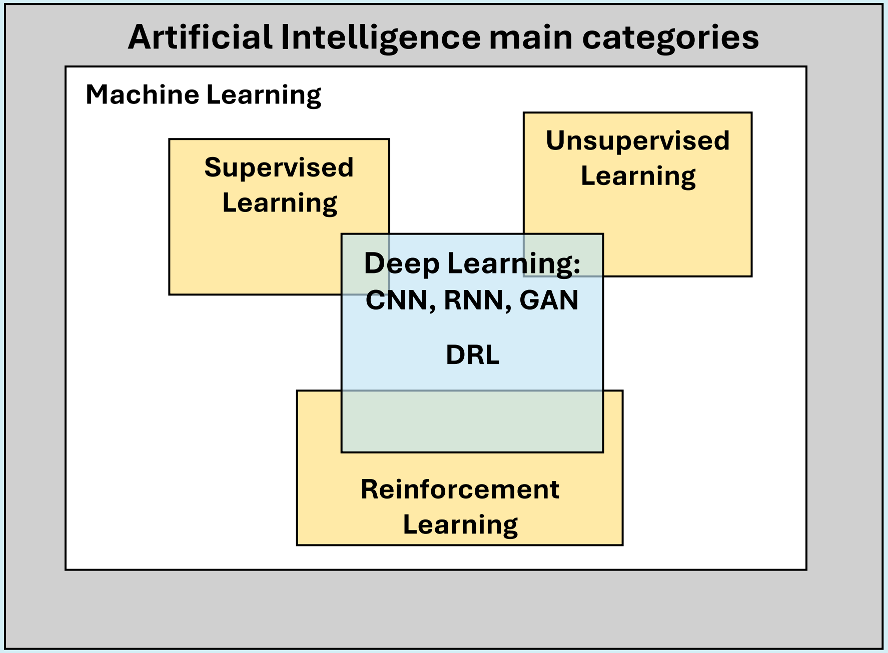


Source: ETSI GR MEC 017

4. Support Technologies, Integration

4.9 Artificial Intelligence/ Machine Learning (AI/ML)

- **Supervised Learning (SL)**
  - The input objects (e.g., a vector of predictor variables) and a desired output value train a model in order to build a function that maps new data on expected output values.
- **Unsupervised Learning (UL)**
  - The algorithms learn patterns only from unlabeled data. The ML model tries to find similarities, differences, patterns, and structure in data by itself. No prior human intervention is needed
- **Reinforcement Learning (RL)**
  - An intelligent agent ought to take actions in a dynamic environment in order to maximize a cumulative reward
- **Deep learning (DL)**
  - It is based on artificial neural networks (ANNs) with use of multiple layers in the network
- **DRL (RL + DL)**
  - It incorporates DL into the solution, allowing agents to make decisions from unstructured input data without manual engineering of the state space

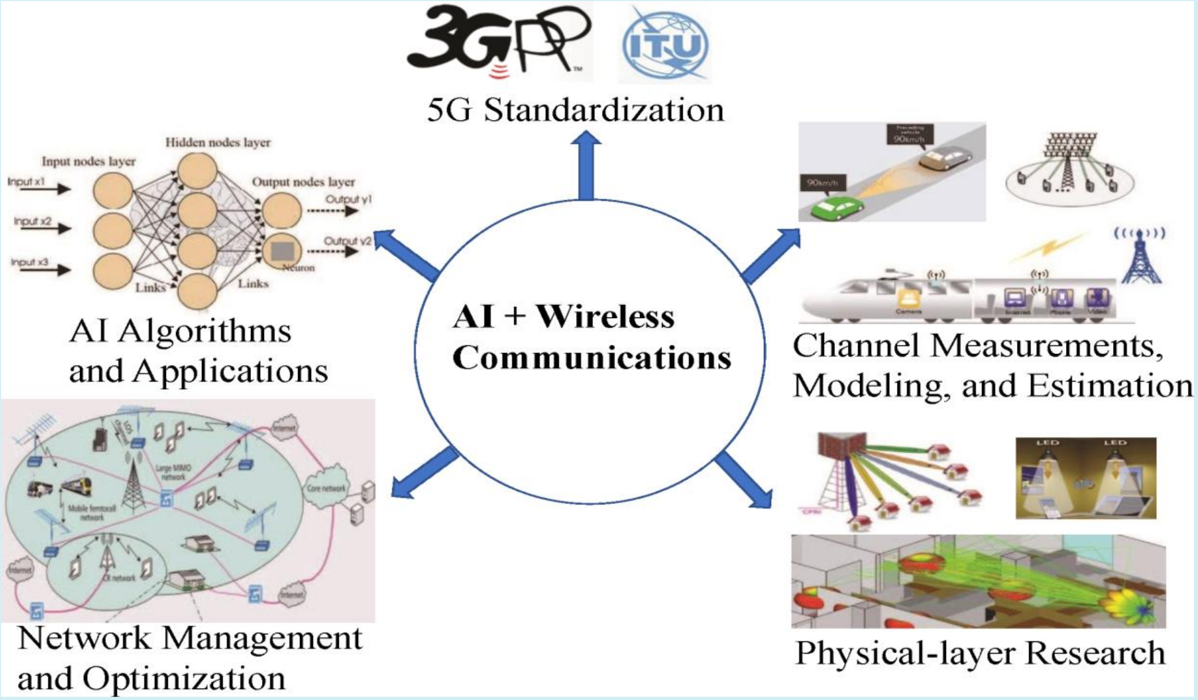


ANN Artificial Neural Networks
CNN Convolutional Neural Network
RNN Recurrent Neural Network
GAN Generative Adversarial Network
DRL Deep Reinforcement Learning

4. Support Technologies, Integration

4.9 Artificial Intelligence/ Machine Learning (AI/ML)

- In 5G, B5G, 6G – the AI/ML can intelligently manage complex network tasks, perform different system optimization problems and improve user experience
- **Examples of Wireless communication domains where AI/ML can contribute or are subject of studies:**

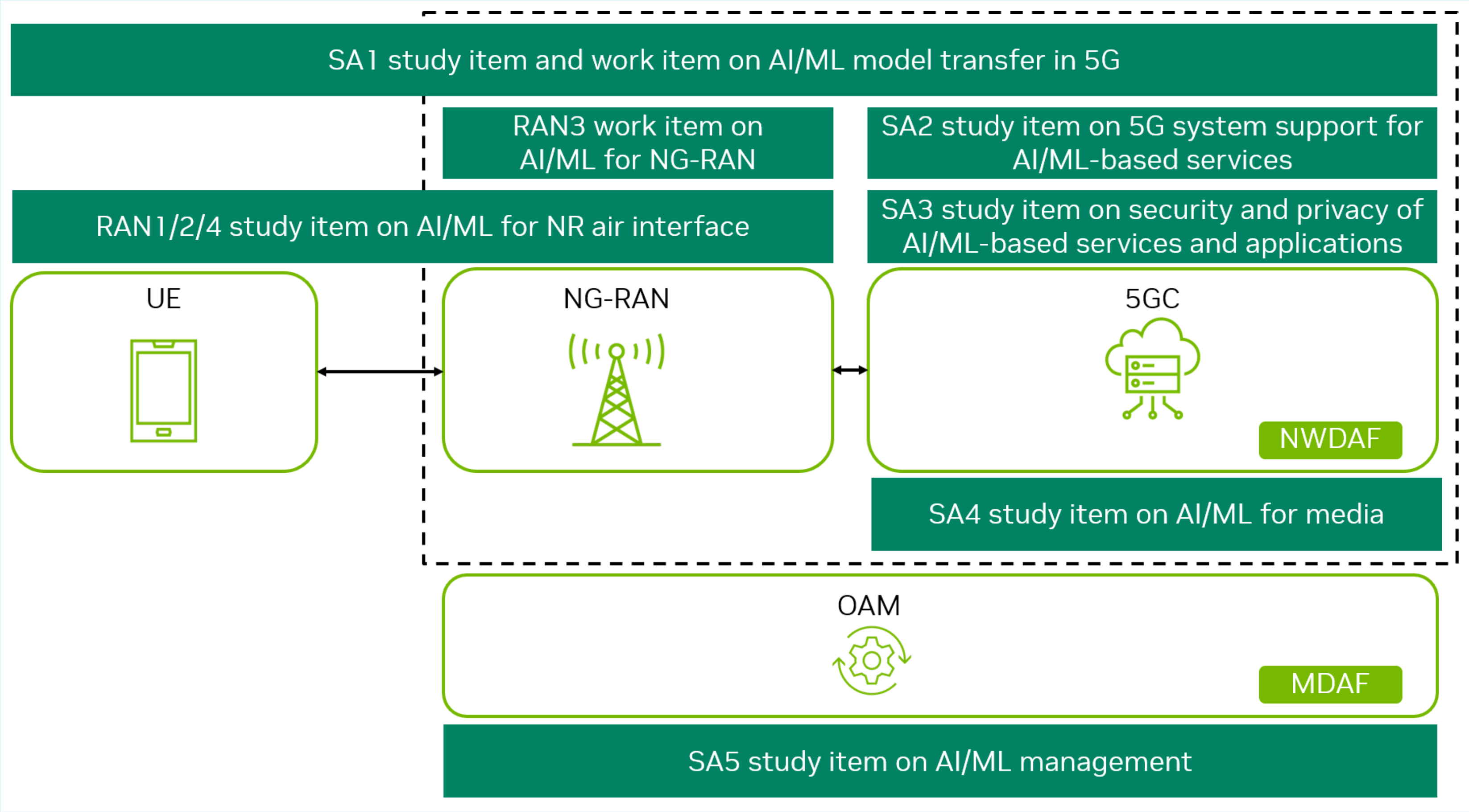


Source: Cheng-Xiang Wang, Marco Di Renzo, Slawomir Stanczak, Sen Wang, and Erik G. Larsson, Artificial Intelligence Enabled Wireless Networking for 5G and Beyond: Recent Advances and Future Challenges, IEEE Wireless Communications, February 2020

4. Support Technologies, Integration

4.9 Artificial Intelligence/ Machine Learning (AI/ML)

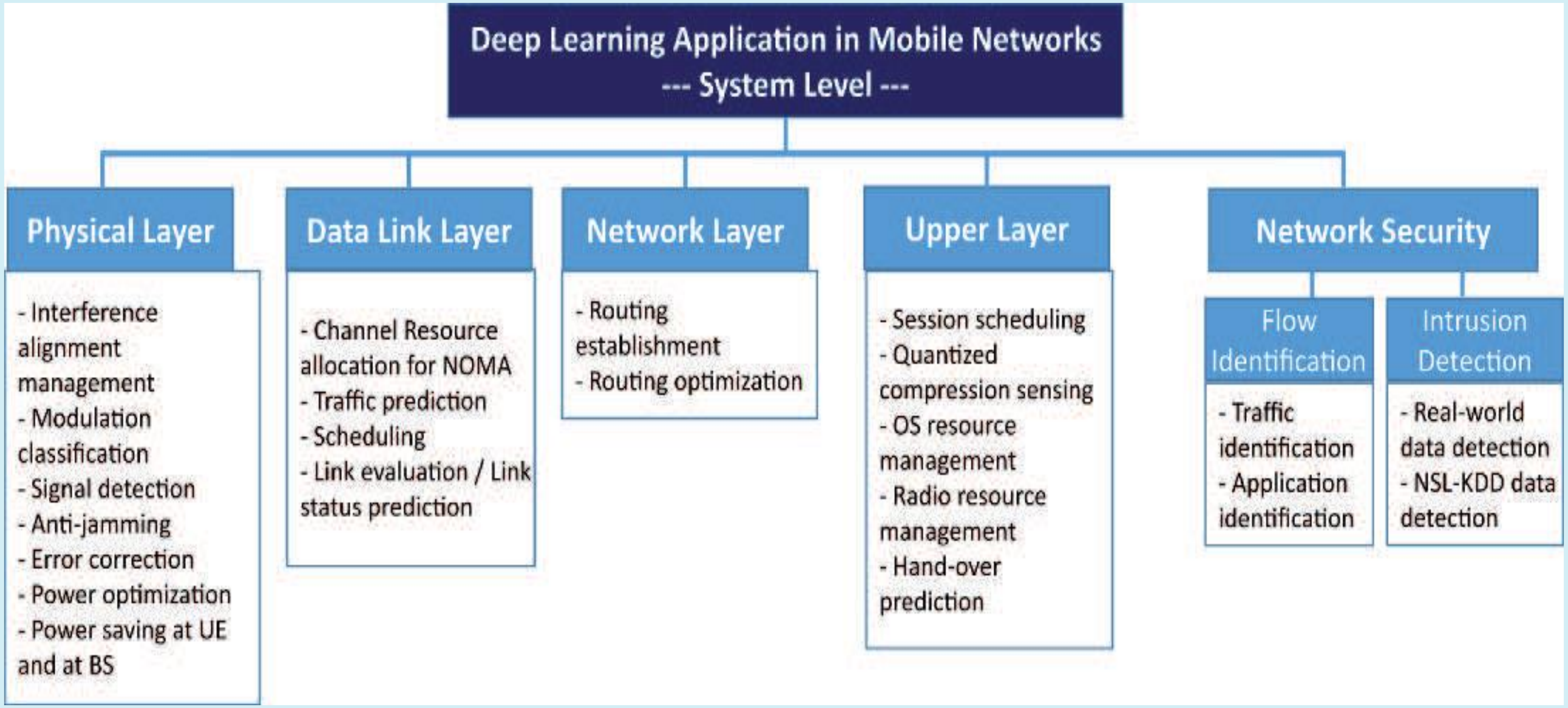
- **Example: AI in 5G-Advanced - 3GPP Release 18** (SA—System Aspects WGs)



Source: X.Lin, Artificial Intelligence in 3GPP 5G-Advanced: A Survey, 2023, https://arxiv.org/abs/2305.05092

4.9 Artificial Intelligence/ Machine Learning (AI/ML)

- **Example: Deep learning** in different architectural layers of 5G/B5G systems

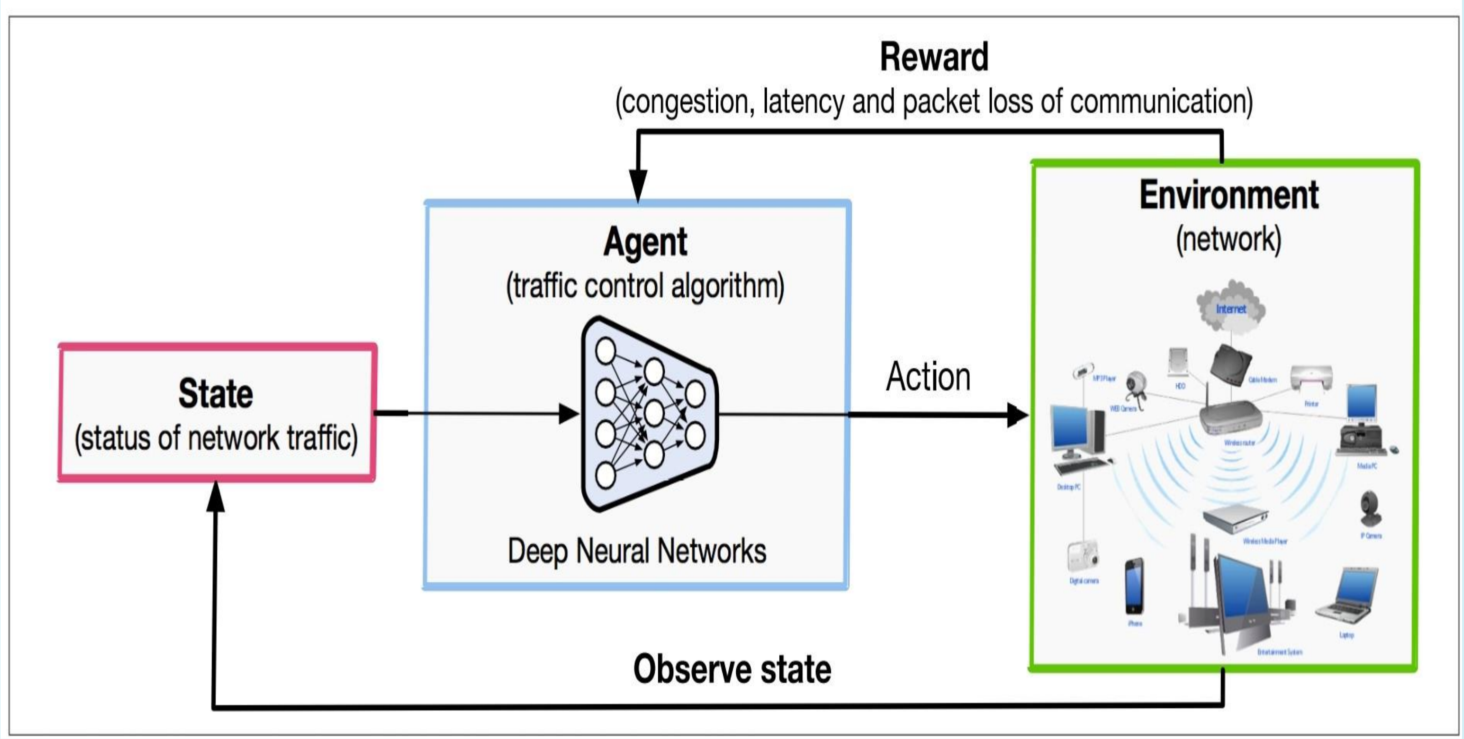


NOMA Non-Orthogonal Multiple Access
NSL-KDD – data base for Intrusion Detection Systems

Source: A. Haidine, F. Z.Salmam, A. Aqqal and A. Dahbi, Artificial Intelligence and Machine Learning in 5G and beyond: A Survey and Perspectives, DOI: http://dx.doi.org/10.5772/intechopen.98517

4.9 Artificial Intelligence/ Machine Learning (AI/ML)

- **Example: Deep Reinforcement Learning** for traffic management problems



Source: Yasin İnal, Artificial Intelligence in 5G Networks
https://www.researchgate.net/publication/356879235

4. Support Technologies, Integration

4.9 Artificial Intelligence/ Machine Learning (AI/ML)

- **Examples of specific ML techniques applied in 5G Systems**
- **Supervised Learning**

Learning Model	5G Application examples
Machine Learning and statistical logistic regression techniques.	Dynamic frequency and bandwidth allocation in self-organized LTE dense small cell
Support Vector Machines (SVM)	Path loss prediction model for urban environments
Neural-Network-based approximation.	Channel Learning to infer unobservable channel state information (CSI) from an observable channel
Supervised Machine Learning Frameworks.	Adjustment of the TDD UL/DL configuration in XG-PON-LTE Systems to maximize the network performance based on the ongoing traffic conditions
Artificial Neural Networks (ANN), and Multi-Layer Perceptrons (MLPs).	Modelling and approximations of objective functions for link budget and propagation loss for next-generation wireless networks

Source: Yasin İnal, Artificial Intelligence in 5G Networks
https://www.researchgate.net/publication/356879235

4.9 Artificial Intelligence/ Machine Learning (AI/ML)

- **Examples of specific ML techniques applied in 5G Systems**
- **Unsupervised Learning**

Learning Model	5G Application examples
K-means clustering, Gaussian Mixture Model (GMM), and Expectation Maximization (EM)	Cooperative spectrum sensing Relay node selection in 5G vehicular networks
Hierarchical Clustering	Anomaly/Fault/Intrusion detection in mobile wireless networks
Unsupervised Soft-Clustering ML Framework	Latency reduction by clustering fog nodes to automatically decide which low power node (LPN) is upgraded to a high power node (HPN) in het cellular networks.
Affinity Propagation Clustering.	Data-Driven Resource Management for Ultra-Dense Small Cells

- **Reinforcement Learning**

Learning Model	5G-Application examples
RL algorithm based on long short-term memory (RL-LSTM) cells	Proactive resource allocation in LTE-U Networks: non- cooperative game which enables SBSs to learn which unlicensed channel, given the long-term WLAN activity in the channels and LTE-U traffic loads
Gradient follower (GF), the modified Roth- Erev (MRE), and the modified Bush and Mosteller (MBM)	Enable Femto-Cells (FCs) to autonomously and opportunistically sense the radio environment and tune their parameters in HetNets, to reduce intra/inter- tier interference
RL with Network assisted feedback	Heterogeneous Radio Access Technologies (RATs) selection

Source: Yasin İnal, Artificial Intelligence in 5G Networks https://www.researchgate.net/publication/356879235

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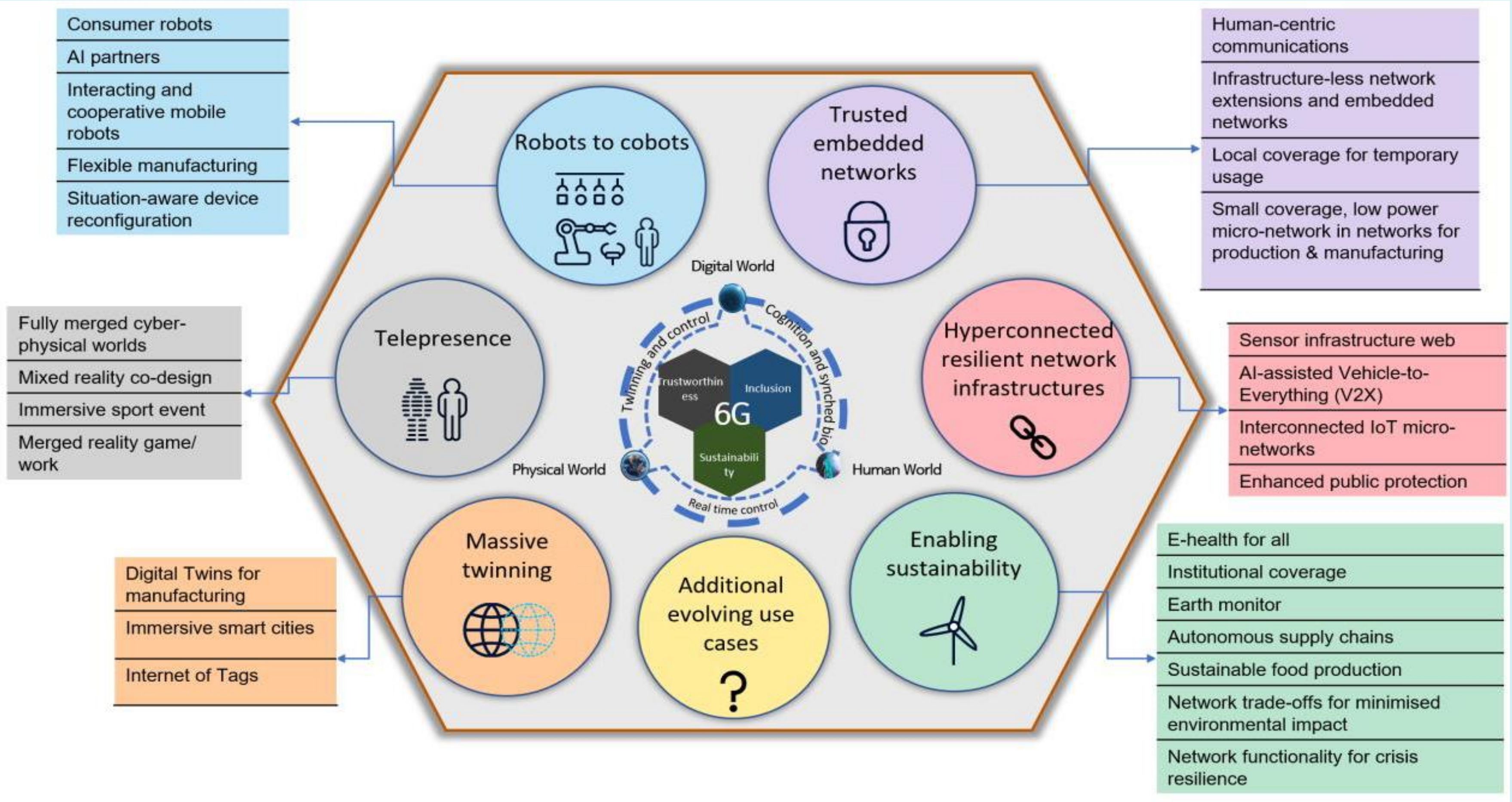
5. 6G Networks

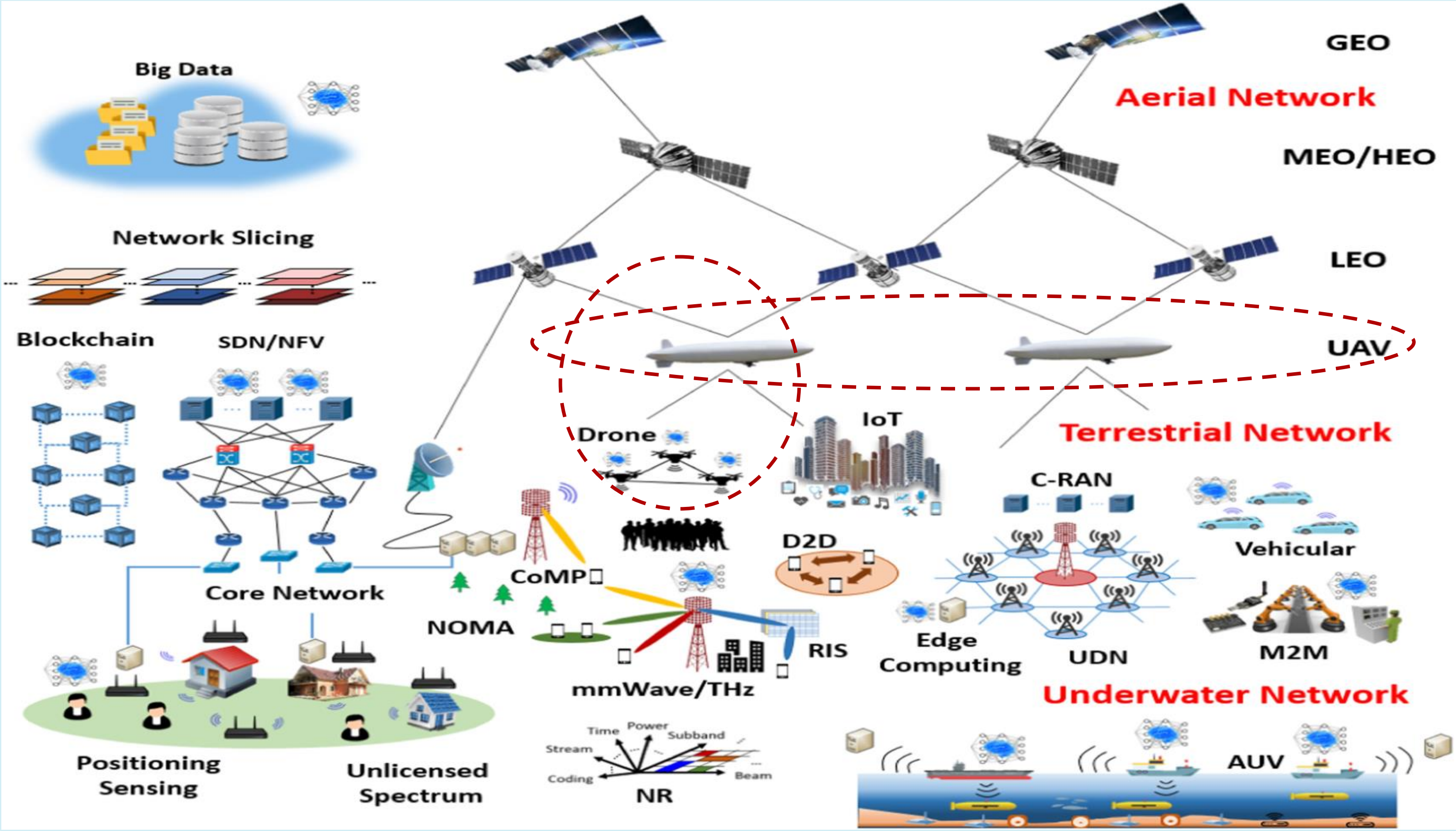
5.1 6G Use cases and applications



Source: 5GPPP Architecture Working Group: The 6G Architecture Landscape, 2023
Source: Hexa-X Deliverable D1.3, "Targets and requirements for 6G – initial E2E architecture", Mar. 2022, https://hexa-x.eu/wp-content/uploads/2022/03/Hexa-X_D1.3.pdf.

5. 6G Networks

5.2 6G landscape



Source: Li-Hsiang Shen, Kai-Ten Feng, and Lajos Hanzo. 2023, Five Facets of 6G: Research Challenges and Opportunities, ACM Comput. Surv. 55, 11, Article 235 , https://doi.org/10.1145/3571072

5. 6G Networks

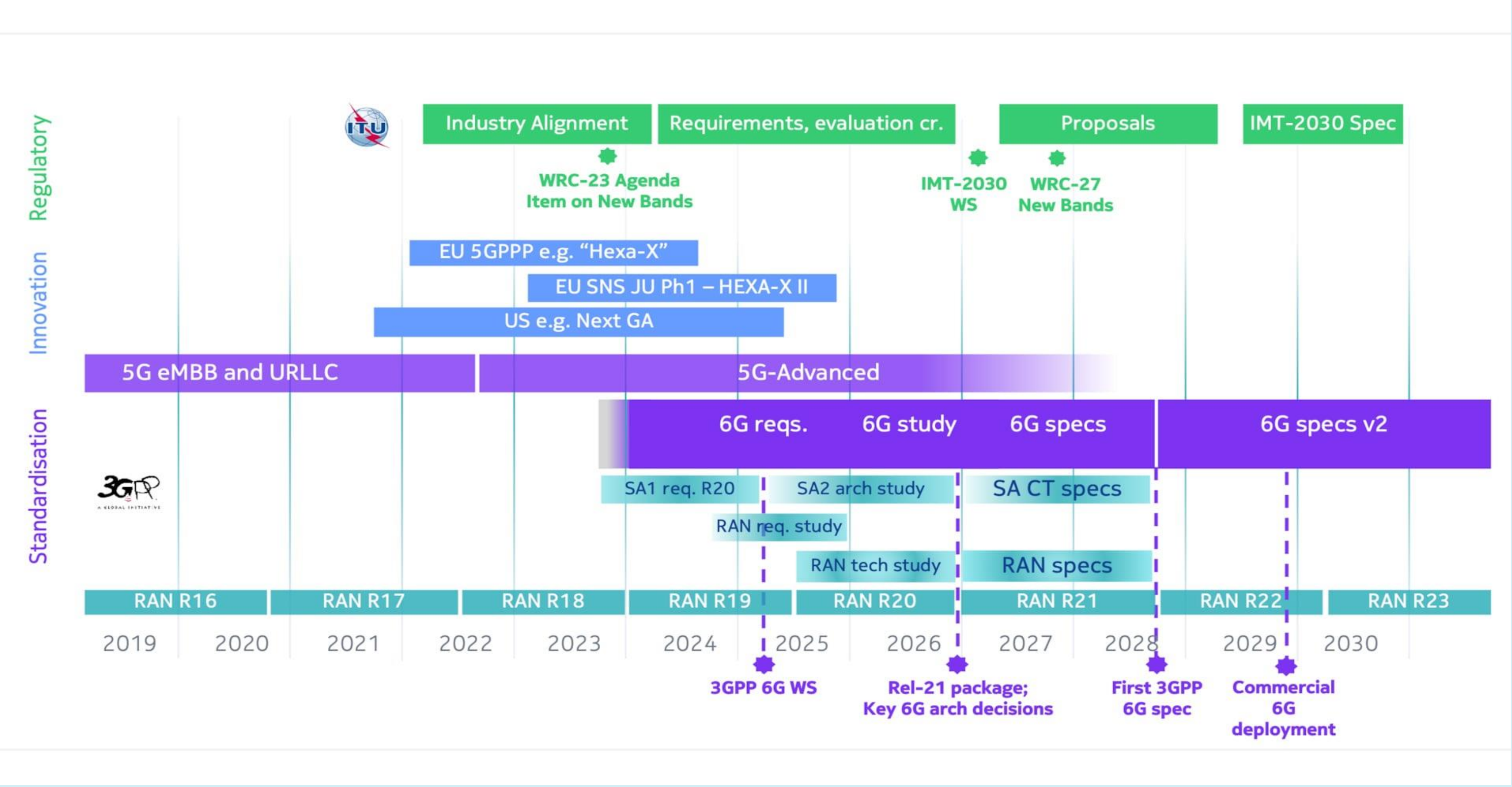
5.2 6G landscape (notations)

Acronyms

AI	Artificial Intelligence
AUV	Autonomous Underwater Vehicle
CoMP	Coordinated Multi-Point
C-RAN	Cloud/Centralized Radio Access Network
D2D	Device to Device
GEO	Geostationary Earth Orbit
HEO	High Earth Orbit
LEO	Low Earth Orbit
LoS	Line of Sight
M2M	Machine to Machine (Communication)
MEO	Medium Earth Orbit
NOMA	Non-Orthogonal Multiple Access
NFV	Network Function Virtualization
NR	New Radio
RIS	Reconfigurable Intelligent Surfaces
SDN	Software Defined Networking
UAV	Unmanned Aerial Vehicle
UDN	Ultra-Dense Networks

5. 6G Networks

5.3 6G specifications - expected evolution

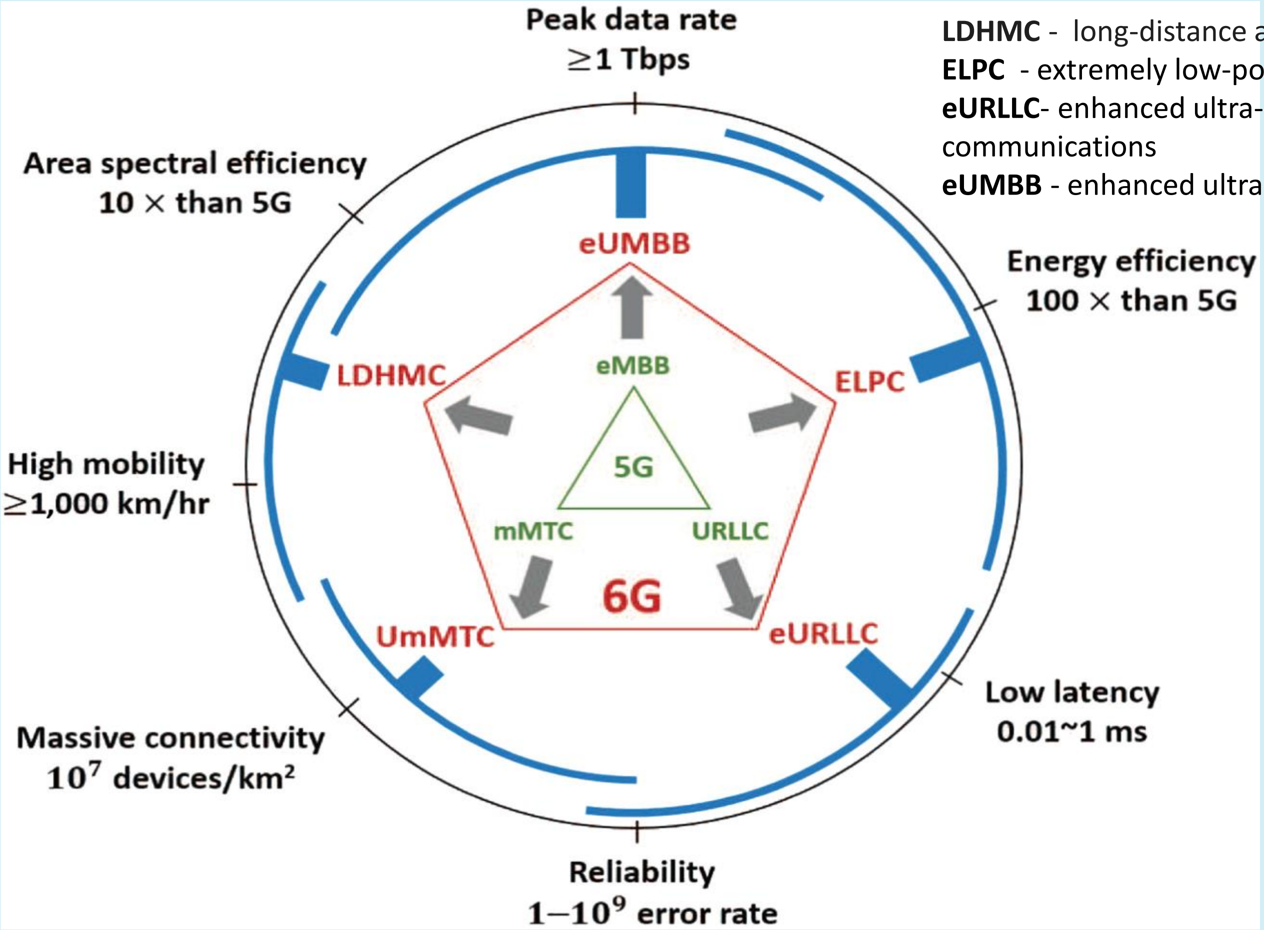


Source: https://www.nokia.com/about-us/newsroom/articles/spectrum-for-6G-explained/

5. 6G Networks

5.4 6G versus 5G in terms of connectivity capabilities

LDHMC - long-distance and high-mobility comm.
ELPC - extremely low-power communications
eURLLC- enhanced ultra-reliable and low latency communications
eUMBB - enhanced ultra-mobile broadband

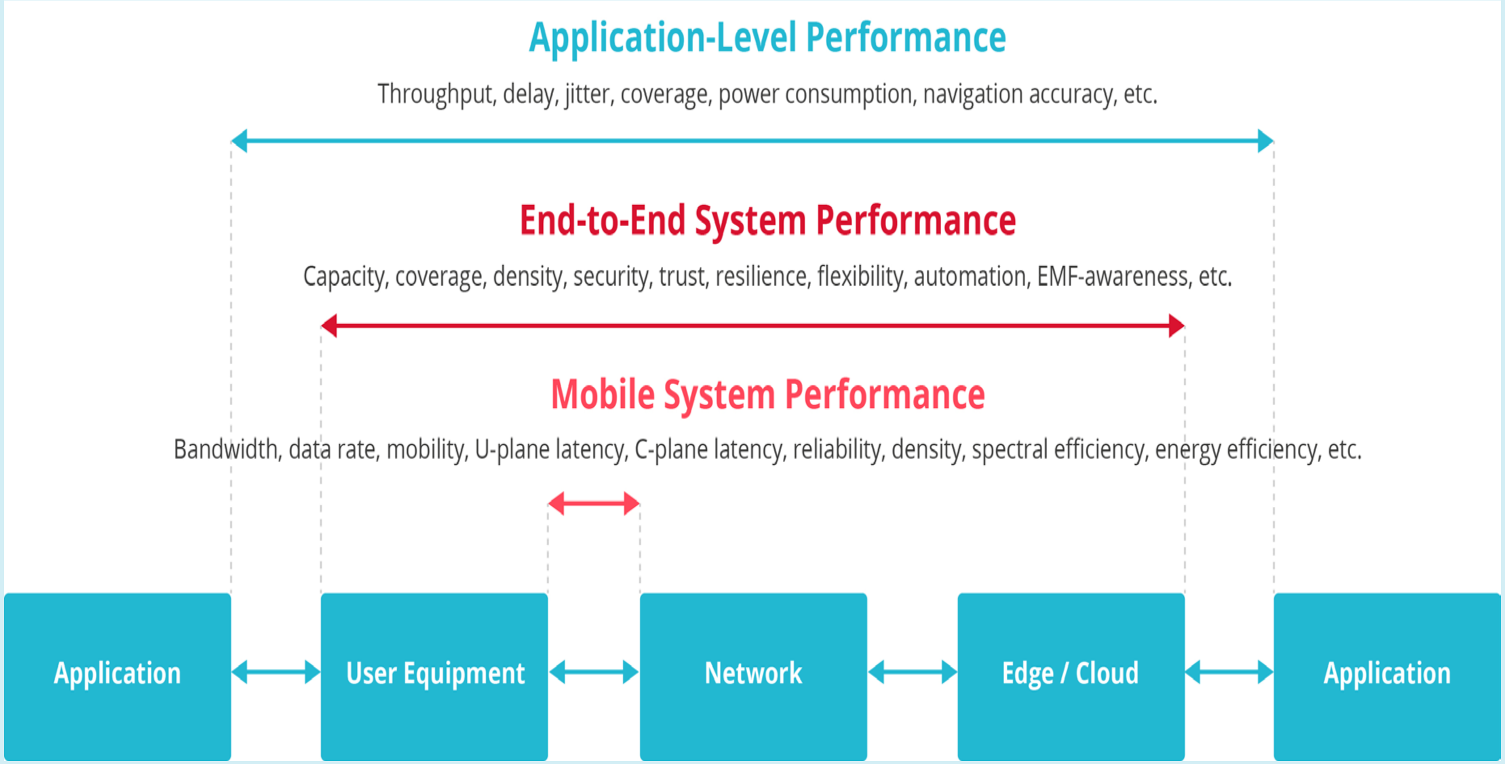


Source: Li-Hsiang Shen, Kai-Ten Feng, Lajos Hanzo, Five Facets of 6G: Research Challenges and Opportunities, ACM Comput. Surv. 55, 11, Article 235 2023, https://doi.org/10.1145/3571072

5. 6G Networks

5.4 6G capabilities – seen from user or application-level perspective

- one should consider the E2E system-level performance
  - sub-network considerations particularly for RAN should be highlighted
  - Figure: different levels of value indicators



Source: NGMN Alliance : 6G Requirements and Design Considerations, 2023
https://www.ngmn.org/publications/6g-requirements-and-design-considerations.html

5. 6G Networks

5.5 6G - advanced network architecture

General concepts

Overview of 6G system

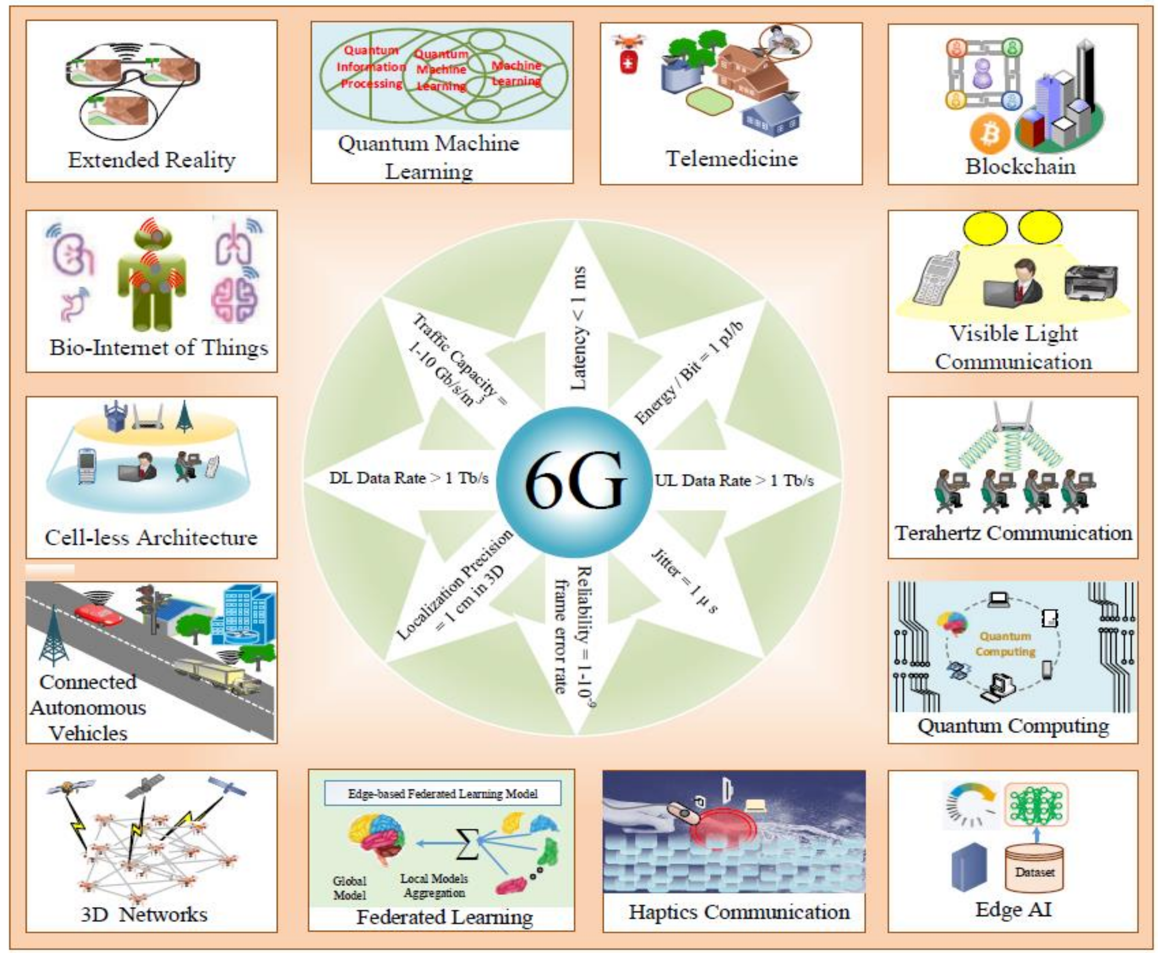
Advanced key requirements: capacity, UL/DL data rate, localization precision, reliability, latency, jitter, energy per bit

Several enabling technologies

Machine learning (quantum), federated learning
Quantum computing
3D networking
Edge AI
Cell-less architecture
Blockchain
Haptic communication
Terahertz communication

Use cases – examples

Connected autonomous vehicles
Telemedicine
Extended reality
Internet of Things



5. 6G Networks

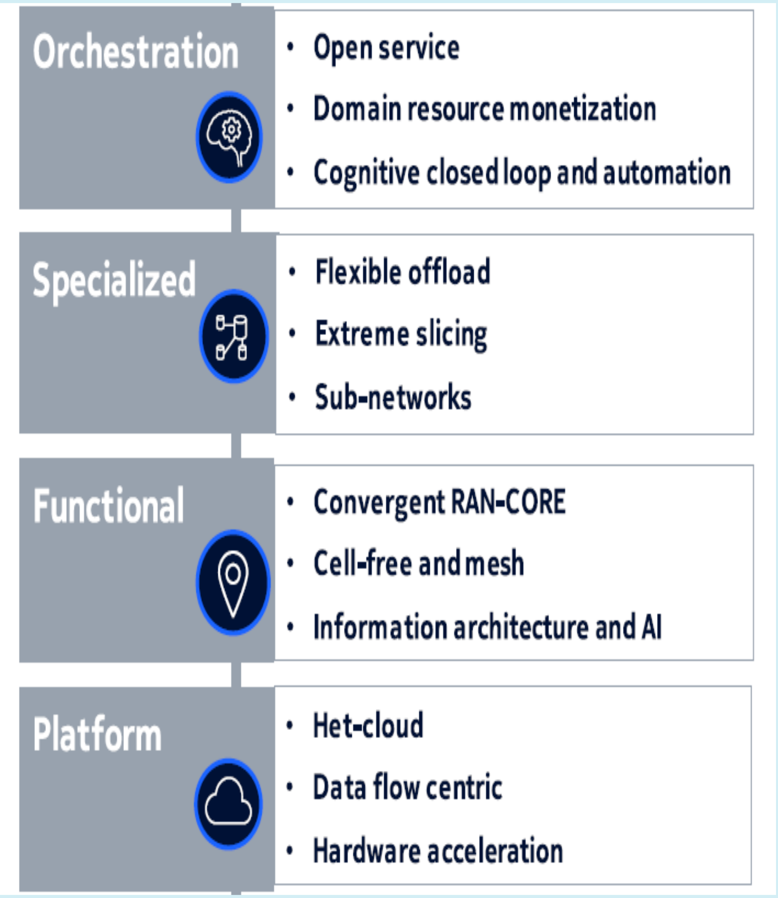
5.5 6G - advanced network architecture

- **6G Architectural framework – building blocks example**
- **Four major interworking components, to provide an open and distributed reference framework**

- **Orchestration component**
  - assures open service enabling and ecosystem play
  - domain resource monetization
  - cognitive closed loop and automation

- **Specialized networks and architectural enablers for**
  - flexible off-load, extreme slicing, sub-networks

- **Functional architecture**
  - RAN- CORE convergence
  - cell free and mesh connectivity
  - information architecture and AI
- **Platform infrastructure:**
  - "heterogeneous-cloud", open, scalable and agnostic run-time environment
  - data flow centricity, hardware acceleration

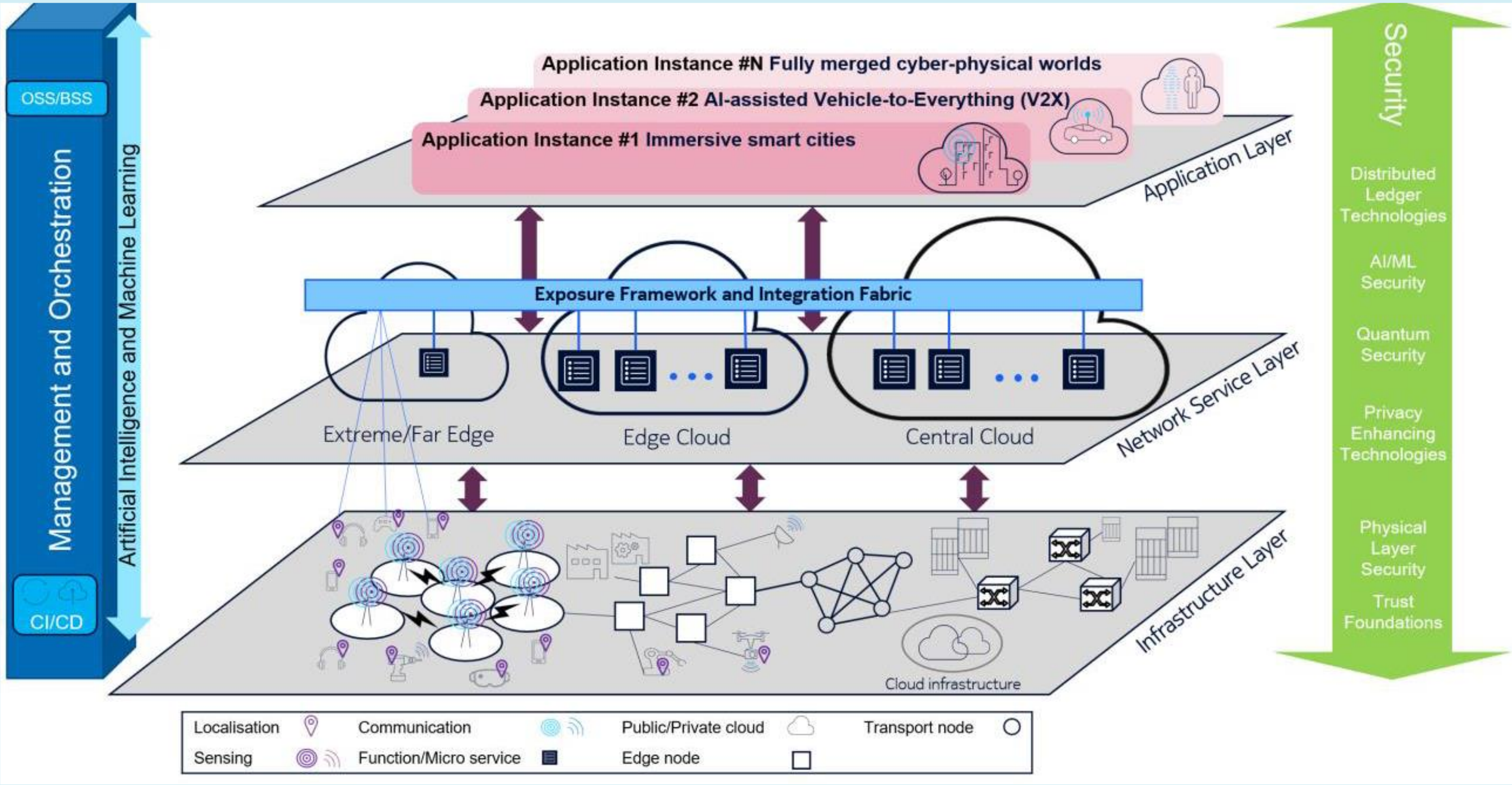


Source: V.Ziegler et al., "6G Architecture to Connect the Worlds", IEEE Access, Sept 2020, https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9200631

5. 6G Networks

5.6 6G – layered architecture

- **High-level view of the 6G layered architecture**

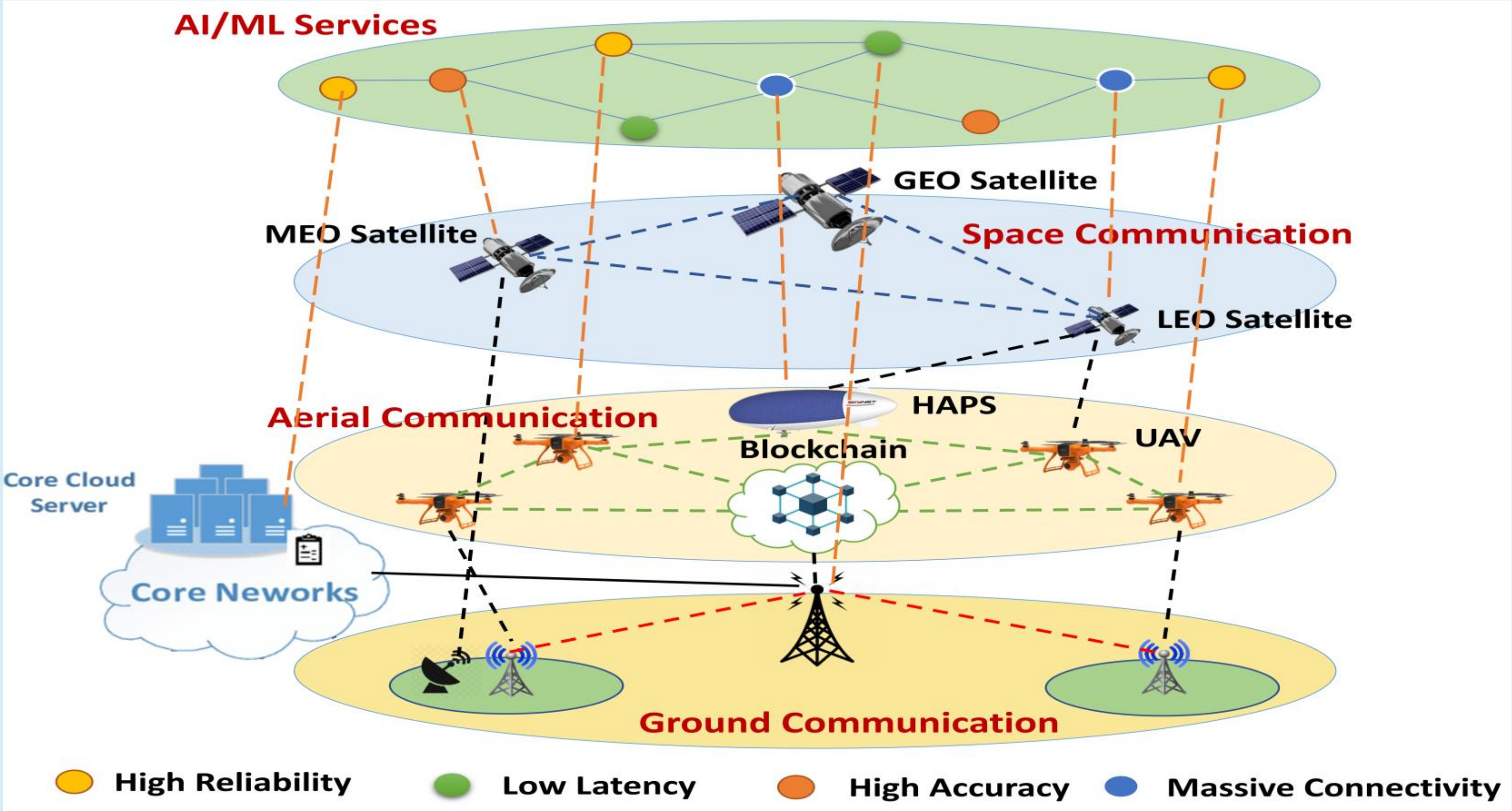


Source: 5G PPP Architecture Working Group: The 6G Architecture Landscape, 2023
Source: Hexa-X Deliverable D1.3, "Targets and requirements for 6G – initial E2E architecture", Mar. 2022, https://hexa-x.eu/wp-content/uploads/2022/03/Hexa-X_D1.3.pdf.

5. 6G Networks

5.7 Example of an architecture for 6G-enabled UAV network

- Interactions among different technologies are shown



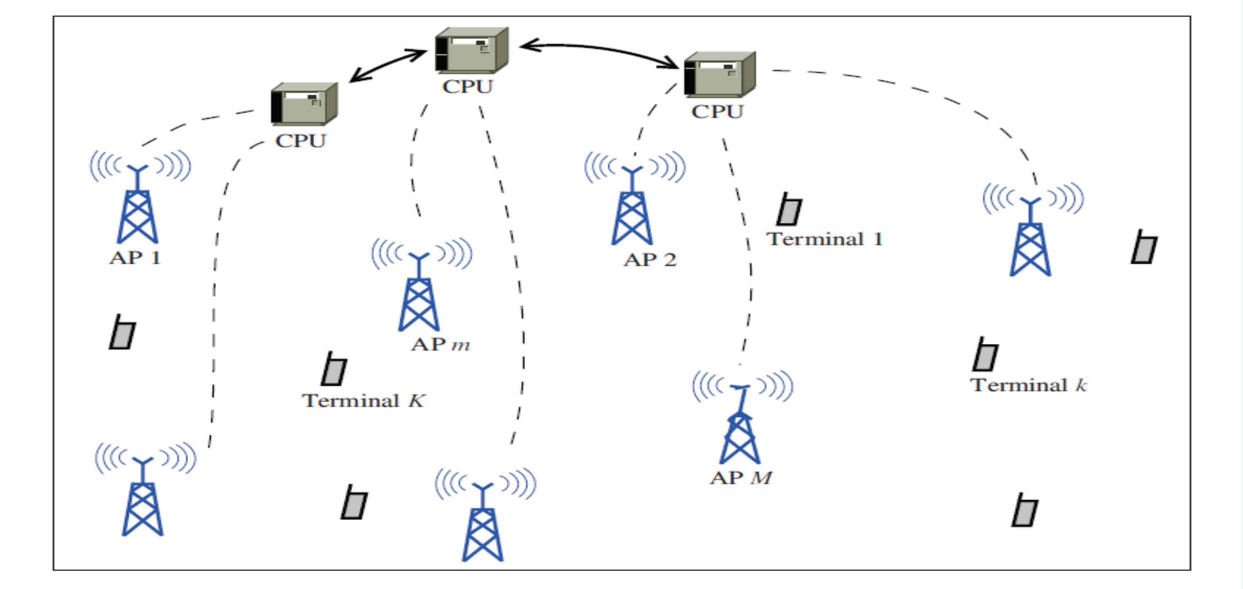
Source: M.A.Khan , N.Kumar,, Syed Agha Hassnain Mohsan, Wali Ullah Khan, M.M. Nasralla, M.H. Alsharif, J.Zywiołek, and I.Ullah, Swarm of UAVs for Network Management in 6G:A Technical Review , https://doi.org/10.48550/arXiv.2210.03234

5.8 Example of 6G feature: Cell-free (CF) architecture

- **Cellular topology limitation**: **boundary effect** - the users at the cell boundary receive weak signal (path loss) and experience strong interference from other cells
- In **5G/B5G/6g and 6G - ultra-densified and heterogeneous BSs/APs deployment is needed** (many small cells). The cell coverage is smaller and the distance between BSs/APs can be ~ tens of meters -interference is higher
- Techniques as MIMO, *Coordinated Multi-Point (CoMP)* tx/rx cannot solve the problem
- **Possible solution:**
  - The **CF (or cell-less) massive MIMO networks** is a practical and scalable version of network MIMO; many APs jointly serve many UEs in the same grid of time frequency resources
  - All APs are distributed in a large area (e.g., the whole city) and connected to one or several CPUs
  - An UE can decide to access several BSs/APs via different ULs and DLs depending on the wireless channel status
  - The BSs/APs do not need to maintain a list of associated UEs; instead, the associated control in a SDN controller will decide which BSs/APs the terminals should be associated via the control link

5.8 Example of 6G feature: Cell-free (CF) architecture

- The SDN controller can create dynamic UL/DLs and backhaul links to support the joint Tx/Rx between terminals and BSs/Aps; the BSs/APs in the same group can inter-cooperate to realize the joint Tx/Rx
  - **CF massive MIMO benefits:** high connectivity, spectral and energy efficiency, simple linear signal processing and low-cost devices
  - **Open research issues:** Scalable signal processing, Scalable power control



X. You, et al., "Towards 6G wireless communication networks: vision, enabling technologies, and new paradigm shifts":, SCIENCE CHINA, Information Sciences, January 2021, Vol. 64 110301:1–110301:74, https://doi.org/10.1007/s11432-020-2955-6

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6. Conclusions

- **5G**
  - Commercial and accelerated 5G deployment in most markets worldwide is on-going or will start soon
  - The architectural evolution of 5G is still running, as it will likely continue for eight more years or so
  - 3GPP Release 18, the start of 5G-Advanced, includes a diverse set of evolutions to boost 5G performance and address a wide variety of new use cases
  - The innovative technology components in 5G-Advanced are essential precursors to key 6G architecture and design
- **6G**
  - **6G architectural research has been successfully initiated**
    - Objectives: flexibility, simplicity, reliability, security, efficiency and automation required to realize the variety of future applications of 6G to consumer and vertical industries
    - The het-cloud platform with new cloud computing capabilities – important component the 6G network
    - Convergent RAN-CORE implemented as micro services and facilitates new cell free and mesh architectures
    - A new data and information architecture will be an essential part of 6G
      - **important role that data and AI/ML optimization** will play in the design and operation of the 6G network

6. Conclusions

- **6G will**
  - adopt more data processing at the edge of the network-computing continuum for critical services
  - target cooperation of a programmable network infrastructures supporting E2E network slicing across multi-domains, multi-operators with assured QoS for multiple tenants
  - support many real-world vertical domains, of interactive services based on distributed intelligence to support decision making
  - intensively apply AI/ML algorithms techniques for system optimization
  - process big data, generated by massively deployed ubiquitous devices at the edge based on a close inter-working between application and network transport layers
  - offer the opportunity to develop semantic approaches, enabling reconfiguration according to the service to be supported (for higher efficiency, lower energy consumption improved QoS/QoE)

6. Conclusions

- **Specific examples of 6G open research issues**

- **Physical and infrastructure Layer**
  - Modeling of Sub-mmWave (THz) Frequencies, High Propagation and Atmospheric Absorption of THz, Spectrum and Interference Management, Beam Management in THz domain, AI /ML mechanisms for PHY layer
- **Management and Control**
  - Resource Management for 3D Networking, Heterogeneous Hardware Management, Autonomous Wireless Systems, Network slicing in mobile environment, AI /ML mechanisms for M&C
- **Enabling technologies**
  - Quantum computing, Blockchain, AI/ML, SDN, NFV, Cloud/Edge computing
- **Device and User Terminal problems**
- **Applications development**
  - IoT, IoV/V2X, UAV, ….
- **Security and privacy at different layers**

- Thank you !
- Questions?

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Wide Area Wireless Networks- from 3G to 6G: evolution, integration, challenges

- **General List of Acronyms** *(other specific acronym groups are listed in the text)*

5G CN	Core Network
5G-AN	5G Access Network
5GS	5G System
AF	Application Function
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
ANN	Artificial Neural Network
AP	Access Point
AS	Access Stratum
AUSF	Authentication Server Function
BBU	Baseband Unit
BS	Base Station
CC	Cloud Computing
CF	Cell Free
CP	Control Plane
CNN	Convolutional Neural Networks
CRAN	Cloud based Radio Access Network
D2D	Device to Device Communication
DL	Downlink
DN	Data Network
DNAI	DN Access Identifier
DNN	Data Network Name
DoS	Denial of Services
DP	Data Plane (a.k.a User Plane UP)
DRL	Deep Reinforcement Learning
EC	Edge Computing

Wide Area Wireless Networks- from 3G to 6G: evolution, integration, challenges

- **General List of Acronyms**

ENaaS	Entertainment as a Service
EPC	Evolved Packet Core
eMBB	Enhanced Mobile Broadband
ePDG	evolved Packet Data Gateway
FC	Fog Computing
FQDN	Fully Qualified Domain Name
GAN	Generative Adversarial Network
GMLC	Gateway Mobile Location Centre
GPS	Global Positioning System
HR	Home Routed (roaming)
IaaS	Infrastructure as a Service
INaaS	Information as a Service
IoT	Internet of Things
IT&C	Information Technology and Communications
ITS	Intelligent Transportation Systems
LADN	Local Area Data Network
LLC	Logical Link Control
LMF	Location Management Function
MANET	Mobile Ad hoc Network
MANO	Management and Orchestration
MCC	Mobile Cloud Computing
MEC	Multi-access (Mobile) Edge Computing
ML	Machine Learning
N3IWF	Non-3GPP InterWorking Function
NaaS	Network as a Service
NAS	Non-Access Stratum

Wide Area Wireless Networks- from 3G to 6G: evolution, integration, challenges

- **General List of Acronyms**

NAI	Network Access Identifier
NEF	Network Exposure Function
NF	Network Function
NFV	Network Function Virtualization
NFVI	NFV Infrastructure
NFVO	NFV Orchestrator
NR	New Radio
NS	Network Service
NSL	Network Slice
NRF	Network Repository Function
NSI ID	Network Slice Instance Identifier
NSSAI	Network Slice Selection Assistance Information
NSSF	Network Slice Selection Function
NSSP	Network Slice Selection Policy
NWDAF	Network Data Analytics Function
ONF	Open Networking Foundation
OS	Operating System
PaaS	Platform as a Service
PCF	Policy Control Function
PKI	Public Key Infrastructure
QoE	Quality of Experience
RAN	Radio Access Network
RL	Reinforcement Learning
RNN	RNN Recurrent Neural Networks
RRH	Remote Radio Head
RSU	Road Side Unit
SA NR	Standalone New Radio

Wide Area Wireless Networks- from 3G to 6G: evolution, integration, challenges

- **General List of Acronyms**

SaaS	Software as a Service
SBA	Service Based Architecture
SBI	Service Based Interface
SD	Slice Differentiator
SDN	Software Defined Networking
SM	Service Management
SMF	Session Management Function
S-MIB	Security Management Information Base
SMSF	Short Message Service Function
S-NSSAI	Single Network Slice Selection Assistance Information
SST	Slice/Service Type
TNL	Transport Network Layer
TNLA	Transport Network Layer Association
TSP	Traffic Steering Policy
UAV	Unmanned Aerial Vehicle
UDM	Unified Data Management
UDR	Unified Data Repository
UDSF	Unstructured Data Storage Function
UL	Uplink
UPF	User Plane Function
URLLC	Ultra Reliability Low Latency Communication

Wide Area Wireless Networks- from 3G to 6G: evolution, integration, challenges

- **List of Acronyms**

V2X	Vehicle-to-everything
VANET	Vehicular Ad hoc Network
VIM	Virtualized Infrastructure Manager
VL	Virtualization Layer
VID	VLAN Identifier
VLAN	Virtual Local Area Network
VM	Virtual Machine
VNF	Virtualized Network Function
VNFM	Virtualized Network Function Manager
WAT	Wireless Access Technologies
WAVE	Wireless Access for Vehicular Environments
WSN	Wireless Sensor Network

- **Backup slides**
  - Note: Particular backup slides provide details of topics previously exposed

3. 5G Networks

3.3.1 5G disruptive capabilities

- **Summary of 5G figures - strong goals - versus 4G:**
  - **1,000 X in mobile data volume** per geographical area reaching a target ≥ 10 Tb/s/km2
  - **1,000 X in number of connected devices** reaching a density ≥ 1M terminals/km2
  - **100 X in user data rate** reaching a peak terminal data rate ≥ 10Gb/s
  - **1/10 X in energy** consumption compared to 2010
  - **1/5 X in E2E latency reaching 5 ms** for e.g. tactile Internet and radio link latency reaching a target ≤ 1 ms, e.g. for Vehicle to Vehicle (V2V) communication
  - **1/5 X in network management** OPEX
  - **1/1,000 X in service** deployment time, reaching a complete deployment in ≤ 90 minutes

3. 5G Networks

3.3.2 Terminology summary in slicing

- **Service** - A SW piece performing one or more functions and providing one or more APIs to apps. or other services of the same or different layers   Services can be combined with other services
  - **Service Instance** - An instance of an EU service or a business service that is realized within or by a network slice
- **Administrative domain (AD)** - A collection of systems and networks operated by a single organization or administrative authority
- **Infrastructure domain** – an admin. domain
  - providing virtualised infrastructure resources or a   composition of resources

- **Tenant: one or more service users** sharing access to a set of physical, virtual resources or service resources (e.g. offered by NFV-MANO framework)

- **Multi-tenancy:** physical, virtual or service resources are allocated so that multiple tenants and their computations and data are isolated from each another

- **Tenant domain:** provides VNFs, and combinations of VNFs into Network Services, and is responsible for their management and orchestration, including their functional configuration and maintenance at application level

See:. L. Geng , et.al., IETF- "Network Slicing Architecture   draft-geng-netslices-architecture-02", 2017
ETSI GS NFV 003 V1.3.1 (2018-01) Network Functions Virtualization (NFV); Terminology for Main Concepts in NFV

3.3.2 Terminology summary in slicing

- **Network Resources**
  - **Resource -** P/V (network, compute, storage) component available within a system (can be very simple or comprised of multiple other resources)
  - **Logical Resource** - An independently manageable partition of a Physical (P) resource, inheriting the same characteristics as the P resource
  - **Virtual Resource** - An abstraction of a P/L resource, maybe with different characteristics and extended capabilities w.r.t the original
  - **Network Function (NF)** - A processing function in a network, including but not limited to network nodes functionality
    - NFs implementation: as a network node on a dedicated HW, or as VNFs
  - **Virtual Network Function (VNF)** - A NF whose functional SW is decoupled from HW
    - It is implemented by **one or more virtual machines (VM)**
  - **Network Element (NE)** - a manageable logical entity uniting one or more network devices. This allows distributed devices to be managed in a unified way using one management system

See:. L. Geng , et.al., IETF- "Network Slicing Architecture draft-geng-netslices-architecture-02", 2017
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4. Support Technologies, Integration

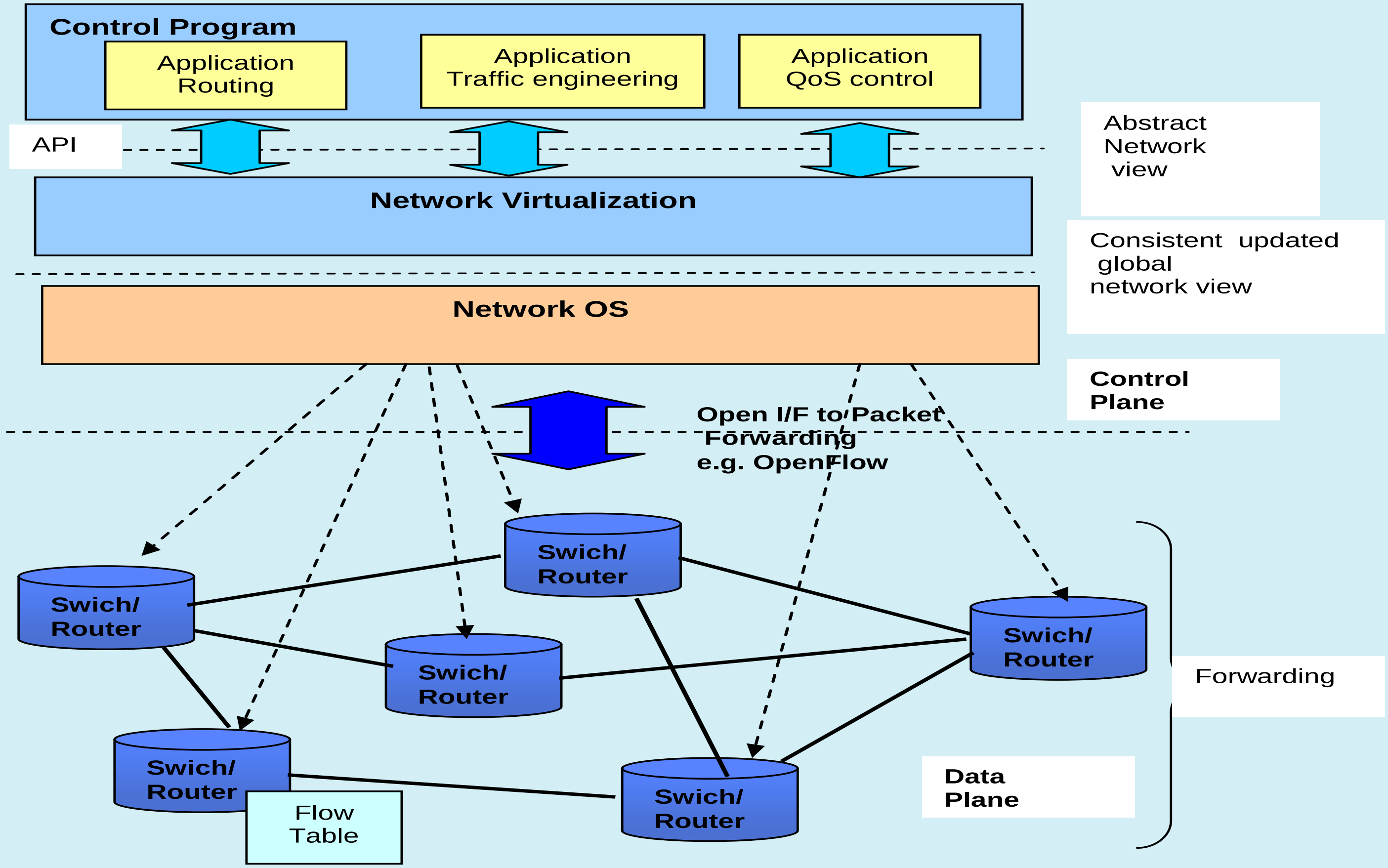
4.1 Software Defined Networking (SDN)

- **SDN main concepts**
  - Architectural: ***Control Plane(CPl)*** (and ***Management Plane-MPl***) are separated from the ***Data Plane (DPl)*** (even physically)
  - Network intelligence (CPl/MPl) is (logically) centralized in SW-based **SDN controller(s),** which maintain a global view of the network.
    - Maintain, control and program DPl state from a central entity
  - Execute CPl /MPl SW on general purpose HW (commodity servers)
    - CPl software and apps are independent from specific networking HW
  - **DPl** (Forwarding plane) **behaviour is programmable** (see the SDN name)
  - The architecture defines the control for a whole network (and not for an individual network device)
  - The network appears to the applications and policy engines as a single, logical switch
    - This simplified network abstraction can be efficiently programmed
  - Flow concept – used in Data /Forwarding Plane

4. Support Technologies, Integration

4.1 Software Defined Networking (SDN)

- **SDN basic architecture**



4. Support Technologies, Integration

4.1 Software Defined Networking (SDN)

- **Flow concept :**
  - *Flow* = a sequence of packets having a least common characteristic (e.g., one or more header fields with the same value)
  - network traffic is identified based on pre-defined match rules that can be statically or dynamically programmed by the SDN control SW
  - the network can be programmed on a per-flow basis

- **SDN advantages:** flexibility, programmability, independence of control and apps from HW, virtualization, cooperates with network function virtualisation, cloud/edge computing
- **SDN still open issues** : native problems of the centralization concept, horizontal and vertical scalability, real –time capabilities, security, integration with traditional networking distributed technologies
- **Network OS**:
  - Distributed system that creates a consistent, updated network view
  - Executed on servers (controllers) in the network
    - Controller examples: NOX, ONIX, ONOS, RYU, HyperFlow, Floodlight, Trema, Kandoo, Beacon, Maestro,..
  - Communicates with Forwarding Elements FE-switches) (via vertical protocol, e.g. OpenFlow), under commands of the control apps.
    - Collect state information from FEs
    - Generate commands to FEs (e.g. install flow tables in FEs)

4. Support Technologies, Integration

4.2 Network Function Virtualization (NFV)

- **NFV – novel architectural development**
  - **NFV decouples the SW implementation of network functions from the underlying HW** by using virtualization and off-the-shelf (COTS) programmable HW (general-purpose servers, storage, software switches)
  - **Network-related functions**, e.g., load balancing, network address translation (NAT), firewalling, intrusion detection, domain name service, caching, etc., can be delivered in software and deployed on general purpose servers

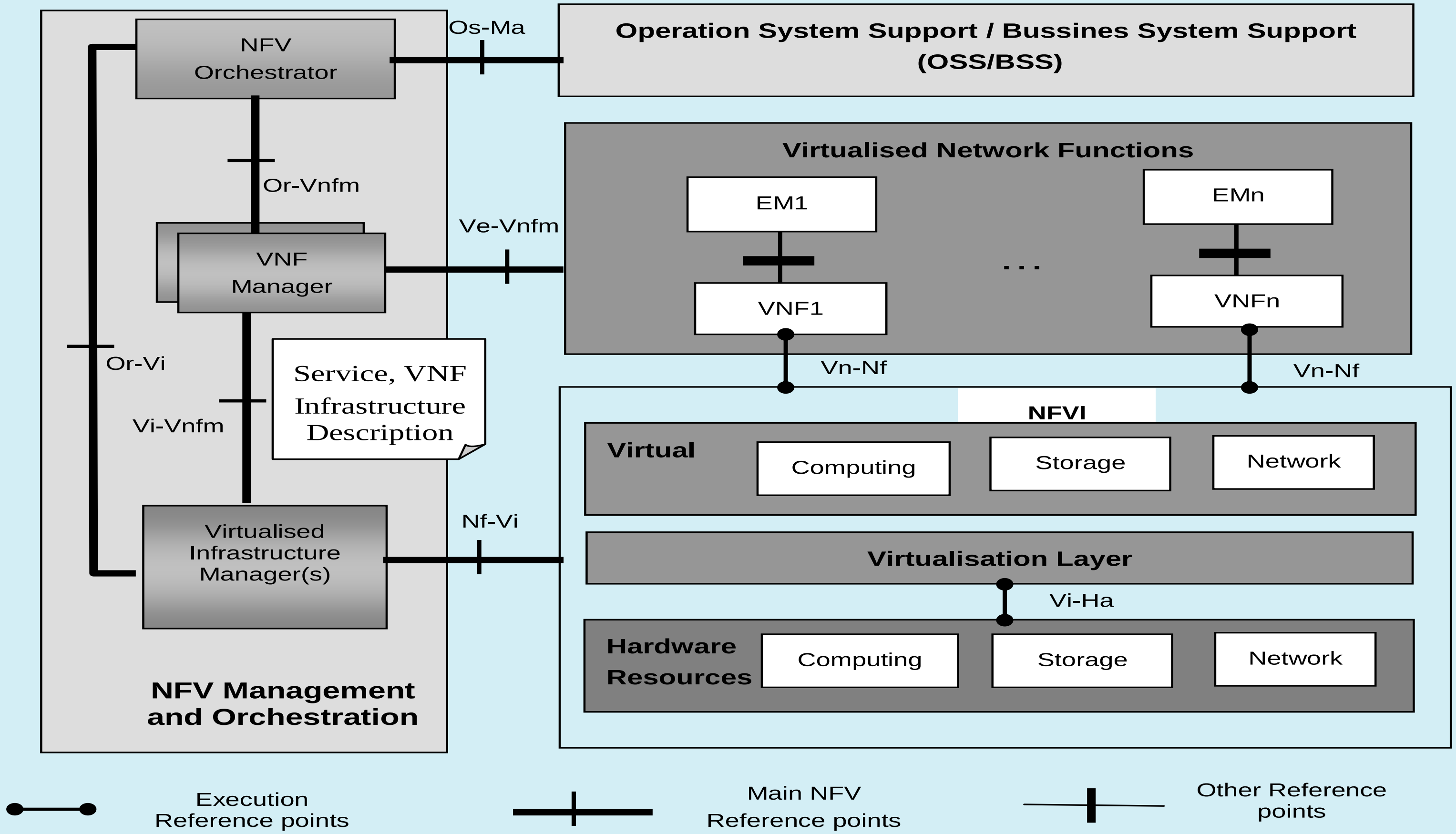
- **Objectives**- efficiency improvement versus traditional dedicated HW-SW implementation :
  - use **(COTS)** HW to provide VNFs, through virtualisation
  - **HW sharing** and reducing the number of different HW architectures
  - **flexibility** in assigning VNFs to HW - **better vertical and horizontal system scalability**
  - **decoupling the networking functionalities from location**
  - **enabling time of day reuse**, enhancing resilience
  - **rapid service development** through software-based service deployment
  - common **automation** and operating procedures
  - reduce power consumption by **migrating workloads within hardware**
  - **standardised and open interfaces** between VNFs infrastructure - management entities and external parties

Source: ETSI GS NFV 002 v1.2.1 2014-12, "NFV Architectural Framework"

4.2 Network Function Virtualization (NFV)

- **NFV challenges:** network performance guarantees for virtual appliances, dynamic instantiation /migration, and efficient placement of **Virtual Network Functions (VNF)**

- **NFV Framework and Reference Architecture**



Source: ETSI GS NFV 002 v1.2.1 2014-12, "NFV Architectural Framework"

4. Support Technologies, Integration

4.2 Network Function Virtualization (NFV)

- **NFV Framework and Reference Architecture**
  - **Operations and Business Support Systems** (OSS/BSS);
  - **Virtualised Network Functions (VNF)** -SW implementations of NFs and runs over the NFVI; This module contains different **Element Management** entities and VNFs
  - **NFV Infrastructure (NFVI) -** all HW and SW components building up the environment in which VNFs are deployed and it can span across several locations, e.g. places where data centres are operated
    - The **network** providing connectivity is part of the NFVI. A NFVI component is an NFVI HW resource that is not field-replaceable, but is distinguishable as a COTS component at manufacturing time
    - **Virtualisation Layer (VL)** abstracts the HW resources and decouples the VNF SW from the underlying HW
      - HW- independent lifecycle for the VNFs
      - abstracting and logically partitioning PHY resources, commonly as a HW abstraction layer
      - enabling the VNF SW to use the underlying virtualised infrastructure
      - providing virtualized resources to the VNF, so that the latter can be executed.
      - the VNFs SW can be deployed on different physical HW resources.
      - **Typical implementation –Hypervisors and Virtual Machines Monitor (VMMs)**

Source: ETSI GS NFV 002 v1.2.1 2014-12, "NFV Architectural Framework"

4.2 Network Function Virtualization (NFV)

- **NFV Framework and Reference Architecture**

- **NFV Management and Orchestration (NFV-MANO) -** orchestration and lifecycle management (LCM) of HW/SW resources that support the infrastructure virtualization
  - NFV MANO focuses on **all virtualisation-specific management tasks** and includes the partial managers for the Data Plane layers:
    - **Virtualised Infrastructure Manager (VIM)**
    - **Virtualised Network Function Manager (VNFM)**
    - **NFV Orchestrator (NFVO).**

  - NFVO optimizes the resource allocation, i.e., manages the **Network Service (NS)** lifecycle, VNF lifecycle (supported by the VNFM) and NFVI resources (supported by the VIM)

  - A **Network Service (NS)** is a composition of NFs defined by its functional and behavioural specification
    - The NSes contributes to the behaviour of the higher layer service (performance, dependability, security, etc., specifications
    - The individual NF behaviours plus a network infrastructure composition mechanism determines the End to End (E2E) NS behaviour.

Source: ETSI GS NFV 002 v1.2.1 2014-12, "NFV Architectural Framework"

4. Support Technologies, Integration

4.9 Artificial Intelligence/ Machine Learning (AI/ML)

- **Artificial Neural Network (ANN)** is inspired from biological neural networks.
  - It "learn" to perform tasks without being programmed with any task-specific rules. It is based on connected nodes -"artificial neurons“. Each connection, can transmit information, a "signal“ from one neuron to another. A neuron that receives a signal can process it and then signal additional artificial neurons connected to it.
- **CNN Convolutional Neural Networks**
  - CNN is a regularized type of feed-forward neural network that learns feature engineering by itself via filters (or kernel) optimization. Vanishing gradients and exploding gradients, seen during backpropagation in earlier neural networks, are prevented by using regularized weights over fewer connections.
- **RNN Recurrent Neural Networks**
  - RNN is one of the two broad types of ANN, characterized by direction of the flow of information between its layers. In contrast to the uni-directional feedforward neural network, it is a bi-directional artificial neural network; it allows the output from some nodes to affect subsequent input to the same nodes.
- **GAN Generative Adversarial Network**
  - In GAN two neural networks contest with each other in the form of a zero-sum game, (i.e., one agent's gain is another agent's loss. Given a training set, GAN learns to generate new data with the same statistics as the training set.
- **DRL Deep Reinforcement Learning**
  - It incorporates DL into the solution, allowing agents to make decisions from unstructured input data without manual engineering of the state space.