Communication technologies: 5G, 5G-Advanced, 6G, .. concepts, architectures, applications, developments, perspectives

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SoftNet-ICSNC 2023, November 13-17, 2023 - Valencia, Spain

- **Acknowledgement**
  This overview and analysis is compiled and structured, based on several public documents, conferences material, studies, research papers, standards, projects, overviews, tutorials, etc. (see specific references in the text and Reference list).

  - The selection and structuring of the material belongs to the author.

  - Given the extension of the topics, this presentation is limited to a high-level overview only.

This work has been partially supported by the NO Grants 2014-2021, under research project contract no. 42/2021, RO-NO-2019-0499 - "A Massive MIMO Enabled IoT Platform with Networking Slicing for Beyond 5G IoV/V2X and Maritime Services" SOLID-B5G, 2020-2023.

Communication technologies: 5G, advanced 5G, 6G, .. concepts, architectures, applications, developments, perspectives

- **Motivation of this talk**
  - Last decade: increasing demand of the current and future networks and services, especially related to mobile communications
  - Complex sets of **requirements**
    - **Infrastructure** : large bandwidth, flexibility, capacity, mobility, geographic coverage, large communities of users, response time, number of terminals, energy saving, space communications, etc.
    - **User applications and services**: flexibility, integration, intelligent behaviour, large set of service types, security and privacy, etc.)
    - **Integration and novel technologies** aspects: Global Internet, Cloud computing, Artificial Intelligence
  - Driving forces for novel generation communication technologies: 5G, 6G,..development: IoT, smart cities, industry, governance, IoV/automotive, safety/emergency, entertainment, environment, etc.
  - Many R&D projects related to different areas of 5G, 6G, ..
  - Significant field deployment of 5G, in many countries, research started for 6G
  - Standardization/fora organizations –iinvolved
    - 3GPP, 5GPP, ETSI, ITU-T, GSMA, ONF, NGNM, IETF, IEEE, etc.

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1. Communication technology evolution

1.1 Key Drivers, Requirements

- **Driving factors for cellular network evolution 3G→ 4G→ 5G → 6G….**
  - devices, data, and data transfer rates
  - continuous growth in wireless user devices, data usage
    - E.g.: 50 billion connected devices (IoT) will utilize the cellular network services until 2025 → high increase in data traffic
  - desired: better quality of experience (QoE)
  - need of extended and new services
  - various needs coming from different domains ("verticals")

- **Three views- generating specific sets-of-requirements**
  - ***user-centric*** (uninterrupted connectivity and communication services, smooth consumer experience)
  - ***service-provider-centric*** (connected intelligent systems, multi-tenant, multi-domain capabilities, large area of IoT services, critical monitoring/tracking services)
  - ***network-operator-centric*** (scalable, energy-efficient, low-cost, efficient management and control, programmable, and secure - communication infrastructure)

1. Communication technology evolution

1.1 Key Drivers, Requirements

- **Mission critical services** -requirements
  - high reliability, global coverage and/or very low latency (currently these features are offered by specialized networks), public safety, mobility capabilities

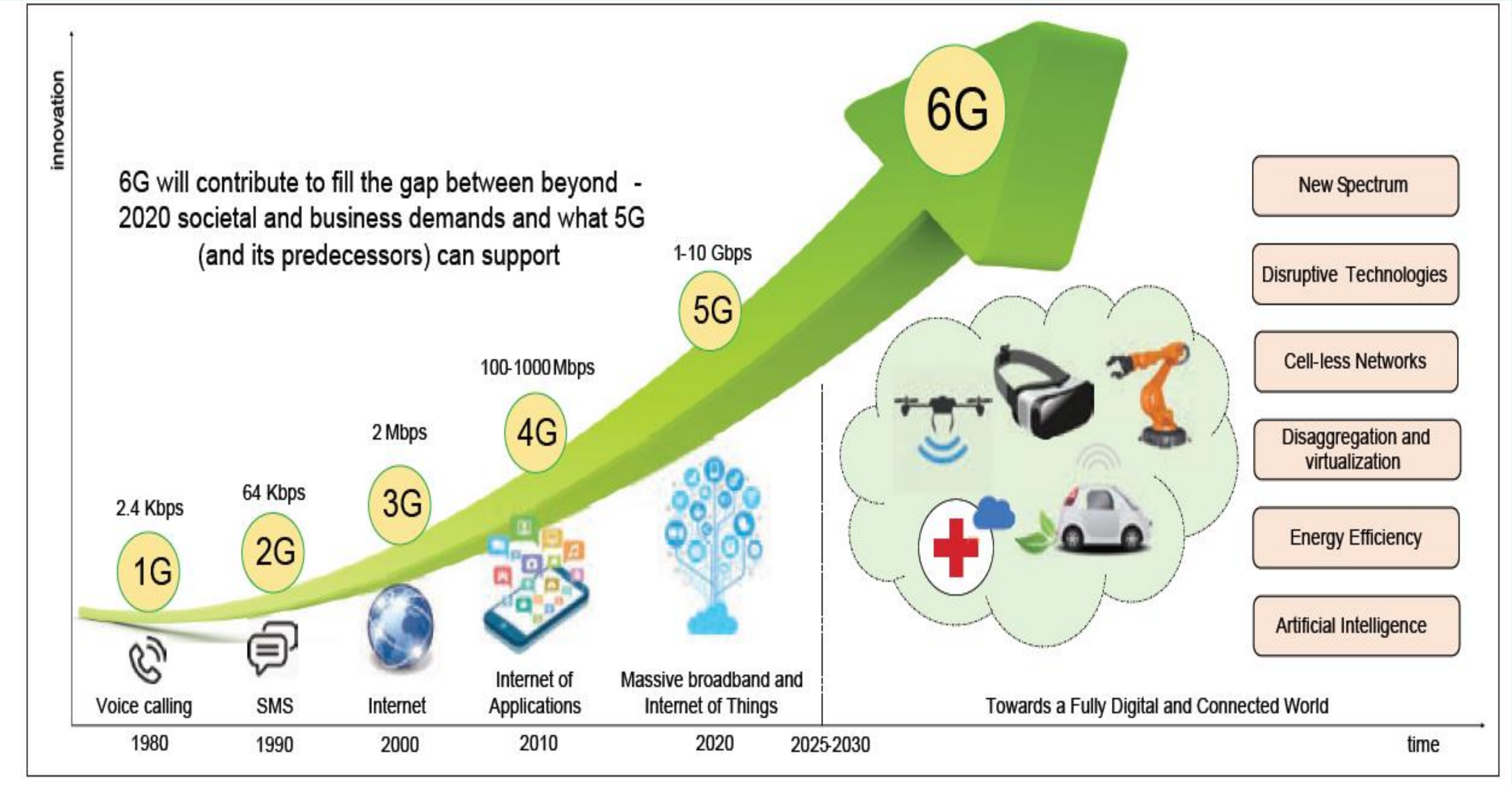
- **5G, 6G, .. should integrate: *networking* + *computing* + *storage* resources into one programmable and unified infrastructure**

  - **optimized** and **dynamic usage** of all distributed resources
  - **convergence of fixed, mobile** and unicast/mcast/broadcast services
  - support **multi tenancy and multi-domain models**, enabling players collaboration
  - cooperation with **cloud/fog/edge computing**
  - usage of **AI technologies** capabilities

1. Communication technology evolution

1.2 Mobile communications evolution

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

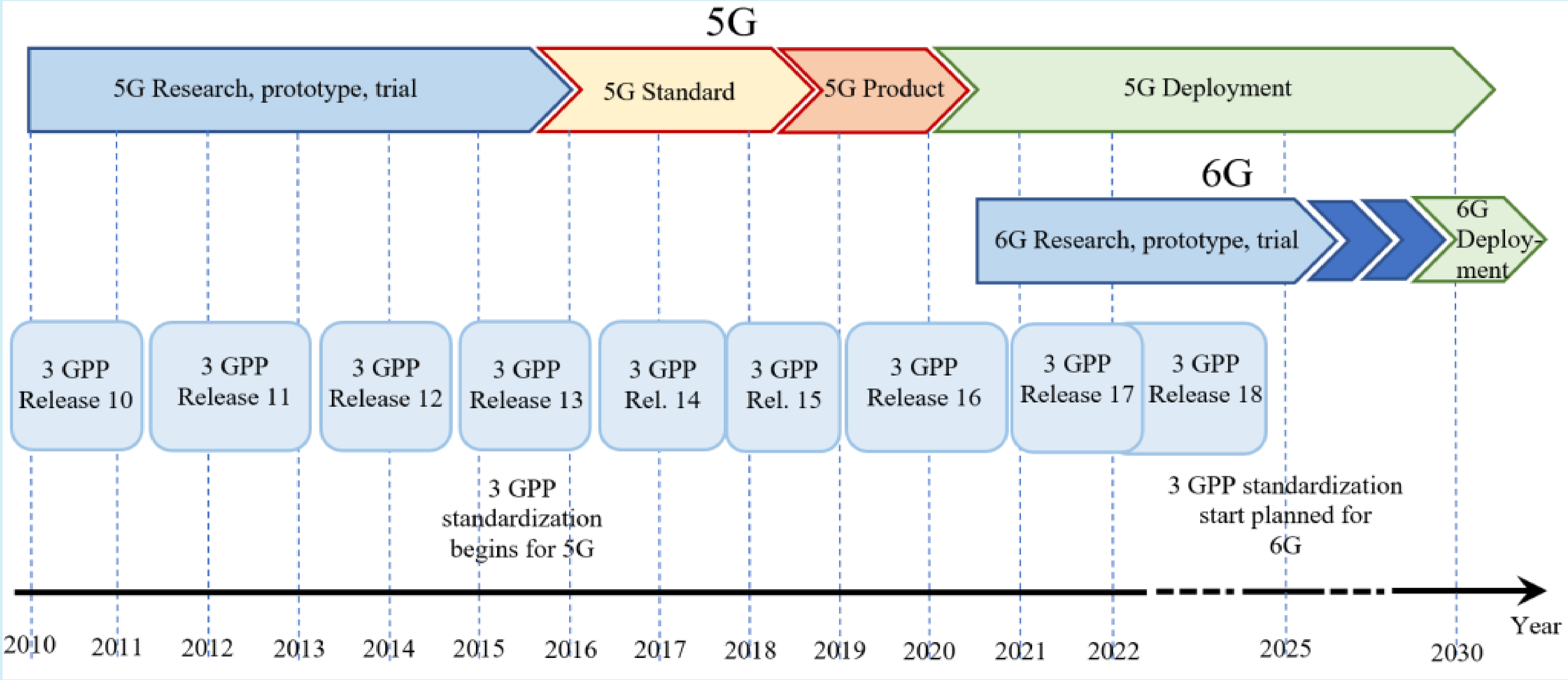


Source: M. Giordani, et al., "Toward 6G Networks:Use Cases and Technologies", IEEE Communications Magazine , March 2020

1. Communication technology evolution

1.2 Mobile communications evolution

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

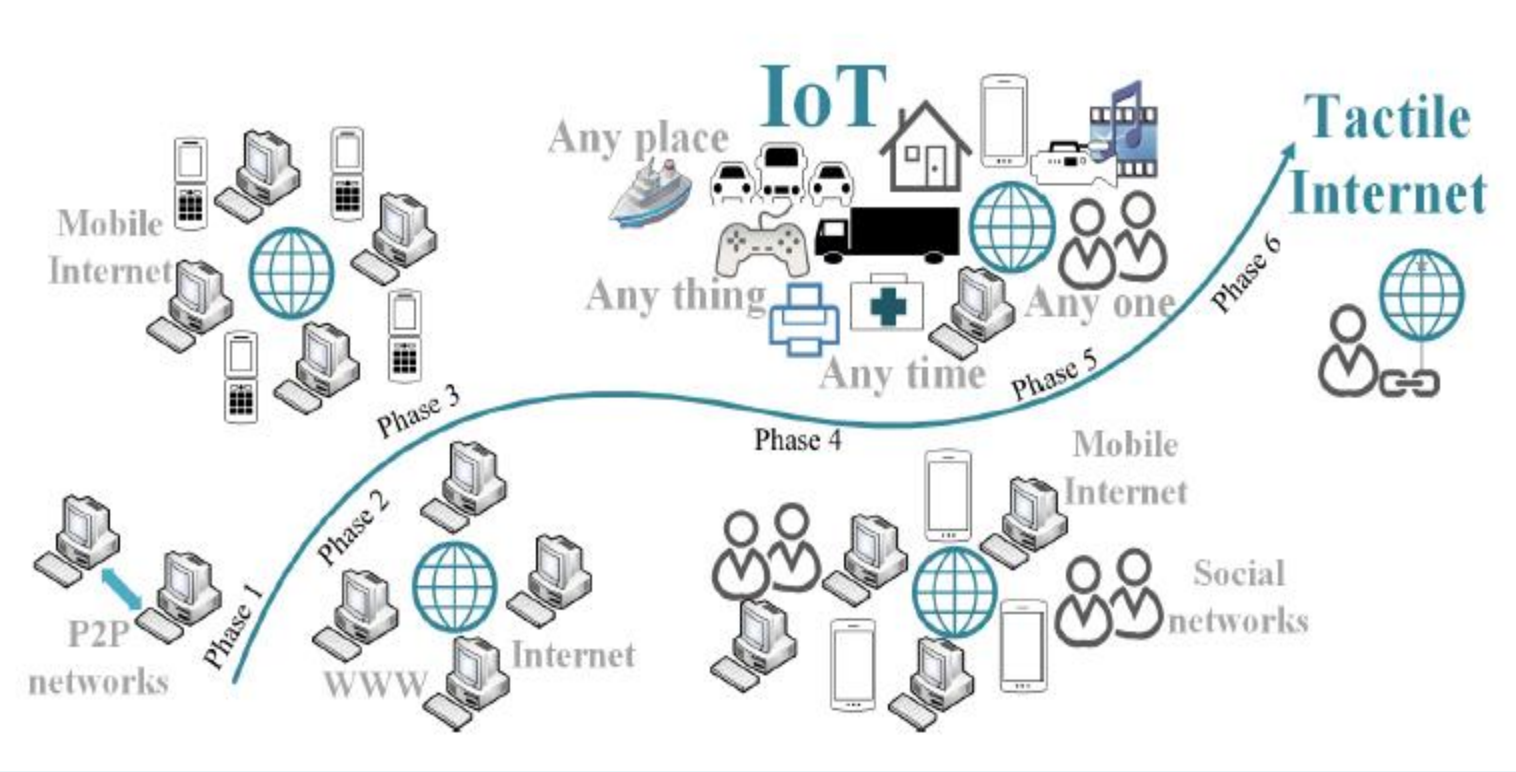


Sources: C. Schroeder, "Early indications of 6G," Microwave Journal, vol. 64, pp. 5–9, 2021.
International Telecommunication Union, IoT Standards Part II: 3GPP Standards. Training on Planning Internet of Things (IoTs) Networks. U.S.: ITU Report, 2018.

1. Communication technology evolution

1.3 Internet evolution

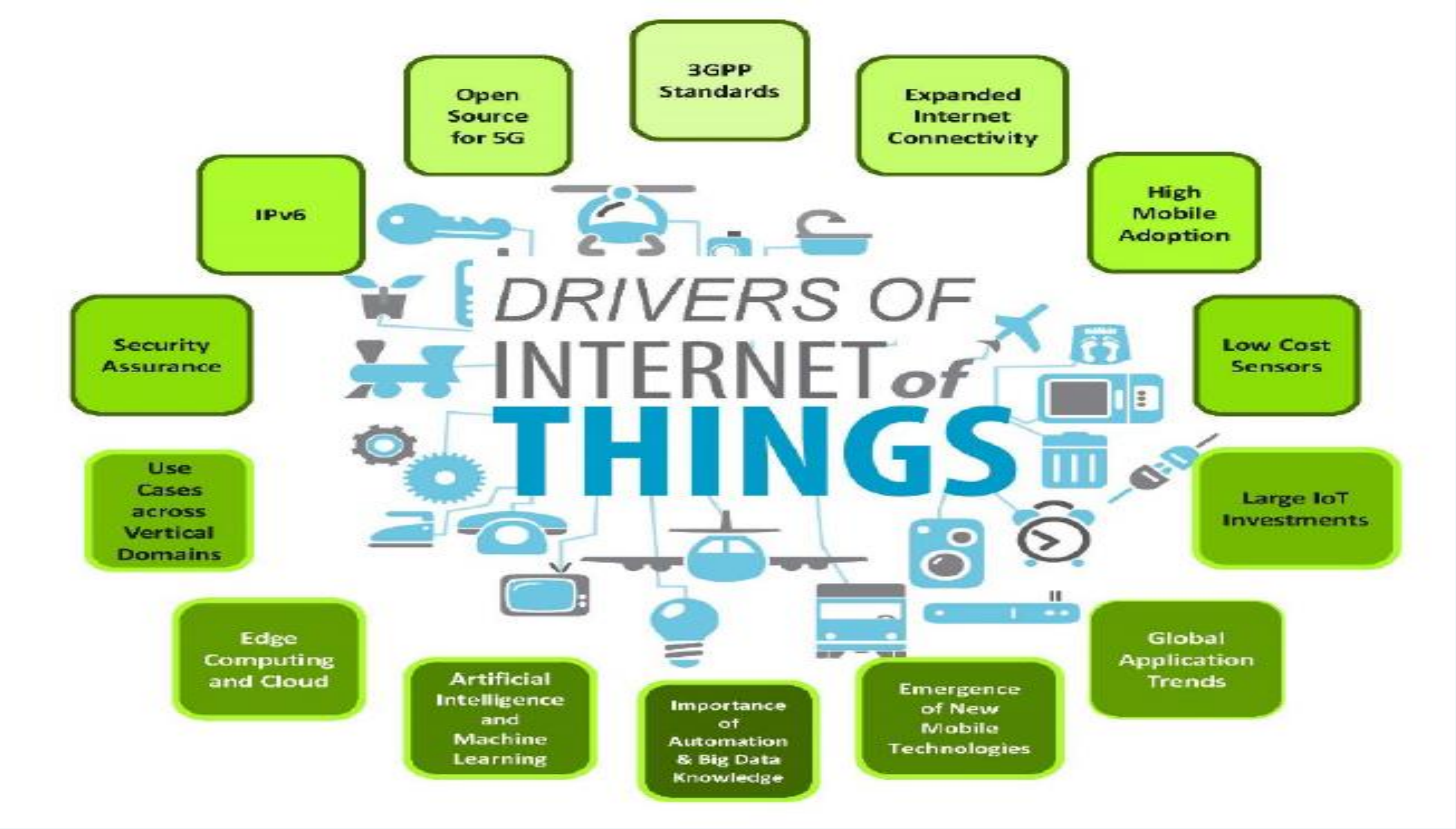
- Several phases: P2P, WWW, Mobile Internet, Social networks, IoT, Tactile Internet, ….
- Today: strong trend to develop and deploy IoT in many domains



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

1. Communication technology evolution

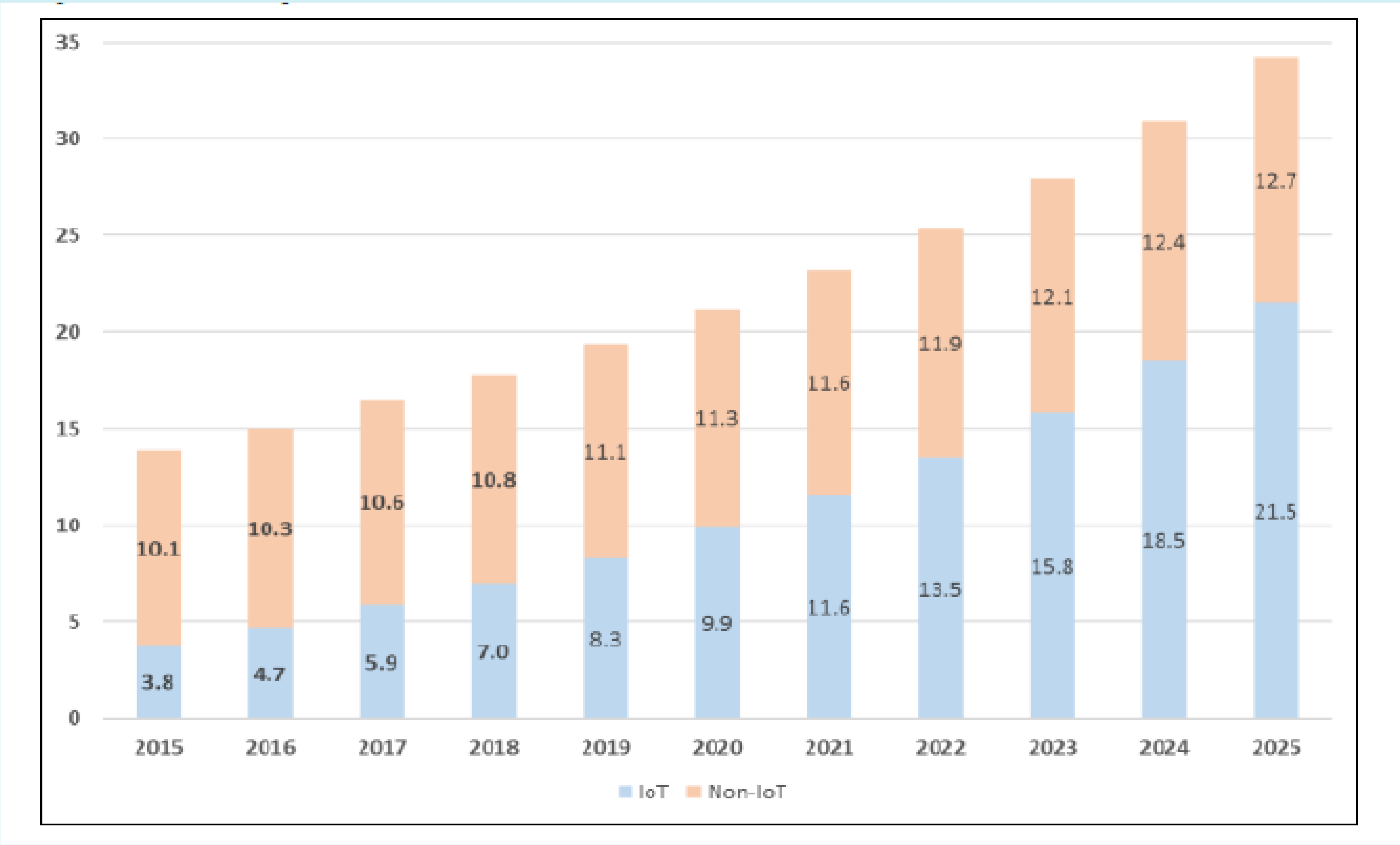
1.4 IoT Market Drivers and Trends- *5G Americas vision*



Source: 5G Americas white Paper, “5G A future of IoT”, July 2019, https://www.5gamericas.org/5g-the-future-of-iot/

1. Communication technology evolution

1.5 Global Number of Connected Devices ($ Billions)



Source: Internet Analytics, August 8, 2018, https://iot-analytics.com/state-of-the-iot-update-q1-q2-2018-number-of-iot-devices-now-7b/.

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2. 5G concepts and high-level architectures

2.1 Key concepts

- **Three main 5G features**
  - ***Ubiquitous connectivity for large sets of users*** *:* devices connected ubiquitously; uninterrupted user experience
  - ***Very low latency*** (~ few ms): 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- should offer 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

2. 5G concepts and high-level architectures

2.2 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

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

- To achieve the required performance, scalability and agility it will rely on
  - Software Defined Networking (SDN)
  - Network Functions Virtualization (NFV)
  - Cloud/Mobile Edge Computing (MEC) /Fog Computing (FC)
  - Artificial Intelligence/ Machine Learning

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

2. 5G concepts and high-level architectures

2.3 5G disruptive 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

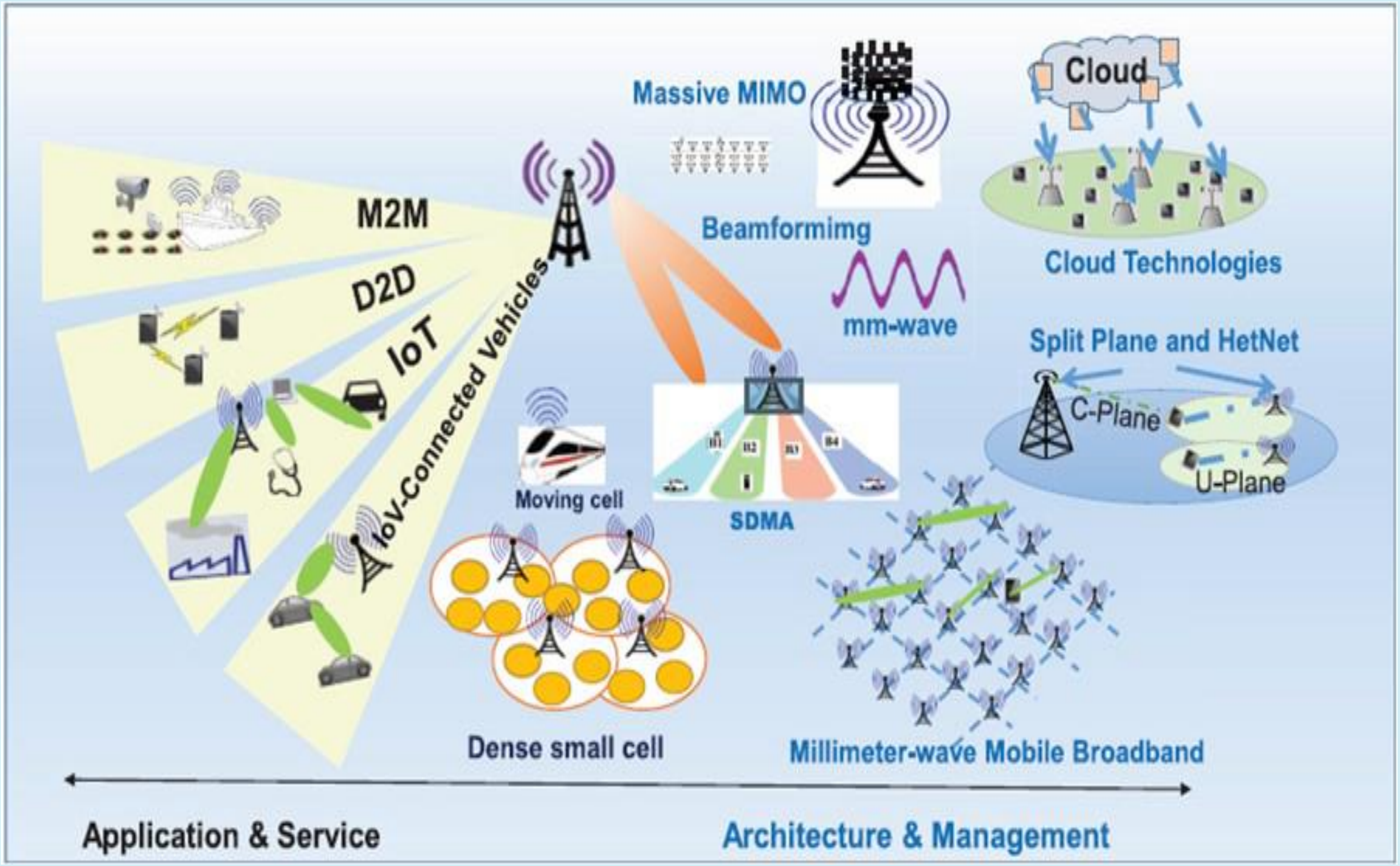
2. 5G concepts and high-level architectures

2.3 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

2. 5G concepts and high-level architectures

2.4 5G generic architecture



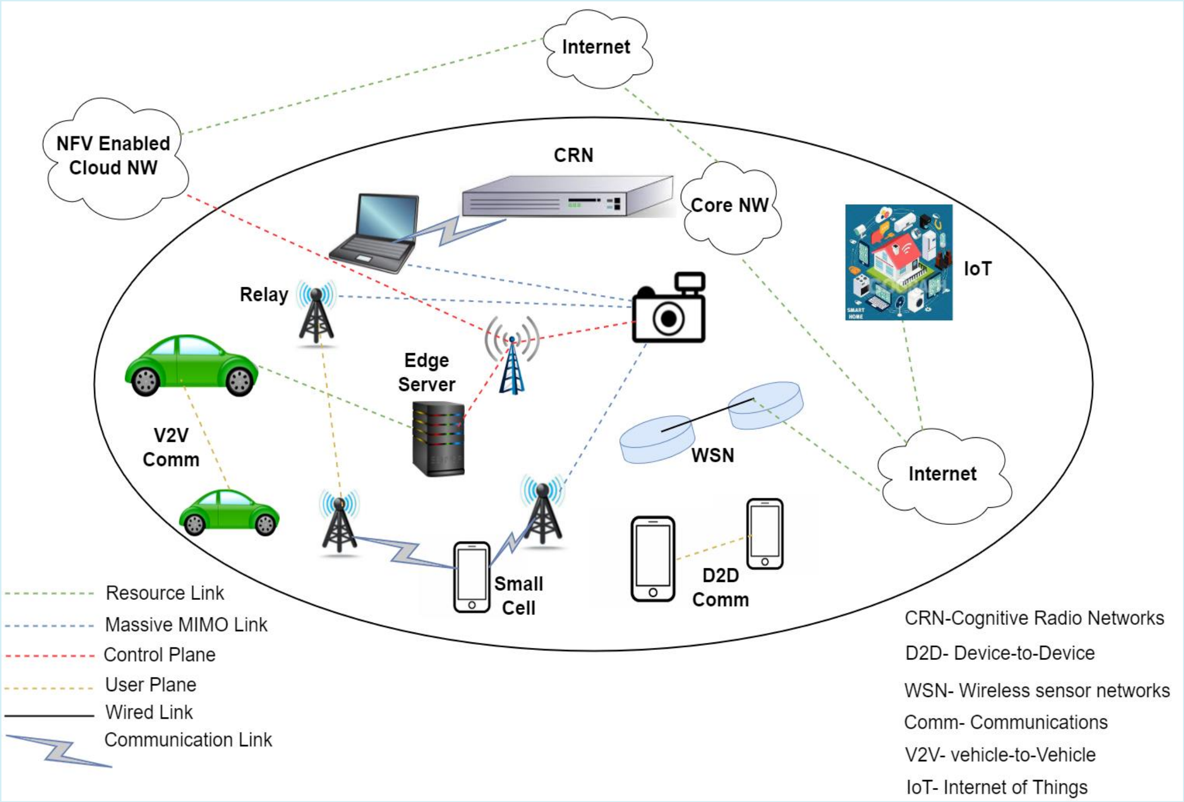
M2M- Machine to Machine
D2D- Device to Device
IoT - Internet of Things
IoV- Internet of Vehicles
MIMO- Multiple Inputs Multiple Outputs

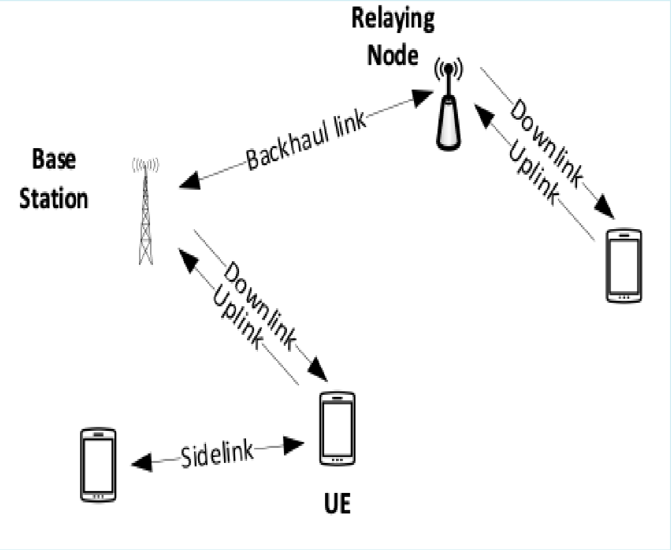
Arhitectural functional planes
C-Plane Control Plane
U-Plane- User Plane

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

2. 5G concepts and high-level architectures

2.4 5G Generic architecture





link types in 5G-3GPP

Source : Olusola T. Odeyomi, , Olubiyi O. Akintade, Temitayo O. Olowu,Gergely Zaruba , A Review of the Convergence of 5G/6G Architecture and Deep Learning

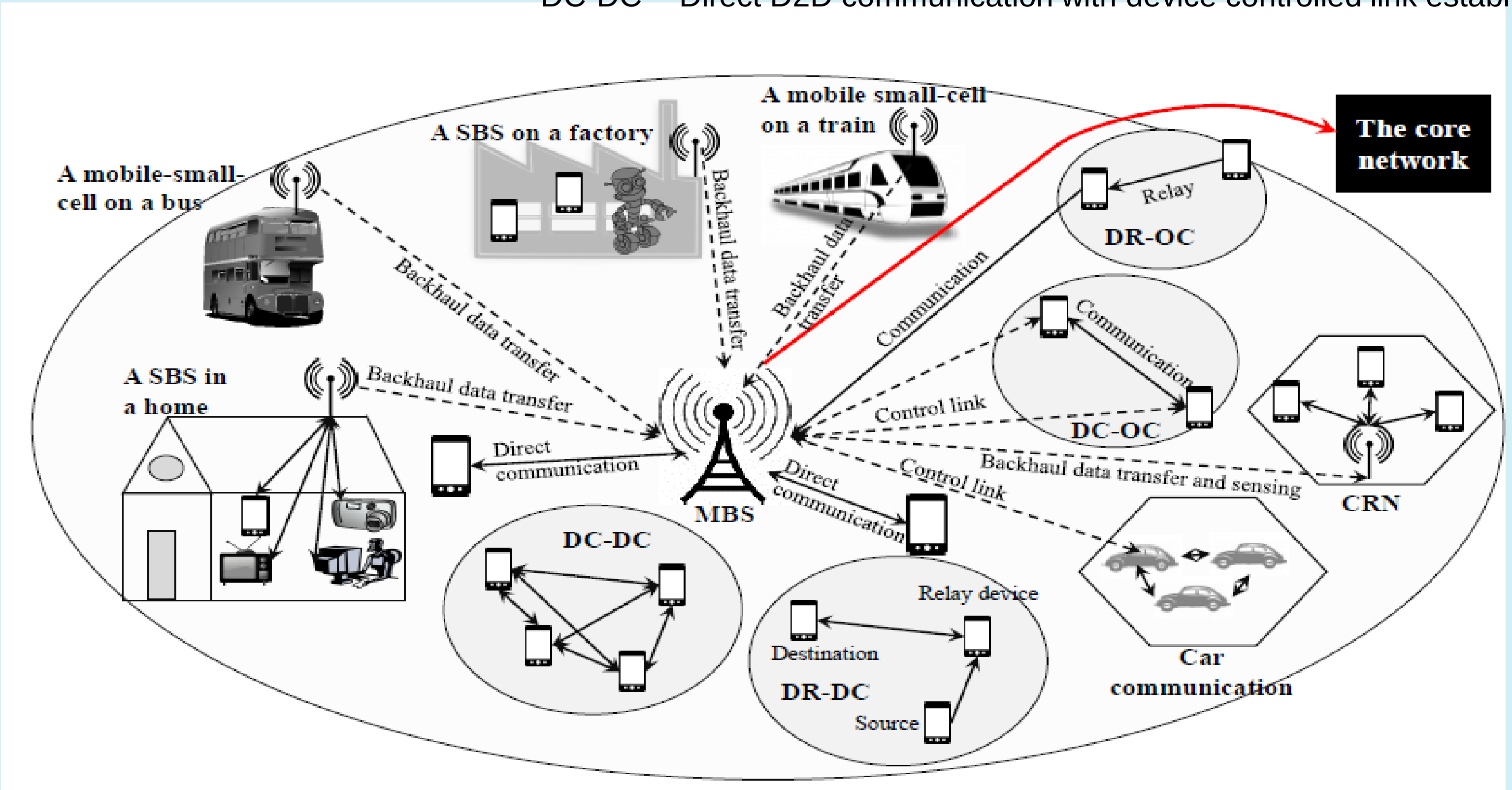
JOURNAL OF LATEX CLASS FILES, VOL. 14, NO. 8, AUGUST 2015, arXiv:2208.07643v1 [cs.LG] 16 Aug 2022

2. 5G concepts and high-level architectures

2.4 5G Generic architecture

- multi-tier arch.: small-cells, mobile small-cells, and D2D- and Cognitive Radio Network (CRN)

DR-OC - Device relaying with operator controlled link establishment
DC-OC - Direct D2D communication with operator controlled link establishment
DR-DC - Device relaying with device controlled link establishment
DC-DC - Direct D2D communication with device controlled link establishment

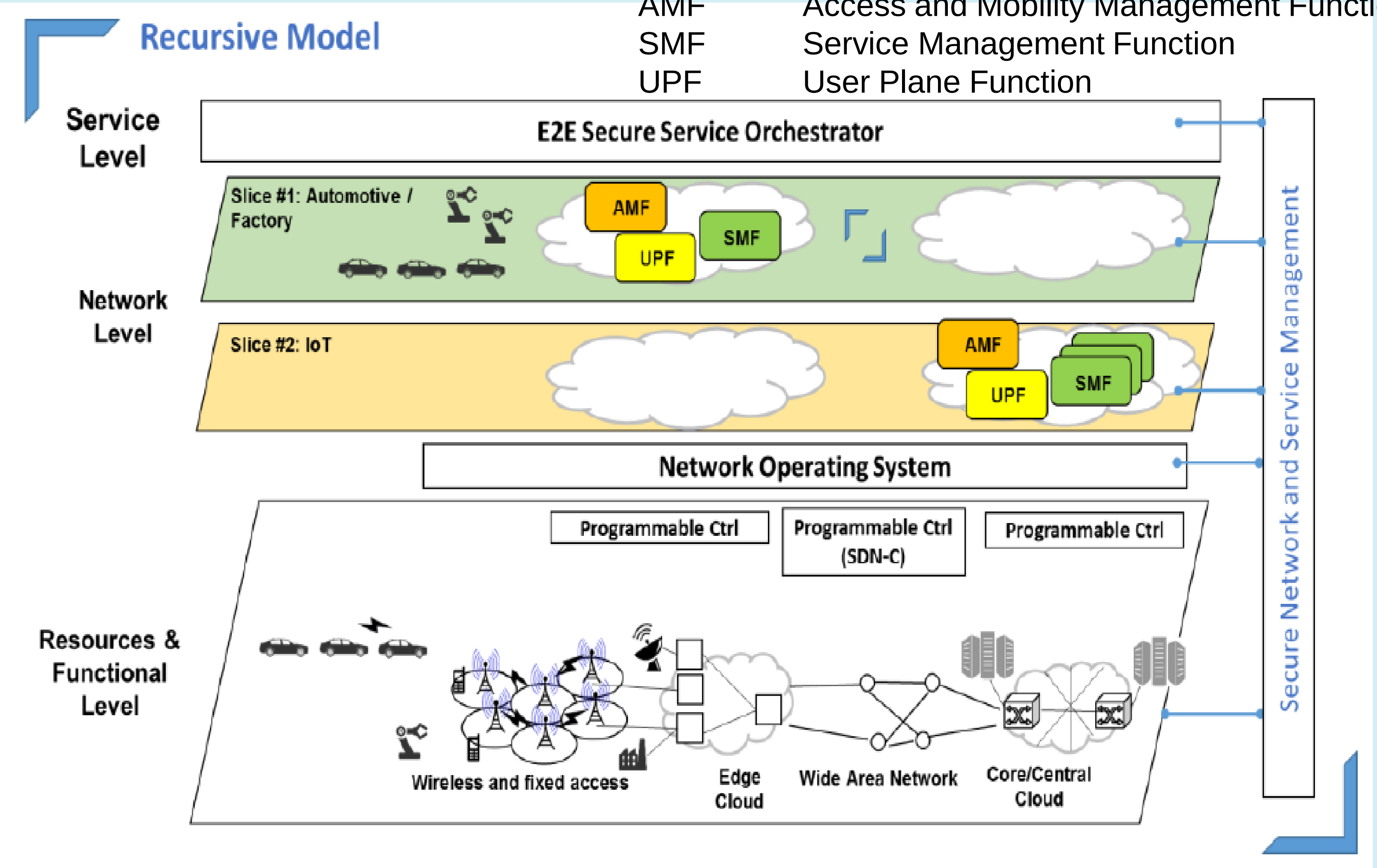


Source: Panwar N., Sharma S., Singh A. K. ‚A Survey on 5G: The Next Generation of Mobile Communication'. Accepted in Elsevier Physical Communication, 4 Nov 2015, http://arxiv.org/pdf/1511.01643v1.pdf

2. 5G concepts and high-level architectures

2.5 5G Layered Architecture - 5GPPP vision

AMF Access and Mobility Management Function
SMF Service Management Function
UPF User Plane Function

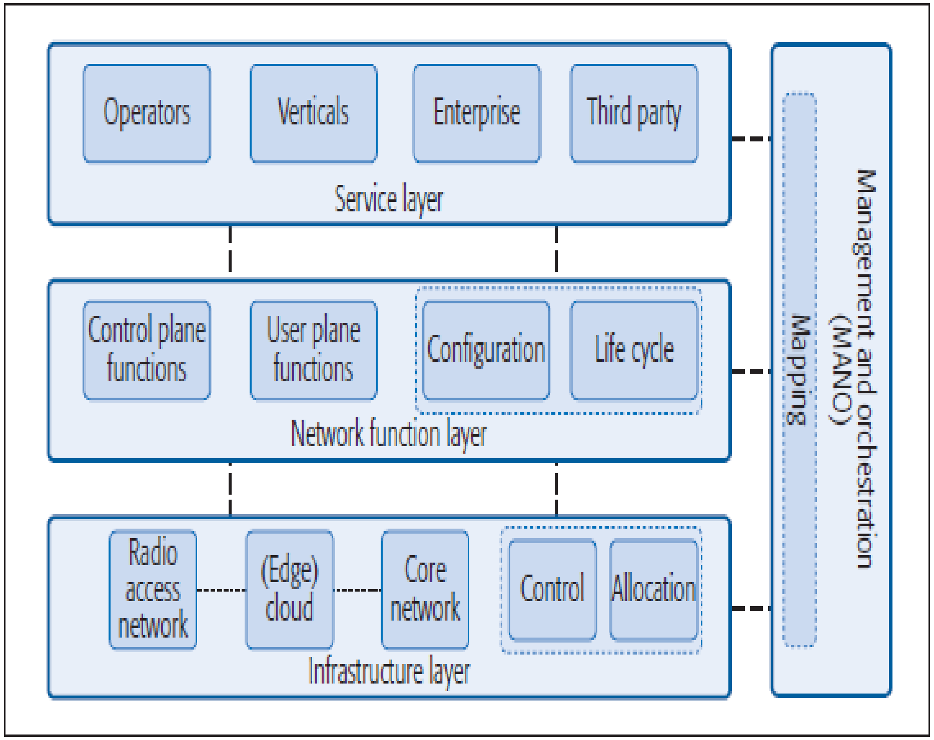


Source: 5GPPP Architecture Working Group , View on 5G Architecture, Version 2.0, December 2017

2. 5G concepts and high-level architectures

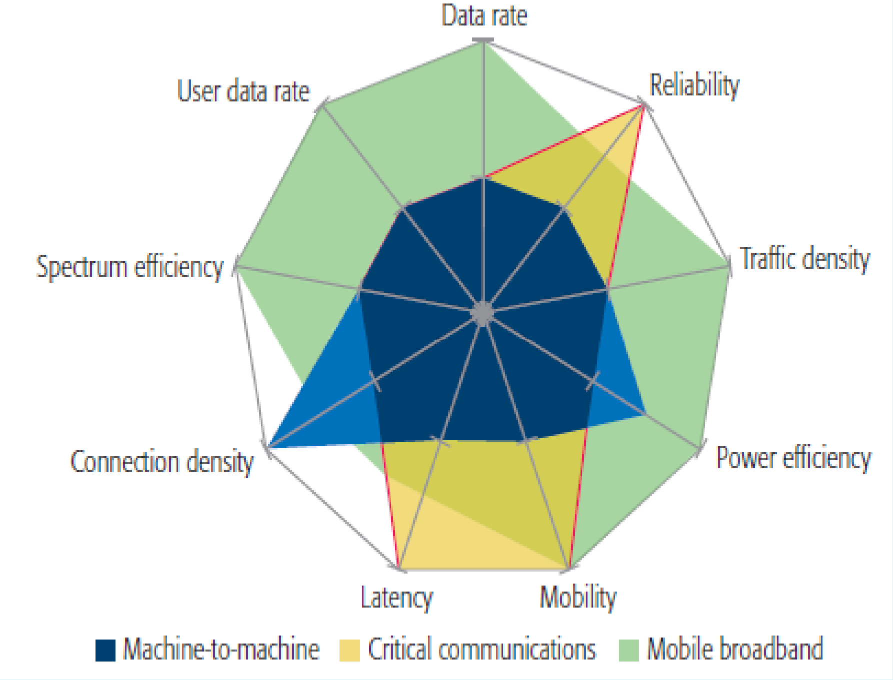
2.5 5G Layered Architecture

- **Generic layered architecture**
  - High level representation



Key 5G use cases and their requirements

- difficult for a traditional unique arch to meet all of them
- **dedicated slicing can be the solution**

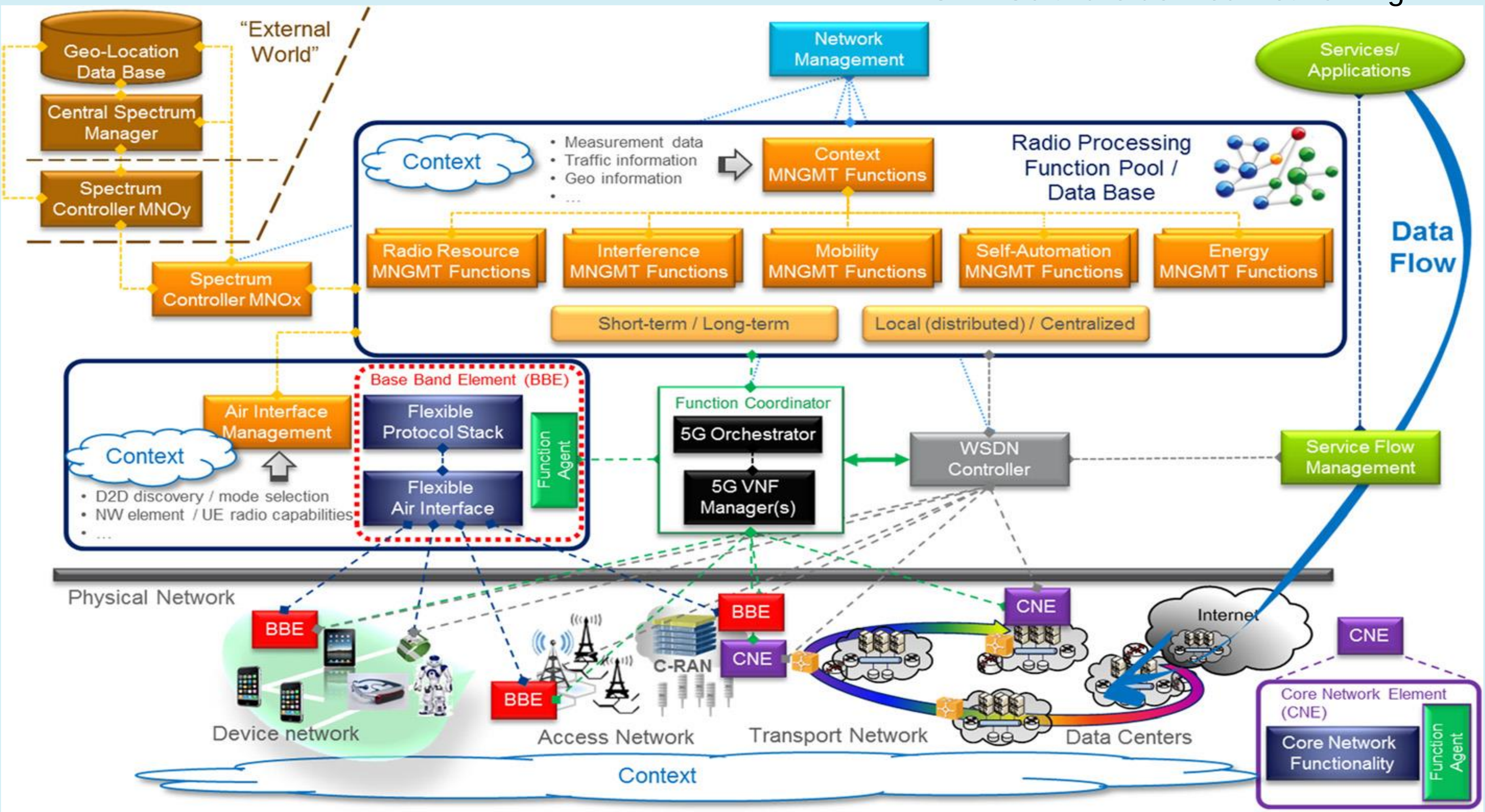


Source: X. Foukas, G. Patounas, A.Elmokashfi, and M.K. Marina, Network Slicing in 5G: Survey and Challenges, IEEE Communications Magazine, May 2017, pp.94-100

2. 5G concepts and high-level architectures

2.5 5G Layered Architecture

BBE- Base Band Element
SDN Software defined Networking



Source: J. F Monserrat, et.al, METIS research advances towards the 5G mobile and wireless system definition, , EURASIP J.on Wireless Communications and Networking (2015) 2015:53 DOI 10.1186/s13638-015-0302-9

2. 5G concepts and high-level architectures

2.6 Categories of 5G main scenarios

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

- **Enhanced Mobile Broadband (eMBB)**
  - **Objectives:** High data rate, large data applications, high capacity
  - **Features:** Transfer high volume of data, billion 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 year battery life
  - Main Applications: IoT, Wearables, Health care monitoring, Smart home/city, Smart sensors

2.6 Categories of 5G main scenarios

- **There are different 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** can be constructed

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

2. 5G concepts and high-level architectures

2.7 3GPP specifications for 5G

- **Release 15:**
  - new 5G air interface (New Radio -NR)
  - for different usage scenarios (eMBB, URLLC, mMTC).
  - NR supports
    - non-standalone (NSA) operation, based on 4G-LTE for initial access and mobility handling
    - standalone (SA) operation (no LTE)
  - NR: high-frequency operation and spectrum flexibility, ultra-lean design, forward compatibility, flexible duplex schemes, low-latency support, advanced antenna technologies, etc.

- **Release 16- enhancements**
  - *Multiple Input Multiple Output (MIMO)* and beamforming enhancements,
  - enhanced *Dynamic Spectrum Sharing (DSS),* reduced latency in dual connectivity and carrier aggregation
  - UE power saving
  - New use cases and deployment scenarios: industrial Internet of Things and URLLC,
  - Operation in unlicensed spectrum,
  - V2X communications, positioning services
  - *Integrated Access and Backhaul (IAB)*

2. 5G concepts and high-level architectures

2.7 3GPP specifications for 5G

- **Release 17**
  - enhancements of MIMO, DSS, power saving, coverage, positioning, and URLLC
  - support for *Reduced Capability (RedCap)* UE
  - operation in frequency bands beyond 52 GHz
  - multicast and broadcast service
  - *Non-Terrestrial Networks (NTNs)*

- **Release 18**
  - started the work for 5G Advanced
  - 3GPP approved its R 18 in Dec 2022
  - ***(to be discussed in Chapter 5)***

2. 5G concepts and high-level architectures

2.8 Trends in 5G networking architecture

Network softwarization: represents sets of functions assuring **programmabil**ity of
- network devices
- **network functions (NF)-** virtual or physical
- **network slices** – logical, on demand, customized networks
- network services and applications
- **Architectural planes**: Data/user, control, management

- **Shift** from network of entities, to **network of (virtual) functions** /capabilities.
  - NFs become units of networking
- **Separation** of concerns between
  - control/ management/ softwarization/ services
  - logical / physical resources functions (connectivity, computing and storage) versus network capabilities
- **On demand composition** of NFs and network capabilities
- Develop network softwarization capabilities in all network segments and network components
- **Edge computing capabilities –**in coperation with central cloud computing

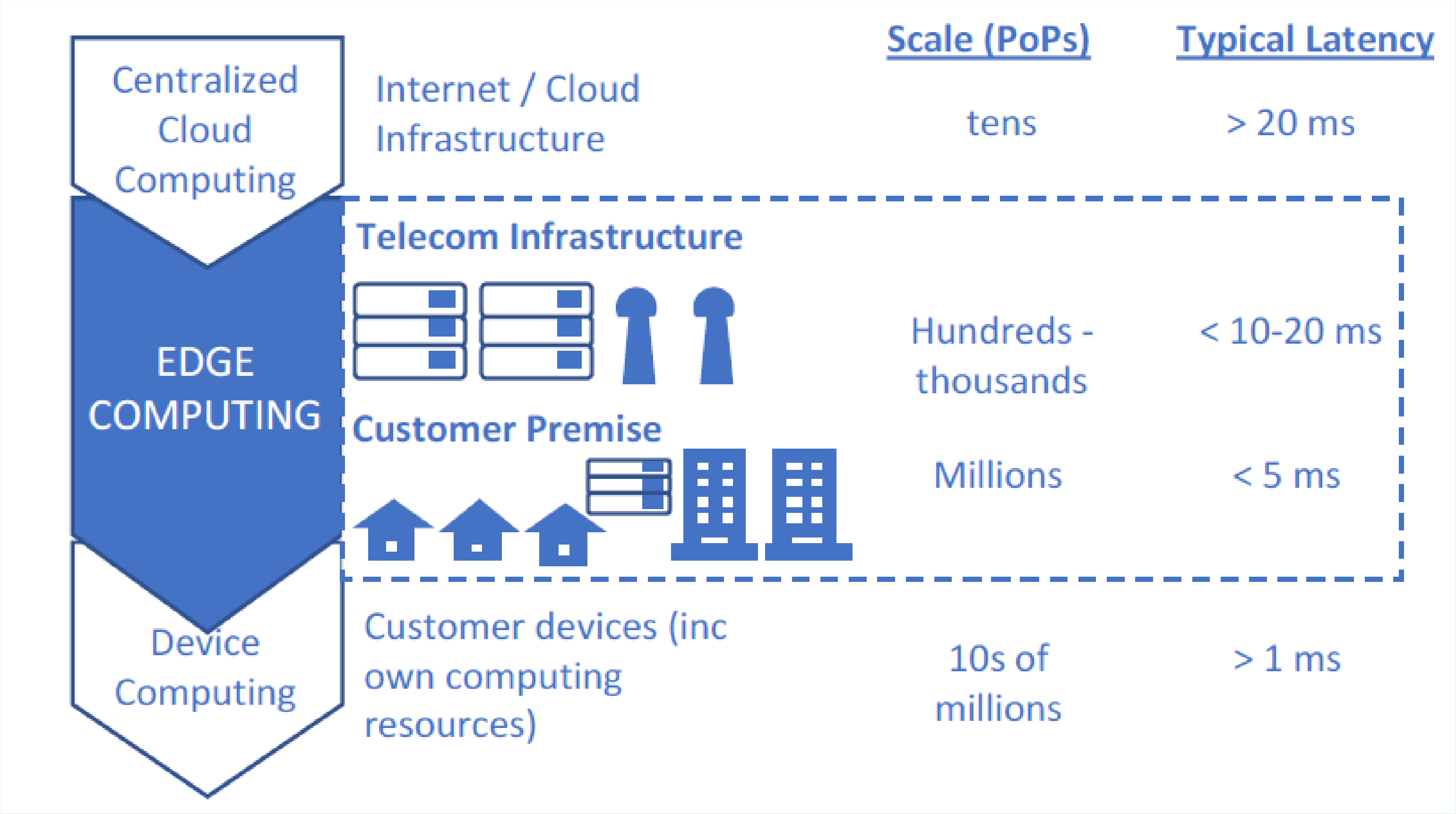
Source: A.Galis, 5G Architecture Viewpoints H2020 5G PPP Infrastructure Association July 2016, August 2017, https://5g-ppp.eu/white-papers/

2. 5G concepts and high-level architectures

2.9 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 **centralised CC Data Center (CCDC)** to the **network, edge and/or terminal devices**
  - EC provides context aware storage and distributed computing at the network edge
  - EC takes benefit from processing power of edge devices and provide faster response to mission critical tasks
  - EC will not replace centralised CC; they are complementary
- **Several solutions for EC (Multi-access Edge Computing, Fog computing, Cloudlets, ..)**

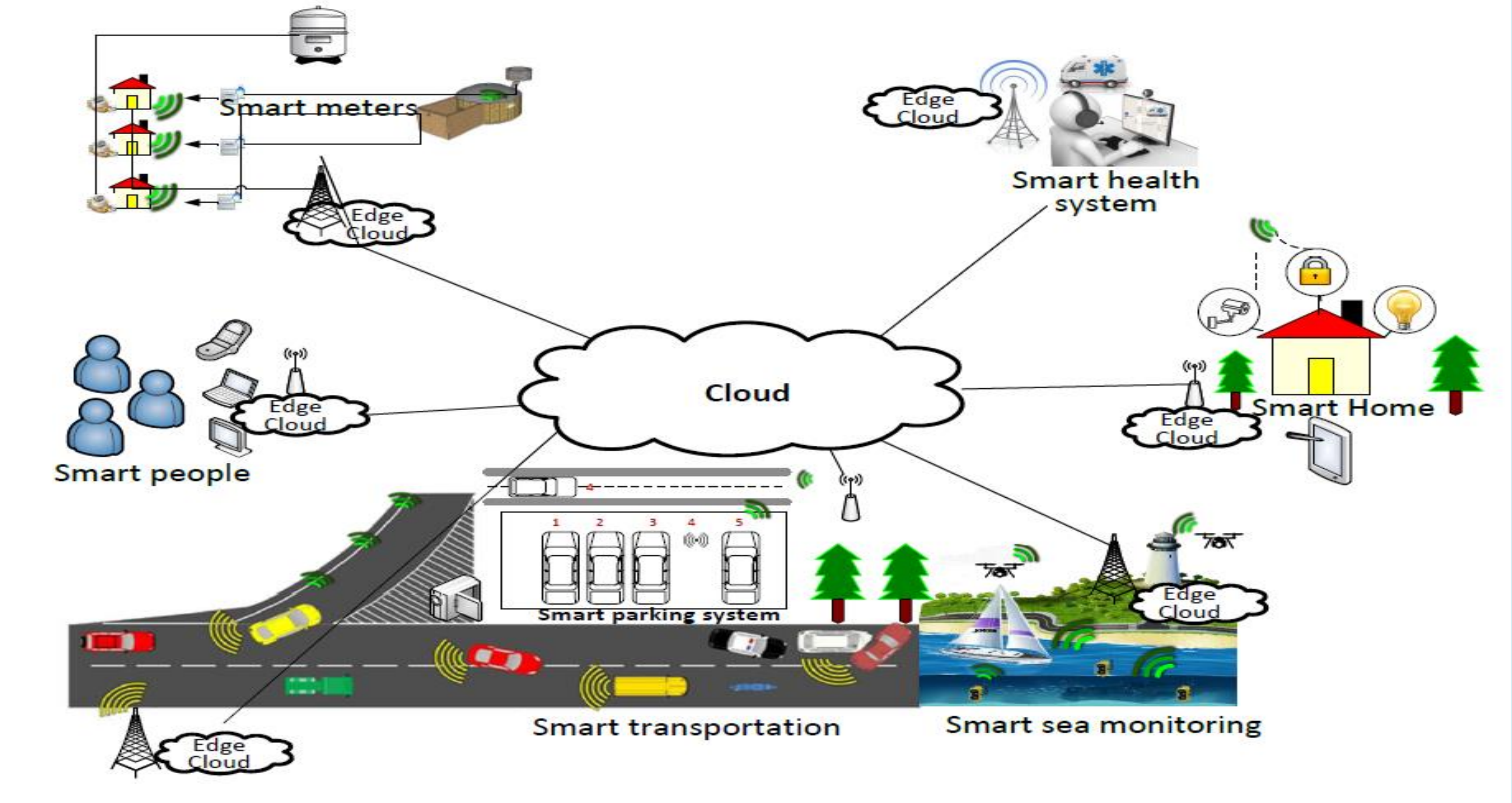
2.9 Edge Computing in 5G architecture



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

2. 5G concepts and high-level architectures

- ## 2.9 Edge Computing in 5G architecture



Source: Wazir Zada Khan, et al., "Edge computing: A survey", in Future Generation Computer Systems, Feb. 2019, https://www.researchgate.net/publication/331362529

2. 5G concepts and high-level architectures

2.9 Edge computing in 5G architecture

- **Specific solutions (Multi-access Edge Computing, Fog computing, Cloudlets, ..)**

  - **Mobile Edge Computing (MEC)** – *ETSI* - an industry spec. ~2014

  - MEC - model for enabling business oriented, CC platform within or close **the Radio Access Network (RAN)** in the proximity of mobile subscribers to serve delay sensitive, context aware applications
    - CC capabilities move close to the Radio Access Networks in 4G, 5G
    - **ETSI :** defined a system architecture and std. for a number of APIs
    - **Multi-access Edge Computing –**extension (>2017) of the initial MEC
      - MEC means today – **multi-access…to include non-cellular actors**

  - **Fog Computing (FC)**
    - FC is extended on a **continuum of devices from CCDC down to the edge of networks,** for secure management and control (M&C)
      - of domain specific HW/SW
      - and standard compute, storage and network functions within the domain
    - FC nodes (FCNs) are typically located away from the main cloud data centers ; IoT- driving factor for FC

2. 5G concepts and high-level architectures

2.9 Edge computing in 5G architecture

- **Cloudlet – developed by** *Carnegie Mellon University* ~2013)
- A cloudlet is middle tier of a 3-tier hierarchy: 'mobile device – cloudlet – cloud'
  - Cloudlet ~ **"data center in a box"** whose goal is to "bring the cloud closer"'
  - **Cloudlets are mobility-enhanced *micro data*** *centers* located at the edge of a network and serve the mobile or smart device portion of the network
    - designed to handle resource-intensive mobile apps. and take the load off both the network and the CCDC and keep computing close to the point of origin of information

- **Micro data centre** – developed by *Microsoft Research- ~2015*
  - extension of today's hyperscale cloud data centers (e.g., Microsoft Azure)
  - to meet new requirements: lower latency, new demands related to devices (e.g. lower battery consumption)

CONTENTS

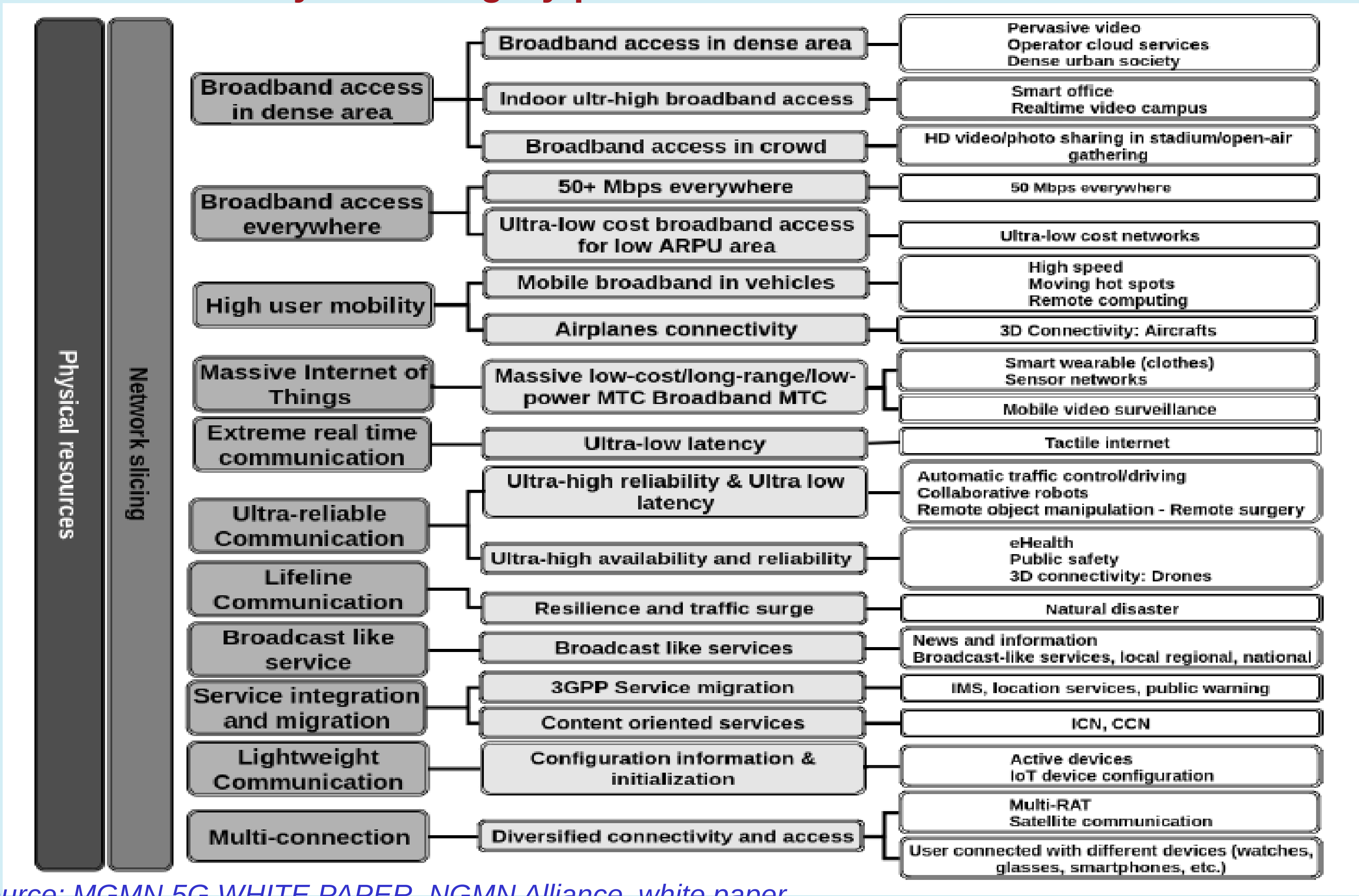
3. Applications and use cases of 5G

3.1 5G Applications and use cases examples

- **Additional requirements (and objectives) :**
  - sustainable and scalable technology
  - cost reduction through human task automation and hardware optimization
  - ecosystem for technical and business innovation
- **Application fields**:
  - Vertical markets
    - Industry, manufacturing
    - Energy, smart grids
    - Internet of Things (IoT)
    - Food and agriculture, environment
    - City management, government
    - Education
    - Healthcare
    - Public transportation,
    - Automotive/IoV, Vehicle to Grid (V2G), V2X
    - Entertainment, tourism
    - …..

3. Applications and use cases of 5G

3,2 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.

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2. 5G concepts and high-level architectures
3. Applications and use cases of 5G
4. Network slicing technology
5. 5G Advanced
6. 6G objectives, use cases and requirements
7. 6G architecture and technologies
8. Conclusions

4. Network slicing technology

4.1 Network slicing concepts

- **General concepts**
  - **End to End (E2E) :** covers all network segments : radio, wire access, transport and edge networks, core (central) network
  - **concurrent deployment of multiple E2E logical, self-contained and independent shared or partitioned networks** on a **common infrastructure platform**
  - **Slices**
    - created by **provisioning**, or **on demand**, each tailored for a given use case, mutually isolated with independent M&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 UC 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 Virtualisation (NFV)** – support technologies provide virtualisation, programmability, flexibility, and modularity to create **multiple network slices**

- **Please see 4.2 Terminology summary- in Backup slides part**

4. Network slicing technologies

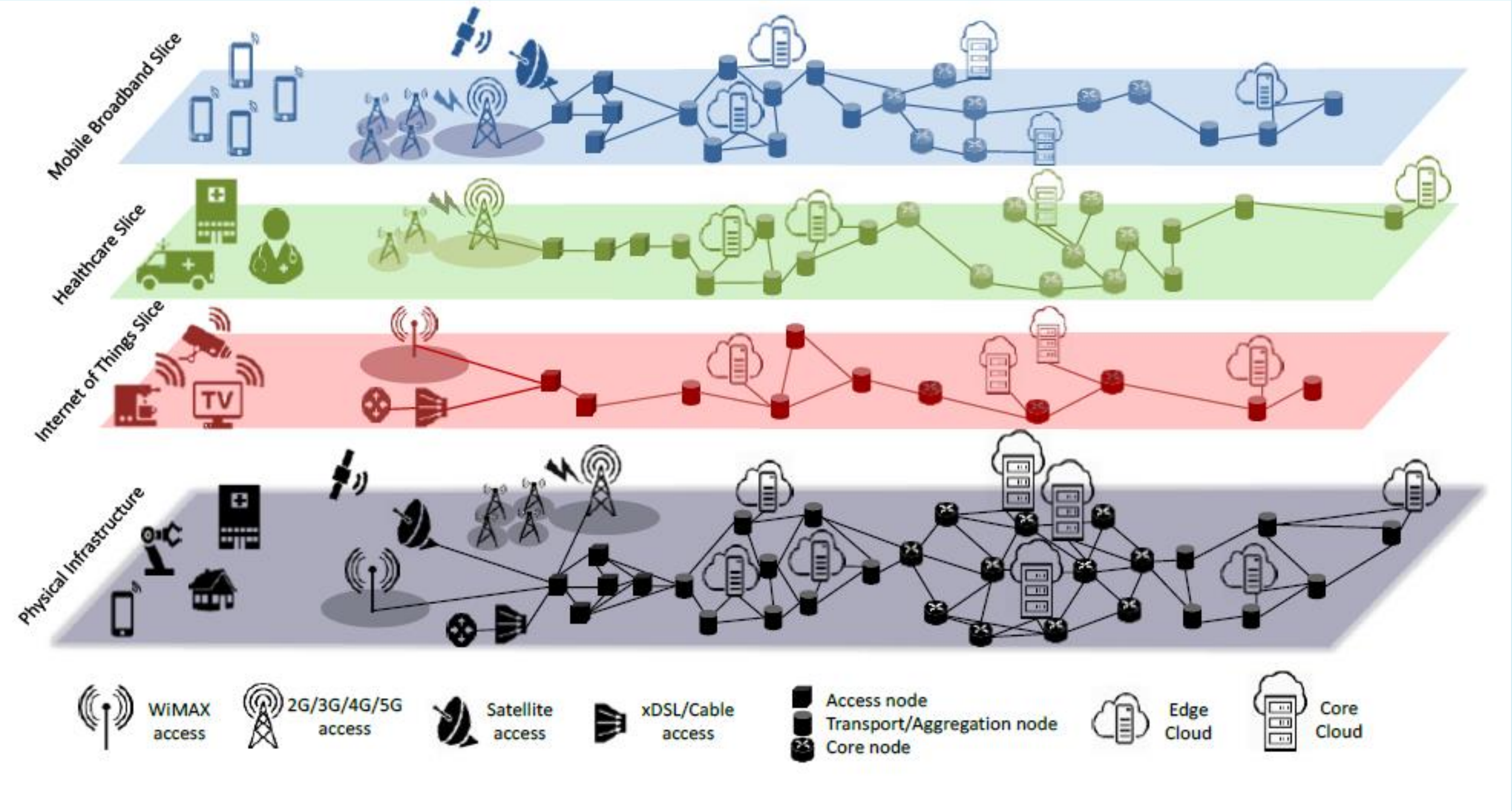
4.2 Network slicing design and management principles

- **Separate the Network slice template (model) design , vs. NS Instance (i.e., specific active slices) operation**
  - **NSI - activated NS, created based on network template**
  - enables the reuse of a network slice
- **NSIs multi-dimensional management:**
  - Reasons: NSI contains multiple technical domains and/or involve multiple admin domains belonging to different operators
- **Common infrastructure-** among tenants from the same operator
- **NSI On-demand customization**
  - capabilities are different within each technical domain
  - the coordination of capabilities is performed via the NSM system during the process of network slice template design, O&M and NSI deployment.

- **Isolation: The architecture must support the NSIs' isolation (O&M, PHY/logical resources, performance, security)**
  - NSIs can be both physically and logically isolated in different levels**.**

4. Network slicing technologies

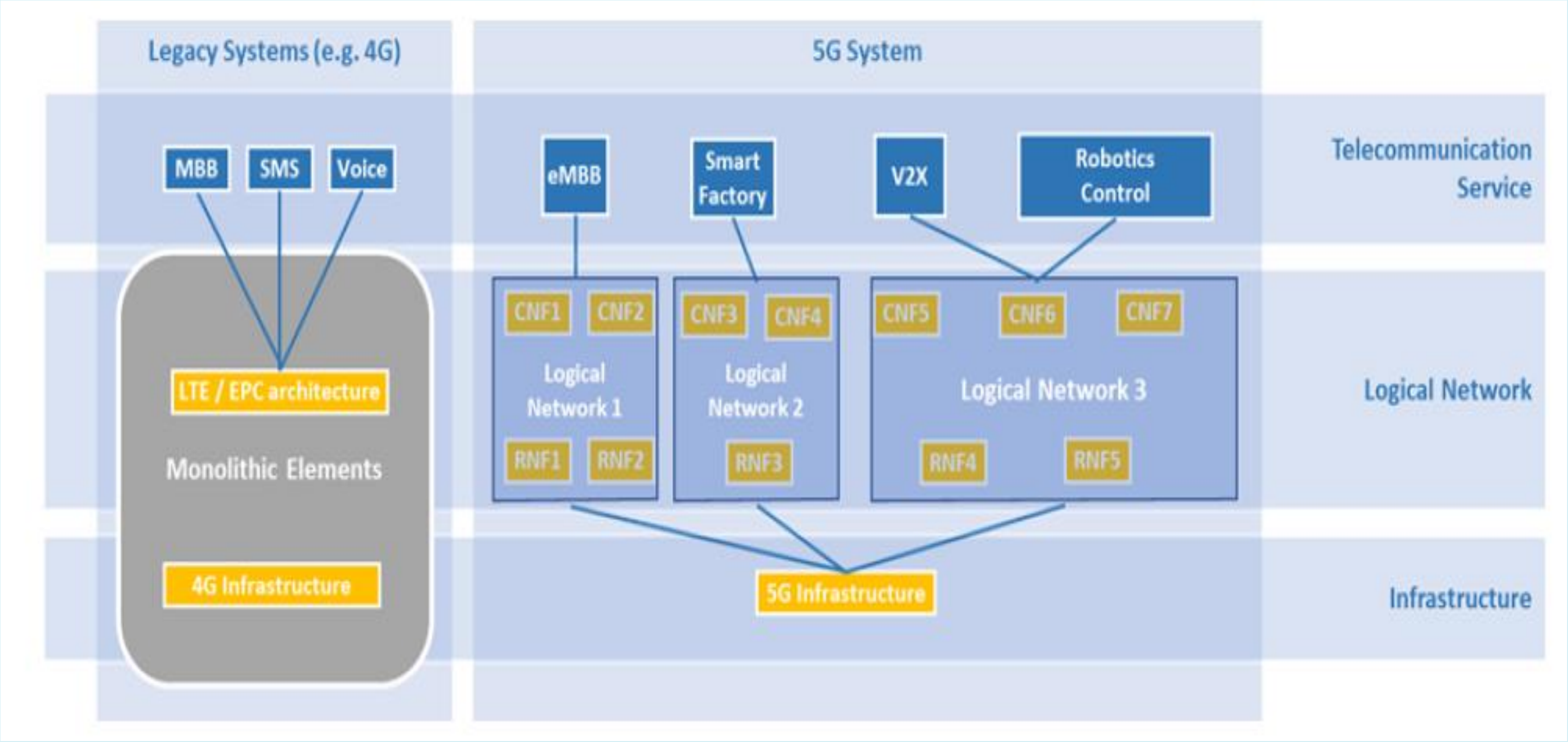
4.3 5G Network slicing generic example



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

4. Network slicing technologies

4.4 4G versus 5G 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

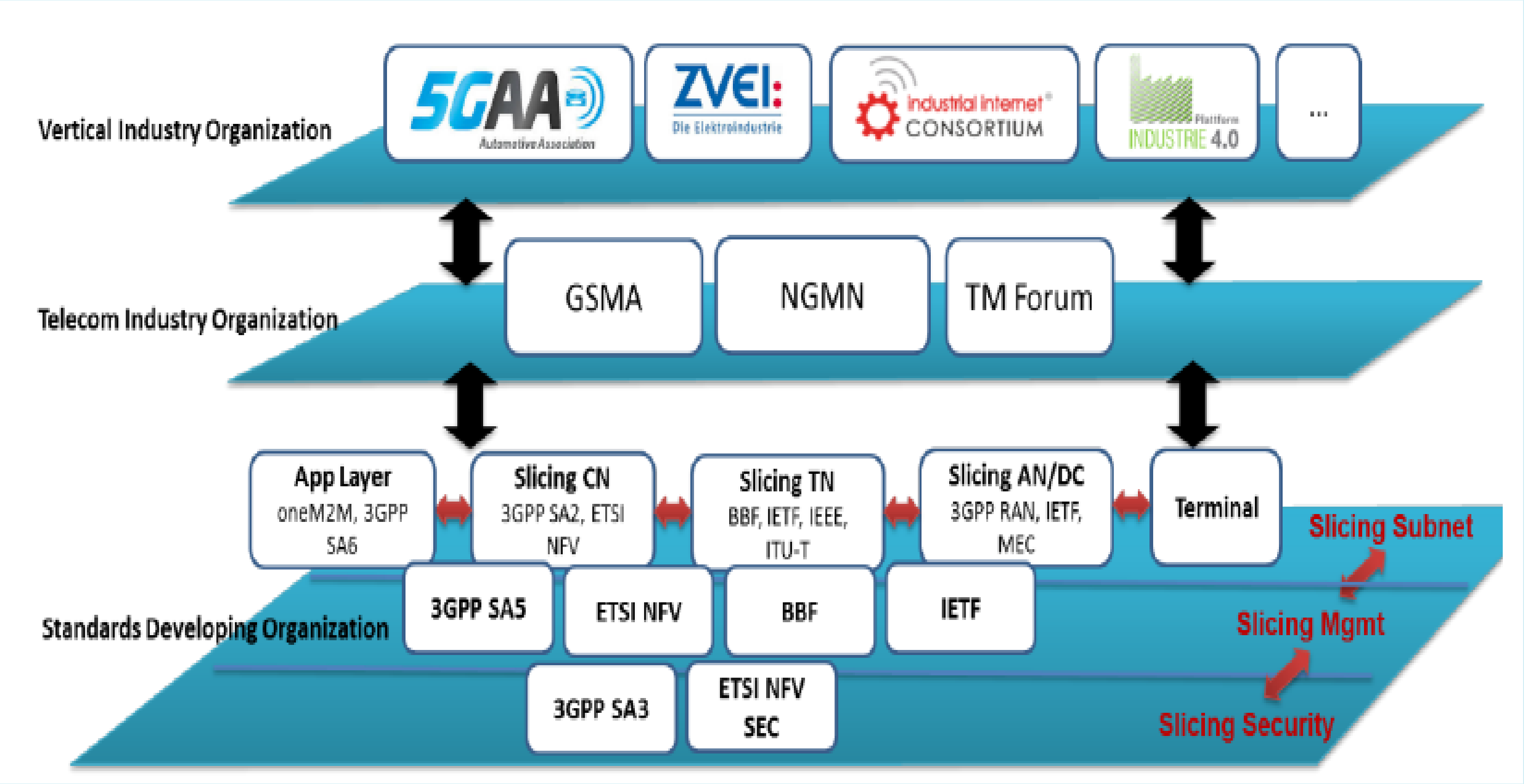
4. Network slicing technologies

4.5 Standardisation effort oriented to slicing

- **European Telecom Std. Institute (ETSI)** –**Next Generation Protocols (NGP)** – Technology independent approach to slicing
  - **ETSI- Network Function Virtualisation (NFV)–** studies on SDN and NFV support for slices
- **3rd Generation Partnership Project (3GPP)** – contributions on RAN, Services and architectures, Core networks and terminals, Mgmt. and orchestration
- **5G-PPP** – details the roles and relationships between different parts of the 5G
- network.
- **Next Generation Mobile Networks (NGMN)** –Slicing concept for 5G with IMT2020
- **Int'l Telecom Union (ITU-T)** – Works on Slices in IMT-2020, SG13 and SG15: management & transport aspects; alignment with 5G
- **Open Networking Foundation (ONF) , Broadband Forum (BBF)**
- **Internet Engineering Task Force (IETF)** – focused more on fixed network and management of network slicing
- **GSM Association (GSMA)-** business aspects, use cases, etc.

4. Network slicing technologies

4.5 Standardisation effort oriented to slicing



Source: GSMA, Network Slicing, - Use Cases and Requirements , April 2018

4. Network slicing technologies

4.6 Business model (actors)- variant of definition

- **Infrastructure Provider (InP)**– owner of the PHY infrastructure (network/cloud/data center) and lease them to operators
  - It can become an ISLP if it leases the infrastructure in slicing fashion

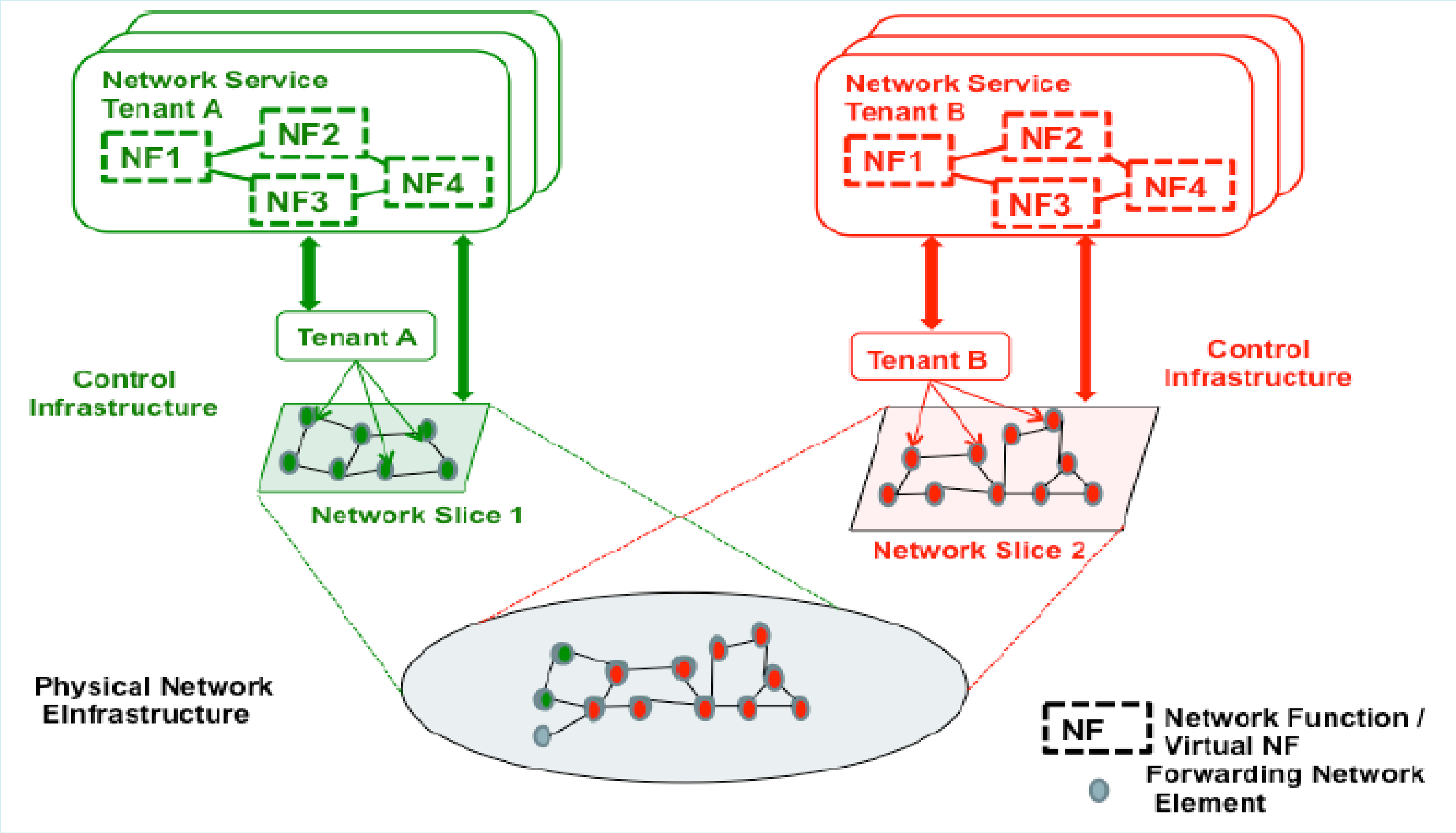
- **Infrastructure Slice Provider (ISLP) –** typically a telecom SP, **owner or tenant** of the infrastructures from which network slices can be created

- **Infrastructure Slice Tenant (IST) -** the user of specific network/cloud/data centre slice, hosting customized services
  - ISTs can request creation of new infrastructure slice through a service model
  - **IST leases virtual resources from one or more ISLP** in the form of a virtual network, where the tenant can realize, manage and provide network services to its users
  - **A network service** is a **composition of NFs,** and it is defined
    - in terms of the **individual NFs**
    - and the **mechanism** used to **connect them**

- **End user:** consumes (part of) the services supplied by the tenant, ***without providing them to other business actors.***

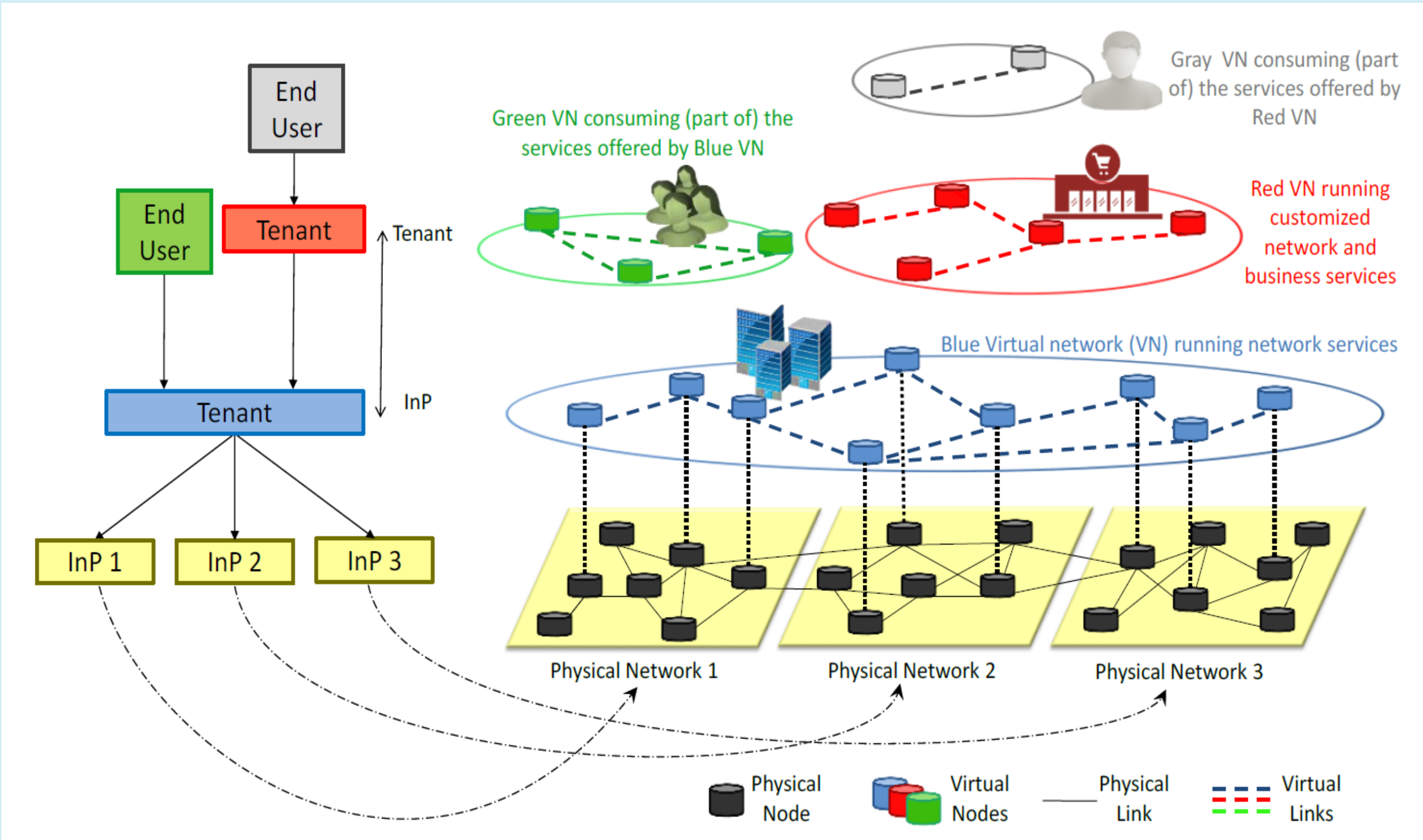
Source: A.Galis and K.Makhijani, Network Slicing Landscape: A holistic architectural approach, orchestration and management with applicability in mobile and fixed networks and clouds, v1.0, Network Slicing Tutorial – IEEE NetSoft 2018

4.6 Business model (actors)



Source:A. Galis, Towards Slice Networking, presentation at IETF98 -, March 2017; https://github.com/netslices/IETF-NetSlices

4.7 Network slicing recursive model



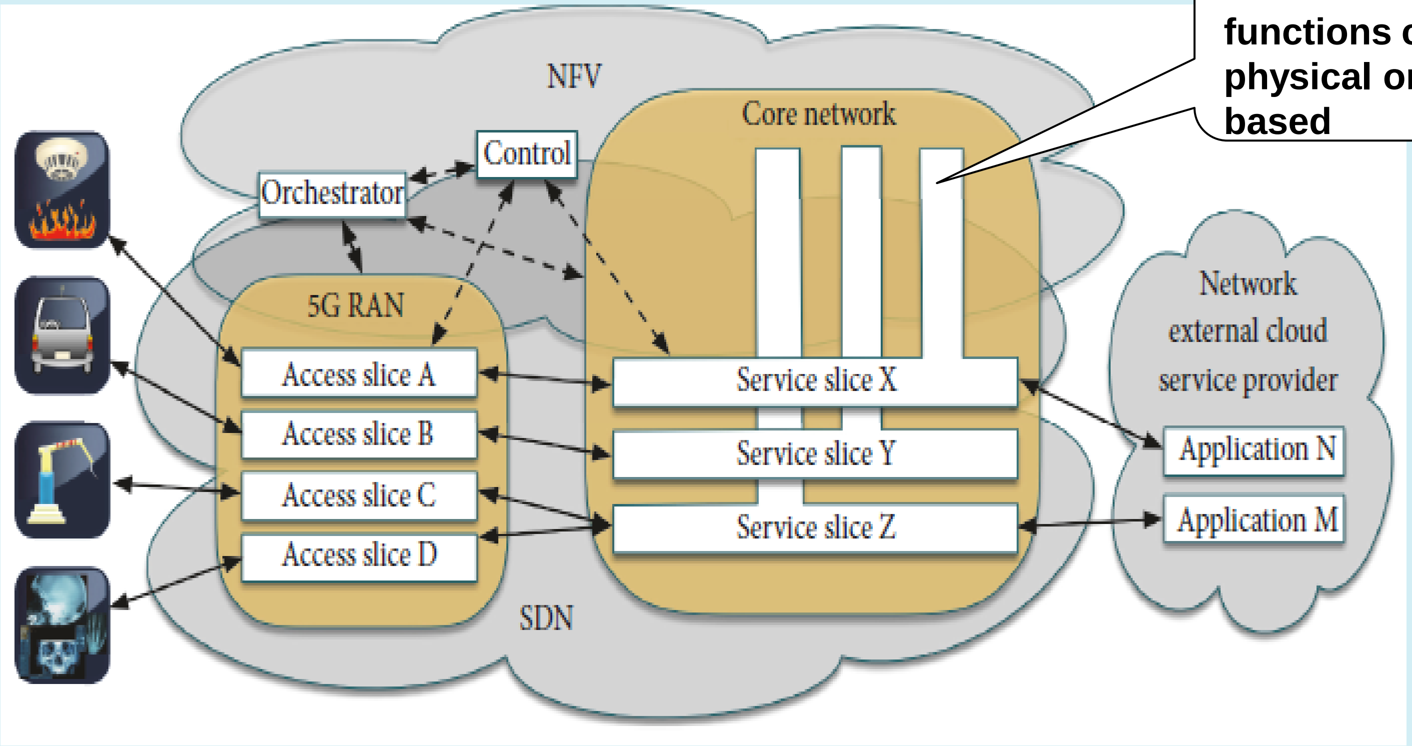
Source: J. Ordonez-Lucena, P. Ameigeiras, D. Lopez, J.J. Ramos-Munoz, J. Lorca, J. Folgueira, Network "Slicing for 5G with SDN/NFV: Concepts, Architectures and Challenges", IEEE Communications Magazine, 2017

4. Network slicing technologies

4.8 Generic slicing architecture with SDN and NFV support

- **Potential solution scenarios for support of multiple slices per UE**
  - Three groups of solutions defined by 3GPP

The network functions can be physical or NFV-based



Source: G. Nencioni et al., Orchestration and Control in Software-Defined 5G Networks: Research Challenges, Wiley, Wireless Communications and Mobile Computing Volume 2018, Article ID 6923867, pp. 1-19, https://doi.org/10.1155/2018/6923867https://www.hindawi.com/journals/wcmc/2018/6923867/

4. Network slicing technologies

4.9 Verticals and Use cases

- **Specific slices can be constructed**
- **Augmented Reality (AR)/ Virtual Reality (VR)**
  - Strong-Interactive VR: Audio-visual interaction
  - Strong-Interactive VR: Low-delay speech and video coding
  - Strong-Interactive AR: Use Cases
- **Automotive (CV2X)**
  - Infotainment
  - Telematics
  - Road Safety and Efficiency:
    - road warning, information sharing
  - Advanced Driving Service
    - Cooperative driving
    - Platooning
    - Tele-operation
- **Energy**
    - Smart-grids, Micro-grids
    - Smart meters and aggregator gateways
    - Electricity traffic scheduling

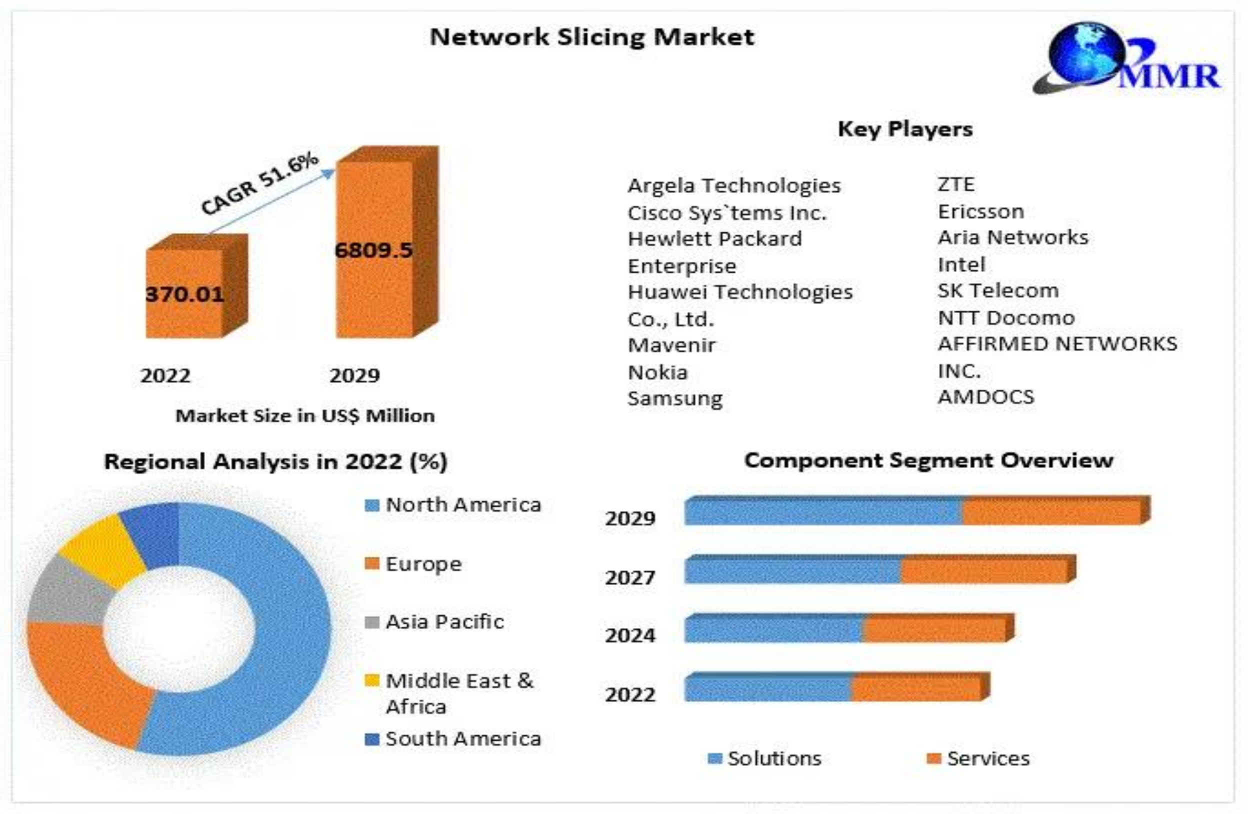
4.9 Verticals and Use cases (cont'd)

- **Healthcare**
  - Hospitals, Ambulances, and care homes
  - Health and wellness monitoring
  - Remote healthcare, Remote surgery
- **Industry 4.0, Manufacturing**
  - Augmented reality, Control-to-control (C2C)
  - Motion control, Mobile robots and mobile platforms
  - Mobile Control Panels with Safety Functions, Closed-loop control
  - Process monitoring, Plant asset management
- **Internet of Things for Low Power Wide Area Applications**
  - Asset Tracking and monitoring, Waste management, Smart parking, Smart manhole, Water metering, Gas Metering
- **Public Safety**
  - Mission critical : Push-To-Talk, data, video, IoT
- **Smart Cities**
  - Intelligent lighting
  - Public safety
  - Emergency service management

4. Network slicing technologies

4.10 5G slicing Market figures

- Network Slicing Market size : ~ US$ 370.01 Mn. in 2022
- the total revenue is expected to grow at 51.6 % through 2023 to 2029, reaching nearly US$ 6809.5 Mn.



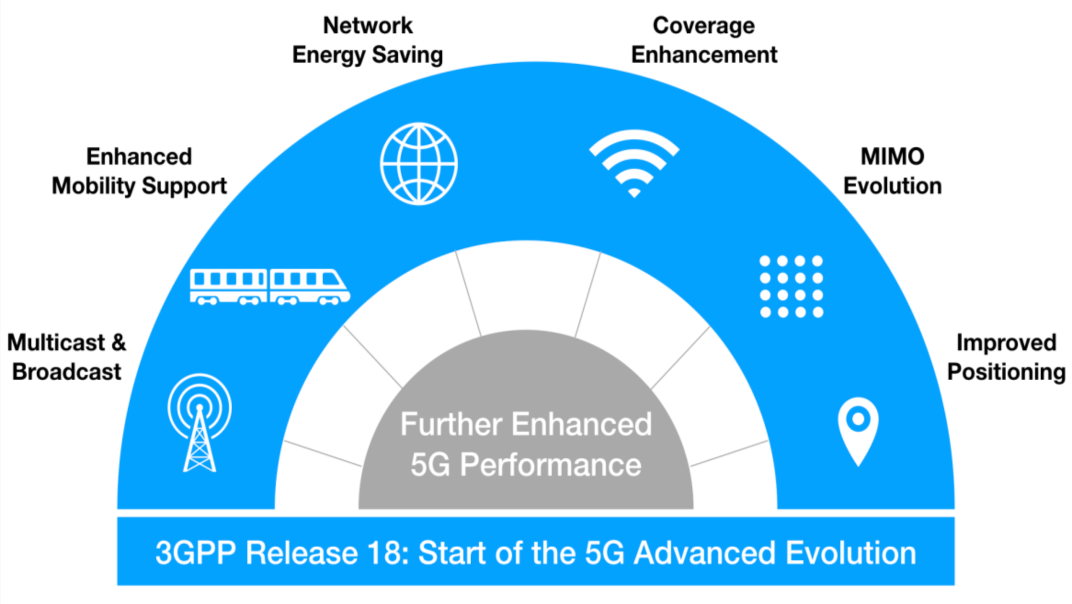
Source: https://www.maximizemarketresearch.com/market-report/global-network-slicing-market/4561/

CONTENTS

5. 5G Advanced

5.1 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

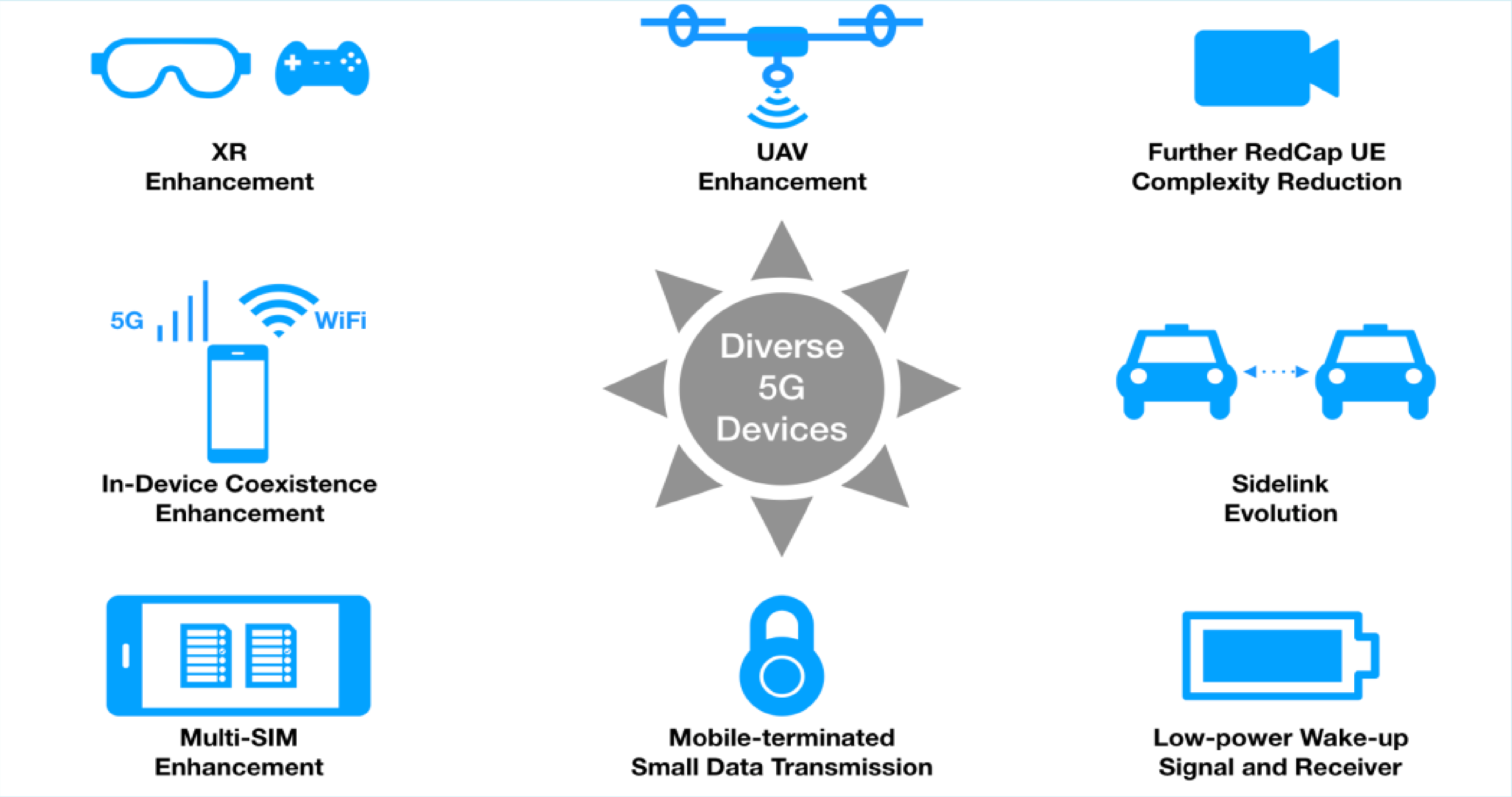
- **5G Performance Enhancements**
- **Flexible Spectrum Applications**
- **Diverse Devices**
- **Evolved Network**
- **Data and AI/ML driven 5G**

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

5. 5G Advanced

5.1 5G-Advanced- Second phase of 5G standardization

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



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

5. 5G Advanced

5.1 5G-Advanced- Second phase of 5G standardization

- Phase 2, 3 for some previous specifications (italics) and new developments
- **5G Advanced architecture**
  - *5G system architecture* *(Phase 3)*
  - *Network Slicing* *(Phase 3)*
  - *Enablers for Network Automation for 5G* *(Phase 3)*
  - *Edge Computing* *(Phase 2)*
  - *Enhanced support of Non-Public Networks* *(Phase 2)*
  - *Satellite access* *(Phase 2)*
  - *5G User Equipment (UE) Policy* *(Phase 2)*
  - *5G Access and Mobility (AM) Policy* *(Phase 2)*
  - *UAS, UAV & UAM* *(Phase 2)*
    - Unmanned Aircraft Systems (UAS)
    - Unmanned Aerial Vehicle (UAV)
    - Urban Air Mobility (UAM)
  - Personal IoT Networks
  - Access Traffic Steering, Switching & Splitting
  - Vehicle Mounted Relays
  - Generic group management, exposure & communication enhancement
  - User Plane Functions enhanced
  - 5G Timing features enhancement (resiliency, sensitivity) for URLLC

Source: https://ro.scribd.com/document/629742332/Release-18-features-tsg95-v03

5. 5G Advanced

5.1 5G-Advanced- Second phase of 5G standardization

- **5G Advanced services- examples**
  - *5GC location services* *(Phase 3)*
  - *5G multicast-broadcast services* *(Phase 2)*
  - *Proximity-based Services in 5GS* *(Phase 2)*
  - *Reduced capability devices (RedCap) in 5G New Radio (NR)* *(Phase 2)*

  - XR (Extended Reality) & media services
  - **System Support for AI/ML-based Services**
  - Evolution of IMS multimedia telephony service
  - System Enabler for Service Function Chaining
  - Ranging based services & sidelink positioning
  - Seamless *User Equipment (UE)* context recovery
  - *Multimedia priority service (MPS)*
    - when access to EPC/5GC is WLAN

Source: https://ro.scribd.com/document/629742332/Release-18-features-tsg95-v03

5. 5G Advanced

5.1 5G-Advanced- Second phase of 5G standardization

- **Management, Orchestration and Charging**
- **Operations, Administration, Maintenance and Provisioning (OAM&P):**
  - **Intelligence and Automation**:
    - Self-Configuration of RAN NEs, Enhanced autonomous network levels,
    - Enhanced intent driven management services for mobile networks
    - **AI/ ML-based management and control**
    - Enhanced management aspects related to NWDAF
  - **Management Architecture and Mechanisms**
    - Network slicing provisioning rules
    - Enhanced service-based management architecture
  - **Support of New Services**
    - *Enhanced and new aspects of energy efficiency for 5G (Phase 2),*
    - Enhanced management of Non-Public Networks, Network and Service
    - Operations for energy utilities, Key Quality Indicators (KQIs) for 5G service experience
    - Deterministic communication service assurance
- **Charging:**
  - *Charging aspects for enhanced support of Non-Public Networks (Phase 3)*

5. 5G Advanced

5.1 5G-Advanced- Second phase of 5G standardization

- **Other 5G Advanced features – summary**
- **Security and Privacy**
  - *Mission critical security enhancements* *Phase 3*
  - 3GPP SECAM and SCAS (SeCurity Assurance Methodology/Specifications) for virtualized network and Management Function (MnF)
  - Security and privacy aspects of RAN & SA features
- **Multimedia Codecs, Systems and Services**
  - **Systems & Media Architecture**
    - 5G Media, Service Enablers, Split-Rendering for images, Mapping Extended Reality to 5G
  - **Media:** Video codecs, Media Capabilities for Augmented Reality Glasses, AI / ML Study
  - **Real-Time Communications:** XR conversational services, WebRTC-based services and collaboration models
  - **Immersive Voice & Audio**
    - A/V Codecs Extension; Terminal Audio quality performance and Test methods
  - **Streaming & Broadcast services**
    - 5G Media Streaming Enhancements (5GMS) : slicing, latency, background traffic, 5GMS Uplink
    - Further MBS Enhancements (free to air, hybrid unicast/broadcast)

5. 5G Advanced

5.1 5G-Advanced- Second phase of 5G standardization

- **Other 5G Advanced features – summary**
- **Radio architectural layers 1, 2, 3 enhancements**
  - **Layer 1** : MIMO, **AI/ML**, energy saving, *New Radio (NR)* enhancements, NR sidelink evolution, etc.
  - **Layer 2:** Mobility, Non-Terrestrial Network (NTN), multicast/broadcast services, etc.
  - **Layer 3 :** UTRAN/E-UTRAN/NG-RAN architecture & related network interfaces, etc.

- **Radio Performance and Protocol enhancements**
  - Revisited RF and NR requirements, frequency ranges
  - Enhancement on NR and *Multi-RAT Dual Connectivity (MR-DC),* Measurements
  - NR demodulation performance evolution
  - Simplification of band combination (700/800/900MHz specification)
  - NR Base Station (BS) RF requirement evolution
  - Support of intra-band non-collocated ENDC,
    - ENDC- or *E-UTRAN New Radio – Dual Connectivity*, is a *Non-Standalone (NSA)* feature
    - the mobile devices can access both 5G and 4G LTE networks at the same time
    - Enhanced NR support for high-speed train scenarios
    - BS/UE EMC enhancements
  - Air-to-ground network for NR
  - etc.

Source: https://ro.scribd.com/document/629742332/Release-18-features-tsg95-v03

5. 5G Advanced

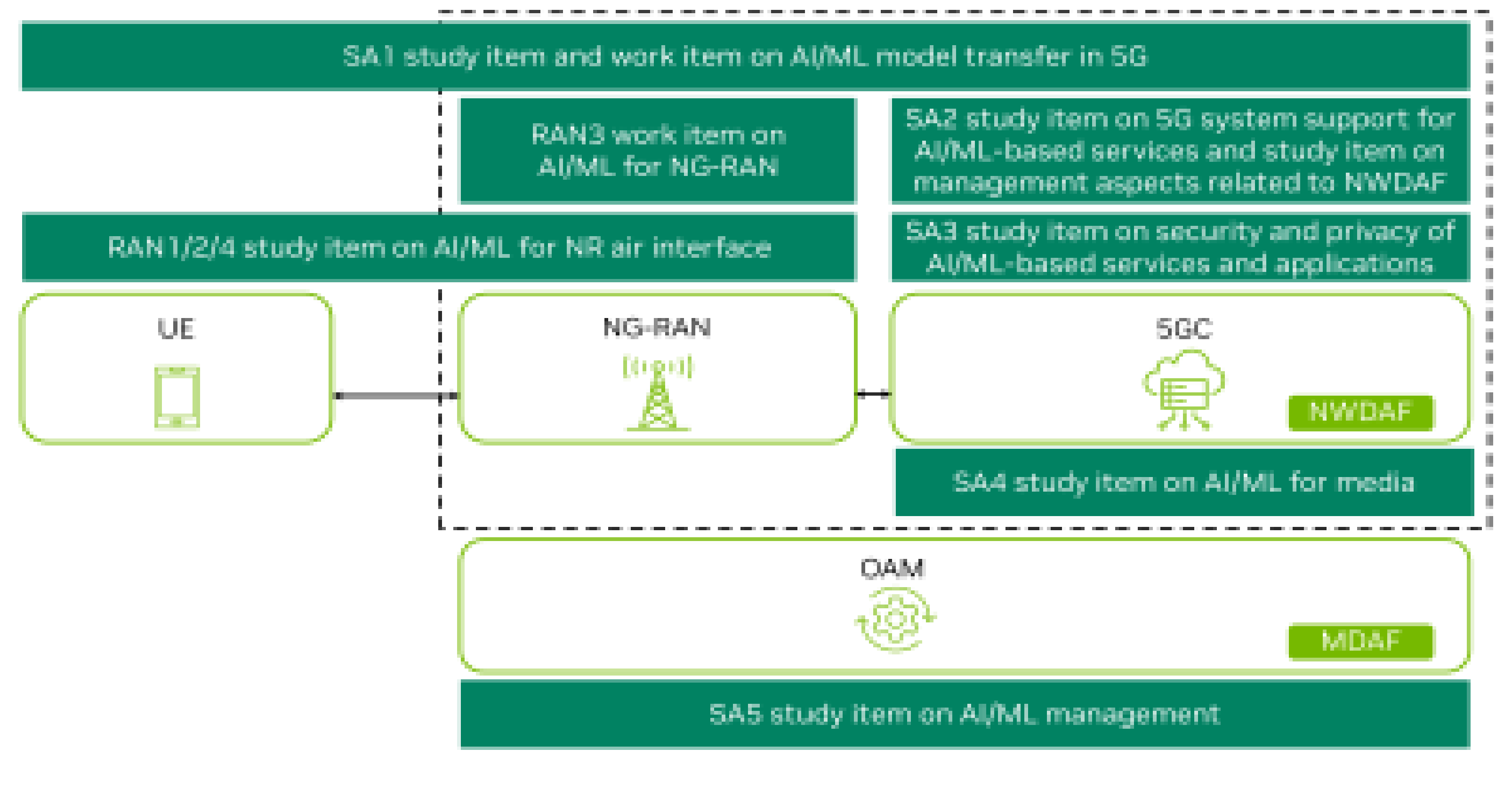
5.1 5G-Advanced- Second phase of 5G standardization -3GPP Release 18

Category	Approved item	Study/work item
Further enhanced 5G performance	RP-213554: Study on network energy savings for NR	Study item
	RP-213579: Further NR coverage enhancements	Work item
	RP-213565: Further NR mobility enhancements	Work item
	RP-213598: NR MIMO evolution for downlink and uplink	Work item
	RP-213568: Enhancements of NR multicast and broadcast services	Work item
	RP-213588: Study on expanded and improved NR positioning	Study item
Flexible spectrum use	RP-213603: NR support for dedicated spectrum less than 5MHz for FR1	Work item
	RP-213575: Enhancement of NR dynamic spectrum sharing (DSS)	Work item
	RP-213577: Multi-carrier enhancements for NR	Work item
	RP-213591: Study on evolution of NR duplex operation	Study item
Diverse 5G devices	RP-213589: In-device co-existence (IDC) enhancements for NR and MR-DC	Work item
	RP-213584: Dual Tx/Rx multi-SIM for NR	Work item
	RP-213587: Study on XR enhancements for NR	Study item
	RP-213661: Study on further NR RedCap UE complexity reduction	Study item
	RP-213645: Study on low-power wake-up signal and receiver for NR	Study item
	RP-213583: Mobile terminated-small data transmission for NR	Work item
	RP-213678: NR sidelink evolution	Work item
	RP-213600: NR support for UAV (uncrewed aerial vehicles)	Work item
Evolved network topology	RP-213677: Study on enhancement for resiliency of gNB-CU-CP	Study item
	RP-213601: Mobile IAB	Work item
	RP-213700: Study on NR network-controlled repeaters	Study item
	RP-213585: NR sidelink relay enhancements	Work item
	RP-213690: NR NTN (non-terrestrial networks) enhancements	Work item
Data-driven and AI-powered 5G	RP-213602: Artificial intelligence (AI)/machine learning (ML) for NG-RAN	Work item
	RP-213553: Further enhancement of data collection for SON/MDT in NR and EN-DC	Work item
	RP-213594: Enhancement on NR QoE management and optimization for diverse services	Work item
	RP-213599: Study on artificial intelligence (AI)/machine learning (ML) for NR air interface	Study item

5. 5G Advanced

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

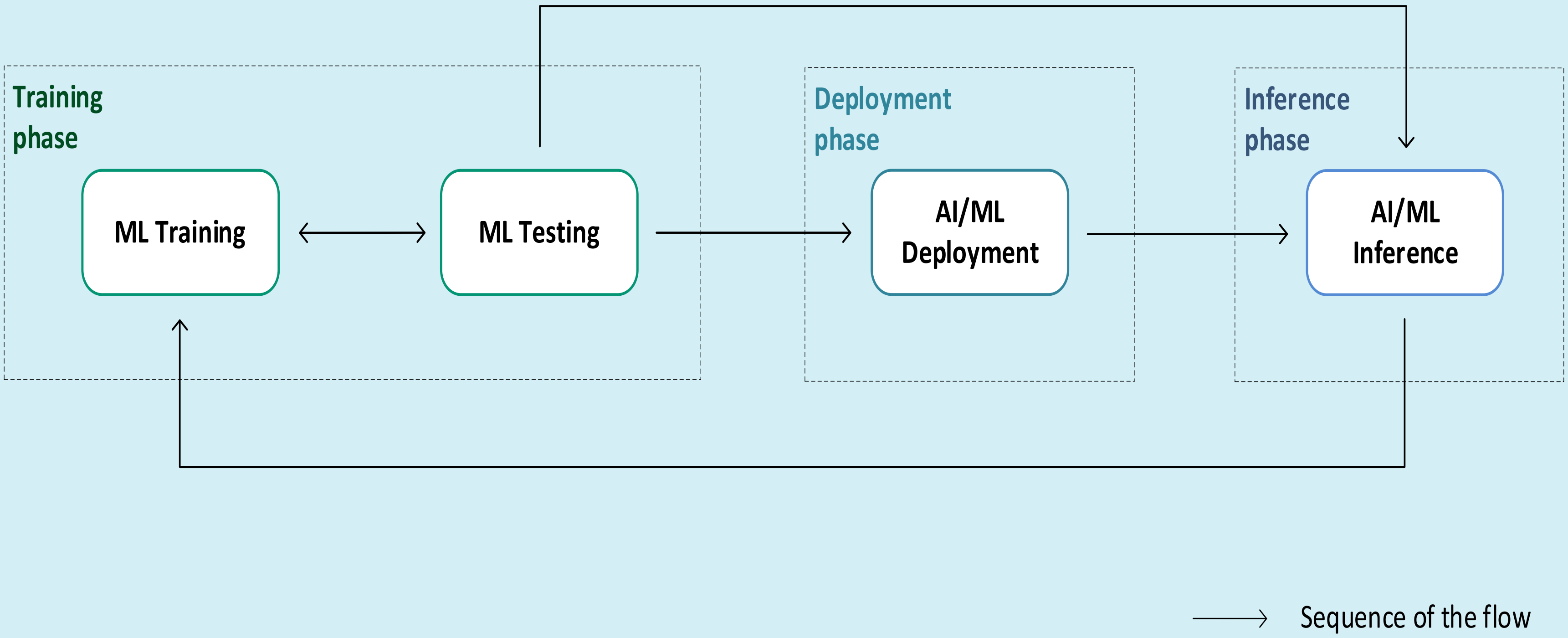
- AI/ML - manage complex networks intelligently, address system optimization problems, and improve user experience in 5G toward the (6G)
- **An overview of AI in 5G-Advanced in 3GPP Release 18** (SA—System Aspects WGs)



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

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

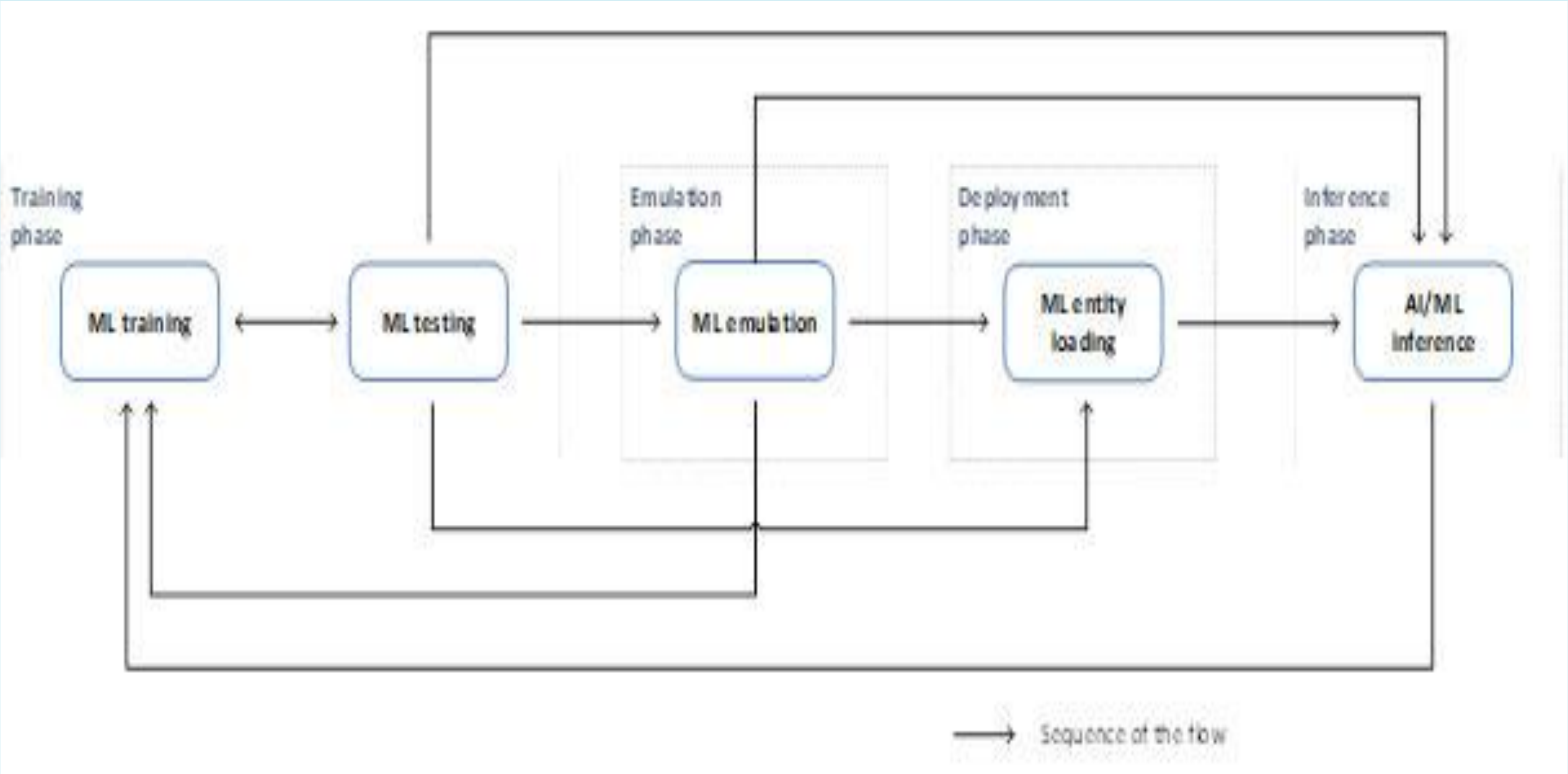
- AI/ML is used to manage complex networks intelligently, address system optimization problems, and improve user experience in 5G toward the (6G)
- **AI/ML operational workflow**



Source: 3GPP TR 28.908 V18.0.0 (2023-09), TSG Services and System Aspects; Study on AI/ML management (Release 18)

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

- **AI/ML operational workflow (cont'd)- detailed flow**



Source: https://www.3gpp.org/technologies/ai-ml-management

5. 5G Advanced

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

- **AI/ML operational workflow** (cont'd)- **detailed flow**
- **Training phase:**
  - **ML training**:
    - Initial training and re-training, of an ML entity or a group of ML entities
    - It also includes validation of the trained ML entity to evaluate the performance variance when the ML entity performs on the training data and validation data
      - If the validation result does not meet the expectation (e.g., the variance is not acceptable), the ML entity will be re-trained
  - **ML testing**:
    - testing of the validated ML entity to evaluate the performance when it performs on testing data
    - If the result meets the expectation, the ML entity may proceed to the next phase, otherwise re-training
- **Emulation phase (**optional**):**
  - Running an ML entity or AI/ML inference function for inference in an emulation environment
  - Purpose : evaluate the inference performance of the ML entity or AI/ML inference function in the emulation environment (prior to applying it to the target operational) network or system

Source: https://www.3gpp.org/technologies/ai-ml-management

5. 5G Advanced

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

- **AI/ML operational workflow** (cont'd)- **detailed flow**

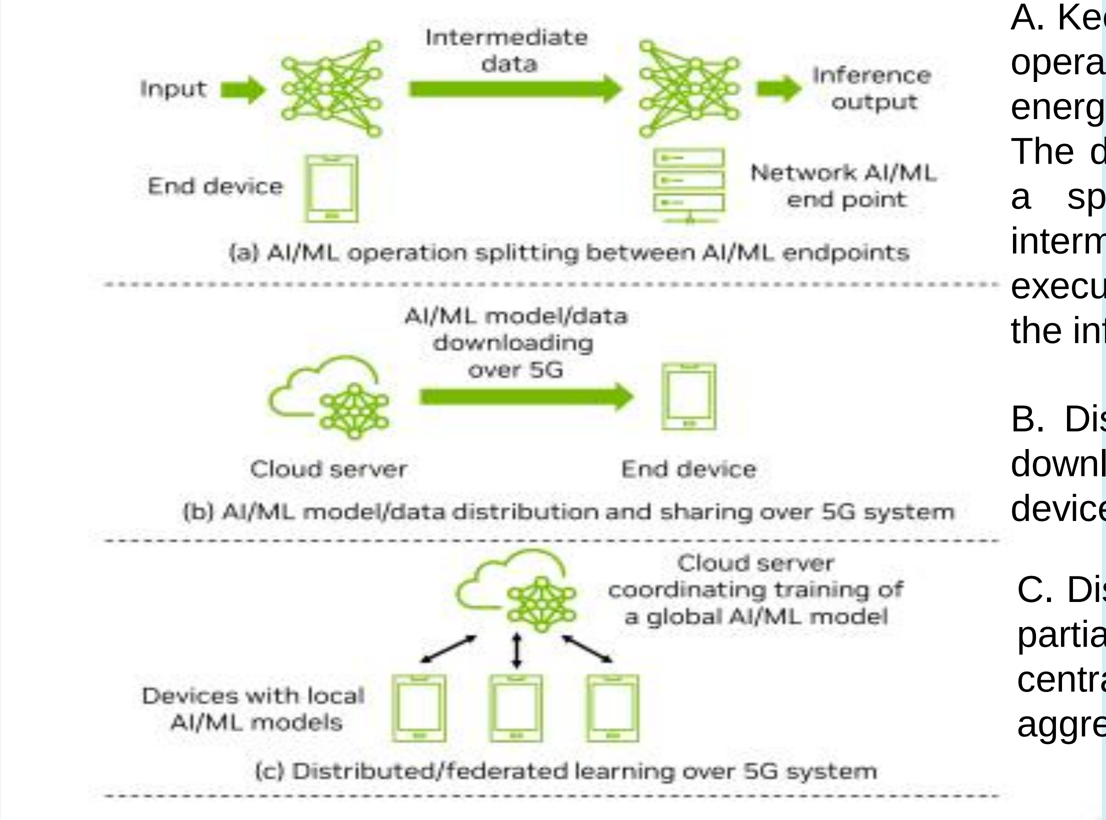
- **Deployment phase:**
  - **ML entity loading**: loading of a trained ML entity into the target AI/ML inference function which will use it for inference.
  - NOTE: The deployment phase may not be needed in some cases, for example when the training function and inference function are co-located.
- **Inference phase:**
  - **AI/ML inference**: performing inference using the ML entity by the AI/ML inference function.

Source: https://www.3gpp.org/technologies/ai-ml-management

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

- **Application Layer AI/ML Operation in 5G System**

  - **Types of AI/ML operations in 5G system identified by 3GPP SA1 in Release 18**



A. Keep privacy- or latency-sensitive parts of the operation in UE but offload the computation- or energy-intensive parts o to network endpoints. The device executes the operation/model up to a specific part/layer and then sends the intermediate data to the network endpoint which executes the remaining parts/layers and feeds the inference results back to the device.

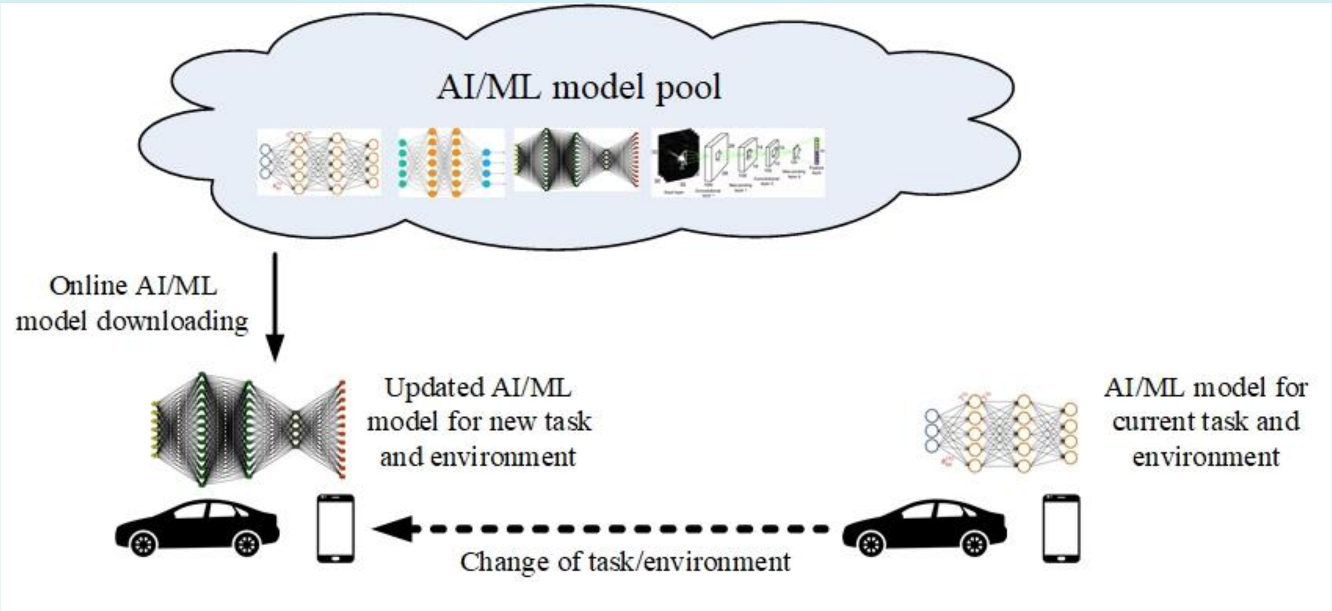
B. Distribution and sharing - adaptive model: downloading from a network endpoint to the devices when needed.

C. Distributed/federated learning; UEs perform partial training based on local data and a central entity trains a global model by aggregating the local results from the UEs.

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

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

- **Application Layer AI/ML Operation in 5G System** (cont'd)
  - **Types of AI/ML operations in 5G system identified by 3GPP SA1 in Release 18**
  - **Case B: Online model distribution** (i.e. new model downloading)
    - an AI/ML model can be distributed from a NW endpoint to the devices when they need it to adapt to the changed AI/ML tasks and environments.



Source: 3GPP 3GPP TR 22.874 V18.2.0 (2021-12), TSG Services and System Aspects;Study on traffic characteristics and performance requirements for AI/ML model transfer in 5GS (Release 18),

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

- **Application Layer AI/ML Operation in 5G System** (cont'd)

- **Types of AI/ML operations in 5G system identified by 3GPP SA1 in Release 18 (cont'd)**

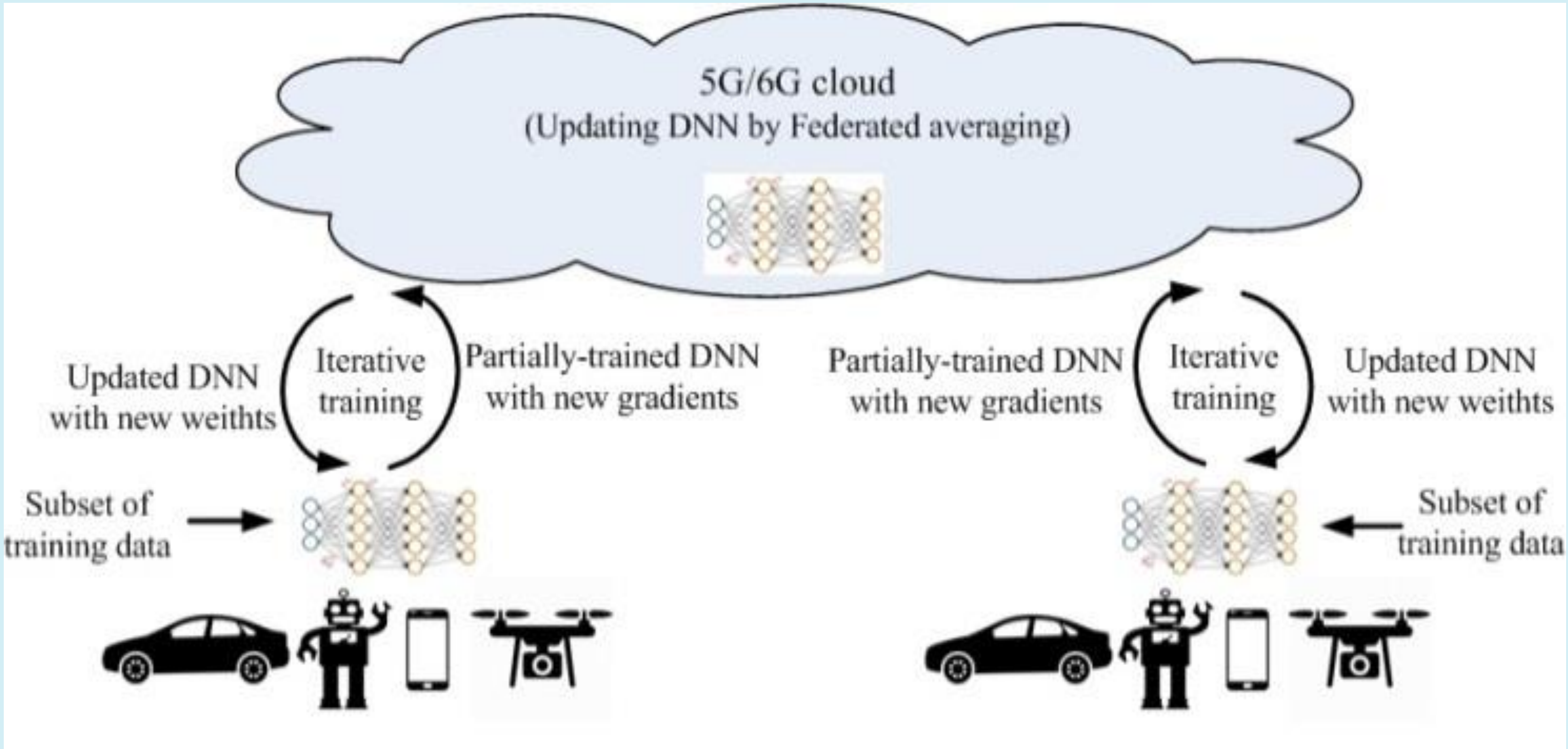
  - **Case C: Federated Learning over 5G system**
  - **(see next slide)**
    - The cloud server trains a global model by aggregating local models partially-trained by each end devices
    - Within each training iteration, a UE performs the training based on the model downloaded from the AI server using the local training data
    - Then the UE reports the interim training results to the cloud server via 5G UL channels
    - The server aggregates the interim training results from the UEs and updates the global model
    - The updated global model is then distributed back to the UEs and the UEs can perform the training for the next iteration.

Source: 3GPP 3GPP TR 22.874 V18.2.0 (2021-12), TSG Services and System Aspects;Study on traffic characteristics and performance requirements for AI/ML model transfer in 5GS (Release 18),

5. 5G Advanced

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

- **Application Layer AI/ML Operation in 5G System** (cont'd)
- **Types of AI/ML operations in 5G system identified by 3GPP SA1 in Release 18 (cont'd)**
  - **Case C: Federated Learning over 5G system**



Source: 3GPP 3GPP TR 22.874 V18.2.0 (2021-12), TSG Services and System Aspects;Study on traffic characteristics and performance requirements for AI/ML model transfer in 5GS (Release 18),

5. 5G Advanced

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

- **AI/ML 5G system support**
  - **3GPP System Aspects (SA1)** WG identified potential **new service and performance requirements** (related to the support of application layer AI/ML operation in UE)
  - **3GPP SA2,** WG (dedicated to 3GPP **system architecture**) had completed a study in R18 on 5G system support to facilitate the application layer AI/ML operation
    - It explored **several possible architectural and functional extensions** to support app. layer AI/ML operation, finalized with a set of general architecture principles.
      - **Example of one principle** : responsibility for application layer AI/ML decisions and their internal operational logic lies with the *application function (AF)* and UE application client

        The network does not need to know the internal workings of AI/ML services, but can differentiate AI/ML-related traffic from other user services-related traffic (by using detection mechanisms)
      - **Enhancing external parameter provisioning** to 5GC to facilitate application layer AI/ML operation

        - recommended : the AF can provision the 5GC with new parameters of expected UE behavior and confidence and/or their accuracy, the expected inactivity time for AI/ML traffic, etc.

Source: 3GPP TR 23.700-80, "Study on 5G system support for AI/ML-based services," V18.0.0, December 2022.

5. 5G Advanced

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

- **AI/ML 5G system support**
- **3GPP SA2,** WG (cont'd)
  - **Key issue** : 5GC information exposure to authorized third party for application layer AI/ML operation.
    - User consent –needed for exposing UE-related info or data analytics to third parties
  - **Key issue** : 5G system assistance to federated learning operation
    - Recommendation: specifying a new member selection assistance functionality
      - i.e., the 5GC capability to generate a list of candidate UEs and additional information in response to a request from the AF
    - The AI/ML-based application can utilize the new member selection assistance functionality to choose federated learning members

- **3GPP WG SA5** has initially started the work for AI/ML mgmt. in Rel-17 Management Data Analytics (MDA) TS 28.104
  - conclusion: a generic mechanism for managing the ML training for any kind of AI/ML enabled capabilities is needed
- In Rel-18, SA5 AI/ML management development work started with a dedicated study which has recently been completed and documented in TR 28.908
  - The specification work will continue in TS 28.105 in Rel-18. planned to be completed and published during 2024.

Source: 3GPP TR 23.700-80, "Study on 5G system support for AI/ML-based services," V18.0.0, December 2022.

5. 5G Advanced

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

- **AI/ML 5G system support**
- **AI/ML management capabilities**
- (TR 28.908) - more than 40 use cases related to the management of AI/ML, categorized into the management capabilities for the four corresponding operational phases in the AI/ML workflow
- **Management capabilities for training phase**
  - **ML training management**: the MnS consumer can
    - request the ML entity training,
    - consume and control the producer-initiated training
    - set a policy for the producer-initiated ML entity training
      - (e.g., conditions to trigger the ML (re)training based on the AI/ML inference performance)
    - manage the ML entity training/retraining process, training performance management, and training data management.
  - **ML validation**:
    - includes validation to evaluate the performance of the ML entity to identify the variance of the performance on the training and validation data
    - If the variance is not acceptable, then re-training

Source 1: 3GPP TR 28.908 V18.0.0 (2023-09), TSG Services and System Aspects; Study on AI/ML management (Release 18); Source 2: https://www.3gpp.org/technologies/ai-ml-management

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

- **AI/ML 5G system support**
- **AI/ML management capabilities** (cont'd)
- **Management capabilities for training phase** (cont'd)

  - **ML testing management**:
    - allows the MnS consumer to request the ML entity testing, and to receive the testing results
    - It may also include capabilities for selecting the specific performance metrics to be used or reported by the ML testing function
    - MnS consumer can
      - set a policy for a producer-initiated ML entity testing after training and validation
      - report back on the outcome
      - trigger ML entity re-training based on the ML entity testing performance requirements

Source 1: 3GPP TR 28.908 V18.0.0 (2023-09), TSG Services and System Aspects; Study on AI/ML management (Release 18); Source 2: https://www.3gpp.org/technologies/ai-ml-management

5. 5G Advanced

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

- **AI/ML 5G system support**
- **AI/ML management capabilities** (cont'd)
- **Management capabilities for emulation phase**
  - **AI/ML inference emulation:**
    - an MnS consumer can request an ML inference emulation for a specific ML entity or entities to evaluate the inference performance in an emulation environment
    - (prior to applying it to the target network or system)
  - **ML inference emulation management:**
    - this capability allows an authorized MnS consumer (e.g., an operator) to manage or control and monitor a specific ML inference emulation process
      - e.g., to start, suspend or resume the inference emulation, and to receive the emulation
- **Management capabilities for deployment phase**
  - **AI/ML deployment control and monitoring**: capabilities for loading the ML entity to the target inference function. It includes informing the consumer when new entities are available, enabling the consumer to request the loading of the ML entity or to set the policy for such deployment and to monitor the deployment process.

Source 1: 3GPP TR 28.908 V18.0.0 (2023-09), TSG Services and System Aspects; Study on AI/ML management (Release 18);
Source 2: https://www.3gpp.org/technologies/ai-ml-management

5. 5G Advanced

5.2 Artificial Intelligence/ Machine Learning (AI/ML) based functionalities

- **AI/ML 5G system support**
- **AI/ML management capabilities** (cont'd)
- **Management capabilities for inference phase**
  - **AI/ML inference control:** allows an MnS consumer to control the inference, i.e., activate/deactivate the inference function and/or ML entity/entities (e.g., instant activation, partial activation, schedule-based or policy-based activations, configure the allowed ranges of the inference output parameters, or the context for performing inference
  - **AI/ML inference performance evaluation:** allows the MnS consumer to monitor and evaluate the inference performance of an ML entity or an AI/ML inference function
  - **AI/ML inference orchestration:** the MnS consumer can orchestrate the AI/ML inference functions ,e.g., knowledge of capabilities of the inference functions, the expected and actual running context of ML entity, the AI/ML inference performance, the AI/ML inference trustworthiness, etc.

- **Common management capabilities for all phases**
  - **AI/ML trustworthiness management**: allowing the MnS consumer to configure, monitor and evaluate the trustworthiness of an ML entity. This applies to the ML entity at every operational phase of the AI/ML operational workflow.

Source: https://www.3gpp.org/technologies/ai-ml-management

CONTENTS

6. 6G objectives, use cases and requirements

6.1 6G Objectives

Why 6G?

- **Today- 5G is a strong technology intensively developed; however, it has limitations w.r.t. future needs**

- ***6G Vision for 2030***
  - ***the society will be data driven, served by near instant, unlimited wireless connectivity***

- **6G objectives:**
  - meet **novel network demands**
    - ultra-high reliability, high capacity and efficiency, and low latency, answering the new needs of economic, social, technological, and environmental context of the 2030 era
  - **integration** of the space, aerial, terrestrial, and maritime communications into a robust network

6. 6G objectives, use cases and requirement

6.1 6G Objectives

- **Large range of network services, high-level services and applications**

  - Extensive connectivity
  - Unmanned mobility
  - 3D networking capabilities
  - Mobile broadband reliable and low-latency communication
  - Massive URLLC (mURLLC)
  - Wearable displays, mobile robots and drones, specialized processors
  - New devices replacing smart phones

  - XR/AR/VR, Holographic tele-presence (teleportation)
  - eHealth
  - Industry 4.0 and robotics
  - Telepresence - high resolution imaging and sensing
  - Distributed AI, haptic communication
  - Autonomous connected vehicles
  - Human-centric services
  - Bio-Internet of things (B-IoT), nano-Internet of things (N-IoT)

6. 6G objectives, use cases and requirements

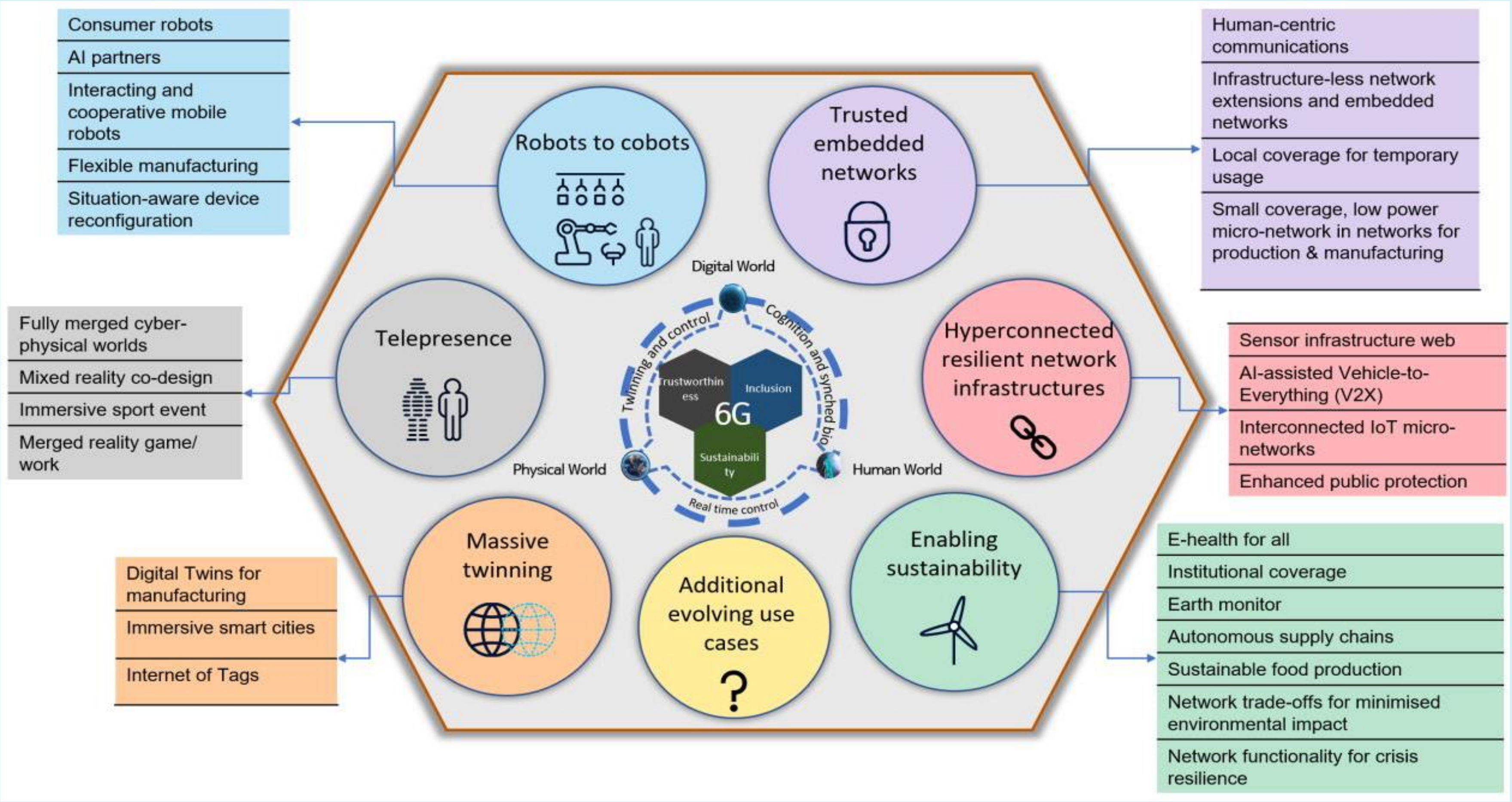
6.2 Use cases and applications

- *NGMN Alliance vision : 6G Requirements and Design Considerations, 2023*
- **Potential use cases**
  - **Enhanced human communication**
    - XR immersive holographic telepresence communication
    - Multi-modal communication for teleoperation
    - Intelligent interaction: sharing of sensation, skills & thoughts
  - **Enhanced machine communication**
    - Robot Network Fabric
    - **Collaborative robots** (**cobots)**, intended for direct human –robot intraction
  - **Advanced services**
    - 3D hyper-accurate positioning localization, and tracking
    - Interactive mapping, digital twins & virtual worlds
    - Automatic detection protection & inspection
    - Digital healthcare
    - Smart Industry
    - Trusted composition of services
  - **Advanced networking**
    - Trusted Native AI – AIaaS
    - Coverage expansion
    - Energy Efficiency

6. 6G objectives, use cases and requirements

6.2 Use cases and applications

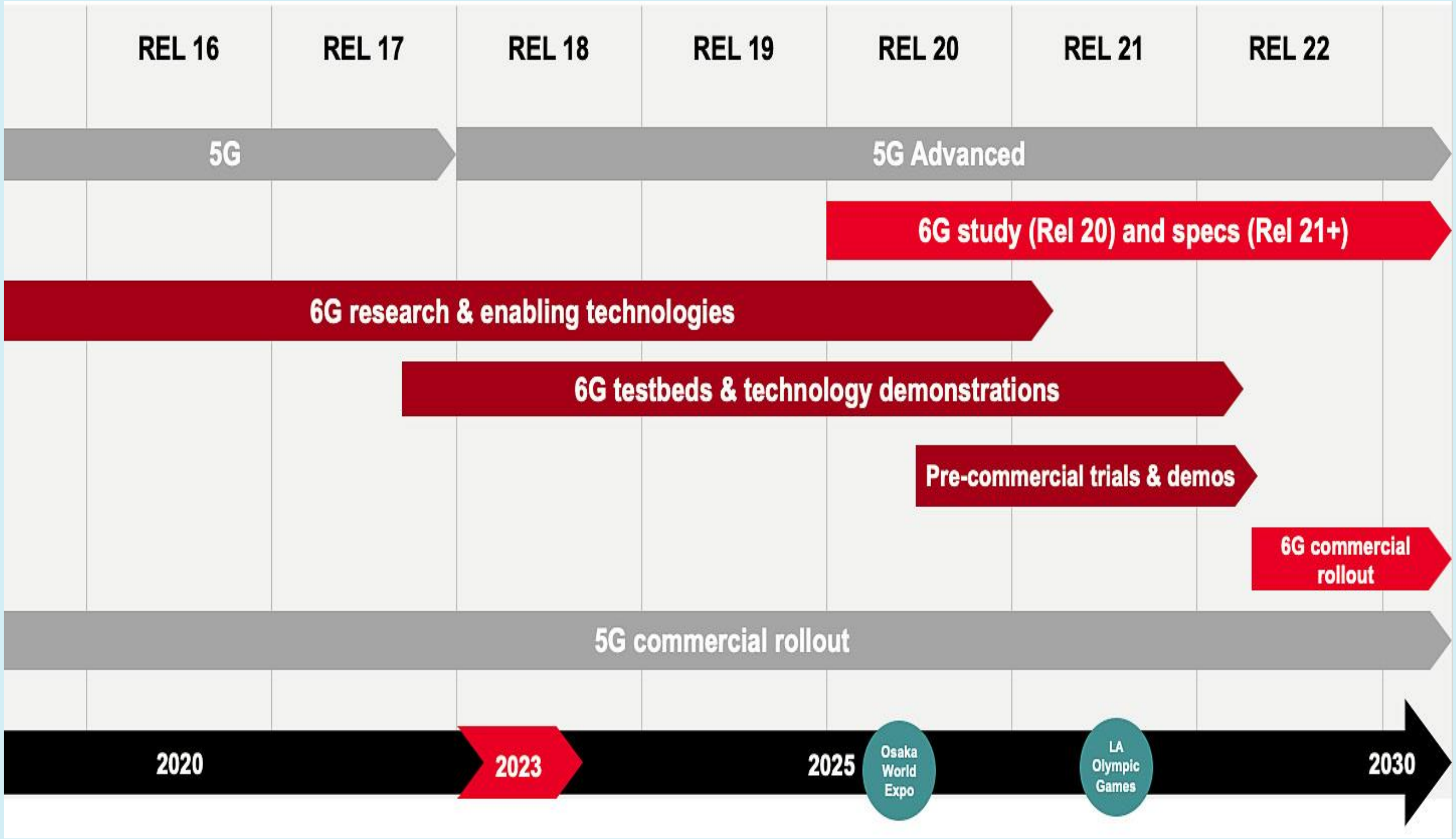
- **Family of Use cases**



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.

6. 6G objectives, use cases and requirements

6.3 3GPP expected evolution 5G to 6G

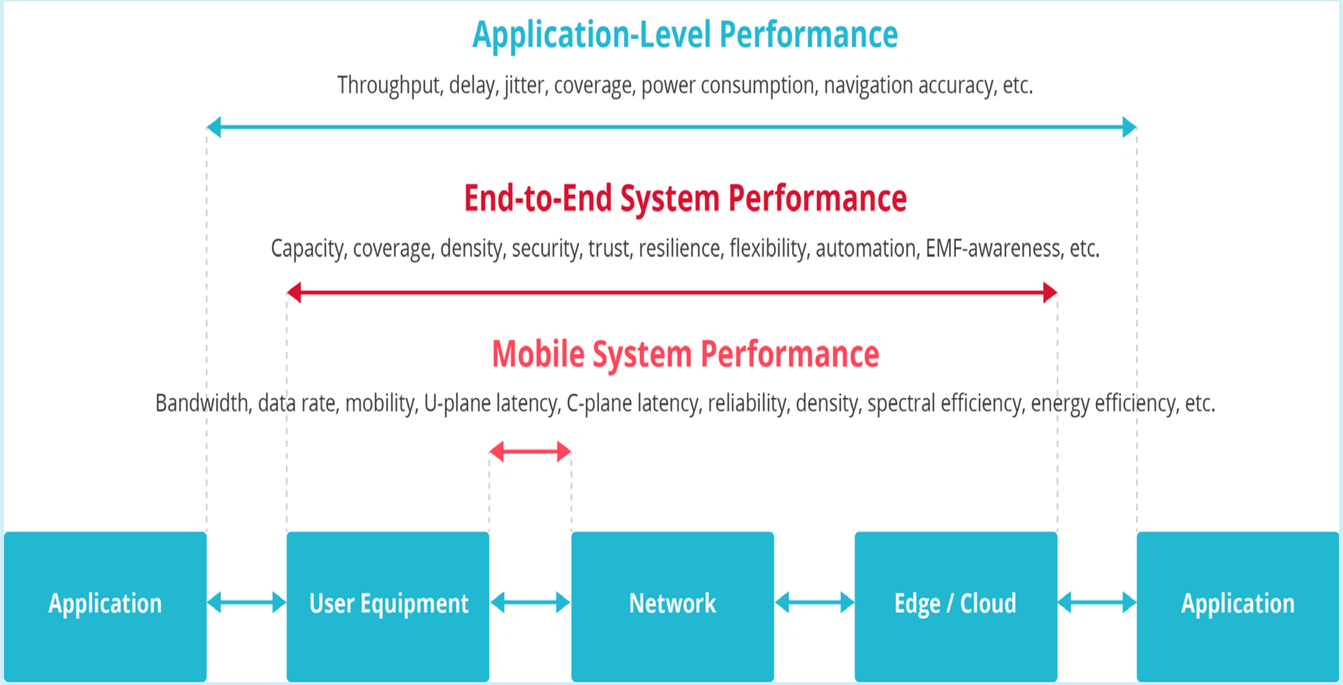


Next-Generation Wireless: A Guide to the Fundamentals of 6G , https://www.keysight.com/us/en/home.html

6. 6G objectives, use cases and requirements

6.4 6G capabilities – seen from user or application-level perspective

- 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

6. 6G objectives, use cases and requirements

6.5 General 6G requirements

- **Essential 6G requirements -summary**
- High data rate per user/device (10–100 times greater than 5G)
- Wide geo coverage
- Very larger number of connected devices
- Distributed massive MIMO
- High and reliable connectivity
- 2D, 3D and low latency communications
- Digital inclusion, digital twin
- Energy efficiency, Environmental impact
- Real-time dynamic analysis and self-awareness
- Trust and security mechanisms
- Automated network programmability,
- Intensive AI/ML support, integration of Clud/Edge/Fog computing
- Advanced orchestration, management and control, network slicing
- Support massive Internet of Things (IoT)
- Integrate virtual reality (VR) and augmented reality (AR) into one extended reality (XR)
- Generate large amounts of data through the Internet of Everything (IoE)
- Support for regulated and public safety services
- Large range of services for all types of domains
- Backward compatibility (4G, 5G, WiFi, fixed access, etc.)

6. 6G objectives, use cases and requirements

6.5 General 6G requirements

- **Essential 6G requirements for network evolution**
- **Digital inclusion**
  - Universal access to digital services with good QoS/QoE level and in an economically accessible way
    - 6G coverage of sparsely populated areas in an economically viable way
    - User interfaces to 6G should be simple and support intuitive interactions
    - Digital inequity of 6G services should be avoided
- **Energy efficiency**
  - Need for environmental sustainability of networks, low-cost operations, networks' scaling ability, to meet future capacity demand
    - many operators have made strong commitments w.r.t reaching carbon neutrality and net-zero carbon emission, during the 6G-era
  - Guidance:
    - Improvements in energy efficiency; the improvements should exceed the forecast growth in traffic volume to reduce overall energy consumption
    - Energy consumption figures need to be comparable and interoperable between equipment suppliers ; they must be made available at all levels of the system to enable 6G system wide monitoring and optimization
    - Low energy consumption is needed of end user devices (e.g., IoT)

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

6. 6G objectives, use cases and requirements

6.5 General 6G requirements

- **Essential 6G requirements for network evolution** (cont'd)
- **Environmental impact**
  - **Metrics for environmental reporting** are about: climate change, natural resources, pollution and waste, and environmental opportunities
  - **Service providers** should report their own impact and but those of their supply chain reflecting the products that are purchased and consumed.
  - The overall environmental impact of 6G should be minimised.
  - **Guidance:**
    - A 6G BS should be able to **record and adapt its RF emission levels** (number of beams, beam occupancy and radiated power), to follow any given RF profile
    - **Resources** consumed during the manufacturing of network equipment and terminals should be **monitored and reported** as required
    - **Greenhouse gas** emitted over the complete life cycle, e.g., manufacture and operation to end of life of network equipment and terminals should be **monitored**
    - The **impact of real-estate assets** (e.g., antenna structures, equipment cabinets, data centers) and their resource consumption should be **monitored**
    - Common indicators should be defined in 6G design to allow comparison and to ease the elaboration of the environmental impact of 6G-based services

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

6. 6G objectives, use cases and requirements

6.5 General 6G requirements

- **Essential 6G requirements for network evolution** (cont'd)
- **Native trustworthiness**
- NIST definition of **trustworthiness** : **security (confidentiality, integrity, availability), privacy, reliability, resilience, and safety**
- The 6G system should
  - be **protected** from unintended/unauthorized access, protect personal and sensitive data, even in untrusted multi-party ecosystems
  - **deliver stable and predictable performance** in expected conditions and able to return to predictable performance in the event of unexpected conditions
  - **operate safely** w.r.t. life, health, property, or data of teleco system stakeholders and the physical environment
- **Guidance**: the 6G system should
  - provide **high levels of resilience, security, safety, reliability, and privacy**
  - be **quantum robust** in face of the introduction of quantum computing
  - **Protect**
    - **digital identities** and prevent from unauthorised access
    - privacy sensitive data in terms of confidentiality, integrity, availability and anonymity
  - include security assurance schemes for the whole lifecycle from the products design to network deployment and operation.

6. 6G objectives, use cases and requirements

6.5 General 6G requirements

- **Essential 6G requirements for network evolution** (cont'd)
- **Support for regulated and public safety services**

- 6G interworking with 5G – needed, to provide continuity and a smooth transition to 6G
- **Imperative:** national and regional regulatory requirements must be supported at the 6G launch

- **Voice communication services**
  - they will be enriched , e.g., to convey emotions and personality
  - mobile voice services are real-time critical services;need low delay and no interruptions noticeable to the user
  - enabling seamless and high-quality voice calls across multiple generations of radio access are major 6G requirements
  - emergency services still require support for voice communications

- **Messaging services**
  - support for interoperable message services is needed, from social interactions to business applications

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

6. 6G objectives, use cases and requirements

6.5 General 6G requirements

Essential 6G requirements for network evolution (cont'd)

- **Automation of end to end service delivery**
- Need to **dynamically provide and adapt** the services to the **customers' requirements**
- Automation of service delivery is critical for operators and will allow them to:
  - **Optimize the time** required to deliver a custom service and reduce the risk of erroneous configuration instruction
  - **Manage dynamically adaptive networks**,
    - to adapt to changing customer demand or network topology evolution

- **6G networks should be capable** of:
  - Full-system **standardized monitoring** (collect the required data to feed automation algorithms.
  - Support **different configurable trade-offs** between several possible optimisation objectives (e.g., energy, capacity, resilience) and switch between them depending
  - Support a **standardized or at least uniform service description** framework.
- Provide **flexible and configurable network functions** at the access and core layers

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

6. 6G objectives, use cases and requirements

6.5 General 6G requirements

- **Automated network programmability**
- **Programmability of concatenated resource** segments is required for a system-wide automation of E2E slicing
  - with **dynamic adaptability** to system conditions, service assurance and life-cycle management, without human intervention.
- **Resource allocation for a E2E** network slice
  - Should be able to spans the different segments of core, edge, transport
    - with heterogeneous coverage footprints, to fit various deployment scenarios.
- **Architectural shifts** should be possible for an effective management of the IP bearer network and resource allocation across the different segments of an E2E system
- A **concatenated routing of resources,** across the different segments of an E2E system, for a given E2E slice, will enhance the granularity of the network programmability
- Self-organising automation of a concatenation of resource segments, include (through service awareness):
  - compatibility with existing networks and heterogeneous cloud networks
  - agility of service provisioning and ubiquitous connectivity
  - deterministic quality improved granularity of resource allocation,
- These attributes should be met, together with optimized performance, extensibility, and scalability

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

6. 6G objectives, use cases and requirements

6.5 General 6G requirements

- **Artificial intelligence and compute related capabilities**
- AI as a service (AIaaS) - new enabler for the 6G system
- **AI-based apps**. (hosted and taken care of by the 6G system), will provide:
- **Comm. services** between intelligent agents well suited for AI requirements
- **Computing power** to efficiently host AI-based applications; a 6G system should
  - support for **large AI models,** to ease training with its data sharing capabilities and to support large scale distributed learning
  - **speed up delivery of reliable and accurate inference results** while protecting data privacy and sovereignty
  - provide superior **energy efficiency** compared to classical implementations
- **Specific capabilities** to be supported by 6G systems
  - The volume of training / updating data could be massive, for large scale distributed learning deployment → AIaaS requires high uplink traffic capacity
  - **Sensitive collected and storage training data** need to be processed with **privacy** and **transparent** handling
  - **E2E latency (**communication + inference computing time) for some apps.
- **Ability to manage model training / updating,** model deployment, and model storage, and to facilitate model download.
- Ability to **manage and coordinate AI capable computing resources**.
- *Source: NGMN Alliance : 6G Requirements and Design Considerations, 2023*
  https://www.ngmn.org/publications/6g-requirements-and-design-considerations.html

CONTENTS

7. 6G architecture and technologies

7.1 6G - advanced network architecture

General concepts

Overview of 6G system

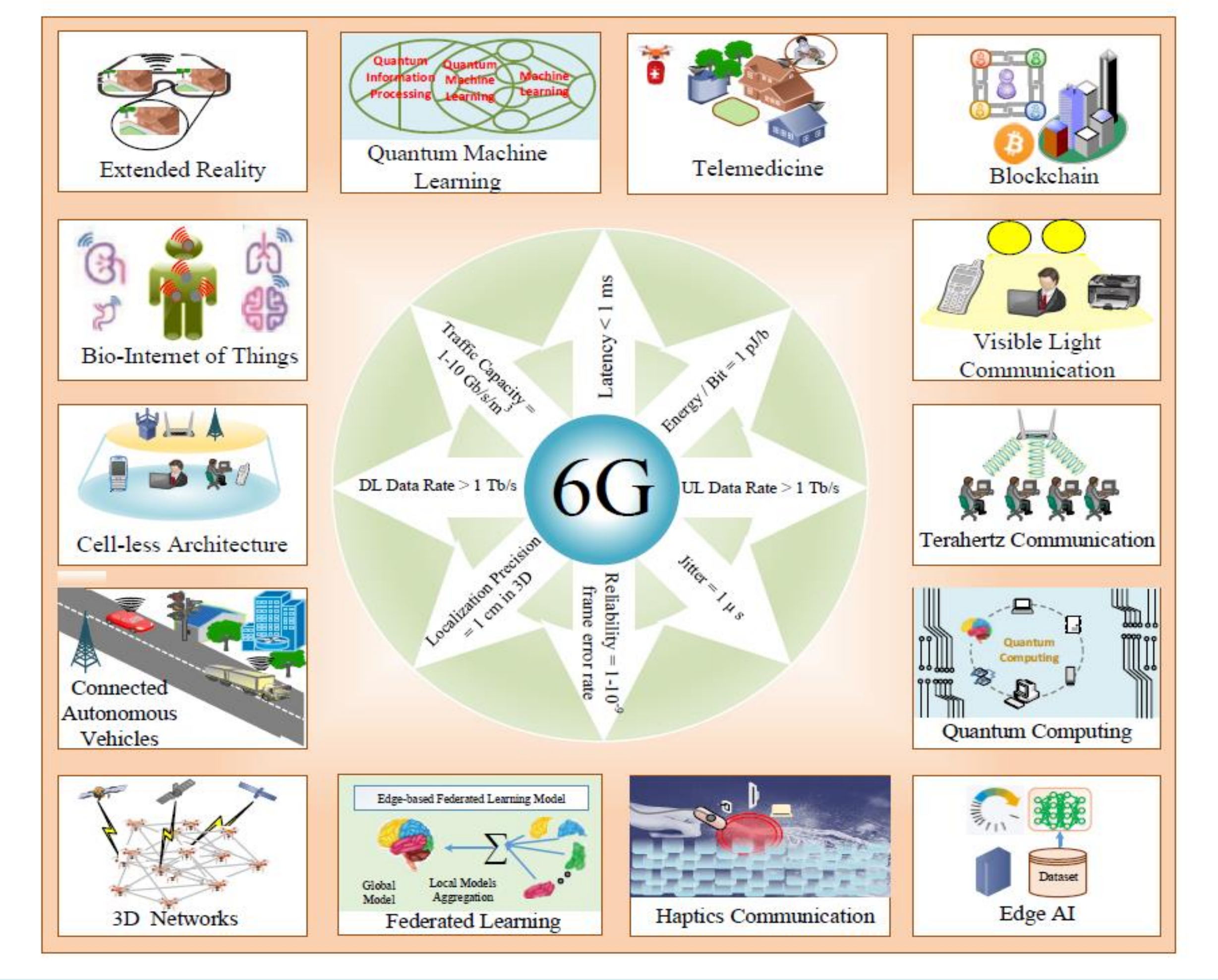
Advanced key requirements: capacity, UL/DL data rate, localization precision, reliability, latency, jitter, energy per bit

Several enabling technologies

Machine learning (quantum), federated learning
Computing (quantum)
3D networking
Edge Artificial Intelligence
Cell-less architecture
Blockchain
Haptic communication
Terahertz communication

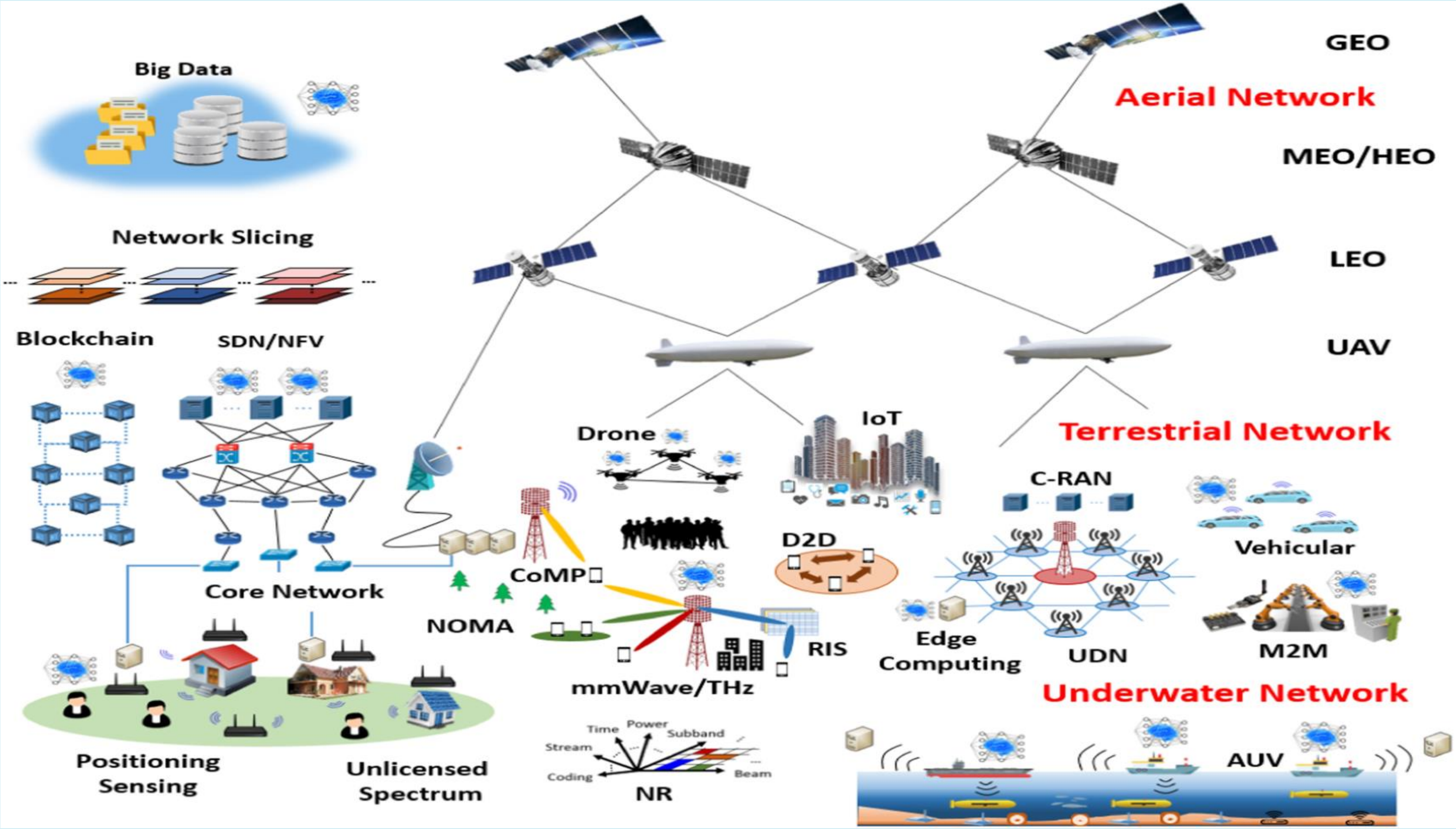
Use cases – examples

Connected autonomous vehicles
Telemedicine
Extended reality
Internet of Things



7. 6G architecture and technologies

7.1 6G – advanced network architecture



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

7. 6G architecture and technologies

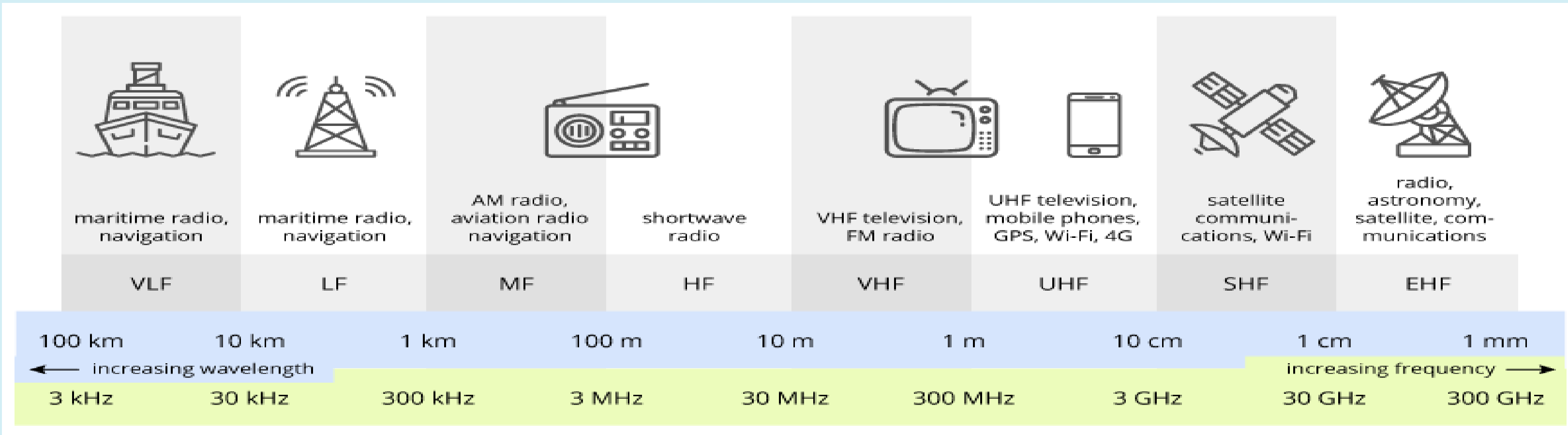
7.1 6G –advanced network architecture (notations)

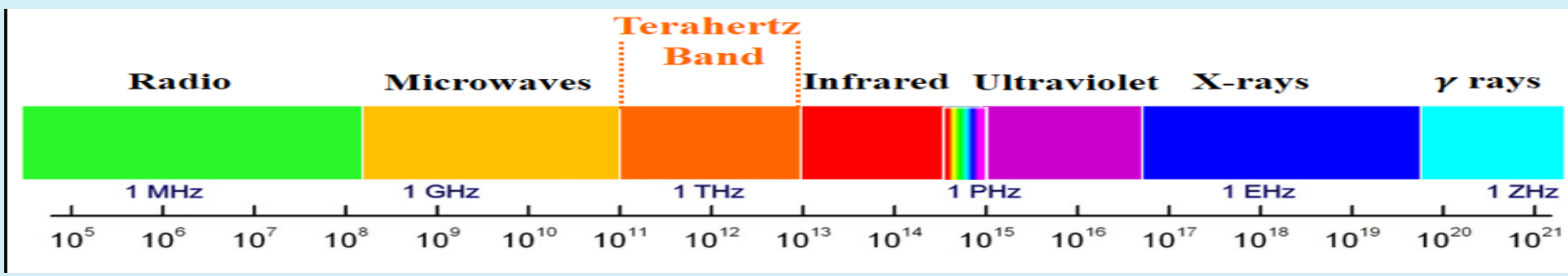
Acronyms

AI	Artificial Intelligence
AUV	Autonomous Underwater Vehicle
CoMP	Coordinated Multi-Point
C-RAN	Cloud/Centralised 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

7. 6G architecture and technologies

- **7.2 3GPP expected evolution 5G to 6G-details**
- **Radio frequency bands (source: ITU-T)**





Terahertz radiation –a.k.a **submillimeter radiation**, **terahertz waves**, **tremendously high frequency** (**THF**), **T-rays**, **T-waves**, **T-light**, **T-lux** or **THz** –within the ITU-designated band of frequencies [0.3 to 3 THz], i.e., [300–3,000 GHz] /1–0.1 mm

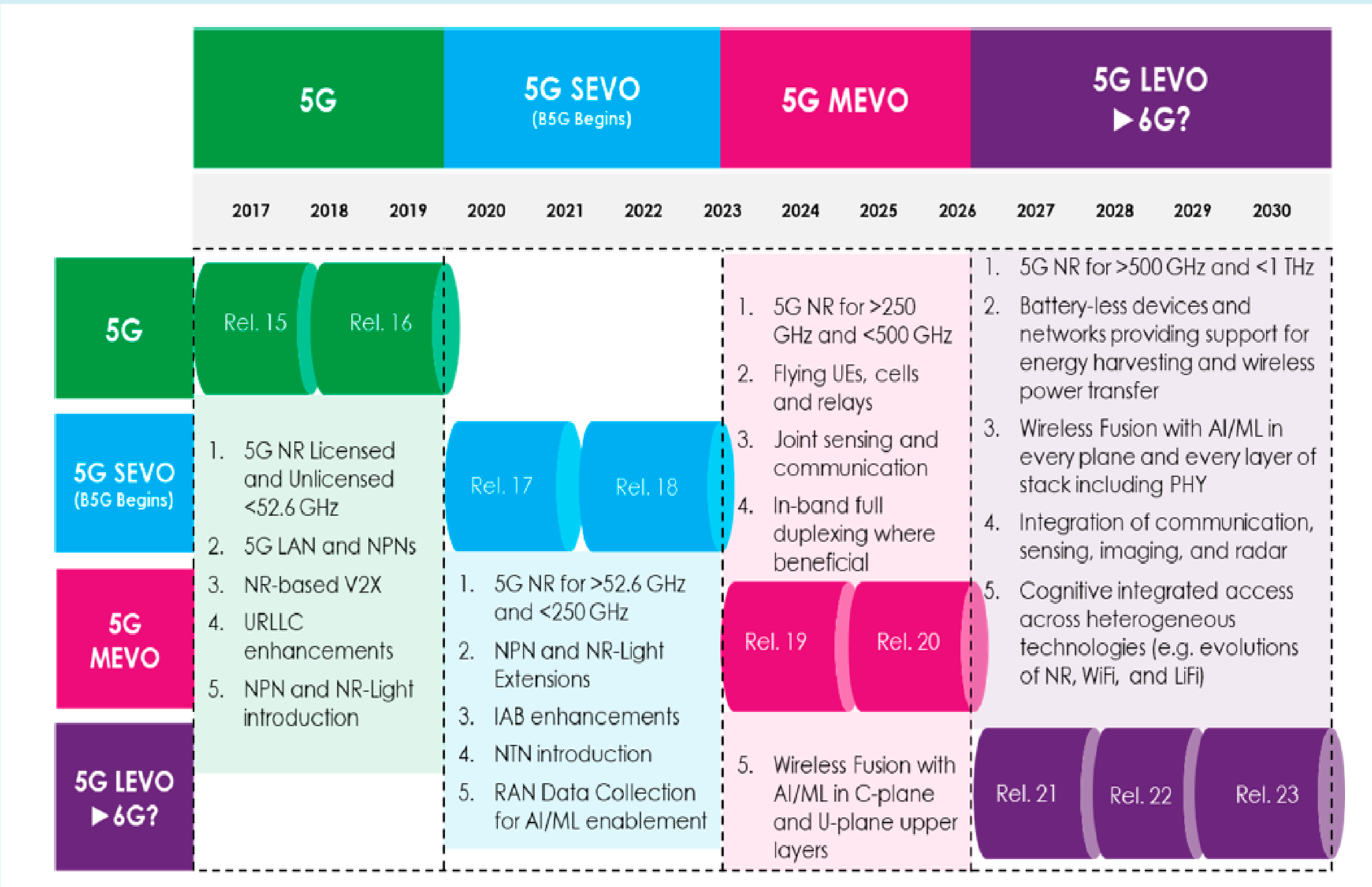
The upper boundary is somewhat arbitrary and is considered by some sources as 30 THz.

6G will considers the bands: 7 to 20 GHz, W-band (above 75 to 110 GHz), D-band (110 to 175 GHz), bands between 275 and 300 GHz, and in THz range (0.3 to 10 THz).

7. 6G architecture and technologies

7.2 3GPP expected evolution 5G to 6G-details

Roadmap to 2030 ; SEVO, MEVO, LEVO, 6G – Short, medium, long term evolution , 6G



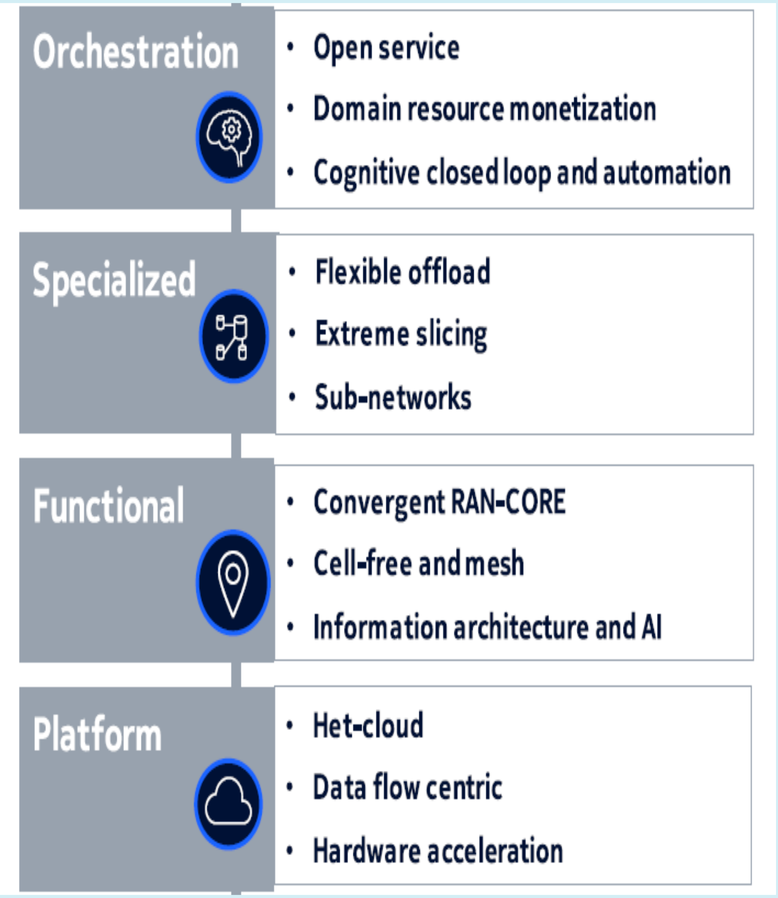
AI – Artificial Intelligence
C-Plane – Control Plane
KPI- Key Performance Indicators
IAB -Integrated Access and Backhaul
NR- 5G New Radio
NPN-5G Non-Public Network
NTNs - Non-Terrestrial Networks
ML – Machine Learning
PHY- Physical Layer
RAN – Radio Access Network
UE- User Equipment
U-Plane - User Plane
URLLC- Ultra Reliable Low Latency Communication
V2X – Vehicle to Everything

7.3 6G –Architectural components

- **6G Architectural framework – building blocks example**

- **Four major interworking components, to provide an open and distributed reference framework**

- **Platform infrastructure:**
  - **"heterogeneous-cloud", open, scalable and agnostic run-time environment**
  - **data flow centricity, hardware acceleration**
- **Functions (functional architecture)**
  - **RAN- CORE convergence**
  - **cell free and mesh connectivity**
  - **information architecture and AI**
- **Specialized networks and architectural enablers for**
  - **flexible off-load, extreme slicing, sub-networks**
- **Orchestration component**
  - **assures open service enabling and ecosystem play**
  - **domain resource monetization**
  - **cognitive closed loop and automation**



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

7. 6G architecture and technologies

7.4 6G - Enabling Technologies - summary

- Several key enablers justify the migration from 5G to 6G networks
- **Categories: physical layer technologies, architectural, and intelligence integration**
- **Physical layer technologies**
  - (MIMO) and mmWave - key enablers of 5G networks and provide required QoS
  - 6G will exploit the unused **terahertz band** and **visible light communications (VLC).**

  - **Terahertz Communications**
    - The RF band is nearly exhausted and not enough to fulfill the 6G requirements
    - Enhanced spectral efficiency in 6G - by expanding the bandwidth by using THz bands and massive MIMO
    - **THz communications** characteristics
      - use the bands 100 GHz …10 THz (0.03 mm – 3 mm wavelengths)
      - ITU-R rec. 275 GHz - 3 THz bands for cellular networks
        - THz-related challenges (due to ultrahigh frequencies)
          - propagation loss, molecular absorption at a higher frequency, high penetration loss for solid objects, antenna design complexity
          - Some frequencies in the terahertz spectrum are more sensitive to atmospheric molecular absorption- need selection of bands.
        - In mmWave, the propagation loss can be controlled using the directional antenna arrays

7. 6G architecture and technologies

7.4 6G - Enabling Technologies - summary

- **Optical Wireless Communication (OWC) Technology**
  - **OWC** key enabler for 6G (it is used partially in 4G/5G)
  - Main OWC technologies: light fidelity, optical camera communication, Visible Light Communication (VLC), and Free Space Optical (FSO) communication
  - OWC - potential to provide ultra-throughput and very low latency
  - **VLC**
    - is proposed to support RF communications using the LED- modulated in intensity
    - IEEE 802.15.7 standard is proposed for VLC, yet not been adopted by 3GPP.
    - It is short-range, requires an illumination source for communication, sensitive to other source, mostly recommended for indoor environments

- **Novel Channel Estimation Techniques**
  - For cellular networks, advanced channel estimation for beam tracking is an important element for UHF
  - In the mmWave domain, design challenges exist for channel estimation techniques due to complex antenna architectures
  - Recent solution- out-of-band estimation, with improvement in the reactiveness of beam management schemes

Source: M.S. Akbar, et. al., 6G Survey on Challenges, Requirements, Applications, Key Enabling Technologies, Use Cases, AI integration issues and Security aspects, arXiv:2206.00868v1 [cs.NI] 2 Jun 2022

7. 6G architecture and technologies

7.4 6G - Enabling Technologies - summary

- **Sensing and Network-Based Localization**
  - 6G - integrated interface to support localization and mapping mechanisms with enhancement in control operations, less interference and novel services for special applications. (e.g., eHealth)

- **Advanced Multiple-Input-Multiple-Output (MIMO)**
  - 6G- MIMO for geographical coverage and spatial multiplexing boosting the spectral efficiency

- **Full-Duplex Communication-issues**
  - Full-duplex in cellular networks uses innovative design of self-interference suppression circuits
    - by improving the antenna design and circuit which reduces the cross-talk between receiver and transmitter
    - enhancing the multiplexing capabilities of the existing cellular systems throughput

Source: M.S. Akbar, et. al., 6G Survey on Challenges, Requirements, Applications, Key Enabling Technologies, Use Cases, AI integration issues and Security aspects, arXiv:2206.00868v1 [cs.NI] 2 Jun 2022

7. 6G architecture and technologies

7.4 6G - Enabling Technologies - summary

- **6G Architectural enablers**

- **Network virtualization**
  - The virtualization can be implemented at functional layers L1, L2 or L3.
  - It will reduce the management burden from HW in a cost-effective way
  - SDN, NFV – used in management and control
  - Centralized virtual controller, responsible for the policy and data forwarding

- **Cell-less architecture and tight Integration of multiple frequencies**
  - The 6G will create a strong relationship between cells and UEs in a cell-less architecture
  - Solution: dual-band techniques with multiple radios
  - Advantages
    - high mobility support with fewer overheads
    - higher user capacity by seamlessly transitioning to multiple heterogeneous links (e.g., to identify the best channel) without any prior configurations
- **3D network heterogeneous architecture**
  - Drones and satellites will use this architecture to improve related QoS
  - Heterogeneous communication architectures could be easily deployed in rural and disaster areas

7. 6G architecture and technologies

7.4 6G - Enabling Technologies - summary

- **6G Architectural enablers**
- **Advanced Access-Backhaul Network (Free Space Optical - FSO) Integration**
  - To provide ultrahigh data rates which also require sufficient expansion of backhaul capacity
  - Future VLC and THz implementations will use a massive number of devices, which need backhaul connectivity with the core network and neighboring nodes

  - FSO typically uses very narrow spectrum laser beams as carrier signals that provides high speed data communication between two fixed nodes over distances up to few kilometers, inherent security (i.e., light is confined in a zone), large reuse factor and immunity to electromagnetic interference with other communication equipment
  - FSO can be operated by using VL and UV spectra and do not require illumination

  - At remote geographical locations (e.g., sea, space and underwater), optical fibre cannot be used as a backhaul network.
    - FSO backhaul network is a potential communication system
    - FSO performs like an optical fibre network and provides similar communication services

7. 6G architecture and technologies

7.4 6G - Enabling Technologies - summary

- **6G Architectural enablers**

- **Energy harvesting for low-power consumption Network**
  - Energy is extracted from external sources (solar, thermal, wind, and kinetic energy, etc.), and then preserved for wireless autonomous devices
  - As 6G networks deal with a massive number of interconnected smart devices (e.g., IoT devices) that require energy resources to keep the device alive
  - There is still a need to identify the suitable energy-efficient mechanisms for such devices

- **Blockchain**
  - Blockchain efficiently manages huge datasets (e.g., for IoT) by using the of distributed ledger technology
  - A distributed ledger's database operates in a distributed manner by using various nodes
  - Every node replicates a copy of the ledger
  - The nodes can work independently without involving a centralized node
  - The data is managed in the form of blocks that are connected securely
  - The blockchain can manage huge data (e.g., involved in IoTs-based systems)

7. 6G architecture and technologies

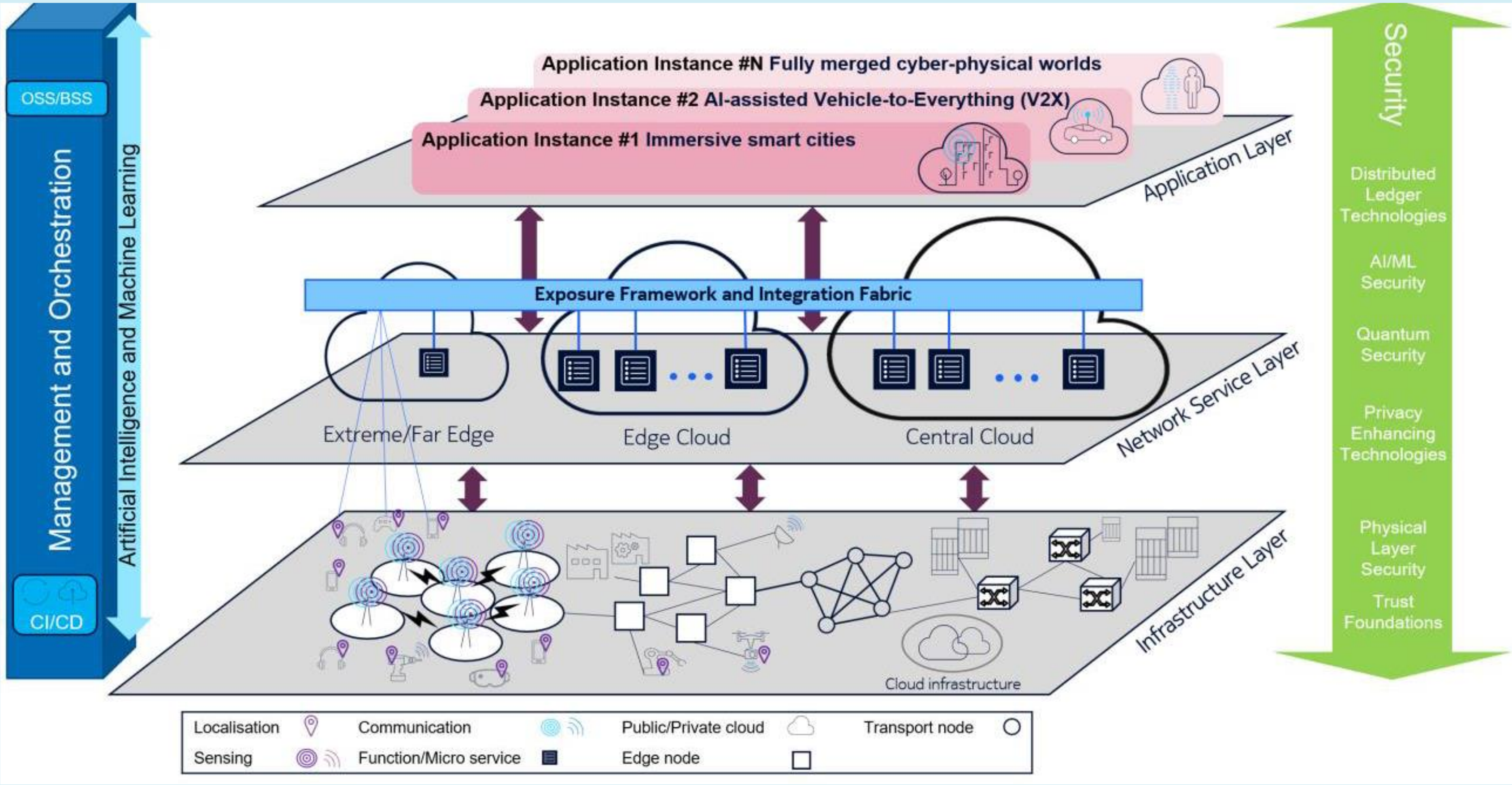
7.4 6G - Enabling Technologies - summary

- **6G Architectural enablers**
- **Integration of wireless information and energy transfer** (WIET)
  - innovative technology usable in for 6G networks
  - utilizes the wireless spectrum for communication
  - can be very useful for battery-less devices
  - the 6G BSs will be used for transferring power as WIET uses the same fields and waves used in communication systems. WIET
  - will allow the development of battery-less smart devices, charging wireless networks, and saving the battery life-time of other devices
- **Artificial Intelligence in 6G**
  - 5G only integrates partial AI/ ML techniques
  - in 6G networks, AI and ML will be fully integrated
  - **Unsupervised (UL) and Reinforcement Learning (RL)** –major candidates for 6G networks
  - Reason:
    - Big data will be generated in 6G
    - It is difficult to assign labels as required in **supervised learning**
      - **UL and RL in cooperation** could produce efficient autonomous systems
  - **Supervised learning** techniques are also proposed

7. 6G architecture and technologies

7.5 6G – layered architecture

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

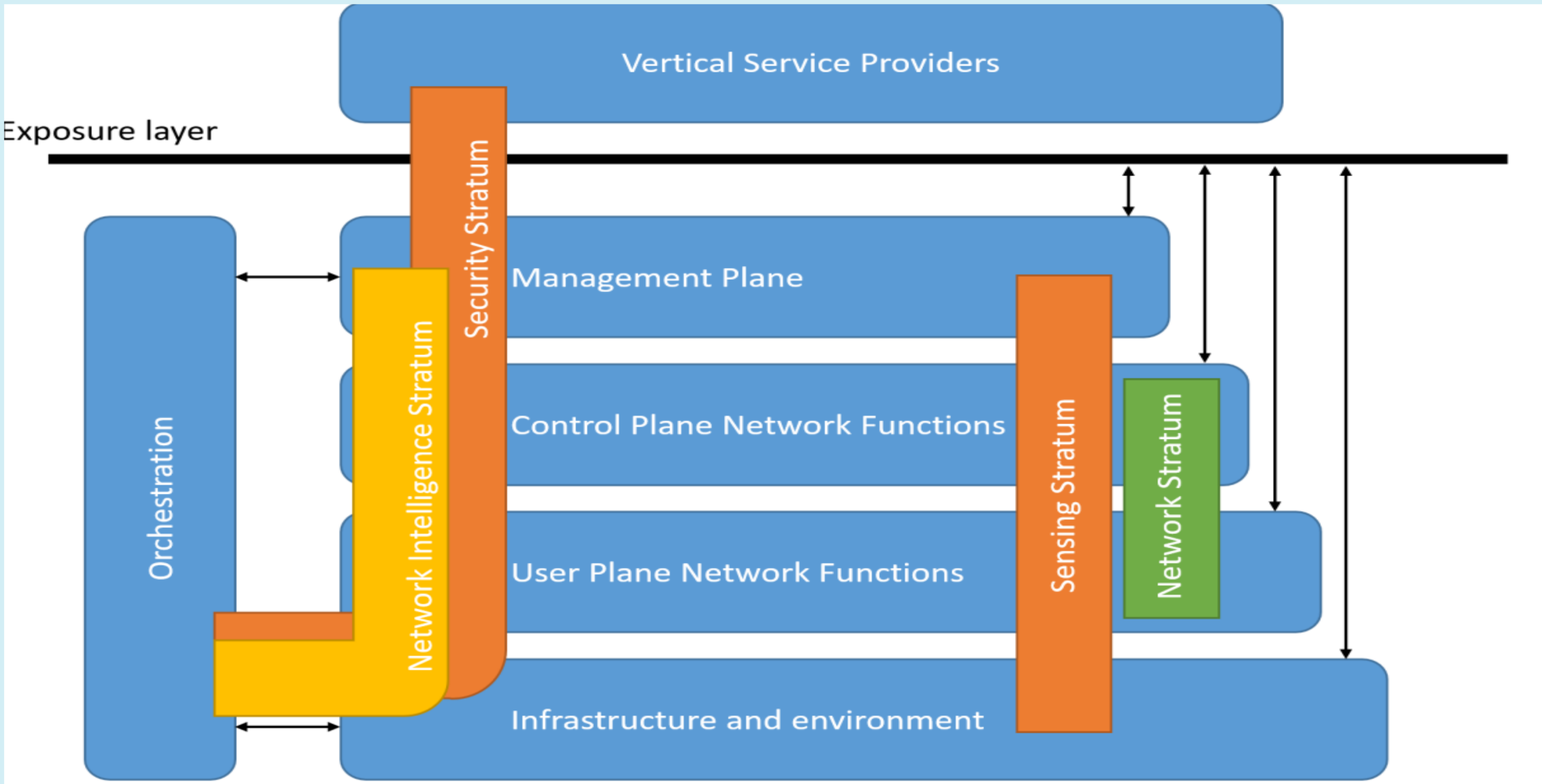


Source: 5G PPP Architecture Working Group: The 6G Architecture Landscape, 2023
Source: Hexa-X Deliverable D1.3, "Targets and requirements for 6G – initial E2E architecture", Mar. 2022, https://hexa-x.eu/wp-content/uploads/2022/03/Hexa-X_D1.3.pdf.

7. 6G architecture and technologies

7.5 6G –layered architecture

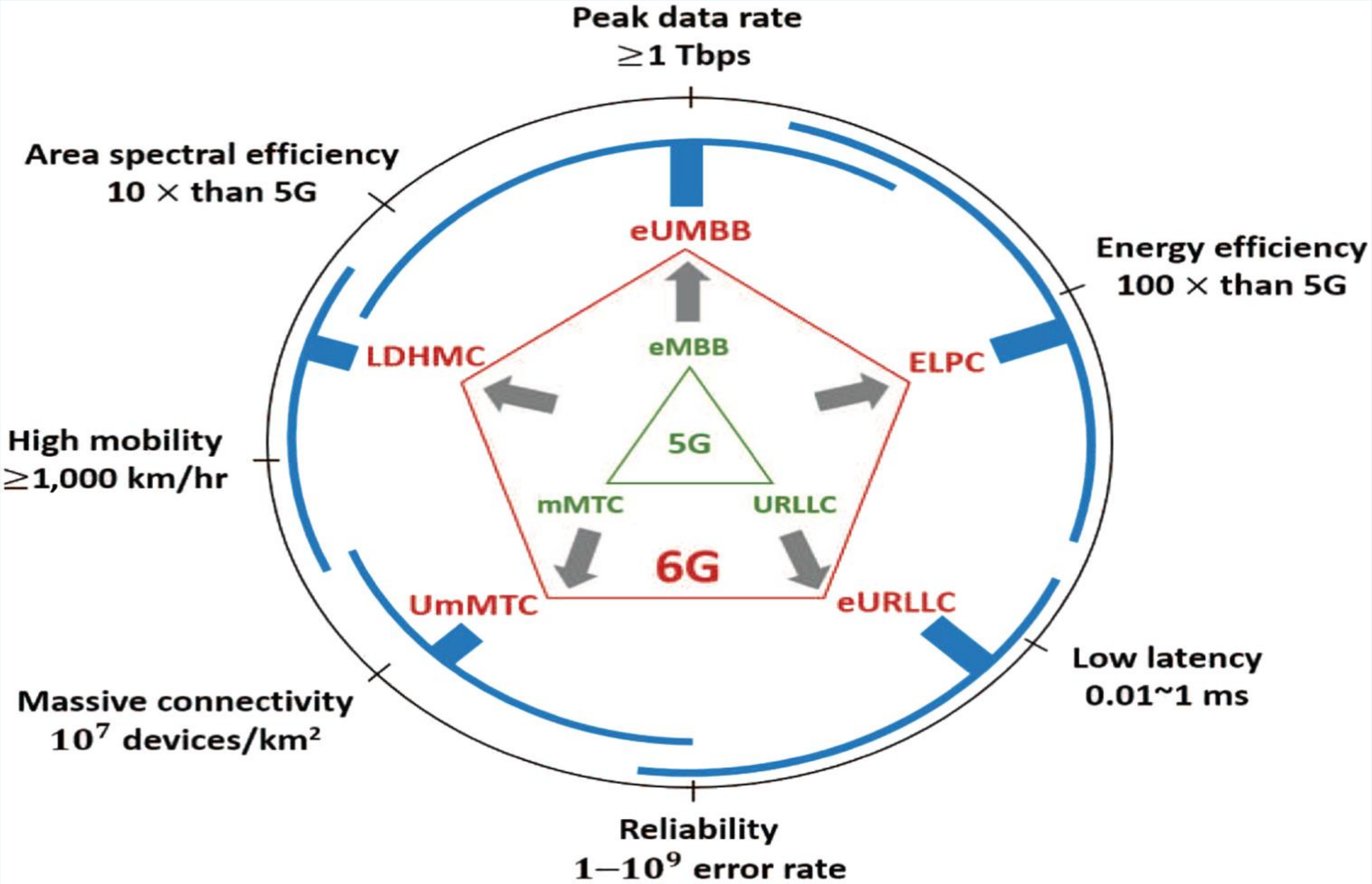
- **Multi-plane view of the 6G layered architecture**



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.

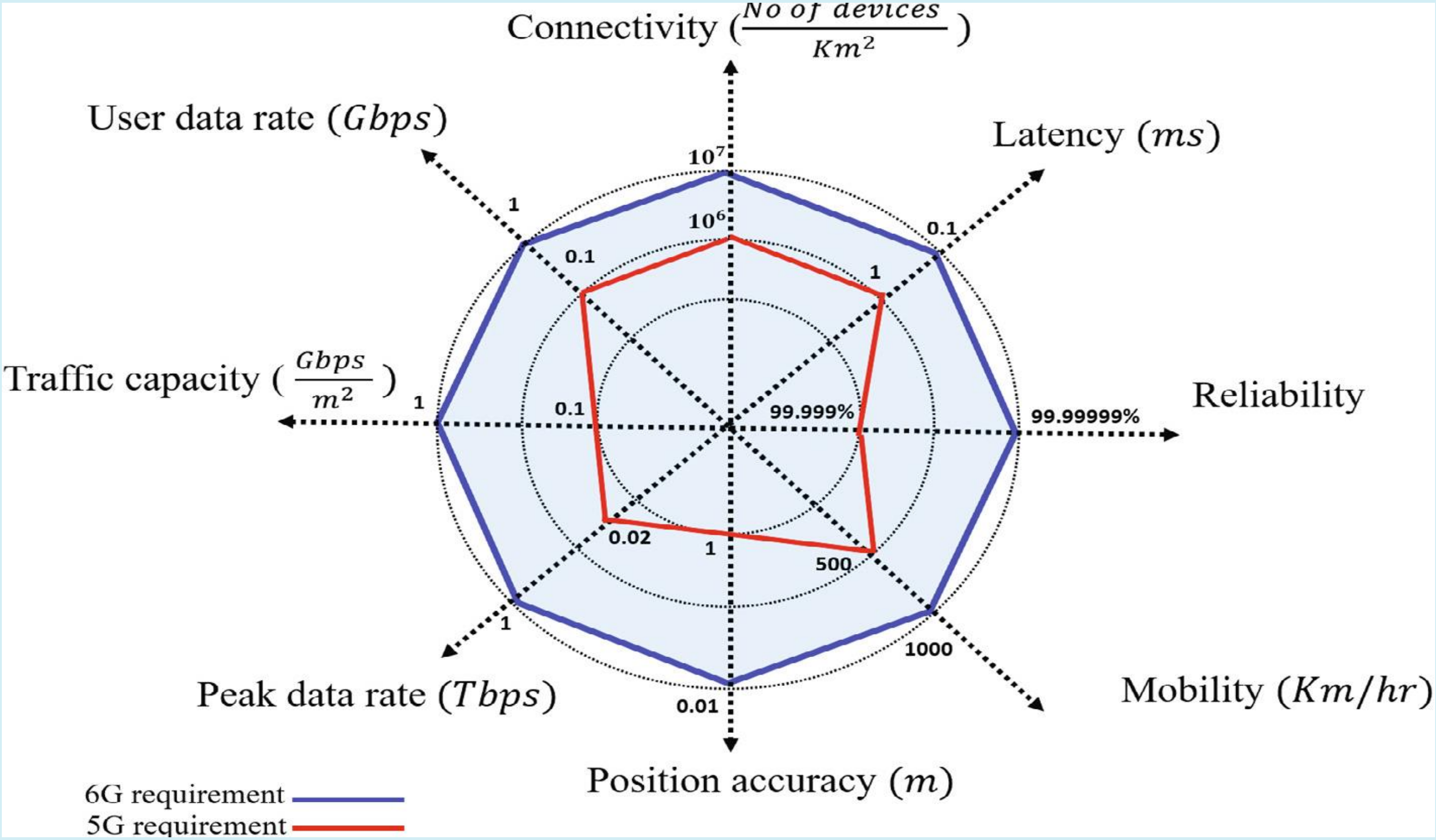
7. 6G architecture and technologies

7.6 6G versus 5G in terms of connectivity capabilities



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

7.6 6G versus 5G in terms of connectivity capabilities



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

7. 6G architecture and technologies

7.7 Specific aspects

6G - Enabling Technologies for Advanced Network Architectures

- **Software Defined Networking and Network Function Virtualization (SDN/NFV)**
- **SDN and NFV cooperation in 6G**
  - **Hybrid SDN - concept**
    - both **centralized and decentralized paradigms** coexist and communicate together to different degrees to configure, control, change, and manage network behavior for optimizing network performance and user experience
    - **management of heterogeneous infrastructure** and interaction between several networks is important
    - introduction of AI allows increased automation of SDN networks
  - **NFV**
    - key enabler for 5G (**network virtualization** in the RAN, access, transport, core)
    - provide infrastructure for **network slicing** (multiple virtual networks to support different RANs or various services)
    - enable the 5G networks to support **serviced-based architecture** by dynamically creating **service chains**
    - makes the 5G networks elastic and scalable, improves the agility and simplifies the management
    - **All the above NFV features are also valid in 6G**

7.7 Specific aspects

6G - Enabling Technologies for Advanced Network Architectures

- **Challenges for Network slicing in 6G**
  - **(1) Slice isolation- important property of network slicing**
    - to guarantee the QoS in each slice: different areas of isolation should be realized, including traffic, bandwidth, processing, and storage
    - the main challenge is the M&C; it needs to accommodate different isolation techniques in different domains and operators
    - there is not yet a final standardized network slice architecture
    - the isolation techniques significantly rely on the SDN and NFV technologies, which are not yet fully mature
  - **(2) Dynamic slice creation and management**
    - efficient **dynamic (on demand)** slice creation and deletion is necessary
    - **creation or deletions** of slices must **have no effect on the currently running** slices, which involves the isolation and security issues
    - the network slices should be able **to scale dynamically** with the varying load
    - **efficient resource sharing** is needed → issues like isolation and security
    - the **lifecycle management (LCM)** of network slices is a critical problem
      - LCM in multi domain, multi-tenant and multi-operator environment is still a challenge

7. 6G architecture and technologies

7.7 Specific aspects

6G - Enabling Technologies for Advanced Network Architectures

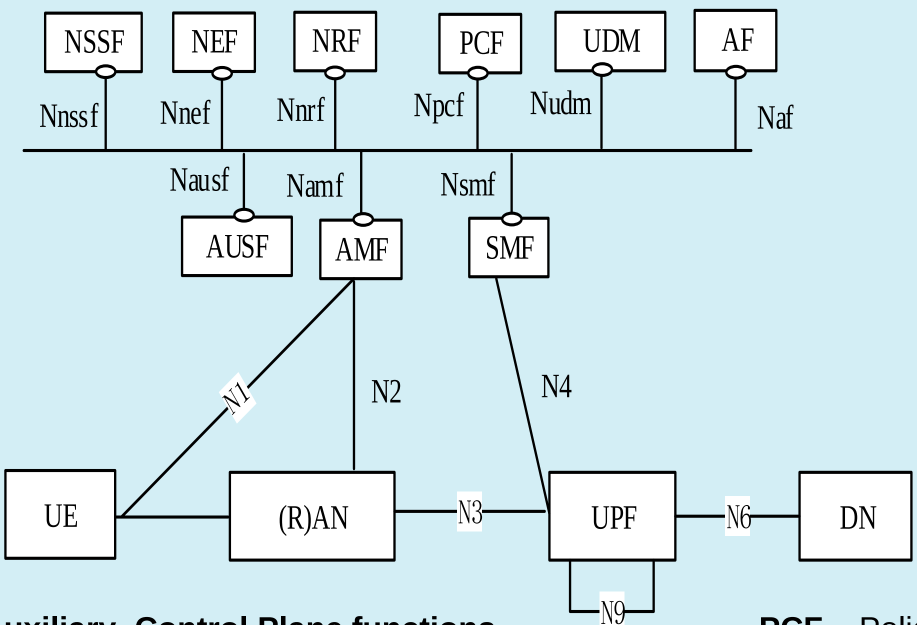
- **Service Based Architecture (SBA)-usage in 6G**
  - The SBA is based on: cloud computing, virtualization, microservice, stateless service, etc.
    - **Cloud computing** provides on-demand computing to the SBA
    - **Virtualization** -flexible and efficient resource management and usability
    - **Microservice -** useful architectural design pattern: the network is divided into small-granularity, highly cohesive, and loosely coupled services
      - Each service can realize a specific functionality
      - A microservice can enable the SBA with flexibility, granularity, and independent scaling
  - **SBA challenges in 5G and 6G**
    - The SBA enables network functions of the SBA to securely communicate
      - within the serving network domain
      - with other network domains
      - E.g., for: network function registration, discovery and authorization security aspects, and protection for service-based interfaces
    - SBA domain security is a new security feature in 5G and 6G
    - To ensure security between UEs in the SBA, security mechanisms such as transport layer security and open authorization are needed

7.7 Specific aspects

6G - Enabling Technologies for Advanced Network Architectures

- **Service Based Architecture (SBA)- 3GPP 5G functional architecture** (cont'd)
  - **Non-roaming reference arch. Service-based interfaces are used within the Control Plane**

Source: 3GPP TS 23.501 V15.2.0 (2018-06), System Architecture for the 5G System; Stage 2, (Release 15)



Notations:

Data Path

UE User Equipment

(R)AN (Radio) Access Network

UPF User Plane Function

DN Data Network e.g., operator services, Internet access or 3rd party services

Control Plane

Main Control Plane functions

AUSF Authentication Server Function

AMF Access and Mobility Mgmt. Function

SMF Session Management Function

Auxiliary Control Plane functions

UDSF Unstructured Data Storage Function

NEF Network Exposure Function

UDR Unified Data Repository

SEPP Security Edge Protection Proxy

PCF Policy Control Function

NSSF Network Slice Selection Function

NRF Network Repository Function

UDF Unified Data Management

NWDAF Network Data Analytics Function

7. 6G architecture and technologies

7.7 Specific aspects

6G - Enabling Technologies for Advanced Network Architectures

- **Service Based Architecture (SBA)- and Cognitive Service Architectures (CSA)** (cont'd)
  - The SBA of 5G core network is based on coarse-grained configuration
    - It lacks real-time perception and dynamic adaptation to the change of service demand
  - The **SBA of 6G core network is** significantly based on **cognitive function (**CSA)
  - **CSA features; SBA allows to:**
    - recognize target behaviors, scene semantics and user characteristics
    - adaptively adjust the network services through the unified service description method
  - **Needed: a cognitive interface, a lightweight learning agent, and a distributed service analyzing module**
    - The **cognitive interface**, supports the ability of situation cognition and can perceive the change of service demand in a fine-grained way
    - The **lightweight learning agent** makes decisions according to gained information by rule matching or approximate reasoning
    - Simultaneously, the **distributed service analyzing** module evaluates the service running state and provides a reference for the decision making of a lightweight learning agent
  - CSA implements a **complete cognitive closed loop** of perception, decision-making, and evaluation
  - **CSA can get strong support from AI**

7. 6G architecture and technologies

7.7 Specific aspects

6G - Enabling Technologies for Advanced Network Architectures

- **Service Based Architecture (SBA)- and Cognitive Service Architectures (CSA)** (cont'd)
  - **6G core network functions will migrate to the edge of the network (i.e., edge core)**
  - 6G core network (CN) will leverage edge computing to form a multi-center architecture to provide efficient, flexible, ultra-low delay, and ultra-large capacity network services
  - The original 5G CN running in the cloud will no longer directly participate in the control of the network
    - It just helps edge cores to communicate with each other
    - The network response delay is reduced
    - The network management flexibility is improved
    - The CSA will realize the whole network coverage from the core network to the UE
      - So, the UE can adopt a variety of communication modes and can switch seamlessly if needed
      - Edge core supports service adaptation, migration, collaboration, and evolution through **distributed service agents** running in edge core
  - **Edge core discovers migration requirements and** completes migration decisions through service cognition and invokes various modules through the north interface of the network layer to realize various processes such as state data transmission, cell handover, and user session switching
  - The whole process ensures low delay and transparency for users

7.7 Specific aspects
6G - Enabling Technologies for Advanced Network Architectures

- **Cell-free (CF) Architectures**
- **Why cell free?**
  - A cellular topology limitation : **boundary effect**- the users at the cell boundary receive weak signal (due to path loss) and experience strong interference from other cells
    - that was acceptable in the past and current mobile networks
  - In beyond **5G and 6G systems**, the **high data rate** demand causes **ultra-densified and heterogeneous BSs/APs deployment**
  - The cell coverage is smaller and the distance between BSs/APs is ~ tens of meters
  - Such **densification → more interference**; the boundary effect is a main bottleneck of cellular systems; it cannot be solved by any technology
  - Despite techniques as MIMO, CoMP with joint transmission, and distributed antenna systems, the ability to overcome this bottleneck is limited

7. 6G architecture and technologies

7.7 Specific aspects

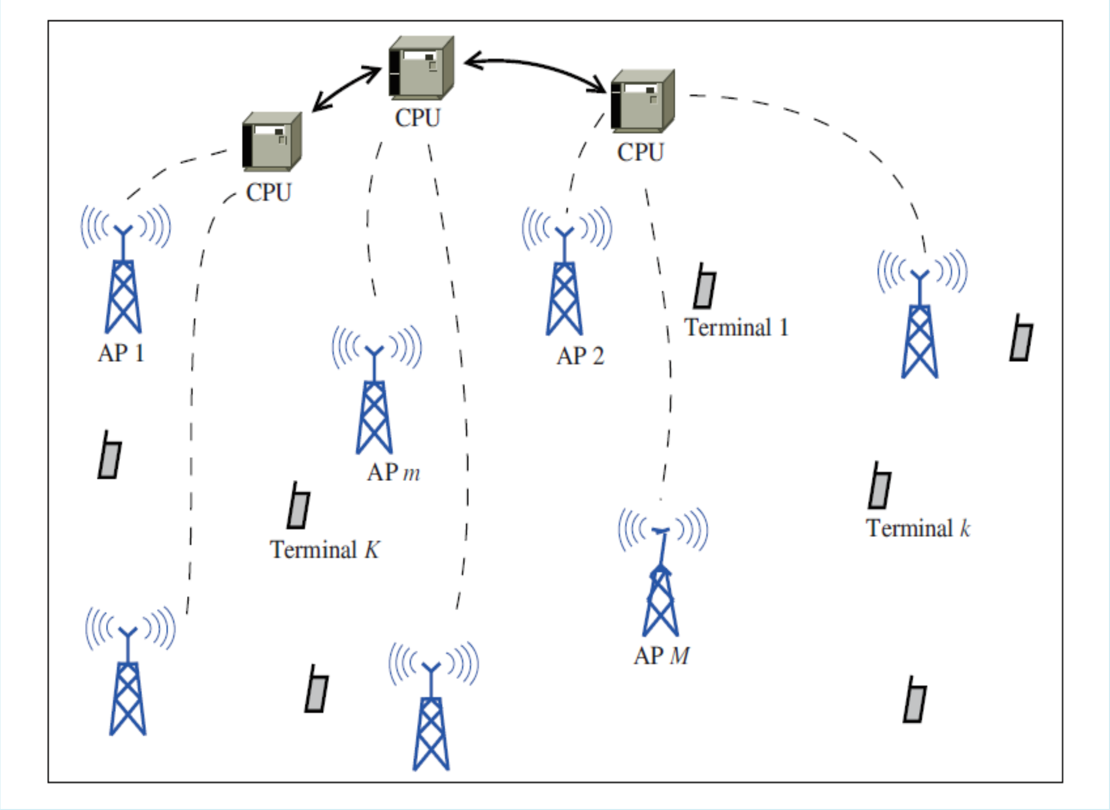
6G - Enabling Technologies for Advanced Network Architectures

- **Cell-free (CF) Architectures** (cont'd)
  - **Possible solution:**
    - The **CF (or cell-less) massive MIMO networks** is a practical and scalable version of network MIMO (next slide figure)
    - Many **APs jointly serve many user terminals** in the same time frequency resources
    - All APs are distributed in a large area (e.g., the whole city) and connected to one or several CPUs
    - In such a network, a terminal can decide to access several BSs/APs via different Uls and DLs and downlinks depending on the wireless channel status and its demands
    - The BSs/APs do not need to maintain a list of associated terminals
      - Instead, the associate control in a SDN controller will decide which BSs/APs the terminals should be associated via the control link

7.7 Specific aspects

6G - Enabling Technologies for Advanced Network Architectures

- **Cell-free (CF) Architectures** (cont'd)
  - The Tx control in 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 for a specified terminal
  - **CF massive MIMO benefits:**
    - High network connectivity (coverage probability)
    - Huge spectral and energy efficiency
    - Simple linear signal processing and low-cost devices
  - **Open research issues:**
    - Scalable signal processing
    - Scalable power control



Source: 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

7. 6G architecture and technologies

7.7 Specific aspects

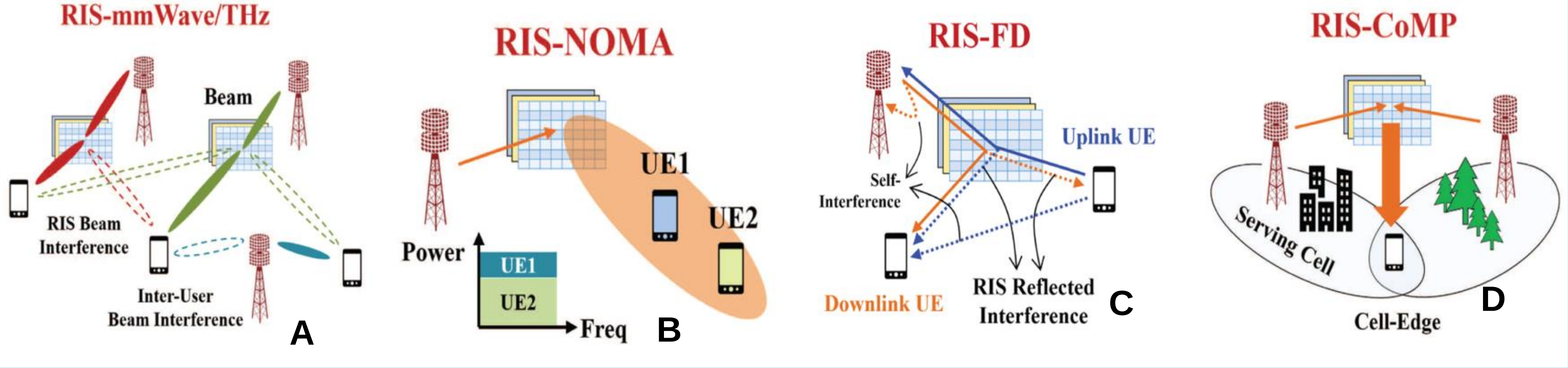
- **Non-Orthogonal Multiple Access (NOMA)**
  - **OMA- Orthogonal multiple access) –**traditional methods -FDMA, TDMA, CDMA
    - main benefit - no interference among users; hence low-complexity detectors with linear complexity can separate the different users' signals
    - OMA limitation: the maximum number of supportable users is restricted
  - **NOMA - can support a higher number of users** than the number of orthogonal resource slots, with the aid of non-orthogonal resource allocation
    - **Solution: sophisticated inter-user interference cancellation** at the cost of an increased receiver complexity
    - **main NOMA** schemes categories: **power-domain** and **code-domain NOMA**
  - **Power-domain NOMA**
    - different users are assigned different power levels according to their channel quality
    - the **same time-frequency-code resources are shared** among multiple users
    - At the receiver side, it is exploited the users' power-difference, in order to distinguish different users based on successive interference cancellation (SIC).
  - **Code-domain NOMA**
    - similar to CDMA or multi-carrier CDMA (MC-CDMA), except for its preference for using low density sequences or non-orthogonal sequences having a low cross-correlation

Source: L. Dai, et.al., , A Survey of Non-Orthogonal Multiple Access for 5G
IEEE COMM. SURVEYS & TUTORIALS, VOL. 20, NO. 3, 2018

7. 6G architecture and technologies

7.7 Specific aspects

- **Reconfigurable Intelligent Surfaces (RIS)**
  - It **extends the coverage area**, reduces the power consumption, enhances the data rates
  - RIS is composed of numerous metamaterial elements, which can reflect the received waves, while adjusting their phases **without complex signal processing**
- **RIS-empowered mmWave/THz** transmissions
  - The fixed BS can beamform its mmWave/THz signals to the RIS, which may reflect them to arbitrary transmit directions (**Figure A**)
  - RISs may circumvent blocking the line-of-sight (LOS) paths of mmWave/THz carriers
  - But they create extra interference, which should be managed
  - **Solution**: to jointly design the active beamforming at the BS and the passive phase shift-based beamforming at the RIS to meet different requirements



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 (February 2023), https://doi.org/10.1145/3571072

7. 6G architecture and technologies

7.7 Specific aspects

- **Reconfigurable Intelligent Surfaces (RIS)** (cont'd)
- **RIS-empowered multiuser** transmissions
  - ***RIS-NOMA*** schemes impose extra interference due to the superposed signals of the 3D resource domains
    - The RIS –NOMA (**Figure B)** can generate specific channel features for readily distinguishing the overlapped NOMA signals
    - RIS-NOMA can extend the coverage area to provide services for distant cell-edge users; Open issue: joint design of the different resource NOMA domains and RIS
  - ***RIS-FD*:**
    - As for FD transmission, RISs can adjust their phase shifts to cancel or alleviate the self-interference of FD, where the UL and DL signals may become orthogonal in terms of their directions **(Figure C)**
    - The RISs are intrinsically operated at FD which directly reflect arbitrary incident signals (the FD trs. indicates the co-existence of two transmission directions including DL signals (i.e., BS to UE) and simultaneous UL access)
    - Additional interference emerges from the RISs, which should be jointly considered in RIS-FD design
    - Achievement- higher area spectral efficiency than conventional FD with no RIS

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 (February 2023), https://doi.org/10.1145/3571072

7. 6G architecture and technologies

7.7 Specific aspects

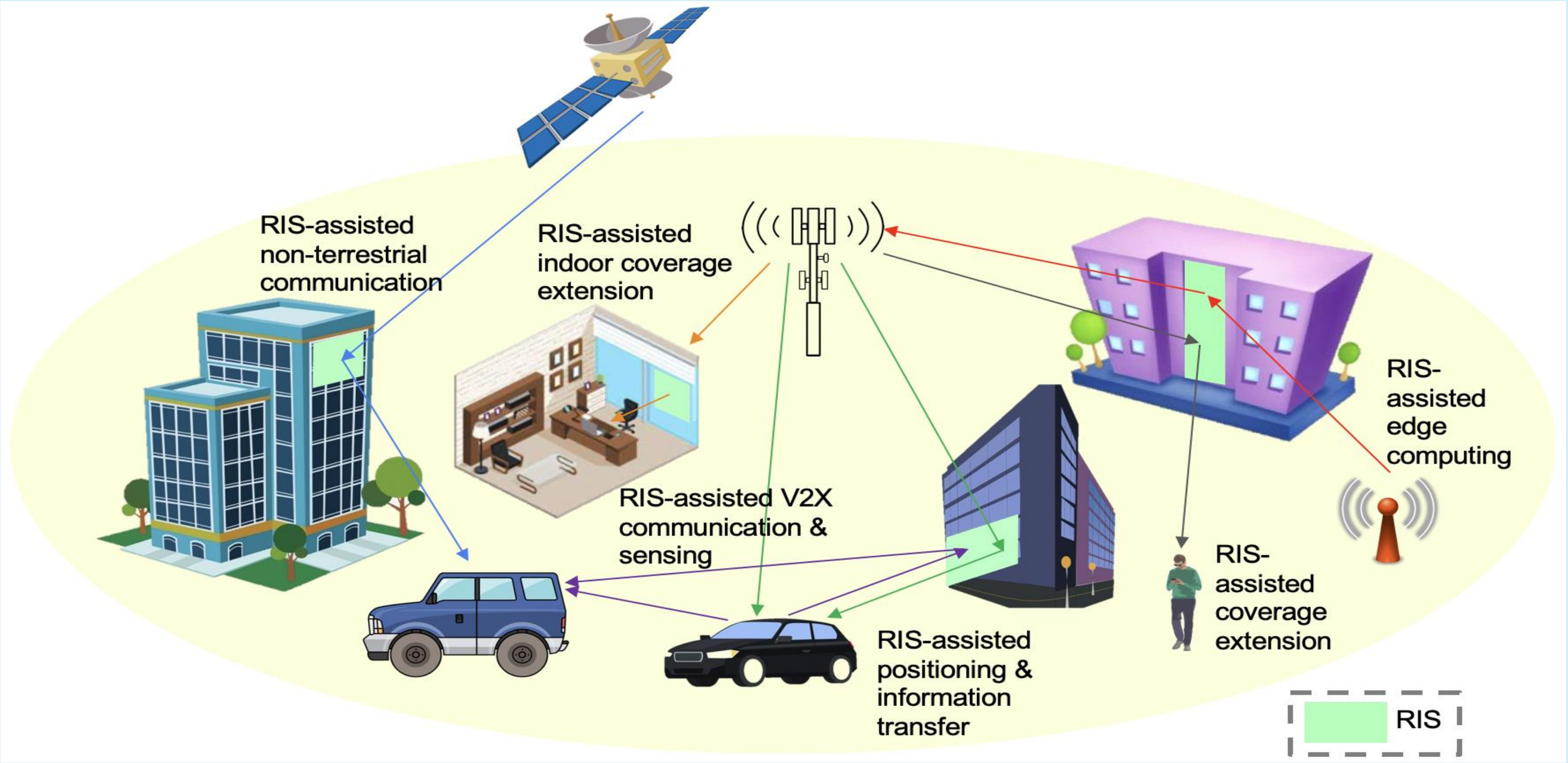
- **Reconfigurable Intelligent Surfaces (RIS)** (cont'd)
- **RIS-empowered multiuser** transmissions (cont'd)
  - ***RIS-CoMP***
    - **Conventional Coordinated Multi-Point (CoMP)** improves the low signal quality of cell-edge users
      - by turning the interference into useful source of desired signal energy with aid of RIS-CoMP (Figure D)
  - The transmitter dissipates less power than conventional CoMP
  - CoMP-RIS should be jointly designed for improving the area spectrum/energy efficiency Open issues still exist (BS backbone bottlenecks, channel estimation and synchronization, etc.)
  - It is not possible to perfectly synchronize an user equipment (UE) with more than one BS

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 (February 2023), https://doi.org/10.1145/3571072

7. 6G architecture and technologies

7.7 Specific aspects

- **Reconfigurable Intelligent Surfaces (RIS)** (cont'd)
- Anticipated typical use cases of RISs



Source: Wanshi Chen, et al., 5G-Advanced Towards 6G: Past, Present, and Future arXiv:2303.07456v1 [cs.IT] 13 Mar 2023

7. 6G architecture and technologies

7.7 Specific aspects

AI/Machine Learning in 6G

AI/ML Terminology

A2C	Actor-Critic
AEs	Auto Encoders
ANN	Artificial neural network
KNN	*k*-nearest neighbor
CAT	Channel-aware Transmission
CNN	Convolutional neural network
DDPG	Deep deterministic policy gradient
DNN	Deep neural network
DRL	Deep reinforcement learning
DQN	Deep Q network QL
EM	Expectation-maximization
FCM	Fuzzy C-means
FL	Federated learning
GAN-DDQN	Generative adversarial network - deep distributional Q network
GNN	Graph neural network
HMM	Hidden Markov model
IRL	Inverse reinforcement learning
LDA	Latent Dirichlet Allocation
LSTM	Long short-term memory
ML-CAT	Machine Learning CAT
pCAT	Predictive CAT
PCA	Principal component analysis
PG	Policy Gradient
PPO	Proximal Policy Optimization
QL	Q learning
RBM	Restricted Boltzmann Machine
RL	Reinforcement learning
RNN	Recurrent neural network
SARSA	State–action–reward–state–action
SVM	Support vector machine
SOM	Self-Organizing Maps

7. 6G architecture and technologies

7.7 Specific aspects

- **Machine Learning in 6G**
  - Many ML techniques are candidates to support 6G functionalities
  - ML has been used partially also in 5G systems
- ***Types of ML - summary***
- **Supervised Learning (SLn) -**mostly used for classification and regression problems
  - **trained using a labeled data-set**

  - ***Examples of typical SLn algorithms***
    - **Artificial Neural Networks (ANN)** applied also for Uln and RL
    - Extensions/variants of ANNs
      - **Deep Neural Network (DNN)/Convolutional Neural Networks (CNN)**
      - **Recurrent Neural Network (RNN)** with variant **Long Short Term Memory** (LSTM)
    - Others: **support vector machine (SVM), k-Nearest Neighbor (kNN), naive Bayes, random forest, decision tree**

Source: Anita Patil, Sridhar Iyer, Rahul Jashvantbhai Pandya. Machine Learning Algorithms for 6G Wireless Networks: A Survey. https://www.researchgate.net/publication/359277495

Source: Nei Kato, Bomin Mao, Fengxiao Tang, Yuichi Kawamoto, and Jiajia Liu,Ten Challenges in Advancing Machine Learning Technologies toward 6G, IEEE Wireless Communications • June 2020, Digital Object Identifier:10.1109/MWC.001.1900476

7. 6G architecture and technologies

7.7 Specific aspects

- **Machine Learning in 6G** (cont'd)
- ***Types of ML – summary (cont'd)***
- **Unsupervised Learning (ULn)**
  - they **are given a set of unlabeled data** to correctly predict the output
  - mostly used for clustering and aggregation, but possibly for regression problems
  - ***Examples of typical ULn algorithms***
    - **K-means, Self-Organizing Maps (SOMs), Hidden Markov Model (HMM), Auto Encoders (AEs), Generative Adversarial Network (GAN), Principal Component Analysis (PCA), Restricted Boltzmann Machine (RBM), fuzzy C-means** etc.
  - Some ULn machines can enhance the performance of **Deep Learning (DL)** algorithms such as CNNs and LSTM algorithms
- **DL** use a cascade of multiple layers of nonlinear processing units for feature extraction and transformation. Each layer uses the output from the previous layer as input
  - learn in SLn (e.g., classification) or Uln and/or unsupervised (e.g., pattern analysis) manners
  - learn multiple levels of representations that correspond to different levels of abstraction; the levels form a hierarchy of concepts

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 (February 2023), https://doi.org/10.1145/3571072

Source: Vasileios P. Rekkas et al., Machine Learning in Beyond 5G/6G Networks—State-of-the-Art and Future Trends, Electronics 2021, 10,2786. https://doi.org/10.3390/electronics10222786

7. 6G architecture and technologies

7.7 Specific aspects

- **Machine Learning in 6G** (cont'd)
- ***Types of ML – summary*** *(cont'd)*
- **Reinforcement Learning (RL)**
  - **based on a feedback** performance indicator **(reward**) conceived from the model's environment; the model pursues the ideal performance of the output by maximizing the indicator of the reward
  - RL - **trial and error procedure**: an **agent** interacts with the environment and based on whether the action tried was good or bad, gets feedback in terms of reward or penalty
    - **The software agents** take actions in an environment so as to maximize the cumulative reward.
  - **RL is a hybrid of SLn and Uln**: indirect supervision is used for the model to understand and learn the ideal system's performance; there is no available training dataset paired with the desired output
  - ***Examples of typical RL algorithms***
    - **value-based** (e.g., Q-learning, SARSA)
    - **policy-based** algorithms, e.g., **Policy Gradient (PG), Proximal Policy Optimization (PPO) and Actor-Critic (A2C)**
    - **Deep Reinforcement Learning (DRL), e.g., Deep Q network (DQN) Deep Deterministic Policy Gradient (DDPG)**
      - DRL = RL + DL; RL defines the objective; DL gives the mechanism

7. 6G architecture and technologies

7.7 Specific aspects

- **Machine Learning in 6G** (cont'd)
- ***Types of ML – summary*** *(cont'd)*
- **Federated Learning (FL)**
  - In a typical training cycle of FL, a dedicated edge server initially broadcasts a global machine-learning model to participating edge devices
  - Then the edge devices utilize their local data to calculate their respective model updates and transfer them to the edge server for further aggregation and
  - global model updates.
  - The FL training process is carried out iteratively in multiple communication rounds.
  - The dataset of *N* edge devices is { *D*1, *D*2, *D*3,⋯, *DN* }

  - The traditional method is to upload the dataset and train the model in the central server, whereas FL coordinates the local training of many data users through the network to update the parameters interactively with the global model on the server side

  - It cooperatively optimizes the common objective function to obtain the final ML model

Source: ZHAO Moke, HUANG Yansong, LI Xuan, Federated Learning for 6G: A Survey From Perspective of Integrated Sensing, Communication and Computation, 2023, DOI: 10.12142/ZTECOM.202302005 https://kns.cnki.net/kcms/detail/34.1294.TN.20230516.1539.004.html,

7. 6G architecture and technologies

7.7 Specific aspects

- **Machine Learning in 6G** (cont'd)
- **ML potential applications in 6G**
- **Supervised Learning**
  - **Physical ,data link and network layers**
    - Optimum UM-MIMO beamforming for mmWave/THz (DNN, CNN)
    - Device-free positioning and detection sensing (KNN, RNN, LSTM)
    - Channel estimation (DNN, CNN, ARN)
    - Adaptive bit allocation (DNN)
    - Beam selection (KNN & SVC)
    - Beam prediction (DNN, GRU)
    - RSS prediction (ANN)
    - Path loss (Random Forest, KNN)
  - **Traffic management**
    - Channel and traffic classification and prediction (SVM, LDA, Bayesian)
  - **Mobility**
    - Trajectory prediction (CBTL, Deep CNN)
    - Mobility-based handover mechanism (SVM, LDA LSTM)

7. 6G architecture and technologies

7.7 Specific aspects

- **Machine Learning in 6G** (cont'd)

- **ML potential applications in 6G** (cont'd)
- **Supervised Learning** (cont'd)
  - **General management**
    - Caching (ANN, DNN)
    - Fault detection (Support Tucker Machine)
    - Automatic management of integrated 6G RAT (GNN, Decision Tree)
  - **Data processing**
    - Big data processing for IoT (DNN, CNN, RNN, LSTM)
  - **Multi-domain and multi-services**
    - Services 6G multi-network and multi-service optimization (DNN, GNN)
  - **Security**(ANN, LSTM, CNN)
  - **Cyber Security** (SVM)

Source: Vasileios P. Rekkas et al., Machine Learning in Beyond 5G/6G Networks—State-of-the-Art and Future Trends, Electronics 2021, 10,2786. https://doi.org/10.3390/electronics10222786

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7.7 Specific aspects

- **Machine Learning in 6G** (cont'd)
- **ML potential applications in 6G** (cont'd)
- **Unsupervised Learning**
  - **Physical, data link and network layers**
    - Wireless channel detection and generation (SVD, Autoencoder, GAN)
    - Grant-free transmissions (HMM, EM)
    - 6G network function and BS deployment (K-means)
    - Power allocation (K-means)
    - D2D systems optimization (PC algorithms)
    - Modulation recognition (CNN, LSTM)
    - Channel estimation (DetNet, LSTM)
    - Unlicensed spectrum sensing (HMM, EM)
    - MIMO Sum rate (DNN)
  - **Mobility**
    - User's mobility estimation (Discrete Markov chain model
    - User's location (HMM)
    - High-precision trajectory tracking (K-means, HMM)

See also the 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 (February 2023), https://doi.org/10.1145/3571072

7. 6G architecture and technologies

7.7 Specific aspects

- **Machine Learning in 6G** (cont'd)
- **ML potential applications in 6G** (cont'd)
- **Unsupervised Learning** (cont'd)
  - **Security**
    - Security (Non-parametric Bayesian approach Unsupervised trained DRL, GMM, CNN,SAE)
    - Security and privacy enhancement (Autoencoder, GAN)
  - **Data processing**
    - 6G network data augmentation (GAN)
    - Server data dimension reduction (PCA)
  - **Management**
    - Fault mgmt. (k-means clustering, Fuzzy C-means clustering, LOF, LoOP, Kohonen's SOM)
  - **Traffic**
    - Data rate, traffic load (Unsupervised UE association algorithms)
  - **UAV**
    - UAV Clustering (k-means clustering & Q-learning)
    - UAV location (MLP, LSTM)
  - **Services :** VLC (k-means, CAPD)

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

7. 6G architecture and technologies

7.7 Specific aspects

- **Machine Learning in 6G** (cont'd)
- **ML potential applications in 6G** (cont'd)
- **Reinforcement Learning**
  - **Physical, data link and network layers**
    - Transmission and traffic scheduling (Q learning, DQN, DDPG, Monte Carlo)
    - Enhanced 6G RRM for diverse tele-traffic demands (DQN, DDPG, Monte Carlo)
    - Network power control based on wireless experts' experience (IRL, DDPG)
    - Spectrum allocation (NAAC)
    - Channel selection (Q-learning)
    - Network numerology adaptation (Q learning, DQN, DDPG)
  - **Management**
    - Spectrum allocation per network slice (GAN-DDQN)
    - Resource allocation (Q-learning)
    - Resource management (DRL)
    - Resource allocation, joint user control (Actor-critic)
    - Resource allocation, offloading decision (SAQ-learning,BLA-MAQ algorithm)
    - Cloud/edge computing resource management (Q learning, DQN, DDPG)

Source: Vasileios P. Rekkas et al., Machine Learning in Beyond 5G/6G Networks—State-of-the-Art and Future Trends, Electronics 2021, 10,2786. https://doi.org/10.3390/electronics10222786

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 (February 2023), https://doi.org/10.1145/3571072

7.7 Specific aspects

- **Machine Learning in 6G** (cont'd)
- **ML potential applications in 6G** (cont'd)
- **Reinforcement Learning** (cont'd)
  - **Services**
    - QoS-guaranteed virtual networks (DQN, DDPG)
    - New user contention and accessing schemes (Q learning)
  - **Energy**
    - Energy consumption (Deep Q-learning)
    - Dynamic power allocation (Deep Q-learning)
  - **Data processing**
    - Data rate (RL-CAT, RL-pCAT)
    - Caching (MDP-based algorithm, Deep actor-critic, MAMAB)

Source: Vasileios P. Rekkas et al., Machine Learning in Beyond 5G/6G Networks—State-of-the-Art and Future Trends, Electronics 2021, 10,2786. https://doi.org/10.3390/electronics10222786

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 (February 2023), https://doi.org/10.1145/3571072

CONTENTS

8. 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

8. 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.
  - process big data, generated by massively deployed ubiquitous devices at the edge
    - be 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)

8. Conclusions

- **6G Examples of open research issues**
  - Advanced AI/ML-based wireless networks and communications, unlicensed spectrum access
  - Connectivity: intelligent, deep, ubiquitous, holographic, massive MIMO, new multiuser transmission
  - 2D, 3D integrated networking
  - Network softwarization, network slicing
  - Architecture: next-generation core, integration access-core, cell-less, service based
  - Advanced AI/ML-based network orchestration, management and control
  - Cloud/Edge/Fog computing, quantum computing
  - Security and privacy at different layers
  - Multiple wireless services
  - 6G support for IoT services
  - 6G support for Internet of vehicles services

- Thank you !
- Questions?

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- **List of Acronyms**

5G CN	Core Network
5G-AN	5G Access Network
5GS	5G System
5QI	5G QoS Identifier
AF	Application Function
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
AS	Access Stratum
AUSF	Authentication Server Function
BBU	Baseband Unit
BSF	Binding Support Function
CA	Certificate Authority
CaaS	Cooperation as a Service
CAPIF	Common API Framework for 3GPP northbound APIs
CC	Cloud Computing
CP	Control Plane
CP	Control Plane
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 (User Plane UP)

Communication technologies: 5G, advanced 5G, 6G, ..

- **List of Acronyms**

ENaaS	Entertainment as a Service
ePDG	evolved Packet Data Gateway
FAR	Forwarding Action Rule
FAST	Fast Application and Communication Enabler
FC	Fog Computing
FQDN	Fully Qualified Domain Name
GMLC	Gateway Mobile Location Centre
GPS	Global Positioning System
GUAMI	Globally Unique AMF Identifier
HR	Home Routed (roaming)
IaaS	Infrastructure as a Service
INaaS	Information as a Service
INS	Insurance
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
LRF	Location Retrieval Function
MANET	Mobile Ad hoc Network
MCC	Mobile Cloud Computing
MEC	Multi-access (Mobile) Edge Computing
MPS	Multimedia Priority Service
N3IWF	Non-3GPP InterWorking Function
NaaS	Network as a Service

Communication technologies: 5G, advanced 5G, 6G, ..

- **List of Acronyms**

NAI	Network Access Identifier
NEF	Network Exposure Function
NF	Network Function
NFV	Network Function Virtualisation
NGAP	Next Generation Application Protocol
NR	New Radio
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
OBU	On Board Unit
OIF	Optical Internetworking Forum
ONF	Open Networking Foundation
PaaS	Platform as a Service
PCF	Policy Control Function
PEI	Permanent Equipment Identifier
PKI	Public Key Infrastructure
PSA	PDU Session Anchor
QFI	QoS Flow Identifier
QoE	Quality of Experience
RAN	Radio Access Network
RRH	Remote Radio Head
RSU	Road Side Unit
SA NR	Standalone New Radio

Communication technologies: 5G, advanced 5G, 6G, ..

- **List of Acronyms**

SaaS	Software as a Service
SBA	Service Based Architecture
SBI	Service Based Interface
SD	Slice Differentiator
SDN	Software Defined Networking
SEAF	Security Anchor Functionality
SEPP	Security Edge Protection Proxy
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
SSC	Session and Service Continuity
SSE	Smart Safety and Efficiency
SST	Slice/Service Type
TNL	Transport Network Layer
TNLA	Transport Network Layer Association
TSP	Traffic Steering Policy
UDM	Unified Data Management
UDR	Unified Data Repository
UDSF	Unstructured Data Storage Function
UL	Uplink
UPF	User Plane Function
URSP	UE Route Selection Policy

Communication technologies: 5G, advanced 5G, 6G, ..

- **List of Acronyms**

V2X	Vehicle-to-everything
VANET	Vehicular Ad hoc Network
VID	VLAN Identifier
VLAN	Virtual Local Area Network
VM	Virtual Machine
WAT	Wireless Access Technologies
WAVE	Wireless Access for Vehicular Environments
WSN	Wireless Sensor Network

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- **Backup slides**

4.2 Terminology summary

- **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
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4. Network slicing technologies

4.2 Terminology summary

- **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
ETSI GS NFV 003 V1.3.1 (2018-01) Network Functions Virtualisation (NFV); Terminology for Main Concepts in NFV