Cellular and 5G Support for Internet of Things Connectivity

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1. INTRODUCTION

- **Acknowledgement**

  - This presentation **is a short overview, compiled and structured based on several public documents** such as: conference proceedings, studies (overviews, tutorials, research papers), standards, projects, etc. (see specific references in the text and in the Reference list).
  - **The topic selection, text organization and explanations belong to this author.**
  - **Notes:**
    - Given the extension of the topics, this **presentation is limited to a high level overview only**, mainly on conceptual, architectural and a few specific design aspects.
    - Some examples taken from the literature, projects, etc., are selected to illustrate architecture and implementations of 5G solutions to support IoT connectivity.

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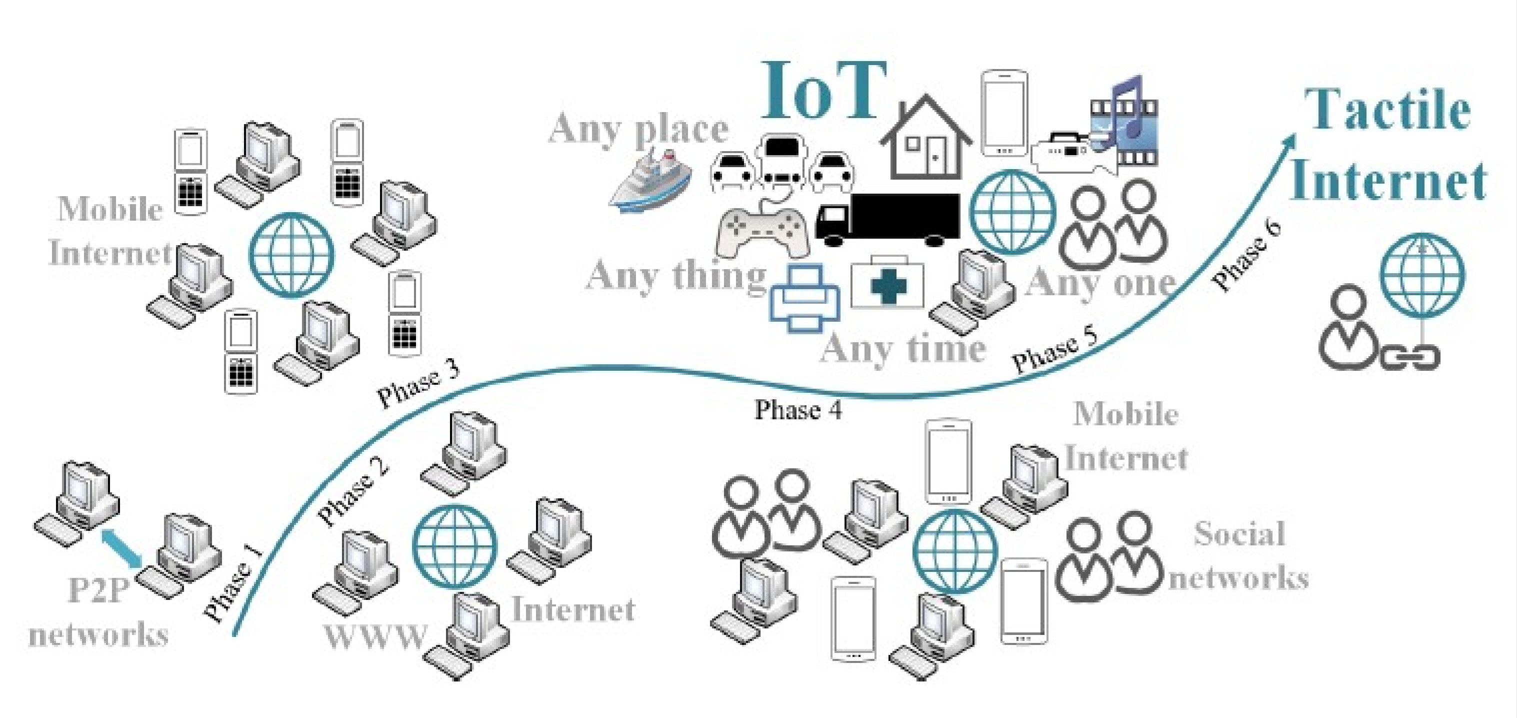
1. INTRODUCTION

- **Internet of Things (IoT)**
  - Traditional basic Internet communication : human-to-human (H2H) and human to machine (H2M)
  - **IoT:**
    - Internet evolution that mainly adds **machine-to-machine (M2M)** communications
    - provides connectivity for ***everyone*** and ***everything***
    - embeds intelligence in Internet connected objects, allowing them to communicate, exchange information, take decisions, invoke actions aiming to provide a large range of services
    - allows autonomous and secure connection and exchange of data between real world devices and applications
  - **Traditional Internet terminal devices** : personal computers, laptops, tablets, smart phones, PDAs and other hand-held embedded devices
  - **IoT objects:** sensor devices, communication infrastructure, computational and processing unit (may be placed in clouds), decision making and action invoking system
    - The objects have certain unique features and are uniquely identifiable and accessible via the Internet
    - IoT objective: huge set of terminals/objects accepted (many “things”!)

1. INTRODUCTION

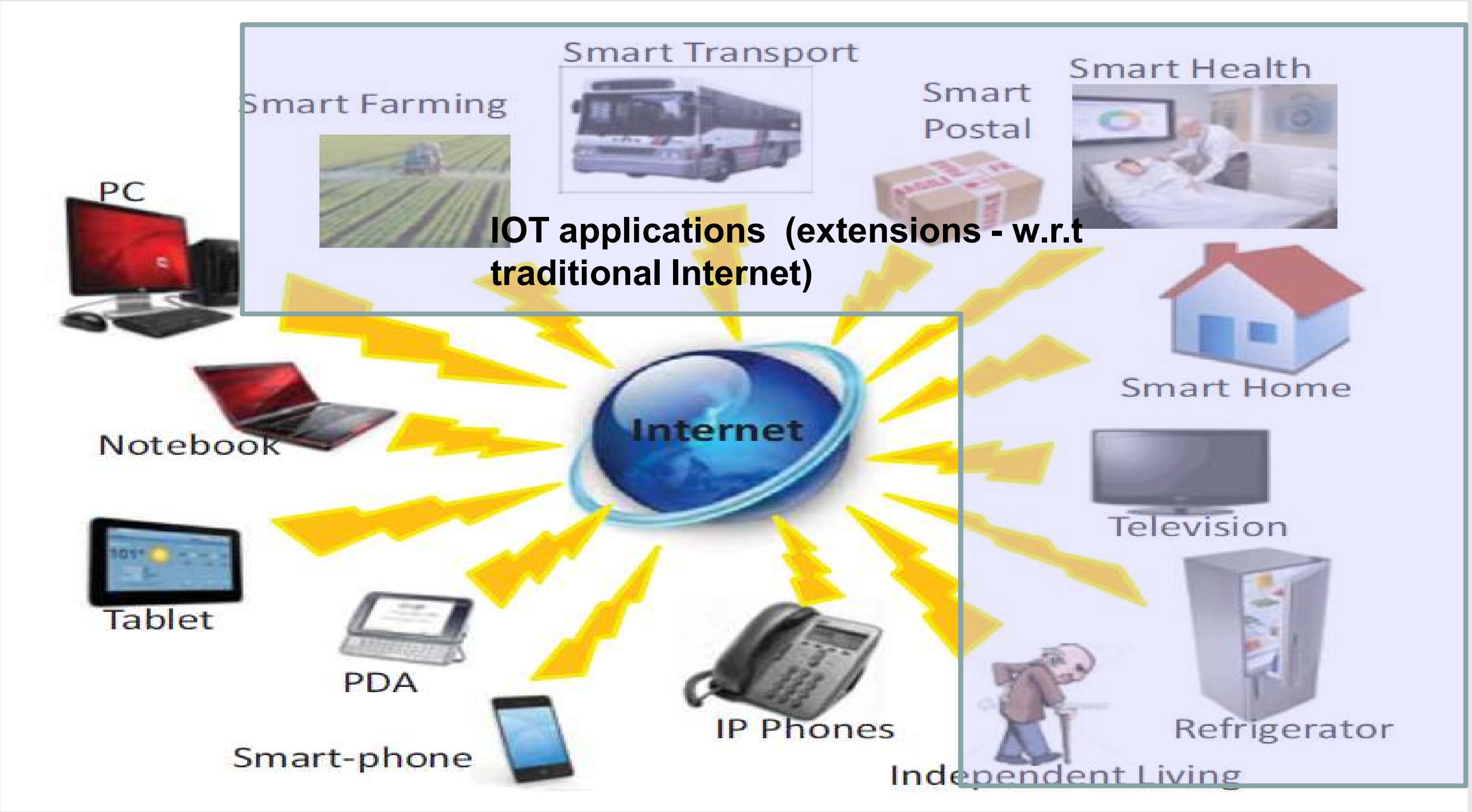
- **Internet evolution**
  - Several phases: P2P, WWW, Mobile Internet, Social networks, **IoT**, Tactile Internet, ….
  - Today: strong trend to develop and deploy IoT in many domains



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

1. INTRODUCTION

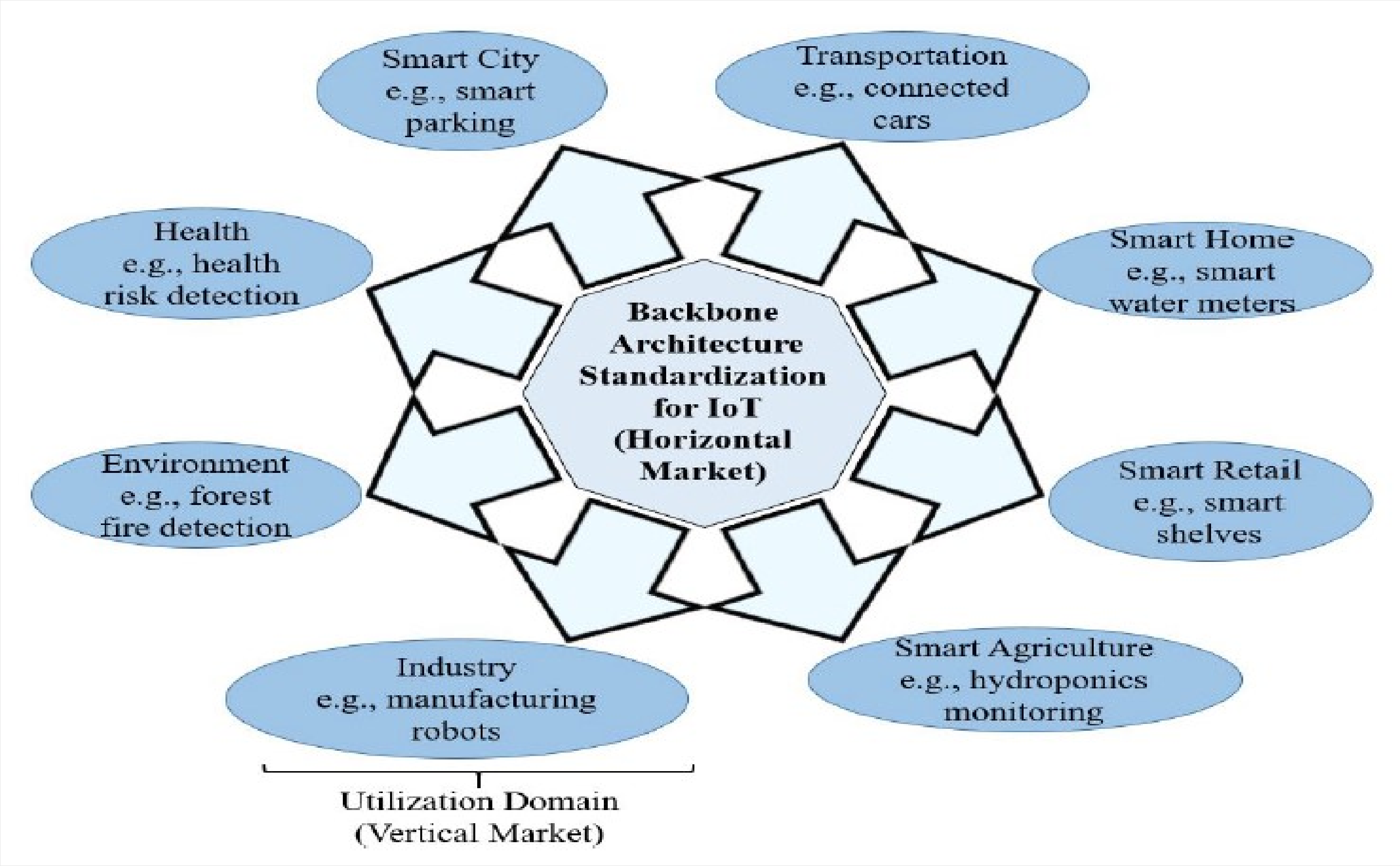
- **Internet of Things (IoT) – applications-** examples



Source: R,Khan et al., "Future Internet: The Internet of Things Architecture, Possible Applications and Key Challenges", Dec. 2012, https://www.researchgate.net/publication/261311447

1. INTRODUCTION

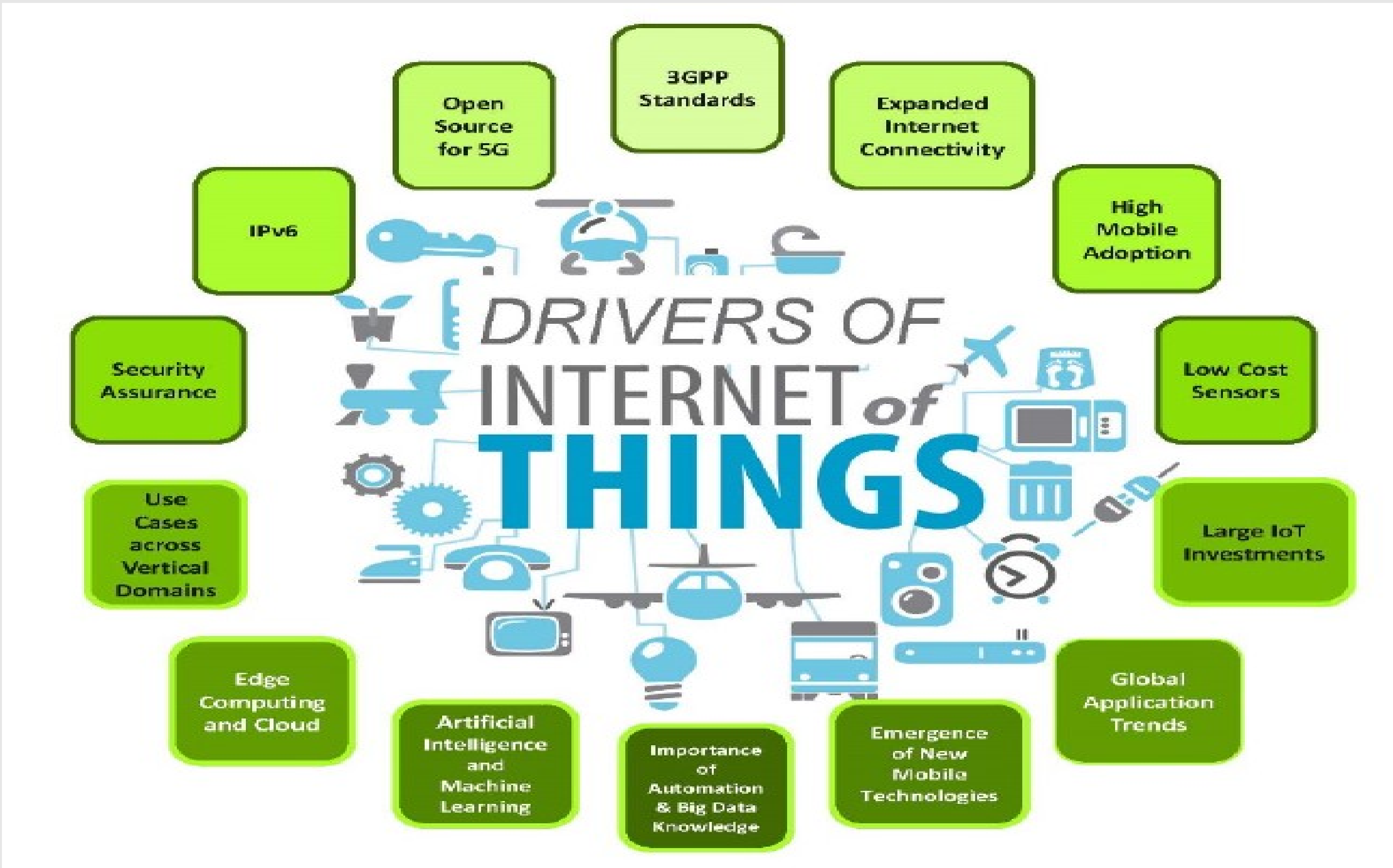
- **IoT applications and utilization domains: -** many "verticals"



Source: J.Ding, M.Nemati, C.Ranaweera, and J.Choi, "IoT Connectivity Technologies and Applications:A Survey" arXiv:2002.12646v1 [eess.SP] 28 Feb 2020.

1. INTRODUCTION

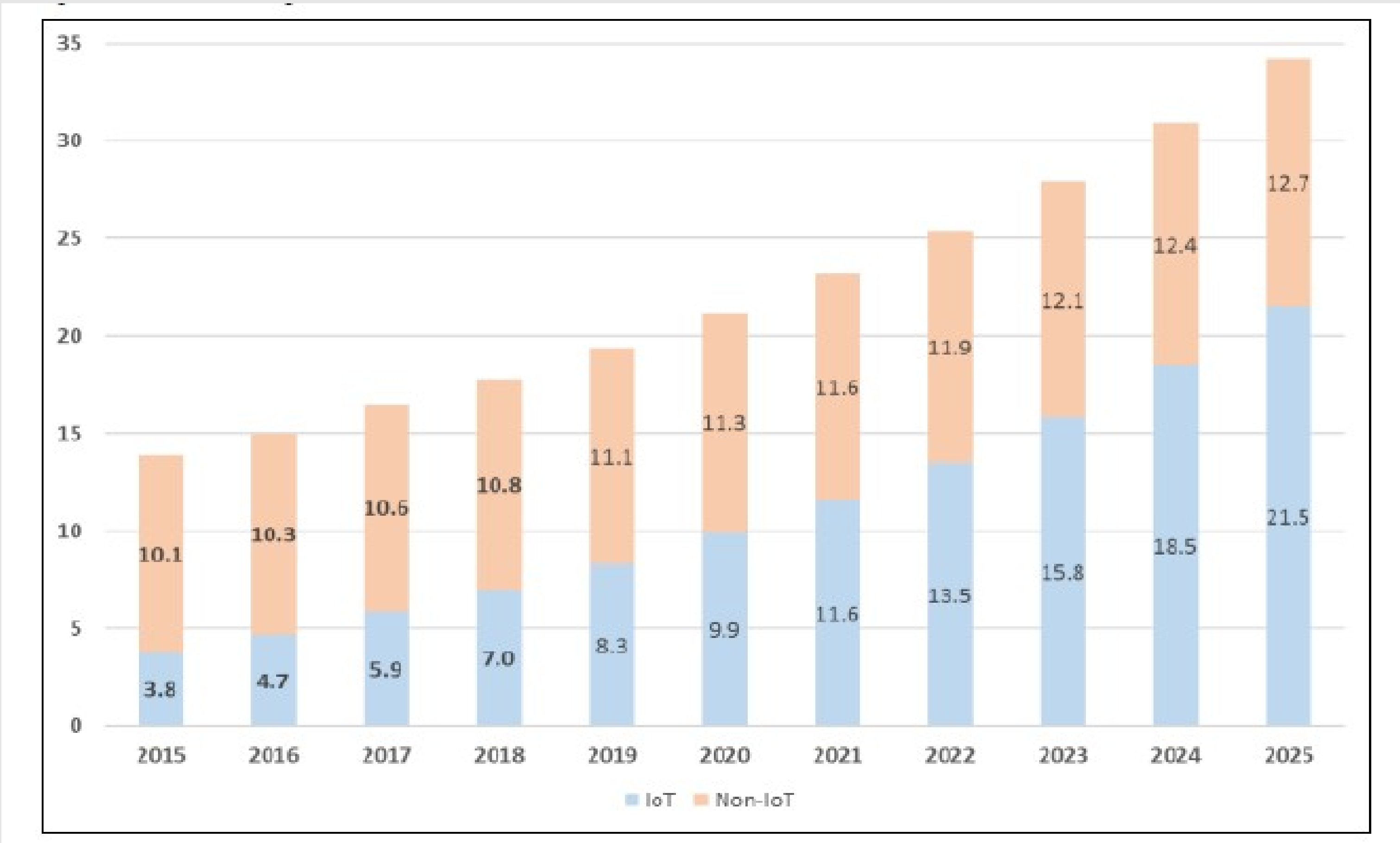
- **IoT Market Drivers and Trends-** *5G Americas vision*



Source: 5G Americas white Paper, "5G A future of IoT", July 2019, [*https://www.5gamericas.org/5g-the-future-of-iot/*](https://www.5gamericas.org/5g-the-future-of-iot/)

1. INTRODUCTION

- **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/.

1. INTRODUCTION

- **Internet of Things (IoT)- ITU Definition**
  - **IoT** : a global infrastructure for the information society, enabling advanced services by interconnecting (Phy/V) things based on existing and evolving interoperable ICT
    - *Source: Recommendation ITU-T Y.2060*

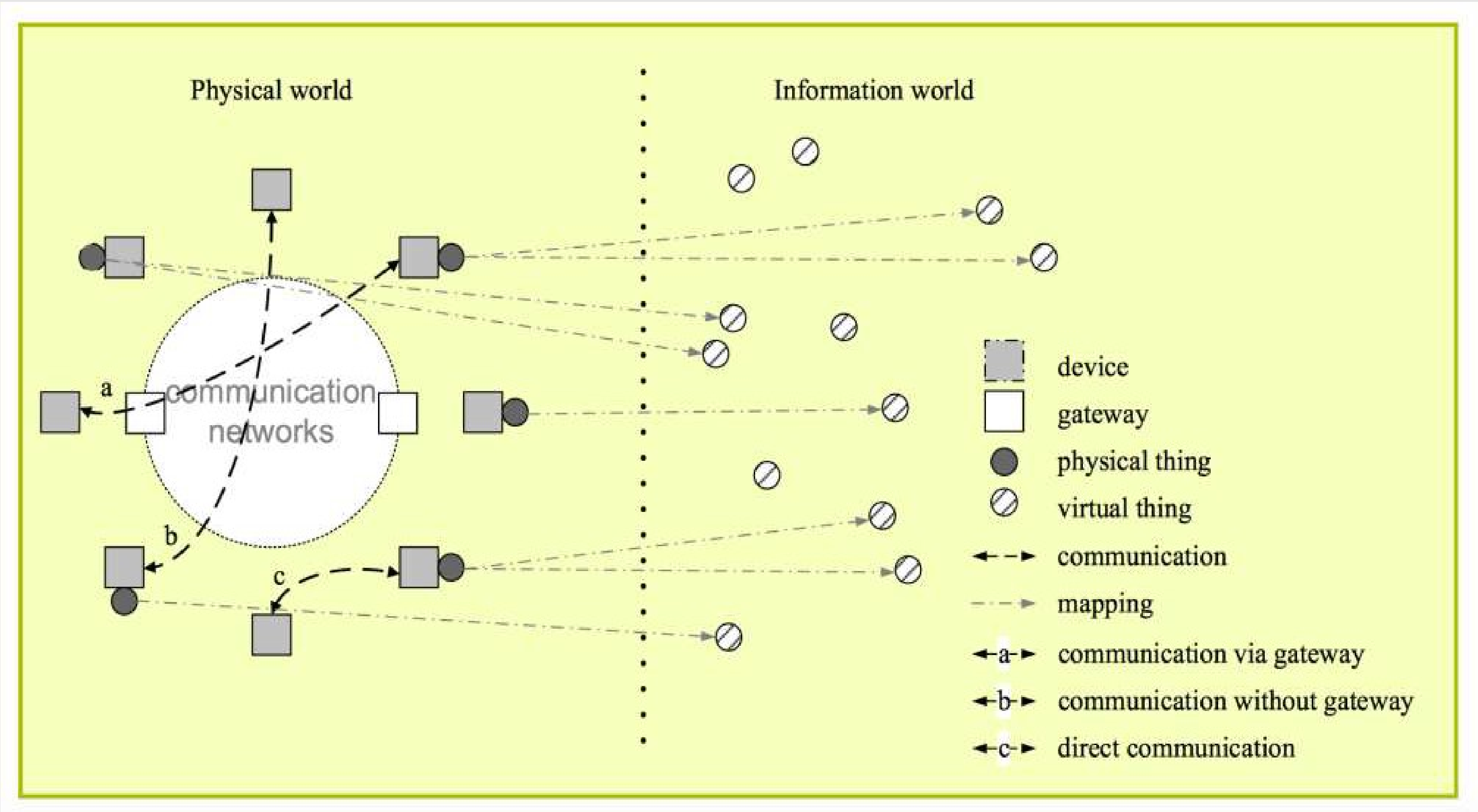
  - **Things:** objects of the physical world (physical things) or the information world (virtual world) which are capable of being identified and integrated into regional or global communication networks
    - They have associated information, which can be static and dynamic

    - Things/Objects systems differentiate according to:

      - The coverage **range** (short, medium, long)
      - The **type of interaction** with the system (i.e., service type):
        - » Alarms (transmission initiated by the end-device only, according to the events, bursty traffic)
        - » Measurements (triggered either by the end-device or by the system)
        - » Control (transmissions initiated by the system)
        - » Combination of these

1. INTRODUCTION

- **Internet of Things (IoT)- ITU vision**
  - *Physical* and *virtual* things and communication types



- *Source: Recommendation ITU-T Y.2060*

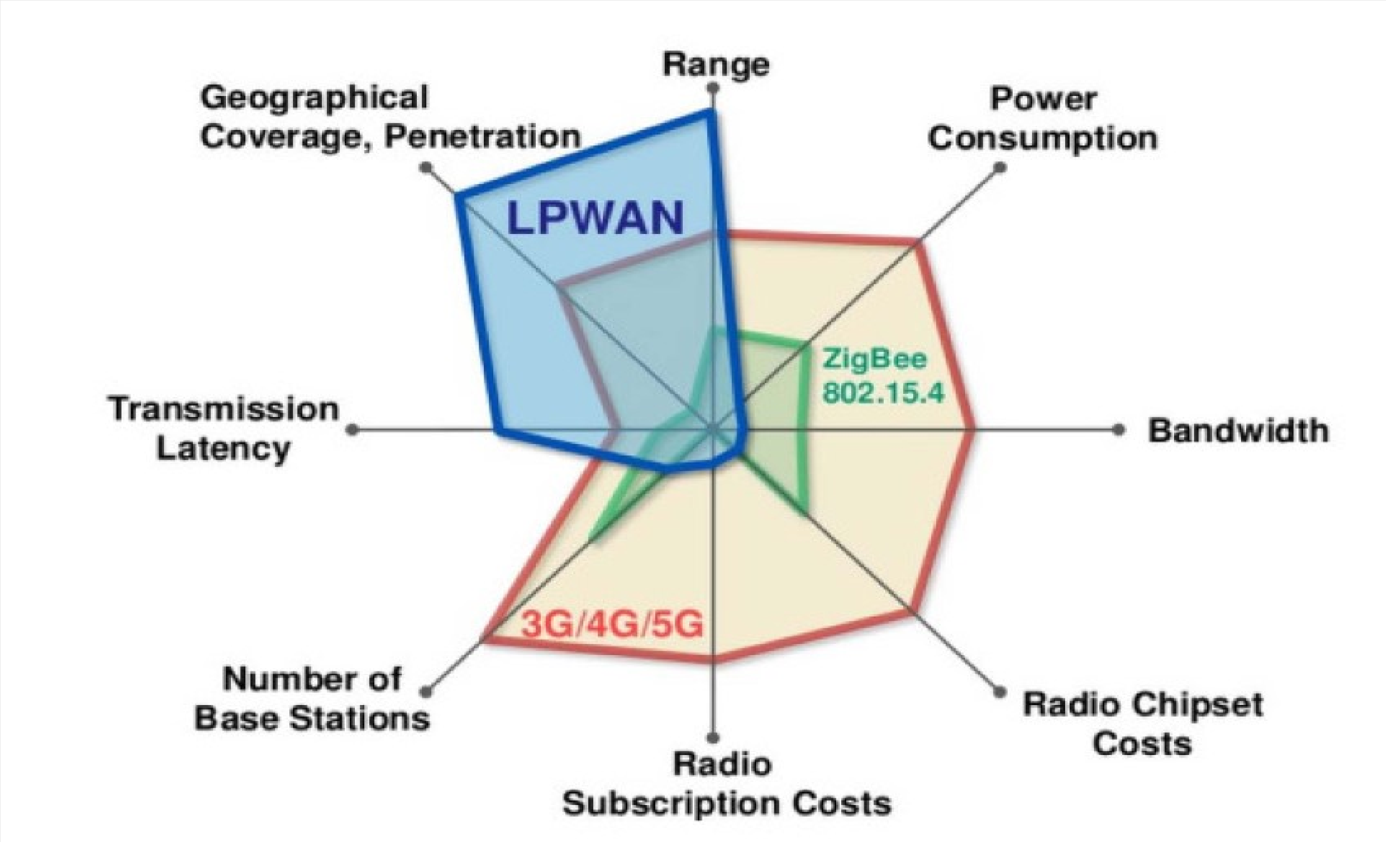
1. INTRODUCTION

- **IoT General Characteristics**
  - Low power, low or medium bit rate, low cost (network and end devices)
    - High bit rate are needed in special applications only
  - Geographical range
    - *Short* (first type of technologies) or
    - *Long* (second type of technologies)
  - Long battery duration (years)
  - Location: in any area (deep indoor, urban areas (home, health, administration, city facilities, transportation) industrial environment, rural/ forests/ agricultural areas, desert, vehicular domain, …

- **IoT communications specifics – versus - cellular**
  - Low**:** cost, power, processing/storage capacity, bitrate
  - Long: battery duration, range
  - Higher number of connections
  - Smaller size devices
  - Larger range of latencies required
  - Simple network architecture and protocols

1. INTRODUCTION

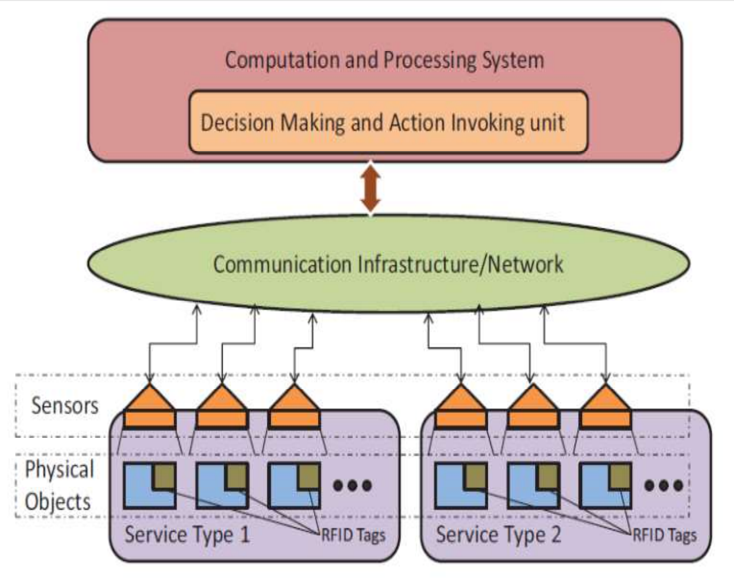
- **Examples of communication technologies and IoT characteristics**
  - LPWAN- Low Power Wide Area Network



Source: ITU-T S.Tabanne, "IoT systems overview", 30 Sept.-03 Oct. 2019, Bangkok, Thailand, https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/SiteAssets/Pages/Events/2019/ITU-ASP-CoE-Training-on-/IoT%20systems%20overview.pdf

1. INTRODUCTION

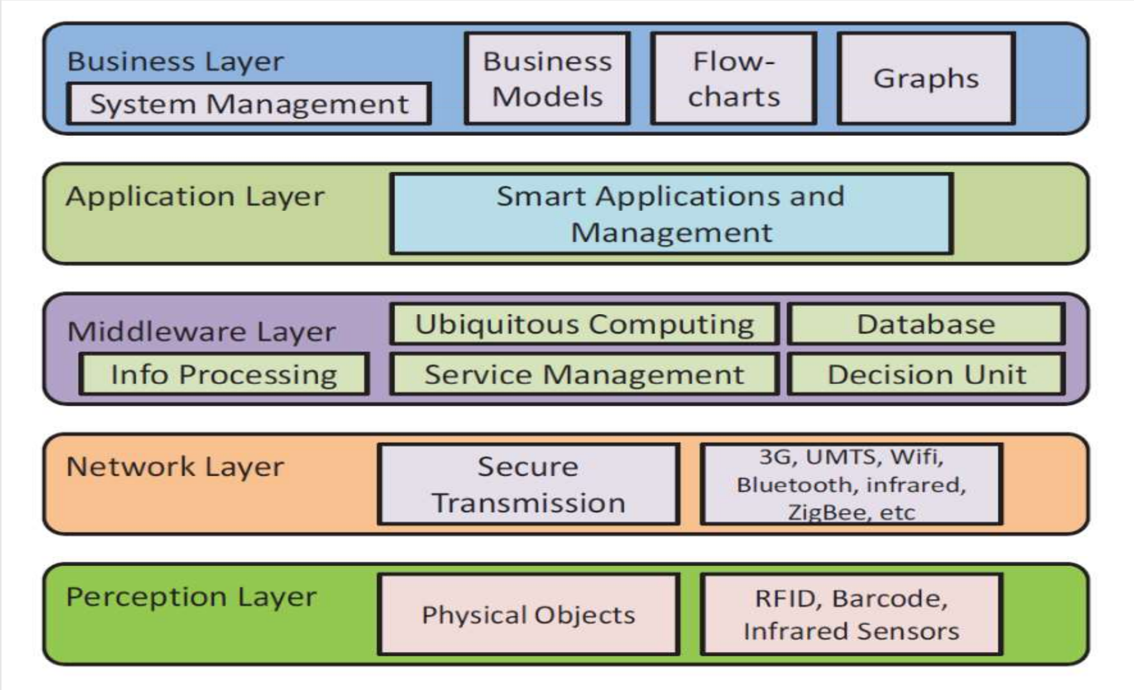
- **The basic IoT workflow**
  - **Object sensing, identification and communication of object specific information**
    - The information is the sensed data about temperature, orientation, motion, vibration, acceleration, humidity, chemical changes in the air etc., depending on the type of sensors
    - A combination of different sensors can be used for the design of smart services
  - **Trigger an action**
    - the received object information is processed by a smart device/system
    - that then determines an automated action to be invoked
  - **The smart device/system**
    - provides rich services
    - includes a mechanism to provide feedback to an administrator about the current system status and the results of actions invoked



Example of a basic IoT system

1. INTRODUCTION

- **IoT functional layered architecture**
  - Note : there are several visions/variants on functional layer split
  - **4 -layer model**
    - Sensing and Identification, Network Infrastructure, Information Processing, Integrated Applications
  - **5 -layer model**
    - Note : here, the *Network layer* include the traditional *Data link layer*



1. INTRODUCTION

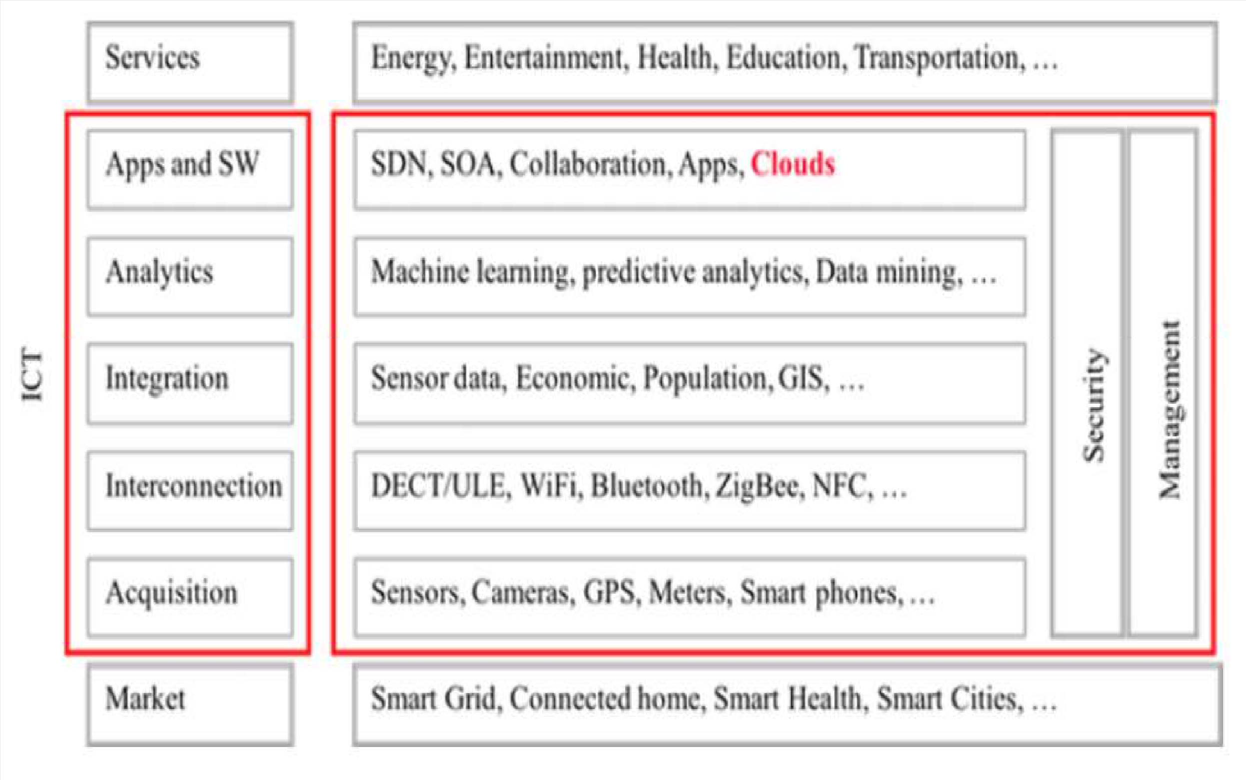
- **IoT layered functional architecture** (cont'd)
  - **Perception Layer (PL)** (a.k.a *Device Layer*)
    - includes physical objects (e.g., sensor devices)
      - the sensors could be (but not limited) RFID, 2D-barcode, or Infrared sensor depending upon objects identification method
    - identifies and collects objects specific information from sensor devices (location, temperature, orientation, motion, vibration, acceleration, humidity, chemical changes in the air, etc.)
    - passes the information to the upper *Network layer* for its transmission to the information processing system
  - **Network Layer (NL) (**a.k.a *Transmission Layer*)
    - securely transfers the information received from sensor devices to the *Middleware layer* for processing system
    - Large set of technologies/protocols available : wired/ wireless – IEEE 802.11, IEEE 802.15 (Bluetooth), Infrared, ZigBee, 3G/4G/5G, LPWAN, etc.
  - **Middleware Layer (ML)**
    - The devices over the IoT implement different type of services
      - Each device usually connects and communicates with only other devices which implement the same service type
    - ML is responsible for the *service management* and has a link to the *database*
      - It receives the information from NL and store it in the database
    - ML performs info processing and ubiquitous computation and takes automatic decision based on the results

1. INTRODUCTION

- **IoT layered functional architecture** (cont'd)
  - **Application Layer (AL)**
    - provides global management of the application based on the objects info processed in the ML layer
    - The applications can be smart health, smart farming, smart home, smart city, industrial, intelligent transportation, etc.
  - **Business Layer (BL)**
    - responsible for the management of overall IoT system including the applications and services
    - It builds **business models**, (like graphs, flowcharts, etc.) based on the data received from AL
    - **The real success of the IoT technology depends not only on technical solutions but also on some good business models**
      - able to meet the requirements of specific applications and also to accommodate various actors to cooperate
    - Based on the analysis of results, BL can determine the future actions and business strategies

1. INTRODUCTION

- **IoT ecosystem model - example**
  - Layered model also, but oriented more to the business vision



Source: T. Salman, R.Jain, "A Survey of Protocols and Standards for Internet of Things", https://arxiv.org/ftp/arxiv/papers/1903/1903.11549.pdf

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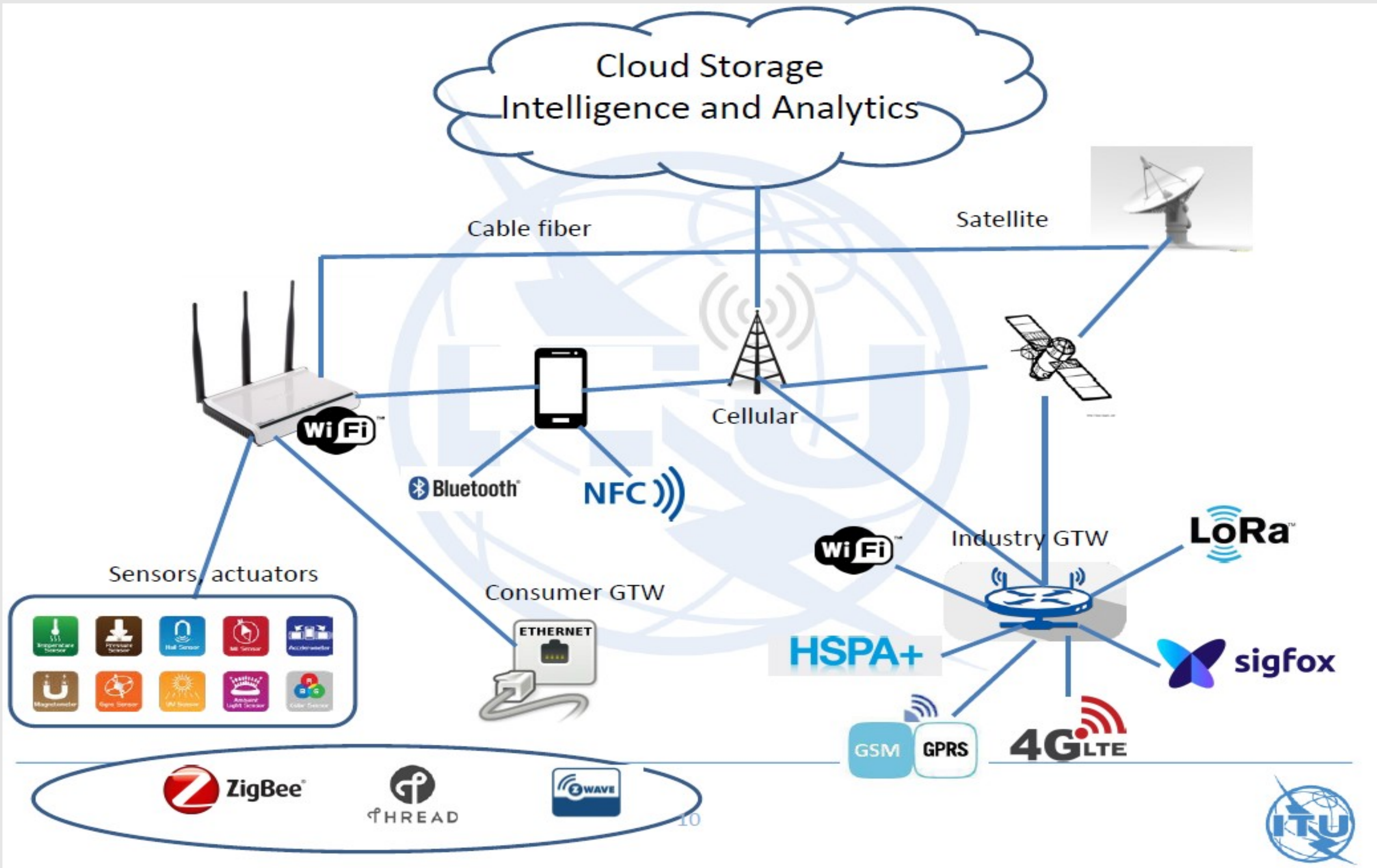
2. IoT Connectivity

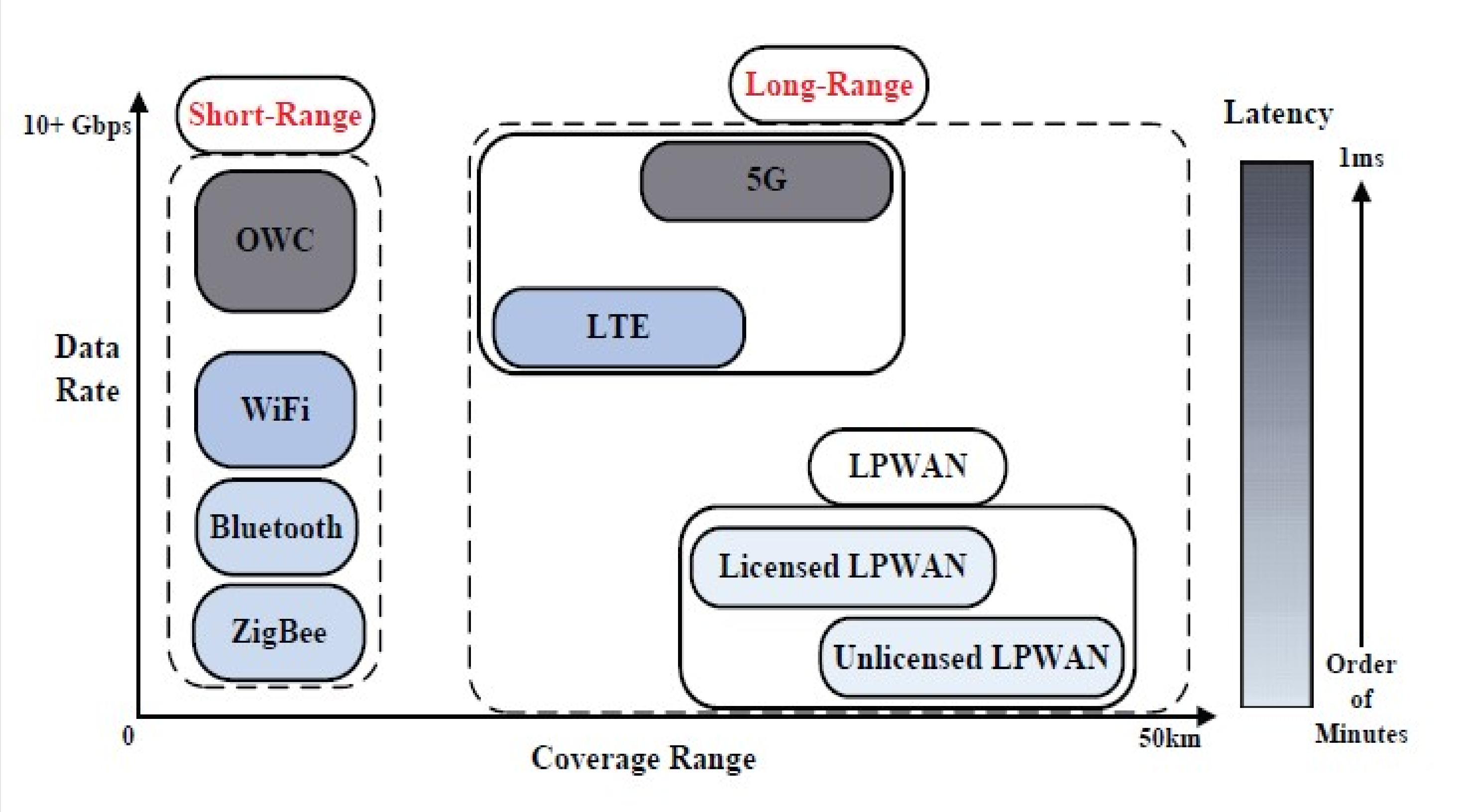
- **IoT Connectivity:** mainly deals with network layer functions
- **IoT general architecture (ITU- vision)**



Source: ITU, S.Tabanne, "Internet of Things: A technical overview of the ecosystem", "Developing the ICT ecosystem to harness Internet-of-Things (IoT)", 28-30 June 2017, Mauritius

2. IoT Connectivity

- **IoT connectivity- related protocols**
  - They belong to the first two lower architectural layers (perception, network)
  - Figure: IoT connectivity technologies in terms of : *data rate*, *coverage*, *latency*



Source: J.Ding, M.Nemati, C.Ranaweera, and J.Choi, "IoT Connectivity Technologies and Applications:A Survey" arXiv:2002.12646v1 [eess.SP] 28 Feb 2020.

2. IoT Connectivity

- **IoT connectivity- related protocols** (cont'd)
- **Focus: on the interconnection layer**
  - **Basic architectural layers: Data link**, **Network**, and **Transport/session** layers
    - *See the figure on next slide*
  - **Data and Control architectural planes**
    - **Data link layer**
      - connects two IoT elements (e.g., two sensors or a sensor and GW device that connects a set of sensors to the Internet)
      - multiple sensors could exist, to communicate and aggregate information before getting to the Internet
    - **Network layer**
      - Encapsulation protocols
      - Routing protocols
    - **Session layer**
      - enable messaging among various elements of the IoT communication subsystem
  - **Security and management architectural planes**
    - Depicted as vertical entities – meaning that they can interact with, and control all other layers

2. IoT Connectivity

- **IoT connectivity- related protocols** (cont'd)
  - **Protocol mapping on architectural layers**

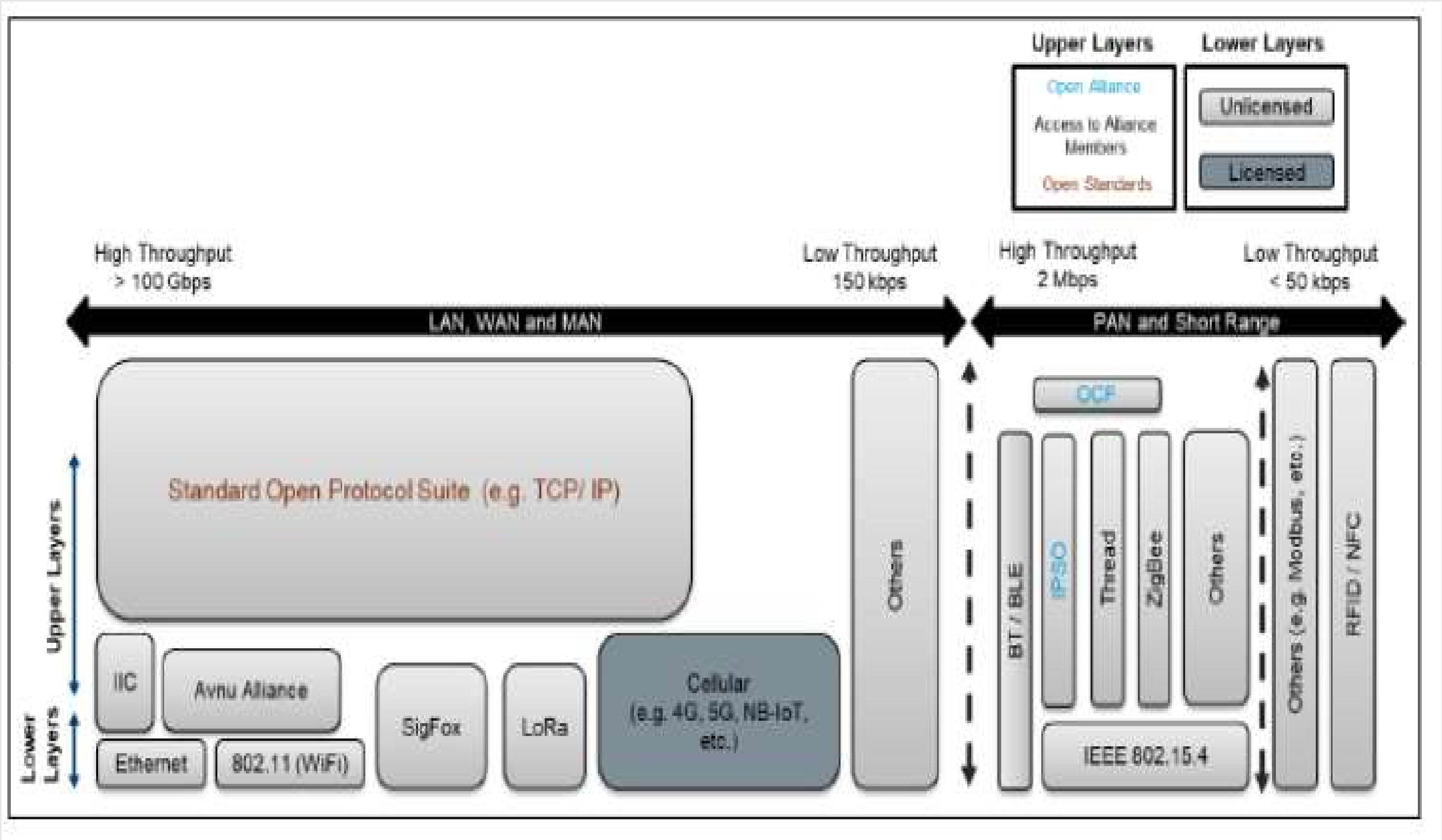
Layer	Protocols	Security	Management
Session	MQTT, SMQTT, CoRE, DDS, AMQP , XMPP, CoAP, IEC,…	IEEE 1888.3, TCG, OAuth 2.0, SMACK, SASL, EDSA, ace, DTLS, Dice, …	IEEE 1905, IEEE 1451, TR-069, OMA-DM, LWM2M, IEEE 1377, IEEE P1828, IEEE P1856
Network	Encapsulation 6LowPAN, 6TiSCH, 6Lo, Thread… Routing RPL, CORPL, CARP		
Datalink	WiFi, Bluetooth Low Energy, Z-Wave, ZigBee Smart, DECT/ULE, 3G/LTE, NFC, Weightless, HomePlug GP, 802.11ah, 802.15.4e, G.9959, WirelessHART, DASH7, ANT+, LTE-A, LoRaWAN, ISA100.11a, DigiMesh, WiMAX, …		

See the list of acronyms

Sources: T.Salman, R.Jain "Networking Protocols and Standards for Internet of Things", 2015 https://www.cse.wustl.edu/~jain/cse570-15/ftp/iot_prot/, T. Salman, R.Jain, "A Survey of Protocols and Standards for Internet of Things", https://arxiv.org/ftp/arxiv/papers/1903/1903.11549.pdf

2. IoT Connectivity

- **IoT connectivity- related protocols** (cont'd)
  - **Technologies and connectivity standards**



Source: "IoT- High Level Functional Architecture"
https://www.mcmc.gov.my/skmmgovmy/media/General/pdf/MTSFB0652019-IOT-HIGH-LEVEL-FUNCTIONAL-ARCHITECTURE.pdf

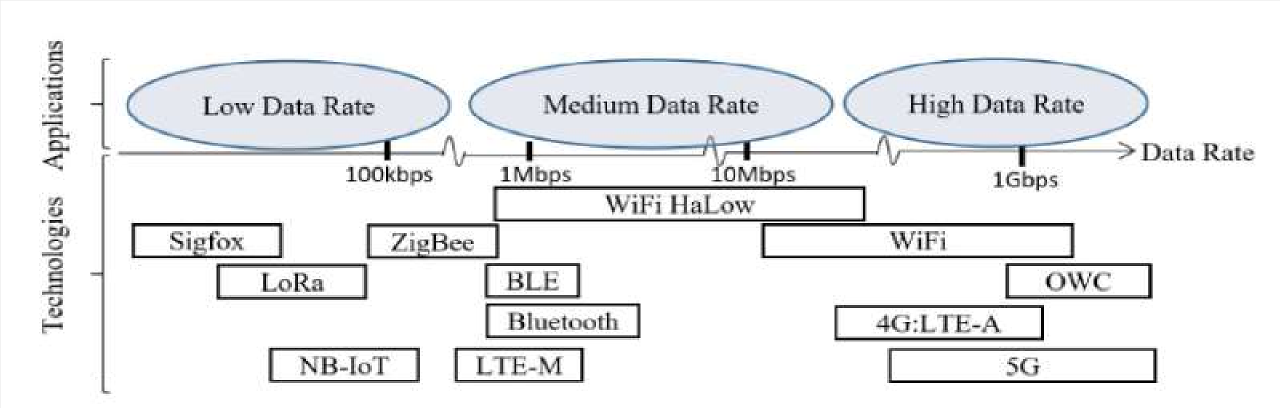
2. IoT Connectivity

- **IoT connectivity- related protocols** (cont'd)
  - **Range-related taxonomy (typical examples)**
  - **Fixed & Short Range**
    - RFID
    - Bluetooth/BLE
    - Zigbee
    - WiFi
    - IEEE 802.11ah, IEEE 802.15.4e
  - **Long Range technologies**
    - Non 3GPP Standards (LPWAN)
      - LoRaWAN
      - Sigfox
      - Weightless
      - RPMA
      - ….
    - **3GPP Standards**
      - LTE-M
      - NB-IOT
      - EC-GSM
      - 5G and IoT

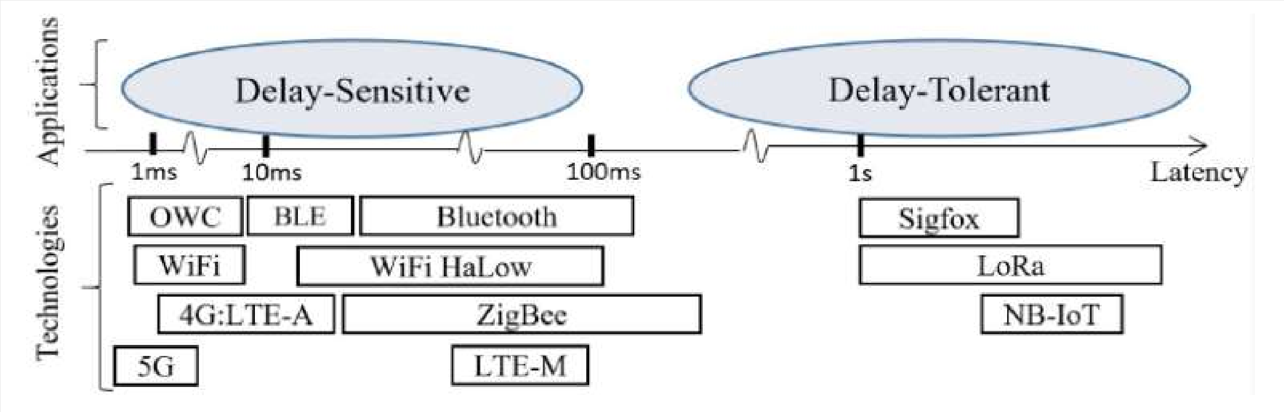
2. IoT Connectivity

- **IoT connectivity- related protocols** (cont'd)

IoT Protocols: different data rates capabilities



IoT Protocols: different latencies capabilities



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2. IoT Connectivity

- **IoT applications**, **use-cases** and **connectivity technologies**

Requirement	App. category	Use-cases (e.g.,)	Connectivity technologies
End-user-type	Human-oriented	Smart phone	Legacy cellular technologies, LTE/LTE-A, 5G, WiFi/WiFi HaLow, OWC
	Machine-oriented	Monitoring sensors	Bluetooth/BLE, ZigBee, LPWAN, WiFi/WiFi HaLow, OWC
Data rate	High data-rate	Streaming video cameras	LTE/LTE-A, 5G, OWC, WiFi
	Medium data-rate	Connected cooking systems	Bluetooth/BLE, ZigBee, LTE-M, WiFi HaLow
	Low data-rate	Energy & water meters	NB-IoT, Sigfox, LoRa, ZigBee
Latency	Delay-sensitive	Autonomous vehicles, health-care sensors	LTE/LTE-A, 5G, OWC, WiFi/WiFi HaLow, Bluetooth/BLE, LTE-M
	Delay-tolerant	Waste management sensors	ZigBee, Sigfox, NB-IoT, LoRa
Coverage	Long-range	UAVs, smart farming sensors	LTE/LTE-A, 5G, LoRa, Sigfox, NB-IoT, LTE-M, WiFi HaLow
	Short-range	Smart home appliances	Bluetooth/BLE, ZigBee, OWC, WiFi
Power	Low power	Tracking sensors, smart retail sensors	Bluetooth, ZigBee, LTE/LTE-A, 5G, WiFi
	Ultra low power	Pollution monitoring sensor	BLE, WiFi HaLow, LPWAN: LoRa, Sigfox, LTE-M, NB-IoT
Reliability	Mission critical	Real-time patient surveillance, autonomous vehicles	LTE/LTE-A, 5G, WiFi/WiFi HaLow, OWC
	Mission non-critical	Smart farming sensors	LPWAN: LoRa, Sigfox, LTE-M, NB-IoT
Mobility	High mobility	Autonomous vehicles	LTE/LTE-A, 5G
	Low mobility	Smart traffic lights	LPWAN, Bluetooth/BLE, ZigBee

Source: J.Ding, M.Nemati, C.Ranaweera, and J.Choi, "IoT Connectivity Technologies and Applications:A Survey" arXiv:2002.12646v1 [eess.SP] 28 Feb 2020.

2. Iot Connectivity

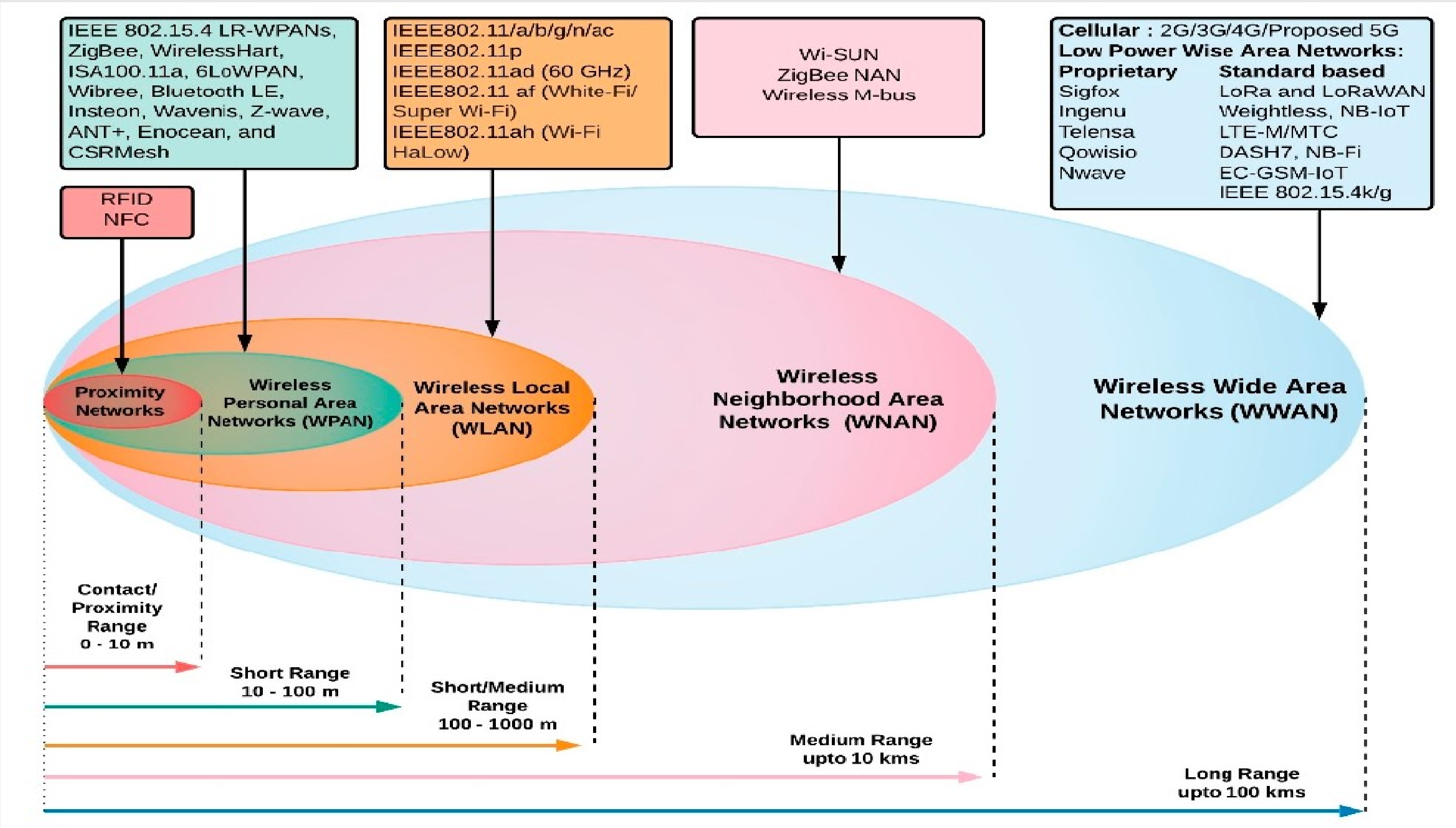
- **IoT connectivity- related protocols – quantitative comparison**

Technology	Frequency	Data Rate	Range	Power Usage	Cost
2G/3G	Cellular Bands	10 Mbps	Several Miles	High	High
Bluetooth/BLE	2.4Ghz	1, 2, 3 Mbps	~300 feet	Low	Low
802.15.4	subGhz, 2.4GHz	40, 250 kbps	> 100 square miles	Low	Low
LoRa	subGhz	< 50 kbps	1-3 miles	Low	Medium
LTE Cat 0/1	Cellular Bands	1-10 Mbps	Several Miles	Medium	High
NB-IoT	Cellular Bands	0.1-1 Mbps	Several Miles	Medium	High
SigFox	subGhz	< 1 kbps	Several Miles	Low	Medium
Weightless	subGhz	0.1-24 Mbps	Several Miles	Low	Low
Wi-Fi	subGhz, 2.4Ghz, 5Ghz	0.1-54 Mbps	< 300 feet	Medium	Low
WirelessHART	2.4Ghz	250 kbps	~300 feet	Medium	Medium
ZigBee	2.4Ghz	250 kbps	~300 feet	Low	Medium
Z-Wave	subGhz	40 kbps	~100 feet	Low	Medium

Source: "IoT Standards and Protocols", https://www.postscapes.com/internet-of-things-protocols/#protocols

2. IoT Connectivity

- **IoT connectivity- related protocols** (cont'd)
  - **Technologies comparison**



Source: B.S.Chaudhari, M.Zennaro and S.Borkar, "LPWAN Technologies: Emerging Application Characteristics, Requirements, and Design Considerations", Future Internet 2020, 12, 46; doi:10.3390/fi12030046 www.mdpi.com/journal/futureinternet

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3. Cellular technologies for IoT

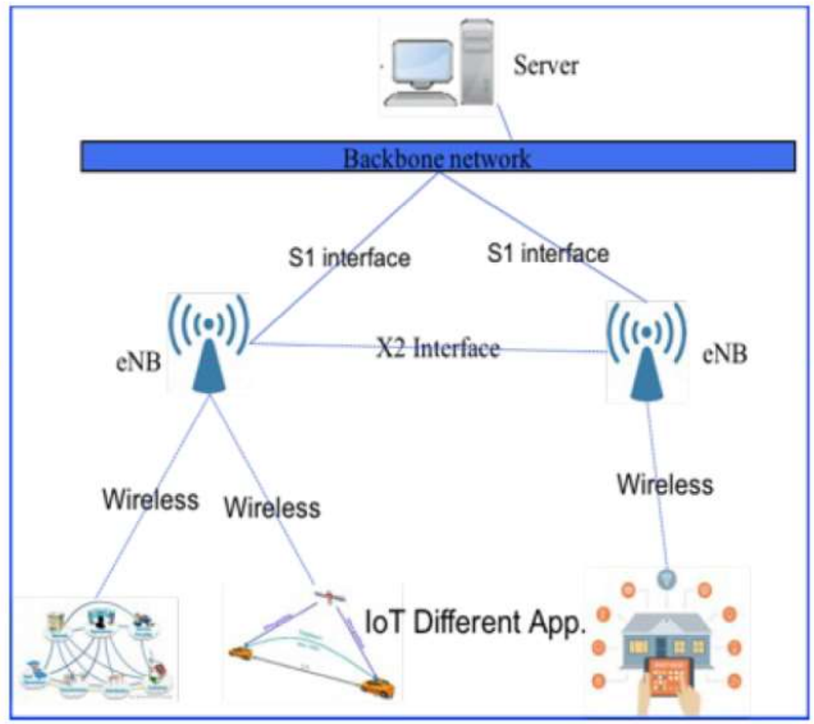
- **LTE- 4G-5G**
  - LTE and 5G -important technologies to support IoT
  - Standardized (4G), LTE/LTE-Advance (LTE-A)
    - ITU, 3GPP main standardization actors
    - successfully deployed worldwide
    - however, it was mainly designed to support conventional high speed HTC
  - **5G – major advantages over 4G** *(see Chapter 4, for details)*
    - Throughput, latency, density of terminals, coverage, power efficiency, etc.
    - Flexibility (multi-tenant, multi-domain, multi-oprator)
    - Advanced management and control (based on NFV, SDN, virtualization)
    - 5G slicing concept

Connectivity characteristics – comparison LTE – 5G

	LTE/LTE-A	5G
Round trip latency	15ms	1ms
Peak data rate	1Gbps	20Gbps
Available spectrum	3GHz	30GHz
Channel bandwidth	20MHz	100MHz below 6GHz 400MHz above 6GHz
Frequency band	600MHz to 5.925GHz	600MHz to 80GHz
Uplink waveform	SC-FDMA	Option for CP-OFDM

3. Cellular technologies for IoT

- **LTE- A general architecture**
  - **Core network- (CN)**
    - contains the architectural planes : data, control, management
    - controls the mobile devices , realizes Internet connection, control of mobile devices, performs complex management and control actions
  - **Radio Access Network (RAN)**
    - essentially contains architectural planes data and control
    - assures the connectivity (L1, L2, L3) via radio interfaces between mobile nodes and base stations (eNB)
- **Mobile devices**



Source: T.Salman, R.Jain, A Survey of Protocols and Standards for Internet of Things, Advanced Computing and Communications, Vol. 1, No. 1, March 2017.

3. Cellular technologies for IoT

- **LTE IoT**
- **3GPP** : a suite of two **complementary** narrowband **LTE IoT** technologies in Rel13:
    - **eMTC (enhanced Machine-Type Communication),** also known as LTE-M (Machine-Type Communication)
    - **NB-IoT (NarrowBand-Internet of Things)**
  - collectively referred to as LTE IoT
  - optimized for lower complexity/power, deeper coverage, and higher device density
  - seamlessly coexisting with other LTE services

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

3. Cellular technologies for IoT

- **Low Power WAN (LPWAN) – licensed spectrum**
  - Standardized by the 3GPP
  - **LPWAN, LTE-M** and **NB-IoT** – promising standards (see the 3GPP Rel-13 in 2016)
  - both standards are developed based on LTE
  - Random access procedure (RA) of a terminal to access the network – similar to LTE
    - using the contention-based physical random access channel (PRACH) for initial access of the mobile terminal to the network
- **LTE-M**
  - Is an LTE simplified version low cost, low power –attractive for IoT
  - **Main LTE-M characteristics:**
    - support for MTC and also for voice communications
    - uses OFDMA in downlink and SC-FDMA in uplink
    - low bandwidth 1.4MHz (reduced hardware cost)
    - working mode: half duplex or full duplex

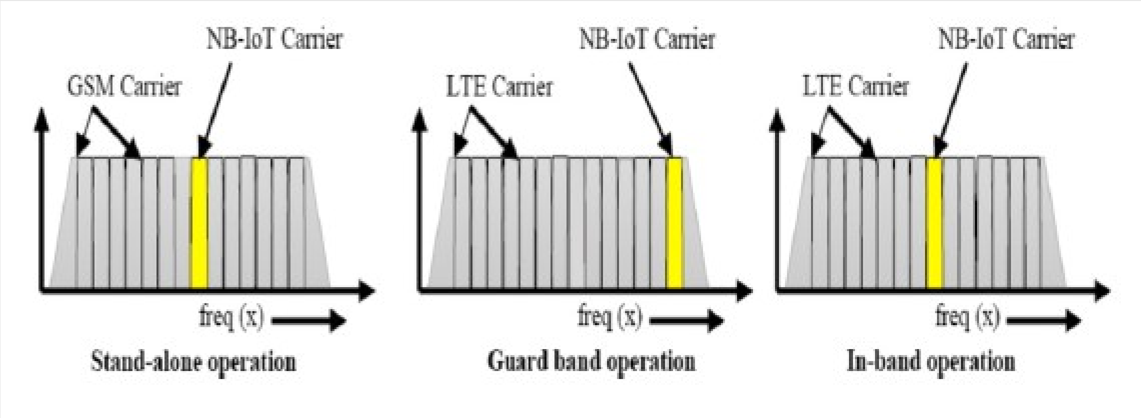
    - 3GPP Rel-14 and Rel-15 have added enhanced capabilities related to data rate, latency, coverage

3. Cellular technologies for IoT

- **Low Power WAN (LPWAN) – licensed** (cont'd)
- **NB-IoT**
- It is a **LTE based system**, using a single narrow band (200KHz), with low complexity of the baseband functions
  - designed to serve a large area, low-cost terminals, high density of terminal devices and procedures which can allow a long battery life
  - **NB-IoT characteristics**:
    - OFDMA with 15KHz spacing between subcarriers on downlink
    - SC-FDMA with 15KHz or 3.75 KHz on *uplink*
    - half-duplex mode
    - larger coverage area w.r.t LTE
    - three operation modes *inband*, *standalone* and *guard-band*
      - *inband* – one or more LTE resource blocks (*physical resource blocks (PRBs) within an LTE carrier*) are reserved for IoT
      - *standalone*- NB-IoT can be deployed inside one or more global mobile communication systems (e.g., GSM)
      - *guard-band- NB* –IoT can be used inside the guard-band LTE

3. Cellular technologies for IoT

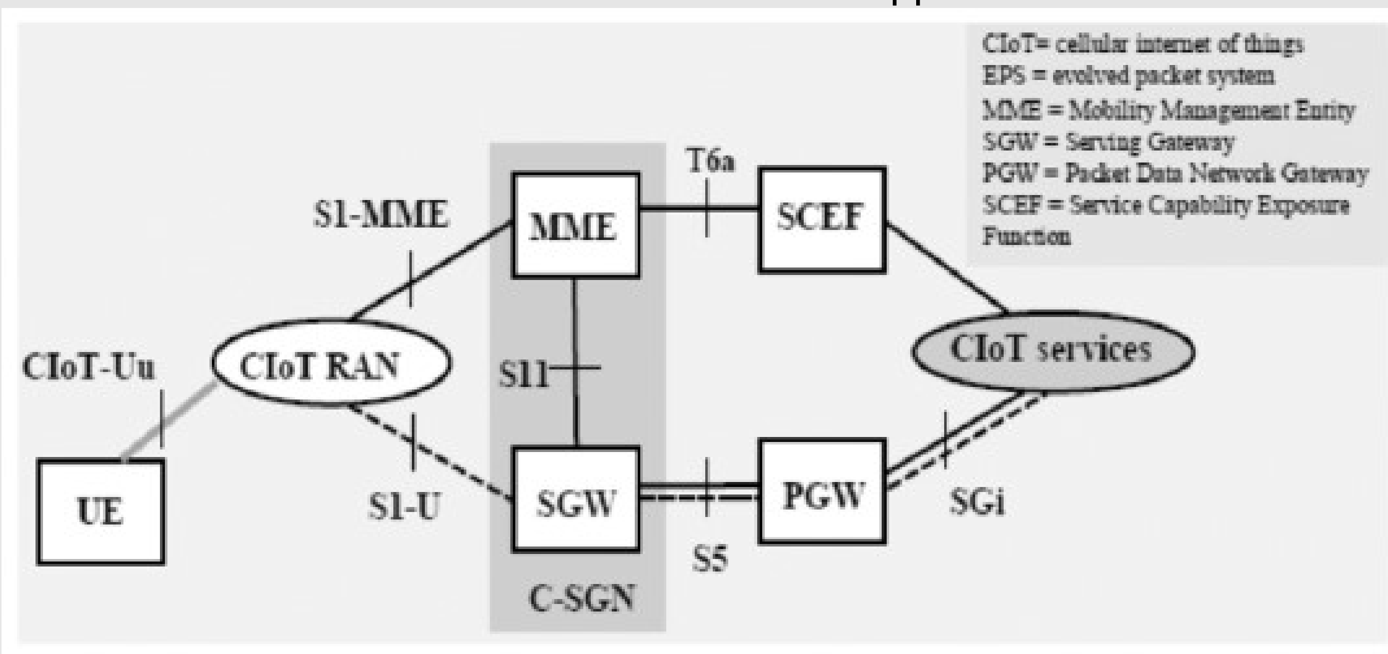
- **Low Power WAN (LPWAN) – licensed** (cont'd)
- **NB-IoT**
  - to increase the battery life, two mechanisms exist (in both NB-IoT and in LTE-M)
    - *power saving mode (PSM)* – maintains a terminal registered to the network, but allows it to enter in sleep mode and disable some functions like *paging listening* or *link quality measurements*
    - *expanded discontinuous reception (eDRX)* - allows a mobile terminal to negotiate when to enter the sleep state and for how long



Source: R.S.Sinha, Y.Wei, S.Hwang, "A survey on LPWA technology: LoRa and NB-IoT", ICT Express 3 (2017) 14–21, www.elsevier.com/locate/icte

3. Cellular technologies for IoT

- **Low Power WAN (LPWAN) – licensed (cont'd)**
- **NB-IoT (cont'd)**
  - **NB-IoT Network** architecture
    - LTE functional blocks are present in the Core network
    - The CIoT RAN can be customized for IoT applications



Source: R.S.Sinha, Y.Wei, S.Hwang, "A survey on LPWA technology: LoRa and NB-IoT", ICT Express 3 (2017) 14–21, www.elsevier.com/locate/icte

3. Cellular technologies for IoT

- **Low Power WAN (LPWAN) – licensed** (cont'd)
- **LTE-M versus NB-IoT comparison**

	LTE-M	NB-IoT
RA protocol (based on PRACH)	Slotted-ALOHA	Slotted-ALOHA
Modulation type	QPSK/QAM	BPSK/QPSK
Frequency	Licensed LTE bands	Licensed LTE bands
Bandwidth	1.4MHz	200kHz
Bidirectional	Full/Half-duplex	Half-duplex
Link budget	153dB	164dB
Maximum data rate	1Mbps	250kbps
Maximum payload length	1000bits	1000bits
Coverage	Few kilometers	1km (urban), 10km (rural)
Interference immunity	Low	Low
Battery life	10 years	10 years
Localization	Yes	Yes
Mobility	Yes	Yes

Source: J.Ding, M.Nemati, C.Ranaweera, and J.Choi, "IoT Connectivity Technologies and Applications: A Survey" arXiv:2002.12646v1 [eess.SP] 28 Feb 2020.

Contents

4. 5G General Characteristics

- **Three views/sets-of-requirements for 5G**
  - ***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, efficiently managed, programmable, and secure - communication infrastructure)
- **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
- **5G - key enabler for the Internet of Things, M2M**

4. 5G General Characteristics

- **5G Key technological characteristics**
  - Heterogeneous set of integrated air interfaces
  - Cellular and satellite solutions
  - Simultaneous use of different **Radio Access Technologies (RAT)**
    - **Seamless (vertical) 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)

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

4. 5G General Characteristics

- **Network softwarization:** represents sets of functions assuring **programmability** 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) and network capabilities
- **On demand composition** of NFs and network capabilities
- Develop network softwarization capabilities in all network segments and network components.

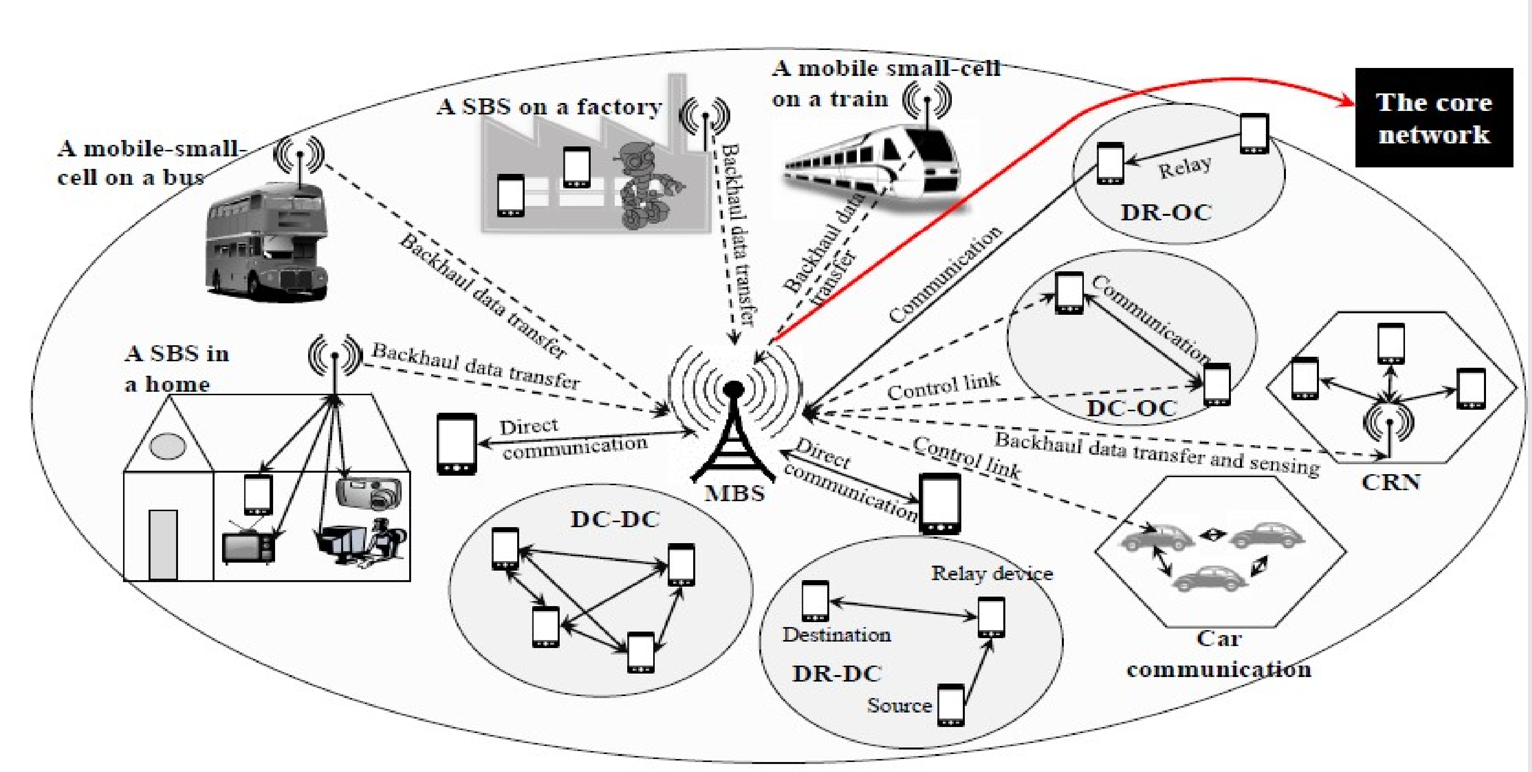
4. 5G General Characteristics

- **Summary of 5G figures - strong goals:**
  - **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

4. 5G General Characteristics

- **5G Generic Architecture**
  - multi-tier arch.: small-cells, mobile small-cells, and D2D- and Cognitive Radio Network (CRN)

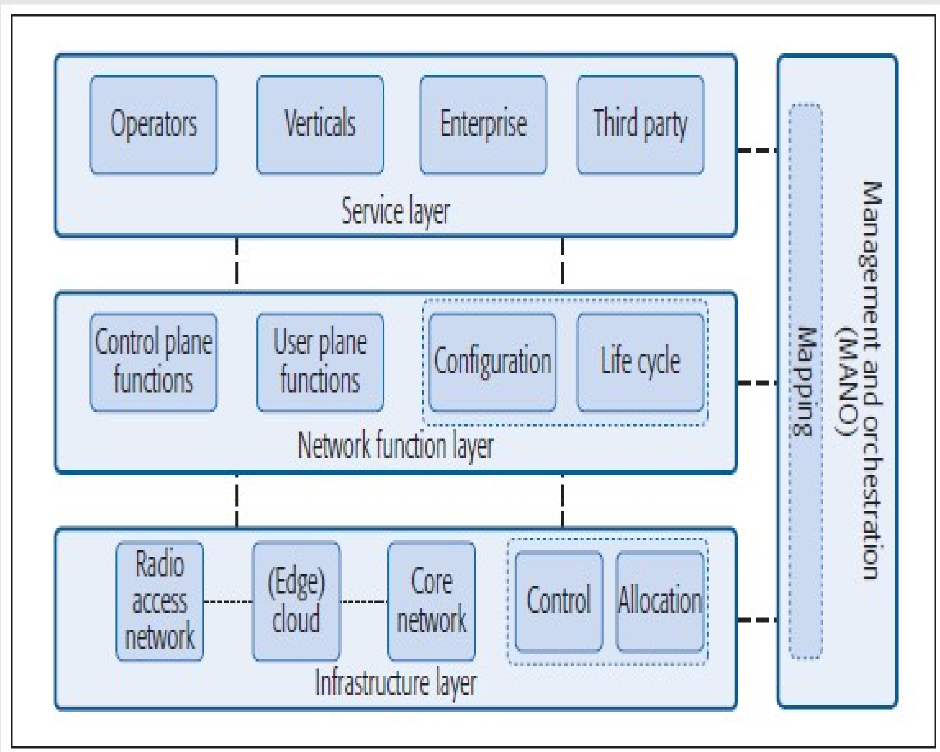
DR-OC - Device relaying with operator controlled link establishment
DC-OC - Direct D2D communication with operator controlled link establishment
DR-DC - Device relaying with device controlled link establishment
DC-DC - Direct D2D communication with device controlled link establishment



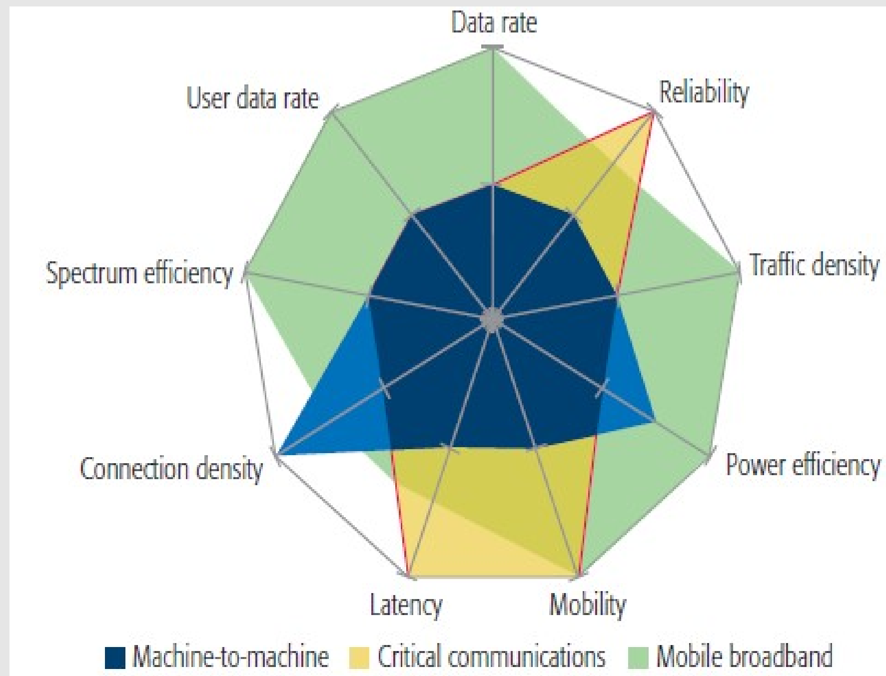
Source: Panwar N., Sharma S., Singh A. K. ,A Survey on 5G: The Next Generation of Mobile Communication'. Accepted in Elsevier Physical Communication, 4 Nov 2015, http://arxiv.org/pdf/1511.01643v1.pdf

5G Layered Functional Architecture

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



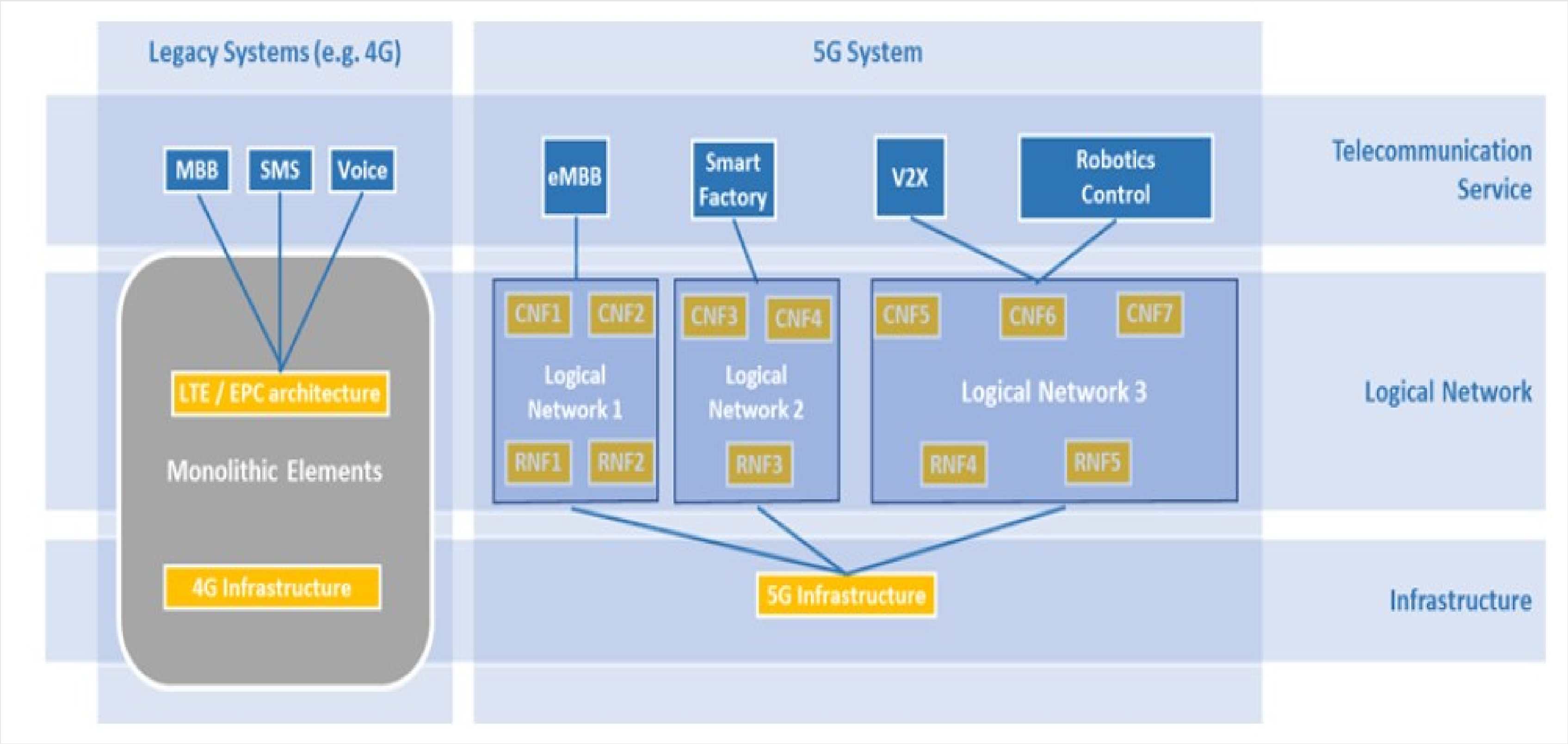
Key 5G use cases and their requirements
- difficult for a traditional unique arch to meet all of them
- **dedicated slicing can be the solution**



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

4. 5G General Characteristics

- **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

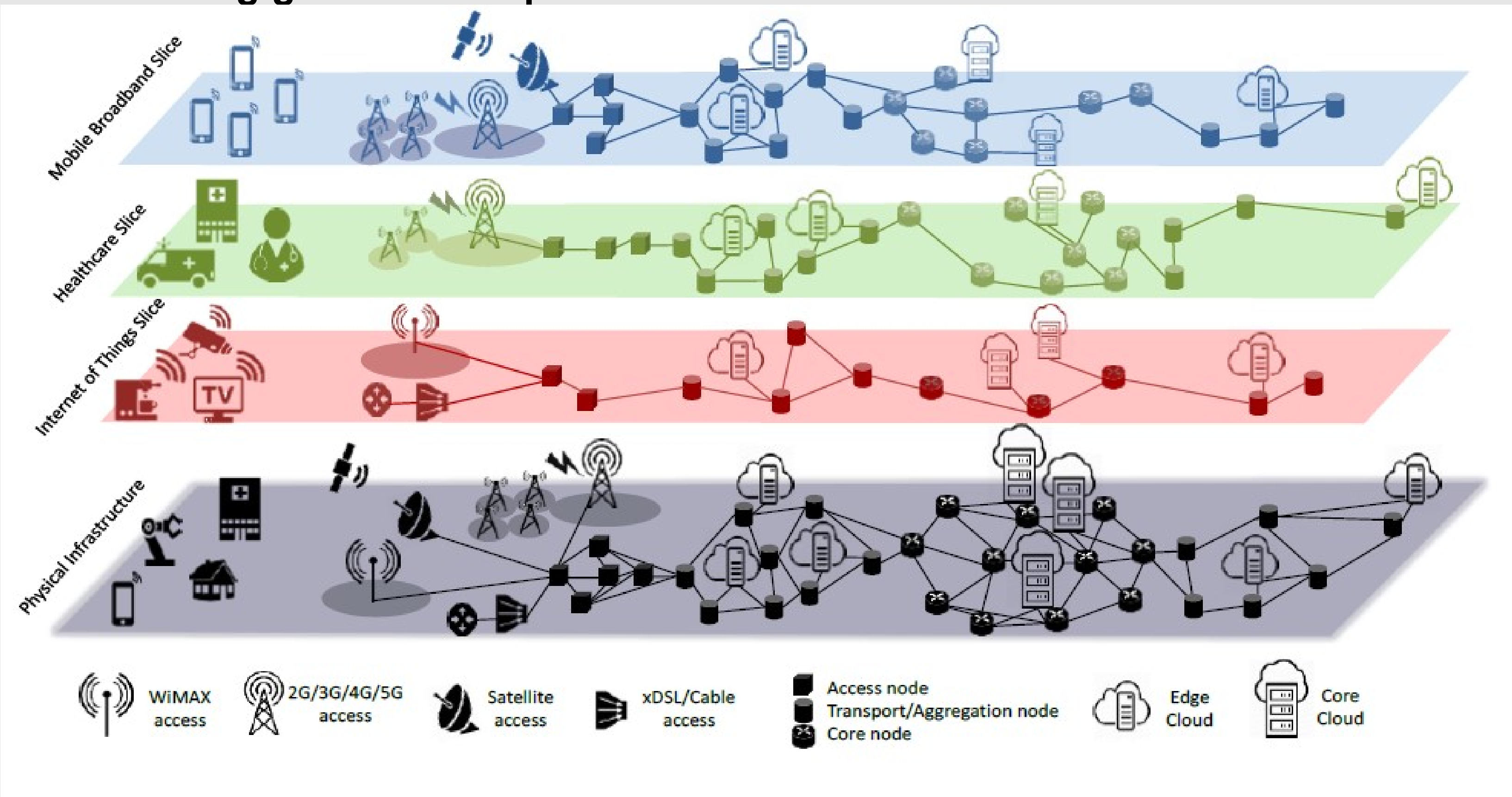
4. 5G General Characteristics

- **5G Network slicing concepts**

- **E2E concept:** covering all network segments : radio, access/edge, wire, core, transport and edge networks.
- **concurrent deployment of multiple E2E logical, self-contained and independent shared or partitioned networks** on a common infrastructure platform
- **Slices**
  - created **on demand**, running on a common underlying (P/V) network, 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 reqs. (e.g., bandwidth, latency, processing, resiliency) coupled with a business purpose
- **SDN and NFV** – support technologies providing virtualization, programmability, flexibility, and modularity to create **multiple network slices** each tailored for a given UC

4. 5G General Characteristics

- **5G Network slicing concepts** (cont'd)
  - **5G slicing generic example**



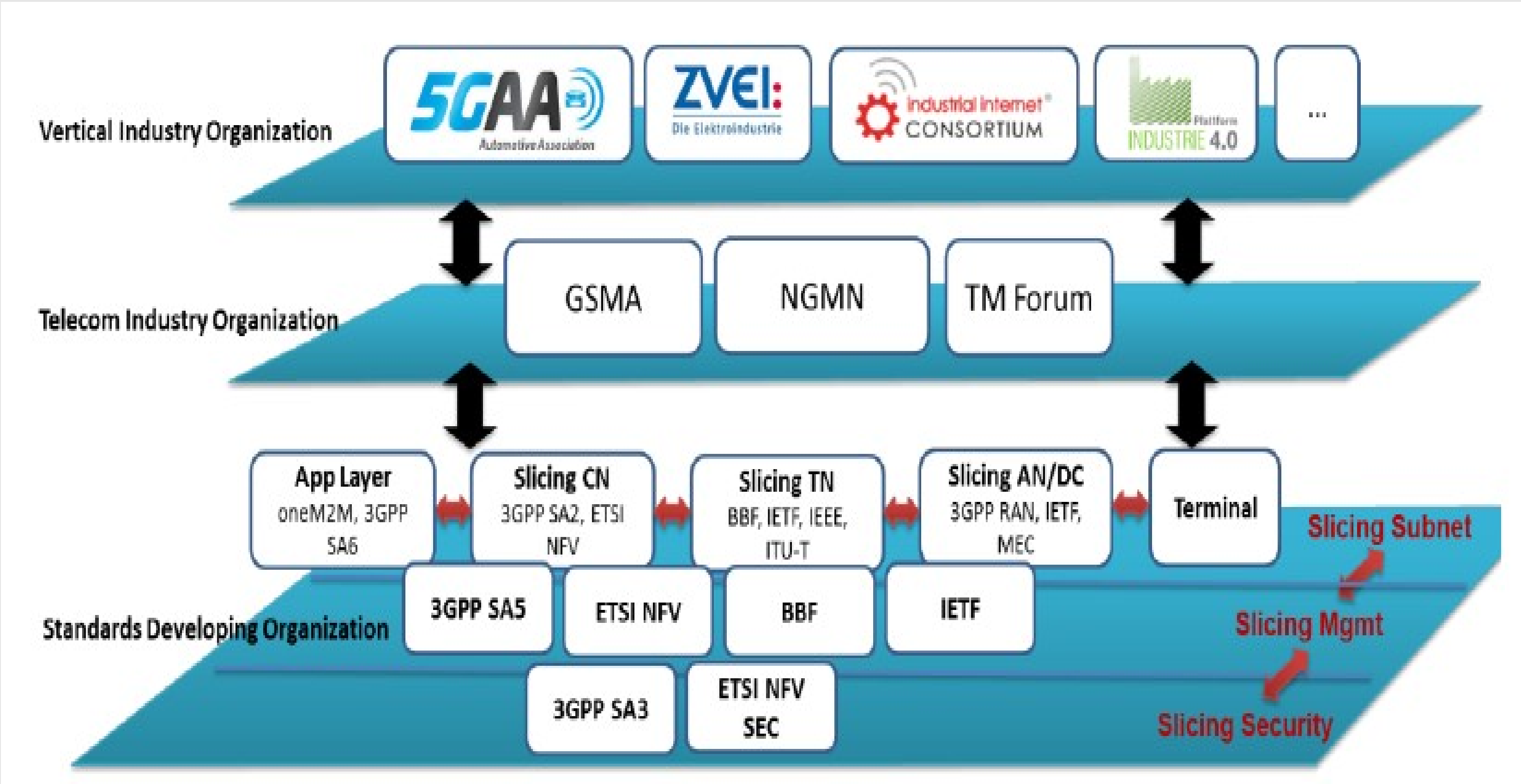
Source: J. Ordonez-Lucena, P. Ameigeiras, D. Lopez, J.J. Ramos-Munoz, J. Lorca, J. Folgueira, Network "Slicing for 5G with SDN/NFV: Concepts, Architectures and Challenges" , IEEE Communications Magazine, 2017, Citation information: DOI 10.1109/MCOM.2017.1600935

4. 5G General Characteristics

- **Standardization work oriented to slicing**
- **European Telecom Std. Institute (ETSI)** –**Next Generation Protocols (NGP)** – Technology independent approach to slicing
  - **ETSI- Network Function Virtualization (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. 5G General Characteristics

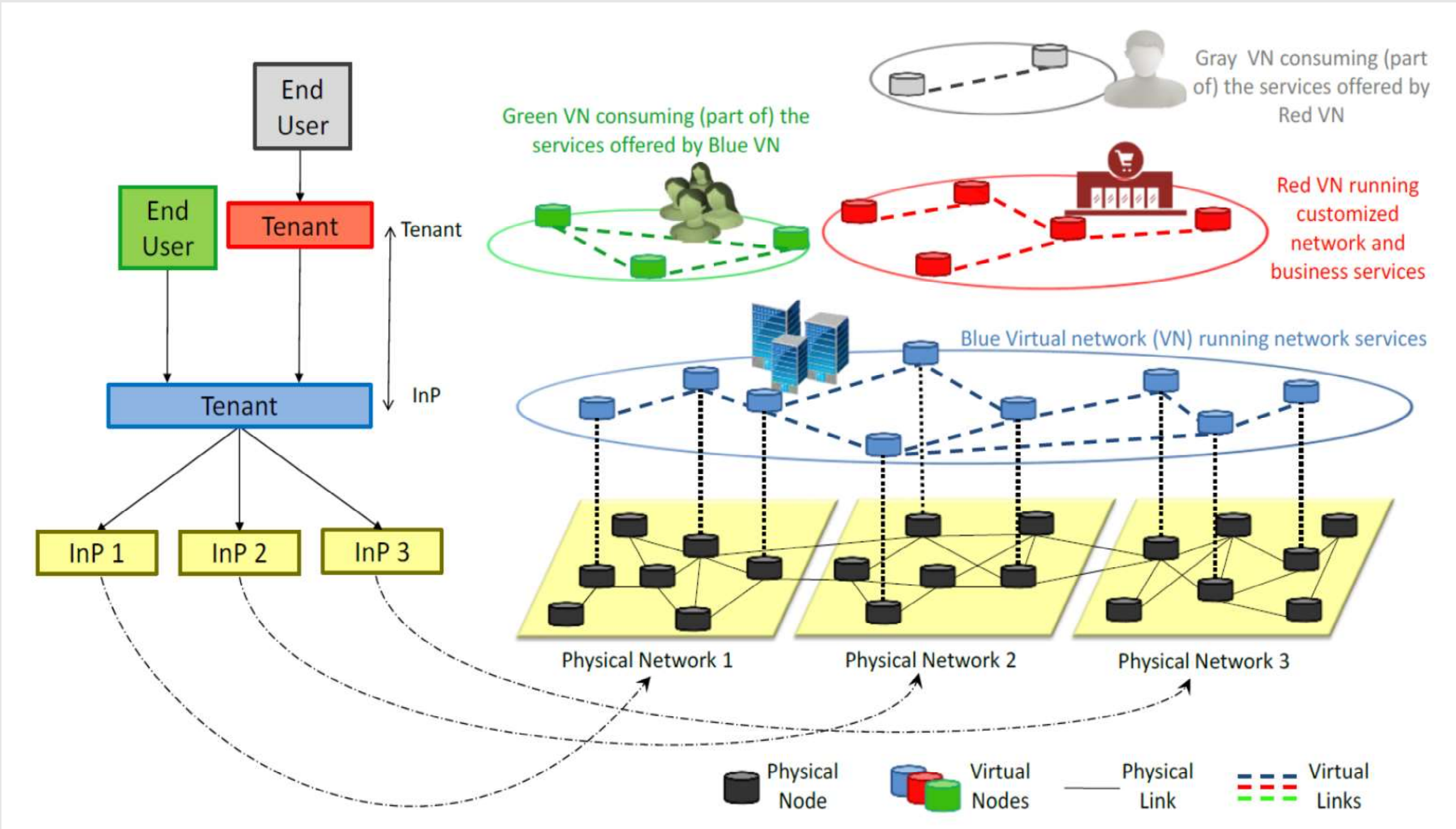
- **Standardization effort oriented to slicing** (cont'd)



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

4. 5G General Characteristics

- **Business model (actors) - example**
  - **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. 5G General Characteristics

- **Categories of 5G fundamental – slicing scenarios**
  - **Massive machine type communication (mMTC) – aiming to IoT apps.**
  - **Ultra reliability low latency communication (URLLC)**
  - **Enhanced mobile broadband (eMBB)**
  - **different requirements on 5G: functional** (e.g. priority, charging, policies, security, and mobility) and **performance** (e.g. latency, mobility, availability, reliability and data rates) -→ **dedicated slices can be constructed**

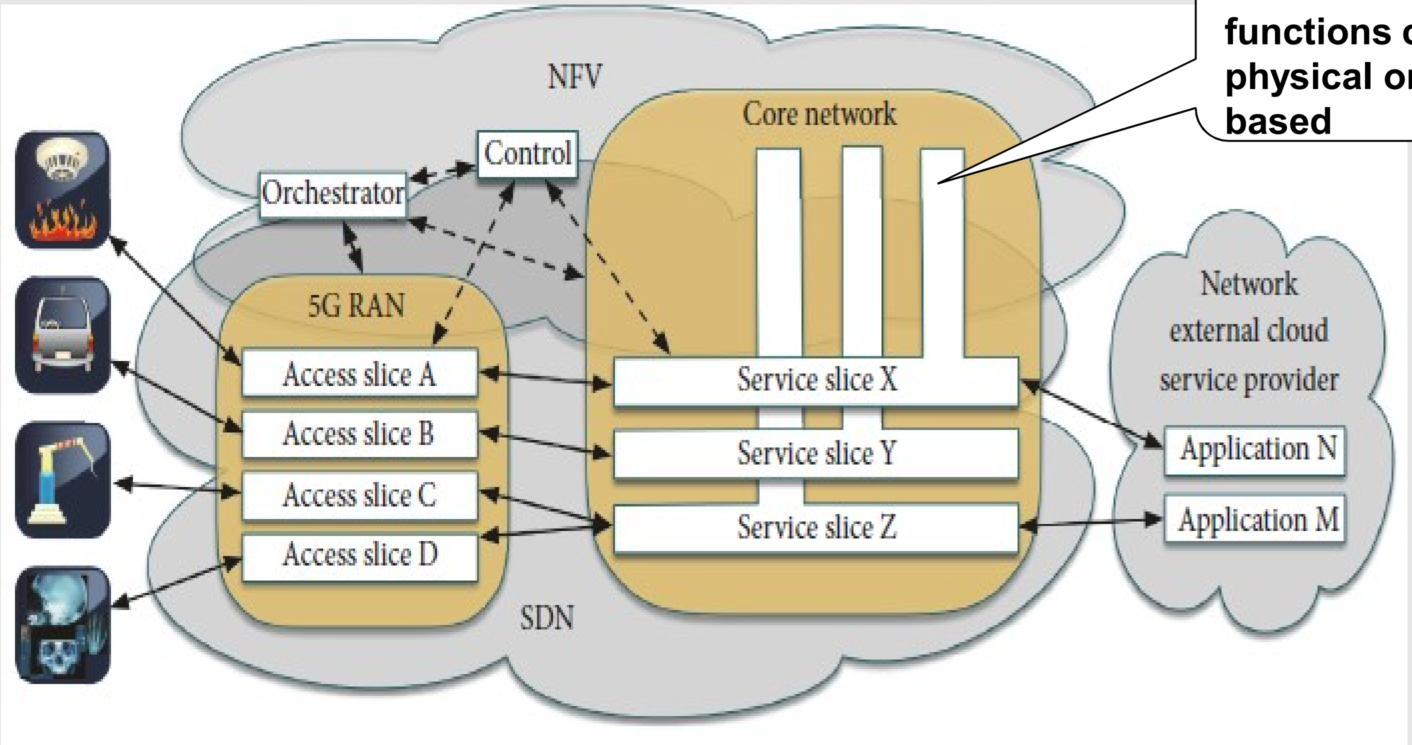
Characteristics	mMTC	URLLC	eMBB
Availability	Regular	Very High	Regular (baseline)
E2E latency	Not highly sensitive	Extremely sensitive	Not highly sensitive
Throughput type	Low	Low/med/high	Medium
Frequency of Xfers	Low	High	High
Density	High	Medium	High
Network coverage	Full	Localized	Full

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

4. 5G General Characteristics

- **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/

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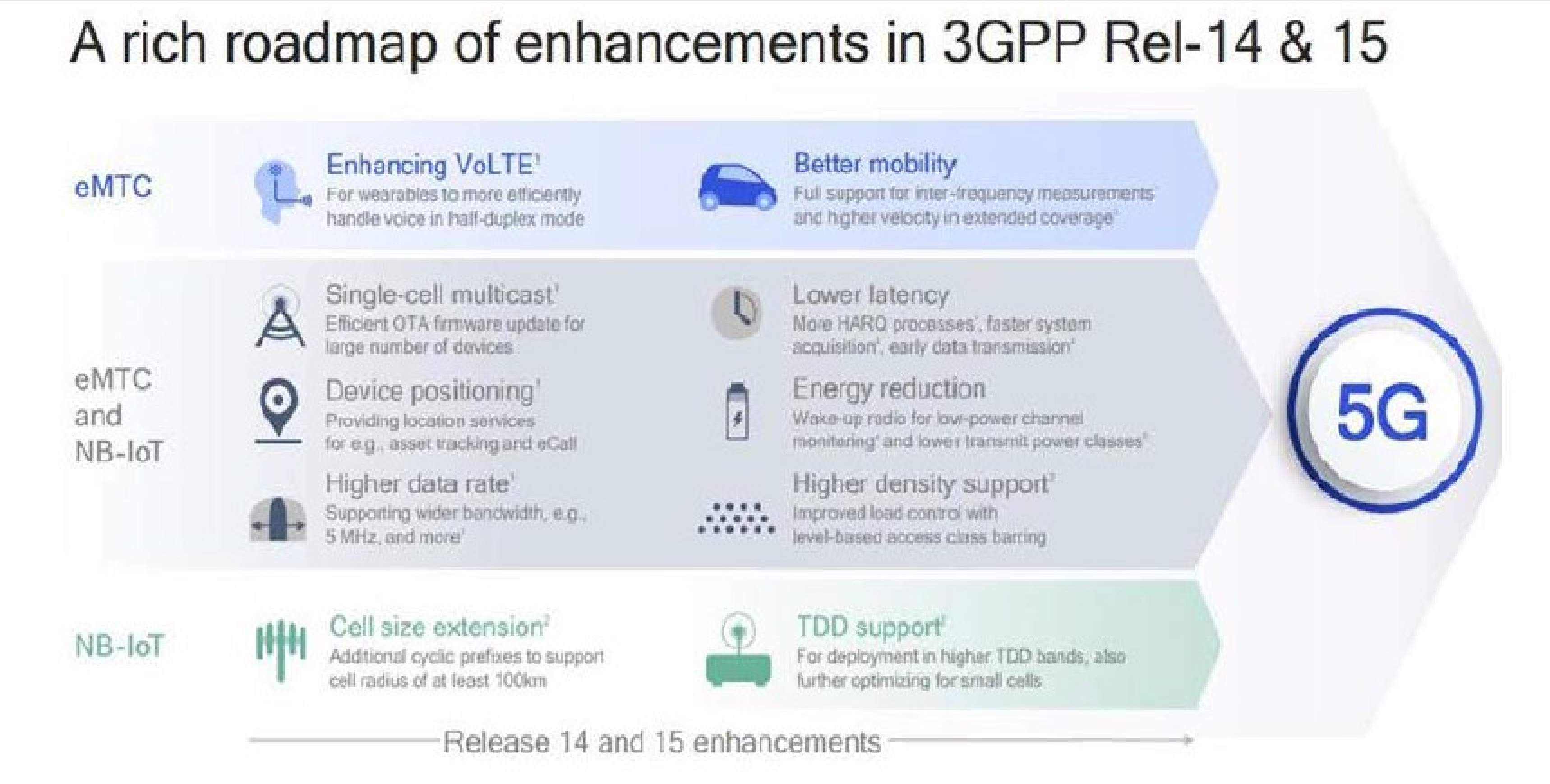
5. 5G solutions for IoT

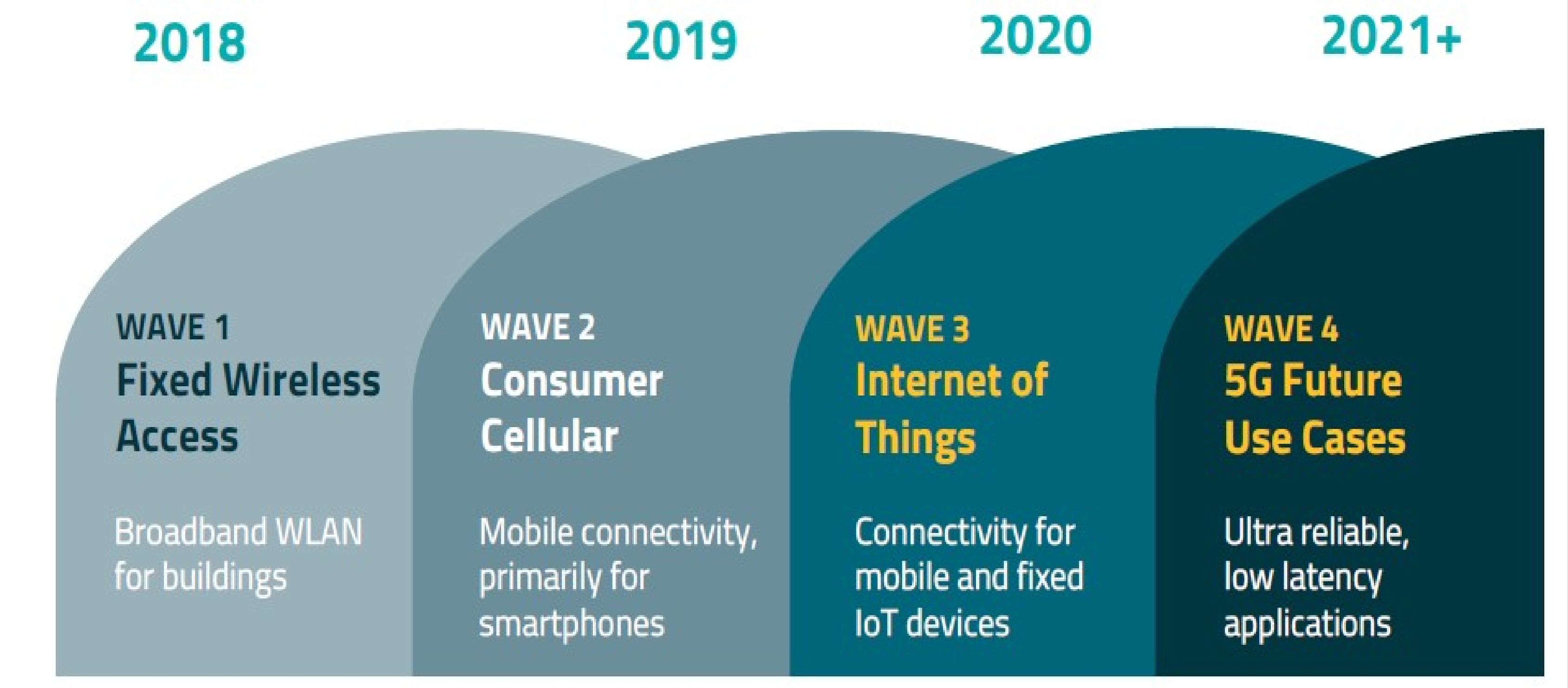
- **3GPP enhancement towards 5G**



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

5. 5G solutions for IoT

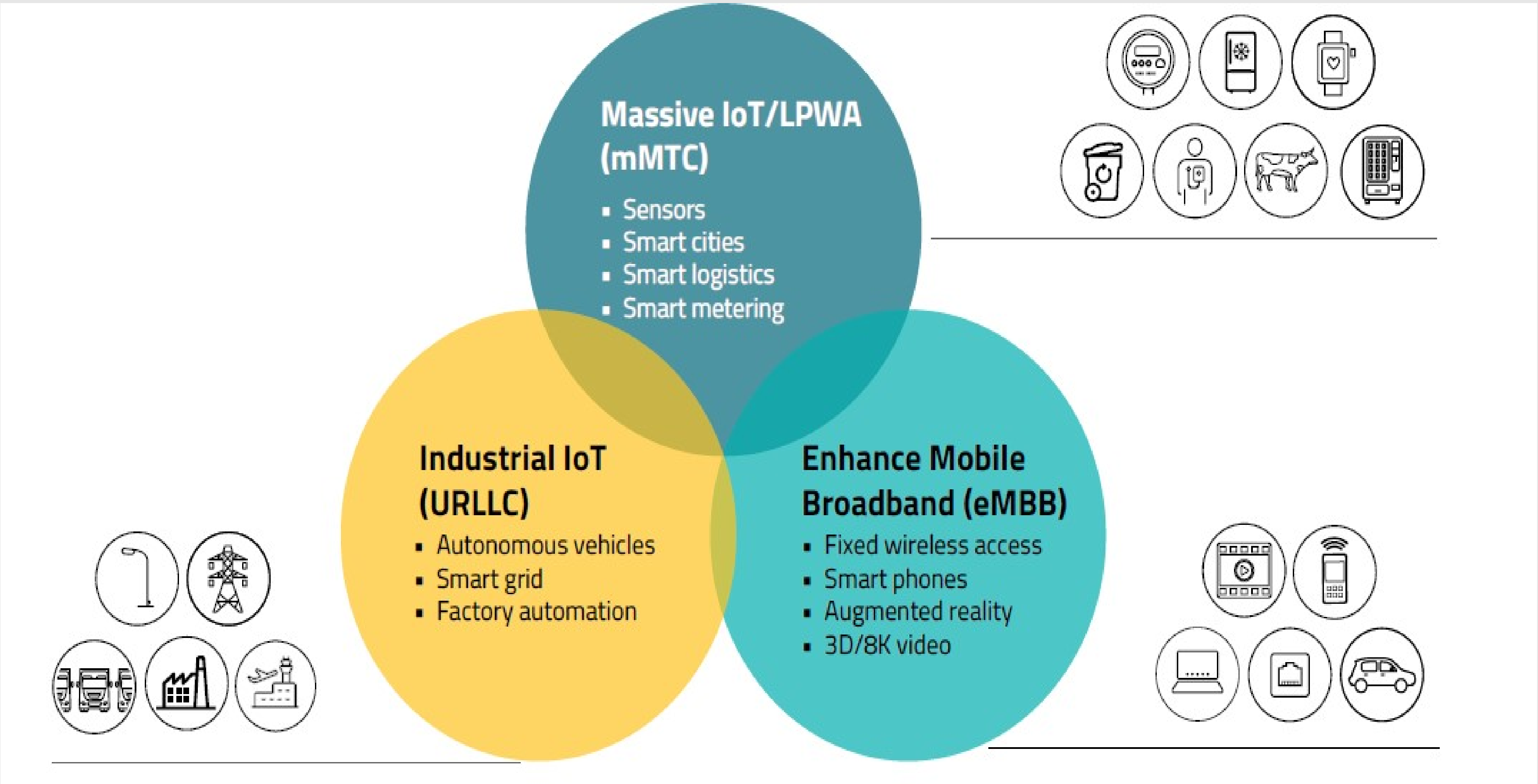
- **5G Commercialization Timeline**
  - **Wave 3 → IoT**



Source: SIERRA WIRELESS White Paper, "5G for IoT?", https://www.sierrawireless.com/resources/white-paper/5g-for-iot/

5. 5G solutions for IoT

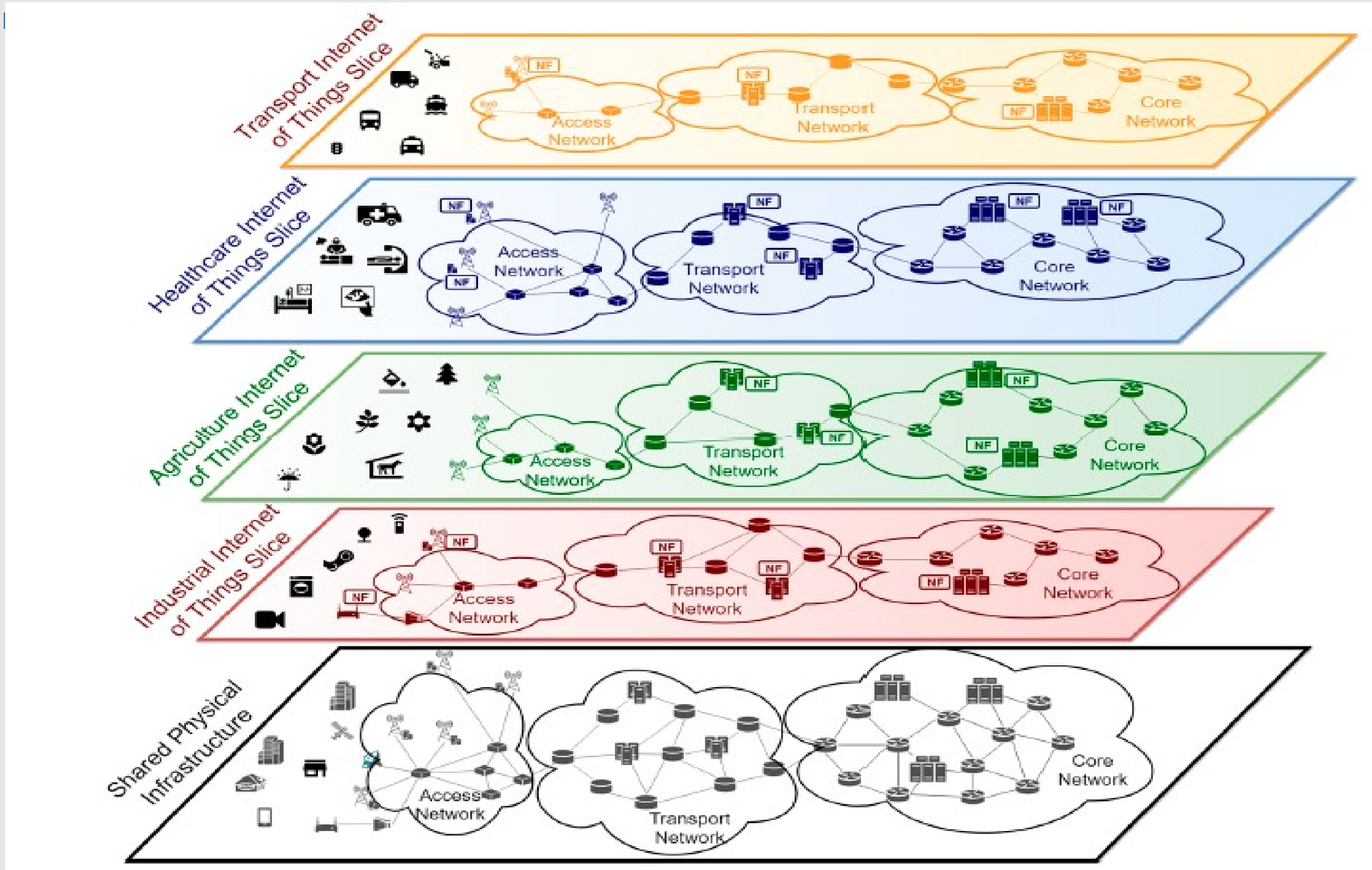
- **5G -Current and Future Use Cases in Consumer and IoT Markets**



Source: SIERRA WIRELESS White Paper, "5G for IoT?", https://www.sierrawireless.com/resources/white-paper/5g-for-iot/

5. 5G solutions for IoT

- **5G –slices for IoT - examples**



Source: J.M Fernandez I.Vidal and F.Valera, "Enabling the Orchestration of IoT Slices through Edge and Cloud Microservice Platform", Sensors 2019, 19, 2980; doi:10.3390/s19132980, www.mdpi.com/journal/sensors

5. 5G solutions for IoT

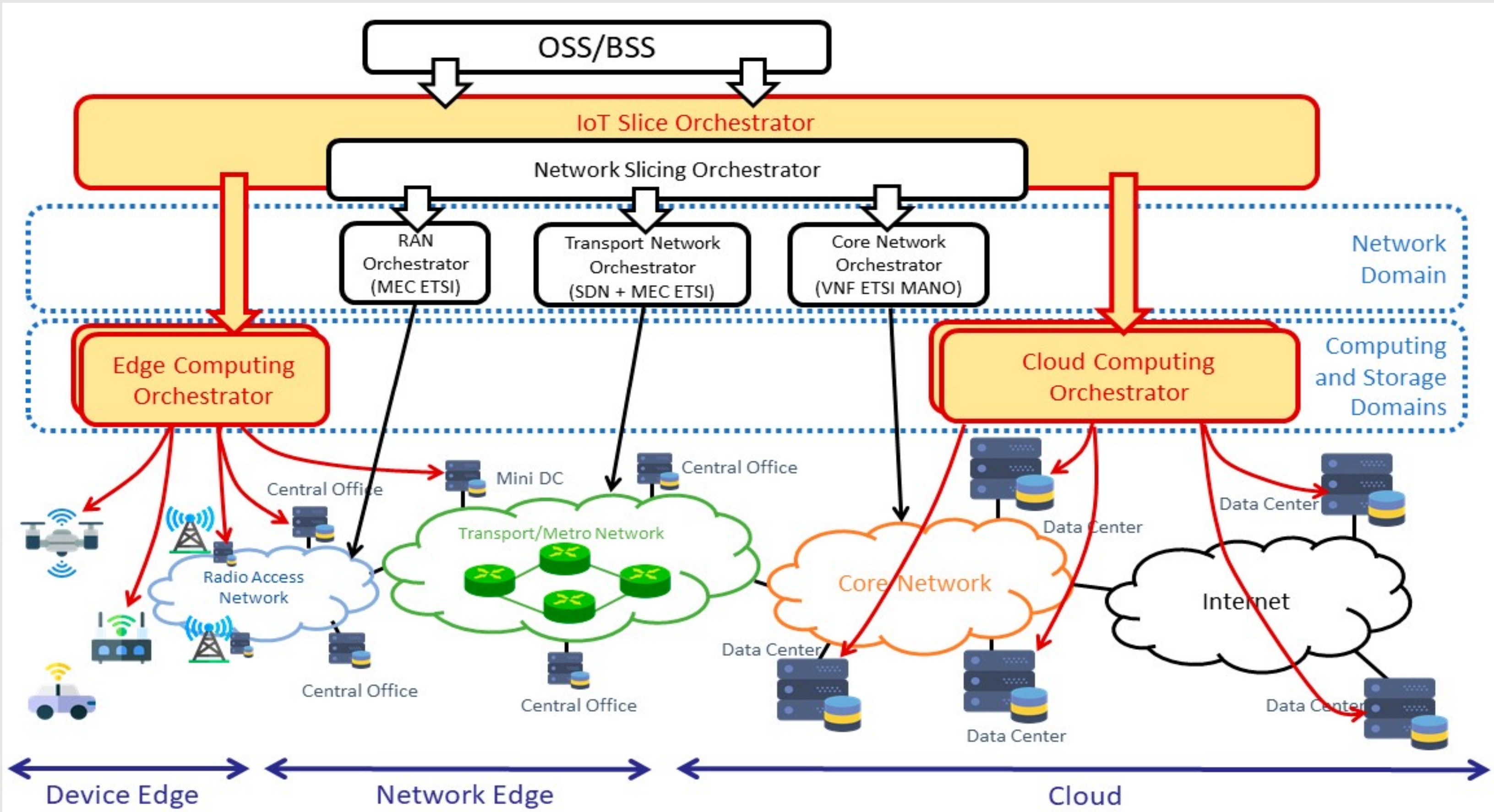
- **5G –slices for IoT – general slice orchestration solution -** example

  Source : J.M Fernandez I.Vidal and F.Valera, "Enabling the Orchestration of IoT Slices through Edge and Cloud Microservice Platform", Sensors 2019, 19, 2980; doi:10.3390/s19132980, www.mdpi.com/journal/sensors

  - *(See next slide)*
  - **Domains:**
    - Radio Access Networks (RAN)
    - Aggregation and transport networks (ATN)
    - Core networks (CN)
    - Edge/cloud infrastructures (ECI)
  - **Slice types:** End to End, Multi-tenant
- **Why IoT slice orchestration?**
  - **IoT slice orchestrator – main orchestration entity in the system**
    - coordinates the deployment and configuration of the software entities (e.g., case network functions) composing an IoT service, and their inter- connectivity
    - provides an interface to the Operations Support System/Business Support System (OSS/BSS)
      - The OSS/BSS may request to IoT Orchestrator to create IoT slices with specific requirements.
    - includes a *network slice coordinator function* (Network Slicing Orchestrator NSO)
      - NSO coordinates the operation of the diverse (regional) network orchestrators operating locally at each network domain.

5. 5G solutions for IoT

- **5G –slices for IoT – general slice orchestration solution** example (cont'd)



Source : J.M Fernandez I.Vidal and F.Valera, "Enabling the Orchestration of IoT Slices through Edge and Cloud Microservice Platform", Sensors 2019, 19, 2980; doi:10.3390/s19132980, www.mdpi.com/journal/sensors

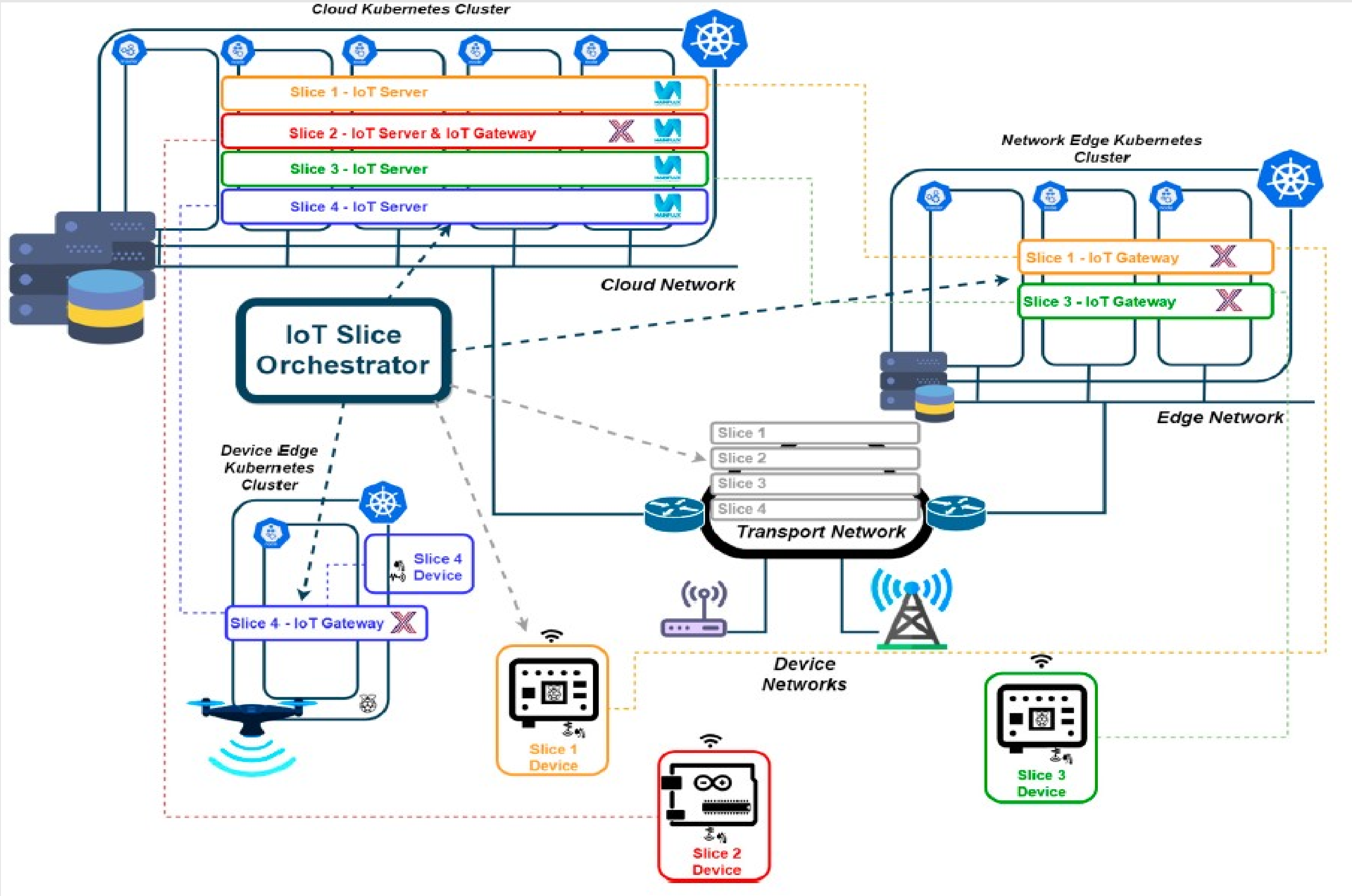
5. 5G solutions for IoT

- **5G –slices for IoT – general slice orchestration solution** example (cont'd)
- **Orchestration entities – hierarchy**
  - **IoT Slice Orchestrator**
  - **Network Slicing Orchestrator** - master
  - **Network domains orchestrators**
    - RAN Orchestrator
      - Possible technology : *Multi-access Edge Computing (MEC-ETSI)*
    - Transport network orchestrator – here one can use technologies like
      - *Software Defined Networking (SDN)* to control the connectivity
      - *MEC- ETSI* for edge cloud computing resources
    - Core network orchestrator
      - *Network Function Virtualization* technologies
      - *ETSI Management and Orchestration* functions - ETSI MANO

  - **Edge Computing Orchestrator**
    - under control of the IoT Slice Orchestrator
    - orchestrates the edge computing functions (in RAN and Transport networks)
  - **Cloud Computing Orchestrator**
    - under control of the IoT Slice Orchestrator
    - orchestrates the central cloud computing functions (Data Ceters connected to Core network or Internet)

5. 5G solutions for IoT

- **5G –slices for IoT – general slice orchestration solution** (cont'd)
  - **Implementation example**



Source : J.M Fernandez I.Vidal and F.Valera, "Enabling the Orchestration of IoT Slices through Edge and Cloud Microservice Platform", Sensors 2019, 19, 2980; doi:10.3390/s19132980, www.mdpi.com/journal/sensors

5. 5G solutions for IoT

- **5G –slices for IoT – general slice orchestration solution** (cont'd)
- **Implementation example (cont'd)**
  - **Principles: microservices**
  - **IoT Gateway** functions (e.g., Edge X Foundry)
  - **IoT Server** functions (e.g. Mainflux)
  - **Implementation Support example**
    - *Kubernetes*
      - System for management of *open source* containers for implementaion automation, scaling and application distribution
      - It offers an automation platform for containerised systems (e.g., . Docker)
      - REST interfaces related to IoT functions orchestration and mcroservces which compose these functions

    - The IoT Orchestrator IoT can deploy *deploy*) IoT servers and IoT Gateways in different locations *(edge/cloud)*
      - In previous slide example the locations are *Kubernetes clusters;* however, any infrastructure (which could host virtualized applications) could be used instead
    - The *cloud network*, *transport network* si *edge network are organized in slices*

    - The IoT Slice Orchestrator controls the subordinate entities in a hub style

5. 5G solutions for IoT

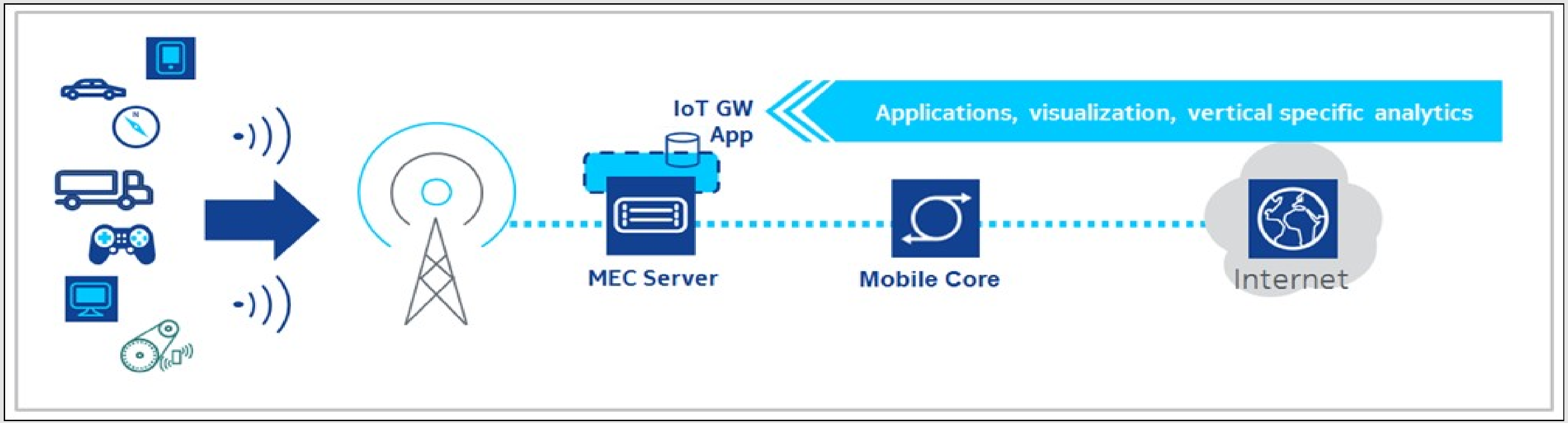
- **5G – IoT and Multi-access Edge Computing (MEC)**

- **Multi-access Edge Computing (** former Mobile Edge Computing)
  - currently being standardized in an ETSI ISG)
  - provides an IT service environment and cloud-computing capabilities at the edge of the mobile network, within the RAN and in close proximity to mobile subscribers
  - **low latency, proximity, high bandwidth, and real-time insight into radio network information and location awareness**
  - natural development in the evolution of mobile base stations and the convergence of IT and telecommunications networking
  - based on a virtualized platform
  - recognized by the **European 5G PPP** (5G Infrastructure Public Private Partnership) as one of the **key emerging technologies for 5G networks** together with
    - Network Functions Virtualization (NFV)
    - Software-Defined Networking (SDN)

  - **IoT is one of the most important MEC application instances**
  - benefits of employing MEC into IoT systems
    - E.g. lowering the amount of traffic passing through the infrastructure and reducing the latency for applications and services
    - Environment/location awareness

5. 5G solutions for IoT

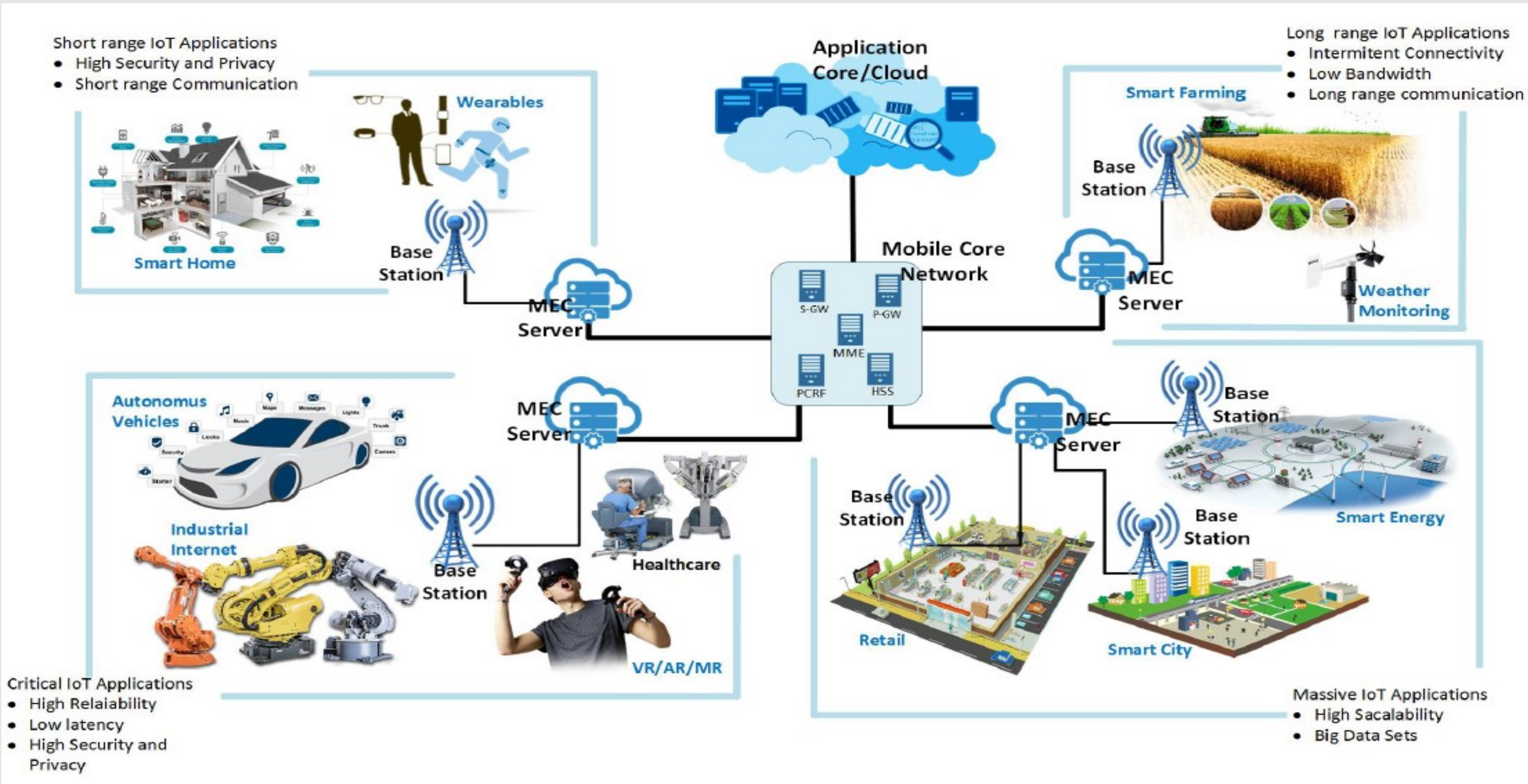
- **5G – IoT and Multi-access Edge Computing**
  - **Example 1: IoT Gateway**
  - IoT requires gateways to aggregate the messages and ensure low latency and security.
  - a real time capability is required and a grouping of sensors and devices is needed for efficient service.
  - IoT devices are resource constrained
    - need to aggregate various IoT device messages connected through the mobile network close to the devices
    - This also provides an analytics processing capability and a low latency response time
    - **MEC could be the solution**



Source: Y.-C. Hu, M. Patel, D. Sabella, N. Sprecher, and V. Young, "Mobile Edge Computing A Key Technology Towards 5G," ETSI White Paper, vol. 11, no. 11, pp. 1–16, 2015.

5. 5G solutions for IoT

- **5G – IoT and Multi-access Edge Computing** (cont'd)
  - **Example 2:Using MEC for different IoT applications**…



Source: Y.-C. Hu, M. Patel, D. Sabella, N. Sprecher, and V. Young, "Mobile Edge Computing A Key Technology Towards 5G," ETSI White Paper, vol. 11, no. 11, pp. 1–16, 2015.

Contents

6. Conclusions

- **IoT connectivity** subsystem – essential part of the IoT assembly
- Large set of technologies and protocols
  - Usually adapted for low bit rate, low power devices
  - Short, medium and long ranges
  - Protocols of different layers
  - Working in licensed or unlicensed bands

- **Cellular systems** – strong candidates to support IoT connectivity
  - LTE-A (NB-IOT, LTE-M, ..)
  - Emergent 5G – able to support
    - Many terminals
    - High bit rates,
    - High density
    - Low power devices
    - Flexibility, virtualization
    - ….

  - 5G slicing – powerful technology to support customization of virtual networks dedicated to different sets of IoT applications

6. Conclusions

- **5G-IoT Research challenges and future directions**
  - Scalability
  - Security and privacy
  - Management of resources at lower layers
  - Network and services management
  - Interoperability (with other IoT technologies)and heterogeneity
  - Network mobility and coverage

  - Many 5G slicing and MEC - still open issues - in IoT environment
    - Multi-domain
    - Multi-tenant
    - Multi-operator
    - E2E
    - Slice creation, isolation, maintenance
    - ….

Thanks!
Questions?

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List of Acronyms

3GPP 3rd Generation Partnership Project (3GPP)
6Lo IPv6 over Networks of Resource Constrained Nodes
6LoWPAN IPv6 over Low Power Wireless Personal Area Networks
6TiSCH IPv6 over Time Slotted Channel Hopping Mode of IEEE 802.15.4e
ALME Abstraction Layer Management Entity
AMQP The Advanced Message Queuing Protocol
AV Audio-Visual
CA Collision Avoidance
CARP Channel-Aware Routing Protocol
CoAP Constrained Application Protocol
CoRE Constrained RESTful Environment
CORPL Cognitive RPL
CRC Cyclic redundancy check
CSMA Carrier Sense Multiple Access
CSMA/CA Carrier Sense Multiple Access with Collision Avoidance
DAO Destination Advertisement Object
DAO-ACK DAO Acknowledgment
DASH7 Named after last two characters in ISO 18000-7
DDS Data Distribution Service
DECT Digital Enhanced Cordless Telephone
DECT/ULE Digital Enhanced Cordless Telephone with Ultra Low Energy

List of Acronyms

DODAG Information Object
DIS DODAG Information Solicitation
DODAG Destination Oriented Directed Acyclic Graph
eNB E-UTRAN Node B (4G Base station)
EUI-64 Extended Unique Identifier 64-bit
ETSI- European Telecom Std. Institute
FCAPS Fault, Configuration, Accounting, Performance and Security
FDMA Frequency division multiple access
HART Highway Addressable Remote Transducer Protocol
HomePlug-AV HomePlug Audio-Visual
HomePlugGP HomePlug GreenPHY
IBM International Business Machine Corporation
ICMPv6 Internet Control Message Protocol Version 6
ID Identifier
IEEE Institution of Electrical and Electronic Engineers
IETF Internet Engineering Task Force
IoT Internet of Things
IP Internet Protocol
IPv6 Internet Protocol version 6
ISM Industrial, Scientific and Medical frequency band
ITU-T International Telecommunications Union - Telecommunications
ITU International Telecommunications Union
L2CAP Logical Link Control and Adaptation Protocol
LoRaWAN Long Range Wide Area Network

List of Acronyms

LTE-A Long-Term Evolution Advanced
LTE Long-Term Evolution
MANO Management and Orchestration
M2M Machine to Machine
MAC Media Access Control
MQTT Message Queue Telemetry Transport
NFC Near Field Communication
NFV Network Function Virtualization
OASIS Advancing Open Standards in the Information Society
OFDM Orthogonal Frequency Division Multiplexing
OMG Object Management Group
PA Process Automation
PHY Physical Layer
QoS Quality of Service
RAN Radio Access Network
REST Representational State Transfer
RESTful Representational State Transfer based
RFC Request for Comments
RFID Radio-frequency identification
RPL Routing Protocol for Low-Power and Lossy Networks
SDN Software Defined Networking
SIG Special Interest Group
SMQTT Secure MQTT
SOA Services Oriented Architecture

List of Acronyms

SSL Secure Socket Layer
TCP Transmission Control Protocol
TDMA Time Division Multiple Access
TDMA Time Division Multiple Access
TEDS Transducer Electronic Data sheets
TLS Transport Level Security
TSCH Time-Slotted Channel Hopping
UDP User Datagram Protocol
ULE Ultra-Low Energy
VNF Virtualized Network Function
WIA-PA Wireless Networks for Industrial Automation Process Automation
WiFi Wireless Fidelity
WirelessHART Wireless Highway Addressable Remote Transducer Protocol
WPAN Wireless Personal Area Network
XML Extensible Markup Language
XMPP Extensible Messaging and Presence Protocol