Vehicles to Everything Communications and Services on 5G Technology

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NexComm 2020 Conference, February 23 - 27, Lisbon

Vehicles to Everything Communications and Services on 5G Technology

- **Acknowledgement**
  - This tutorial **is compiled and structured based on several public documents** like: conference proceedings, studies (overviews, tutorials, research papers), standards, projects, etc. (see specific references in the text and the Reference list).
  - **The selection and structure of this material belong to the author.**
  - **Notes:**
    - Given the extension of the topics, this **presentation is limited to a high level overview only**, mainly on conceptual, architectural and specific design aspects.
    - Some examples taken from the literature, projects, etc. are selected to illustrate architecture and implementations of V2X on top of 5G networks – especially in 5G slicing context.

Vehicles to Everything Communications and Services on 5G Technology

- **Motivation of this talk**

- **Vehicles and transportation systems** -essential parts of the today society
  - they are driving factors for the development of vehicular networks and associated services
- **Current solutions**
  - **Intelligent Transport System (ITS) – mature set of standards and implementations**
    - the initial applications aimed the traffic safety and efficiency only
    - ITS includes vehicular communication (VC) and specific communication technologies (wireless- WiFi, cellular; wireline, ..)

- **Recent extension: Vehicle to Everything (V2X) communications and services**

- **Global extension of V2X: Internet of Vehicles (IoV) –**
  - involves Internet and includes heterogeneous access networks
  - IoV – can be seen as a special/extended use case of **Internet of Things (IoT)**

Vehicles to Everything Communications and Services on 5G Technology

- **Motivation of this talk (cont'd)**
- **The 5G (fifth generation) networks, in E2E architectures**
  - 5G← increasing demand of the current and future networks and services (flexibility, bandwidth, traffic capacity, response time, number of terminals, energy saving, etc.)
  - **Driving forces for 5G**: IoT, smart cities, industry, governance, IoV/automotive, safety/emergency, entertainment, environment, etc.

  - Standardization/fora organizations –involved
    - 3GPP, 5GPP, ETSI, ITU-T, GSMA, ONF, NGNM, IETF, IEEE, etc.
  - **5G Network slicing** –dedicated (to specific applications) logical, isolated networks, sharing the same physical network resources
    - multiple tenants, multiple network operators and/or services in multi-domain context

  - **5G – and in particular 5G slicing : strong support for V2X communications and services**
    - **V2X-5G - many research open issues and challenges**

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1. ➡ Vehicular networks- introduction
2. V2X use cases and requirements
3. 5G technology summary
4. V2X on 5G- system architectures and design
5. Examples of V2X 5G systems
6. Conclusions

1. Vehicular networks - introduction

- **1.1 Vehicular communications and services – types**
  - **Basic communications**
    - vehicle-to-vehicle (**V2V**)-direct communications
    - vehicle-to-road/infrastructure (**V2R/V2I**)
  - **Extended communication models :**
    - **Vehicular-to-everything (V2X)** - (see 3GPP Release 14, 15), adds several communication modes:
      - vehicle-to-pedestrian (**V2P**)- direct communication
        vehicle-to-vulnerable road user (VRU)
      - vehicle-to-network (**V2N**)- including cellular networks and Internet
      - Vehicle to sensors (**V2S**)
  - **Typical use cases and services/applications**
    - **Active road safety** applications
      - Warnings, notifications, assistance
    - **Traffic efficiency** and management applications
    - **Infotainment** applications

1. Vehicular networks - introduction

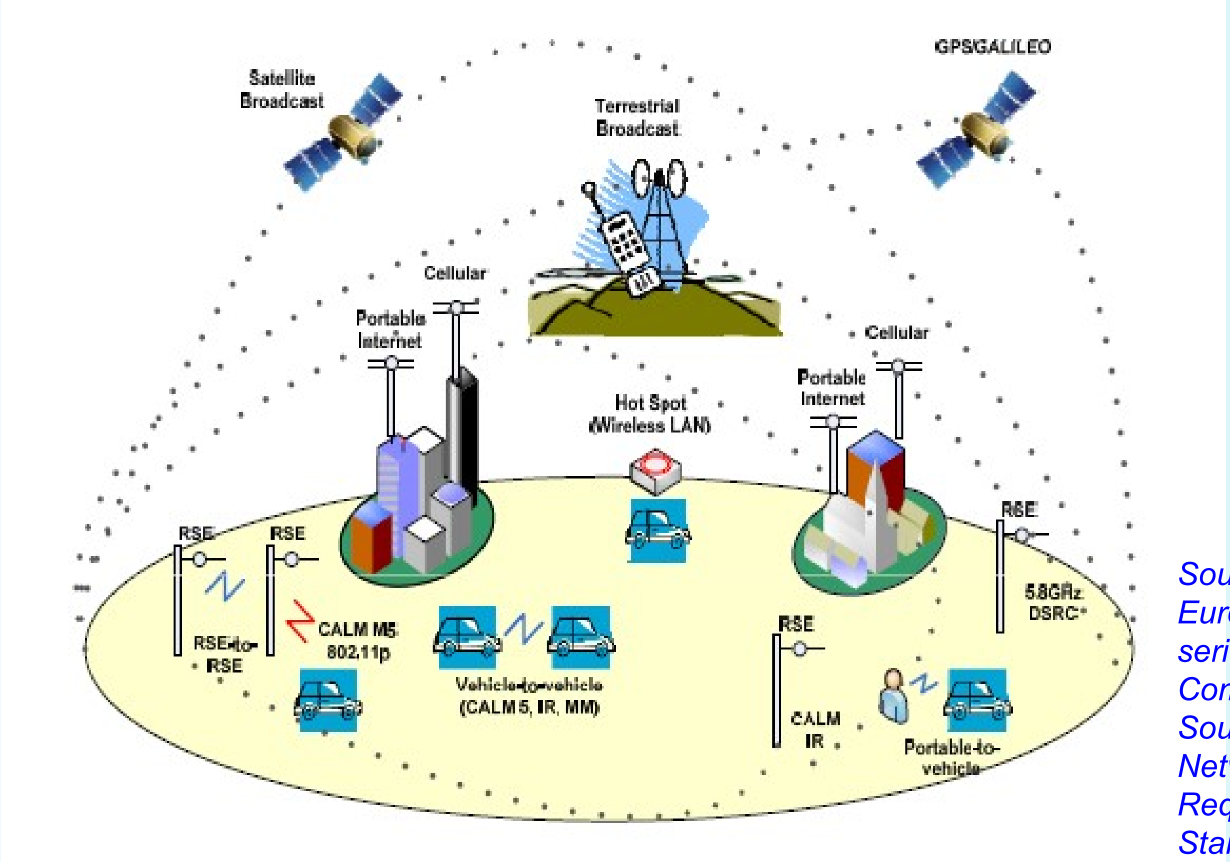
1.2 Current developments in vehicular communications and services

- Intelligent Transport System (ITS)
  - **Advanced technologies using IT&C,** to serve **transport systems**
    - provide innovative services for different modes of transport and traffic management
    - enable users to be informed and make safer, more coordinated, and 'smarter' use of transport networks
  - ITS targets all transport modes
  - **The EU directive (2010) defined ITS as systems in which IT&C are applied in the field of road transport,** including
    - infrastructure, vehicles and users
    - traffic management and mobility management
    - assist drivers with safety and other information
    - applications for passengers
    - interfaces with other modes of transport
  - **ITS: high interest for** companies, operators, government, academia, research; in many countries public and private sector bodies -work on ITS

1. Vehicular networks - introduction

1.2 Current developments in vehicular communications and services

- **Intelligent Transport System (cont'd)**
- Elements of ITS are standardized : on int'l level at e.g., ISO TC204, and on regional levels, e.g., in Europe at ETSI TC ITS and at CEN TC278



ITS Scenario illustration

Source : ETSI EN 302 665 V1.1.1 (2010-09, European Standard (Telecommunications series) Intelligent Transport Systems (ITS); Communications Architecture

Source : G.Karagiannis,et.al.,"Vehicular Networking:A Survey and Tutorial on Requirements,Architectures, Challenges, Standards and Solutions", IEEE Comm. Surveys and Tutorials, 2011

1. Vehicular networks - introduction

1.2 Current developments in vehicular communications and services

- **Intelligent Transportation System** (cont'd)
- **ITS Application categories**
    - Emergency vehicle notification systems
    - Automatic road enforcement
    - Variable speed limits
    - Collision avoidance systems
- **Networks involved in the ITS architecture**
  - **Ad-hoc network**
    - Essentially it is an ad-hoc V2V, connecting also roadside and personal ITS stations; Wireless technologies (limited range)
  - **Access Networks**
    - provides access to specific ITS services and applications
    - interconnect roadside ITS stations and provides communication between entities
    - can be operated by a road operator or other operators
  - **Core networks**
    - provide wide area connectivity

1. Vehicular networks - introduction

1.2 Current developments in vehicular communications and services

- **Intelligent Transport System and CALM**

- **ISO Technical Committee 204**:
  - http://www.sae.org/technicalcommittees/tc204wg16.htm
- WG 16: Wide Area Communications
  - **CALM: Communication Architecture for Land Mobile**
  - SWG 16.0-: SWG 16.6-: Architecture; Media; Network; Probe Data; Application Management; Emergency notifications (eCall); CALM ad-hoc subsystem
- CALM allows V2V, V2I and Internet access through multiple Radio access technologies (RATs)
  - (potentially used simultaneously)
- **Transmission media:**
  - Cellular (CALM 2G/3G) – cf CD 21212 & CD 21213, ...
  - Infrared light (IR) – cf CD 21214
  - Microwave (CALM M5) – cf CD 21215
  - **IEEE 802.11 a/b/g (WIFI)**
  - **IEEE 802.11p (mobile WIFI)**
  - Millimeter waves (CALM MM) – cf CD 21216
  - Microwaves CEN DSRC
- **Network protocol** : IPv6

1. Vehicular networks - introduction

- **1.2 Current developments in vehicular communications and services**
- **DSRC (Dedicated Short Range Communication)**
  - Related to the spectrum dedicated to VC and any type of communication among ITS components (vehicles, infrastructure)
  - two-way wireless system, operating in the 5.9 GHz licensed spectrum band.
  - US *Federal Communications Commission* (FCC) allocated 75 MHz of spectrum in the 5.9 GHz band for ITS - 1999
  - ETSI allocated 30 MHz of spectrum in the 5.9 GHz band for ITS- 2008
    - **Issue:** DSRC systems in Europe, Japan and U.S. are not compatible and include some significant variations (5.8 GHz, 5.9 GHz or even infrared, different baud rates, and different protocols)
- **WAVE (Wireless Access in Vehicular Environment)**
  - basically it defines all MAC/PHY protocols and standards used for vehicular communication (including DSRC)
  - however, the higher layers, such as **IEEE 1609.1-4**, are also considered as part of WAVE
  - **WAVE : IEEE 802.11 (2012) + IEEE 1609.1-4 + SAE 2735** (*Society of Automotive Engineers*)

1. Vehicular networks - introduction

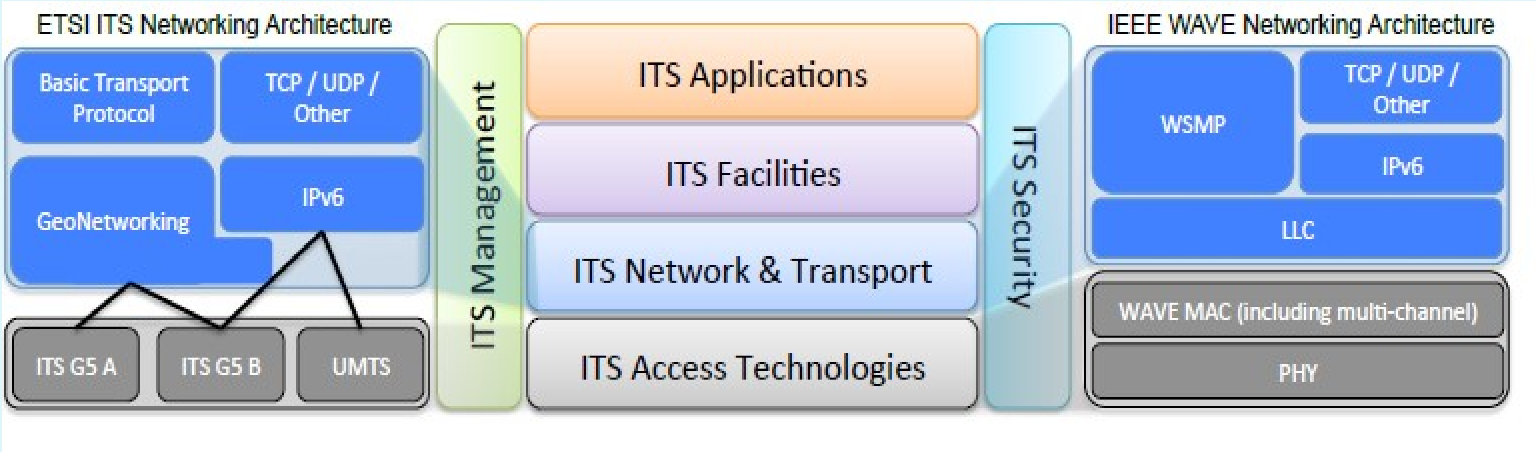
- **1.2 Current developments in vehicular communications and services**
- **DSRC protocol stack in Europe versus US**
- Both have
  - have PHY and MAC layers are based on the IEEE 802.11-2012 (previous IEEE 802.11p) standard.
  - a dual stack architecture, splitting traffic to ITS-specific apps. and generic IP-based apps. (TCP/UDP, IPv6)
  - **Europe:** ETSI ITS G5, with ITS-G5A for safety related apps. and ITS-G5B to non-safety applications
  - **US :** IEEE WAVE standard
- The **main differences are in upper layers** and particularly the network
  - European stack: non-safety applications and are carried by ITS G5 B or UMTS
    - It is possible to translate IPv6 to GeoAddress and use the GeoNetworking layer
    - ETSI for ITS: the Basic Transport Protocol (BTP) - UDP-like
    - GeoNetworking : broadcast, geocast and unicast modes - based on geographic routing

1. Vehicular networks - introduction

- **1.2 Current developments in vehicular communications and services**
- **DSRC protocol stack in Europe versus** US (cont'd)

IEEE WAVE : *Wave Short Message Protocol (WSMP)* as network layer for ITS-specific traffic

- WSMP is based purely on single-hop broadcast, hence no routing protocol is employed, as no application requiring forwarding has been designed in WAVE architecture

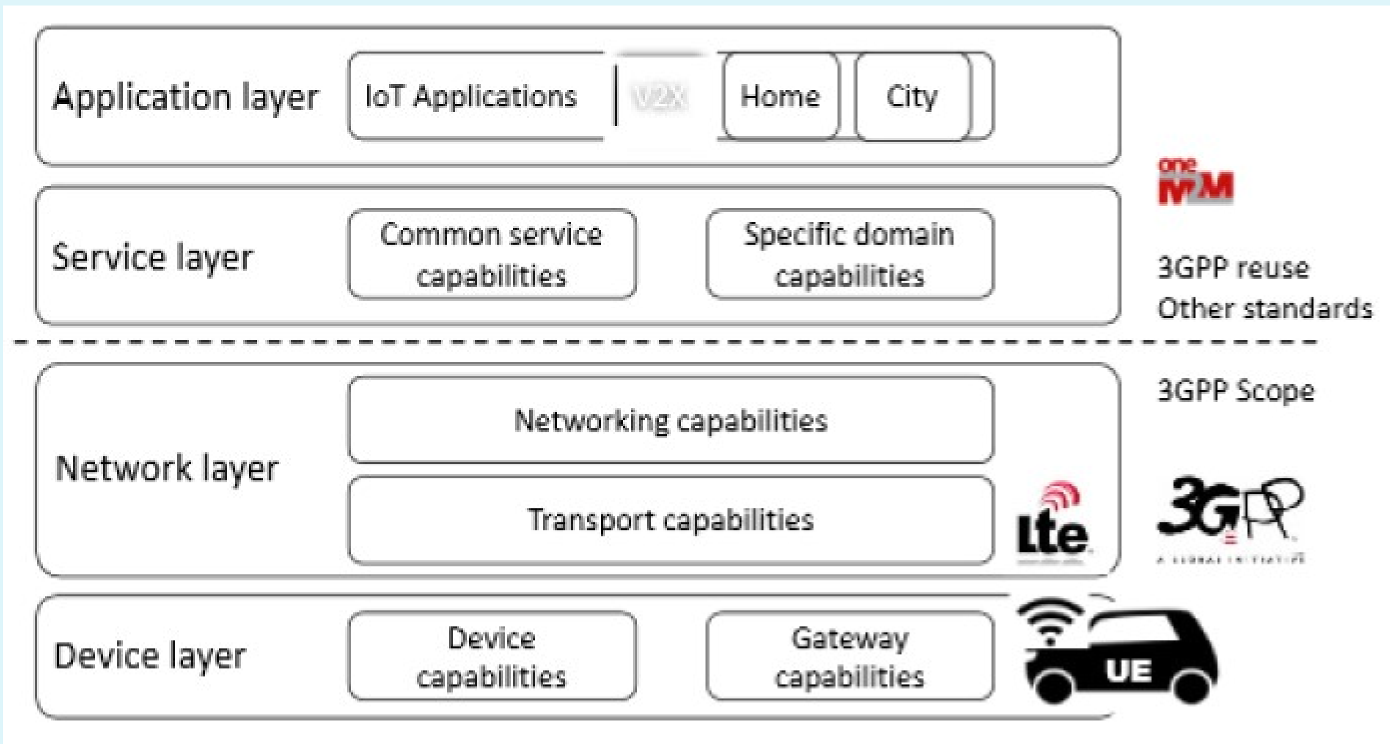


Europe *US*

Source: K.Katsaros and M.Dianati, "A Conceptual 5G Vehicular Networking Architecture", October 2017, https://www.researchgate.net/publication/309149571, DOI: 10.1007/978-3-319-34208-5_22

1. Vehicular networks - introduction

- **1.2 Current developments in vehicular communications and services**
- **Architecture overview for V2X**



Source: U.S. Department of Transportation: "IEEE 1609 – Family of Standards for Wireless Access in Vehicular Environments (WAVE)". https://www.standards.its.dot.gov/Factsheets/Factsheet/80

1. Vehicular networks - introduction

- **1.2 Current developments in vehicular communications and services**
- **Vehicular ad-hoc Networks (VANET)**
  - special class of ***Mobile ad-hoc Network -MANET***); **part of the ITS**

Characteristic	**VANET**
Participating nodes	**Vehicles (OBU) , Roadside unit (RSU)** static and/or mobile nodes
Communication type	**V2V, V2R/V2I, single or multi-hop**
Available bandwidth	e.g. 75MHz band available for VANET in US
Energy constraint	No
Topology	**Variable:** nodes (vehicles) frequently join and leave the network Vehicle movements – may be correlated
Node mobility speed	0 – 40 m per second
Signal reception quality	**Poor signal reception due to the radio: obstacles, (roadside buildings) interferences**
Connection life	Short- depending on road conditions, traffic lights, jams, etc.
Physical Channel	**Fast time varying (blocked transmission by buildings, vehicles)**
Connectivity	**End-to-end connectivity not guaranteed**
Additional sensors	High-quality GPS and digital maps
Infrastructure	Ad-hoc; RSUs can work as gateways to the Internet

1. Vehicular networks - introduction

- **1.2 Current developments in vehicular communications and services**
- **Vehicular ad-hoc Networks (VANET)** (cont'd)
- **Basic VANET system components**
  - **RSU- Road Side Unit, OBU On-board Unit, AU - Application Unit**
- Typically
  - RSU hosts applications that provides services
  - OBU is a peer device that uses the services
- The applications may reside in the RSU or in the OBU (provider/user model)

  - **OBU :**
    - set of sensors *to collect* and *process* the information
    - sending information as messages to other Vs or RSUs

  - Vehicle: may host n≥1 AUs that use the applications offered by the provider, supported by OBU connection capabilities

- The RSU can also connect to the Internet or to another server which allows AU's from multiple vehicles to connect to the Internet

1. Vehicular networks - introduction

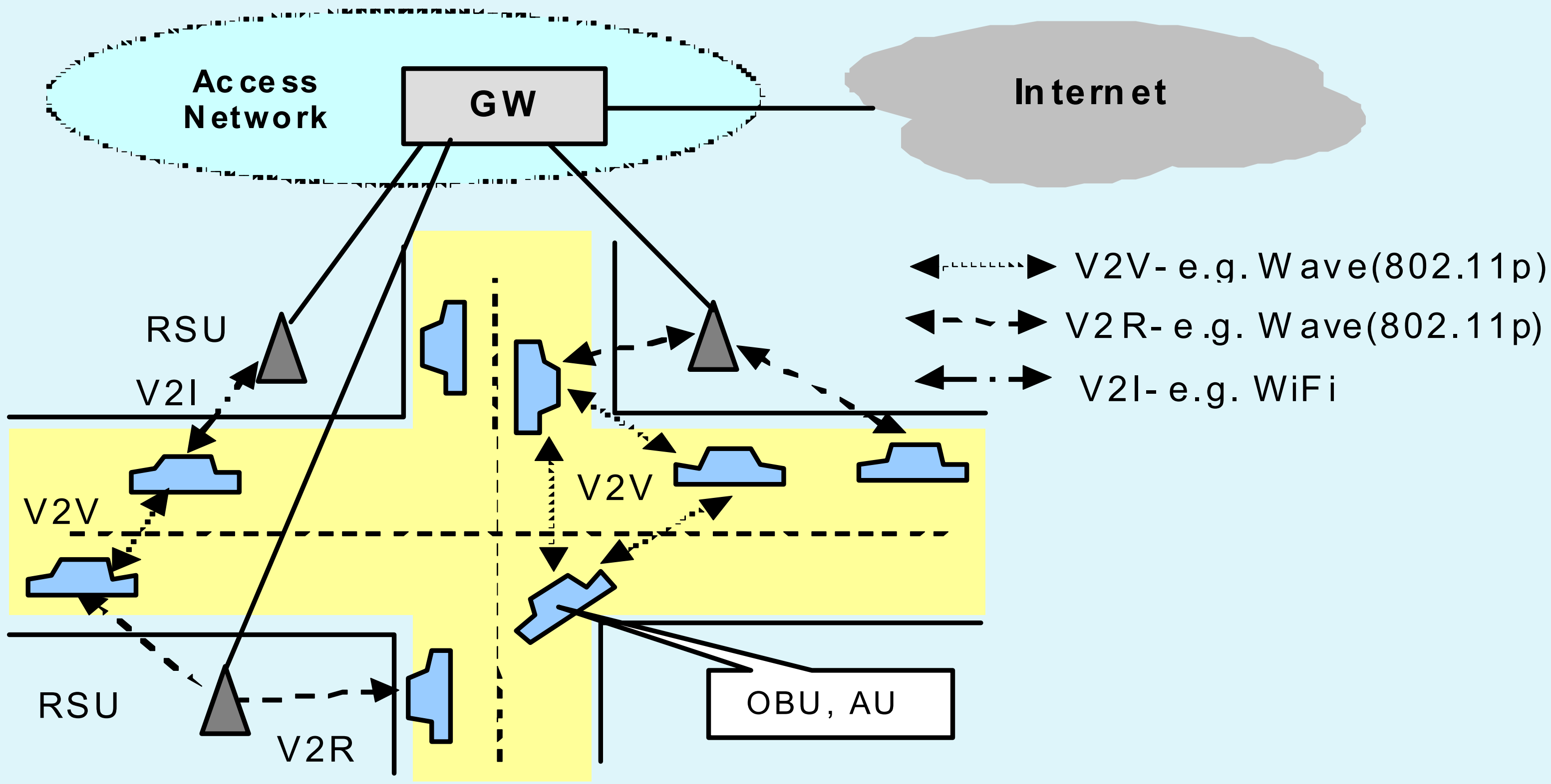
- **1.2 Current developments in vehicular communications and services**
- **Vehicular ad-hoc Networks (VANET)** (cont'd)
- **Basic VANET system components** (cont'd)
- **On-Board Unit (OBU)**
  - In-vehicle; It communicates with other OBUs and RSUs (~router)
  - **Typical structure**
    - transceiver ,RF antenna, wireless channel, processor, R/W memory, user I/F, other OBU internal I/Fs: (e.g., USB and Bluetooth), GPS sensor
    - A *Vehicle Control Unit (VCU)* coordinates with the OBU to collect/disseminate vehicular statistics.
  - A SW **network stack** runs to provide the abstraction of VANET
  - Communication standards: IEEE 802.11-2012, IEEE1609.1, 2, 3 and 4
- **OBU main functionalities**
  - **Data forwarding** on behalf of other OBUs
  - Exchange messages with other OBUs and RSUs
  - **Control functions**:
    - routing, network congestion, control, data security, and IP mobility

1. Vehicular networks - introduction

- **1.2 Current developments in vehicular communications and services**
- **Vehicular ad-hoc Networks (VANET)** (cont'd)
- **Basic VANET system components** (cont'd)
- **RSU- Road Side Unit**
  - antenna, processor, R/W memory, wireless and wired I/Fs to communicate with OBUs, other RSUs and the Internet
  - It can extends the coverage area of OBUs through data forwarding
  - **RSUs are installed** (this is a multi-criteria optimization problem)
    - along the roads, mainly near intersections and gas stations
    - locations of high vehicle density
  - **RSU main functionalities**
    - RF, high power, and long-range antenna
    - Support access to wired channels, (coax, cable or optical fiber cable, with Ethernet-like protocols)
    - Network stack to run a VANET specific network, link, and L1 protocols
    - Forwarding data packets to OBUs in its range and other RSUs
    - Aggregation of safety information from OBUs through safety applications and alarming incoming OBUs
    - GW to provide Internet connectivity to OBUs
  - **Standards to be supported:** IEEE 802.11, and all four IEEE 1609 protocols.

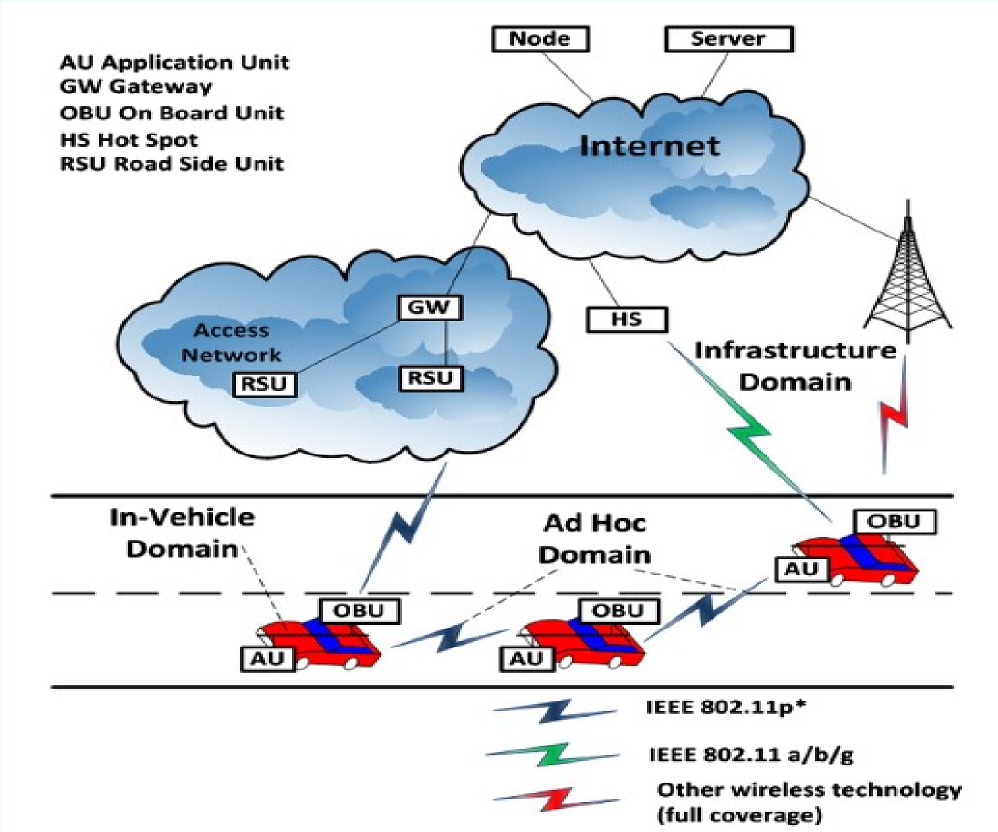
1. Vehicular networks - introduction

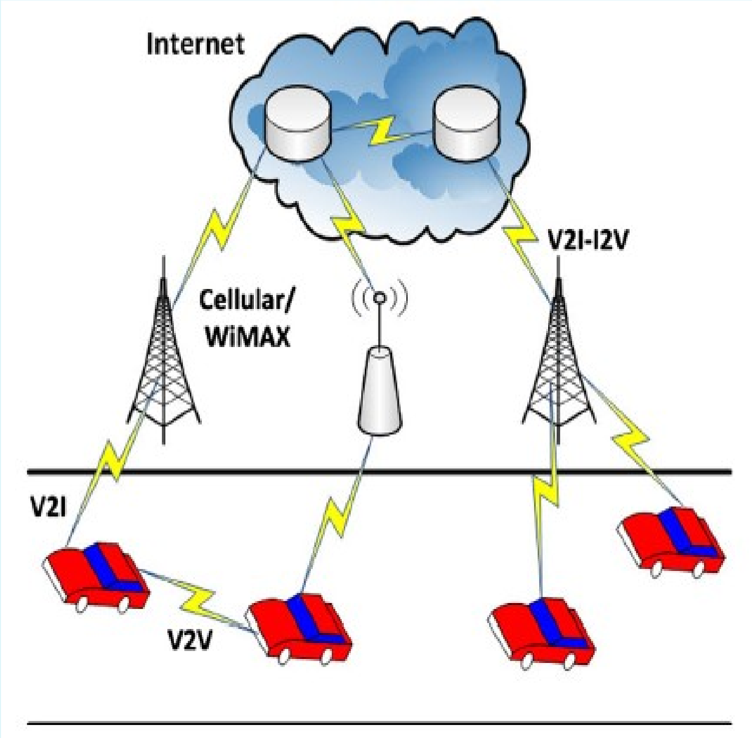
- **1.2 Current developments in vehicular communications and services**
- **Vehicular ad-hoc Networks (VANET)** (cont'd)
- **VANET communication types**
  - **V2V, V2R/V2I**



1. Vehicular networks - introduction

- **1.2 Current developments in vehicular communications and services**
- **Vehicular ad-hoc Networks (VANET)** (cont'd)
- **VANET – communication domains**





Combined DSRC, Cellular, Wi-Fi and WiMAX

Source: S. Sultan, M. Moath Al-Doori, A.H. Al-Bayatti, and H.Zedan "A comprehensive survey on vehicular Ad Hoc Network", J.of Network and Computer Applications, Jan. 2014,

1. Vehicular networks - introduction

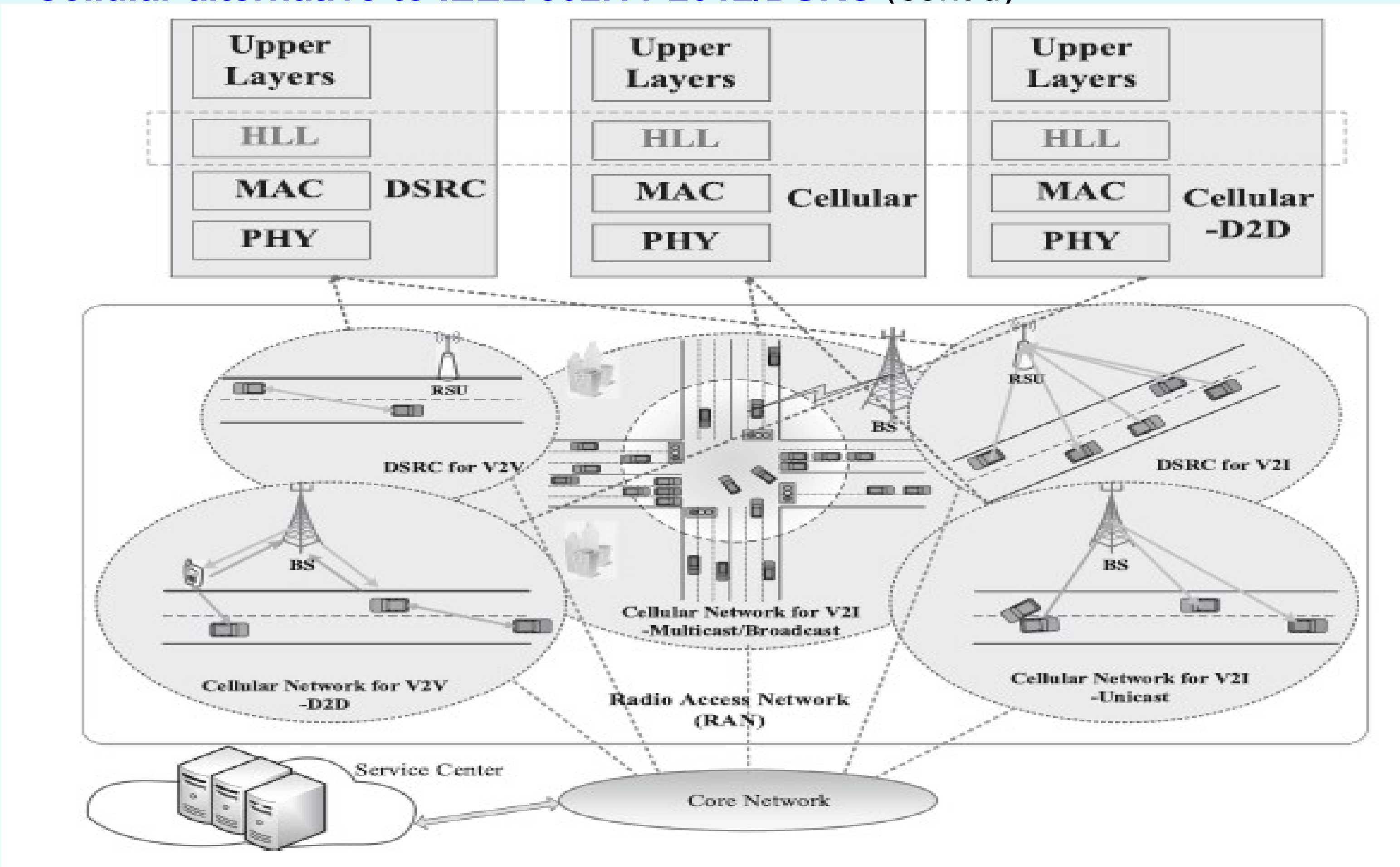
1.2 Current developments in vehicular communications and services

- **Cellular alternative to IEEE 802.11p/DSRC**
  - **C-V2X is a part of the overall 3GPP process to advance cellular systems from 4G to 5G technologies**
  - Standardization
    - LTE Broadcast (3GPP Rel. 9)
    - LTE Direct (3GPP Rel.12)
    - 3GPP Release 14
  - **LTE Direct** : enable direct V2V communications at distances up to hundreds of meters with low alert latency (~ 1 ms)
  - both in-coverage and out-of-coverage (of standard cellular infrastructure)
  - **LTE Broadcast** facilitates V2I and V2N, within traditional cellular infrastructure
    - The V2X servers can broadcast messages to groups while individual vehicles can unicast messages back to the server
      - Vehicle can
        - receive alerts about accidents a few miles ahead up the road
        - connect to smart parking systems to find open available parking spaces

1. Vehicular networks - introduction

1.2 Current developments in vehicular communications and services

- **Cellular alternative to IEEE 802.11-2012/DSRC** (cont'd)



Source : K.Zheng, et.al., "Architecture of Heterogeneous Vehicular Networks", Springer 2016, www.springer.com/cda/.../9783319256207-c1.pdf

1. Vehicular networks - introduction

1.2 Current developments in vehicular communications and services

- **Cellular alternative to IEEE 802.11-2012/DSRC** (cont'd)
  - V2V considered as the 3GPP highest priority, required RAN modifications
    - Direct links over the sidelink PC5 (Rel.12, Rel.14) are based on the customization for the vehicular scenario of Proximity Services (ProSe)
  - **Two communications modes**
    - **Mode 3 (scheduled)**
      - operates only in-coverage of an eNodeB; the RR allocation of is supervised by the network
    - **Mode 4 (autonomous)**
      - supports direct communications over the sidelink (PC5) I/F
      - PC5 comm. use the 5.9 GHz band, independent or even in the absence of a cellular network; ensure high availability under all geographies, regardless of the specific **Mobile Network Operator (MNO)**
      - Vehicles can autonomously access pre-configured resources w.o the network control, both in- and out-of coverage of an eNodeB (e.g., in urban canyons, tunnels)
  - **Higher perf.of C-V2X Mode 4 w.r.t. IEEE 802.11-2012** have been demonstrated the under many circumstances
  - V2N occur over the cellular LTE-Uu I/F, operating in the traditional licensed spectrum, to support both unicast and multicast communications

1. Vehicular networks - introduction

- **1.3 Standardization examples**
- **3GPP (Third Generation Partnership Project)**
  - Specifications for cellular V2X **(C-V2X)** in Release 14, 15
  - TR 23.786 v0.8.0. TSG services and system aspects, **Study on architecture enhancements for EPS and 5G system to support advanced V2X services**, (Rel. 16, Aug. 2018)
- **5GAA (5G Automotive Association -Sept.2016)**
  - major automobile manufacturers and telco players
  - promotes interoperable E2E 5G-based V2X connectivity
- **5G-PPP (5G Infrastructure Public Private Partnership)**
  - projects underway , such as 5GCAR, and 5GCARMEN

- **3GPP documents:** V2X are defined as communications between
  - *(i)* ***V2V*** - vehicles in close proximity (direct)
  - *(ii)* ***V2I*** - vehicles and *a* RSU in radio range (implemented in an eNodeB or in a standalone device (e.g., a traffic light)
  - *(iii)* ***V2P*** - Vehicle-to-Pedestria*n P*= vulnerable road users (e.g., pedestrians, bikers)
  - *(iv)* ***V2N*** - Vehicle-to-Network N represents remote servers and cloud-based services reachable through the cellular infrastructure

1. Vehicular networks - introduction

- **1.3 Standardization examples**
- **3GPP (Third Generation Partnership Project)** (cont'd)
- **Specs. for cellular V2X (C-V2X) Release 14 (2016)** - based on LTE (named LTE-V2X)
  - **C-V2X**
    - Communication types: V2V, V2I and wide area V2N.
    - intends to replace the US promoted DSRC and the Europe-originated Cooperative Intelligent Transport Systems (C-ITS)
    - is a step towards the target of autonomous driving and clues to market influence. C-V2X technology is designed to connect vehicles to each other, to roadside infrastructure, to other road-users and to cloud-based services.
  - **C-V2X modes:**
    - **D2D :** V2V, Vehicle-to-(Roadway) Infrastructure (V2I), (V2P); no mandatory network involvement for scheduling.
    - **Device-to-network (D2N)/V2N**: uses the traditional cellular links to enable cloud services to be part of the E2E solution by means of network slicing architecture for vertical industries.

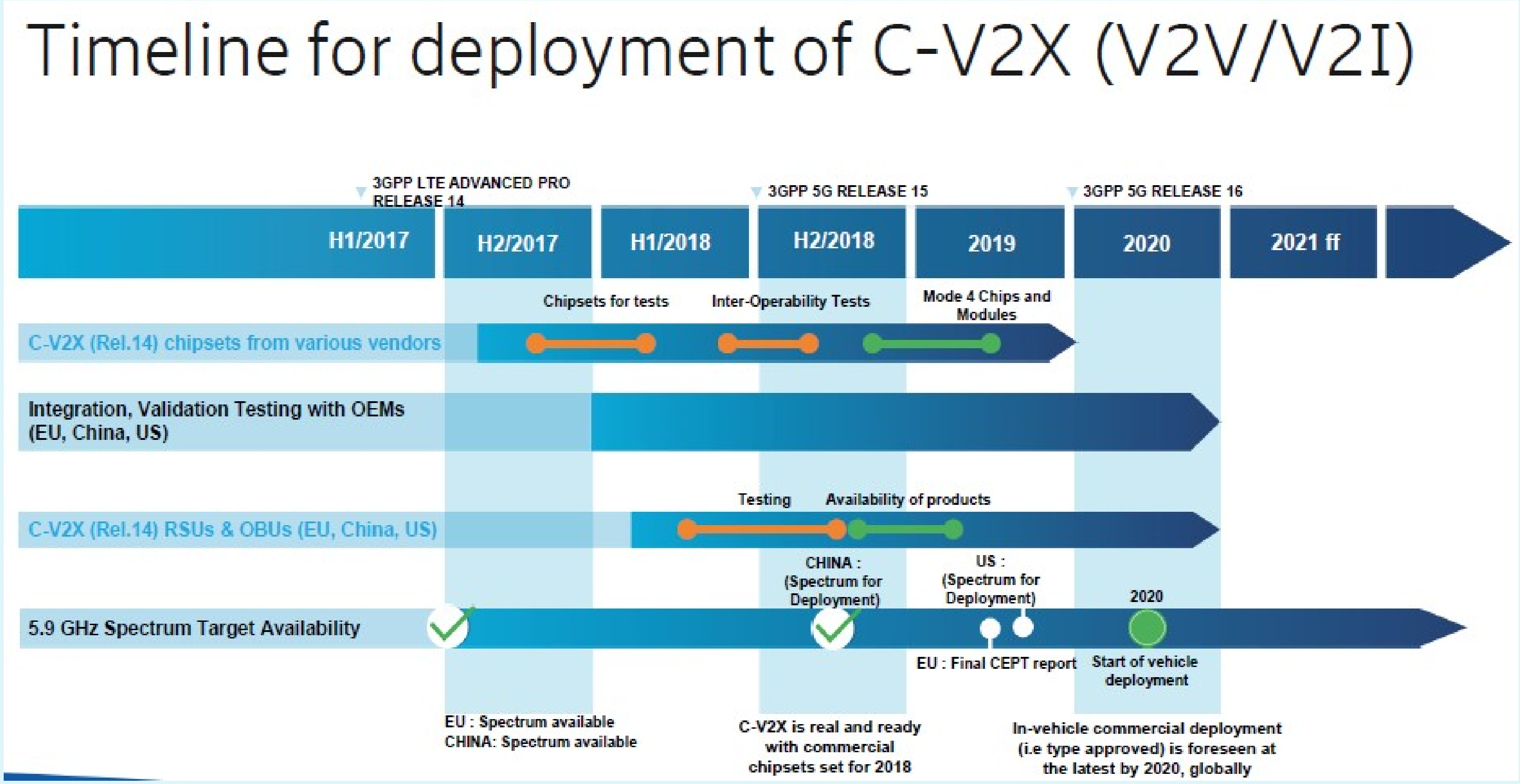
1. Vehicular networks - introduction

- **1.3 Standardization examples**
- **3GPP (Third Generation Partnership Project)** (cont'd)
- **C-V2X Release 14 (2016)** - based on LTE (named LTE-V2X) (cont'd)
  - **Two interfaces:**
  - (i) **wide area network LTE interface (Uu)**
    - connects EU devices and vehicles to mobile network BSs and mobile core networks, for provision of Internet and vehicle to network (V2N) services
  - (ii) **direct communications interface (PC5)**
    - Used for V2V, V2I and V2P connections
    - provides low-latency and high-reliability
    - The LTE-V2X (PC5) interface does not necessarily require assistance from a mobile network
- **3GPP 5G-V2X (Release 15) 2018**
  - C-V2X standardization is based on 5G (named **5G-V2X**)

- **C-V2X Release 16** (in progress) - further enhances the C-V2X functionality
  - C-V2X is inherently future-proof by supporting migration path to 5G

1. Vehicular networks- introduction

- **1.3 Standardization examples** (cont'd)



Source: Friedhelm Ramme, ITS, Transport & Automotive, Ericsson 5G: "From Concepts to Reality" Technology Roadmaps https://5gaa.org/wp-content/uploads/2019/02/Final-Presentation-MWC19-Friedhelm-Ramme-ERICSSON.pdf

1. Vehicular networks - introduction

- **1.4 Advanced vehicular communications and services**

- **V2X, Internet of Vehicles (IoV)**
  - **V2X : V2V, V2R/V2I, V2N, V2P, V2S, ..**

  - **IoV** global network of vehicles – enabled by various ***Wireless Access Technologies (WAT)***
  - involves Internet and includes heterogeneous access networks
  - IoV – can be seen a special use case of ***Internet of Things (IoT)***

  - **IoV Target domains:**
    - Vehicles driving and safety (basic function – in VANET)
    - Novel domains:
      - traffic management, automobile production repair and vehicle insurance, road infrastructure construction and repair, logistics and transportation, etc.

1. Vehicular networks - introduction

- **1.4 Advanced vehicular communications and services**
- **IoV features**(cont'd)
  - ***Commercial , objectives, architecture***
    - business oriented architecture → high opportunities for various apps. (safety, traffic optimization and efficiency, infotainment, etc.)
  - ***Collaboration capabilities:***
    - collaboration between heterogeneous nets, reliable Internet service
  - ***Communication types:***
    - **includes all V2X types of communications:**
  - ***Processing power and decision capabilities:***
    - high capabilities – (cloud based), big data, data mining, ..
  - ***Compatibility with any personal devices***
  - ***Scalability:***
    - scalable (and it integrates various access: VANET, WiFi, 4G/LTE, 5G..)
  - ***Connectivity:***
    - "always-connected"-feature is possible; one can use the best network type
  - ***Network/environment awareness:***
    - global network awareness is possible (cloud-assisted)
  - ***Cloud Computing/Edge computing (CC/EC) compatibility***:
    - the main operations can be based on CC/Edge computing services

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2. V2X use cases, requirements

- **2.1 V2X Applications and services**
- The **5GAA** defined four **V2X** areas :
  - ***Safety*** – contribute to reducing vehicle collisions events
  - ***Convenience*** – help the management of vehicle status and offer special services (e.g. diagnostics, software updates, etc)
  - ***VRU -*** safe interactions between vehicles and non-vehicle road users
  - ***Advanced driving assistance***
    - similar objectives with (safety), but considered as distinct, given their strong interaction with (semi-) autonomous vehicle operation
    - **3GPP-refinement** 3GPP TR 21.915 V15.0.0 (2019-09)
      - ***Vehicles platooning -*** group of vehicles travelling together at short inter-vehicle distances
      - ***Advanced driving*** - vehicles can share local sensor data and driving intentions with neighbor vehicles (trajectories and maneuvers coordination)
      - ***Extended sensors*** - exchange raw/processed sensor data or live video among VUEs, RSUs, VRUs and V2X ASs.
      - ***Remote driving -*** *a remote driver or a* cloud application can tele-operate a (private or public) vehicle

Source: 3GPP TR 21.915 V15.0.0 (2019-09), TSG Services and System Aspects; Release 15
A.Molinaro and C.Campolo, "5G for V2X Communications", https://www.5gitaly.eu/2018/wp-content/uploads/2019/01/5G-Italy-White-eBook-5G-for-V2X-Communications.pdf

2. V2X use cases, requirements

- **2.1 V2X Applications and services**
- **3GPP TR 21.915 V15.0.0 (2019-09)**
- **Vehicle Platooning:** vehicles dynamically form a group travelling together
  - All the vehicles in the platoon receive periodic data from the leading vehicle, in order to carry on platoon operations.
  - This information allows the distance between vehicles to be small, i.e., the gap distance translated to time can be very low (sub second)
  - Platooning apps. may allow the vehicles following to be autonomously driven

- **Advanced Driving:** semi-automated or fully-automated driving
  - Longer inter-vehicle distance
  - Each vehicle and/or RSU shares data obtained from its local sensors with vehicles in proximity, thus allowing vehicles to coordinate their trajectories or manoeuvres
  - Each vehicle shares its driving intention with vehicles in proximity
    - Safer travelling, collision avoidance, and improved traffic efficiency.

Source: 3GPP TR 21.915 V15.0.0 (2019-09), TSG Services and System Aspects; Release 15

2. V2X use cases, requirements

- **2.1 V2X Applications and services**
- **3GPP TR 21.915 V15.0.0 (2019-09)**

- **Extended Sensors:** exchange of raw or processed data gathered through local sensors or live video data among vehicles, RSUs, devices of pedestrians and V2X application servers
  - The vehicles can enhance the perception of their environment beyond what their own sensors can detect and have a more holistic view of the local situation

- **Remote Driving:** enables a remote driver or a V2X application to operate a remote vehicle for those passengers who cannot drive themselves or a remote vehicle located in dangerous environments
  - If variation is limited and routes are predictable, such as public transportation, driving based on cloud computing can be used
  - Access to cloud-based back-end service platform can be considered for this use case group.

Source: 3GPP TR 21.915 V15.0.0 (2019-09), TSG Services and System Aspects; Release 15

2. V2X use cases, requirements

- **2.2 V2X, eV2X use cases examples (3GPP)**
- **Safety and traffic efficiency**
  - **V2V/V2P messages** sent/received (event-driven or periodic)
  - **parameters:** sender vehicle position and kinematics to allow other vehicles and VRUs to sense the surrounding environment
  - **applications** :
    - (i) forward collision warning, (ii) cooperative adaptive cruise control that allows a group of vehicles in proximity to share the same path (a.k.a. platooning); (iii) VRU safety
- **Autonomous driving**
  - more demanding requirements than for V2V safety apps.(reasons: high speed, small inter-vehicle distances)
  - requires full road network coverage to be driverless in all geographies
  - network should support support V2V/V2N communications under high vehicle density
  - video/data exchange over V2N links may be necessary

Sources: 3GPP TR 22.885 V14.1.0, Technical Specification Group Services and System Aspects; Study on LTE support of Vehicle to Everything (V2X) services (Release 14), December 2015.

- *3GPP TR 22.886 V15.0.0, Technical Specification Group Services and System Aspects; Study on enhancement of 3GPP Support to 5G V2X Services (Release 15), December 2016*

2. V2X use cases, requirements

- **2.2 V2X, eV2X use cases examples (3GPP)** (cont'd)
- **Tele-operated driving**
  - Special environments **(**dangerous to humans, in construction, etc.)
  - *drones on wheels* may be remotely leveraged
  - their control - by using camera, status, and sensor data.
  - Use-case :*extreme real-time communications*, with tight requirements for the network to ensure fast vehicle control and feedback
- **Vehicular Internet and infotainment**
  - Web browsing, social media access, files/apps download, and HD video streaming for passengers
  - become more relevant for self-driving vehicles
  - media consumption will increase
- **Remote diagnostics and management**
  - V2X Application Servers or vehicle diagnostic centers (e.g., owned by a car manufacturer) can retrieve information sent periodically by vehicles in V2N mode to track their status for remote diagnostic purposes
  - fleet management apps. may track the vehicle status and position, e.g., for diagnostic activity

2. V2X use cases, requirements

- **2.3 V2X requirements examples**
- **3GPP Requirements of V2X autonomous driving use cases**

Application	Main communication mode	Payload (bytes)	Latency (ms)	Reliability (percentage)	Data rate (Mbps)
Vehicles platooning	V2V, V2I	50-6500	10-20	90-99.999	0.012-65
Advanced driving	V2V, V2I	300-12000	3-100	90-99.999	0.096-53
Extended sensors	V2V, V2I, V2P	1600	3-100	90-99.999	10-1000
Remote driving	V2N	-	5	99.999	25 (Uplink); 1 (Downlink)

- **Challenge: the current** RATs:, IEEE 802.11, LTE and C-V2X Releases14 and 15 cannot efficiently support the above requirements
  - Exploration of more performant solutions is necessary
  - **5G is a powerful candidate** – offering E2E solutions based on 5G slicing
  - 5G offers communication, networking and computing capabilities, in the **Radio Access Network (RAN)** and in the **Core Network (CN)** segments

Source: A.Molinaro and C.Campolo, "5G for V2X Communications", https://www.5gitaly.eu/2018/wp-content/uploads/2019/01/5G-Italy-White-eBook-5G-for-V2X-Communications.pdf

2. V2X use cases, requirements

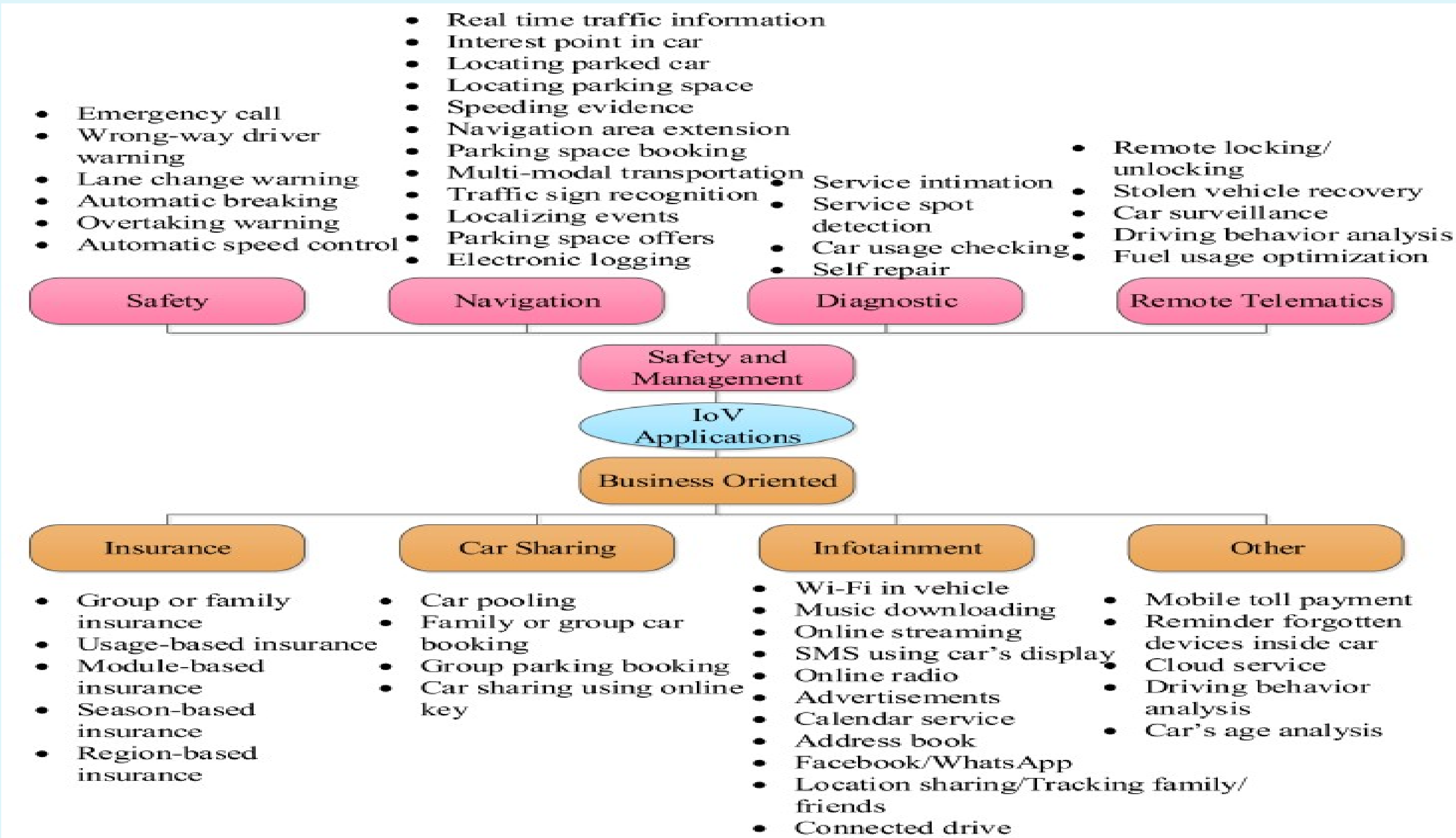
- **2.3 V2X, eV2X requirements examples (3GPP)**

V2X category	**Comm. type**	**Latency**	**Data rate**	**Reliability**
Safety and traffic efficiency	V2V, V2P	~100 ms	Not a concern	In study
Autonomous driving	V2V, V2N, V2I	~1 ms	10 Mbps (downlink/downlink)	~100%
Tele-operated driving	V2N	~20 ms (E2E)	Uuplink: 25 Mbps for video and sensors data Downlink:1 Mbps for app.-related control and command	99.99%
Vehicular Internet and infotainment	V2N	~100 ms (web browsing)	0.5 Mbps (web browsing) Up to 15 Mbps for UHD video streaming	Not a concern
Remote diagnostics and management	V2I, V2N	N.A	Not a concern	Not a concern

Source: C.Campolo, A.Molinaro, A.Iera, F.Menichella, "5G Network Slicing for Vehicle-to-Everything Services", IEEE Wireless Communications, Volume: 24 Issue: 6, DOI: 10.1109/MWC.2017.160040

2. V2X use cases, requirements

2.5 IoV/V2X –extended range of target applications and services



Source: O. Kaiwartya, A.H Abdullah, Y.Cao, et. al., "Internet of Vehicles: Motivation, Layered Architecture, Network Model, Challenges, and Future Aspects" IEEE Access, SPECIAL SECTION ON FUTURE NETWORKS: ARCHITECTURES, PROTOCOLS, AND APPLICATIONS, September 2016

CONTENTS

3. 5G technology summary

3.1 5G Main characteristics

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

- **5G - key enabler for : IoT, M2M, IoV/V2X, Broadband/media services, ….**

- 5G integrates: *networking* + *computing* + *storage* resources into one programmable and unified infrastructure

3. 5G technology summary

- **3.1 5G Main characteristics**

- **5G Key technological 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)

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

3. 5G technology summary

3.1 5G Main 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

3. 5G technology summary

3.1 5G Main characteristics

Network softwarization: represents sets of functions assuring **programmabil**ity of

- network devices
- **network functions (NF)-** virtual (VNF)–cooperating with physical (PNF)
- **network slices** – logical, on demand, isolated customized networks
- network services and applications- supported by slices
- **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.

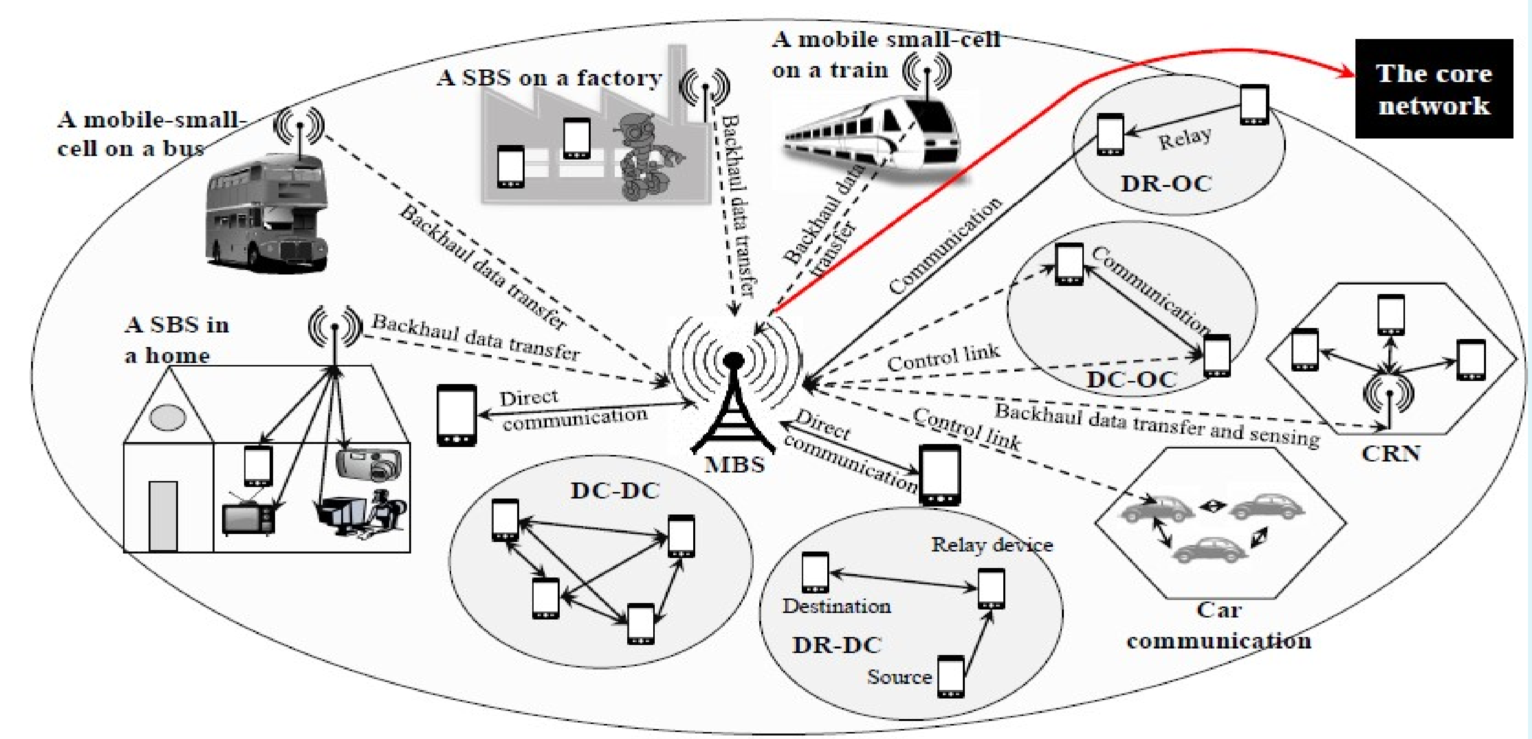
See: A.Galis, 5G Architecture Viewpoints H2020 5G PPP Infrastructure Association July 2016, August 2017, https://5g-ppp.eu/white-papers/

3. 5G technology summary

3.2 5G infrastructure

- multi-tier arch.: small-cells, mobile small-cells, D2D, 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

3. 5G technology summary

3.2 5G infrastructure

- **Deployment options defined for 5G**
- **Non-Stand Alone (NSA)** architecture
  - the 5G RAN also called **New Radio (NR) is used in conjunction with the existing LTE** and EPC infrastructure Core Network (respectively 4G Radio and 4G Core),
  - aims to make the new 5G-based RAT available without network replacement
  - only the 4G services are supported, but enjoying the capacities offered by the 5G Radio (lower latency, etc.)
  - The NSA is known as E-UTRA-NR Dual Connectivity (EN-DC) or Arch. Option 3
- **Stand-Alone (SA)**
  - the NR is connected to the 5G Core Network (CN). In this configuration, the full set of 5G Phase 1 services are supported, as specified in TS 22.261.

Source: GSM Association (GSMA) (2018, April): "Road to 5G: Introduction and Migration", https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

3. 5G technology summary

3.2 5G infrastructure

- **Deployment options defined for 5G**

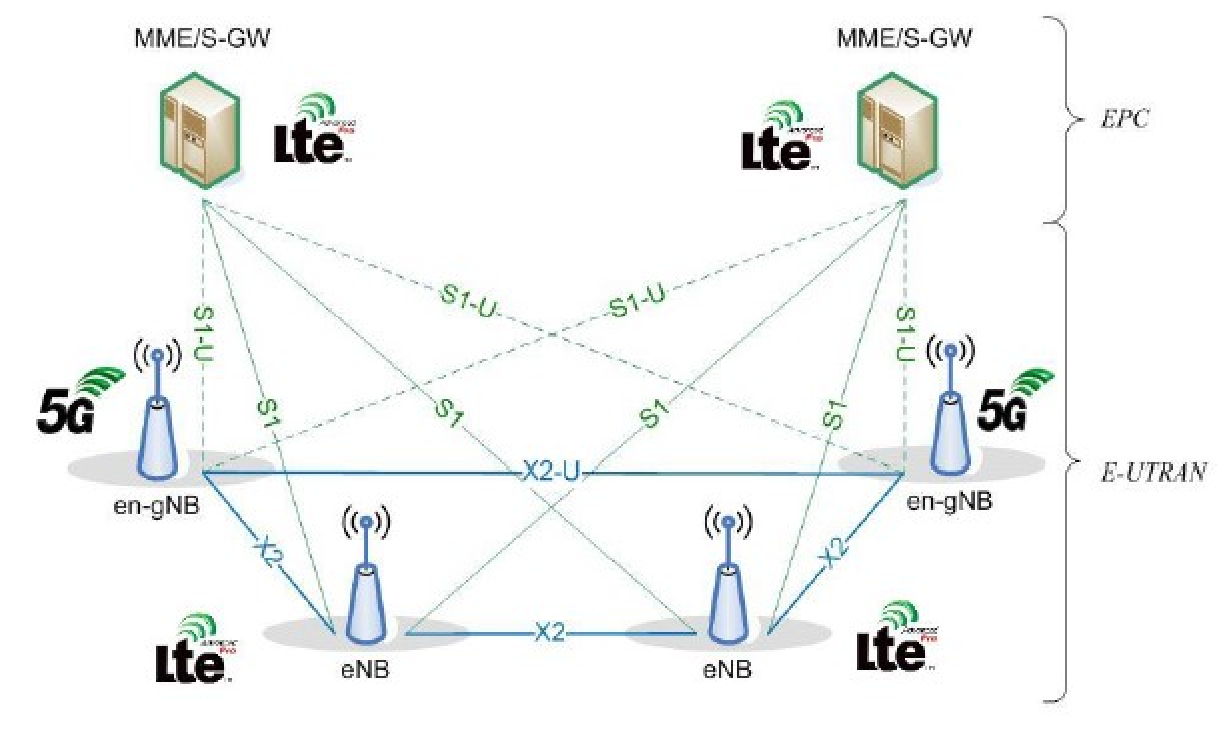
- **NSA details**
  - NR base station (BS) (logical node en-gNB) connects to the LTE BS (logical node eNB) via the X2 interface.
  - X2 I/F has been used so far to connect eNBs, but Release 15 Specs extend it to also support connecting an **eNB** and **en-gNB** in case of NSA operation
  - E-UTRAN for NSA connects to the EPC network using an S1 interface
  - Dual connectivity between eNB (master node) and en-gNB (secondary node) is called EN-DC

Source: GSM Association (GSMA) (2018, April): "Road to 5G: Introduction and Migration", https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

3. 5G technology summary

3.2 5G infrastructure

- **Deployment options defined for 5G** (cont'd)
- **Non-Stand Alone (NSA)** architecture

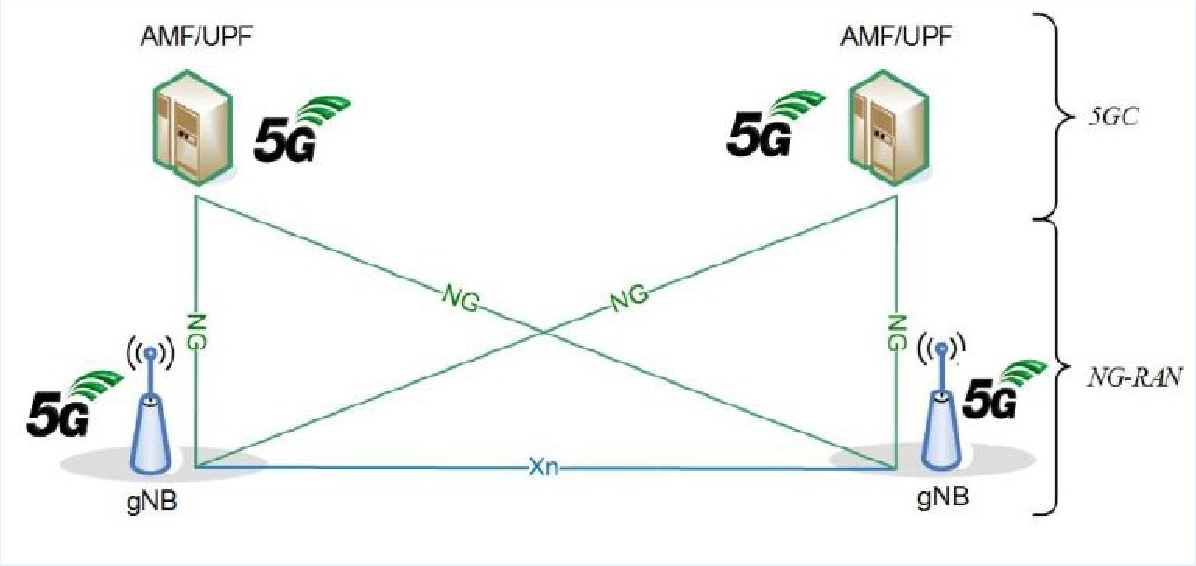


Source: GSM Association (GSMA) (2018, April): "Road to 5G: Introduction and Migration", https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

3. 5G technology summary

3.2 5G infrastructure

- **Deployment options defined for 5G** (cont'd)
- **Stand Alone (SA)** architecture
  - The NR base station (logical node gNB) connects each other via the Xn interface
  - The NG-RAN for SA architecture connects to the 5GC network using the NG interface



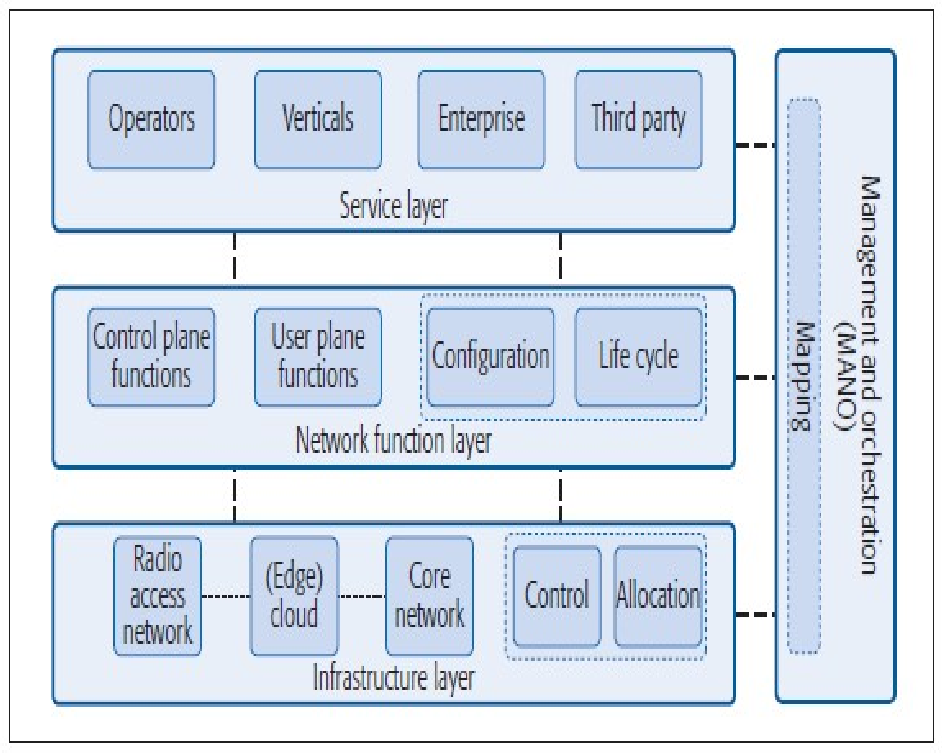
The new radio access technology is called "NR" and replaces "LTE"

The new base station is called gNB (or gNodeB), and replaces the eNB (or eNodeB or Evolved Node B).

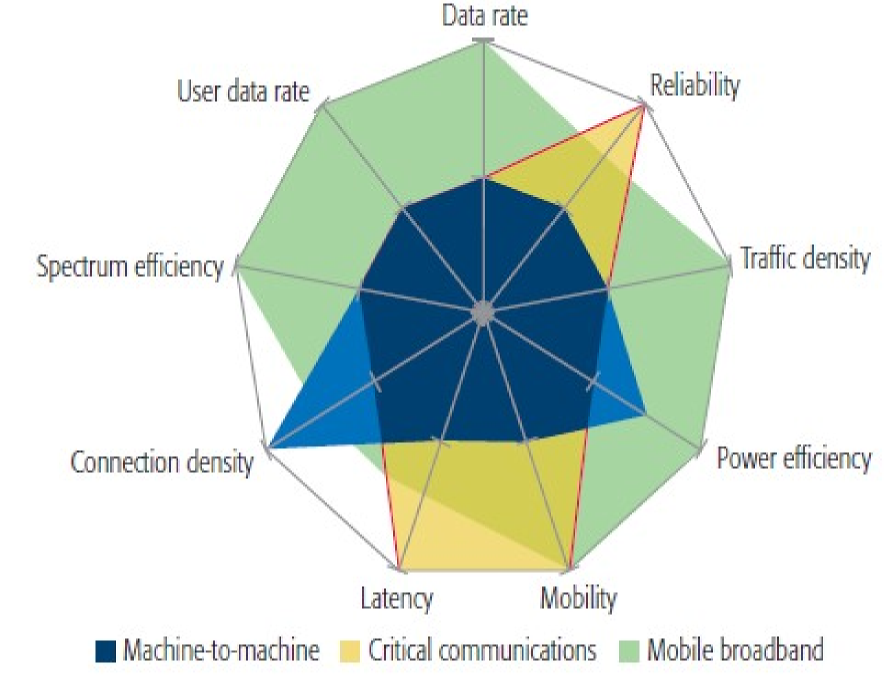
Source: GSM Association (GSMA) (2018, April): "Road to 5G: Introduction and Migration", https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

3.3 5G Layered Architecture

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



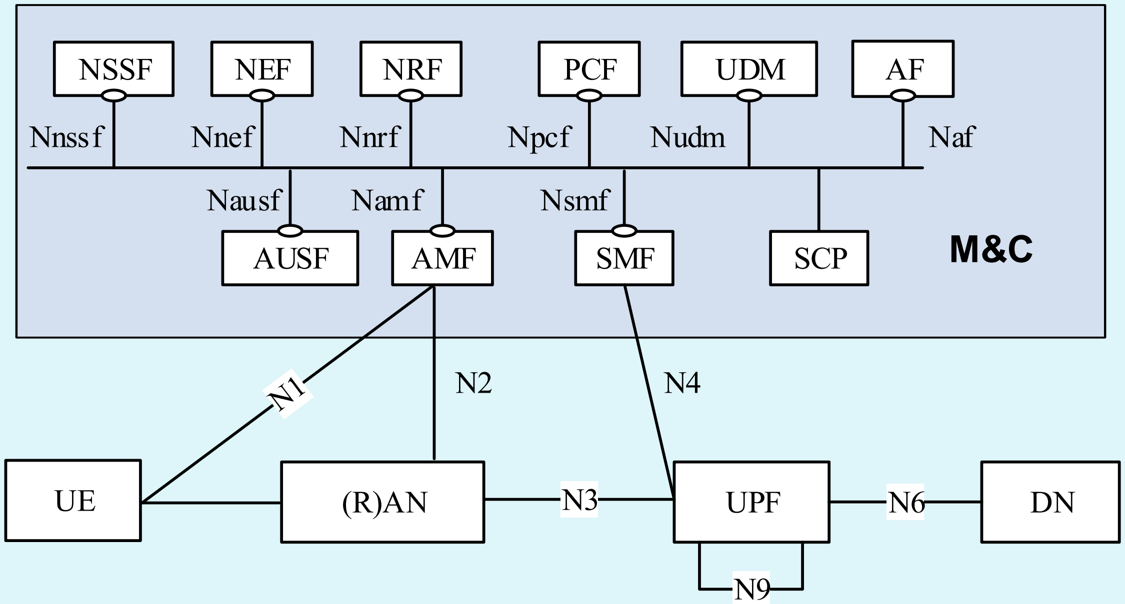
Key 5G use cases and their requirements
- difficult for a traditional unique arch to meet all of them
- **dedicated slicing can be the solution**



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

3.3 3GPP 5G System Reference Architecture

- Non- roaming reference architecture



The architecture also comprises the network entities:
Service Communication Proxy (SCP)
Security Edge Protection Proxy (SEPP)

5G Network functions

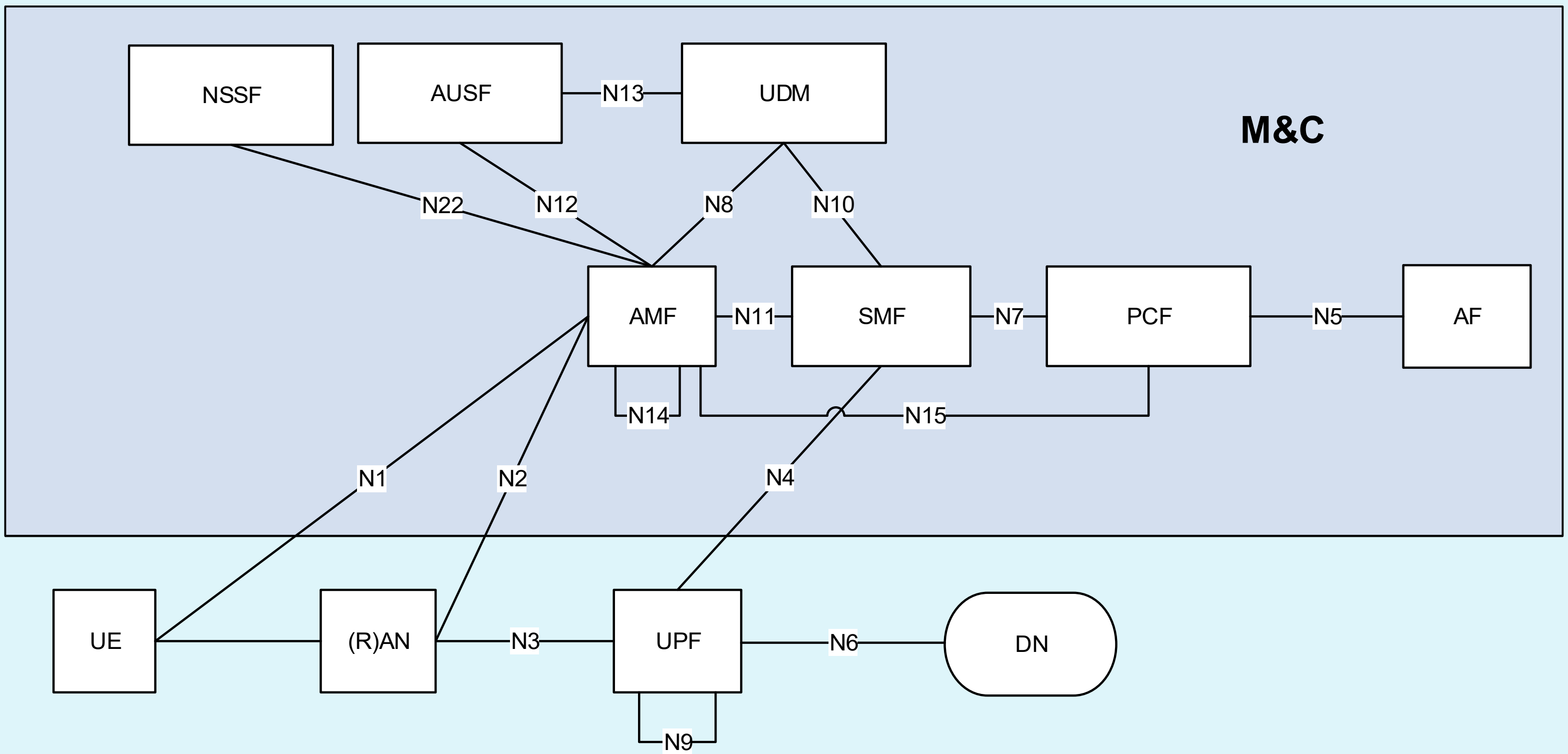
Authentication Server Function (AUSF)
Access and Mobility Management Function (AMF)
Data Network (DN), e.g. operator services, Internet access or 3rd party services
Unstructured Data Storage Function (UDSF)
Network Exposure Function (NEF)
Intermediate NEF (I-NEF)
Network Repository Function (NRF)
Network Slice Selection Function (NSSF)
Policy Control Function (PCF)
Session Management Function (SMF)
Unified Data Management (UDM)
Unified Data Repository (UDR)
User Plane Function (UPF)
UE radio Capability Management Function (UCMF)
Application Function (AF)
User Equipment (UE)
(Radio) Access Network ((R)AN)
5G-Equipment Identity Register (5G-EIR)
Network Data Analytics Function (NWDAF)
CHarging Function (CHF)

Source:3GPP TS 23.501 V16.3.0 (2019-12) TSG and SA, System Architecture for the 5G System; Stage 2 (Release 16)

3. 5G technology summary

3.3 3GPP 5G Reference Architecture

- **Non-Roaming 5G System Architecture** (in reference point (RP) representation)
  - **Nxy- reference points**= direct interfaces between functional blocks



Source:3GPP TS 23.501 V16.3.0 (2019-12) TSG and SA, System Architecture for the 5G System; Stage 2 (Release 16)

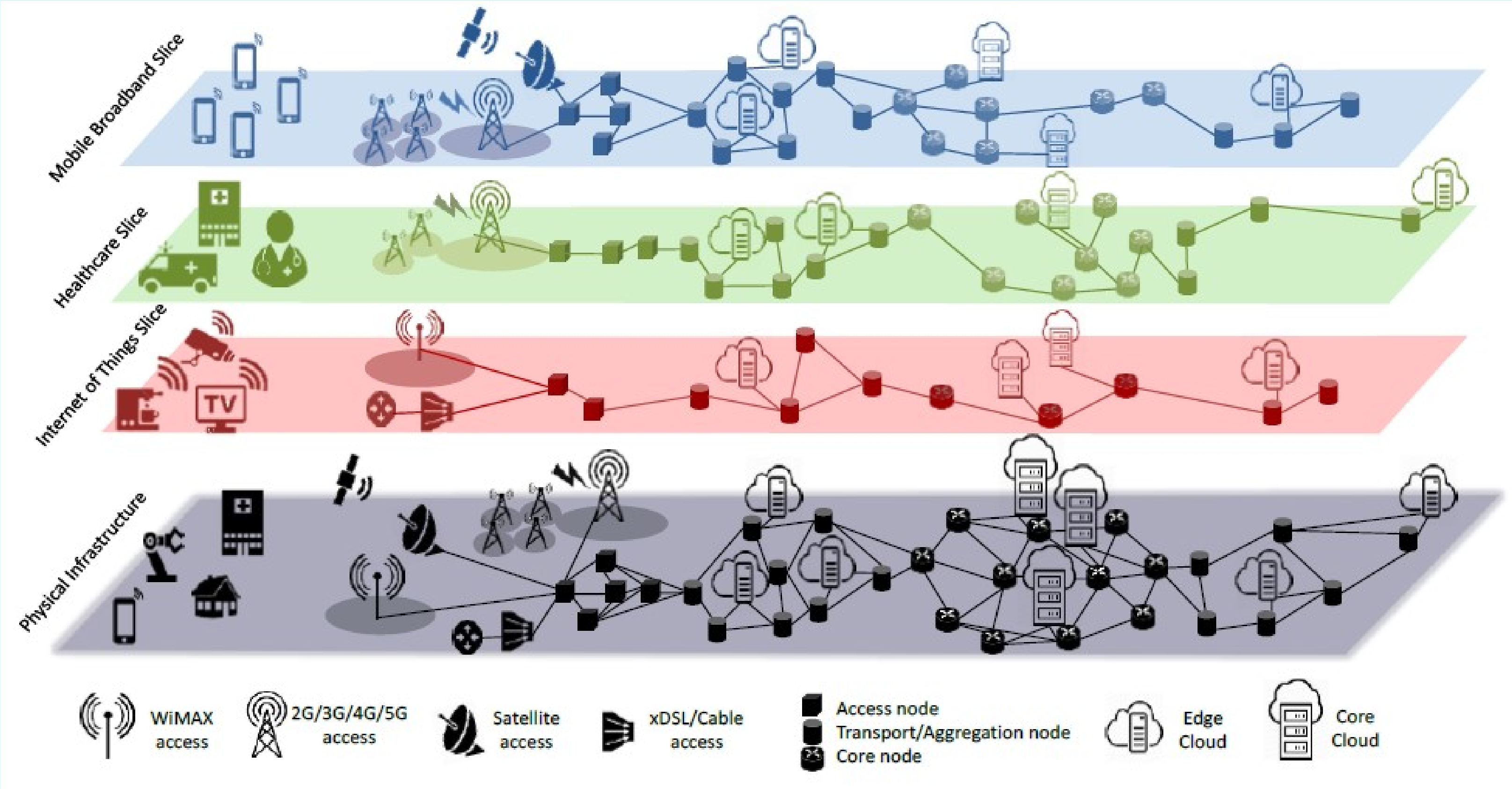
3. 5G technology summary

3.4 Network slicing concepts and architecture

- **Network Slicing** :
  - **E2E concept** covers all network segments : radio or wire access, edge, core, transport networks.
  - **concurrent deployment of multiple E2E logical, self-contained and independent shared or partitioned networks** on a common infrastructure platform
  - **Slices**
    - created **on demand or provisioned** (based on templates)
    - they run on a common underlying (PHY/V) network and are mutually isolated, each one having its own independent M&C
    - **composition** of adequately configured NFs/VNFs, 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** –technologies providing virtualization, programmability, flexibility, and modularity to create **multiple network slices** each tailored for a given UC

3.4 Network slicing concepts and architecture (cont'd)

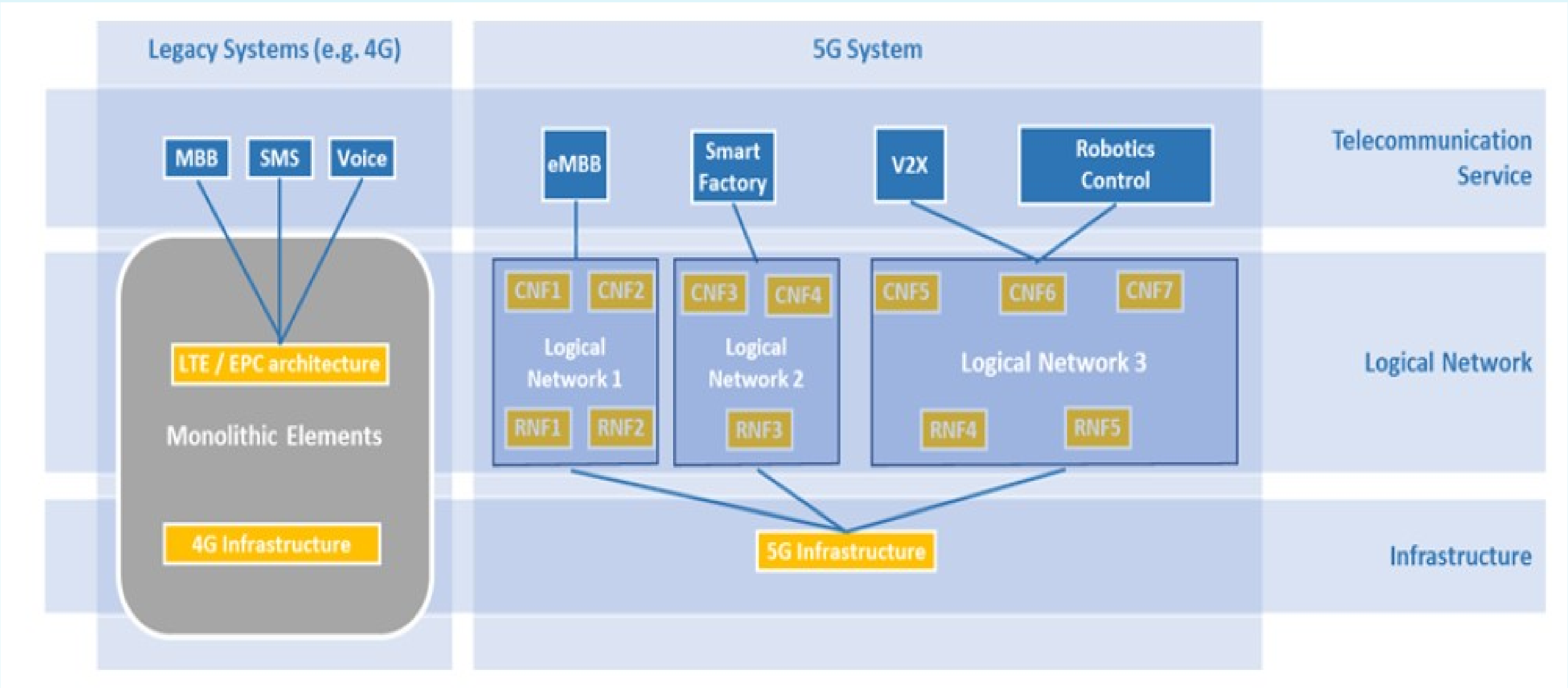
- **5G slicing generic example**



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

3. 5G technology summary

- **3.4 Network slicing concepts and architecture** (cont'd)
- **4G versus 5G slicing concepts**



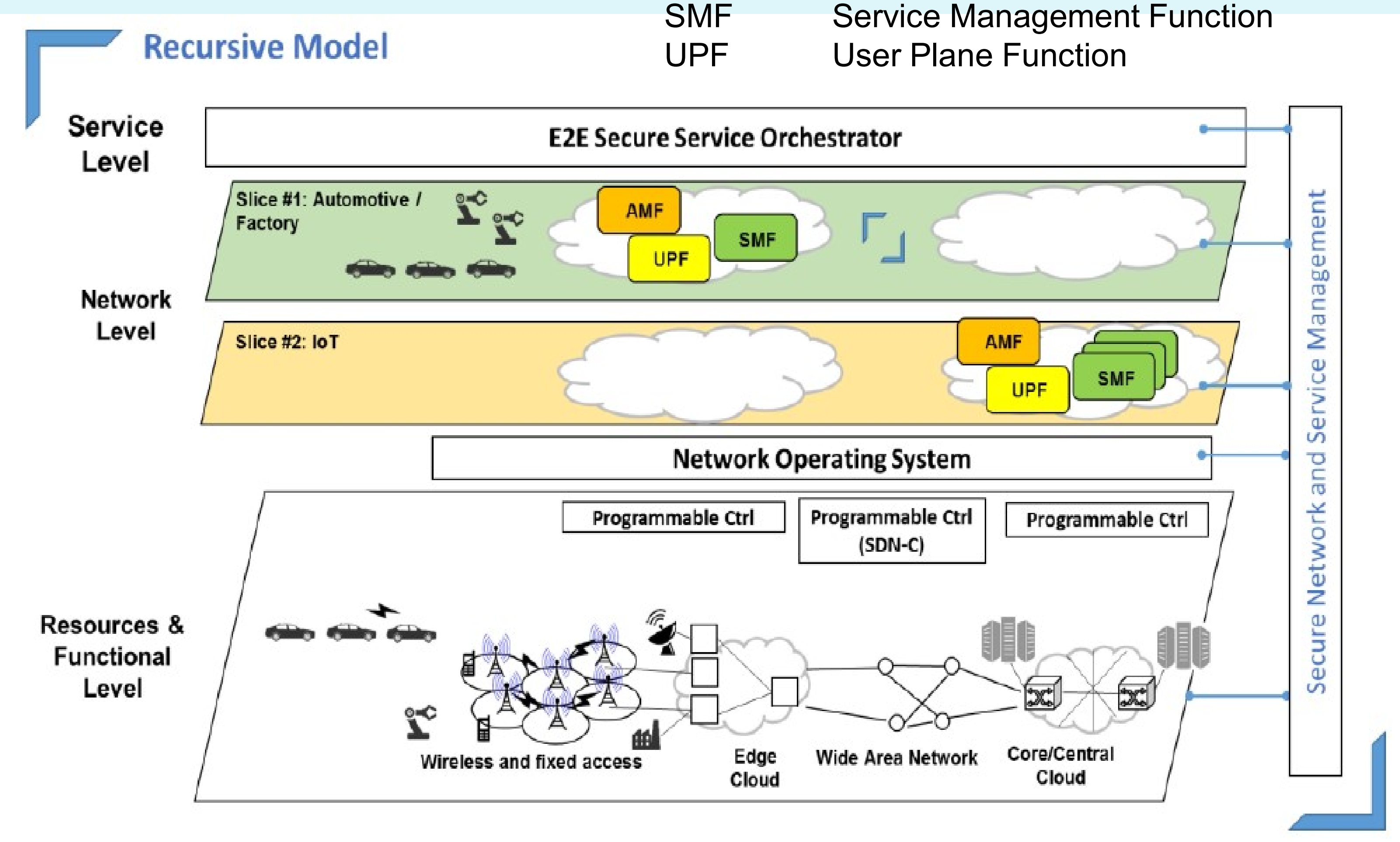
MBB - Mobile Broadband;
LTE - Long Term Evolution (4G) ;
V2X - vehicle to X ; **CNF**- Core Network Functions;
SMS - Short Messages service;
EPC- Evolved Packet Core
RNF- RAN network Functions

3. 5G technology summary

3.4 Network slicing concepts and architecture (cont'd)

- **5GPPP vision**

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

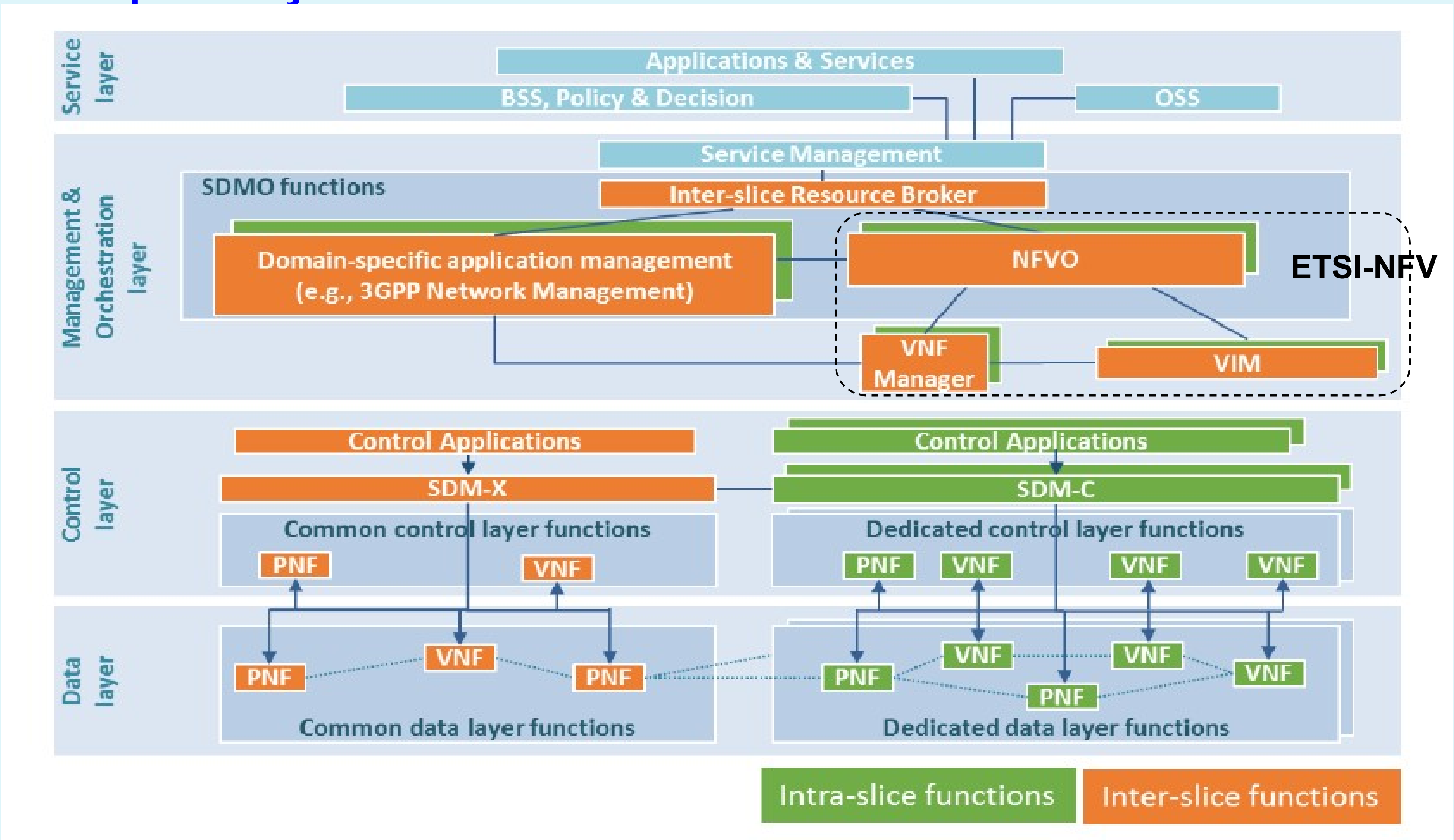


Source: 5GPPP Architecture Working Group , View on 5G Architecture, Version 2.0, December 2017

3. 5G technology summary

3.4 Network slicing concepts and architecture (cont'd)

- **Example of layered architecture**



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

3. 5G technology summary

3.4 Network slicing concepts and architecture (cont'd)

Note: The name "layer" here does not correspond to the classic one;. Here the semantic is rather "plane"

- **Previous slide:**
- **Service layer** includes
  - Business Support Systems (BSSs)
  - Business-level Policy and Decision functions
  - Apps. and services operated by the tenant (includes the E2E orchestration system)
- **Management and Orchestration layer**
  - Service Management function
  - **Software-Defined Mobile Network Orchestrator (SDM-O)**
    - Inter-slice resource Broker (handles cross-slice resource allocation)
    - **ETSI NFV (Mgmt. and Orchestration) MANO** higher level functions (NFVO)
    - Domain specific application manager (e.g., 3GPP Net Mng)
  - ETSI NFV MANO lower level functions (VIM, VNF Manager)
- **Control layer**
  - Software-Defined **Mobile Network Coordinator** (SDM-X) – **inter-slice**
  - Software-Defined **Mobile Network Controller** (SDM-C) – **intra-slice**
  - other control applications
- **Data layer** - VNFs and PNFs needed to carry and process the user data traffic
- **Auxiliary: Multi-Domain Network Operating System Facilities**
  - different adaptors and network abstractions above the networks and clouds heterogeneous fabrics

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

3. 5G technology summary

3.4 Network slicing concepts and architecture (cont'd)

- **Business model (**stakeholders**)-** 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

3. 5G technology summary

3.5 Network slicing components

- **Resources** (two types)
  - **(1) Network Functions (NFs): functional blocks (FB),** providing specific network capabilities to support particular service(s) demanded by each use case; generally implemented as :
    - **SW instances** running on infrastructure resources
    - **Physical NFs** (PNF -a combination of vendor-specific HW+ SW defining a traditional purpose-built physical appliance)
    - **and/or virtualised NFs (VNFs)**

      NF software is decoupled from the HW it runs on
  - **(2) Infrastructure Resources**: heterogeneous [HW + SW] for **hosting** and **connecting** NFs.
    - **Computing, storage and networking resources** (e.g. links and switching/routing devices enabling network connectivity)
    - physical assets for radio access
  - The resources and their attributes are abstracted and logically partitioned
    - leveraging virtualization mechanisms
    - defining virtual resources usable in the same way as physical ones

3.5 Network slicing components (cont'd)

- **Virtualization**
  - It is based on :
    - **resource abstraction** : representation of a resource in terms of attributes that match predefined selection criteria while hiding or ignoring aspects that are irrelevant to such criteria
  - Resources to be virtualised : **physical** or **already virtualised**, supporting a **recursive** pattern with different abstraction layers.
  - **Network virtualisation:** creation of multiple isolated virtual networks, completely decoupled from the underlying PHY network
  - **InPs and tenants can act as virtualisation actors** (recursion principle is valid)
    - **Recursion:**
      - a tenant at one layer can acts as the InP for an upper layer
      - a tenant can provide network services to an end_user/another tenant
  - VNFs can be implemented independently on different platforms and hosted in cloud/edge (e.g. MEC) facilities

3. 5G technology summary

3.5 Network slicing components (cont'd)

- **Orchestration** **-** key process for network slicing
  - **General definition : bringing together and coordinating disparate things into a coherent whole**
  - an orchestrator coordinates seemingly disparate network processes for creating, managing and delivering services.
  - **Open issue: a unified vision and scope of orchestration has not been fully agreed upon (2016-17)**

  - **Open Network Foundation (ONF)** **definition/vision on orchestration**
    - **continuing** process of **selecting resources** to fulfil client service demands in an optimal manner
    - **optimization policy** can be applied to govern orchestrator behaviour
      - to meet all the specific policies and SLAs associated with clients (e.g. tenants or end users) that request services
    - "**continuing**" meaning : available resources, service demands and optimization criteria **may change in time**

3. 5G technology summary

3.5 Network slicing components (cont'd)

- **Orchestration** (cont'd)
  - ONF: orchestration is also a defining characteristic of an SDN controller
  - orchestrator functions include
    - client-specific service demand validation; resource configuration; event notification
- **Open issue:** in network slicing orchestration cannot be performed by a single centralized entity;
- Reasons:
  - **complexity** and broad scope or orchestration tasks
  - need to preserve **management independence** of the domains
  - need to support the possibility of **recursion.**
- **Some proposal**
  - **Each virtualization actor should have an orchestration entity**
  - The entities should **exchange information** and delegate functionalities between them
    - to ensure that the services delivered at a certain abstraction layer satisfy the required performance levels with optimal resource utilisation

3. 5G technology summary

3.6 Categories of 5G fundamental scenarios

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

Applicable to V2X

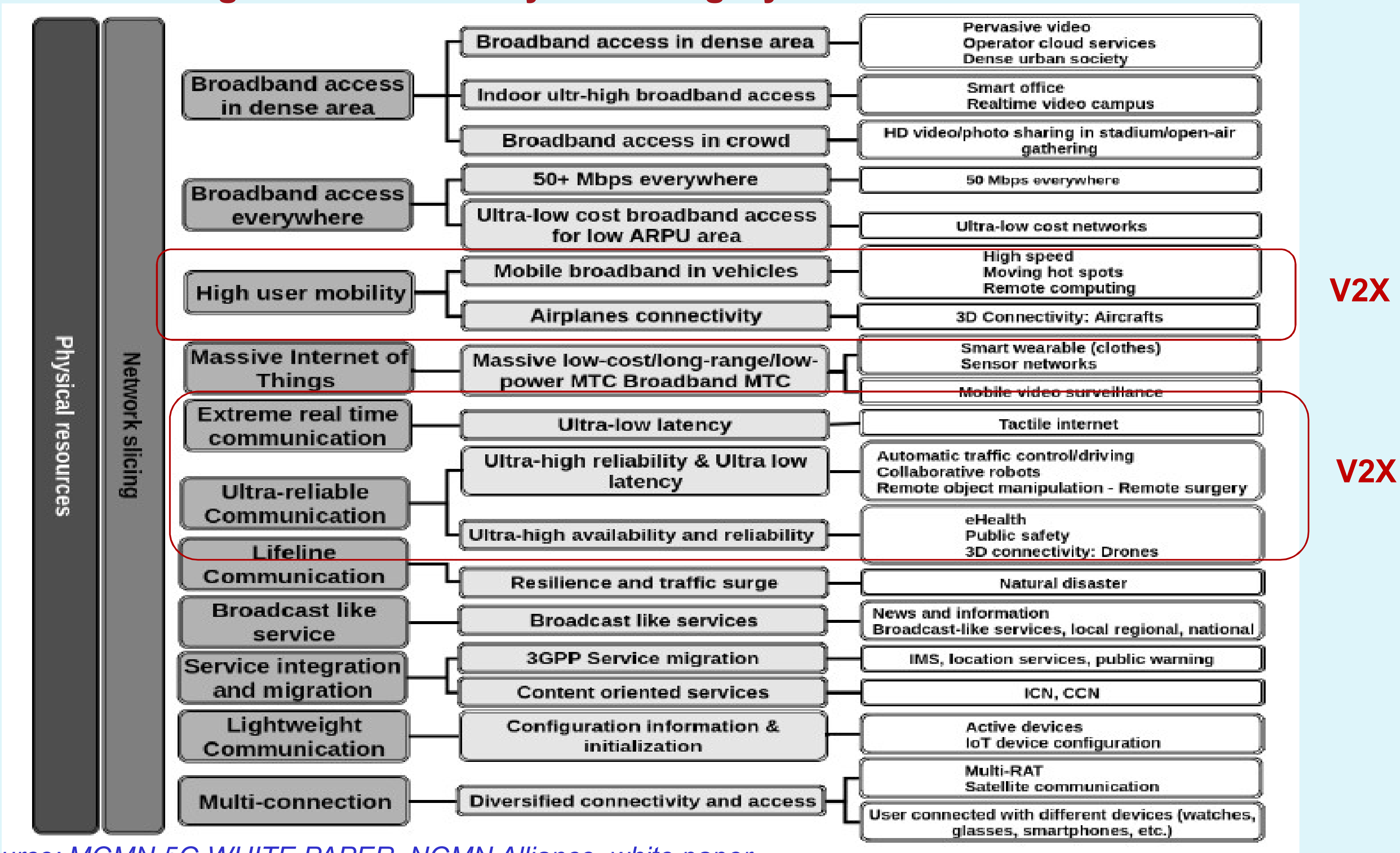
- **different requirements on 5G: functional** (e.g. priority, charging, policies, security, and mobility) and **performance** (e.g. latency, mobility, availability, reliability and data rates) -→ **dedicated slices can be constructed**

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

3. 5G technology summary

3.7 5G Slicing Use-cases family and category – from 3GPP and NGMN



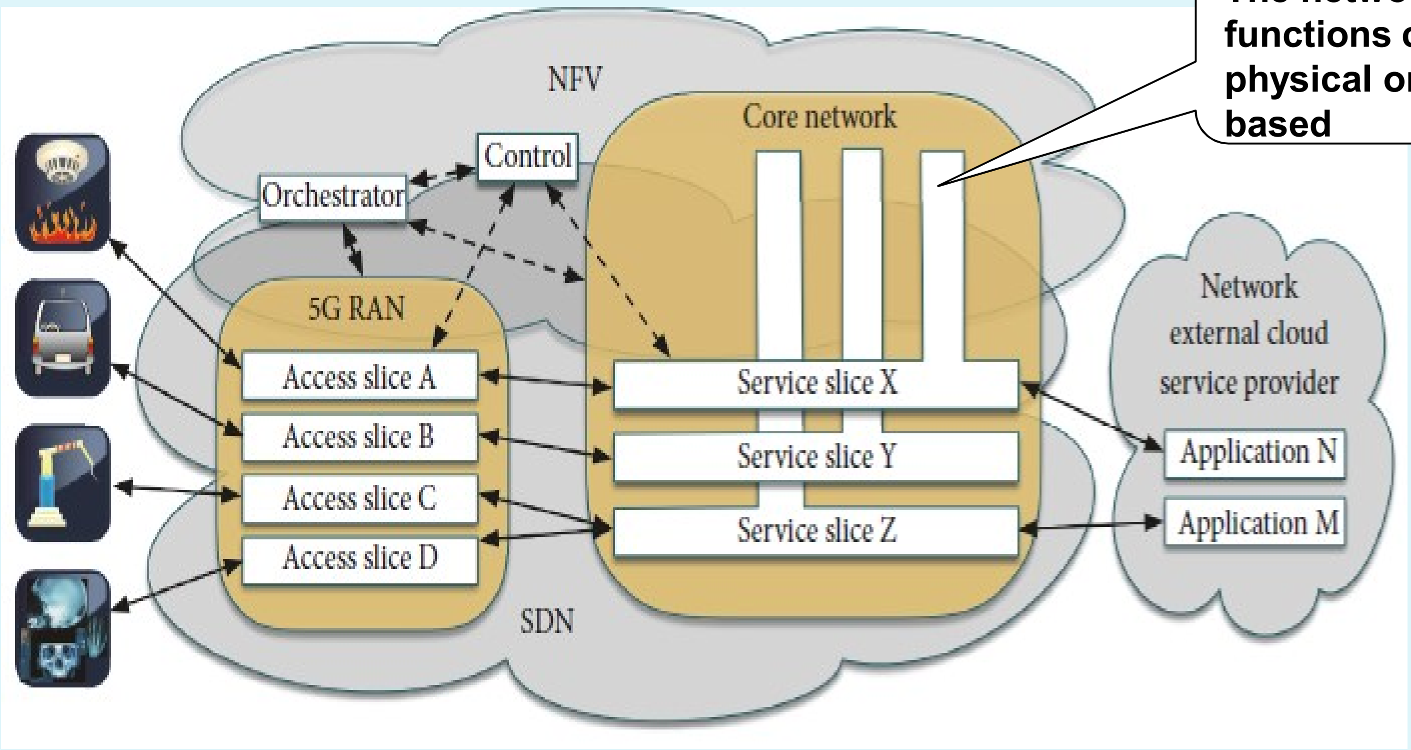
Source: MGMN 5G WHITE PAPER, NGMN Alliance, white paper, https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf, Feb. 2015.

3. 5G technology summary

3.8 Generic slicing architecture with SDN and NFV support

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

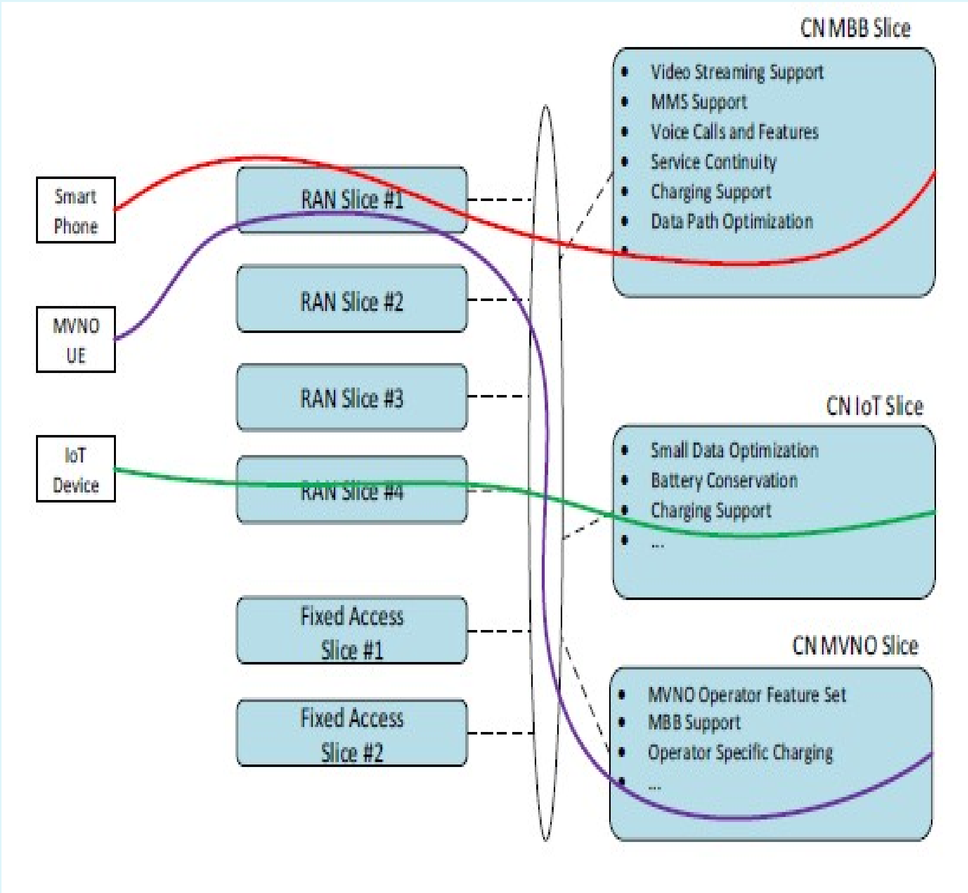
The network functions can be physical or NFV-based

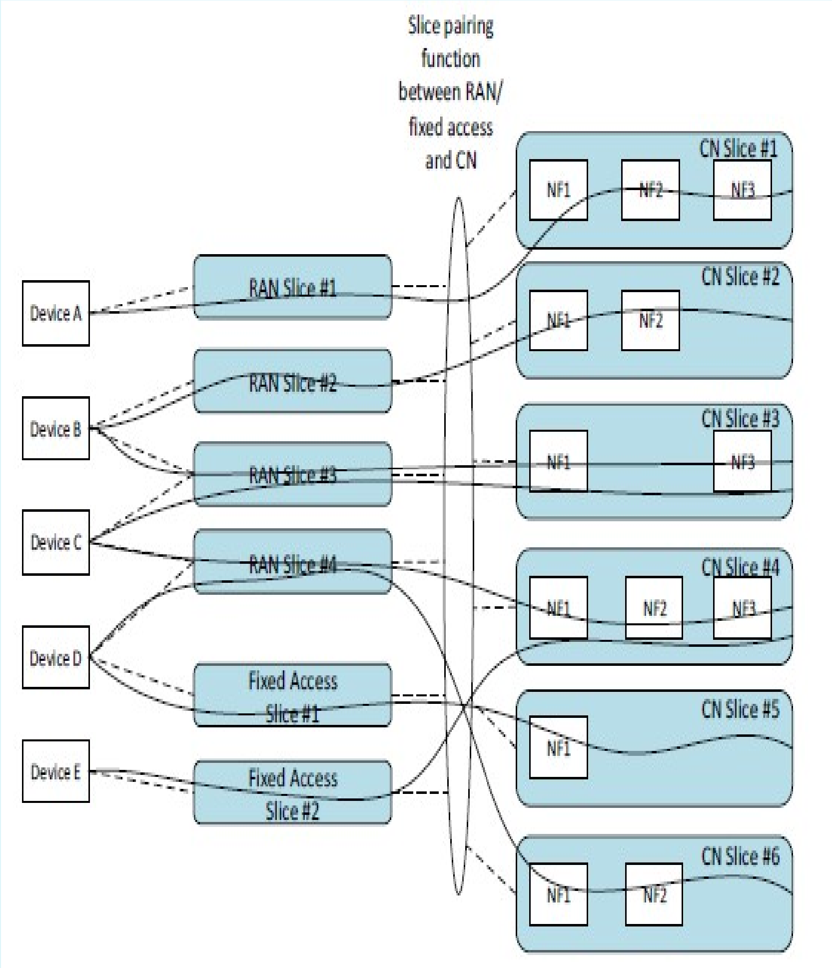


Source: G. Nencioni et al., Orchestration and Control in Software-Defined 5G Networks: Research Challenges, Wiley, Wireless Communications and Mobile Computing Volume 2018, Article ID 6923867, pp. 1-19, https://doi.org/10.1155/2018/6923867https://www.hindawi.com/journals/wcmc/2018/6923867/

3. 5G technology summary

- **3.9 Generic slicing variants**
- **UE Connection with the Network Slices**





Source: 5G Americas, Network Slicing for 5G Networks & Services, 2016, http://www.5gamericas.org/files/3214/7975/0104/5G_Americas_Network_Slicing_11.21_Final.pdf

3. 5G technology summary

3.9 Generic slicing variants (cont'd)

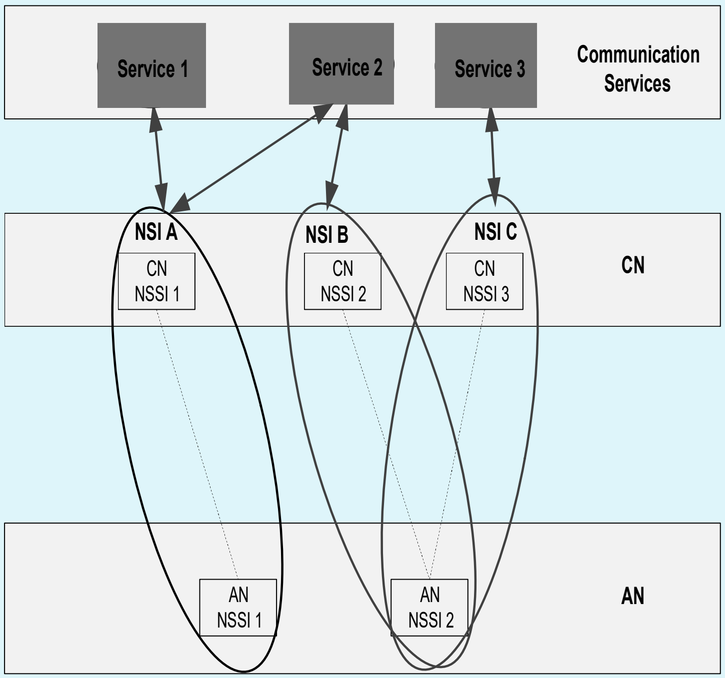
- **Previous slide: Flexible architecture w.r.t. inter-connection between UEs, the Network Slices and Network Slice subnets**

  - Interconnection between RAN/Fixed_access slices and CN slices – flexible
    - via - slice pairing function
      - between RAN and CN
      - between radio PHY and RAN
    - PHY can also be sliced
  - The same UE can connect simultaneously to several different slices
  - RAN and CN slices are customised (e.g., CN-MBB, CN-MVNO, CN-IoT)
  - A given type of NF can be used in several different slice instances
    - NFs can be appropriately chained cf. NFV technologies
  - The same **Network Slice Subnet Instance (NSSI)** can be shared by several Network Slice Instances (NSI)

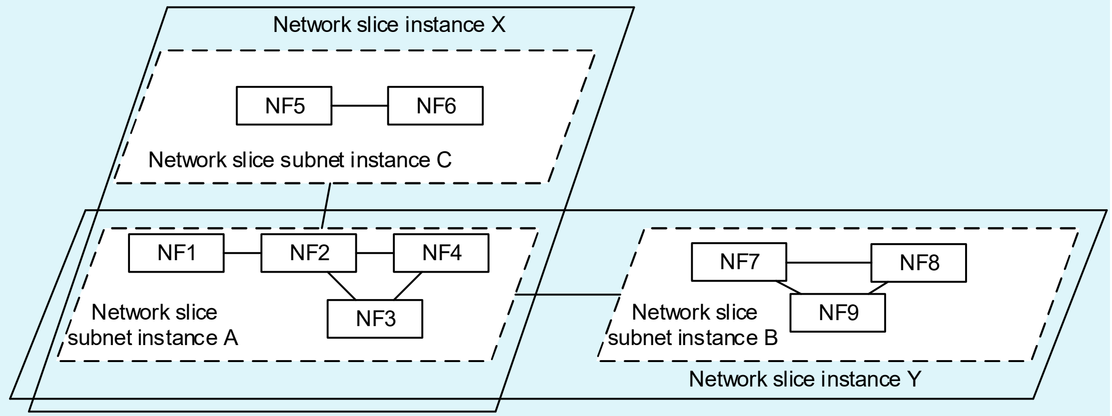
3. 5G technology summary

3.9 Generic slicing variants (cont'd) – examples

End to End services provided by NSI(s)



One NSSI can contribute to several NSIs
E.g., NSI X and Y composed by NSSI A, B and C

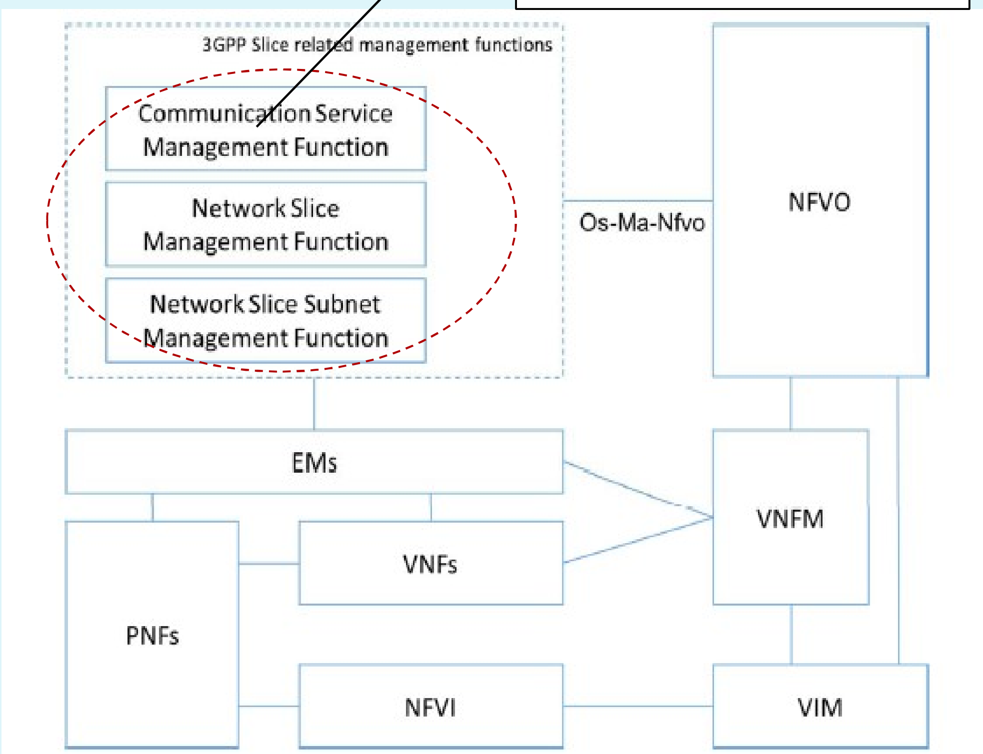


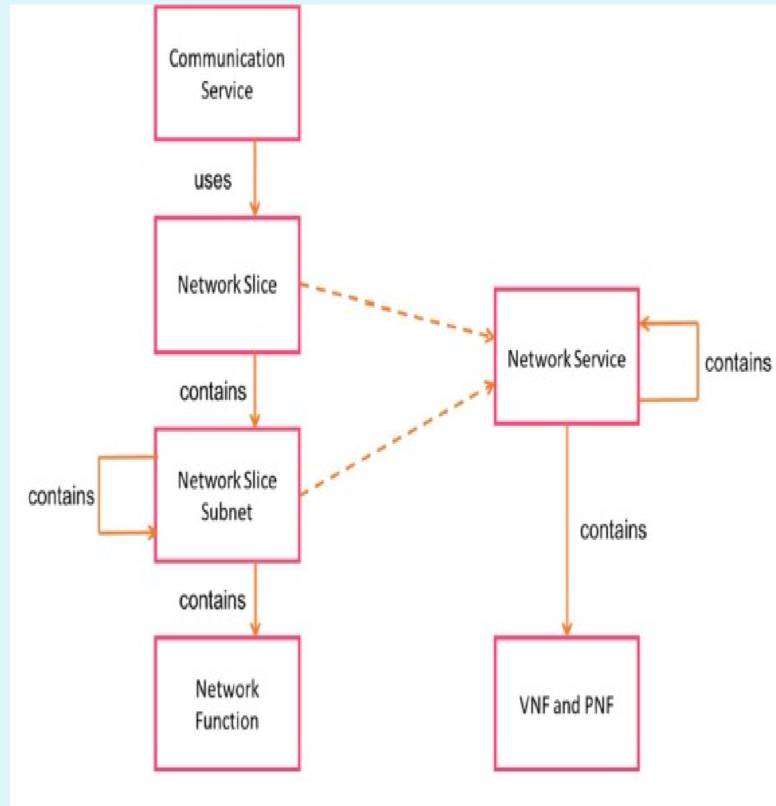
Source: 3GPP TR28.801 V15.1.0 (2018-01), Study on management and orchestration of network slicing for next generation network, (Release 15)

3.10 ETSI and 3GPP functional architectures for slicing support

- **Network slice management (NSM) in NFV framework**

New slicing mgmt. components added to NFV framework





Relating the information models

Source: ETSI GR NFV-EVE 012 V3.1.1 (2017-12), Release 3; NFV Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework

3.10 ETSI and 3GPP functional architectures for slicing support

- **Network slice management (NSM) in NFV framework** (cont'd)

- **Three layered functions** related to NS mgmt.
  - **Communication Service Management Function (CSMF):** translates the communication service requirements to NS requirements
    - The CSMF has I/F with **(NSMF)**
  - **Network Slice Management Function (NSMF) -** mgmt. (including lifecycle) of NSIs. It derives NS subnet requirements from the NS related requirements
    - NSMF has I/F with NSSMF and the CSMF.
  - **Network Slice Subnet Management Function (NSSMF) –** mgmt (including lifecycle) of NSSIs.
    - The NSSMF communicates with the NSMF.
- The **Os-Ma-NFVO Reference Point** (RP) is the I/F with NFV-MANO.

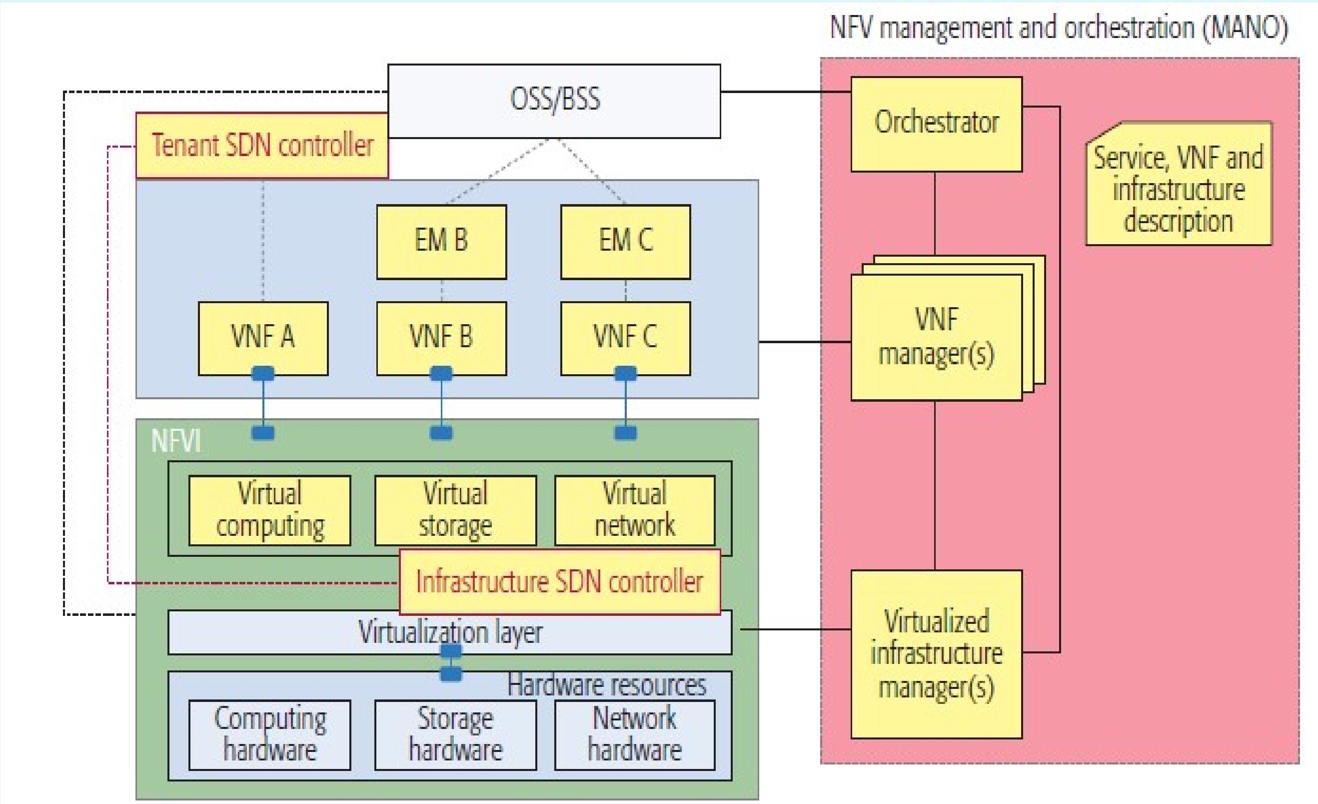
- The NSMF and/or NSSMF need to determine
  - the **type of NS or set of NSs, VNF and PNF** that can support the resource requirements for a NSI or NSSI,
  - and whether new instances of these NSs, VNFs and the connectivity to the PNFs need to be created or existing instances can be re-used

See ETSI GR NFV-EVE 012 V3.1.1 (2017-12), Release 3; NFV Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework

3. 5G technology summary

3.10 ETSI and 3GPP functional architectures for slicing support

- **Network slice management (NSM) in SDN/NFV integrated framework**
- Two level SDN controller hierarchy



NFV -Network Function Virtualization
EM - Element Manager
MANO - Management and Orchestration (NFVO – NFV Orchestration
VNFM – VNF Manager
VIM -Virtual Infrastructure Manager
VNF/PNF – Virtual/Physical Network Function
NFVI -NFV Infrastructure
NS-Network Service
OSS-Operations Support System

Sources: ETSI GS NFV-EVE 005, "NFV; Ecosystem; Report on SDN Usage in NFV Architectural Framework," v. 1.1.1, Dec. 2015; J. Ordonez-Lucena, et al, "Network "Slicing for 5G with SDN/NFV: Concepts, Architectures and Challenges", IEEE Communications Magazine, May 2017, pp. 80-87

3. 5G technology summary

3.10 ETSI and 3GPP functional architectures for slicing support

- **Network slice management (NSM) in SDN/NFV integrated framework** (cont'd)
- **Two level SDN controller hierarchy** (cont'd)
  - **Each controller**
    - centralizes the control plane functionalities
    - provides an abstract view of all the connectivity-related components it manages

- **Infrastructure SDN controller (IC)**
  - ***it sets up and manages the underlying networking resources*** to provide the required **VM connectivity to support the above communicating VNFs**
  - **VIM manages the IC** (VIM can be seen as a SDN application)
  - IC may change infrastructure behavior **on-demand according to VIM specifications**, adapted from tenant requests.

- **Tenant SDN controller (TC):**
  - instantiated in the tenant domain
    - as one of the VNFs
    - or as part of the NMS,
  - ***TC dynamically manages the pertinent VNFs*** used to realize the tenant's network service(s). These VNFs are the underlying **forwarding plane resources** of the TC.
  - The applications running on top of TC (e.g. the OSS) trigger the operation and management tasks that the TC carries out

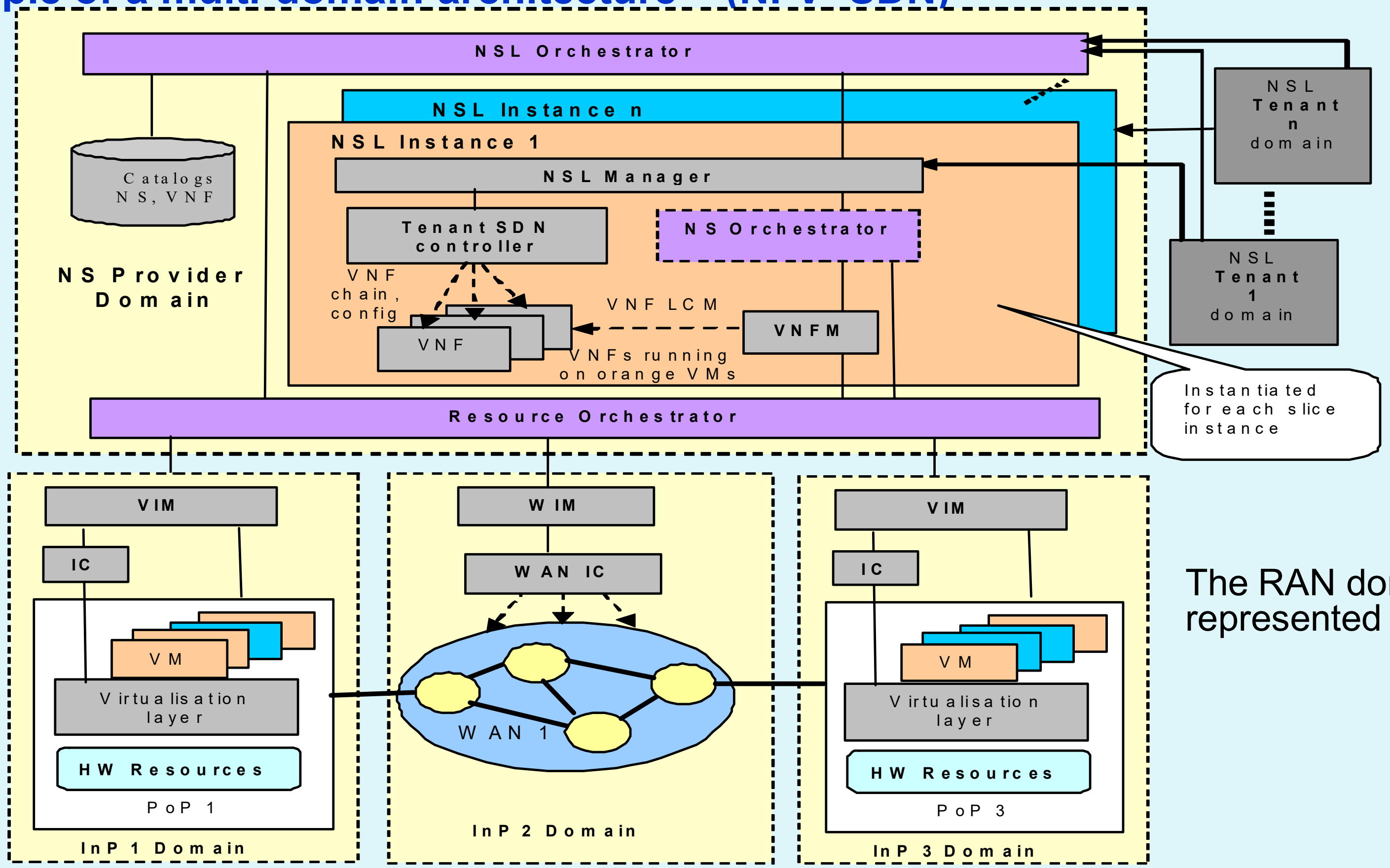
3. 5G technology summary

3.10 ETSI and 3GPP functional architectures for slicing support

- **Network slice management (NSM) in SDN/NFV integrated framework** (cont'd)
- **Two level SDN controller hierarchy** (cont'd)
  - **Controllers' southbound interfaces**
    - Programmable southbound interfaces (protocols like- OpenFlow, NETCONF or I2RS)
  - **Abstraction**
    - **IC provides an underlay** to support the deployment and connectivity of VNFs
    - **TC provides an overlay** comprising tenant VNFs that, properly composed, define the network service(s)
    - **The IC and TC have to coordinate and synchronize their actions.**
    - **Each tenant can independently manage on its slice(s).**
  - **Different views on resources**
    - The IC is **not aware** of the number of slices that utilize the VNFs it connects, nor the tenant(s) which operates such slices.
    - **For the TC the network is abstracted in terms of VNFs**
      - The TC does not know how those VNFs are physically deployed.
  - The service and tenant concept mentioned here can be extended to higher abstraction layers by applying the recursion principle

3.10 ETSI and 3GPP functional architectures for slicing support (cont'd)

- **Example of a multi-domain architecture – (NFV+SDN)**



The RAN domain is not represented in the figure

Adapted from source: J.Ordonez-Lucena, et.al., "The Creation Phase in Network Slicing: From a Service Order to an Operative Network Slice", European Conference on Networks and Communications (EuCNC), 2018, https://arxiv.org/abs/1804.09642 and ETSI GR NFV-EVE 012 V3.1.1 (2017-12), Release 3; NFV Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework

3. 5G technology summary

3.10 ETSI and 3GPP functional architectures for slicing support (cont'd)

- **Example of a multi-domain architecture NFV + SDN** (cont'd):
  - **Several tenants** each one creating managing and running its own slices
    - **Examples: Healthcare tenant; (V2X) -Automated driving tenant**
  - **Multi-domain:** Data centers, networking, ..
  - The **NSLIs run in parallel** on a shared underlying **NFVI** (three different InPs)
  - Each NFVI-PoP has a single VIM instance that directly configures and manages the virtualisation containers and their underlying hardware.
  - A **WAN Infrastructure Manager (WIM**) instance enables connectivity between NFVI-PoPs in each WAN domain

  - Each **tenant** uses **NFVI resources** supplied by the **underlying InPs** to serve the needs of the slices in the tenant domain
  - This scenario is aligned with the **NFVI as a Service (NFVIaaS)** approach discussed in ETSI GR NFV-IFA 028
  - The tenants and slices are isolated from each other

  - **VIMs and WIMs should support multi-tenancy** offering separate NFVI resources to subscribed tenants through dedicated interfaces.

Source: ETSI GR NFV-EVE 012 V3.1.1 (2017-12), Release 3; NFV Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework

3. 5G technology summary

3.10 ETSI and 3GPP functional architectures for slicing support (cont'd)

- **Example of a multi-domain architecture NFV + SDN (cont'd):**
- **The NSL provider**
  - can simultaneously operate multiple NSLIs
  - rents the infrastructure resources owned by the InPs

- A **NSL instance (NSLI)** may be composed of one or more **Network Service (NS) instances**
  - The NSLI can consist
    - of an instance of a simple NS.
    - of an instance of a composite NS.
    - of a concatenation of simple and/or composite NS instances
- **A NSL instance**
  - can span several ***Infrastructure Providers* (InP)** and/or admin. domains
  - **has its own MPI** plane and this provides **isolation across NSLIs**
    - **NSL Manager**
    - **Network Service Orchestrator (NSO)**
    - **Tenant SDN Controller**
    - **VNF Manager (VNFM)**

  - The VNFM(s) and the NSO perform the required **life cycle** operations (e.g. instantiation, scaling, termination, etc.) over the instances of the VNFs and NS(s), respectively.

3. 5G technology summary

- **3.10 ETSI and 3GPP functional architectures for slicing support** (cont'd)
- **Example of a multi-domain architecture NFV + SDN** (cont'd)
- **NSL Orchestrator (NSLO)**
  - highest layer of the architecture
  - **key role in the creation** phase and also in the **run-time** phase

  - **NSLO- role at creation phase**
  - NSLO receives the order to deploy a NSLI for a tenant (or the Slice Provider decides to construct a slice)
    - NSLO needs to have information (including on multi-domain) as to be able to check the feasibility of the order
    - if feasible, then triggers the instantiation of the NSL
    - To accomplish this, NSLO interacts with RO, and accesses the VNF and NS Catalogues
    - The catalogues contain VNF and NS descriptors, exposing the capabilities of all the VNFs and NSs that an NSL provider can select for the NSLs.

  - **NSLO role at run-time**
  - NSLO performs policy-based inter-slice operations
    - e.g.: it analyzes the perf and fault management data received from the operative NSLIs instances to manage their SLAs)
    - If SLA violations, the NSLO decides modify/correct some NSLIs

3. 5G technology summary

- **3.10 ETSI and 3GPP functional architectures for slicing support** (cont'd)
- **Example of a multi-domain architecture NFV + SDN** (cont'd)
- **The NSLO and Resource Orchestrators are multi-domain capable**

- **Resource Orchestration (RO)**
  - uses the resources (supplied by the VIMs/WIMs), and dispatches them to the NSL instances in **an optimal way**
  - knows the resource availability in each domain (**this supposes a set of inter-domain interactions**)

- **NFVI level**
  - NFV and SDN solutions are applied
  - Management and Control (M&C)
    - VIM
    - WIM
    - SDN Infrastructure controllers
  - **VIMs**
    - have resource pooling mechanisms to provide subscribed tenants with isolated resource environments endowed with high availability and fault resilience features for tenant VNFs deployment
  - **WIMs**
    - have mechanisms (see the ONF TR 527) to simultaneously manage a number of virtual topologies in the WAN with different levels of abstraction

3. 5G technology summary

3.10 ETSI and 3GPP functional architectures for slicing support (cont'd)

- **Example of a multi-domain architecture NFV + SDN** (cont'd)

- **Two level hierarchical SDN control**
  - **Tenant controller (TC) and infrastructure SDN controller,** each logically placed in different administrative domains.
- **Tenant Controller (**it can be deployed as a VNF itself)
  - dynamically configures and **chains VNFs (graphs)** to realize NSs in the tenant domain
  - only controls the SW apps. of the VNFs for configuration and chaining purposes, but not their underlying NFVI resources
  - offers a set of dedicated northbound I/Fs that allows slice's clients (and thus tenant's clients) to interact with the slice

- **Infrastructure Controller**
  - manages and controls the NFVI network resources (placed in a NFVI-PoP or a WAN) to set up the connectivity for communicating the tenant VNFs in the infrastructure domain (i.e., among the virtualization containers that host the tenant VNFs' SW applications) under VIM control

3. 5G technology summary

3.10 ETSI and 3GPP functional architectures for slicing support (cont'd)

- **Example of a multi-domain architecture NFV + SDN** (cont'd)

- **Security**
  - Each **admin domain may have its own security domain**
    - e.g.: one security domain for eachInP, one security domain for each tenant, and one (or more) security domain(s) for each slice.
  - clients may come from different organizations
    - the definition of separate security domains in the slice is required to preserve security and privacy isolation between clients
    - the abstraction and isolation that the TC enables with its northbound interfaces helps to accomplish this.

- **This deployment enables recursion** (identified in ETSI GS NFV-IFA 009) as one of the key features for network slicing (some clients of a given tenant in turn can act as tenants as well)

3. 5G technology summary

3.10 ETSI and 3GPP functional architectures for slicing support (cont'd)

- **Example of a multi-domain architecture NFV + SDN** (cont'd)

- **General steps performed by the M&O (i.e., higher layer NSLO and RO) for a slice instance creation**
  - a. **Service ordering**
    - NSL provider
      - constructs a *Service Catalogue* (business-driven), containing for each service a *service template*, specifying the service offering
        - The Catalogue contains NSLs specifications optimized for different usage scenarios
      - offers APIs to tenants for a dialogue
      - dialogue → catalogue-driven NSL *service order* (info to be mapped on RAN, transport, and core network domains)
  - **b. Network slice resource description**
  - **c. Admission control**
  - **d. Optimization and Resource Reservation**
  - **e. Network slice preparation**

3. 5G technology summary

3.11 Network slice life cycle management

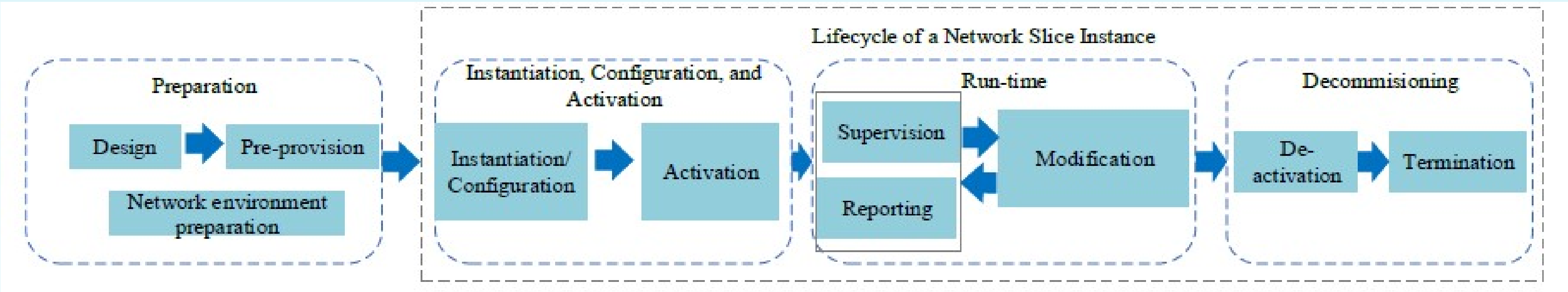
- Functions provided by the NSM system in several phases for a NSI life cycle
  - **Preparation phase**
  - **Instantiation, Configuration and Activation phase**
  - **Run-time phase**
  - **Decommissioning phase**
- Details:
  - **Preparation phase** **(**the NSI does not exist yet)
    - creation and verification of NS template(s)
    - preparation of the necessary network environment to support the NSIs lifecycle (e.g., provisioning databases)
  - **Instantiation / configuration**
    - It can include **instantiation, configuration and activation** of other shared and/or non-shared NFs
    - All resources shared/dedicated to the NSI are created and configured, i.e. to a state where the NSI is ready for operation.
    - Activation : makes the NSI active, e.g. diverting traffic to it

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

3. 5G technology summary

3.11 Network slice life cycle management (cont'd)

- Functions provided by the NSM system in several phases for a NSI life cycle
  - **Run-time phase**
    - NSI handles traffic to support services of certain type(s)
    - **Supervision/reporting** (e.g. for KPI monitoring)
    - **Modification** could be: upgrade, reconfiguration, NSI scaling, changes of NSI capacity, changes of NSI topology, association and disassociation of network functions with NSI
  - **Decommissioning phase**
    - **Deactivation** (taking the NSI out of active duty)
    - Free the dedicated resources (e.g. **termination** or re-use of network functions) and configuration of shared/dependent resources
    - Finally, the NSI does not exist anymore



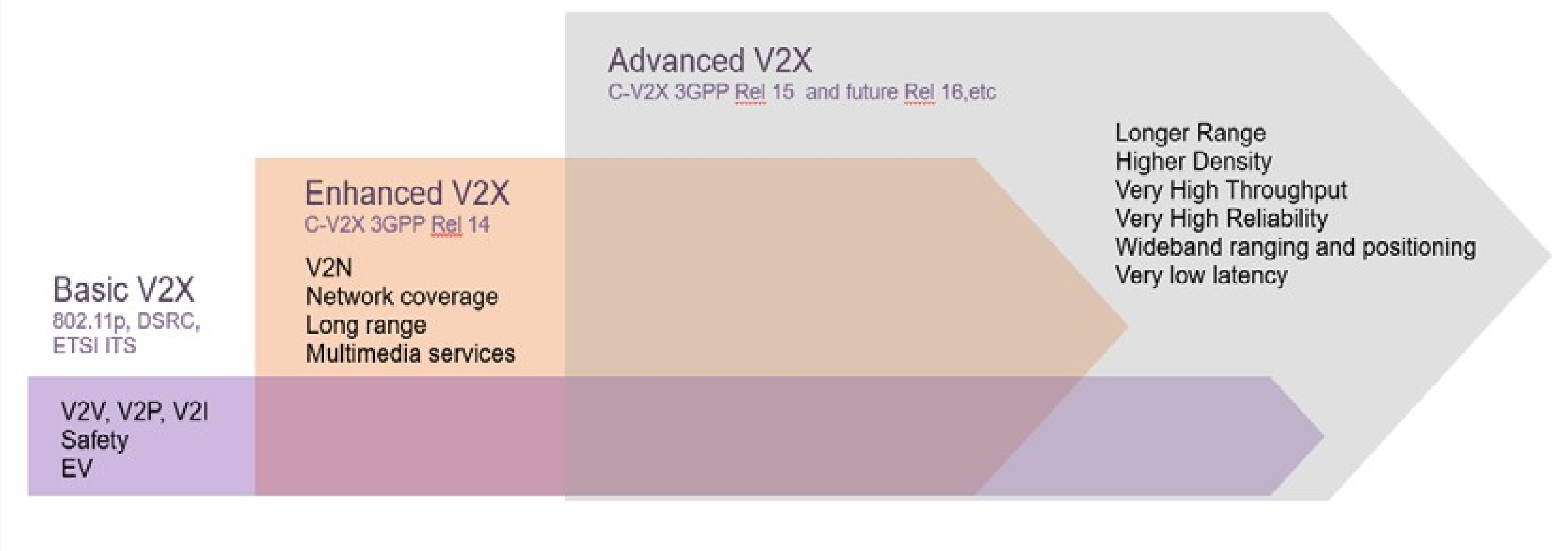
Source: End to End Network Slicing – White paper 3 Outlook 21, Wireless World , Nov 2017

CONTENTS

4. V2X on 5G- system architectures and design

4.1 V2X evolution

- V2X -802.11p supported a limited set of basic safety services
- 3GPP Rel.14: extended V2X :
  - low-bandwidth safety apps … to high-bandwidth apps
- **3GPP Rel. 15 and 16 →more V2X services**: longer range, higher density, very high throughput and reliability, highly precise positioning and ultra-low latency
- V2X's evolution to 5G is via the 3GPP "New Radio (NR)" access technologies

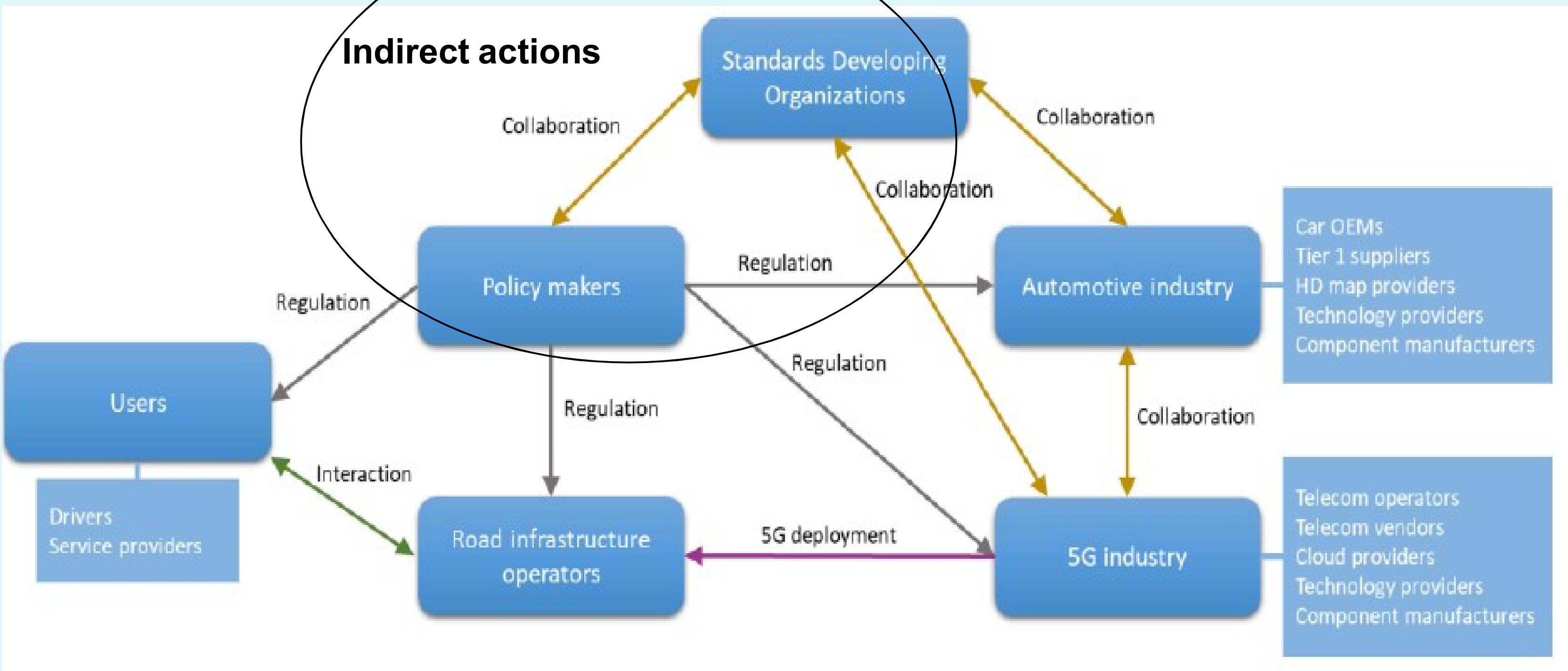


Source: https://www.5gamericas.org/wp-content/uploads/2019/07/2018_5G_Americas_White_Paper_Cellular_V2X_Communications_Towards_5G__Final_for_Distribution.pdf

4. V2X on 5G- system architectures and design

4.1 V2X on 5G – main stakeholders and relationships

- Main stakeholder categories involved in 5G V2X
  - 5G industry, automotive industry, Standards Developing Organizations (SDOs), road infrastructure operators, policy makers, and users



Source: 5G-PPP Automotive Working Group A study on 5G V2X Deployment, V1.0, February 2018 , https://5g-ppp.eu/wp-content/uploads/2018/02/5G-PPP-Automotive-WG-White-Paper_Feb.2018.pdf

4. V2X on 5G- system architectures and design

4.2 V2X Candidate technologies

- **Major V2X technologies**
  - IEEE 802.11p
  - LTE and 5G
  - low-power wide-area network (LPWAN)—for V2I special use cases (e.g., smart city parking).

Technology	Region	Standard
802.11p	US	IEEE 802.11-2012, IEEE 1609.2 - .4, SAE J2735 and SAE J2945/x series
802.11p	Europe	"ITS-G5", ETSI ITS series
802.11p	Japan	ARIB STD-109
Cellular LTE	Global	3GPP TS 22.185, TS 23.285 for V2X and LTE, and TS 36 series for radio access
Cellular 5G	Global	3GPP TS 22.186; TS 23.501 for network architecture 3GPP 38 series for the radio access

Source: https://www.5gamericas.org/wp-content/uploads/2019/07/2018_5G_Americas_White_Paper_Cellular_V2X_Communications_Towards_5G__Final_for_Distribution.pdf

4. V2X on 5G- system architectures and design

4.2 V2X candidate technologies (cont'd)

- **General Comparison DSRC, LTE Rel.14 C-V2X and 5G C-V2X (2018)**

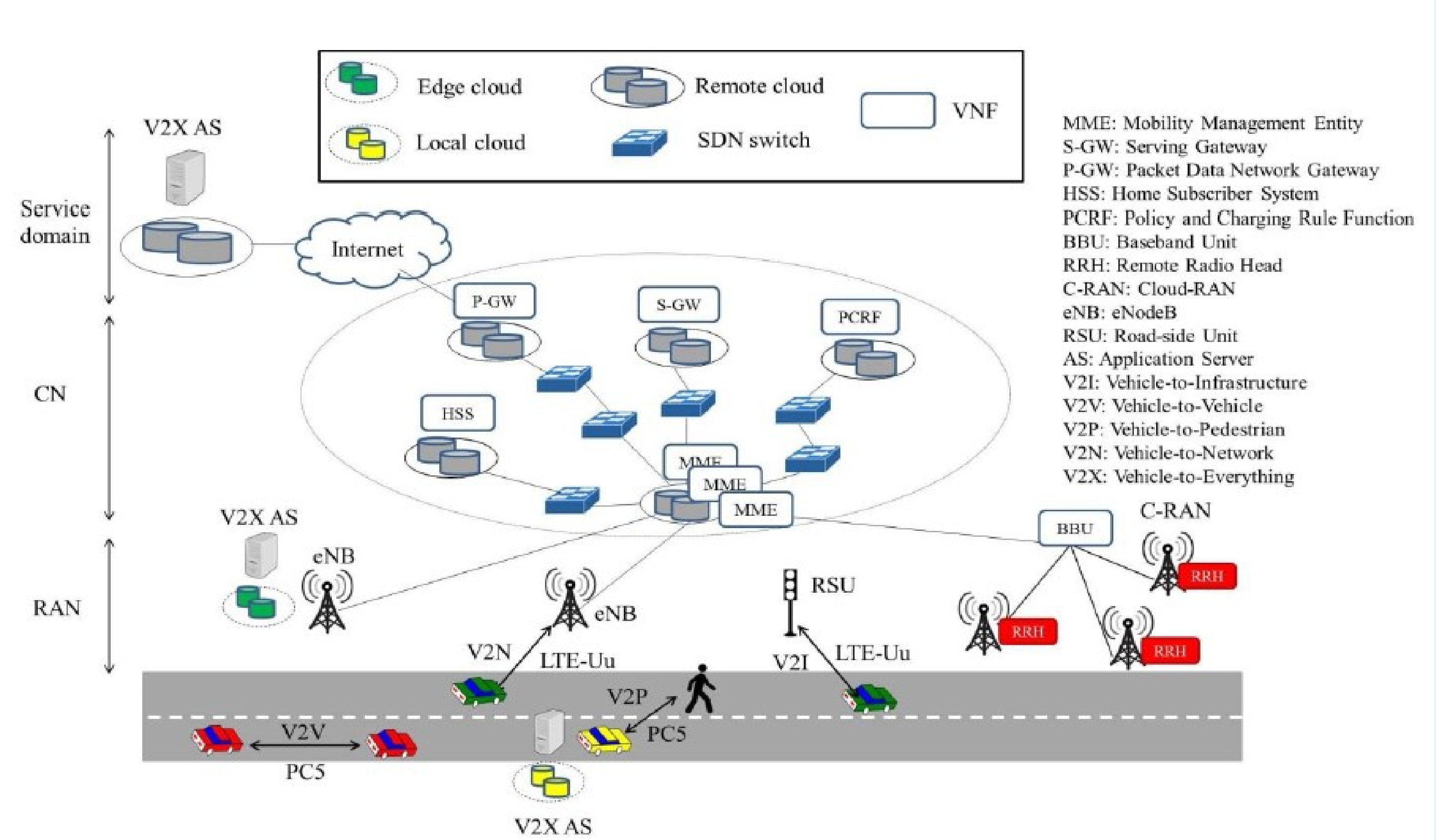
KEY ELEMENTS	DSRC/ IEEE 802.11	Rel 14 C-V2X	5G C-V2X (Rel 15,16) (expected)
Out-of-network operation	✓	✓	✓
Support for V2V	✓	✓	✓
Support for safety-critical uses	✓	✓	✗ *
Support for V2P	✓	✓	✓
Support for V2I	*limited*	✓	✓
Support for multimedia services	✗	✓	✓
Network coverage support	*limited*	✓	✓
Global economies of scale	✗	✓	✓
Regulatory/testing efforts	✓	*limited*	✗
Very high throughput	✗	✗	✓
Very high reliability	✗	✗	✓
Wideband ranging and positioning	✗	✗	✓
Very low latency	✗	✗	✓

Source: https://www.5gamericas.org/wp-content/uploads/2019/07/2018_5G_Americas_White_Paper_Cellular_V2X_Communications_Towards_5G__Final_for_Distribution.pdf

4. V2X on 5G- system architectures and design

4.3 V2X in 5G network - general architecture

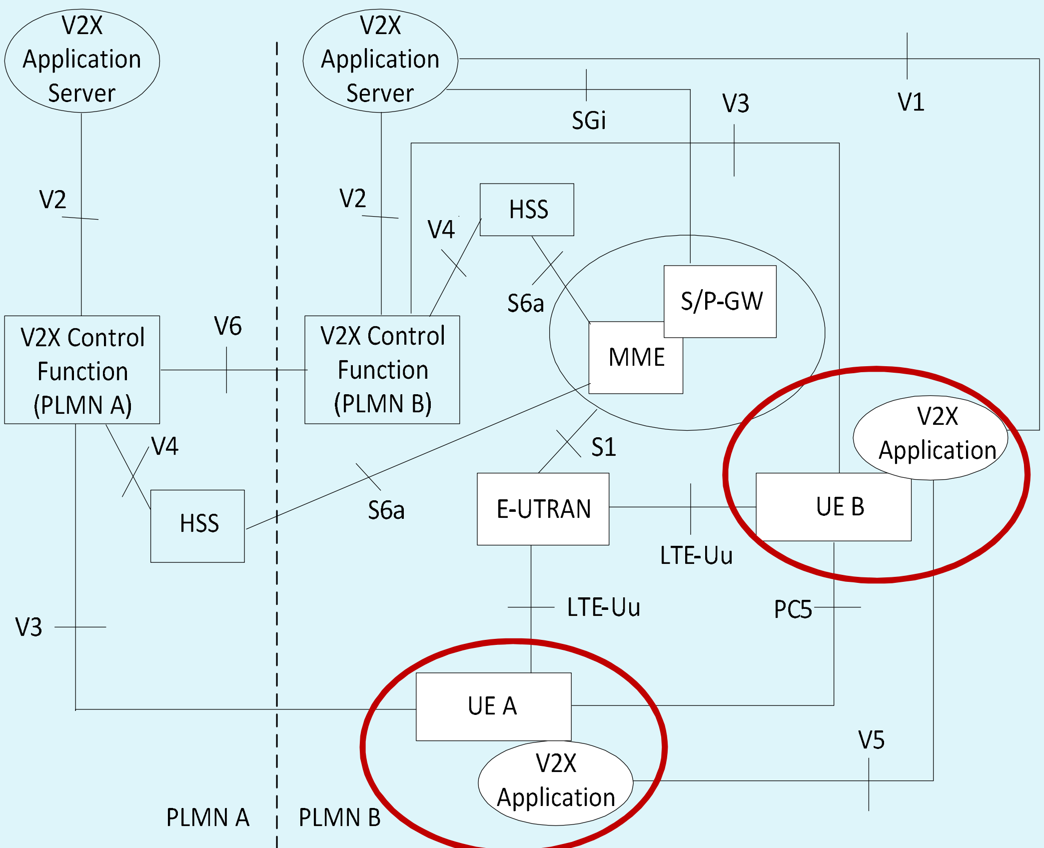
- network functional blocks are taken from 4G/LTE



Source: C.Campolo, A.Molinaro, A.Iera, F.Menichella, "5G Network Slicing for Vehicle-to-Everything Services", IEEE Wireless Communications, Volume: 24 Issue: 6, DOI: 10.1109/MWC.2017.160040

4. V2X on 5G- system architectures and design

- **4.4 V2X in 5G network – reference functional architecture**
- **Roaming reference architecture for PC5 and LTE-Uu based V2X communication**



LTE Core network entities
MME- Mobility Management Entity
HSS- Home Subscribes System
S/P-GW- Servicg/Packet Gateway

E-UTRAN - Evolved Universal Terrestrial Radio Access Network
UE A uses a subscription of PLMN A and UE B uses a subscription of PLMN B

UE A is roaming in PLMN B while UE B is not roaming.

A V2X Application Server may connect to multiple PLMNs, e.g. :
-one V2X Application Server can connect with the V2X Control Function in PLMN A and the V2X Control Function in PLMN B

Source: 3GPP TS 23.285 V16.2.0 (2019-12) 3GPP TSG SSA Architecture enhancements for V2X services(Release 16)

4. V2X on 5G- system architectures and design

- **4.4 V2X in 5G network – reference functional architecture**
- **Reference architecture for PC5 and LTE-Uu based V2X communication**
- **Entities**
  - **V2X Control Function (V2X CF)**
  - is the logical function used for V2X network related actions
  - In **3GPP TS 23.285 V16.2.0 (2019-12)** spec. it is assumed that there is only one logical V2X CF Control in each PLMN that supports V2X Services
  - **V2X CFcapabilities**
    - provision the UE with necessary parameters in order to use V2X communication in this specific PLMN
    - to provision the UE with needed parameters when the UE is "not served by E-UTRAN".
    - to obtain V2X ***User Service Descriptions*** **(USDs)** for UEs to receive MBMS based V2X traffic, through V2 reference point from the V2X Application Server.
    - to obtain the parameters required for V2X communications over PC5 reference point, from the V2X Application Server via V2 Ref.Point

Source: 3GPP TS 23.285 V16.2.0 (2019-12) 3GPP TSG SSA Architecture enhancements for V2X services(Release 16)

4. V2X on 5G- system architectures and design

- **4.4 V2X in 5G network – reference functional architecture**
- **Reference architecture for PC5 and LTE-Uu based V2X communication**
- **Entities** (cont'd)
  - **Application Server (AS)**
  - V2X AS-es (e.g., in different domains) inter-exchange V2X messages
    - The I/F between V2X AS and the methods of the exchange of messages between V2X AS-es are out of scope of 3GPP
  - **V2X AS capabilities**:
    - Receives/delivers unicast data from/to UE
    - Performs **Multicast Broadcast Media Service (MBMS)** data
    - Maps the geo-location information to cell IDs and manipulate UE-network parameters for broadcast/multicast
    - Cooperate for activating/deactivating/modifying the MBMS bearer
    - Provides to V2X Control Function the V2X USDs for UE (to allow receiving MBMS based V2X traffic)
    - Provides the parameters for V2X communications
      - over PC5 reference point to V2X CF
      - over PC5 reference point to UE

Source: 3GPP TS 23.285 V16.2.0 (2019-12) 3GPP TSG SSA Architecture enhancements for V2X services(Release 16)

4. V2X on 5G- system architectures and design

- **4.4 V2X in 5G network – reference functional architecture**
- **Reference architecture for PC5 and LTE-Uu based V2X communication**
- **Entities (cont'd)**
- **User Equipment**
  - UE may support the functions:
    - **Exchange of V2X control info between UE and the V2X CF** over the V3 RP
    - Procedures for **V2X communication over PC5 RP** and/or LTE-Uu RP
    - Configuration of parameters for V2X communication (e.g., destination Layer-2 IDs, RR parameters, V2X AS address information, mapping between service types and V2X frequencies)
      - These parameters can be pre-configured in the UE, or, if in coverage, provisioned by signalling over the V3 Reference Point from the V2X Control Function in the HPLMN.
    - **Provided with V2X USDs** for receiving MBMS based V2X traffic
      - via existing MBMS service announcement mechanisms,
      - or provisioned from V2X Control Function, or provisioned from the V2X Application Server via V1 reference point.
    - Provisioned with V2X Server USDs for receiving V2X AS information via MBMS

- **ME-UTRAN, S-GW, P-GW, HSS are 4G/LTE functional entities**

Source: 3GPP TS 23.285 V16.2.0 (2019-12) 3GPP TSG SSA Architecture enhancements for V2X services(Release 16)

4. V2X on 5G- system architectures and design

4.5 5G slicing for V2X

- **V2X services require complex features** which do not map exactly on the basic reference slice types: eMBB, URLLC and mMTC
- Different V2X dedicated slicing solutions have been proposed
  - **Traffic safety and efficiency** services –slice (V2V, V2P, V2I)
    - periodic and event-driven messages (carrying position and kinematics information of vehicle)
    - vehicles can broadcast messages to surrounding environment
    - **low latency and high reliability requirements**
  - **Autonomous driving** services –slice (V2V, V2I, V2N)
    - **ultra low-latency** V2V RAT connection mode
    - additional RAN/CN functions (e.g., for network-controlled resource allocation over the PC5I/F - in eNB)
    - mobility, authentication, authorization and subscription management (MME and HSS).
    - low-latency and reliable video/data exchange needs to be supported with a V2X AS, **deployed at the network edge**

Sources: J.Mei, X.Wang, and K.Zheng, "Intelligent Network Slicing for V2X Services Towards 5G", arXiv:1910.01516v1 [cs.NI] 3 Oct 2019
C.Campolo, A.Molinaro, A.Iera, F.Menichella, "5G Network Slicing for Vehicle-to-Everything Services", IEEE Wireless Communications, Volume: 24 Issue: 6, DOI: 10.1109/MWC.2017.160040

4.5 5G slicing for V2X (cont'd)

- Different V2X dedicated slicing solutions have been proposed (cont'd)
  - **Tele-operated driving slice**
    - **ultra-low latency and highly-reliable E2E** connectivity between the controlled vehicle and the remote operator (typically hosted outside the CN ; data flows passes through a P-GW).
    - such services are activated under special circumstances only
  - **Vehicular Internet and Infotainment – slice**
    - use **multiple RATs** for a high throughput
    - the contents can be located in the remote/edge cloud (e.g., server co-located in eNodeBs- MEC technology)
    - **multiple MME instances** may be required depending on the users mobility degree
  - **Vehicle management and remote diagnostics** slice
    - support the exchange of low-frequency small amounts of data between vehicles and remote servers outside the core network
    - **DPI and CPI handle multiple interactions**

Sources: C.Campolo, A.Molinaro, A.Iera, F.Menichella, "5G Network Slicing for Vehicle-to-Everything Services", IEEE Wireless Communications, Volume: 24 Issue: 6, DOI: 10.1109/MWC.2017.160040

4. V2X on 5G- system architectures and design

4.6 V2X slice design issues

- **The general approach of V2X 5G slicing involve *multi-tenant, multi-domain multi-operator and E2E* capabilities**
  - ***E2E* V2X** slices need **dynamic composition of different slice instances** in the RAN and in the CN segments.
    - E.g., some functions in CN can be shared by several specific slices (authentication/ authorization), while each slice in RAN domain is differently customized
  - 3GPP proposed for slices creation a ***multi-dimensional slice descriptor***
    - It contains among others: ***Tenant ID*** (e.g., the car manufacturer, the road authority), ***Slice Type*** (e.g., vehicular infotainment, remote diagnostic), but also some additional specific parameters like: position/kinematics parameters
  - A vehicle can be a ***multi-slice device***, able to *simultaneously* attach to multiple slices
  - ***Multi-tenancy*** and ***multi-operator*** : - **different providers** can offer **different services** mapped onto **different slices**, over the infrastructure owned by **different network operators**

4. V2X on 5G- system architectures and design

4.7 Core network slicing aspects

- The **Control Plane** in 4G/5G comprise MME, HSS, PCRF , etc. entities
- **Mobility Management Entity (MME)**
  - Roles: managing mobility, session, authentication, and authorization procedures

  - **MM overload is possible** in V2X due to high vehicle speed
  - isolation between V2X slices is necessary v.s. other (non-V2X) slices with similar functionalities but having lower mobility (e.g., for pedestrian/indoor UEs)
  - V2X –**possible design solution:** ***multiple MME instances*** (deployed as VNFs) and interconnected, to meet the needs of the V2X slices

  - The **MME can be decomposed** having different MM functions co-located with the eNodeBs, to ensure low-latency signaling procedures
    - The basic MM functions can intercommunicate with other CN functions (e.g authentication and authorization (AU), or with HSS) via SDN-controlled paths.

4.7 Core network slicing aspects (cont'd)

- **evolved Multimedia Broadcast Multicast Service (eMBMS)**
  - This service is **needed in autonomous driving slice** with the ***on-the-fly*** activation to allow the dissemination of road safety information on a traffic event
  - **Nodes supporting eMBMS functionalities**, i.e., the Broadcast multicast service center (BM-SC), the MBMS-GW and the MME, are **typically located in the CN**
    - Problem: the delay(backhaul) between the BM-SC and the eNodeB may be non-negligible
  - Solution based on decoupling of the Control Plane (CP) User Plane (UP)
    - the UP of MBMS CN functions (BM-SC, MBMS-GW) can be moved closer to the eNodeB, using NFV approach
    - proposed in 3GPP TR 23.785 V1.1.0, TSG Services and System Aspects; Study on Architecture Enhancements for LTE support of V2X services (Release 14), 2016

4. V2X on 5G- system architectures and design

4.7 Core network slicing aspects (cont'd)

- **Application Servers (AS)**
  - The AS can be deployed outside the LTE network (e.g., in cloud facilities) or closer to the vehicles
  - Edge technology **Mobile Multi-access Computing (MEC)** enable V2X AS instances to **run close to the users**, e.g., at the eNodeB premises (e.g. to serve critical operations of autonomous vehicles)
    - Advantage for traffic AS - collecting sensor and vehicle-generated data, and locally processing them
  - NFV and MEC can also support Infotainment servers **to move the UP functions closer to the UE**
  - The placement of the V2X AS in remote cloud facilities, outside the operator's network, is still preserved , for delay-tolerant services
  - A vehicular **infotainment slice can perform edge caching** and coupled with *pre-fetching* strategies that let the content follow the vehicular UEs

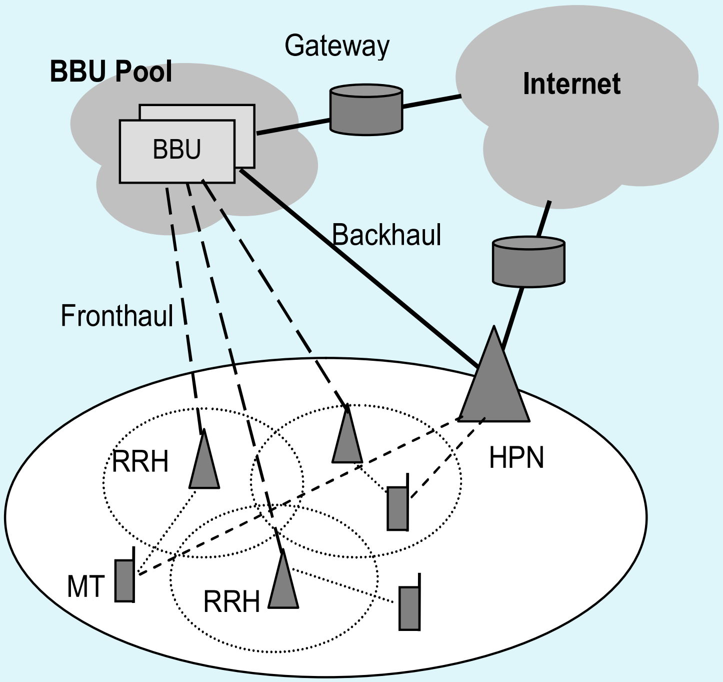
  - **Mobility prediction models** can enhance the V2X slicing functionalities (optimization of the V2X resource planning and traffic engineering is possible)

4.8 RAN slicing aspects

- **RAN architecture**
- The Cloud-RAN (C-RAN) technology splits the radio and baseband processing
  - **Radio functions** – in **Remote Radio Heads (RRH)**
  - **Baseband processing** migrated to the cloud and forming a **BBU pool**
  - **H-CRAN Heterogeneous Cloud Radio Access Networks (**HetNet)
    - Solve heterogeneity and some CRAN drawbacks
    - **Components**
      - **Low Power Nodes** (**LPN) (** e.g., pico BS, femto BS, small BS , etc to increase capacity in dense areas with high traffic demands.
      - **High power node** (**HPN),** (e.g., macro or micro BS) combined with LPN to form a HetNet
- **V2X slices could benefit from the on-demand deployment of RAN functions achieved through C-RAN**

4. V2X on 5G- system architectures and design

- **4.8 RAN slicing aspects** (cont'd)
- **5G System Architecture in Heterogeneous -CRAN approach**
- **C-RAN/H-CRAN resources in the pool can be dynamically allocated** (by using NFV), to eNodeBs according to the network load
  - this ensures adaptability to the non-uniform vehicular traffic
  - the pooled BBU centralized processing (v.s. distributed processing in each eNodeB), reduces the handover signaling time



Simplified H-CRAN architecture

BBU- baseband (processing) unit
HPN – High Power Node
LPN- Low Power Node
RRH – Remote Radio Head

RRHs include only partial PHY functions
The model with these partial functionalities is denoted as PHY_RF

4.8 RAN slicing aspects (cont'd)

- **Radio Access Technology (RAT) selection**
  - 5G should be able to integrate 3GPP (4G, 5G New Radio) and non-3GPP (e.g., 802.11) technologies
  - In the V2X context
    - cellular technologies provide nearly ubiquitous coverage,
    - 802.11 OCB (**O**utside the **C**ontext of a **B**SS), mainly conceived for V2V over unlicensed spectrum
  - **V2X slice configuration** involves:
    - **selection of the RAT** (or combination of RATs) to satisfy its KPIs
    - **modification to adapt** to changing network conditions
      - e.g., to increase the V2I connectivity the usage of multiple RATs may be configured
- **Time-frequency resources for V2X at Phy level**
  - different time/frequency numerology should be adopted (e.g., flexible frame structure to match high Doppler effects under high speeds)
  - variable Transmit Time Interval, (**TTI**), length e.g.:
    - large TTI (~1 ms) for vehicular infotainment slice
    - short TTIs (~0.125 ms) to provide fast feedback/retransmission for the tele-operated driving slice

4. V2X on 5G- system architectures and design

4.8 RAN slicing aspects

- **Communication types and modes**
- The V2X slice configuration includes the mapping of a traffic flow onto a
- ***communication type*** (sidelink or cellular) and ***mode*** (**unicast, multicast or broadcast**)
- E.g.: autonomous driving slice
  - default on **sidelink** communications for **local interactions**
  - **trigger PC5 →LTE-Uu I/F** whenever mobility, time-varying density, geographical conditions require reconfiguration (comm. type switching)

- Usage of **unicast/ multicast/ broadcast modes**:
  - **Unicast** (reliable) can be used
    - in safety-critical applications,(e.g., platooning)
    - for V2I and V2N uplink communications and for tele-operated driving in both directions.
  - **Multicast** - could be used by RSUs/eNBs to reach multiple UEs over a wide area (e.g., for accident/congestion warnings dissemination).
  - **Broadcast**- specified in 3GPP Rel. 14 for V2V/V2P safety services

4. V2X on 5G- system architectures and design

4.8 RAN slicing aspects (cont'd)

- **Radio resource allocation**
  - Usually the **RAT scheduler** of a (in eNodeB) can **be shared among multiple slices**
    - It allocates resources to different slices (*inter-slice*) and to different UEs within a slice (*intra-slice*)
  - Slicing of radio resources is performed in the time/frequency domains (e.g., LTE resource blocks)
  - **Intra- and inter-V2X slice isolation** can be helped by **geo-location based resource assignment**
  - Different slices can apply **different packet forwarding** treatments (e.g., priority, throughput), as specified by the QoS class identifier (QCI) of a bearer

Sources:
3GPP TR 23.785 V1.1.0, TSG Services and System Aspects; Study on Architecture Enhancements for LTE support of V2X services (Rel.14), 2016
-C.Campolo, A.Molinaro, A.Iera, F.Menichella, "5G Network Slicing for Vehicle-to-Everything Services", IEEE Wireless Communications, Volume: 24 Issue: 6, DOI: 10.1109/MWC.2017.160040

4.8 RAN slicing aspects (cont'd)

- **Radio resource allocation**
- **3GPP TR 23.785 V1.1.0**, TSG Services and System Aspects; Study on Architecture Enhancements for LTE support of V2X services (Rel.14), 2016- defines
  - V2X requirements of latency (50 ms packet delay budget) and reliability (10^{-2} packet error rate) over the LTE-Uu interface
  - However, **more stricter QCIs are needed (e.g., 1 ms latency) for V2X slices like autonomous and tele-operated driving**

- **Scheduling types**
  - ***dynamic scheduling*,** based on each UE's buffer status and channel state information is appropriate for vehicular infotainment slice
  - ***semi-persistent scheduling*** - periodical allocation of resources (it means -no additional signaling) is indicated for traffic patterns with a predictable frequency and packet size
    - E.g., autonomous driving and remote diagnostic slices.

4. V2X on 5G- system architectures and design

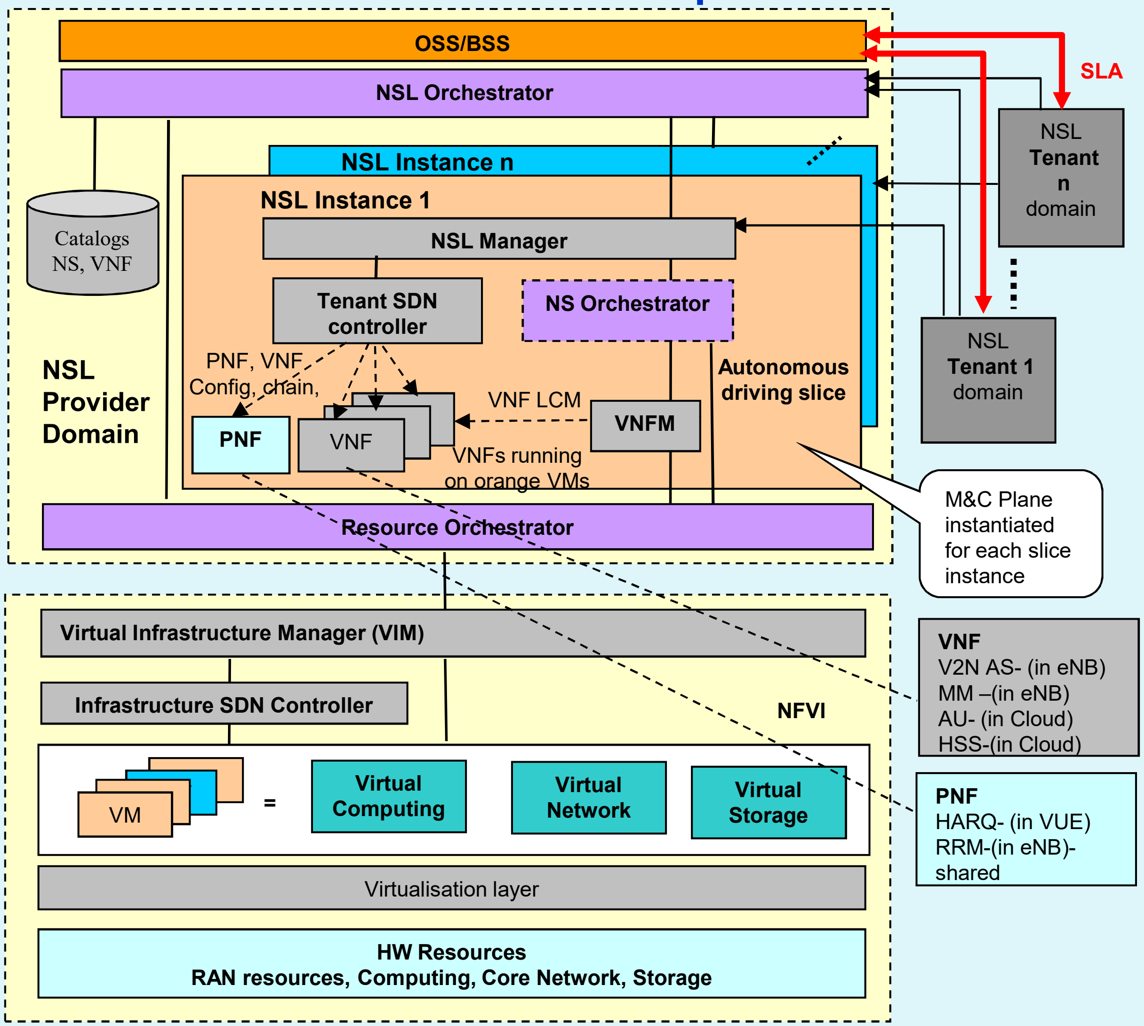
4.9 V2X User device slicing aspects

- **Slicing may be extended to vehicular user device**
- **Problem:** Vehicular and VRUs' **Ues may have different capabilities →** traffic pattern parameters should be differently configured in the two device types **for the same slice** (e.g., supporting safety services)
- The network usually keep the control over the V2V/V2P sidelink (e.g., in the scheduled mode
  - However, some control could be splitted between the RAN/CN and the UE. **Examples:**
    - **retransmissions *locally handled*** by the vehicular UEs over the PC5 links in the autonomous driving slice
    - ***adaptation of link parameters*** (e.g., tx power, modulation and coding scheme) –UE
    - out-of-coverage UE should be capable of *autonomously selecting the set of slices configuration*, which better serve its interest
  - At higher arch. layers: a vehicular **UE can locally host a lightweight V2X AS instance** (e.g., as a container) to serve other UEs in proximity (e.g., a pedestrian UE owning a smartphone)

4. V2X on 5G- system architectures and design

4.10 V2X slicing functional architecture

- **Functional architecture example – for autonomous driving slice**



Adapted from sources:

ETSI GR NFV-EVE 012 V3.1.1 (2017-12), Release 3; NFV Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework

C.Campolo, et al., "5G Network Slicing for Vehicle-to-Everything Services", IEEE Wireless Communications, Volume: 24 Issue: 6, DOI: 10.1109/MWC.2017.160040

J.Ordonez-Lucena, et.al., "The Creation Phase in Network Slicing: From a Service Order to an Operative Network Slice", European Conference on Networks and Communications (EuCNC), 2018, https://arxiv.org/abs/1804.09642

4.10 V2X slicing functional architecture (cont'd)

- **Functional architecture example**
  - **Management and control: NFV + SDN+ slicing**
  - Main slicing architecture concepts applied + **V2X specialization functions**
  - Functional entities/layers
    - **OSS/BSS** – Operation/Business Support System
    - **NSLP** - Network slice provider
    - **NFVI**- Network Function Virtualization Infrastructure including HW resources
    - **NSL Tenants + End users**

- **Slicing management and orchestration** - include
  - **Slice description**
    - includes the SLA requirements as agreed by vertical segments
    - OSS/BSS monitors the SLA assurance
    - the description is translated to network elements
  - **Slice instantiation**:
    - identification of: CP/UP architecture, interfaces, sets of slice-specific and common VNFs/PNFs in the CN and RAN
    - a tenant SDN controller will control their interconnection and parameter settings
  - **Slice lifecycle management (LCM) -** configuration, adaptation and monitoring to fulfill isolation constraints and agreed SLAs.

4. V2X on 5G- system architectures and design

4.10 V2X slicing functional architecture

- **Functional architecture example – for autonomous driving slice** (cont'd)
- **Notations** (previous slide)
- **General (5G slicing, NFV)**
  - SDN Software Defined Networking
  - SLA – Service Level Agreement
  - MANO- Management and Orchestration
  - NS – Network Service
  - NSO- Network Service Orchestrator
  - NSL - Network Slice
  - NSLO - Network Slice Orchestrator
  - RO- Resource Orchestrator
  - VNF – Virtualized Network Function
  - PNF- Physical Network Function
  - VNFM – VNF Manager
  - LCM – Life Cycle Management
  - VIM – Virtual Infrastructure Manager
  - IC- Infrastructure SDN Controller
- **V2X –dedicated entities**
  - AS- Application Server
  - AU- Authentication and Authorization Management
  - MM Mobility Management
  - V2N – Vehicle to Network
  - RRM – Radio Resource Management
  - HARQ- Hybrid Automatic Repeat Request

4. V2X on 5G- system architectures and design

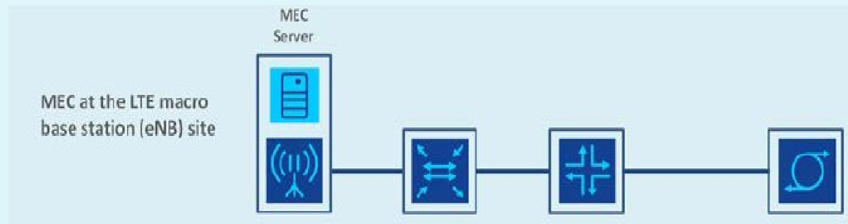
4.11 Multi-access Edge Computing in 5G V2X

- **Mobile Edge Computing (MEC)** – *ETSI* - an industry spec. ~2014
  - MEC – Cloud Computing platform within **the network edge (e.g. RAN)-** close to mobile subscribers to serve delay sensitive, context aware applications
  - CC capabilities go close to the edge in 4G, 5G
  - **ETSI :** defined a system architecture and std. for a number of APIs
- **Multi-access Edge Computing** – recent extension (>2016) of the initial MEC
  - MEC means today – **multi-access and includes non-cellular actors**
  - **Main involved actors:** ETSI (>2014), 3GPP, ITU-T
  - Operators and industry : DOCOMO,Vodafone, TELECOM Italia) IBM, Nokia, Huawei, Intel, etc.
  - **MEC can offer ultra-low latency, high-bandwidth and direct access to real-time RAN information**
    - (information like subscriber location, cell load, channels load, etc.) useful for applications and services to offer **context-related services**
  - **Operators can open the RAN edge to third-party partners**
  - **Features as proximity, context, agility and speed →** novel opportunities for Mobile Network Operators (MNOs), SP/CP, Over the Top (OTT) players and Independent Software Vendors (ISVs)

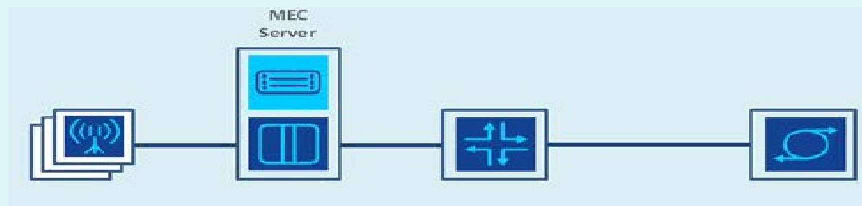
4. V2X on 5G- system architectures and design

- 4.11 Multi-access Edge Computing in 5G V2X
- **Possible Deployment Scenarios (ETSI)**
  - The **MEC server** can be deployed in several variants- example for 3G
  - Note: the multi-technology (LTE/3G) cell aggregation site can be indoor or outdoor

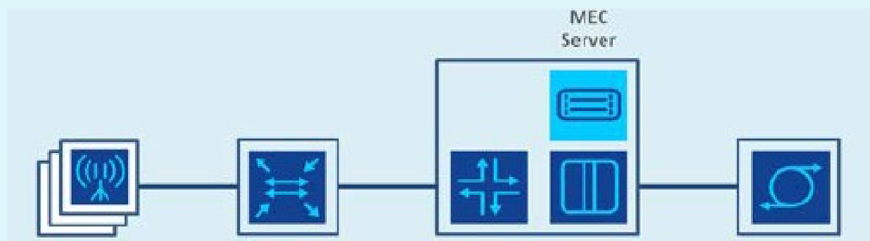
MEC at the LTE macro base station (eNB) site



MEC at the multi-technology (3G/LTE) cell aggregation site

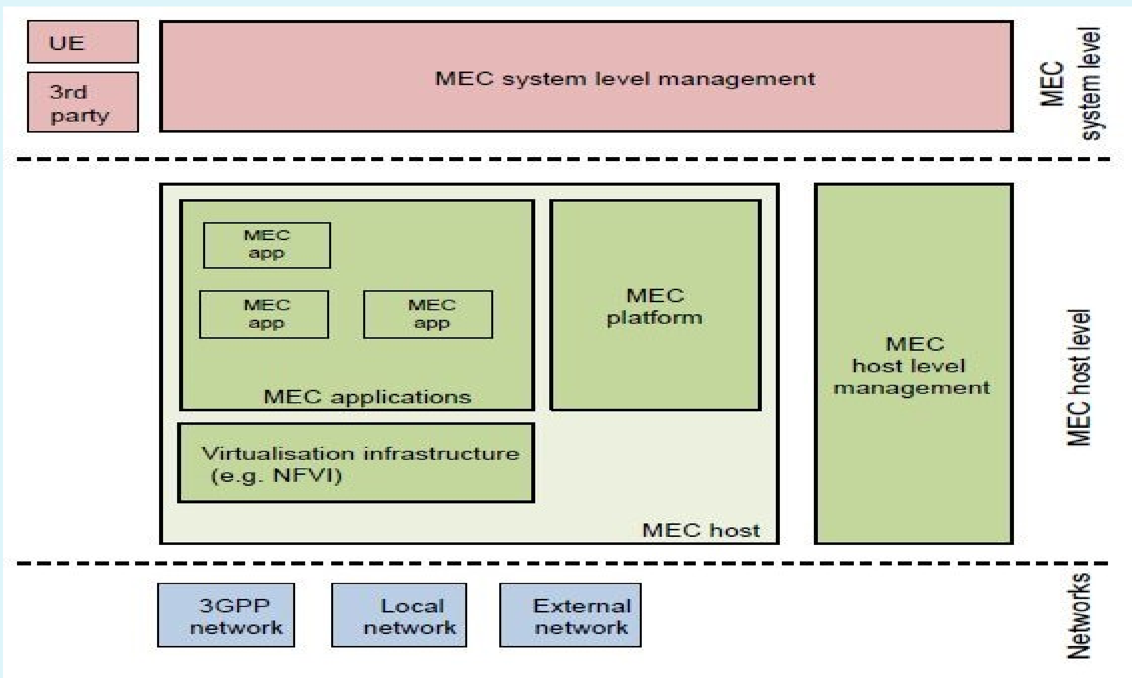


MEC at the 3G Radio Network Controller (RNC) site



Source: https://portal.etsi.org/Portals/0/TBpages/MEC/Docs/Mobile-edge_Computing_-_Introductory_Technical_White_Paper_V1%2018-09-14.pdf
Mobile-Edge Computing – Introductory Technical White Paper

- **4.11 Multi-access Edge Computing in 5G V2X**
- **MEC Architecture**
  - **Key element : (MEC) IT application server** – can be integrated in edge/RAN
    - The MEC server provides computing resources, storage capacity, connectivity, and access to user traffic and radio and network information



Source : ETSI MEC ISG, "Mobile Edge Computing (MEC); Framework and reference architecture," ETSI, DGS MEC 003, April 2016.
http://www.etsi.org/deliver/etsi_gs/MEC/001_099/003/01.01.01_60/gs_MEC003v010101p.pdf

- **4.11 Multi-access Edge Computing in 5G V2X**
- **MEC Architecture** (cont'd)
- **Architectural levels**
  - ***Network level entities*** comprising connectivity to LANs, cellular networks and external networks (e.g., Internet)
    - **Multi-access:** Extension to include non-cellular networks
  - ***MEC host level*** where the MEC host sits along with its associated management
  - ***MEC system level management*** **has a** global view of the whole MEC system, i.e., the **collection of MEC hosts** and the associated management subsystem

- **Functional Entities**
  - **ME application:** application instantiable on a ME host
    - It can potentially provide or consume ME services

  - **ME host:** entity containing a **ME platform** and a **virtualisation infrastructure** to provide *compute, storage and network* resources to ME apps.

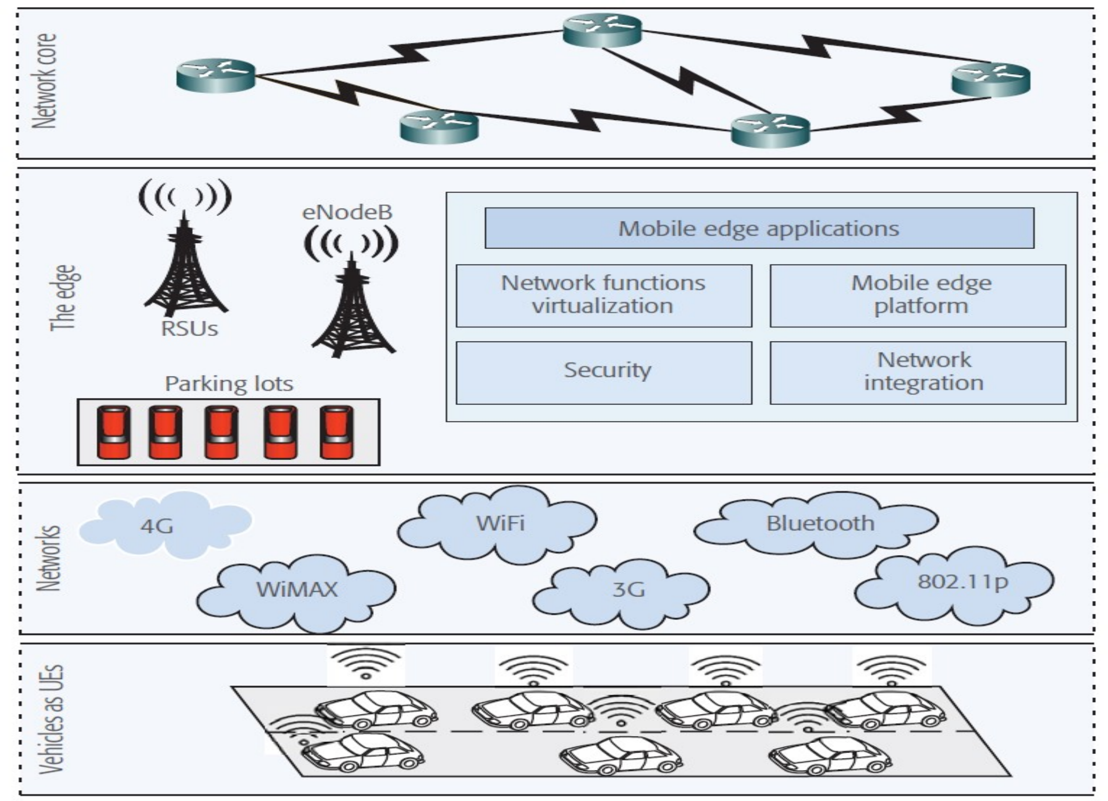
  - **ME platform:** set of functionality
    - required to run ME apps. on a specific ME host virtualization infrastructure
    - and to enable them to provide and consume ME services
    - It can provide itself a number of ME services

- **4.11 Multi-access Edge Computing in 5G V2X**
- **MEC Architecture** (cont'd)
- **Functional Entities**
  - **ME host level management:** components handling the management of the ME specific functionality of a particular ME platform, ME host and the ME applications running on it
  - **ME system:** collection of ME hosts and ME management necessary to run ME apps. within an operator network or a subset of an operator network
  - **ME management:**
    - **system level management:** components which have the overview of the complete ME system
    - and **mobile edge host level management**
  - **ME service:** service provided via the ME platform either
    - by the **ME platform** itself
    - or, **by a ME application**

4. V2X on 5G- system architectures and design

4.11 Multi-access Edge Computing in 5G V2X

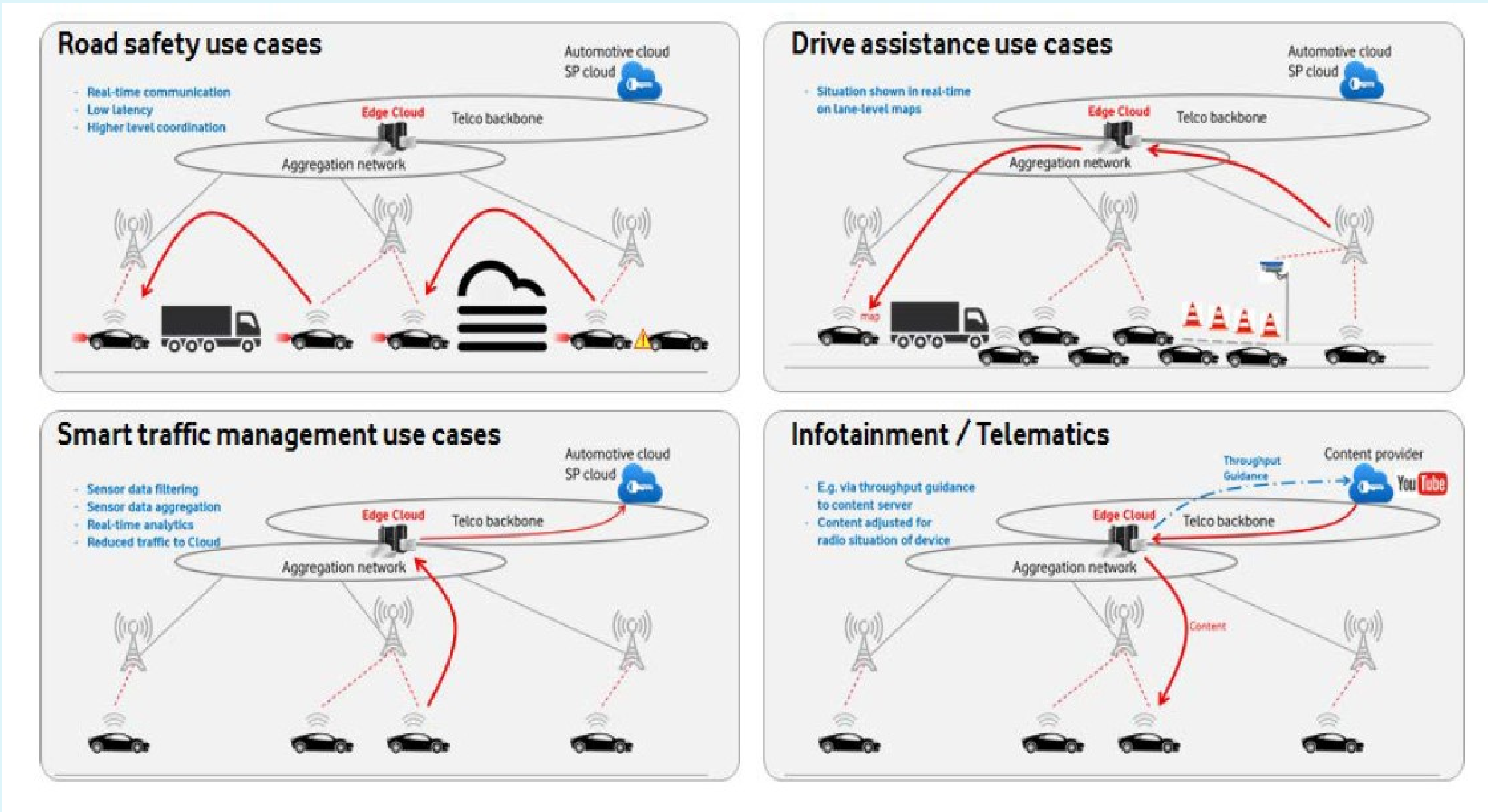
- MEC - major technology in the 5G ecosystem, to ensure **URLLC** for **V2X communication** and also to deploy services at appropriate locations
- **Generic architecture-example**



Source: S.A.Ali Shah, E.Ahmed, M.Imran, and S.Zeadally, "5G for Vehicular Communications", IEEE Communications Magazine, January 2018, pp.111-117

4.11 Multi-access Edge Computing in 5G V2X

- **MEC - V2X examples of use cases**

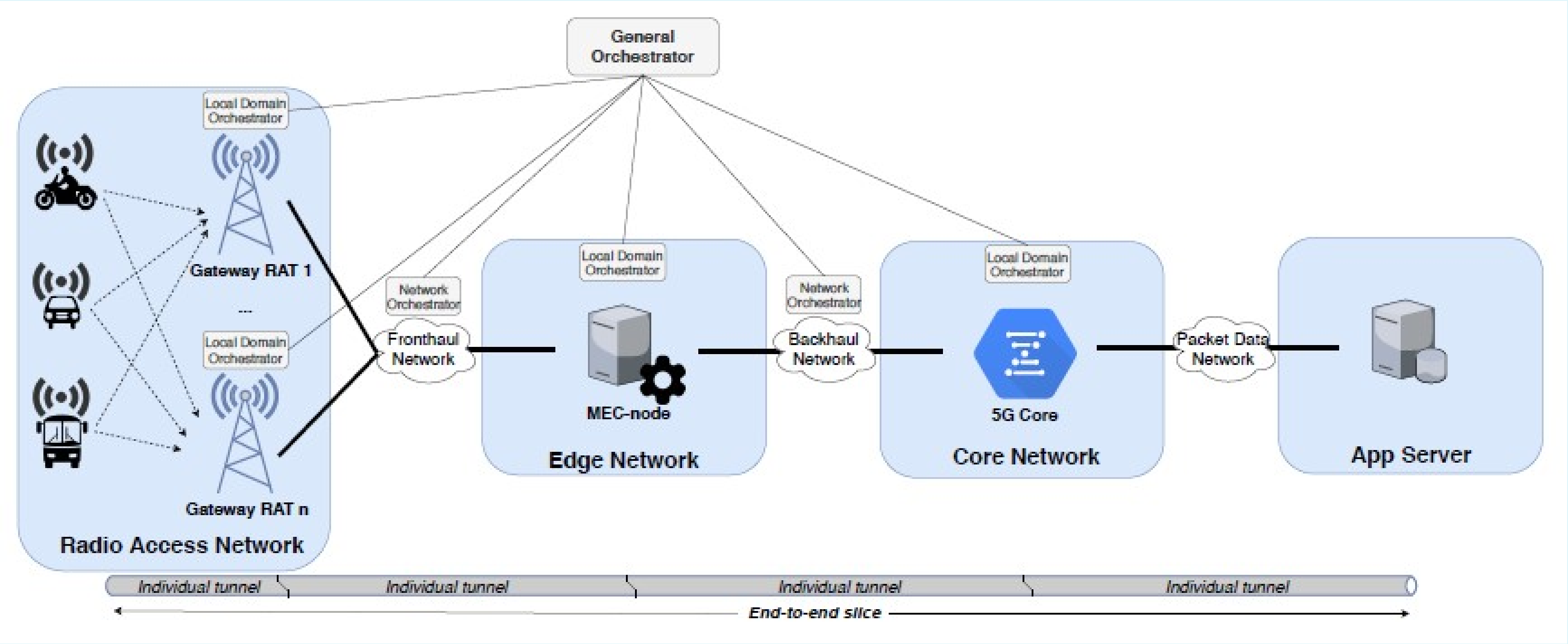


Source: ETSI, "Multi-access Edge Computing (MEC); Study on MEC Support for V2X Use Cases," Tech. Rep., March 2018 https://portal.etsi.org/webapp/workProgram/Report_WorkItem.asp?wki_id=52949.

4. V2X on 5G- system architectures and design

4.12 Multi-RAT 5G slicing framework

Example



Source: Ramon Sanchez-Iborra et.al., "Empowering the Internet of Vehicles with Multi-RAT 5G Network Slicing", https://www.ncbi.nlm.nih.gov/pubmed/31337087

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5. Examples of V2X 5G systems

V2X oriented projects

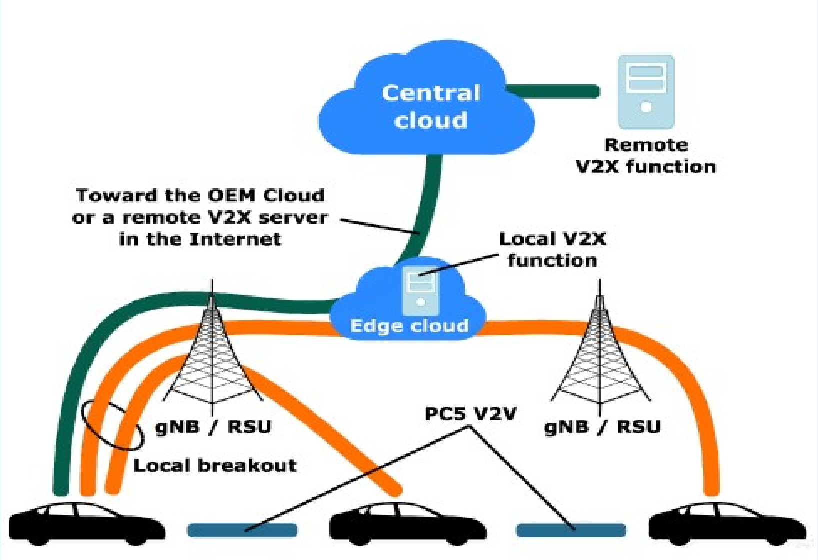
- **5GCAR: Fifth Generation Communication Automotive Research and innovation**
  H2020-ICT-2016-2, 2017-2019, https://5g-ppp.eu/5gcar/, https://5gcar.eu
- **Main objectives**
  - Develop an overall **5G system architecture;** optimized **E2E V2X network connectivity** for highly reliable and low-latency V2X services
    - Support for security and privacy, QoS and traffic in a multi-RAT and multi-link V2X system
  - Interworking of **multi-RATs** (embedding existing solutions and 5G V2X solutions)
  - Develop an **efficient, secure and scalable sidelink interface** for low-latency, high-reliability V2X communications
  - **5G radio-assisted positioning techniques** for both vulnerable road users and vehicles to increase the availability of very accurate localization
  - Identify **business models** and spectrum usage alternatives to support a wide range of 5G V2X services
  - **Concepts demonstration and validation**, evaluation of the quantitative benefits of 5G V2X solutions using automated driving scenarios in test sites

Source: 5GCAR: Fifth Generation Communication Automotive Research and innovation H2020-ICT-2016-2, https://5g-ppp.eu/5gcar/

5. Examples of V2X 5G systems

V2X oriented projects

- **H2020 5GCAR** (cont'd)
- **Use cases selected**
  - Lane merge (Cooperative maneuver)
  - See-through (Cooperative perception)
  - Network assisted vulnerable pedestrian protection (Cooperative safety)
  - High definition local map acquisition (Autonomous navigation)
  - Remote driving for automated parking



5GCAR is focused on automotive needs and redefines the E2E concept

One end: a road user (vulnerable /vehicle)

The other end

can either be a remote server, a server located at the edge of the cellular network, or a vehicle in proximity

V2X include messages

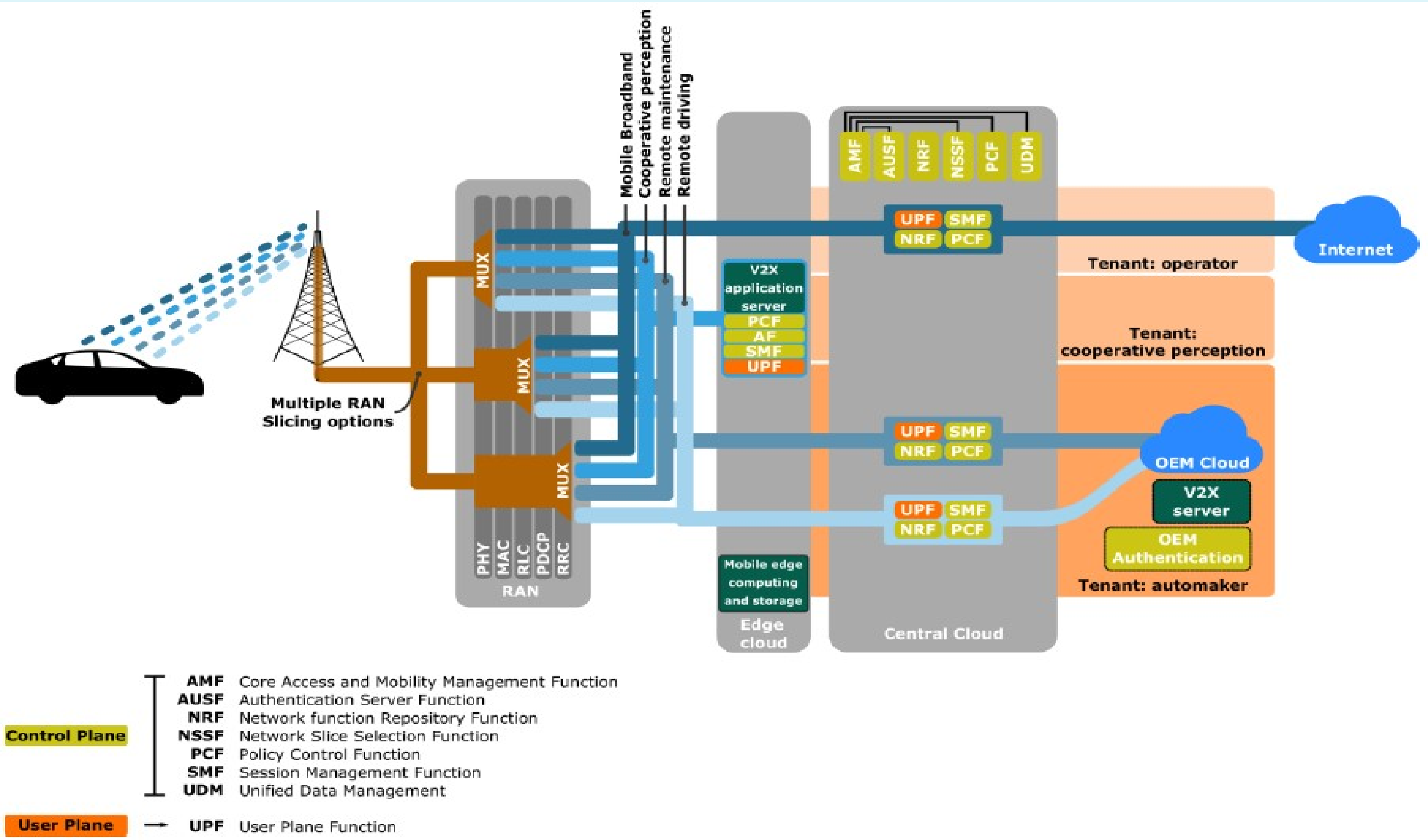
- directed to servers located in the Internet
- locally routed by the infrastructure (in local breakout configuration),
- direct V2V transmissions over the PC5 interface (unicast and broadcast)

Source: 5GCAR: Fifth Generation Communication Automotive Research and innovation H2020-ICT-2016-2, https://5g-ppp.eu/5gcar/

5. Examples of V2X 5G systems

V2X oriented projects

- **H2020 5GCAR** (cont'd)- **Example of 5G V2X sliced network scenario**



Source: 5GCAR: Fifth Generation Communication Automotive Research and innovation H2020-ICT-2016-2, https://5g-ppp.eu/5gcar/

5. Examples of V2X 5G systems

V2X oriented projects

- **H2020 5GCAR** (cont'd)
- **Example of 5G V2X sliced network scenario** (cont'd)

- **Multi-tenancy** scenario, with three tenants
  - **operator** (which **is also the mobile service provider**, owning and operating the physical network infrastructure)
  - **automaker** offering connected services
  - **cooperative perception**, i.e. the service enabling road users to periodically exchange their status (position, speed, heading, etc.)

- Each **tenant offers different types of services**, with custom requirements and routing paradigm, which are mapped onto separate slices

Source: 5GCAR Deliverable D4.1, Initial design of 5G V2X system level architecture and security framework Version: v1.0, 2018. http://www.5g-ppp.eu/

5. Examples of V2X 5G systems

V2X oriented projects

- **H2020 5GCAR** (cont'd)
- **Example of 5G V2X sliced network scenario** (cont'd)
- **Multi-tenancy** scenario
- **eMBB slice**
  - The **operator** controls the **evolved Mobile Broadband (eMBB)** slice
    - which serves the on board infotainment, (reception of data flows (audio, video) from servers on the public network)
    - Provide also - best effort wideband connectivity to the internet
    - Most of the CP/UP functions (routing and forwarding, session management and charging) are concentrated in the central cloud
    - The 5G architecture enables the implementation of **advance caching** of popular content in the edge cloud for optimizing the network efficiency

Source: 5GCAR Deliverable D4.1, Initial design of 5G V2X system level architecture and security framework Version: v1.0, 2018. http://www.5g-ppp.eu/

5. Examples of V2X 5G systems

V2X oriented projects

- **H2020 5GCAR (**cont'd)
- **Example of 5G V2X sliced network scenario** (cont'd)
- **Multi-tenancy**
- **Automakers** (also referred to as OEMs) develop tailored services- special slice
  - 5GCAR preliminary architecture, consider two : **remote maintenance,** and **remote driving**, having different sets of requirements
  - The **remote maintenance** could be partially associated to a mMTC-like type
    - the **vehicles upload** to the manufacturer's cloud small amount of diagnostic data with relatively low frequency (~ daily), with low priority, updating the service with the current state of the vehicle's apparatus
    - the **cloud feeds back maintenance information** and alerts to the driver when an intervention on the vehicle is required

Source: 5GCAR Deliverable D4.1, Initial design of 5G V2X system level architecture and security framework Version: v1.0, 2018. http://www.5g-ppp.eu/

5. Examples of V2X 5G systems

V2X oriented projects

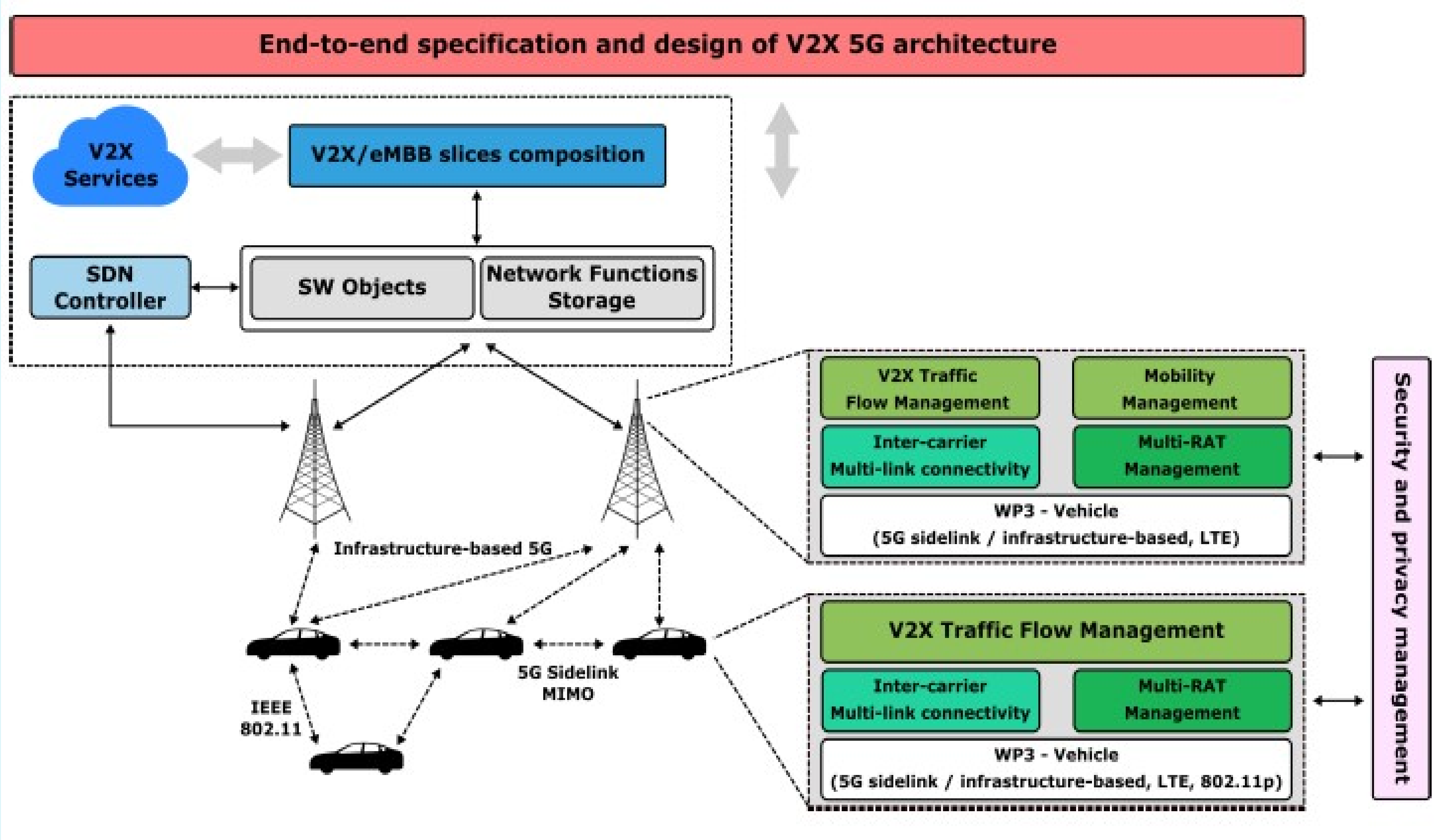
- **H2020 5GCAR** (cont'd)
- **Example of 5G V2X sliced network scenario** (cont'd)
  - The **remote driving UC** may be associated to a URLLC-type
    - the automaker's **V2X server issues r-t commands** to remotely drive the vehicle, (to be received within few ms and with high reliability
    - This UC may also be associated to a r-t video flow from the vehicle to the V2X function, to **feedback in r-t the result** of the driving manoeuvers
    - Very lean network architecture: few functions are crossed by the data flow to reduce the processing delays to a minimum.
- The **cooperative perception** service
  - characterised by **the local validity of the traffic** generated by road users, as status messages are meant to be distributed to other road users in proximity in the shortest possible delay
  - the cooperative perception slice only extends into the RAN and the edge cloud, wherein the V2X application server is located

Source: 5GCAR Deliverable D4.1, Initial design of 5G V2X system level architecture and security framework Version: v1.0, 2018. http://www.5g-ppp.eu/

5. Examples of V2X 5G systems

V2X oriented projects

- **H2020 5GCAR** (cont'd)
- 5GCAR V2X system and architecture



Source: 5GCAR Deliverable D4.1, Initial design of 5G V2X system level architecture and security framework Version: v1.0, 2018. http://www.5g-ppp.eu/

5. Examples of V2X 5G systems

V2X oriented projects

- **H2020 project 5G-DRIVE, 2018-2021,** *https://5g-drive.eu/about-5g-drive/*
- **5G** Harmonise**D** **R**esearch and Tr**I**als for ser**V**ice **E**volution
  - EU and China (2018-2021) - trial and validate the interoperability between EU & China 5G networks operating at 3.5 GHz bands for enhanced Mobile Broadband (eMBB) and 3.5 & 5.9 GHz bands for V2X scenarios
- **Technical objectives**
  - Build pre-commercial **E2E testbeds** in two cities with sufficient coverage to perform extensive eMBB and IoV trials. Joint test specifications
  - Develop and trial key **5G technologies and services,** including (but not limited to) massive **MIMO** at 3.5GHz, **E2E network slicing**, **mobile edge computing (MEC)** for low latency services and V2X, **SDN for transport and core network**, and **network and terminal security**
  - Develop and trial cross-domain **network slicing techniques** across two regions
  - Demonstrate **IoV services** using V2N and V2V communications operating at 3.5GHz and 5.9GHz, respectively.
  - Analyse potential **system interoperability issues** identified during the trials in both regions and to provide recommendations to address them accordingly

Source: https://5g-drive.eu/about-5g-drive/

5. Examples of V2X 5G systems

V2X oriented projects

- **H2020 project 5G-DRIVE, 2018-2021,** *https://5g-drive.eu/about-5g-drive/*

- **Enhanced Mobile Broadband (eMBB)** on the 3.5 GHz band, - for early introduction of very high data rate services
  - Applications used to test and validate the use of eMBB: typical mobile broadband services e.g., **Virtual and Augmented Reality (VR, AR).**

- **Internet of Vehicles (IoV)** based on LTE-V2X
  - 5.9 GHz band for V2V, V2I services,
  - 3.5 GHz band for V2N communications

- **Key targets**:
  - **optimization of the band usage** in multiple scenarios with different coverage
  - **validation of the geographic interoperability** of the 3.5 and 5.9 GHz bands for these use cases

Source: https://5g-drive.eu/about-5g-drive/

5. Examples of V2X 5G systems

V2X oriented projects

- **H2020 project 5G-DRIVE, 2018-2021,** *https://5g-drive.eu/about-5g-drive/*
- **Use Case 1: Green Light Optimal Speed Advisory (GLOSA)**
  - GLOSA is a *Cooperative Intelligent Transportation System signage (C-ITS)* service
    - **informs end users** (EU) about the speed that needs to be sustained (within legal limits) to reach an upcoming traffic light in green status
    - **provides EUs with short-term information** on upcoming traffic light status to optimise traffic flows, to prevent speed limits violations, improve fuel efficiency and reduce pollution
    - **a RSU co-located with a traffic light** (it has access to its internal finite state machine), broadcasts timing information about the traffic light's "red", "amber" and "green" status via **Signal Phase and Timing messages (SPAT)**
      - Neighbouring vehicles receive these messages and process them locally along with their own positioning, speed and direction data (amongst others)

Source: https://5g-drive.eu/about-5g-drive/

5. Examples of V2X 5G systems

V2X oriented projects

- **H2020 project 5G-DRIVE, 2018-2021**, *https://5g-drive.eu/about-5g-drive/*
- **Use Case 1: Green Light Optimal Speed Advisory (GLOSA)** (cont'd)

- The most relevant **service-level performance indicators**
  - **Packet error rate (PER):** ratio of unsuccessfully received packets in the OBU vs. total number of packets sent by the RSU (in percentage)
  - **Latency:** the RAN contribution to the total elapsed time, measured from the instant the RSU sends a packet to the moment when the OBU receives it (in ms)

Source: https://5g-drive.eu/about-5g-drive/

5. Examples of V2X 5G systems

V2X oriented projects

- **H2020 project 5G-DRIVE, 2018-2021,** *https://5g-drive.eu/about-5g-drive/*
- **Use Case 2: Intelligent Intersection**
  - It deals with **safety on intersections**: infrastructure detection of situations that are difficult to be perceived by vehicles themselves
  - **Example :** a vehicle wants to make a right turn while parallel VRUs also have a green phase and right of way (permissive green for motorized traffic)

- **Relevant KPIs**
  - **Note: due to the safety critical use case: contextual KPIs are required to get a more predictable latency**
  - **Packet error rate (PER):** ratio of unsuccessfully received packets in the OBU vs. total number of packets sent by the RSU (percentage)
  - **Latency**: the RAN contribution to the total elapsed time, measured from the instant the RSU sends a packet to the moment when the OBU receives it (in ms)
  - **Total active stations**: tracks how many other stations were active at the same time while in communication range of the test subject
  - **Total channel load in Mbps:** helps to determine how much interference can be expected
  - **Total rate of messages/sec on channel**

Source: https://5g-drive.eu/about-5g-drive/

CONTENTS

6. Conclusions

- **The 5G-based V2X solutions development : significant direction of work among the 5G objectives (supported services applications)**

- Many SDOs provide **advanced V2X specs** and novel use cases leveraging the enhancement that 5G will bring to the radio access and network infrastructure.

- **3GPP Releases 15 and 16, 5G** add advanced V2X features with **longer range, higher density, very high throughput and reliability, sub-meter positioning and ultra-low latency**
- **5G slices dedicated to V2X services – powerful and efficient approach for V2X systems**
- **Many research and implementation projects** and trials are in development
- **Equipment manufacturers** around the globe are already producing million connected car packages a month, which is expected to increase every year
- The **basic safety services** aimed by **Release 14 LTE-based V2X** will remain an integral part of the V2X communication ecosystem
  - 4G LTE provides support for the **integration of WiFi and the unlicensed spectrum**
  - 5G extension: integrating of, but not limited to, 3G, 4G, WiFi, Zig-Bee, and Bluetooth
- **5G-V2X is currently embedded in a more general framework - Internet of Vehicles (IoV)**

6. Conclusions

- An important feature of V2X-V2X will be the **proximity service (ProSe)** (to provide awareness by discovering devices and services using relevant locality information)
  - **IoT ProSe**
    - allows **spontaneous interactions opportunities** within a certain proximity
    - provides **ad hoc location discovery** and communication opportunities (e.g., moving vehicles on roads).
    - can be used as a **communication platform in public safety scenarios**

- **Research challenges**
  - ***Interference at Lower Altitudes****:* Vehicles should discover and communicate with their neighbors frequently
    - The V2X services need to adapt from the BS- based to D2D communication
  - ***Spectrum Allocation Policies:*** the allocation should be made dynamic with policies based on the vehicle's perspectives including,(but not limited to), the message priority, QoS) and security
  - ***Development of MEC solutions for V2X-5G***
    - ***Handover Management among Heterogeneous ANs***
      - ETSI has designed a basic architecture for MEC
      - However, during mobility the vehicles may switch to multiple RATs
      - The MEC specs must have support and availability for multiple RATs

6. Conclusions

- ***Development of MEC solutions for V2X-5G***
  - **Cost Effectiveness of the Edge Deployment**
    - The cost effectiveness for MEC large-scale deployment must beconsidered
    - The V2X RSUs can also be used for hosting some of the cloud services besides eNB stations
    - A balance of development costs between RSUs and eNBs is necessary

- ***V2X-5G slicing (still open research issues)***
  - Business models and verticals
  - Translating V2X requirements into slice technical specs
  - Resource management optimization algorithms and procedures for V2X resource reservation and allocation (in RAN and CN segments)
    - Utilization of new techniques based on AI/Machine learning/AI
  - Real-time, reliability and security of V2X-5G slices
  - Lifecycle management of V2X-5G slices (including the slice updates)
  - Mobility management in slicing context
  - Multi-tenant and multi-domain aspects
  - Slice isolation (performance, security)
  - Data management and analytics
  - Efficient cooperation between SDN, NFV, cloud/edge technologies

- Thank you !
- Questions?

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Vehicles to Everything Communications and Services on 5G Technology

- **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)

- **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

- **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
ONF	Open Networking Foundation
PaaS	Platform as a Service
PCF	Policy Control Function
PKI	Public Key Infrastructure
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

- **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

- **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

- Backup slides

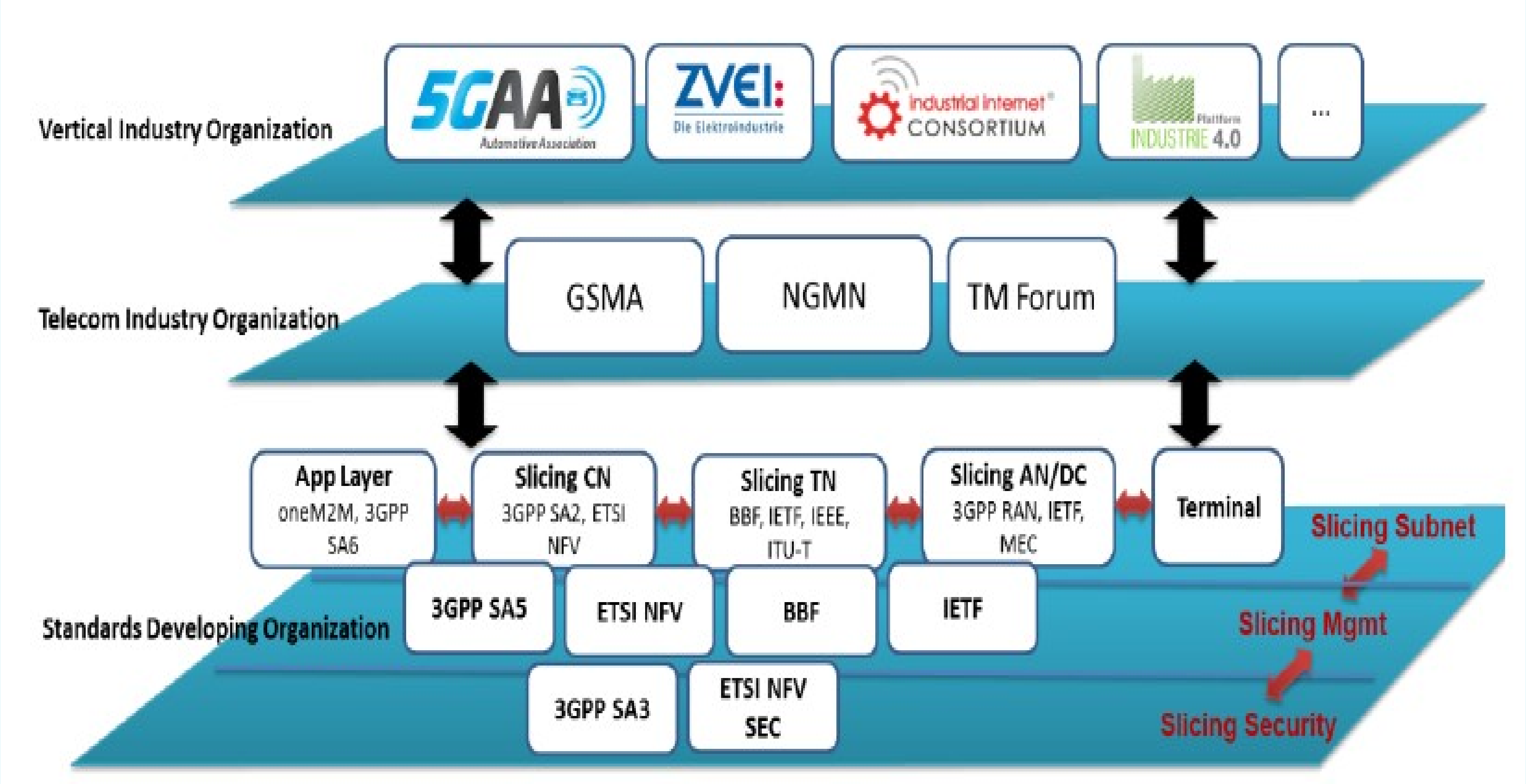
3. 5G technology summary

3.13 Standardisation work 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.

3. 5G technology summary

3.13 Standardisation work oriented to slicing (cont'd)



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