Edge Computing Support for V2X Communications on 5G Technology

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Edge Computing Support for V2X Communications on 5G Technology

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- **Expertise:** telecommunications and computer networks architectures, technologies and services: network architectures and services, management/control/data plane, protocols, 4G/5G, QoS assurance, multicast and multimedia services over IP networks

- **Our UPB team:**
  - **Recent research interest :** Software Defined Networking (SDN), Network Function Virtualization (NFV), Fog/edge computing, 5G networking and slicing, vehicular communications.
  - **Partners in many research European** and bilateral projects in the above domains

Edge Computing Support for V2X Communications on 5G Technology

- **Acknowledgement**
  - The major part of this presentation **is compiled and structured based on several public documents**: conference proceedings, studies (overviews, tutorials, research papers), standards, research projects, etc. (see specific references in the text and the Reference list).
  - **The selection and structure of this material belong to the author.**
  - An example of architecture is taken form a new research int'l project (2021-2023) "**A Massive MIMO Enabled IoT Platform with Networking Slicing for Beyond 5G IoV/V2X and Maritime Services" – with partners from Romania, Norway, Spain, Canada.**
  - **Notes:**
    - Given the extension of the topics, this **presentation is limited to 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 edge computing support for V2X on top of 5G networks – especially in 5G slicing context.

Edge Computing Support for V2X Communications on 5G Technology

- **Motivation of this talk**

- **Vehicles and transportation systems** -essential parts of the today society
  - Significant development of vehicular networks and associated services
- **Current solutions**
  - **Intelligent Transport System (ITS) – mature set of standards and implementations**
    - initial applications : traffic safety and efficiency - only
    - ITS includes vehicular communication (VC) supported by 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)**

Edge Computing Support for V2X Communications on 5G Technology

- **Motivation of this talk** (cont'd)
- **The 5G (fifth generation) networks, in E2E architectures**
  - 5G← current and future networks and services needs (flexibility, bandwidth, traffic capacity, response time, number of terminals, energy saving, etc.)
  - **Driving forces for 5G**: IoT, **IoV/automotive**, smart cities, industry, governance, safety/emergency, entertainment, environment, etc.
  - **Standardization**/forums organizations –involved
    - 3GPP, 5GPP, ETSI, ITU-T, GSMA, ONF, NGNM, IETF, IEEE, etc.
  - **5G Network slices** –dedicated (to specific applications) logical, isolated networks, sharing the same physical network resources
  - **Edge computing- (Fog/Multi-access Edge Computing) –moves the cloud-like capabilities in proximity of users**
    - **strong support for V2X communications and services**
    - **better real time response**
    - **more efficient data processing**

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2. 5G technology summary
3. Edge computing in 5G
4. V2X on 5G- system architectures and design
5. MEC support for V2X 5G systems
6. Conclusions

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6. Conclusions

1. Vehicle to everything (V2X) communications - 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, i.e., vehicle-to:
      - pedestrian (**V2P**)- direct communication
      - vulnerable road user (**VRU**)
      - network (**V2N**)- including cellular networks and Internet
      - sensors (**V2S**)
  - **Typical use cases and services/applications**
    - **Active road safety** applications
      - Warnings, notifications, assistance
    - **Traffic efficiency** and management applications
    - **Infotainment** applications

1. Vehicle to everything (V2X) communications - introduction

1.2 Current developments in vehicular communications and services

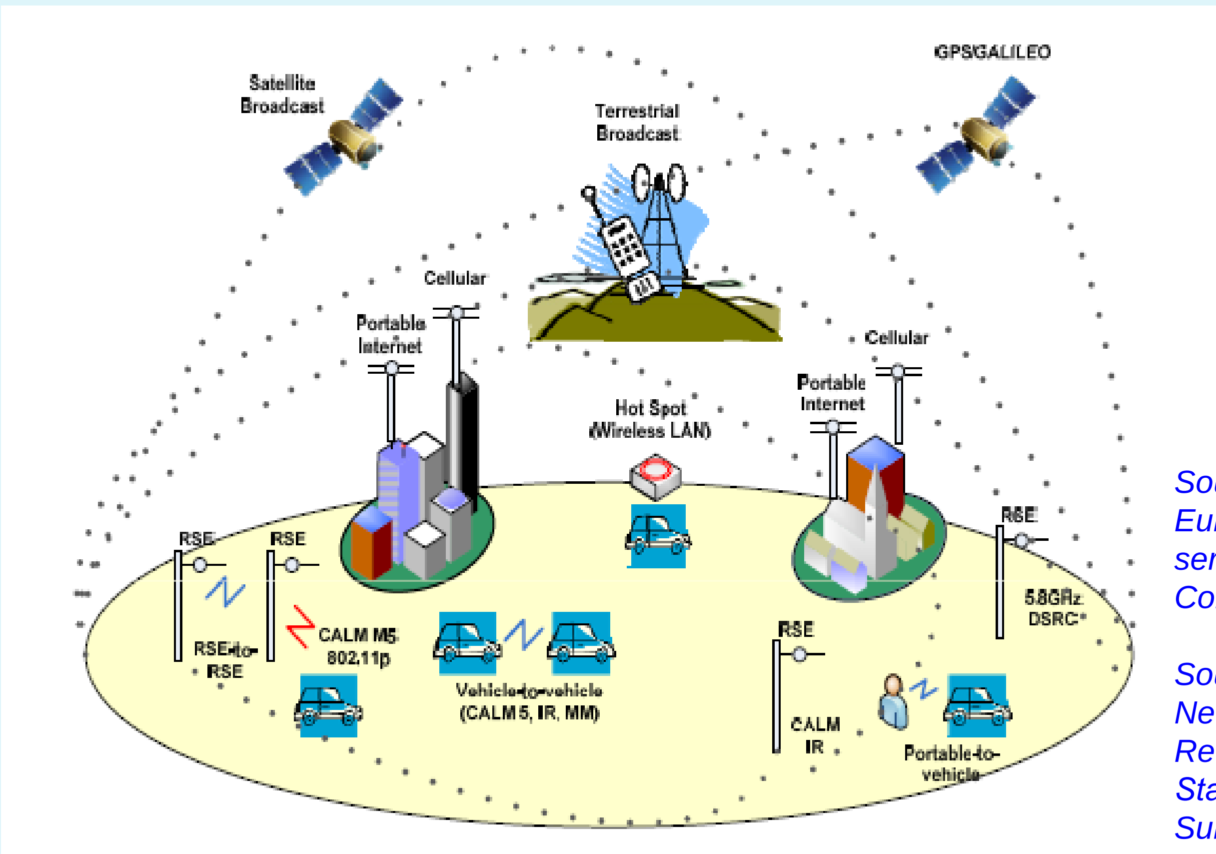
- **Intelligent Transport System (ITS)**
  - **Advanced technologies using IT&C,** to serve **transport systems**
    - provide innovative services for different modes of transport and traffic management
    - enable users to be informed and make safer, more coordinated, and 'smarter' use of transport 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
    - assistance for 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. Vehicle to everything (V2X) communications - 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. Vehicle to everything (V2X) communications - 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. Vehicle to everything (V2X) communications - introduction

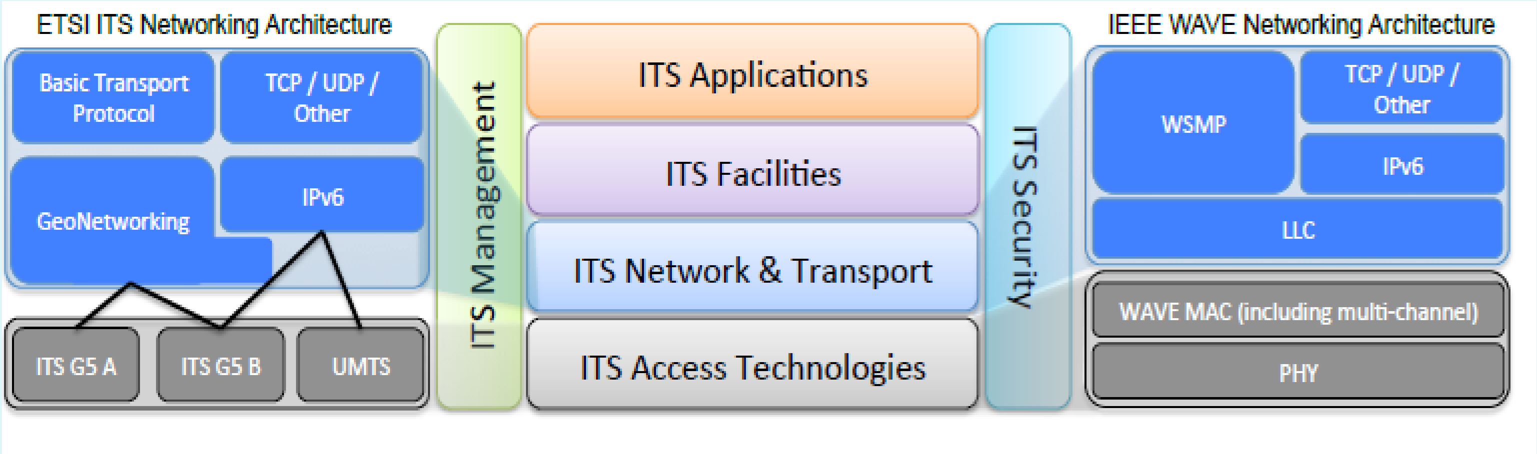
- **1.2 Current developments in vehicular communications and services**
- **DSRC (Dedicated Short Range Communication)**
  - Related to the spectrum dedicated to VC and any type of communication among ITS components (vehicles, infrastructure)
  - two-way wireless system, operating in the 5.9 GHz licensed 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. Vehicle to everything (V2X) communications - 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

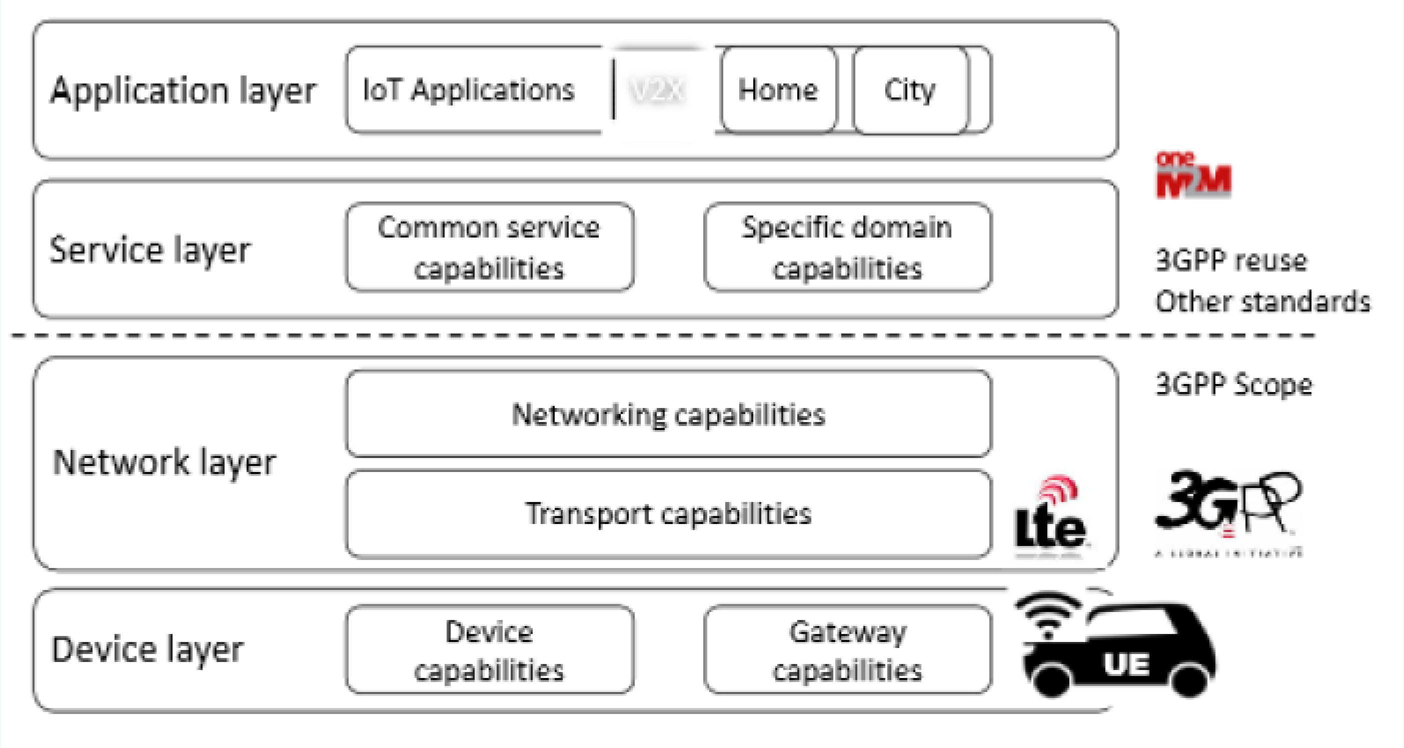


Europe *US*

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. Vehicle to everything (V2X) communications - introduction

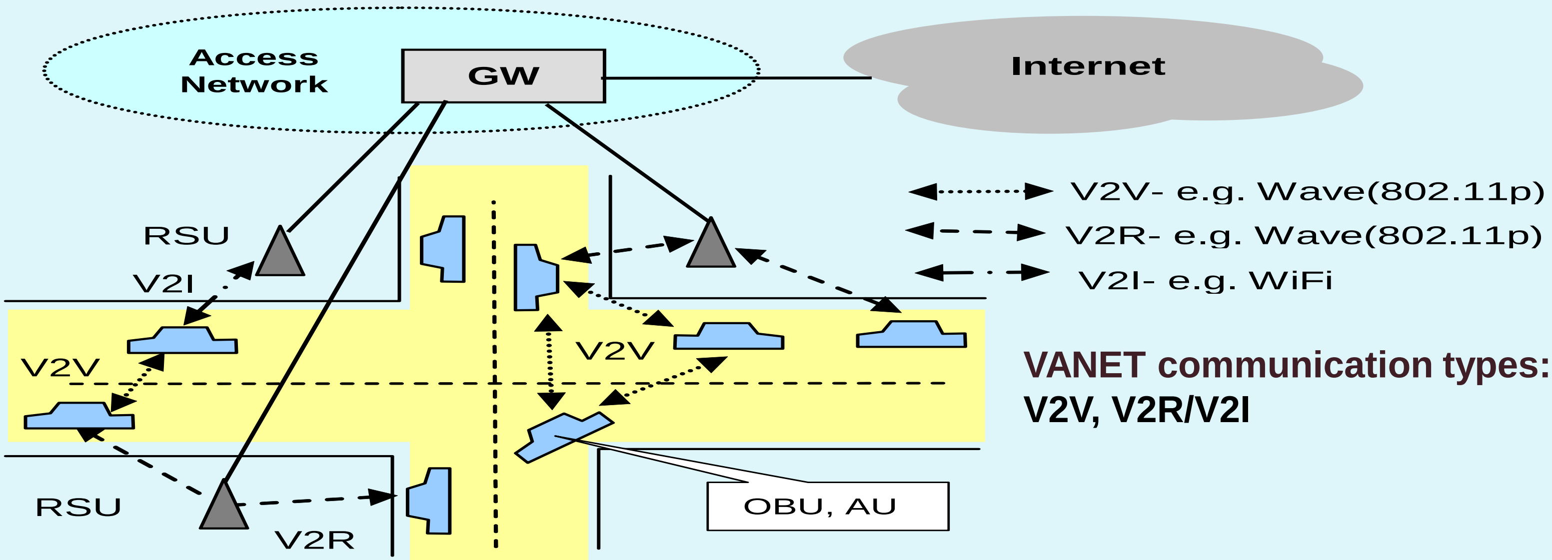
- **1.2 Current developments in vehicular communications and services**
- **Architecture overview for V2X**



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. Vehicle to everything (V2X) communications - introduction

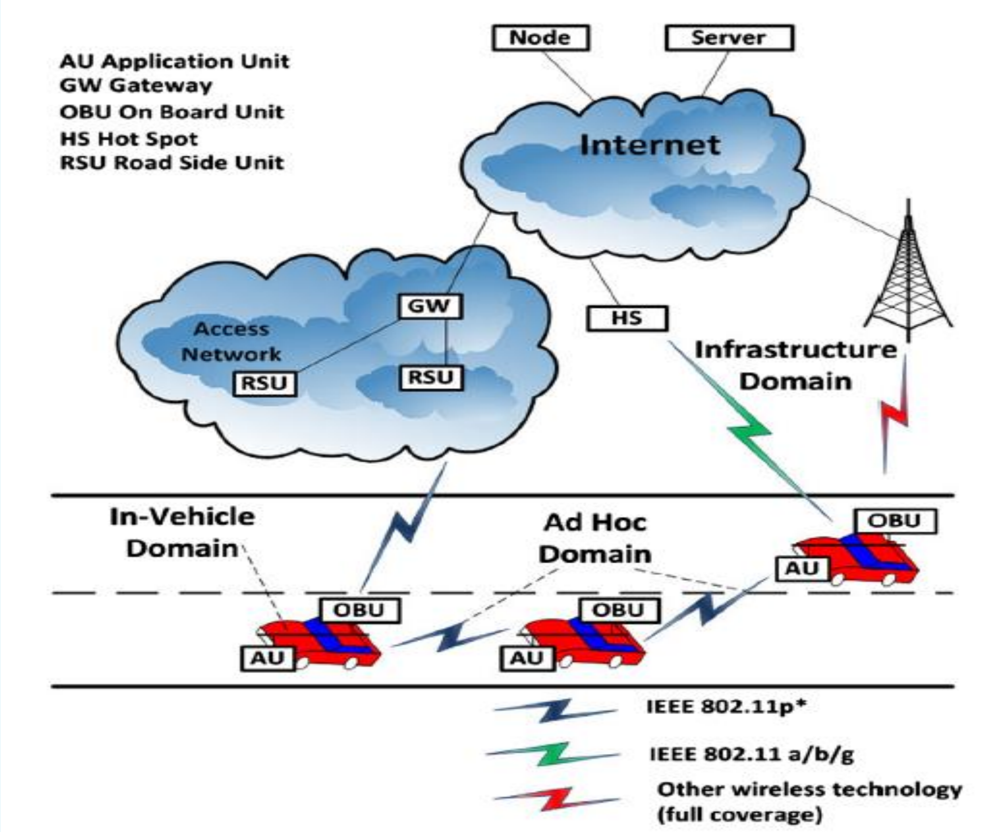
- 1.2 Current developments in vehicular communications and services
- Vehicular ad-hoc Networks (VANET)
- Basic VANET system components
  - **RSU- Road Side Unit, OBU On-board Unit, AU - Application Unit**
- **Typically**
  - RSU hosts apps. that provides services; OBU -peer device that uses the services
  - The apps. may reside in the RSU or in the OBU (provider/user model)
  - Vehicle: may host n≥1 AUs that use the apps. offered by the provider, supported by OBU connection capabilities
-

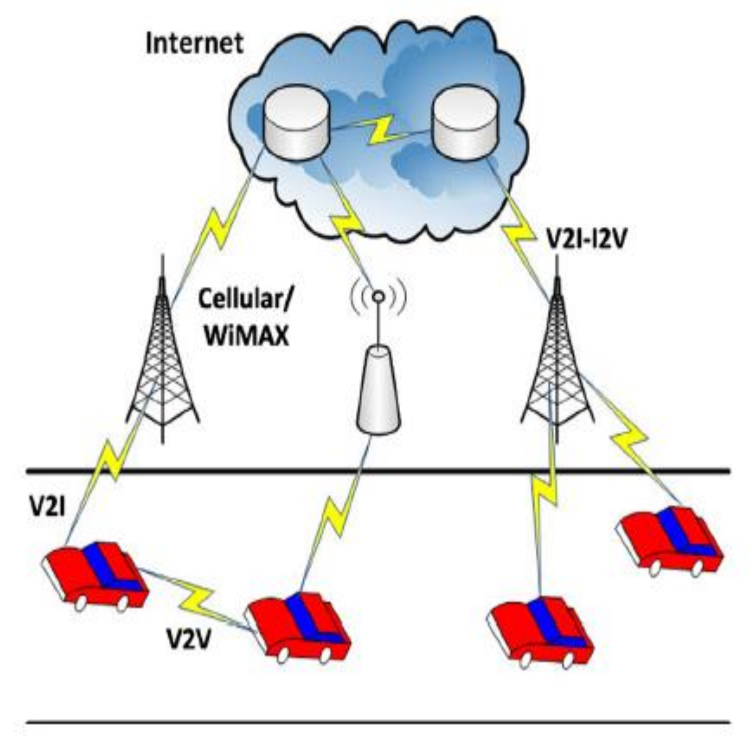


VANET communication types:
V2V, V2R/V2I

1. Vehicle to everything (V2X) communications - 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. Vehicle to everything (V2X) communications - introduction

1.2 Current developments in vehicular communications and services

- **Cellular alternative to IEEE 802.11p/DSRC**
  - **C-V2X belongs to 3GPP advanced cellular systems (4G, 5G)** Standardization
    - LTE Broadcast (3GPP Rel. 9), LTE Direct (3GPP Rel.12), 3GPP Release 14
  - **LTE Direct**: V2V direct communications (< 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 events a few miles ahead up the road; connect to smart parking systems to find open available spaces
  - V2V -> 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)

1. Vehicle to everything (V2X) communications - introduction

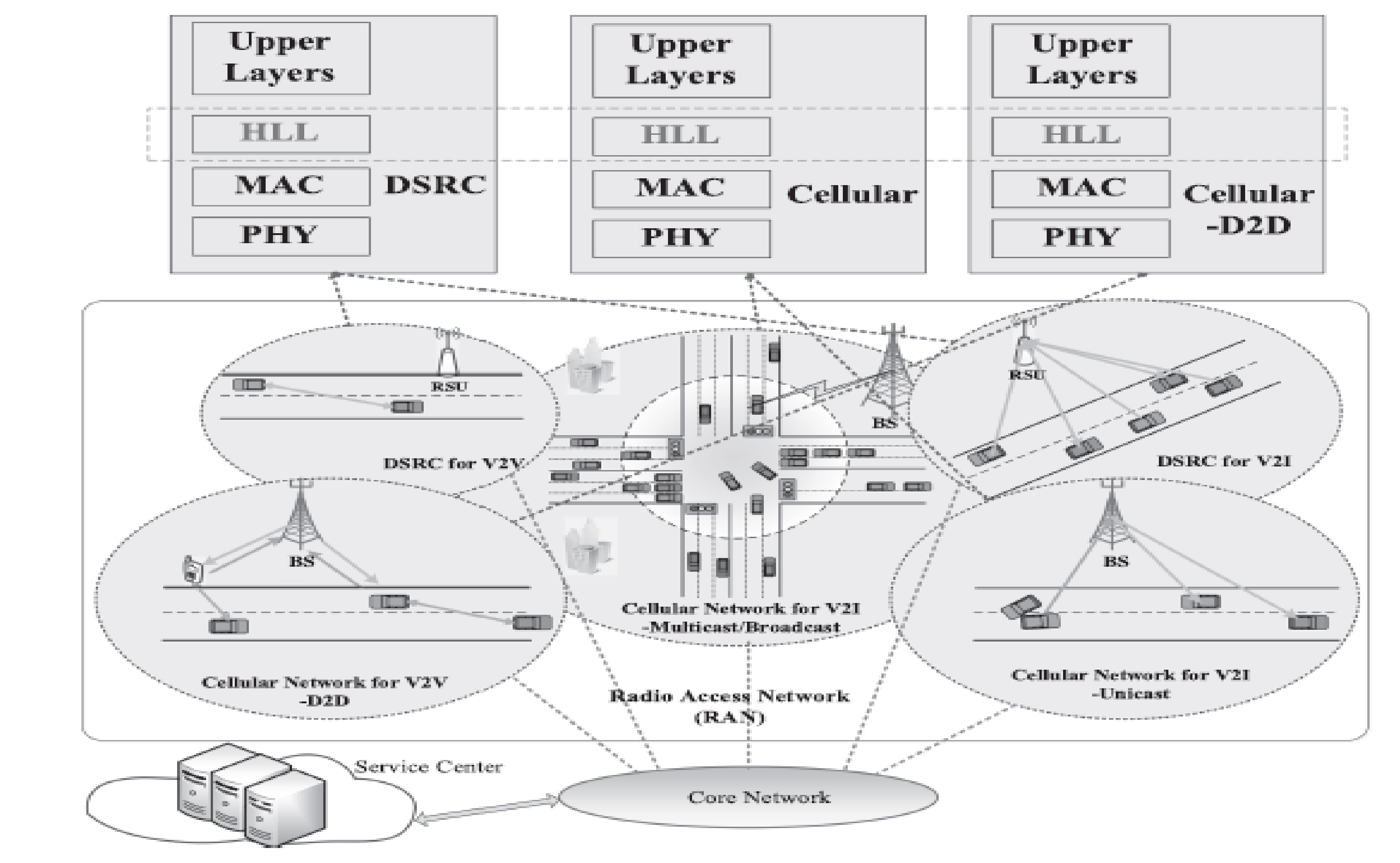
1.2 Current developments in vehicular communications and services

- **Cellular alternative to IEEE 802.11-2012/DSRC** (cont'd)
  - **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. Vehicle to everything (V2X) communications - 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. Vehicle to everything (V2X) communications - 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. Vehicle to everything (V2X) communications - 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, V2R, V2I, wide area V2N, V2U, V2Cloud
    - intends to replace the US promoted DSRC and the Europe-originated Cooperative Intelligent Transport Systems (C-ITS)
    - major target : autonomous driving
  - **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.
  - **Two interfaces:** wide area network LTE interface (Uu); direct communications interface (PC5)

- **3GPP 5G-V2X (Release 15) 2018 -**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. Vehicle to everything (V2X) communications - introduction

- **1.4 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

1. Vehicle to everything (V2X) communications - introduction

- **1.4 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**
  - higher requirements than V2V safety apps. (reasons: high speed, small inter-vehicle distances)
  - requires full road network coverage to be driverless in all geographies
  - network should 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

1. Vehicle to everything (V2X) communications - introduction

- **1.4 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

1. Vehicle to everything (V2X) communications - introduction

- **1.5 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 powerful solutions is necessary
  - **5G plus MEC is a powerful candidate** – offering E2E 5G slicing solutions
    - based on 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

1. Vehicle to everything (V2X) communications - introduction

- **1.5 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

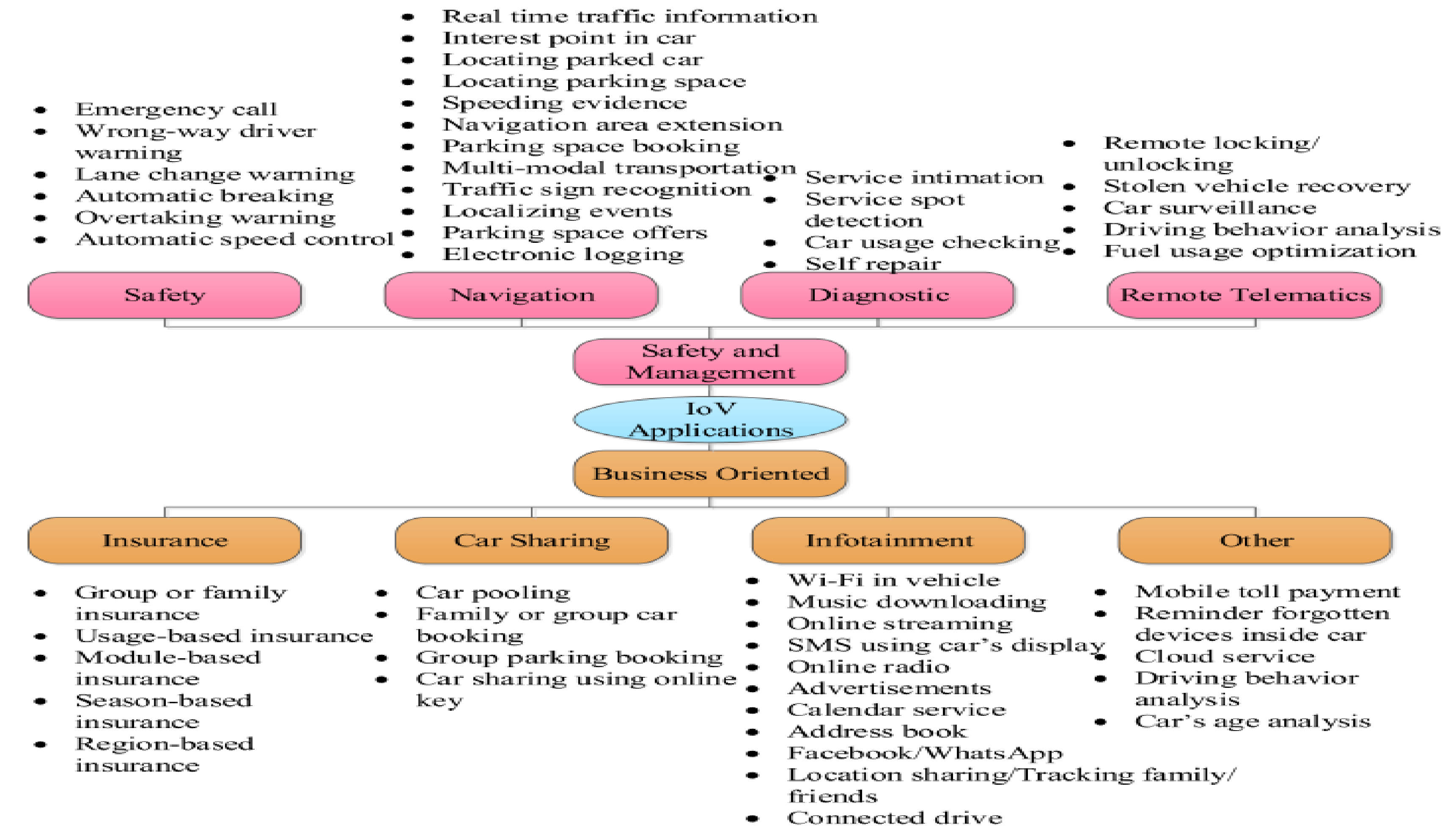
Source: C.Campolo, A.Molinaro, A.Iera, F.Menichella, "5G Network Slicing for Vehicle-to-Everything Services", IEEE Wireless Communications, Volume: 24 Issue: 6, DOI: 10.1109/MWC.2017.160040

1. Vehicle to everything (V2X) communications - introduction

- **1.6 Advanced vehicular communications and services (IoV)**
- **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.
- **IoV features**
  - business oriented architecture
  - collaboration between heterogeneous nets, reliable Internet service
  - communication types-all V2X types; “always-connected”-feature is possible
  - high processing power and decision capabilities
  - compatibility with any personal devices
  - scalability and integration capabilities of various technologies
  - network/environment - global awareness (Edge/cloud-assisted
  - main operations can be based on CC/Edge computing services

1. Vehicle to everything (V2X) communications - introduction

- **1.7 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

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2. 5G technology summary

2.1 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, Very low latency, High-speed Gigabit connection***
- 5G - *user experience continuity* in various situations: high mobility, very dense or sparsely populated areas, heterogeneous access technologies
- **5G - key enabler for : IoT, M2M, IoV/V2X, Broadband/media services, ….**
- 5G integrates: *networking* + *computing* + *storage* resources

- **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
  - **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**

2. 5G technology summary

2.1 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

2. 5G technology summary

2.1 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.

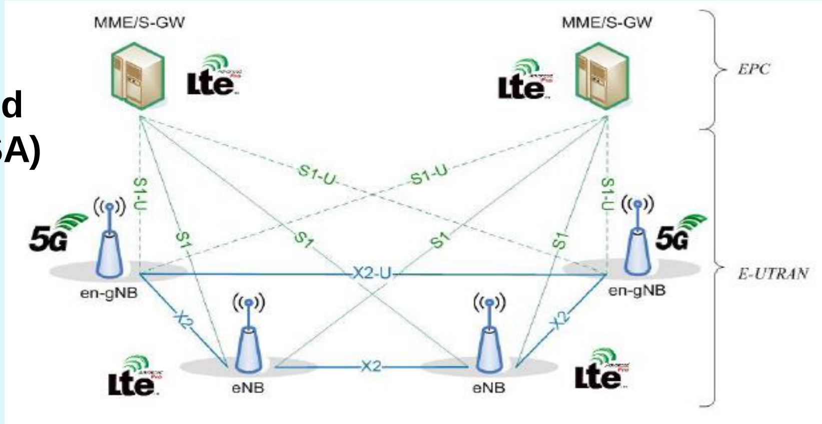
See: A.Galis, 5G Architecture Viewpoints H2020 5G PPP Infrastructure Association July 2016, August 2017, https://5g-ppp.eu/white-papers/

2. 5G technology summary

2.2 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.

Non-Stand Alone (NSA)

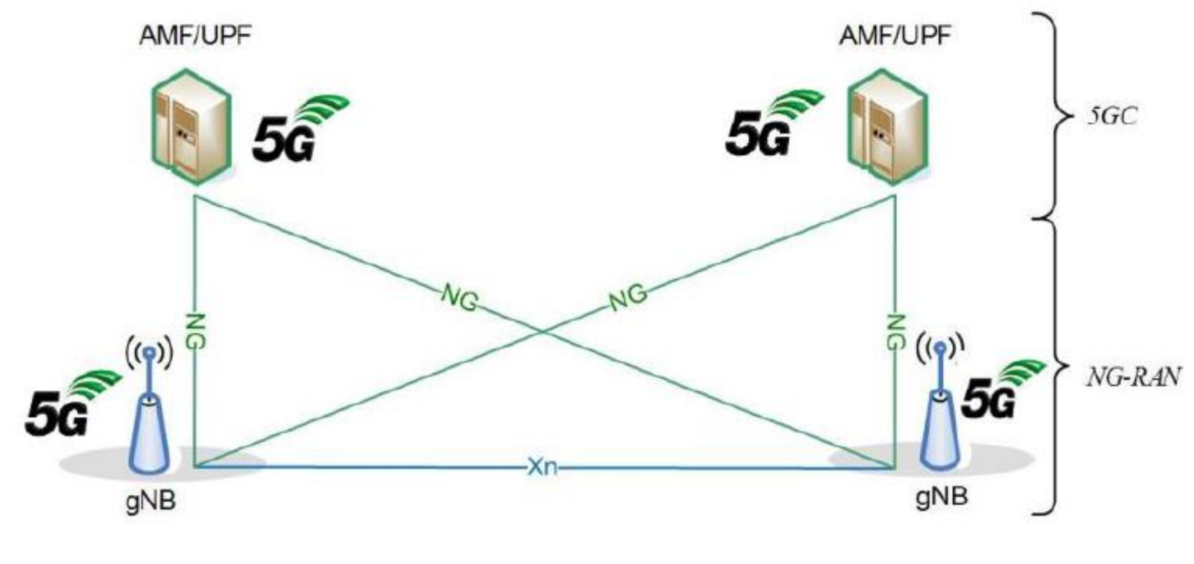


Source: GSM Association (GSMA) (2018, April): "Road to 5G: Introduction and Migration", https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

2. 5G technology summary

2.2 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"

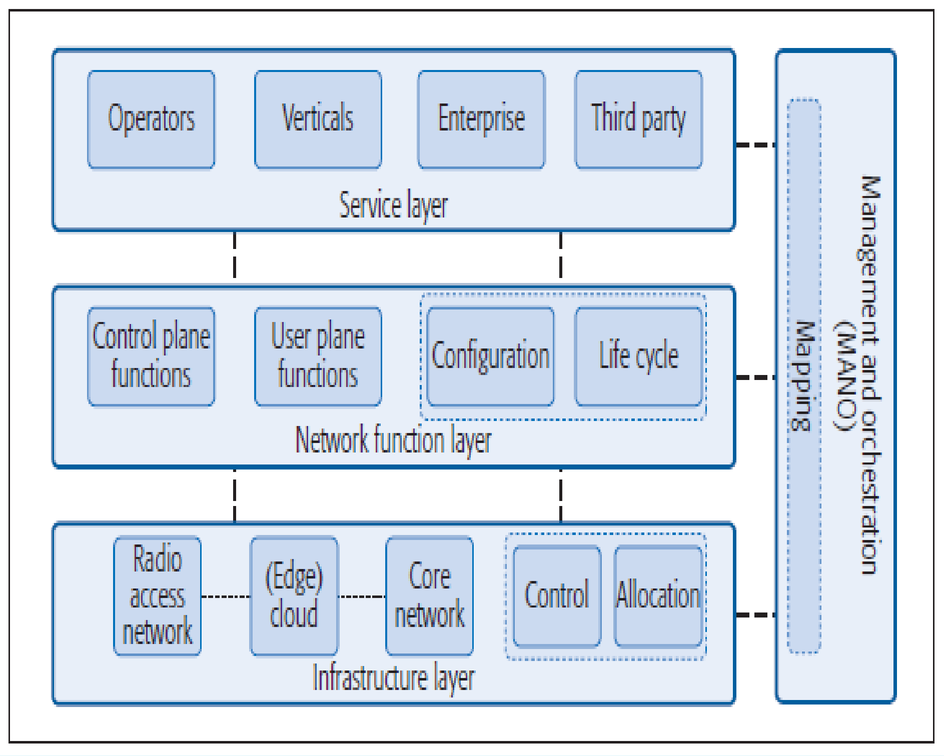
The new base station is called gNB (or gNodeB), and replaces the eNB (or eNodeB or Evolved Node B).

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

2. 5G technology summary

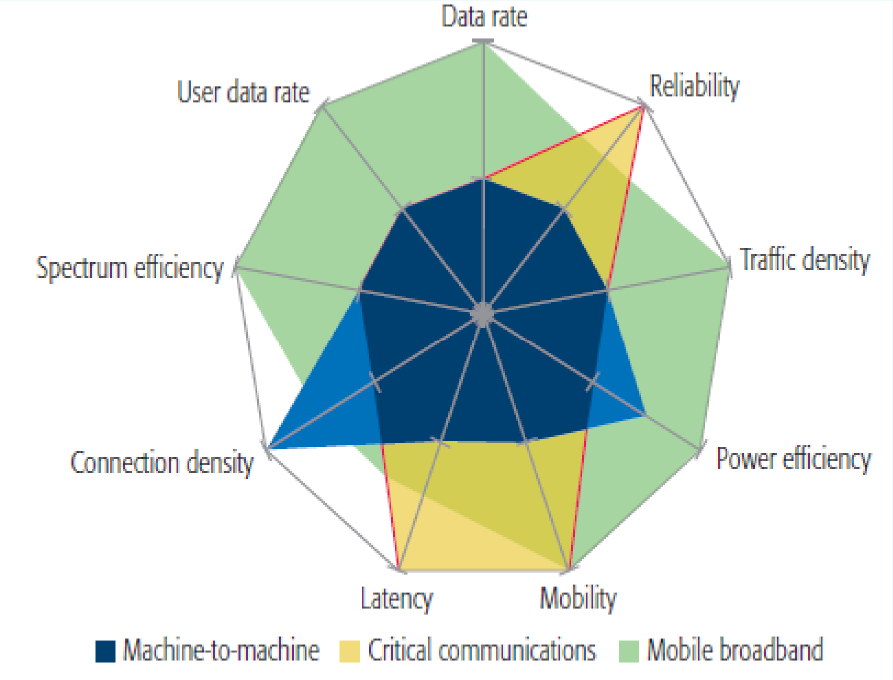
2.3 5G Layered Architecture

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



Key 5G use cases and their requirements

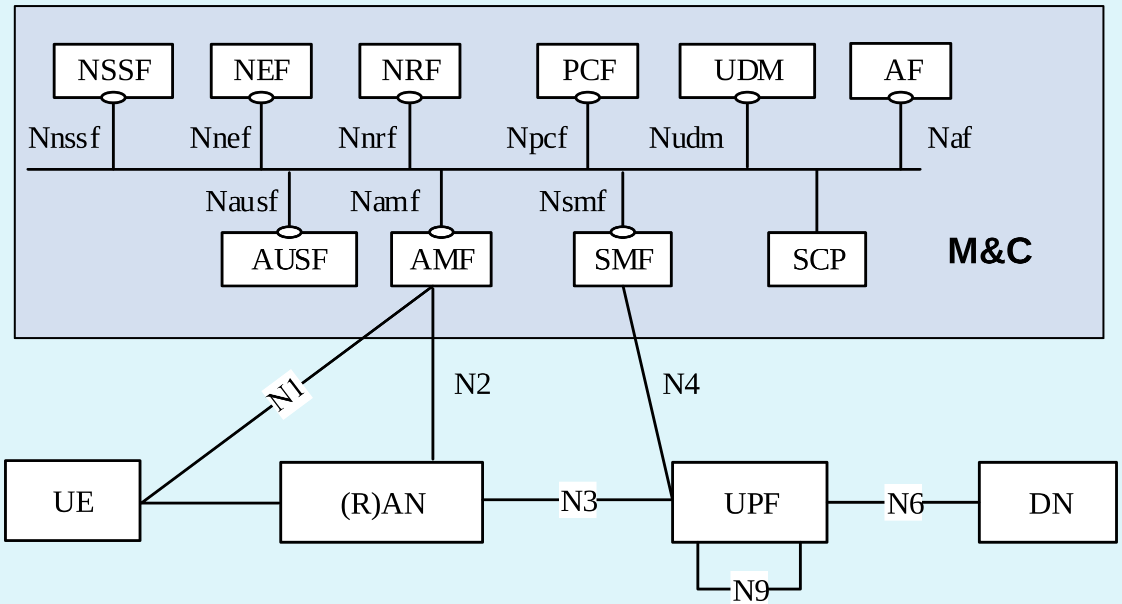
- difficult for a traditional unique arch to meet all of them
- **dedicated slicing can be the solution**



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

2.3 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)

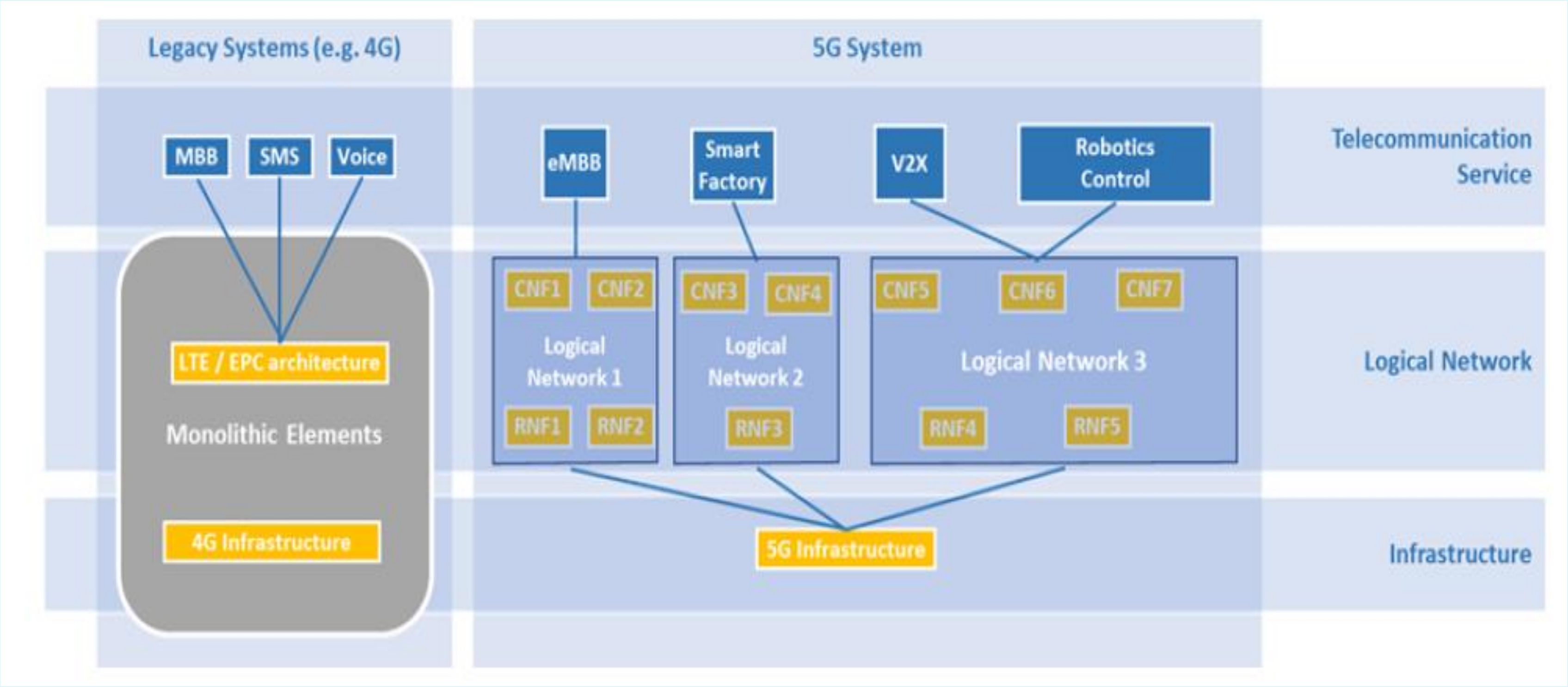
2. 5G technology summary

2.4 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

2. 5G technology summary

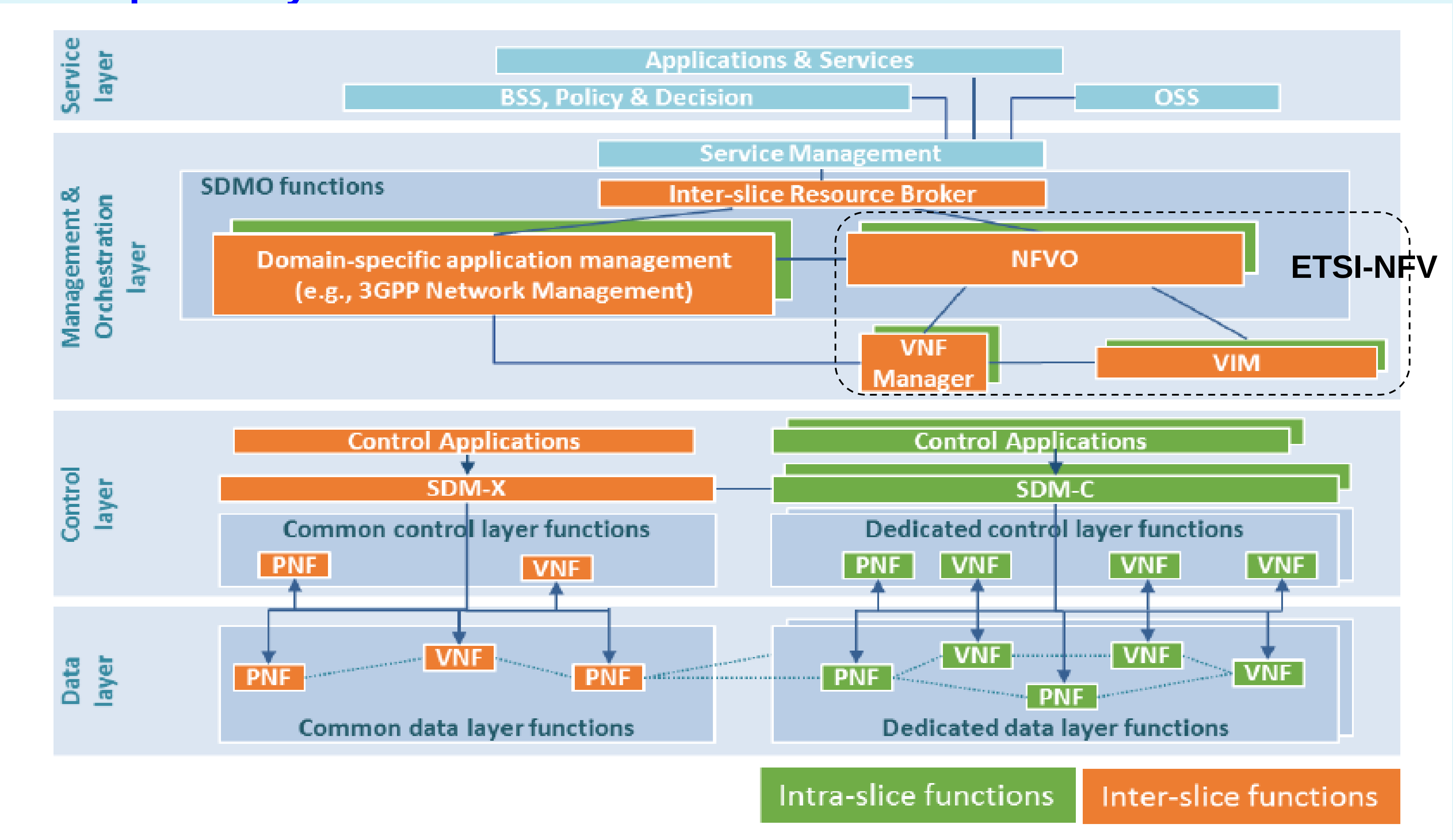
- **2.4 Network slicing concepts and architecture** (cont'd)
- **4G versus 5G slicing concepts**



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

2.4 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

2. 5G technology summary

2.4 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

2. 5G technology summary

2.4 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

2. 5G technology summary

2.6 Categories of 5G fundamental scenarios

- **Massive Machine Type Communication (mMTC)**
- **Ultra Reliability Low Latency Communication (URLLC)**
- **Enhanced Mobile Broadband (eMBB)**

Applicable to V2X

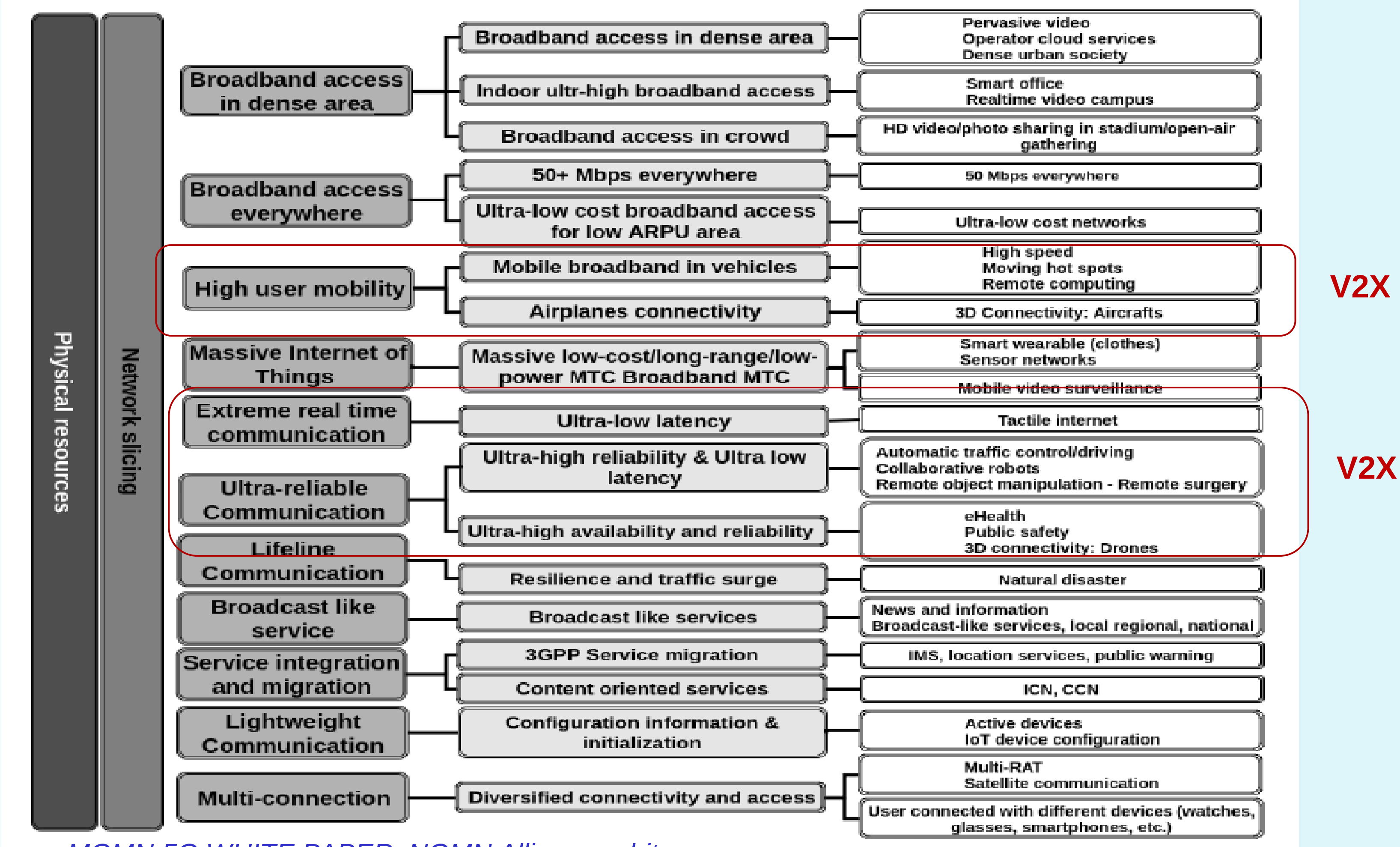
- **different requirements on 5G: functional** (e.g., priority, charging, policies, security, and mobility) and **performance** (e.g., latency, mobility, availability, reliability and data rates) -→ **dedicated slices can be constructed**

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

2. 5G technology summary

2.7 5G Slicing Use-cases family and category – from 3GPP and NGMN



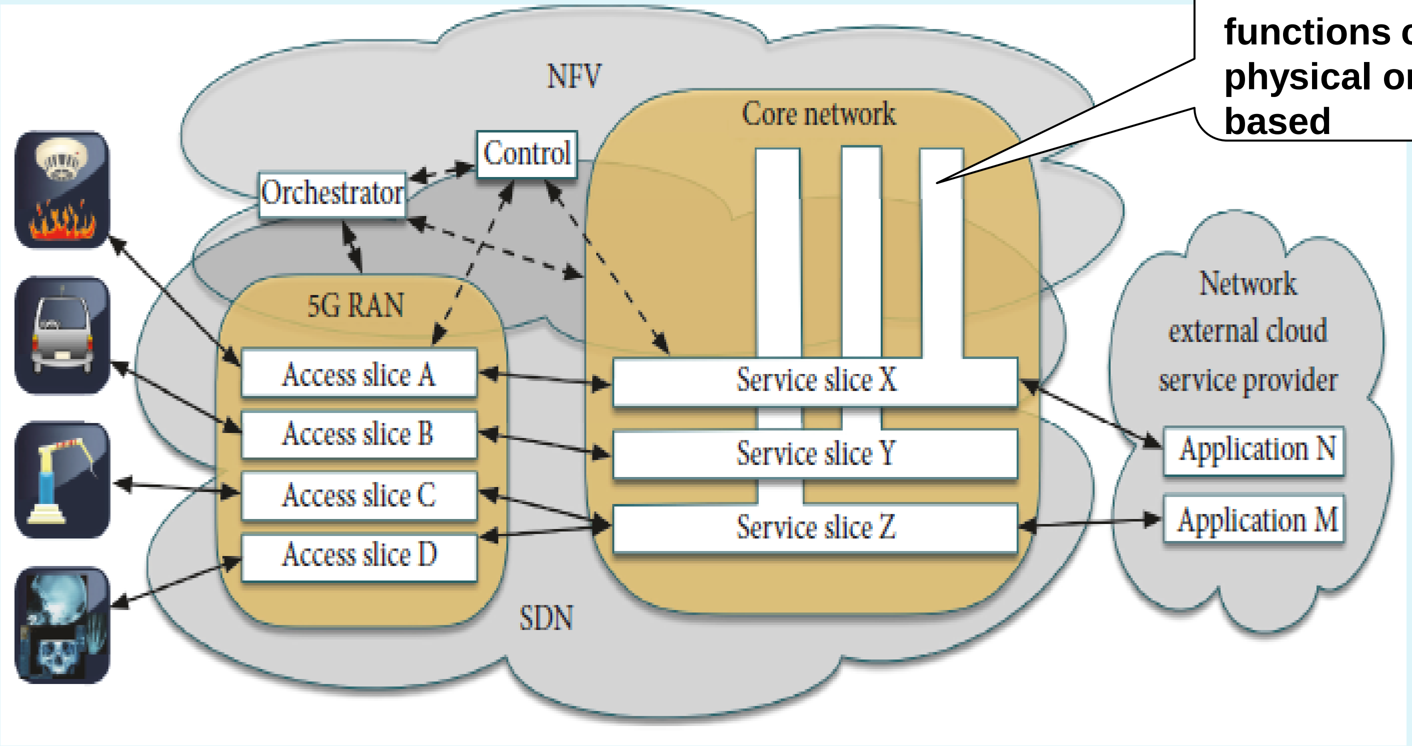
Source: MGMN 5G WHITE PAPER, NGMN Alliance, white paper, https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf, Feb. 2015.

2. 5G technology summary

2.8 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

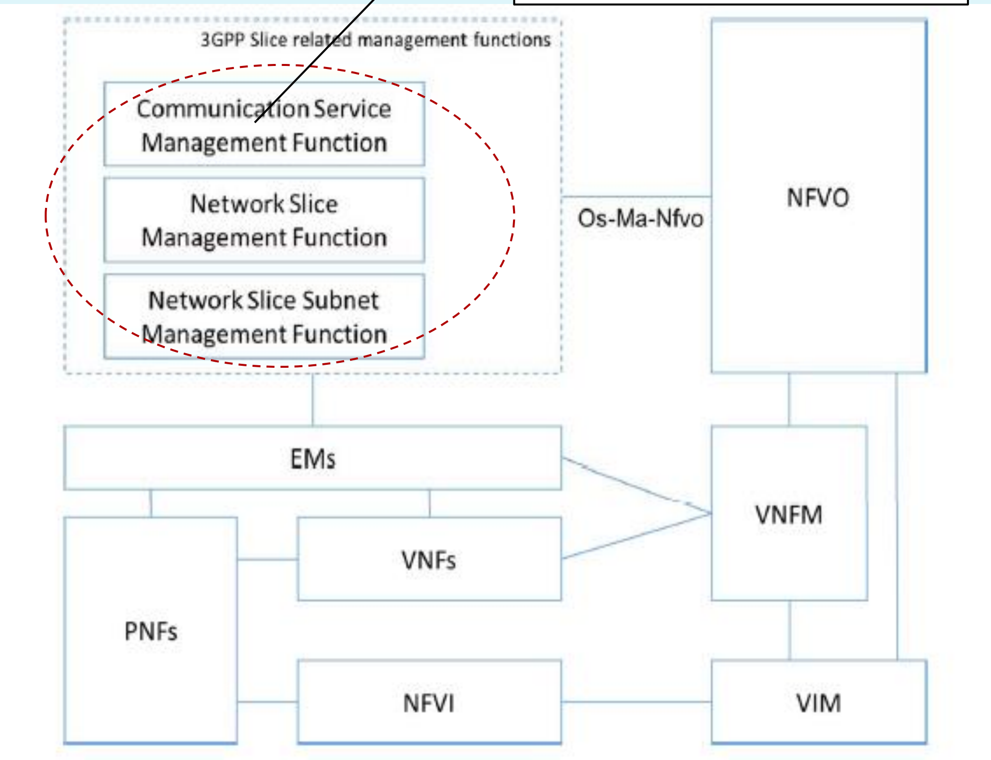


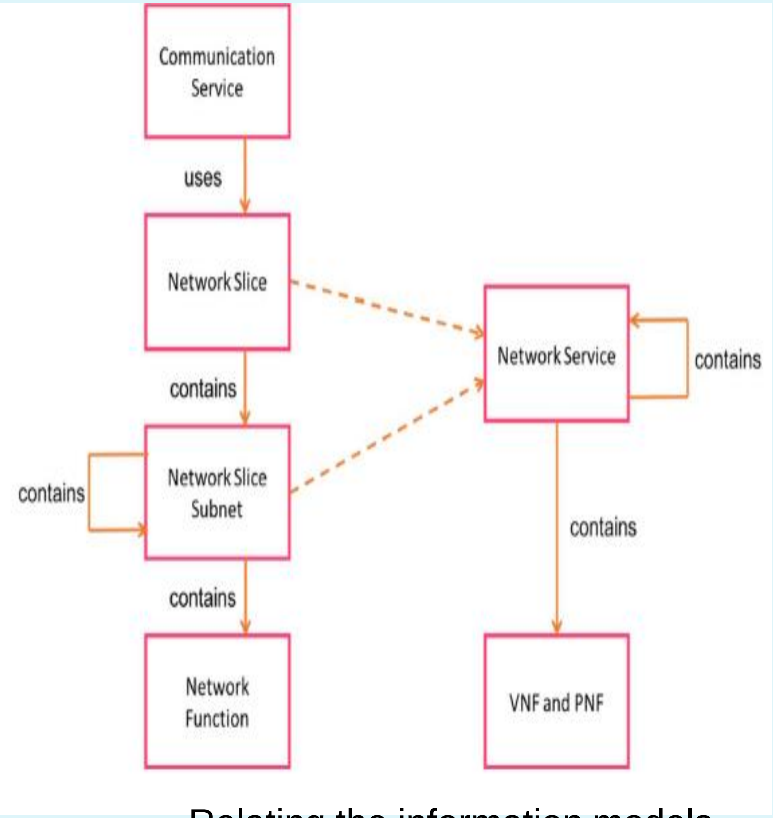
Source: G. Nencioni et al., Orchestration and Control in Software-Defined 5G Networks: Research Challenges, Wiley, Wireless Communications and Mobile Computing Volume 2018, Article ID 6923867, pp. 1-19, https://doi.org/10.1155/2018/6923867https://www.hindawi.com/journals/wcmc/2018/6923867/

2.9 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

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

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

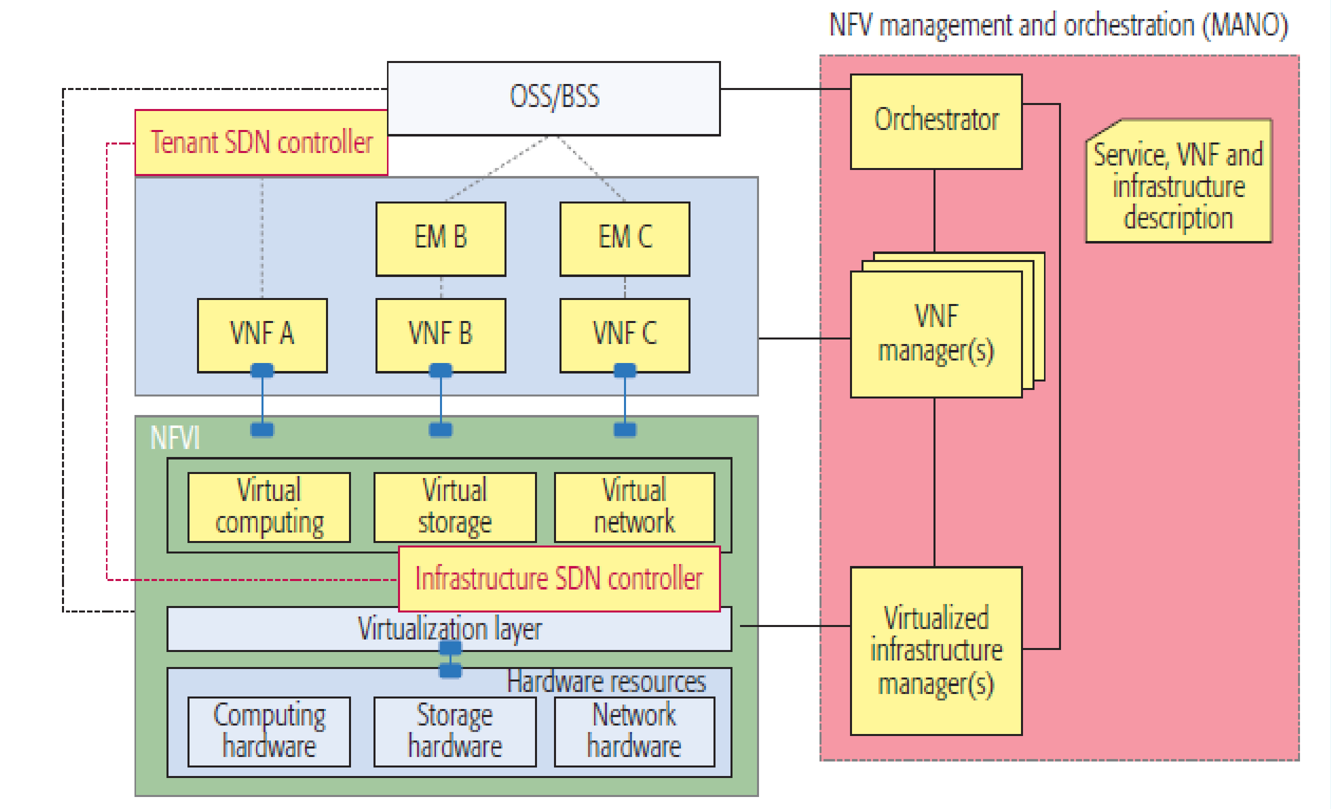
- **Three layered functions** related to NS mgmt.
  - **Communication Service Management Function (CSMF):** translates the communication service requirements to NS requirements
    - The CSMF has I/F with **(NSMF)**
  - **Network Slice Management Function (NSMF) -** mgmt. (including lifecycle) of NSIs. 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

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

- **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

2. 5G technology summary

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

- **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.

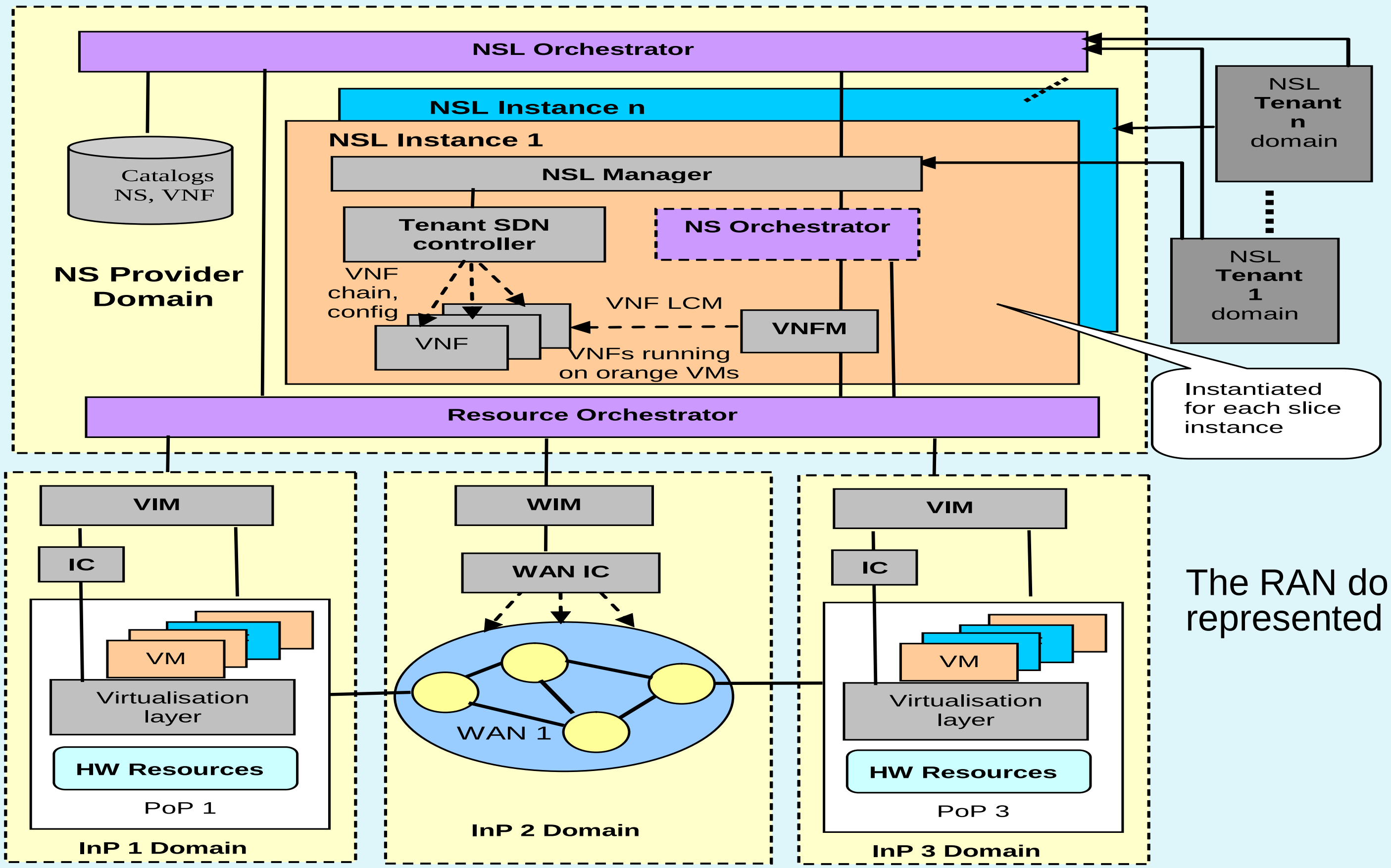
- **Tenant SDN controller (TC):**
  - instantiated in the tenant domain
    - as one of the VNFs
    - or as part of the NMS,
  - ***TC dynamically manages the pertinent VNFs*** used to realize the tenant's network service(s). These VNFs are the underlying **forwarding plane resources** of the TC.
 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

2. 5G technology summary

2.9 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

2.10 Example of slicing in 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

2. 5G technology summary

2.10 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

2. 5G technology summary

2.10 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.

2. 5G technology summary

2.10. 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

2. 5G technology summary

2.10 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

2. 5G technology summary

2.10 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

CONTENTS

1. Vehicle to everything (V2X) communications - introduction
2. 5G technology summary
3. Edge computing in 5G
4. V2X on 5G- system architectures and design
5. MEC support for V2X 5G systems
6. Conclusions

3. Edge computing in 5G

3.1 Edge-oriented computing

- **Edge computing (EC) – generic definition**
  - **EC- autonomous computing model -** many distributed heterogeneous devices that communicate with the network and perform computing tasks (storage, processing)
  - Part of CC capabilities and operations are offloaded from **centralised CC Data Center (CCDC)** to the **network, edge and/or terminal devices**
  - EC provides context aware storage and distributed computing at the network edge
- **Specific definitions (Fog computing, Multi-access Edge Computing, Cloudlets, ..)**

  - **Fog Computing (FC)** - (*CISCO* ~ 2012)
    - (Bonomi- et al.)"*highly virtualized platform providing **compute, storage and networking services** between end devices and traditional CCDC typically, but not exclusively located at the edge of the network*".
    - IoT- driving factor for FC: FC will not replace CC; they are complementary
    - FC is extended on a **continuum of devices from CCDC down to the edge of networks,** for secure management and control (M&C)
      - of domain specific HW/SW
      - and standard compute, storage and network functions within the domain
    - FC enable secure rich data processing applications across the domain
    - FC nodes (FCNs) are typically located away from the main cloud data centers

3. Edge computing in 5G

3.1 Edge-oriented computing (cont'd)

- **Mobile Edge Computing (MEC)** – *ETSI* - an industry spec. ~2014, [5-7]
  - MEC - model for enabling business oriented, CC platform within or close **the Radio Access Network (RAN)** in the proximity of mobile subscribers to serve delay sensitive, context aware applications
  - CC capabilities move close to the **Radio Access Networks** in 4G, 5G
  - **ETSI :** defined a system architecture and std. for a number of APIs
  - **Multi-access Edge Computing –**extension (>2017) of the initial MEC
    - MEC means today – **multi-access…to include non-cellular actors**
- **Cloudlet –** developed by *Carnegie Mellon University* ~2013) [8-9]
  - A cloudlet is middle tier of a 3-tier hierarchy: 'mobile device – cloudlet – cloud'
  - Cloudlet ~ **"data center in a box"** whose goal is to "bring the cloud closer"'
  - **Cloudlets are mobility-enhanced *micro data centers* located at the edge of a network and serve the mobile or smart device portion of the network**
    - designed to handle resource-intensive mobile apps. and take the load off both the network and the CCDC and keep computing close to the point of origin of information
- **Micro data centre** – developed by *Microsoft Research- ~2015* [10]
  - extension of today's hyperscale cloud data centers (e.g., Microsoft Azure)
  - to meet new requirements: lower latency, new demands related to devices (e.g. lower battery consumption)

3. Edge computing in 5G

3.2. Different visions on Edge-oriented computing

Examples

- **OpenFog Consortium vision on FC and EC**
- **Fog computing** :
  - **A horizontal, system-level arch. that distributes computing, storage, control and networking functions closer to the users along <u>a cloud-to-thing continuum.</u>**
  - FC - extends the traditional CC model; implementations of the architecture can reside in multiple layers of a network's topology
  - the CC benefits are extended to FC (containerisation, virtualisation, orchestration, manageability, and efficiency)
  - FC can cooperate with CC
  - **OpenFog reference arch**. includes security, scalability, openness, autonomy, RAS (reliability, availability and serviceability), agility, hierarchy, and programmability
- **EC is seen as different from FC**
  - FC works with the cloud, whereas EC is defined by the exclusion of cloud.
  - FC is hierarchical, where edge tends to be limited to a small number of layers
  - In addition to computation, FC also addresses networking, storage, control and acceleration.

Source[11-12]: OpenFog Reference Architecture for Fog Computing, 2017, www.OpenFogConsortium.org

3. Edge computing in 5G

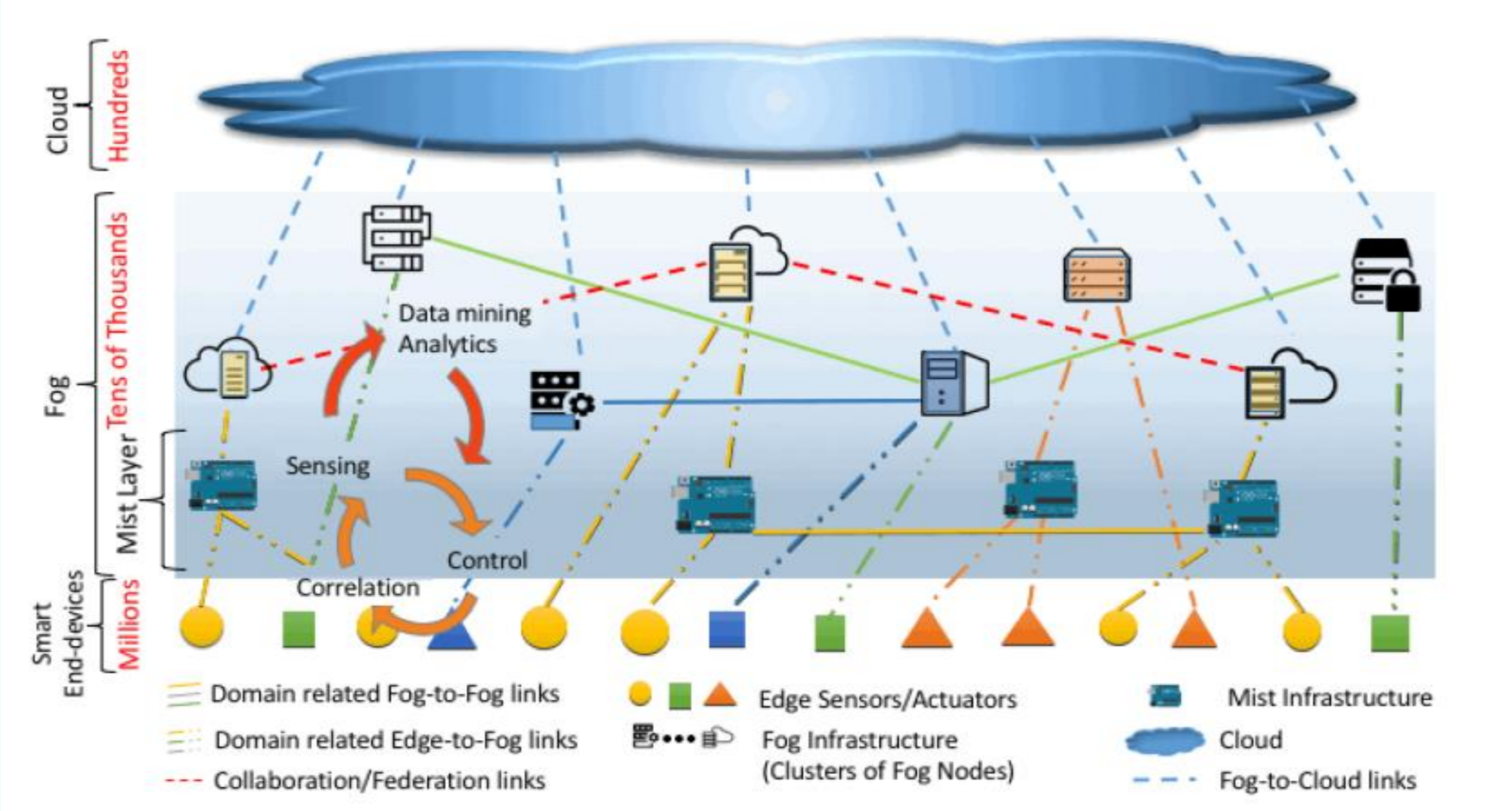
3.2 Different visions on Edge-oriented computing (cont'd)

- **Examples (cont'd)**
- **NIST visions of Fog Computing**
- **FC** : horizontal, physical or virtual resource paradigm that resides **between smart end-devices and traditional cloud or data centers.**
  - **FC** supports vertically-isolated, latency-sensitive applications by providing ubiquitous, scalable, layered, federated, and distributed computing, storage, and network connectivity
  - **Fog Computing Characteristics**
    - Contextual location awareness, and low latency
    - Geographical distribution with predominance of wireless access
    - Large-scale sensor networks
    - Very large number of nodes
    - Support for mobility
    - Real-time interactions
    - Heterogeneity
    - Interoperability and federation
    - Support for real-time analytics and interplay with the Cloud

Source [13]: M.Iorga et. al., NIST Special Publication 800-191 (Draft) 1, The NIST Definition of Fog Computing, 2017

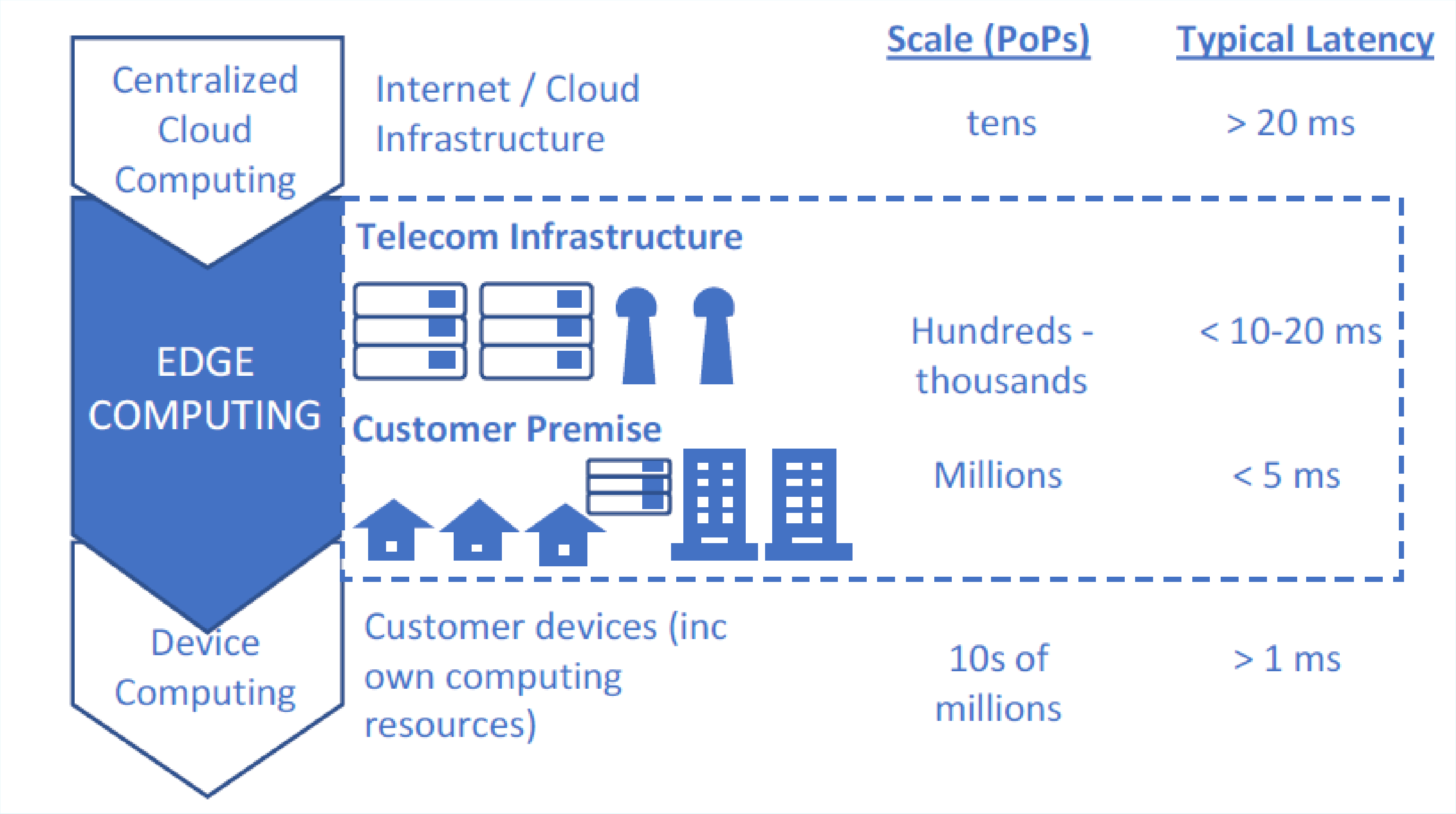
3.2 Different visions on Edge-oriented computing

- **Examples (cont'd)**
- **NIST definition of Fog Computing**



Source [13]: M.Iorga et. al., NIST Special Publication 800-191 (Draft) 1, The NIST Definition of Fog Computing, 2017

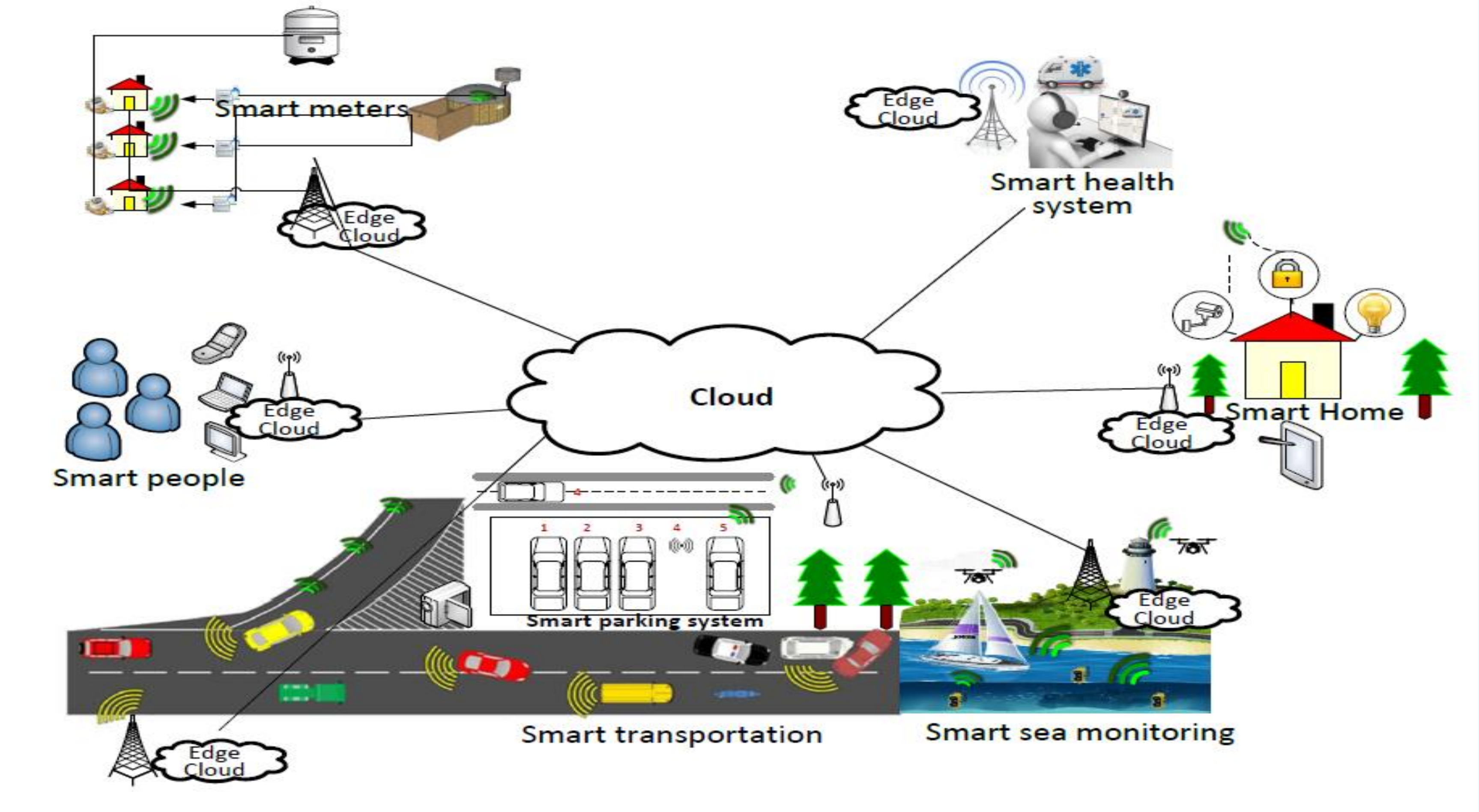
3.3 Edge Computing Location



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

3. Edge computing in 5G

3.4 Edge computing applications- examples



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

3. Edge computing in 5G

3.5 Multi-access Edge computing (MEC)- ETSI Reference architecture

- **ETSI** developed the **Reference Architecture (RA)** to support the requirements defined for Multi-access Edge Computing in ETSI GS MEC 002
- The RA described shows the functional elements that compose the multi-access edge
- system, including the
  - **MEC platform**
  - **MEC management**
  - **Reference Points (RP)** between them
- The functional elements and RPs describe the high-level functionality of the different functional elements

- The MEC RA supports several MEC services

- MEC enables the **implementation of MEC applications** as software-only entities that run on top of a **Virtualisation infrastructure,** which is located in or close to the network edge.

- The MEC framework defines the general entities involved
- These can be grouped into **system level, host level** and **network level entities**.

ETSI GS MEC 003 V2.2.1 (2020-12), Multi-access Edge Computing (MEC); Framework and Reference Architecture

3. Edge computing in 5G

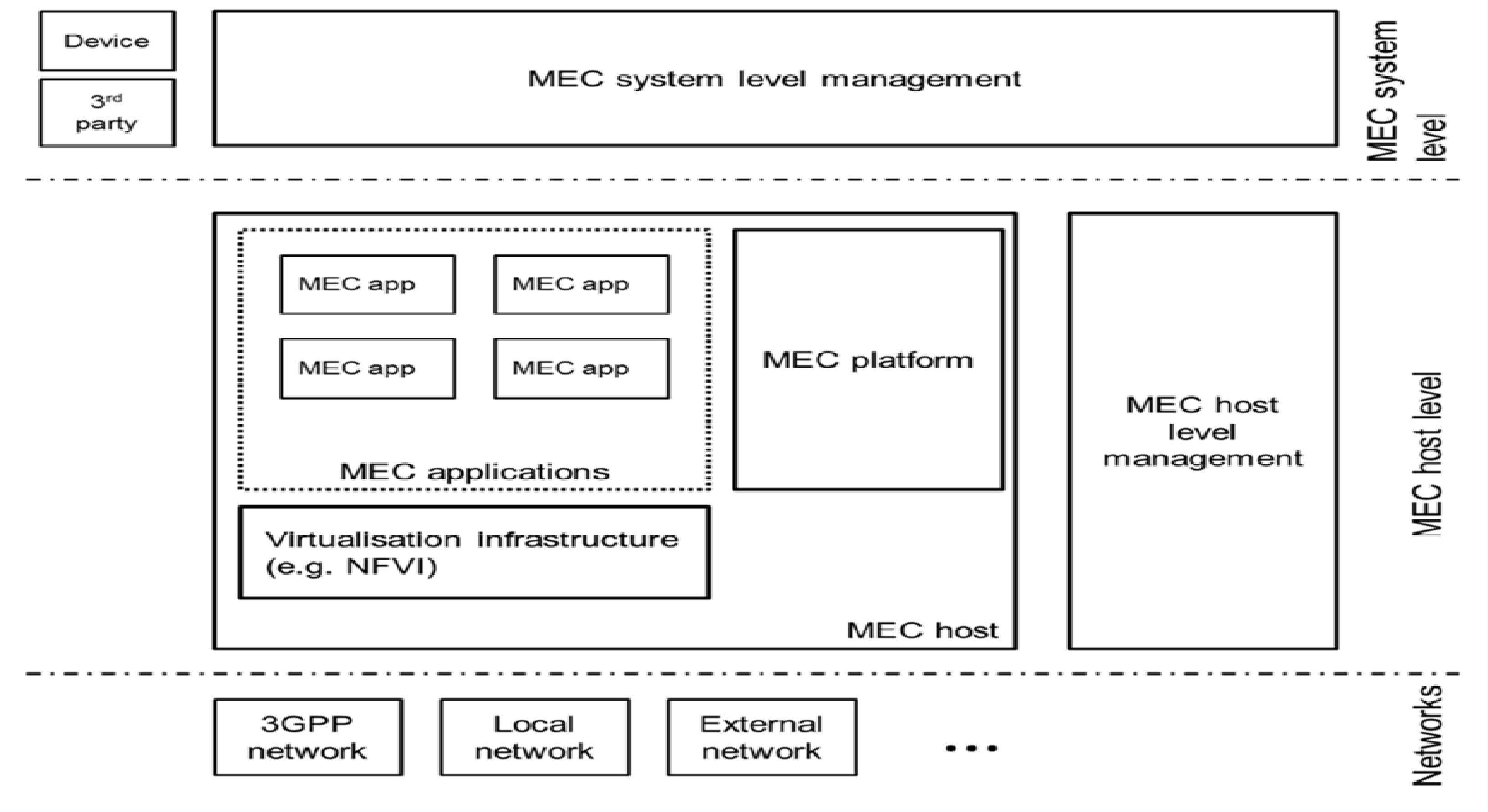
3.5 Multi-access Edge computing- ETSI Reference architecture

- **Multi-access Edge Computing** entities:
  - **MEC host,** including : MEC platform, MEC applications, Virtualisation Infrastructure
  - **MEC system level management**
  - **MEC host level management**
  - external related entities, i.e. network level entities
- **MEC main services**
  - **Radio Network Information (RNI)** service, provides authorized applications with radio network related information
  - **Location services** provides authorized applications with location-related info
  - **Traffic Management Services**- optional services are supported:
    - BandWidth Management (BWM) service
    - Multi-access Traffic Steering (MTS) service
  - **Inter-MEC system communication-** addresses the requirements:
    - A MEC platform should be able to discover other MEC platforms that may belong to different MEC systems
    - A MEC platform should be able to exchange information in a secure manner with other MEC platforms that may belong to different MEC systems
    - MEC application should be able to exchange information in a secure manner with other MEC applications that may belong to different MEC systems

Adapted from ETSI GS MEC 003 V2.2.1 (2020-12), MEC Framework and Reference Architecture

3.5 Multi-access Edge computing- ETSI Reference architecture

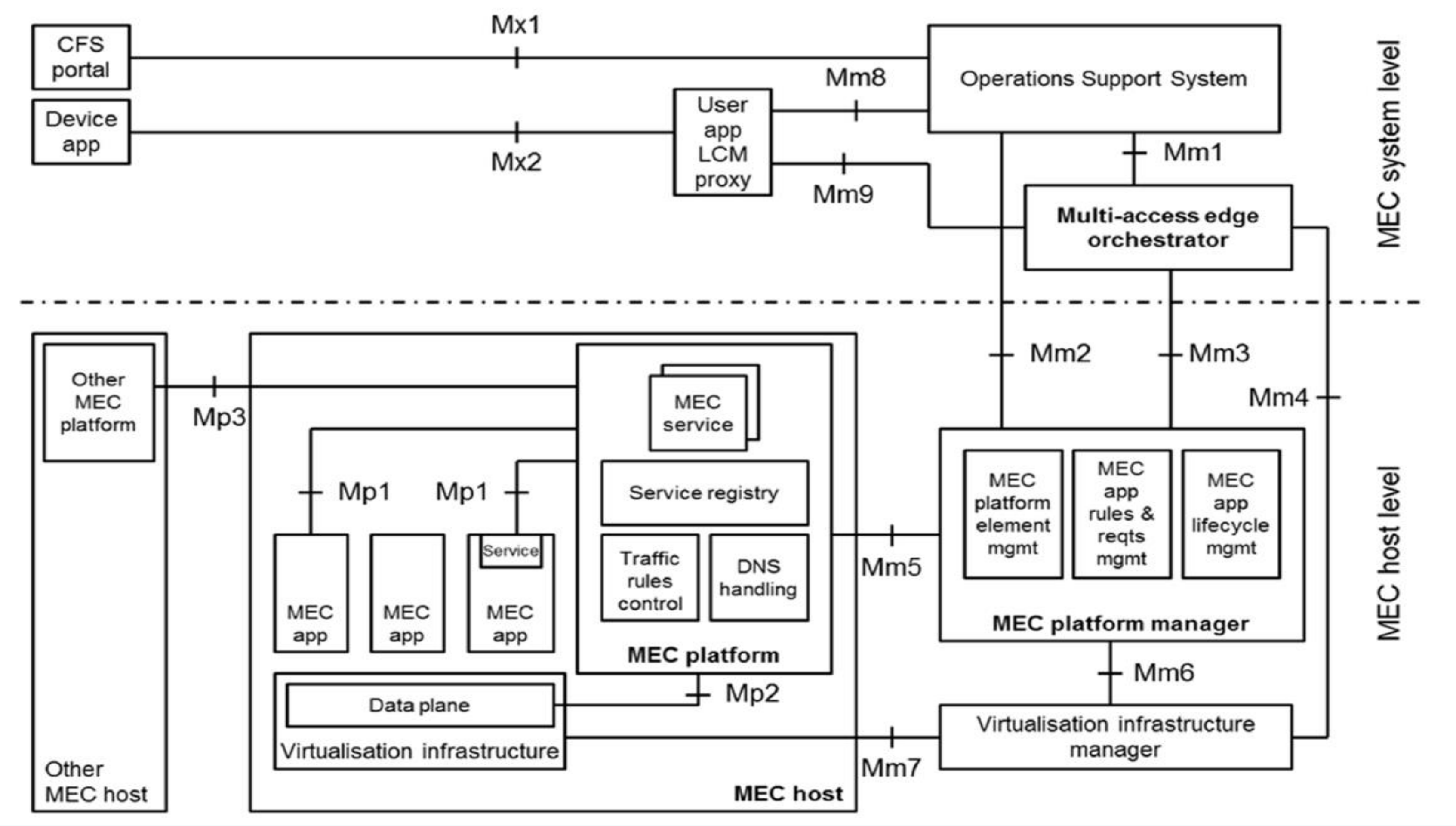
- **Multi-access Edge Computing framework**



Source: ETSI GS MEC 003 V2.2.1 (2020-12), MEC Framework and Reference Architecture

3. Edge computing in 5G

3.5 Multi-access Edge computing- ETSI Reference architecture



ETSI GS MEC 003 V2.2.1 (2020-12), MEC Framework and Reference Architecture

3. Edge computing in 5G

3.5 Multi-access Edge computing- ETSI Reference architecture

- **Previous slide**
  - **three groups of reference points (RP) defined between the system entities:**
    - RPs regarding the MEC platform functionality (Mp);
    - management RPs (Mm)
    - RPs connecting to external entities (Mx)
  - **MEC system** : **MEC hosts** and the **MEC management** (to run MEC apps) within an operator network or a subset of an operator network
    - **MEC host:** a **MEC platform** and a **Virtualisation Infrastructure (VI)**
      - **MEC platform :** collection of essential functionality required to run MEC applications on a particular VI and enable them to provide and consume MEC services.
        The MEC platform can also provide services
      - **Virtualisation Infrastructure** provides compute, storage, and network resources, for the purpose of running MEC applications
    - **MEC applications are instantiated on the VI** of the MEC host based on configuration or requests validated by the MEC management.

Adapted from Source ETSI GS MEC 003 V2.2.1 (2020-12), MEC Framework and Reference Architecture

3. Edge computing in 5G

3.5 Multi-access Edge computing- ETSI Reference architecture

- **MEC management** : **MEC system level management** and the **MEC host level management**
  - **MEC system level management** includes the Multi-access edge orchestrator as its core component, which has an overview of the complete MEC system.
  - **MEC host level management :**
    - **MEC platform manager** and the **Virtualisation infrastructure manager**
    - It handles the management of the MEC specific functionality of a particular MEC host and the applications running on it

- **Architectural levels specific aspects**
  - ***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

Adapted from Source ETSI GS MEC 003 V2.2.1 (2020-12), MEC Framework and Reference Architecture

3. Edge computing in 5G

- **3.5 Multi-access Edge computing- ETSI Reference architecture**
- **About 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
  - **ME management:**
    - **system level management:** components which have the overview of the complete ME system
    - and **mobile edge host level management :** handles the management of the ME specific functionality of a particular ME platform, ME host and the ME applications
  - **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 service:** service provided via the ME platform either
    - by the **ME platform** itself
    - or, **by a ME application**

Adapted from Source ETSI GS MEC 003 V2.2.1 (2020-12), MEC Framework and Reference Architecture

3. Edge computing in 5G

3.5 Multi-access Edge computing- ETSI Reference architecture

- **Multi-access edge system reference architecture variant for MEC in Network Function Virtualisation (NFV)**
  - **MEC** and **Network Functions Virtualisation (NFV)** are complementary concepts
  - The MEC architecture allows a number of different deployment options of MEC system
    - ETSI GR MEC 017 : analysis of solution details of the deployment of MEC in an NFV environment
  - **Here is presented : MEC applications and NFV Virtualised Network Functions (VNF) are instantiated on the same VI**, and the architecture re-uses the ETSI NFV MANO components to fulfil a part of the MEC M&O tasks.

Adapted from Source ETSI GS MEC 003 V2.2.1 (2020-12), MEC Framework and Reference Architecture

3. Edge computing in 5G

3.5 Multi-access Edge computing- ETSI Reference architecture

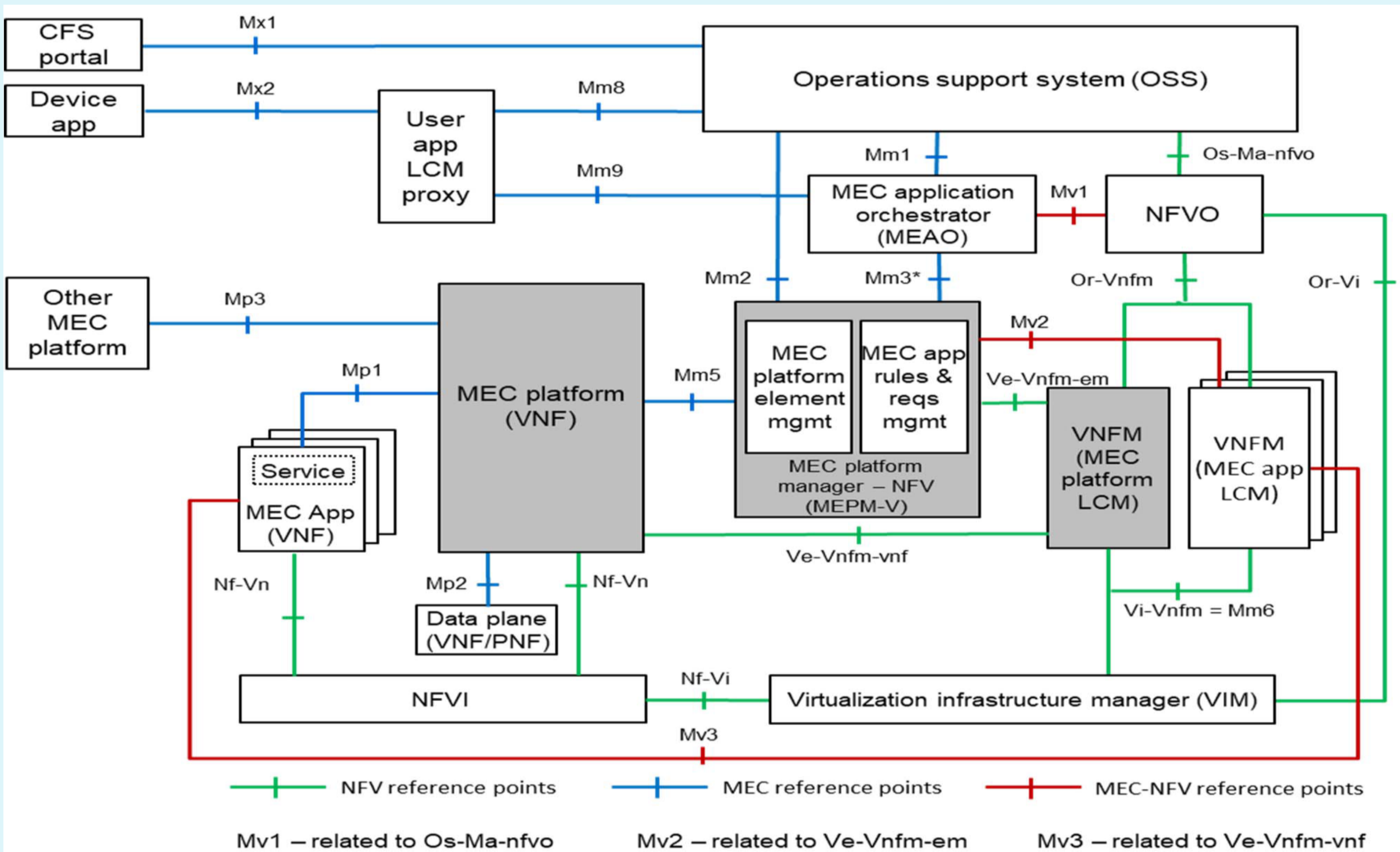
- **Multi-access edge system reference architecture variant for MEC in NFV** (cont'd)

  - In addition to the definitions for the generic RA, the NFV – oriented architecture assumes that
    - The **MEC platform** is deployed as a **Virtualized Network Function (VNF).**
    - The **MEC applications appear as VNFs** towards the ETSI NFV MANO components
    - The **VI is deployed as an NFVI** and is managed by a **VI Manager (VIM)** as defined by ETSI GS NFV 002
    - The **MEC Platform Manager (MEPM)** is replaced by a **MEC Platform Manager - NFV (MEPM-V)** that delegates the VNF lifecycle management to one or more VNF Managers (VNFM).
    - The **MEC Orchestrator (MEO)** is replaced by a **MEC Application Orchestrator (MEAO)** that relies on the **NFV Orchestrator (NFVO)** for resource orchestration and for orchestration of the set of MEC application VNFs as one or more **NFV Network Services (NSs).**

Source ETSI GS MEC 003 V2.2.1 (2020-12), MEC Framework and Reference Architecture

3.5 Multi-access Edge computing- ETSI Reference architecture

- **Multi-access edge reference architecture variant based on NFV Framework**



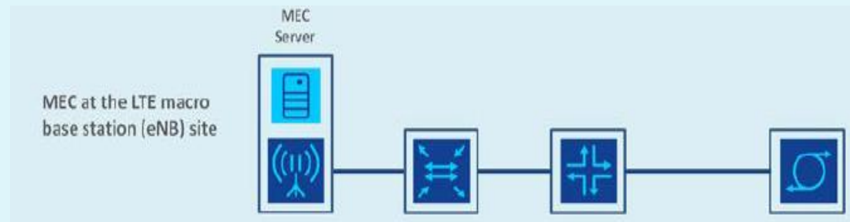
Source ETSI GS MEC 003 V2.2.1 (2020-12), MEC Framework and Reference Architecture

3. Edge computing in 5G

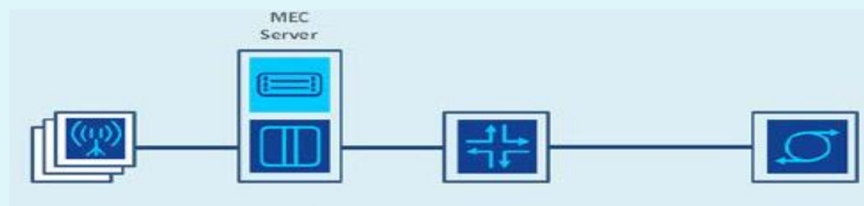
3.6 Possible Deployment Scenarios (ETSI)

- 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

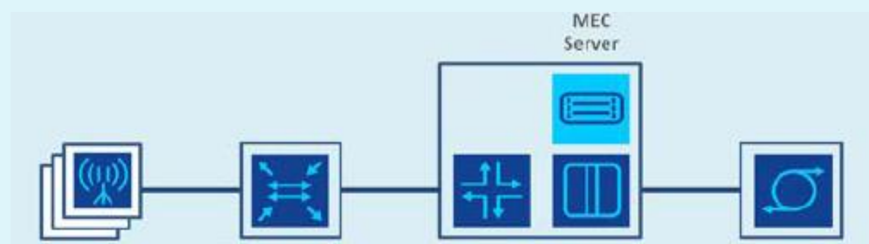
MEC at the LTE macro base station (eNB) site



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



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

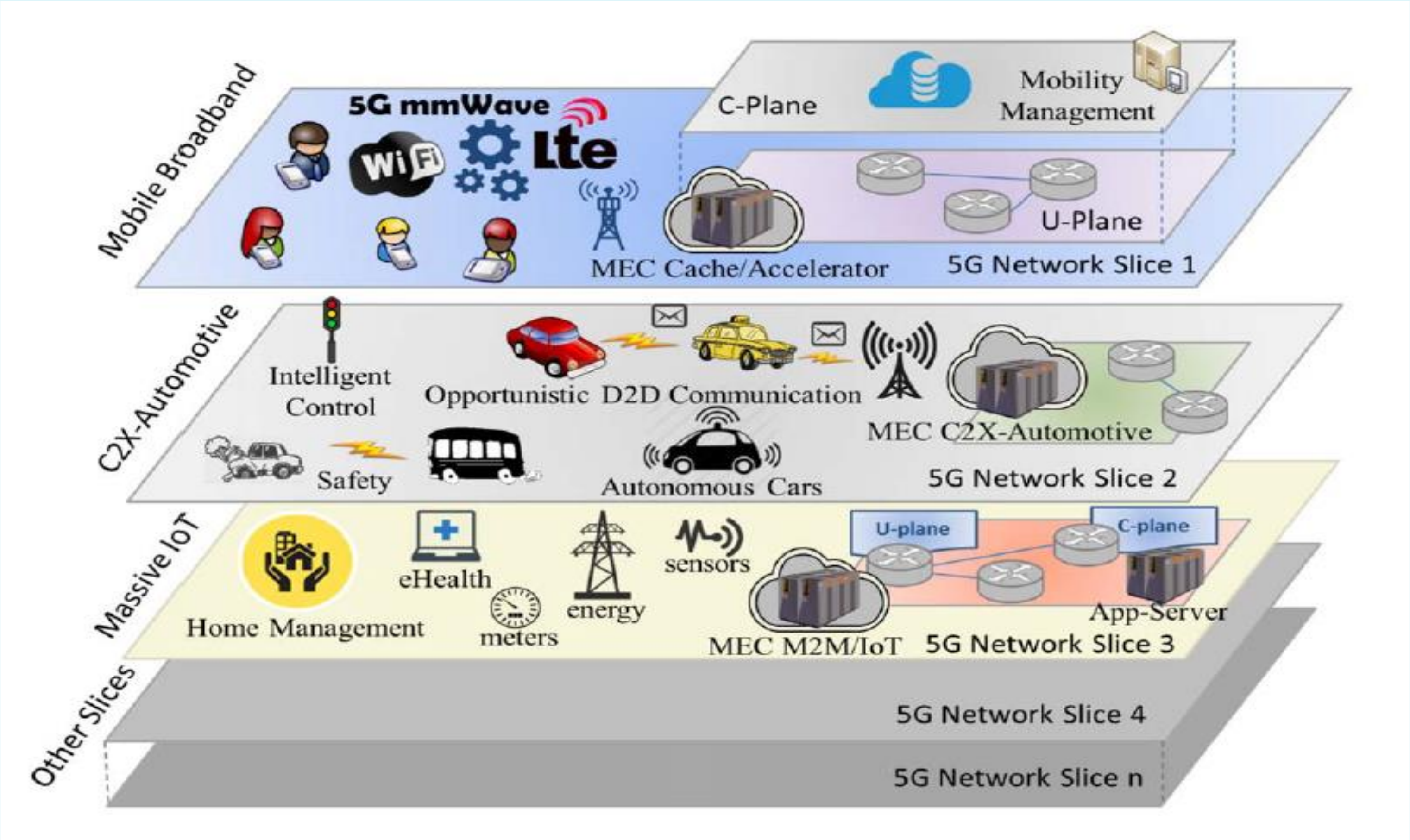


Source: https://portal.etsi.org/Portals/0/TBpages/MEC/Docs/Mobile-edge_Computing_-_Introductory_Technical_White_Paper_V1%2018-09-14.pdf
Mobile-Edge Computing – Introductory Technical White Paper

3. Edge computing in 5G

3.7 MEC in slicing context

- The **MEC role in different dedicated slices**



T.Taleb,et al., "On Multi-Access Edge Computing: A Survey of the Emerging 5G Network Edge Cloud Architecture and Orchestration", IEEE COMMUNICATIONS SURVEYS & TUTORIALS, VOL. 19, NO. 3, THIRD QUARTER 2017 1657

3. Edge computing in 5G

3.7 MEC in slicing context

- The **MEC roles in different dedicated slices** (previous slide)

- **MB slice :** the MEC platform
  - can cache content at the edge increasing the capacity of the mobile backhaul and core network via traffic offloading to the local edge
  - can provide a number of services including, e.g., video accelerator or application aware performance optimization

- **Car-to-X/automotive slice**
  - needs strict latency and scalability with NFs instantiated at the edge
  - MEC may offer such capabilities

- **Massive IoT slice**
  - scalability is important for handling efficiently huge amounts of small data
  - MEC can provide processing and storage for performing signaling optimizations

- To aqchieve service customization in network slicing NFV and SDN technologies can cooperate (in M&C plane) and contribute to coordination for VNF allocation and service provisioning at the edge-cloud

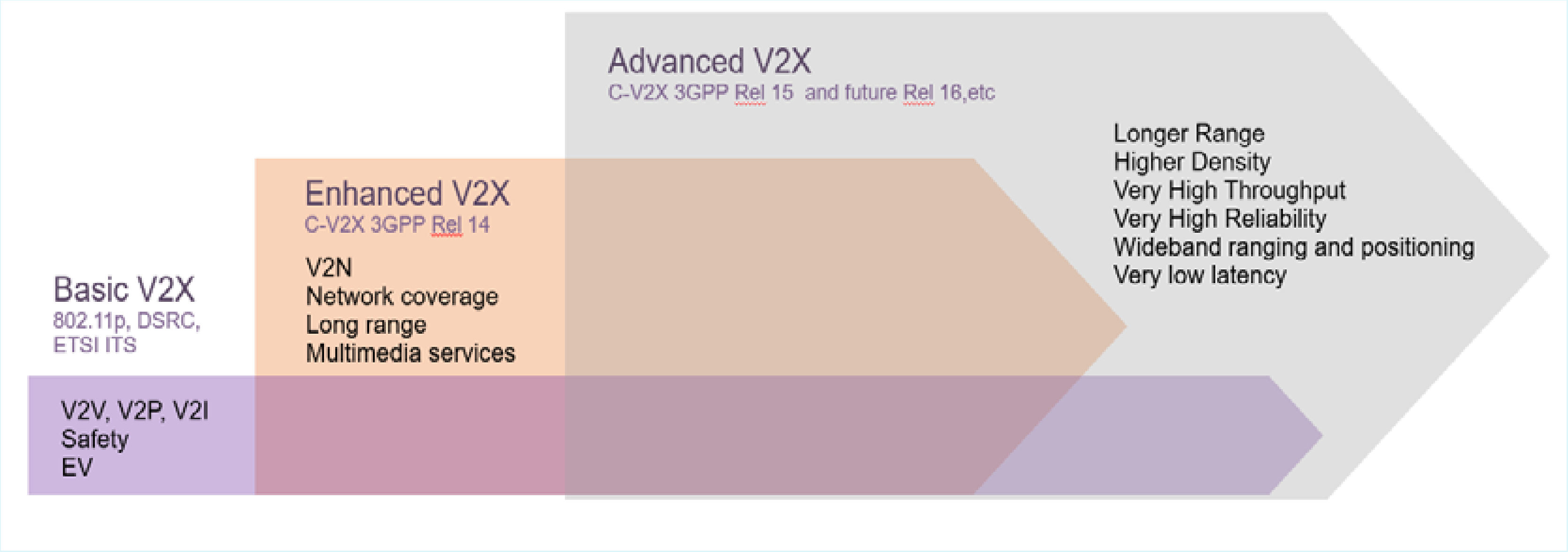
CONTENTS

1. Vehicle to everything (V2X) communications - introduction
2. 5G technology summary
3. Edge computing in 5G
4. V2X on 5G- system architectures and design
5. MEC support for V2X 5G systems
6. Conclusions

4. V2X on 5G- system architectures and design

4.1 V2X evolution

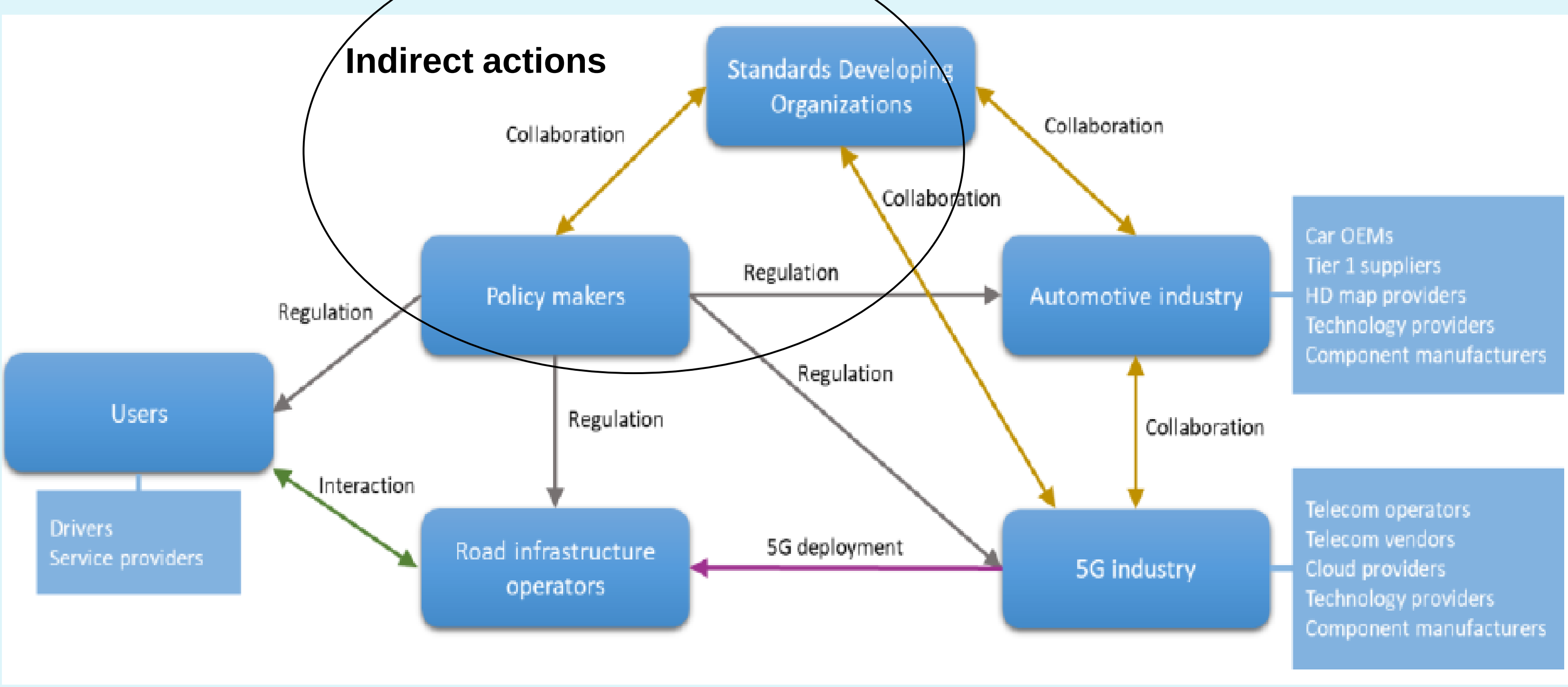
- V2X -802.11p supported a limited set of basic safety services
- 3GPP Rel.14: extended V2X :
  - low-bandwidth safety apps … to high-bandwidth apps
- **3GPP Rel. 15 and 16 →more V2X services**: longer range, higher density, very high throughput and reliability, highly precise positioning and ultra-low 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

4.1 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

4.2 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)**

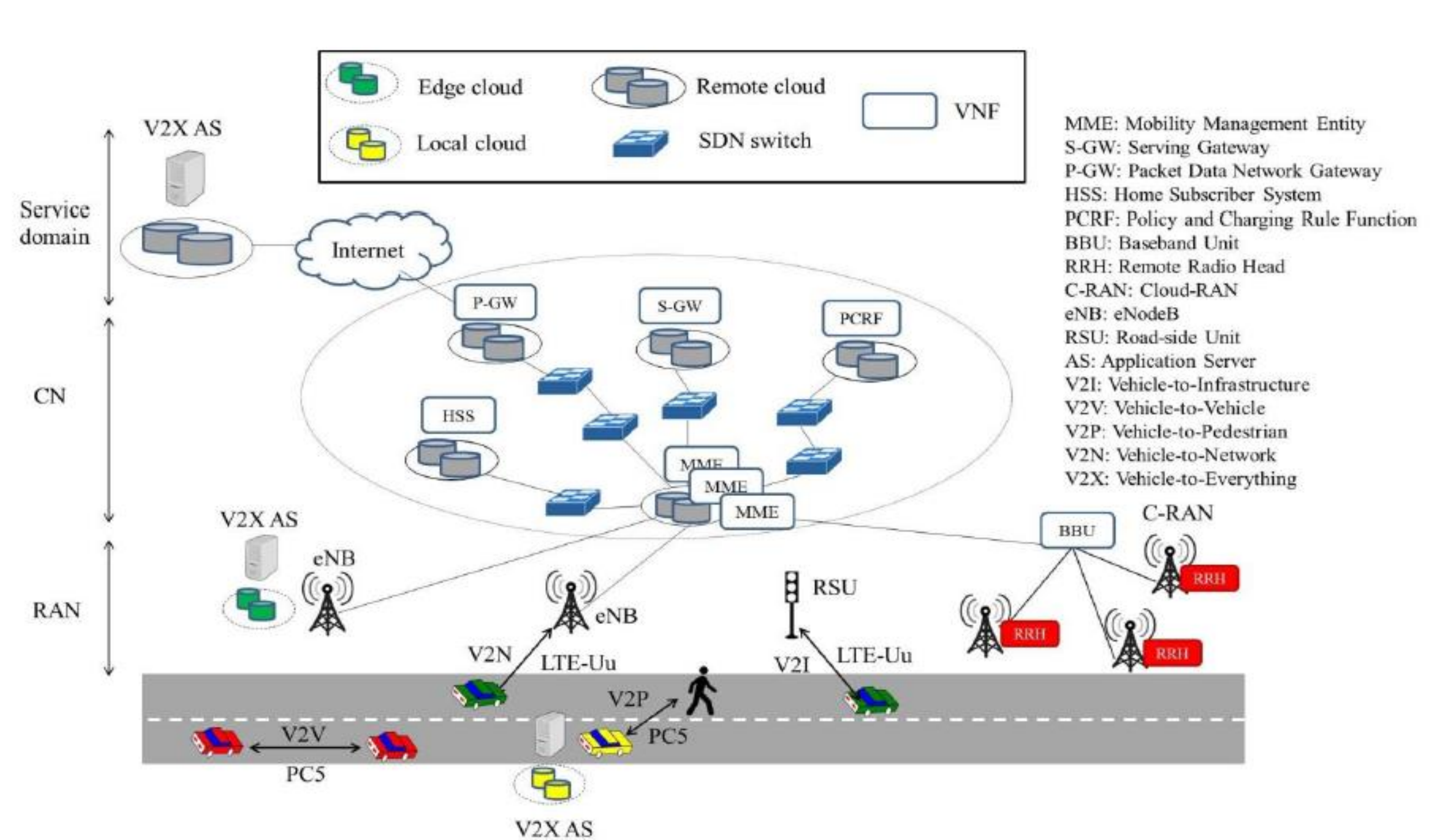
KEY ELEMENTS	DSRC/ IEEE 802.11	Rel 14 C-V2X	5G C-V2X (Rel 15,16) (expected)
Out-of-network operation	✓	✓	✓
Support for V2V	✓	✓	✓
Support for safety-critical uses	✓	✓	✗ *
Support for V2P	✓	✓	✓
Support for V2I	*limited*	✓	✓
Support for multimedia services	✗	✓	✓
Network coverage support	*limited*	✓	✓
Global 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

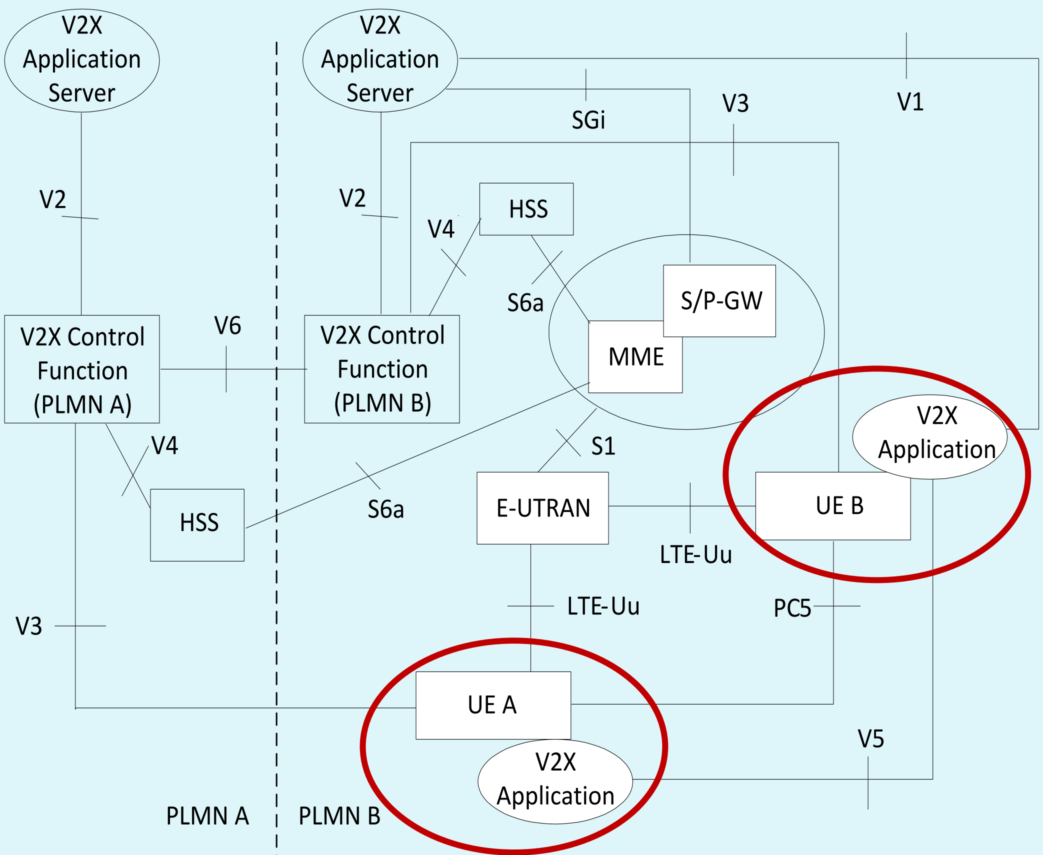
- network functional blocks are taken from 4G/LTE



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)**
  - **3GPP TS 23.285 V16.2.0 (2019-12) -** there is only one logical V2X CF in each PLMN that supports V2X Services
  - **V2X CFcapabilities**
    - provision the UE with necessary parameters in order to use V2X comm.
    - obtains V2X ***User Service Descriptions (*USDs)** for UEs to receive MBMS based V2X traffic, through V2 RP from the V2X Application Server.
    - obtains the parameters required for V2X communications over PC5 RP from the V2X Application Server via V2 RP
  - **Application Server (AS)**
  - V2X AS-es (e.g., in different domains) inter-exchange V2X messages
    - 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 CF the V2X USDs for UE (to allow receiving MBMS based V2X traffic); Provides the parameters for V2X communications over PC5 I/F

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); 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 mgmt. (MME and HSS).
    - low-latency and reliable video/data exchange : supported with a V2X AS, **deployed at the network edge**
  - **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).

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. V2X on 5G- system architectures and design

4.5 5G slicing for V2X (cont'd)

- Different V2X dedicated slicing solutions have been proposed (cont'd)

  - **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

4.6 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)
  - V2X –**design solution:** ***multiple MME instances*** (interconnected VNFs)
  - The **MME can be decomposed** having different MM functions co-located with the eNodeBs, (low-latency signaling)
  - The basic MM functions can intercommunicate with other CN functions (e.g authentication and authorization (AU), or with HSS) via SDN-controlled paths.
- **Evolved Multimedia Broadcast Multicast Service (eMBMS)**
  - **needed in autonomous driving slice, *on-the-fly-***activated to allow the dissemination of road safety information
  - The BM 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) 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
    - See 3GPP TR 23.785 V1.1.0, TSG Services and System Aspects; Study on Architecture Enhancements for LTE support of V2X services (Rel14), 2016

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**

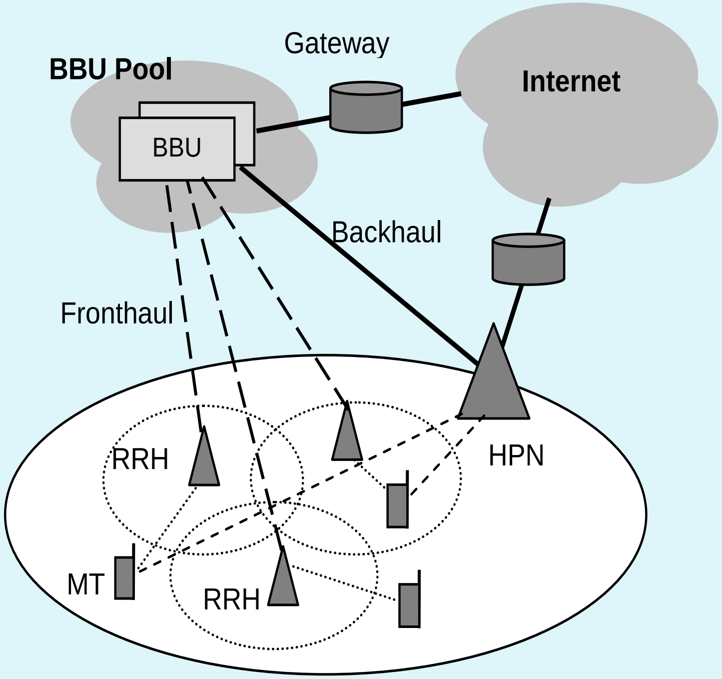
  - **H-CRAN Heterogeneous Cloud Radio Access Networks (**HetNet)
    - Solve heterogeneity and some CRAN drawbacks

    - **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 will integrate 3GPP (4G, 5G New Radio) and non-3GPP (e.g., 802.11) tech.
  - In the V2X context, cellular technologies provide nearly ubiquitous coverage,
    - 802.11 OCB (**O**utside the **C**ontext of a **B**SS), - 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, through usage of multiple RATs

- **Communication types and modes**
- The V2X slicing needs 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** for **local interactions** and **trigger PC5 →LTE-Uu I/F,** whenever mobility, time-varying density, geo conditions require
  - Usage of **unicast/ multicast/ broadcast modes**:
    - **Unicast** (reliable) - safety-critical applications,(e.g., platooning); for V2I and V2N uplink communications and for tele-operated driving in both directions.
    - **Multicast** - RSUs/eNBs can 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

4.8 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. V2X on 5G- system architectures and design

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**

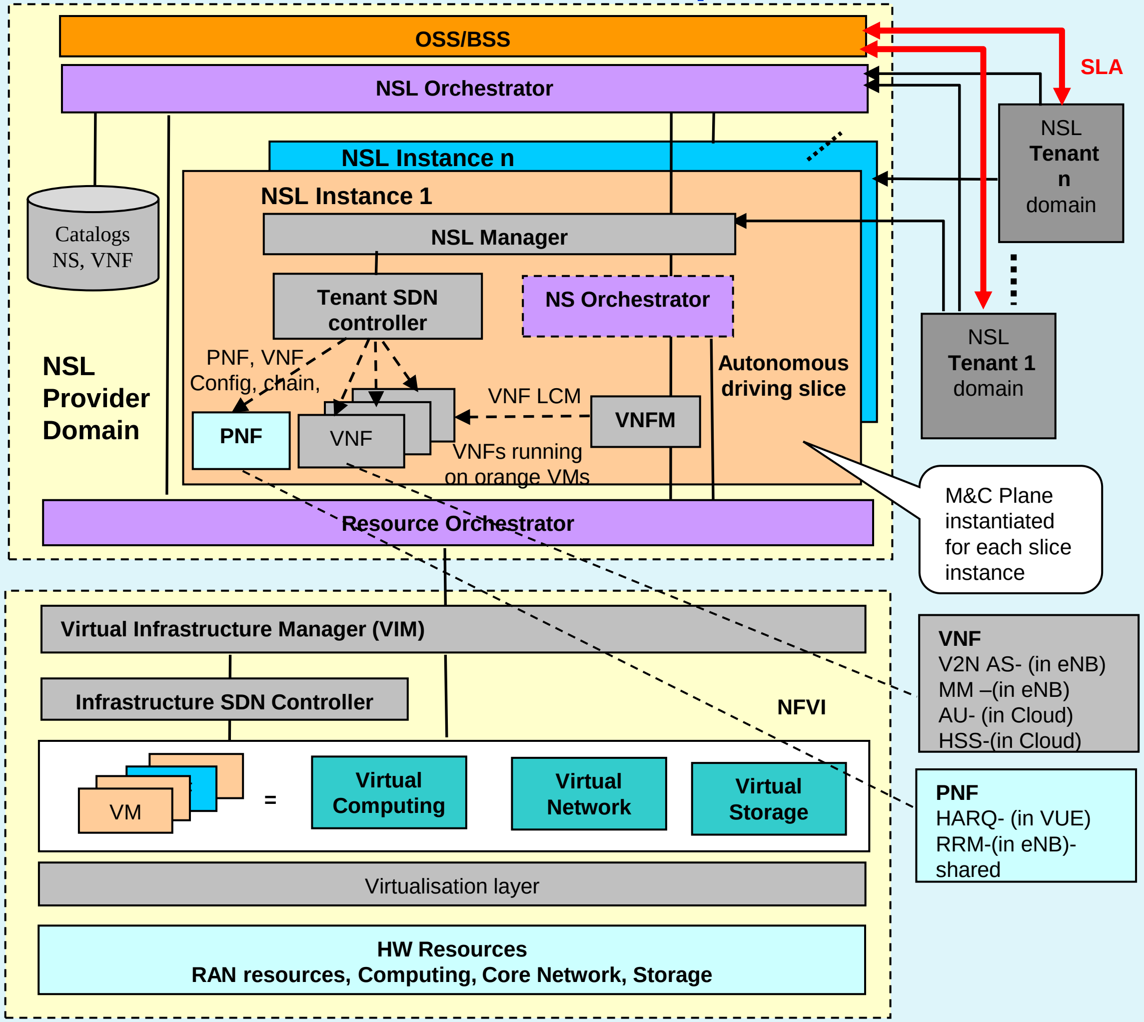
- **Scheduling types**
  - ***dynamic scheduling*,** based on each UE's buffer status and channel state information is appropriate for vehicular infotainment slice
  - ***semi-persistent scheduling*** - periodical allocation of resources (it means -no additional signaling) is indicated for traffic patterns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

4.9 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)

4.10 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

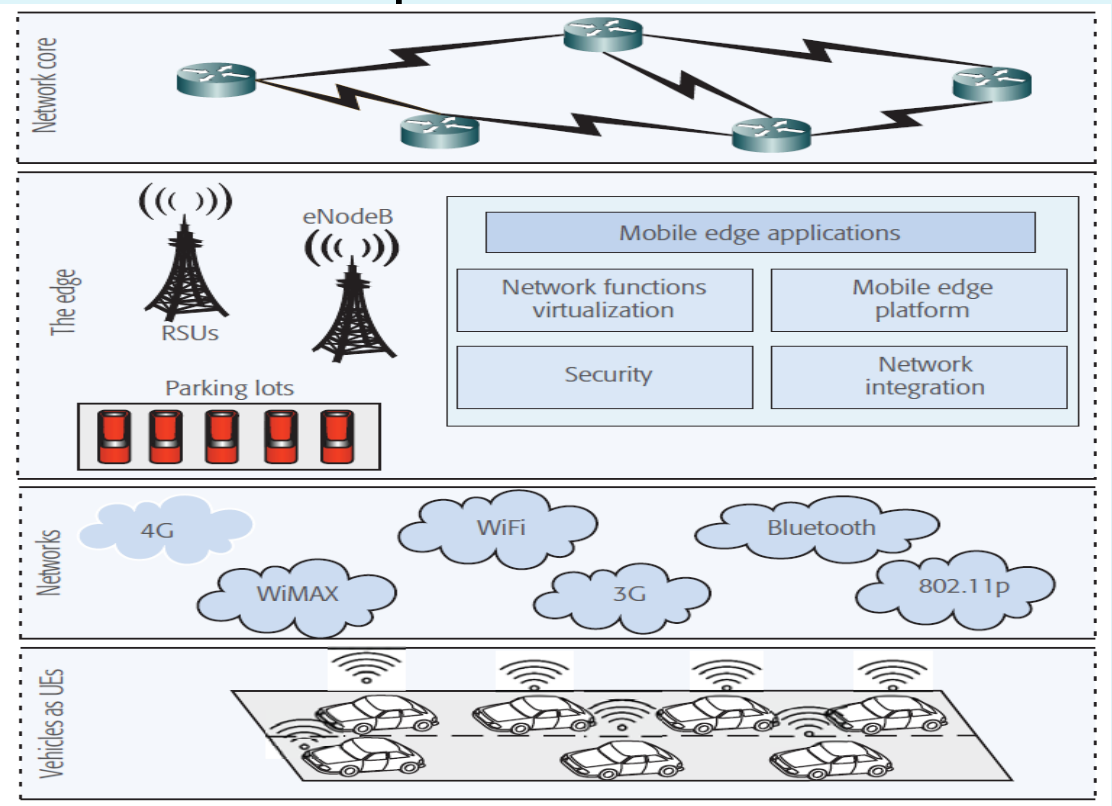
CONTENTS

1. Vehicle to everything (V2X) communications - introduction
2. 5G technology summary
3. Edge computing in 5G
4. V2X on 5G- system architectures and design
5. MEC support for V2X 5G systems
6. Conclusions

5. MEC support for V2X 5G systems

5.1 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

5. MEC support for V2X 5G systems

5.2 Examples of MEC support for V2X Use Cases

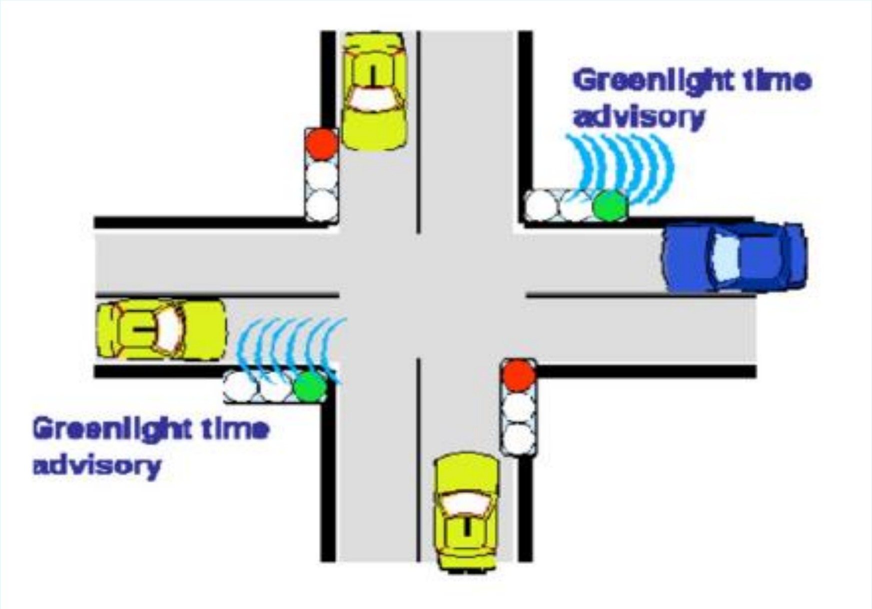
- **V2X use case group "safety“**
  - includes several different types of UCs to support road safety, using the V2I and V2V communication
  - **Intersection Movement Assist (IMA)**
    - IMA purpose: to warn drivers of vehicles approaching from a lateral direction at an intersection (to avoid intersection crossing crashes)
    - Intersection crashes events include: intersection-related, driveway/alley, and driveway access related crashes
  - **Queue Warning (QW)**
    - a queue of vehicles may pose a potential danger and cause delay of traffic, e.g., when a turning queue extends to other lanes
    - using the V2I service, the ***queue information can be made available to other drivers*** beforehand (to minimize the likelihood of crashes)

Source: ETSI GR MEC 022 V2.1.1 (2018-09), Multi-access Edge Computing (MEC);Study on MEC Support for V2X Use Cases

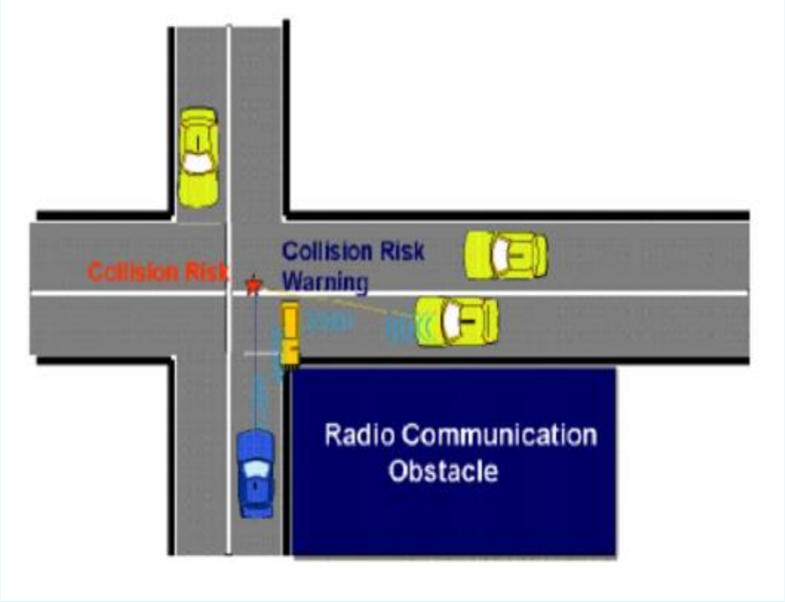
5. MEC support for V2X 5G systems

5.2 Examples of MEC support for V2X Use Cases

- **V2X use case group "safety"**



Example intersection collision warning



Example of intersection management

Source: ETSI GR MEC 022 V2.1.1 (2018-09), Multi-access Edge Computing (MEC);Study on MEC Support for V2X Use Cases

5. MEC support for V2X 5G systems

5.2 Examples of MEC support for V2X Use Cases

- **V2X use case group "safety"** (cont'd)
- **MEC system can provide services such as:**
  - ***network to the vehicle feedback information*****,** predicting whether a communication channel is currently reliable or not (latency, packet arrival rate)
  - ***multi-operator operation*** for V2X mobiles/users to provide service continuity across AN coverage nationwide and across borders of different operators' networks
  - interoperability:
    - ***V2X information exchange among road users*** connected through different access technologies or networks or mobile operators
    - in a multi-operator scenario
      - ***MEC apps*** in different systems can securely ***inter-communicate*** in order to enable synchronization also in absence of cellular coverage (i.e., outside of 3GPP domain)
      - ***MEC apps can securely communicate with the V2X-related 3GPP core*** network logical functions (e.g., V2X control function) and gathering PC5 V2X relevant information (e.g. PC5 I/F configuration parameters) from 3GPP network

5. MEC support for V2X 5G systems

5.2 Examples of MEC support for V2X Use Cases

- **V2X use case group "convenience"**
  - **software updates and other telematics** - which can technically be implemented with existing access technology and are partly already supported by car manufacturers
  - requires cost effective communication between the vehicles and the backend server (e.g., car OEM's server)
  - The MEC system can ***enable multi-operator operation for V2X*** mobiles/users to provide service continuity across AN nationwide and across borders of different operators' networks.
- **V2X use case group "advanced driving assistance“**
  - It can require distribution of a large amount of data with high reliability and low latency
  - use cases would benefit from predictive reliability (vehicles moving along could receive a prediction of the network availability to plan ahead
    - **Real Time Situational Awareness & High Definition (Local) Maps**
      - one should distribute and aggregate locally available information in real time to the traffic participants via road side units (RSU).
    - **See-Through (or High Definition Sensor Sharing)**
      - vehicles (trucks, minivans, cars in platoons) can share camera images of road conditions ahead of them to vehicles which are behind them

5. MEC support for V2X 5G systems

5.2 Examples of MEC support for V2X Use Cases

- **V2X use case group "convenience"** (cont'd)

- **MEC system can enable :**
  - support for ***locally aggregating the rt information*** from the connected nodes with very low latency
  - support for ***locally distributing rt information*** to the connected nodes with very low latency
    - examples of connected nodes are BSs in a mobile network or APs in a WLAN, which are connected to the MEC system
  - providing to the vehicle ***predictive and updated quality related information*** for connectivity parameters (like latency, PER, signal-strength …)
  - ***interoperability***, by supporting V2X information exchange among road users connected through different access technologies or networks or mobile operators
  - ***multi-operator operation*** for V2X mobiles/users to provide service continuity across AN coverage nationwide and across borders of different operators' networks

5. MEC support for V2X 5G systems

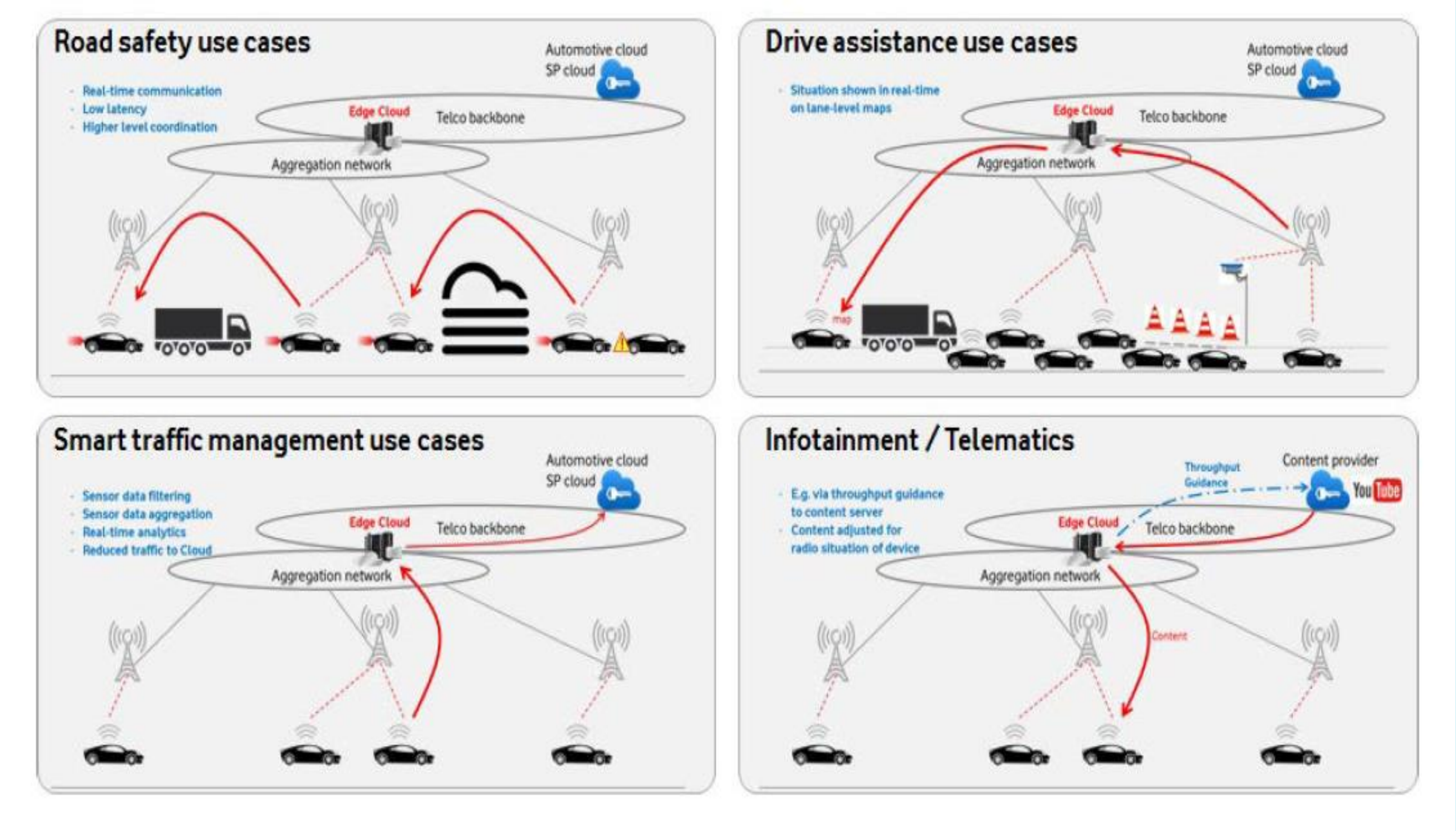
5.2 Examples of MEC support for V2X Use Cases

- **V2X use case group "vulnerable road user" (VRU)**
  - the (VRU) use case covers pedestrians and cyclists
  - requirement: accuracy of the positioning information provided by these traffic participants
  - additional means for better and reliable accuracy is important, to allow a real-world usage of information shared from VRUs
  - cooperation between vehicles and VRUs through their mobile devices (e.g. smartphone, tablets) is important, to improve traffic safety and to avoid accidents

  - **MEC system can provide services such as:**
    - support for ***timely accurate positioning*** assisted by available positioning technologies including radio network functions
    - ***interoperability*** by supporting V2X information exchange among road users
    - ***multi-operator operation*** for V2X mobiles/users to provide service continuity across AQN access network coverage nationwide and across borders of different operators' networks

5. MEC support for V2X 5G systems

5.2 Examples of MEC support for V2X 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.

5. MEC support for V2X 5G systems

5.3 MEC based solutions for V2X support

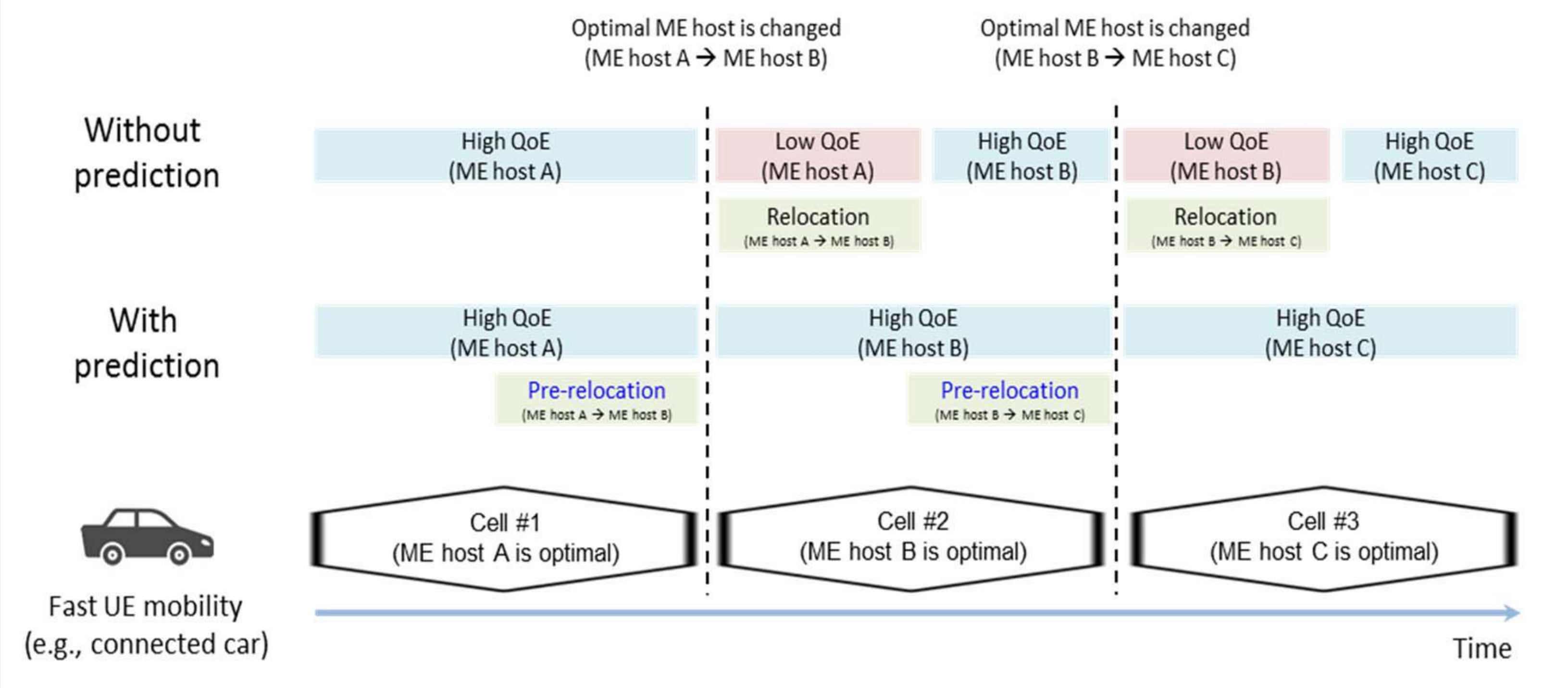
- **V2X Mobility and QoS/QoE support**
  - **Predictive QoS support**
    - ***Handover (HO)*** (between cells) ***prediction*** with the estimated QoS performance (e.g. latency, throughput, reliability) can help the vehicle UEs to select BS or MEC host
    - The transit time in each cell can be estimated by the assistance of the UE application (e.g. the in-car navigation system) or by a MEC based solution
    - The ***location service*** (LS) (e.g. based on the LS defined in ETSI GS MEC 013) may also support prediction of the HO timing by retrieving the location information of vehicle UEs and BSs
    - the estimated QoS performance of the available cells (e.g. based on the RNI service defined in ETSI GS MEC 012 can help with optimal BS and MEC host selection from QoE point of view

Adapted from source: ETSI GR MEC 022 V2.1.1 (2018-09), Multi-access Edge Computing (MEC);Study on MEC Support for V2X Use Cases

5. MEC support for V2X 5G systems

5.3 MEC based solutions for V2X support

- **V2X Mobility and QoS/QoE support** (cont'd)
  - **Pre-relocation of application state information**
  - App. state information to the target MEC host is completed before connecting to the MEC host
  - The MEC system enables the prediction of the HO timing and informs the MEC app. which then initiates state relocation to the optimal MEC host in advance



Source: ETSI GR MEC 022 V2.1.1 (2018-09), MEC;Study on MEC Support for V2X Use Cases

5. MEC support for V2X 5G systems

5.3 MEC based solutions for V2X support

- **V2X Mobility and QoS/QoE support** (cont'd)
  - **Predictive reliability for advanced automatic driving - use cases**
    - **Moving vehicles can receive a prediction of the network availability to plan ahead**
      - **Example 1:** For *High Definition Sensor Sharing* or *see-Through* it is required that a vehicle will know when the data-stream from the other_vehicle or the infrastructure, will be no more available
        - the vehicle can only start an overtaking manoeuvre when it is certain that the information will be available throughout this manoeuvre to be performed
      - **Example 2:** the vehicles enter a tunnel, or approach a jammed part of the city where connectivity is not available, or with a degraded set of parameters.
    - Knowing how the network will look like enable individual vehicles to configure their internal systems (buffers, sensors, etc.) in order to provide and receive information in the required quality

5. MEC support for V2X 5G systems

5.3 MEC based solutions for V2X support

- **Low latency communication support with multi-operator operation**

  - Cross-operator interoperability is critical for V2X apps. enabled in the edge cloud

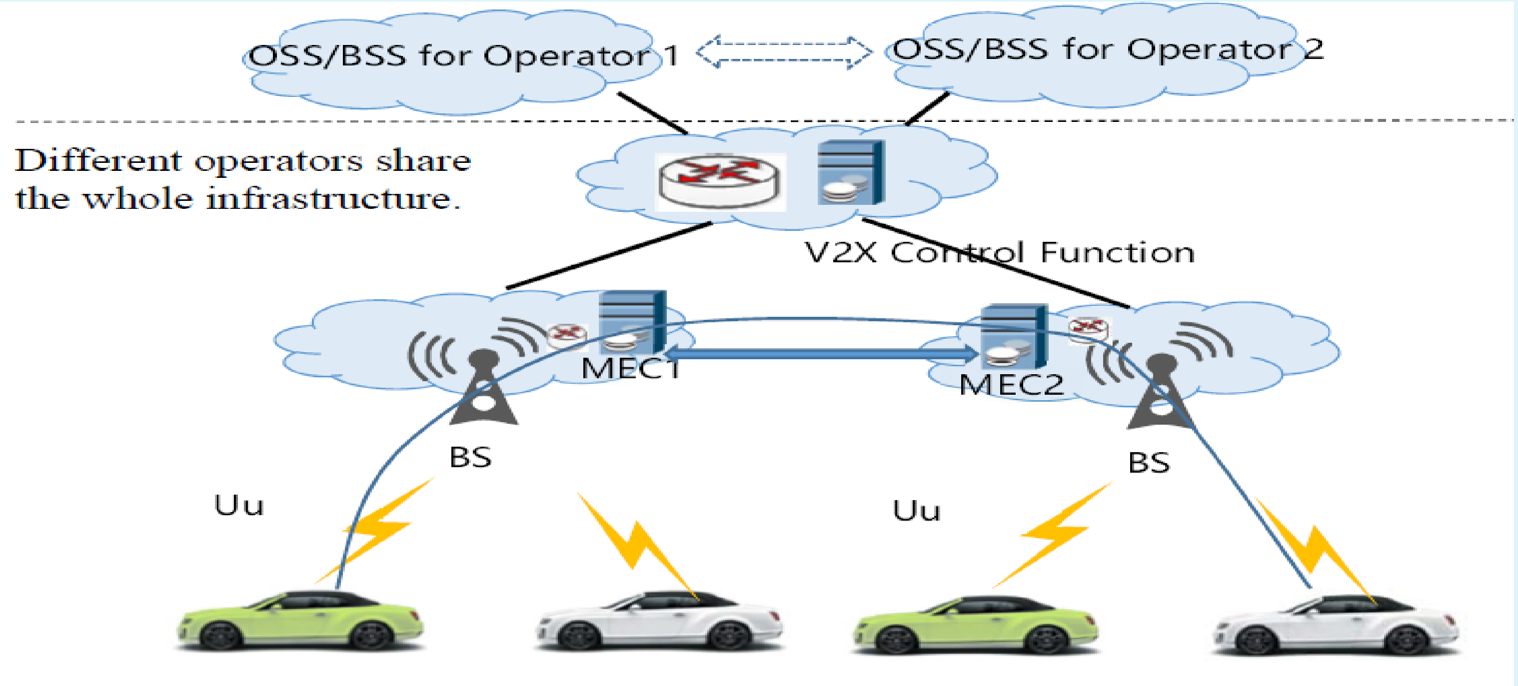
  - App. Providers (AP) need to develop, test, deploy and maintain their apps. based on standard processes and procedures applying to all MEC-enabled networks per country or region
  - Today: APs moves from one or few cloud instances on the Internet to numerous MEC-based instances per country per network operator; It is critical to avoid an excessive effort
  - The E2E latency between the vehicles is determined by the peering points location for data traffic, between the MO networks
  - Horizontal communication path between local peering points can reduce latency

  - **Solution 1: shared underlying network (see next slide)**
  - The underlying network can be s shared between operators (e.g. RAN sharing)
  - The MEC system should also be shared as a part of the unified infrastructure.

5. MEC support for V2X 5G systems

5.3 MEC based solutions for V2X support

- **Low latency communication support with multi-operator operation** (cont'd)
- **Solution 1: shared underlying network (see next slide)**
  - The horizontal (H) communication path between local peering points can lower the latency transmission (due to direct links between the two MEC hosts)
  - Business problem: coordination between operators (e.g., multiple OSSs coordination to the shared orchestrator, etc.)



Source: ETSI GR MEC 022 V2.1.1 (2018-09), MEC;Study on MEC Support for V2X Use Cases

5. MEC support for V2X 5G systems

5.3 MEC based solutions for V2X support

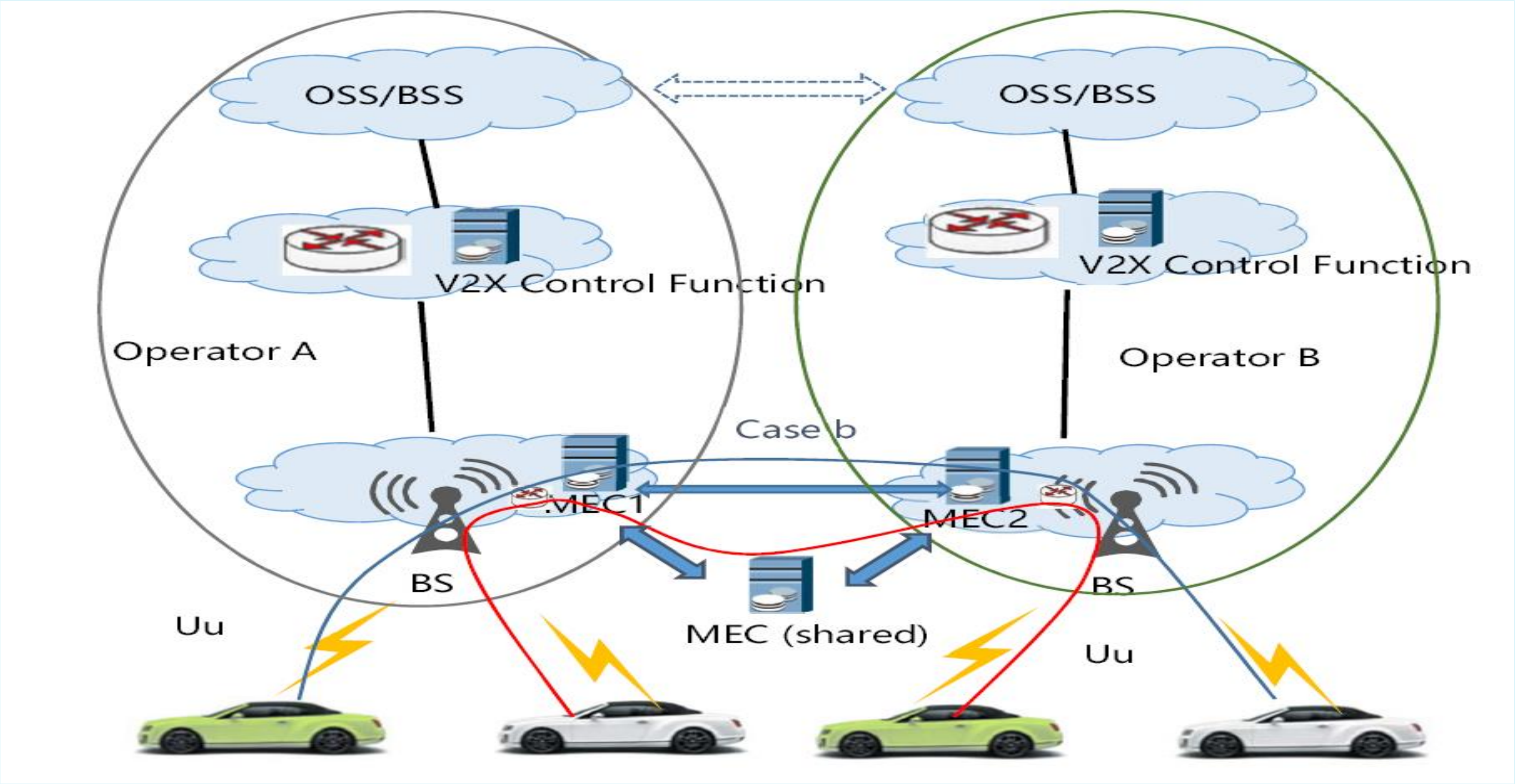
- **Low latency communication support with multi-operator operation** (cont'd)
- **Solution 2: independent underlying network**
  - The underlying networks are independently operated by different operators
  - The MEC system
    - can be shared by the involved operators
    - or offered by a 3rd party,
    - or the MEC systems are run independently by each operator
  - **Key requirement: a coordinated V2X service,** while it could still be run in different operators' MEC systems
  - A direct comm. between the peering points is needed →low latency for V2X services,
    - This is different with the traditional transport network layer arrangements between different PLMNs
  - **Two subcases:**
    - the MEC system is shared by the operators, requiring low latency communication with both underlying networks;
    - the adjacent MEC hosts belong to different operators, requiring the low latency communication path between the peer points.
  - The cases require the coordination between the involved operators in both network planning and especially transport network planning.

Adapted from source: ETSI GR MEC 022 V2.1.1 (2018-09), Multi-access Edge Computing (MEC);Study on MEC Support for V2X Use Cases

5. MEC support for V2X 5G systems

5.3 MEC based solutions for V2X support

- **Low latency communication support with multi-operator operation** (cont'd)
- **Solution 2: independent underlying network**



Adapted from source: ETSI GR MEC 022 V2.1.1 (2018-09), Multi-access Edge Computing (MEC);Study on MEC Support for V2X Use Cases

5. MEC support for V2X 5G systems

5.3 MEC based solutions for V2X support

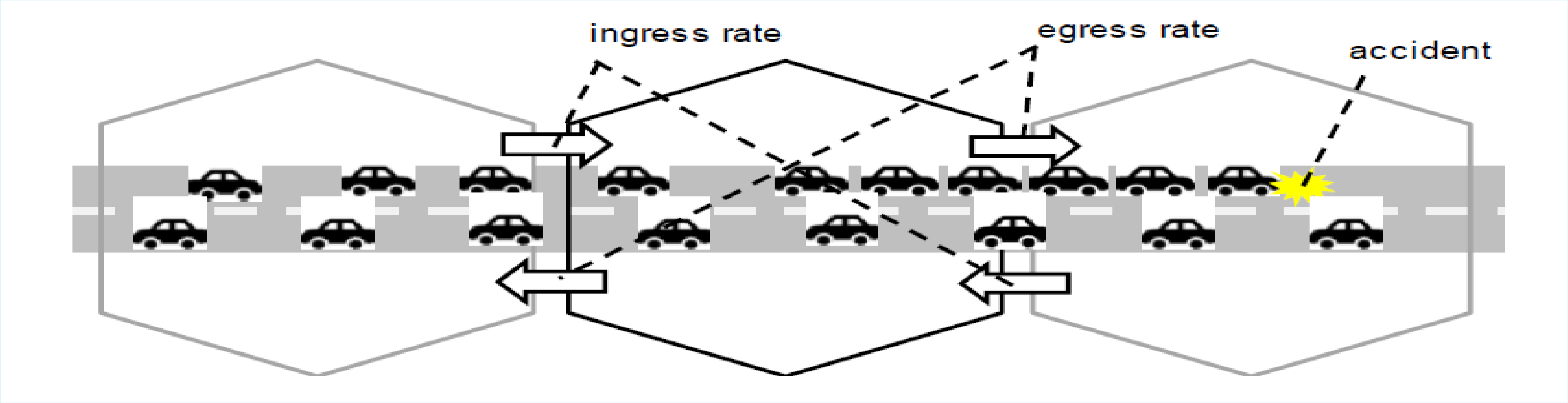
- **Communication traffic coordination with vehicles**
  - Connected vehicles generate various data (w. different requirements) and upload them through the radio network in order to provide V2X services
  - Some communications are rt and need high reliability.
  - The vehicle transportation traffic congestion may give rise to radio network (RN) congestion(e.g., LTE uplinks)
  - Need to harmonise vehicles with MEC system for controlling RN congestion especially in uplink.

  - **Solution 1: provide to vehicles information on communication traffic congestion**
-
    - The MEC system can predictively recognize the RN congestion based on vehicle transitions and then notify it to the vehicle → the transmission of non-rt information can pause
    - RN congestion is in proportion to the number of vehicles, which is correlated by MEC Radio Network Information (RNI) services
    - The estimation of the number of vehicles connecting to a BS helps to predict RN congestion (see figure on next slide)

5. MEC support for V2X 5G systems

5.3 MEC based solutions for V2X support

- **Communication traffic coordination with vehicles** (cont'd)
- **Example of the estimation of transportation mapping to radio cell**
  - The ingress/egress rate of vehicle transitions from/to the adjacent radio cell may be calculated by the MEC services specified in ETSI GS MEC 012 "MEC Radio Network Information API" and ETSI GS MEC 013: "MEC Location API“
  - It also depends on the road structure, and then the estimation accuracy is improved if MEC system can associate road structure with radio cell area
  - The rates are used for predicting the number of vehicles in the next time slot, (e.g., by Markov chain model)
  - Note: a vehicle accident may cause transportation traffic congestion, increasing the number of vehicles in radio cell where the accident occurs, and in turn propagates to the linked cells

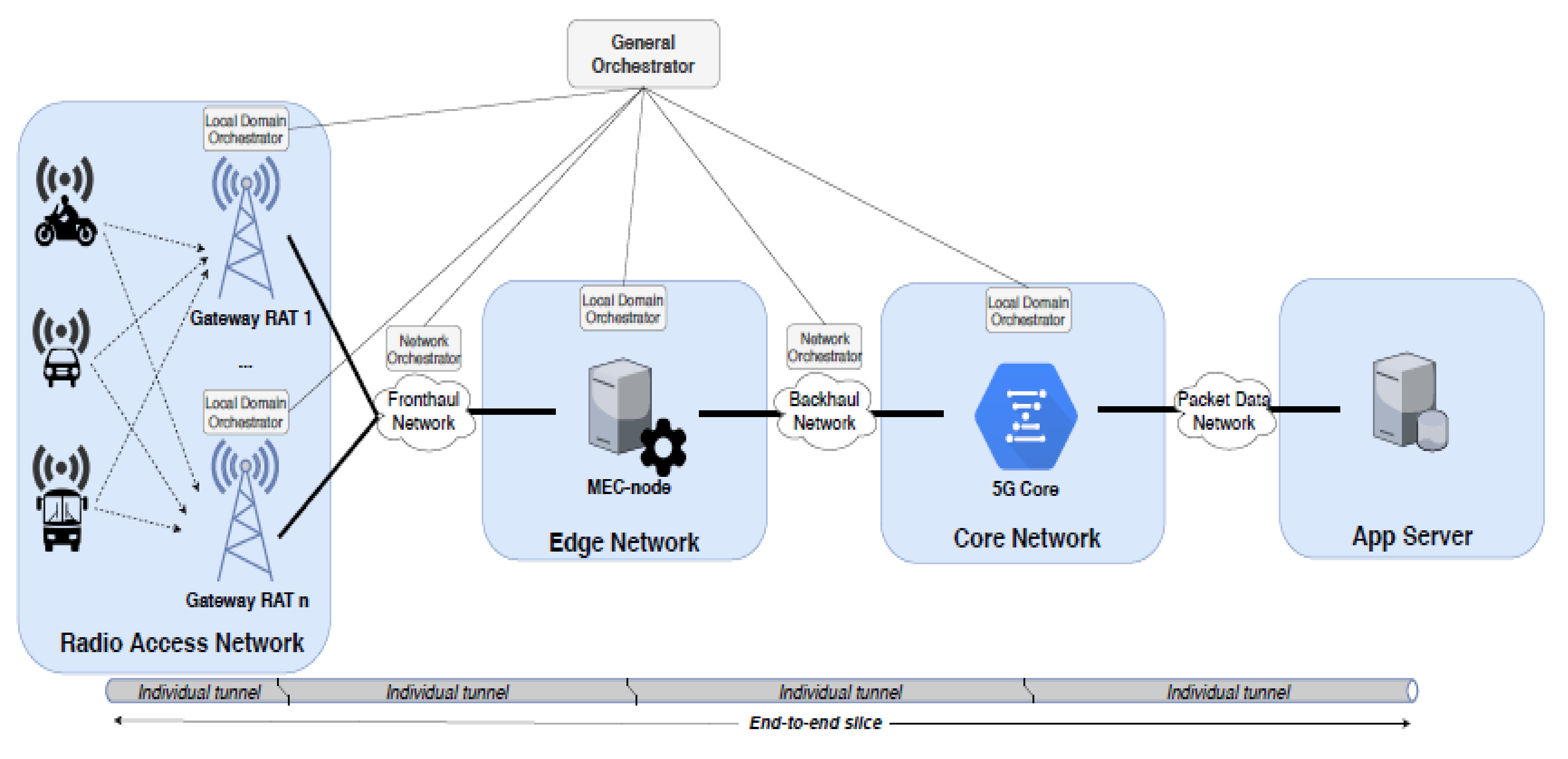


Adapted from source: ETSI GR MEC 022 V2.1.1 (2018-09), Study on MEC Support for V2X Use Cases

5. MEC support for V2X 5G systems

5.3 MEC based solutions for V2X support

- **Example of a multi-RAT end- to end slice with embedded MEC services**

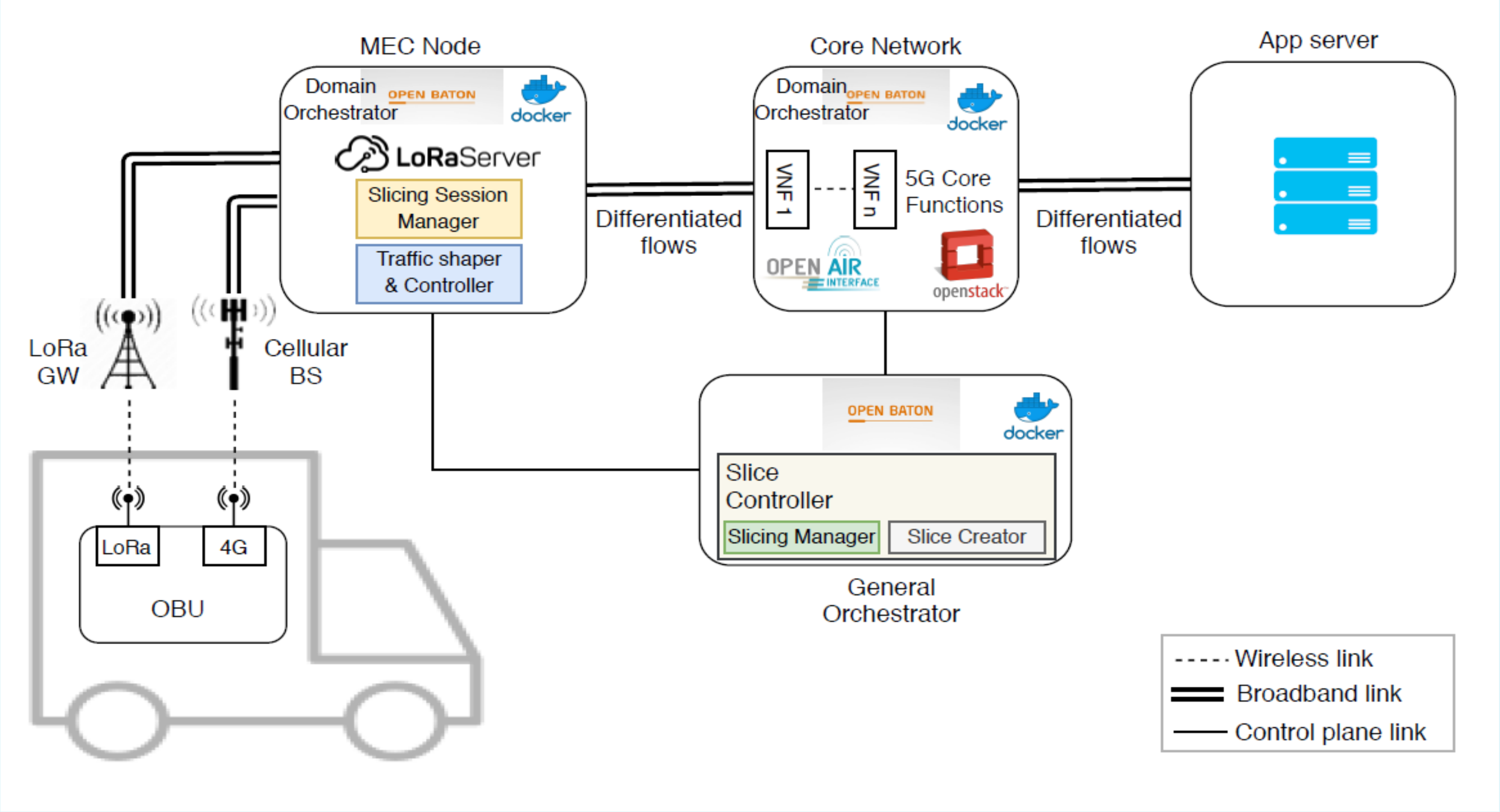


Source: Ramon Sanchez-Iborra et.al., "Empowering the Internet of Vehicles with Multi-RAT 5G Network Slicing", https://www.ncbi.nlm.nih.gov/pubmed/31337087

5. MEC support for V2X 5G systems

5.3 MEC based solutions for V2X support

- **Example of a multi-RAT end- to end slice with embedded MEC services** (cont'd)



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

5. MEC support for V2X 5G systems

5.4 V2X Information Services (VIS)

- **Reference scenarios for the VIS service**

- **ETSI: Multi-X** (X=access, network ,operator) scenarios are the reference assumptions motivating the need for MEC normative work on this area (Figure)

- **Case 1.** V2X services can be
  - managed by **OEMs ("Vehicle OEMs scenario")-** in single and multi-operator scenarios
  - provided by different Nos in the same country and/or in different countries

- **Case 2.** "ITS Operator scenario" may also provide services for different vehicle OEMs.
  - country-wide V2X service, by exploiting different operators' networks (deploying different MEC systems), and offering this service to vehicles belonging to different OEMs.
  - V2X services can be provided by different NOs in the same country and/or in different countries.

Source: ETSI GS MEC 030 V2.1.1 (2020-04), (MEC), V2X Information Service API

5. MEC support for V2X 5G systems

5.4 V2X Information Services (VIS)

- **Reference scenarios for the VIS service** (cont'd)
- **ETSI: Multi-X** (X=access, network ,operator) scenarios are the reference assumptions motivating the need for MEC normative work on this area (Figure)

- MEC VIS) should support C-V2X systems implemented in the most general scenarios
-
  - one may have multiple MEC vendors and the need to enable interoperable data exchange between them
  - multi-operator interoperability is a key aspect for ensuring service continuity.

Vehicle OEM scenario, single MNO
Vehicle OEM scenario, multiple MNO

ITS operator, single MNO	ITS operator, single OEM, single MNO
ITS operator, multiple MNO	ITS operator, multiple OEM, multiple MNO

Source: ETSI GS MEC 030 V2.1.1 (2020-04), (MEC), V2X Information Service API

5. MEC support for V2X 5G systems

5.4 V2X Information Services (VIS)

- **MEC VIS functionalities**
  - **Gathering of PC5 V2X** relevant information from the 3GPP network (e.g. the list of authorized UEs, the information about the authorization based on the UE subscription and the relevant PC5 configuration parameters)
  - **Exposure of this information to MEC apps** (also potentially belonging to different MEC systems)
  - **Enable the MEC apps to communicate securely** with the V2X-related 3GPP core network logical functions (e.g. V2X control function)
  - **Enable the MEC apps in different MEC systems to inter-communicate securely**
  - Possibly **gathering and processing information available in other MEC APIs** (e.g. RNI API (see ETSI GS MEC 012) Location API (see ETSI GS MEC 013), WLAN API (see ETSI GS MEC 028), etc. in order to predict radio network congestion and provide suitable notifications to the UE

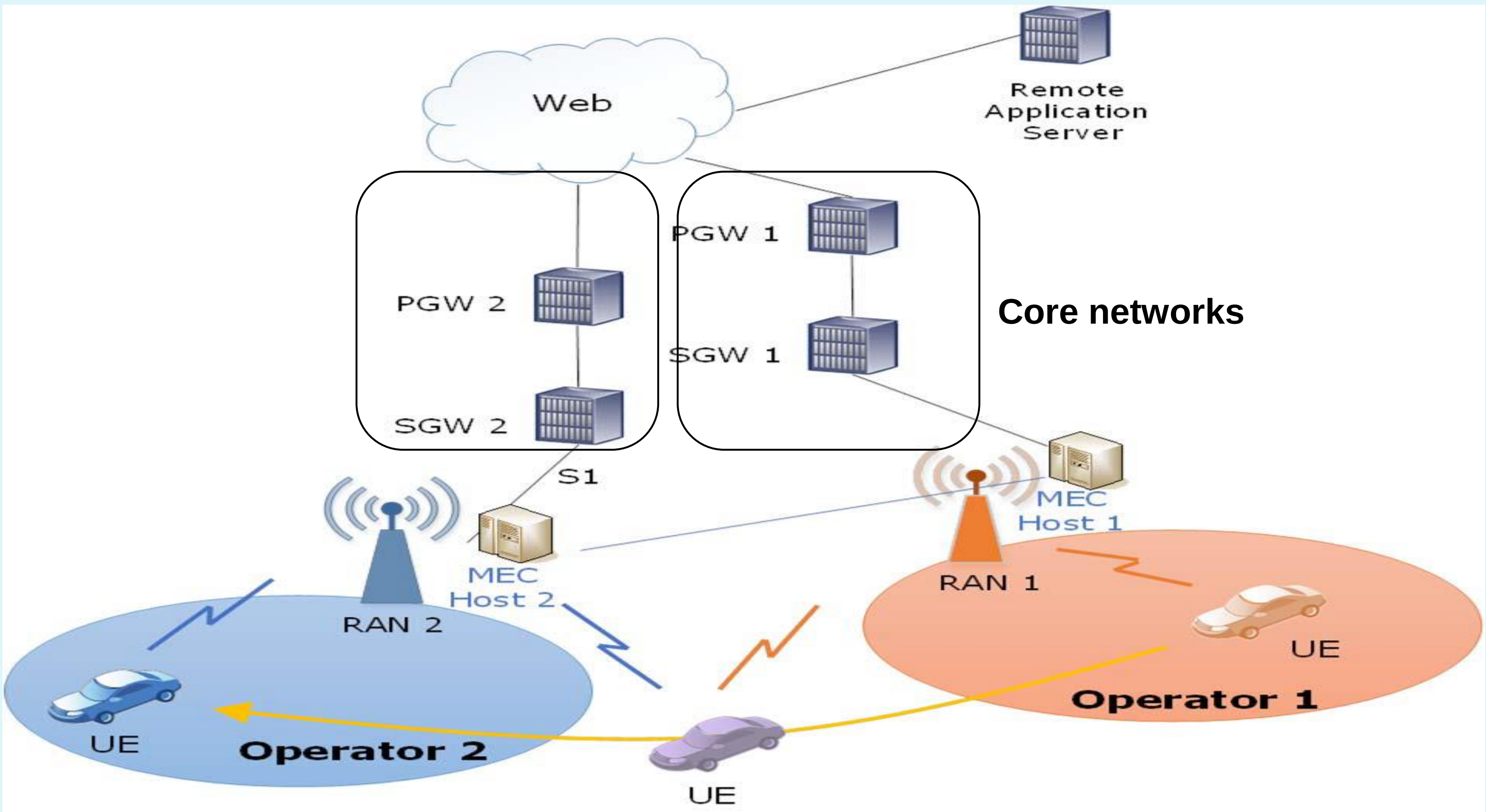
  - **The VIS API provides information to MEC applications in a standardized way**
    - this is essential for interoperability in multi-vendor scenarios
    - however, MEC applications may communicate in a direct way (i.e. without the use of MEC platform)

Source: ETSI GS MEC 030 V2.1.1 (2020-04), (MEC), V2X Information Service API

5. MEC support for V2X 5G systems

5.4 V2X Information Services (VIS)

- **Example of a multi-operator scenario for V2X services**

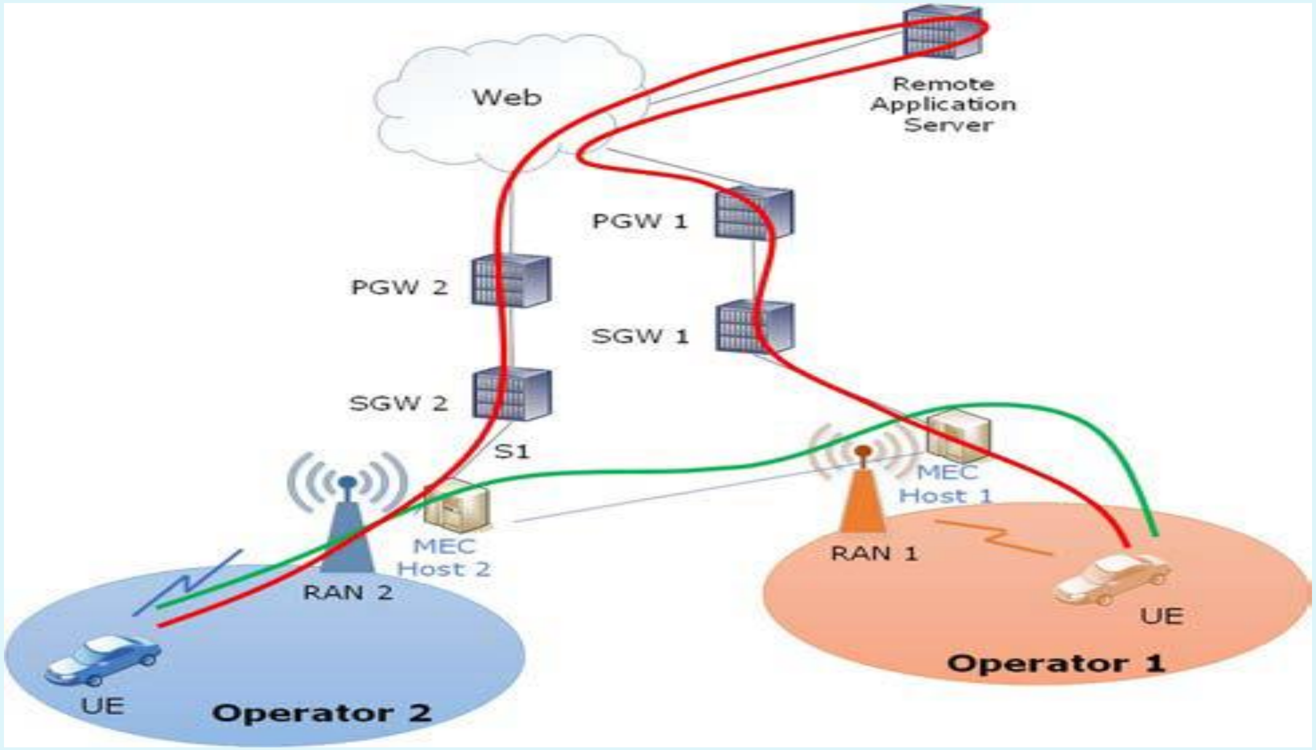


Adapted from Source: ETSI GS MEC 030 V2.1.1 (2020-04), (MEC), V2X Information Service API

5. MEC support for V2X 5G systems

5.4 V2X Information Services (VIS) (cont'd)

- in a traditional V2X system (no VIS service) the interconnection between MNOs is terminated at the remote side; high E2E latency (red line)
- VIS service achieves lower E2E latency (due to a "H communication")
- VIS exposes information on PC5 configuration parameters and manages the multi-operator environment, especially when a UE is out of coverage

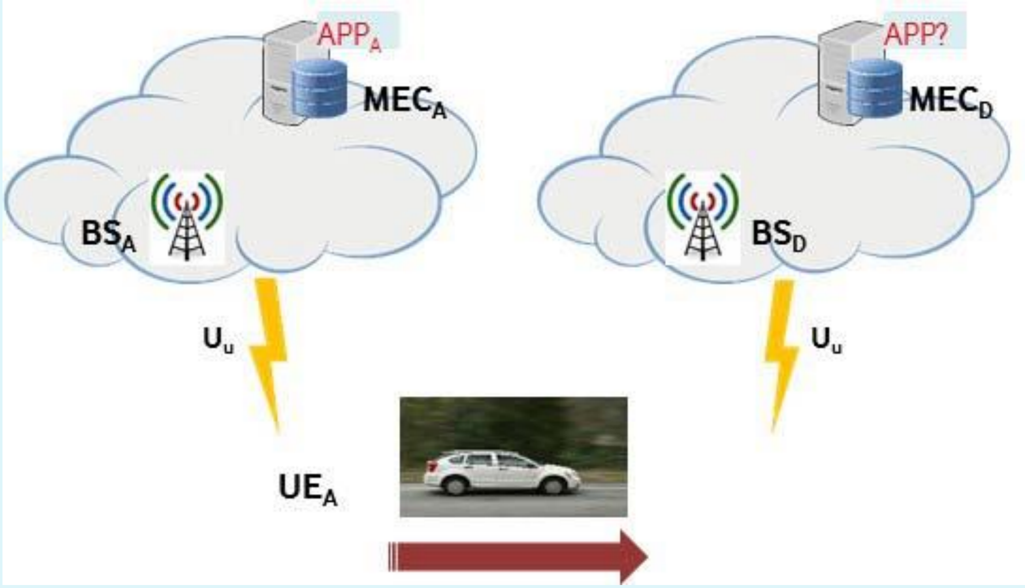


Source: ETSI GS MEC 030 V2.1.1 (2020-04), (MEC), V2X Information Service API

5. MEC support for V2X 5G systems

5.4 V2X Information Services (VIS)

- **V2X service continuity in multi-operator operation scenarios**
  - To maintain the V2X service continuity (with low latency requirement) is a challenge when the road users (e.g. vehicular UEs) are roaming among PLMNs
  - inter-MEC system coordination is required to prepare in advance the UEs in transit and thus reduce the interruption time
    - based on the agreements among operators, roam or HO to a new PLMN

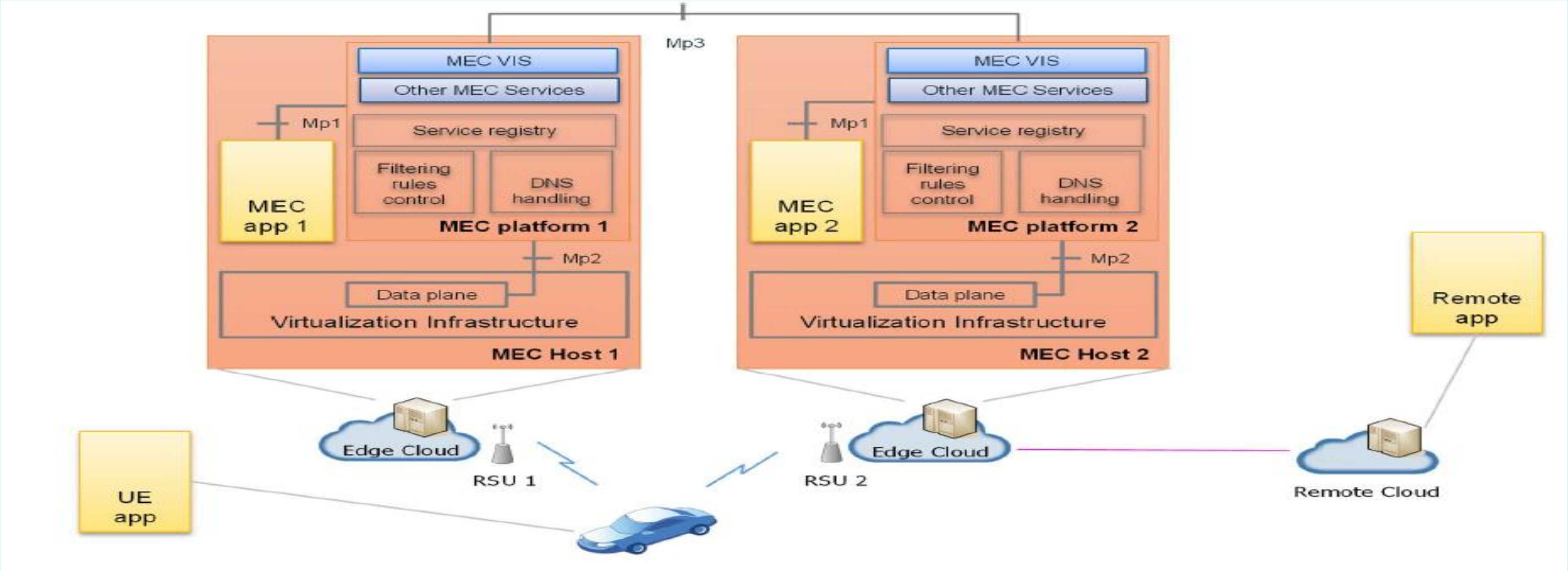


Source: ETSI GS MEC 030 V2.1.1 (2020-04), (MEC), V2X Information Service API

5. MEC support for V2X 5G systems

5.4 V2X Information Services (VIS)

- **Example of application instances in a V2X service with VIS API**
  - Typical V2X system involving multiple MEC hosts and the use of the VIS service.
  - A car is hosting a client app., and is connected to a certain MEC host
  - In multiple MEC hosts context, the VIS permits to expose information between MEC apps. running on different MEC hosts
  - other remote app. server instances can be located somewhere else (e.g. private clouds owned by the operator or by the OEM)
  - The VIS service may be produced by the MEC platform or by the MEC application



Source: ETSI GS MEC 030 V2.1.1 (2020-04), (MEC), V2X Information Service API

5. MEC support for V2X 5G systems

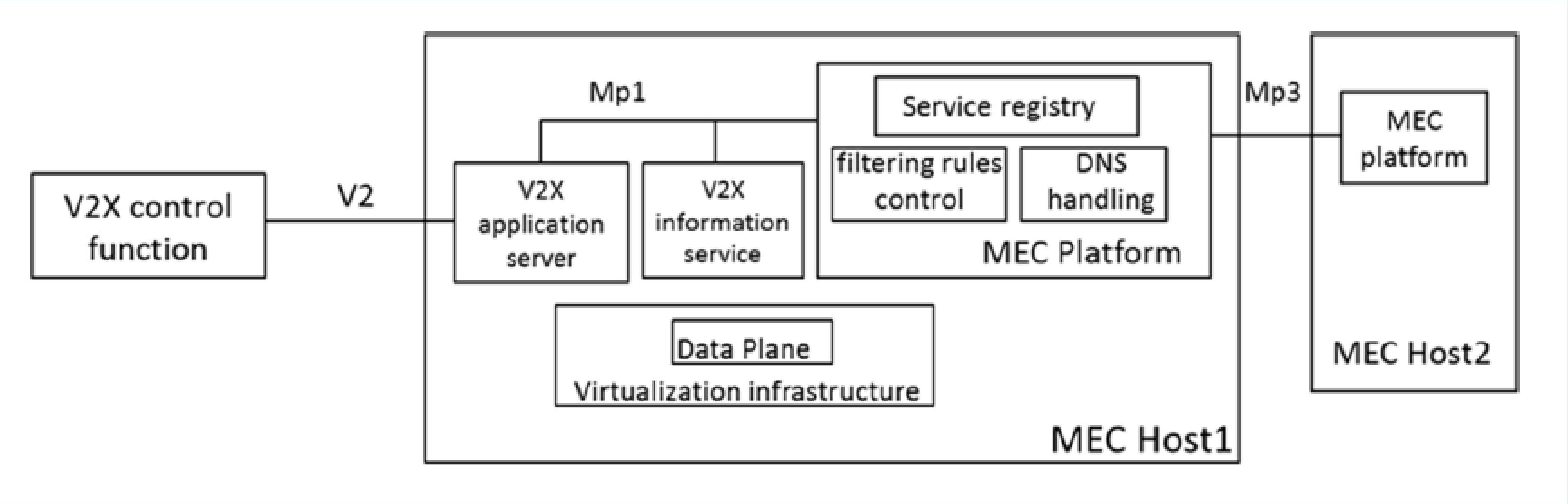
5.4 V2X Information Services (VIS)

- **Example of architecture enabling the communication between the VIS and the V2X Control Function**
  - In a 3GPP network, **V2X applications can be deployed on V2X Application Server**
  - The ***V2X Control Function*** is the NF in core network part, used for V2X network-related actions
  - The **HSS provides the list of the PLMNs,** where the UE is authorized to perform V2X communication over PC5 reference point (RP_ to the V2X Control Function, (ETSI TS 123 285)
  - **V2 is the RP between the V2X Application Server and the V2X Control Function** in the operator's network.
  - The **MEC VIS supports V2X interoperability** in a multi-vendor, multi-network and multi-access environment
    - Therefore, the VIS should obtain the UE's subscription data (e.g. PC5 based V2X communication allowed PLMN), from the V2X Control Function.

5. MEC support for V2X 5G systems

5.4 V2X Information Services (VIS)

- **Example of architecture enabling the communication between the VIS and the V2X Control Function** (cont'd)
  - The V2X Application Server bears multiple V2X apps; it can, therefore, be deployed in MEC platform as an app.
  - The VIS can communicate with the V2X Application Server through Mp1, and it can obtain the UE's V2X subscription data from the V2X Control Function through the V2X Application Server



Source: ETSI GS MEC 030 V2.1.1 (2020-04), (MEC), V2X Information Service API

5. MEC support for V2X 5G systems

5.5 V2X oriented projects - examples

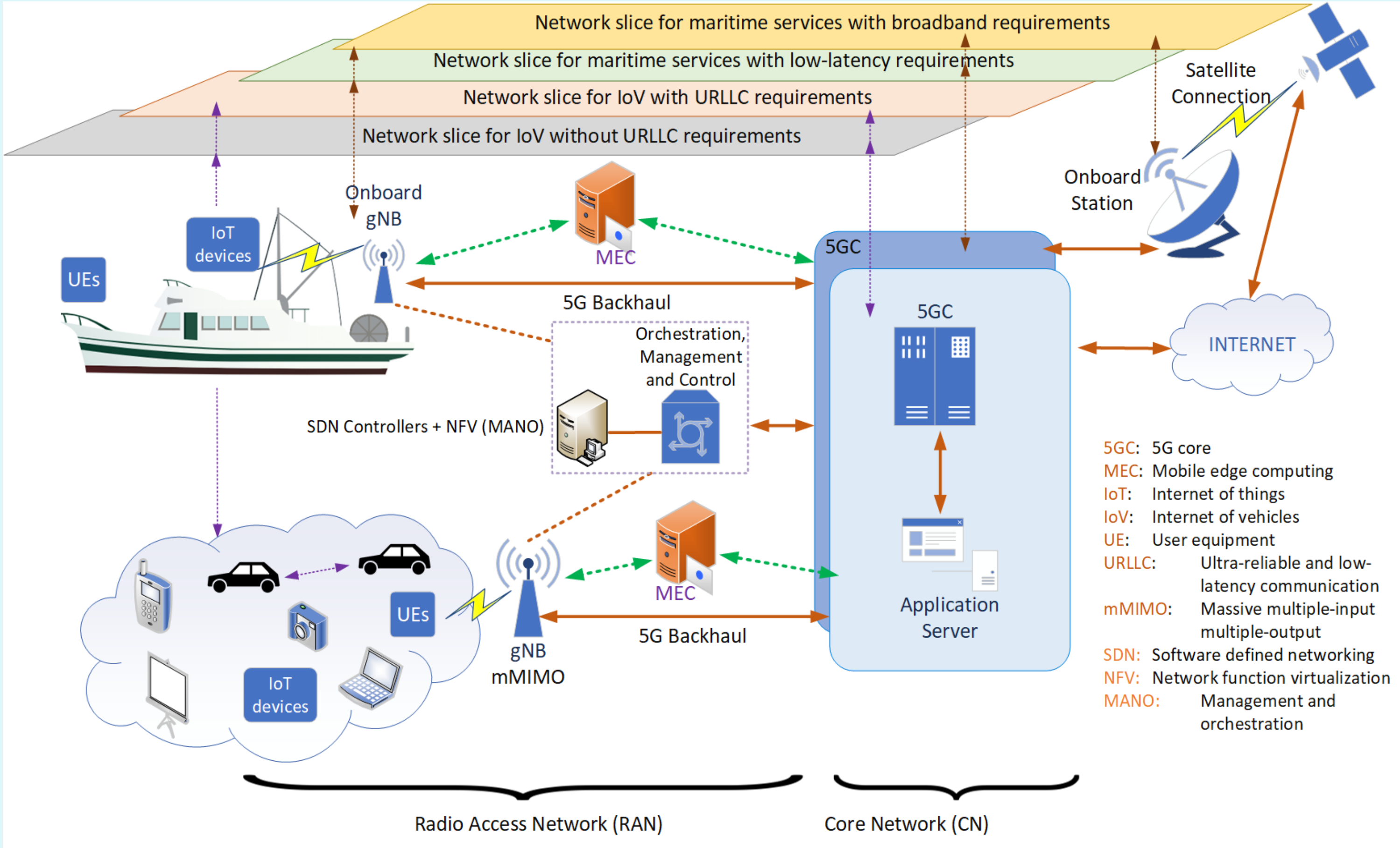
- **"A Massive MIMO Enabled IoT Platform with Networking Slicing for Beyond 5G IoV/V2X and Maritime Services" – (2021-2023), https://solid-b5g.upb.ro/**
- **Partners:**
  - CO – University "Politehnica" of Bucharest, Romania (UPB)
  - P1 – Beia Consult International SRL, Romania (BEIA)
  - P2 – Beam Innovation SRL, Romania (BEAM)
  - P3 – Universitetet i Agder, Norway (UiA)
  - P4 – Telenor Maritime AS, Norway (TM)
  - P5 – Universitat Politècnica de València, Spain (UPV)
  - P6 – Memorial University of Newfoundland, Canada (MUN)

- **Main objectives**
  - **O1**: To develop ultra-low latency massive MIMO based concurrent transmission mechanisms for data collection in massive IoT
  - **O2**: To develop advanced **B5G slicing methods, algorithms, and protocols** with a focus on **Orchestration Management and Control (OMC) of resources and dedicated services for IoV/V2X and maritime services**
  - **O3**: To develop decentralized decision-making mechanisms by introducing data processing capacity and **intelligence to the edge (based on Multi-access (Mobile) Edge Computing (MEC) and machine learning (ML)-to-the-edge**)
  - **O4**: To implement a proof-of-concept *standalone* B5G testbed to demonstrate the orchestration of RAN and CN based **on 5G network slicing and MEC procedures.** Two main use cases, i.e., IoV/V2X and satellite based maritime low-latency services will be considered in the project.

5. MEC support for V2X 5G systems

5.5 V2X oriented projects - examples

- **"A Massive MIMO Enabled IoT Platform with Networking Slicing for Beyond 5G IoV/V2X and Maritime Services" – (2021-2023),** (cont'd)
  - **General architecture**



5. MEC support for V2X 5G systems

5.5 V2X oriented projects - examples

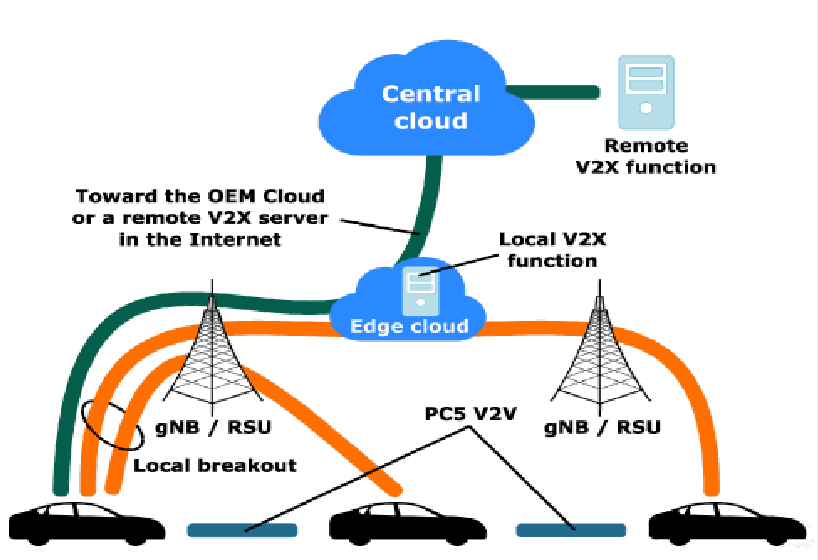
- **5GCAR: Fifth Generation Communication Automotive Research and innovation**
  H2020-ICT-2016-2, 2017-2019, https://5g-ppp.eu/5gcar/, https://5gcar.eu
- **Main objectives**
  - Develop an overall **5G system architecture;** optimized **E2E V2X network connectivity** for highly reliable and low-latency 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. MEC support for 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/

CONTENTS

1. Vehicle to everything (V2X) communications - introduction
2. 5G technology summary
3. Edge computing in 5G
4. V2X on 5G- system architectures and design
5. MEC support for V2X 5G systems
6. Conclusions

6. Conclusions

- **The MEC technology offers powrful features to support V2X/Iov systems**

- **MEC features for V2X/IoV**
  - integrates the Internet and the wireless network
  - adds the functions of computing, storage, and processing in the wireless network close to vehiclesappropriate solution for V2X/IoV communications, applications and services
  - open platform for applications and opens the information interaction between wireless networks
  - reduce the communication delay and creates a strong support for low V2X latency services
  - upgrades the traditional BS to an intelligent BS base station
  - help the road information be rapidly transmitted to the data platform which controls the traffic and implements V2X communication applications
  - in cellular V2X architectures, MEC, SDN and NFV technologies will cooperate inside 5G systems

6. Conclusions

- **The MEC technology offers powerful features to support V2X/Iov systems**

- **MEC features for V2X/IoV**
  - can be embedded in 5G V2X oriented slices
  - provides flexibility for the dynamic placement of the VNFs in charge of managing network traffic
  - can provide solutions for cooperative autonomous driving in 5G-V2X systems
  - can cooperate with Machine Learning techniques for enhanced management (e.g. to solve the resource allocation problem in MEC enabled IoV network based on network slicing)

- **Open research issues**
  - MEC for V2X/IoV is still an emergent technology
  - Many aspects related to dynamicity in mobile context, resource allocation, multi-domain issues, security, reliability and scalability are still to studied more

- Thank you !
- Questions?

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Edge Computing Support for V2X Communications on 5G Technology

- **List of Acronyms**

1G	First Generation of Mobile Networks
2G	Second Generation of Mobile Networks
3G	Third Generation of Mobile Networks
4G	Fourth Generation of Mobile Networks
5G	Fifth Generation of Mobile Networks
3GPP	3rd Generation Partnership Project
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
API	Application Programming Interface
AR	Augmented Reality
AS	Access Stratum
AUSF	Authentication Server Function
BBU	Baseband Unit
BS	Base Station
BSF	Binding Support Function
CA	Certificate Authority
CaaS	Cooperation as a Service
CDMA	Code Devision Multiple Access

Edge Computing Support for V2X Communications on 5G Technology

- **List of Acronyms**

CC	Cloud Computing
CP	Control Plane
CRAN	Cloud based Radio Access Network
D2D	Device to Device
DC	Data Center
DLK	Downlink
DL	Deep Learning
DN	Data Network
DNAI	DN Access Identifier
DNN	Data Network Name
DoS	Denial of Services
DP	Data Plane (User Plane UP)
ENaaS	Entertainment as a Service
eNB	Evolved Node B
ePDG	evolved Packet Data Gateway
ETSI	European Telecommunications Standards Institute
FAST	Fast Application and Communication Enabler
FC	Fog Computing
FDMA	Frequency Devision Multiple Access
GMLC	Gateway Mobile Location Centre
GPS	Global Positioning System
GUAMI	Globally Unique AMF Identifier
HD	High Definition
HetNets	Heterogeneous Networks
HR	Home Routed (roaming)

Edge Computing Support for V2X Communications on 5G Technology

- **List of Acronyms**

Het-MEC	Heterogeneous MEC
IaaS	Infrastructure as a Service
ICI	Inter-Cell Interference
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
LTE	Long-Term Evolution
MANET	Mobile Ad hoc Network
MANO	Management and Orchestration
MCC	Mobile Cloud Computing
MDP	Markov Decision Process
MEC	Multi-access (Mobile) Edge Computing
ML	Machine Learning
MIMO	Multiple-Input and Multiple-Output
mmWave	millimeter Wave
MNO	Mobile Network Operator
N3IWF	Non-3GPP InterWorking Function
NaaS	Network as a Service

Edge Computing Support for V2X Communications on 5G Technology

- **List of Acronyms**

NAI	Network Access Identifier
NEF	Network Exposure Function
NF	Network Function
NFV	Network Function Virtualisation
NFVI	Network Function Virtualisation Infrastructure
NOMA	Non-Orthogonal Multiple Access
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
OFDM	Orthogonal Frequency-Division Multiplexing
OMA	Orthogonal Multiple Access
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
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology

Edge Computing Support for V2X Communications on 5G Technology

- **List of Acronyms**

RL	Reinforcement Learning
RRH	Remote Radio Head
RSU	Road Side Unit
SA NR	Standalone New Radio
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

Edge Computing Support for V2X Communications on 5G Technology

- **List of Acronyms**

TDMA	Time Devision Multiple Access
TNL	Transport Network Layer
TNLA	Transport Network Layer Association
TSP	Traffic Steering Policy
UAV	Unmanned Air Vehicle
UDM	Unified Data Management
UDR	Unified Data Repository
UDSF	Unstructured Data Storage Function
UL	Uplink
UPF	User Plane Function
URSP	UE Route Selection Policy
VF	Virtualised Function
VIM	Virtualised Infrastructure Manager
VNF	Virtualised Network Function
VR	Virtual Reality
WiFi	Wireless Fidelity
WPT	Wireless Power Transfer

- **Backup slides**

1. Vehicle to everything (V2X) communications - 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. Vehicle to everything (V2X) communications - 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