5G Network Slicing for Vehicle-to-Everything Services

Claudia Campolo, Antonella Molinaro, Antonio Iera, and Francesco Menichella

Abstract

The multitude of key vertical markets targeted by 5G networks calls for the support of multiple *network slices* on a common and programmable infrastructure. A network slice is intended as a collection of logical network functions and parameter configurations tailored to support the requirements of a particular service. In this article, we present our vision on the design of 5G network slice(s) customized for vehicle-to-everything services, which involve vehicles exchanging data with each other, with the infrastructure and any communicating entity for improved transport fluidity, safety, and comfort on the road. The suggested slicing solutions involve the partition(s) of the core network and the radio access network resources, as well as configuration of the vehicular end-device functionality, to support different vehicle-to-everything use cases. This research article aims to elaborate on the technological options and enablers, concerns, and challenges for the succesful deployment of 5G slice(s) for multitenant vehicle-to-everything services.

Introduction

Fifth generation (5G) systems are conceived as *highly flexible and programmable end-to-end communication, networking, and computing infrastructures* that provide increased performance in terms of *throughput, latency, reliability, capacity, and mobility* while meeting diversified requirements from multiple services. The International Telecommunication Union (ITU) has categorized these services into major use cases [1]: enhanced mobile broadband (eMBB) including ultra-high definition (UHD) TV, massive machine-type communications (mMTC) for metering, logistics, smart agriculture, and ultra-reliable and low latency communications (URLLC) for autonomous driving and automated factory. Also, the Third Generation Partnership Project (3GPP) [2] and other organizations, such as the Next Generation Mobile Network Alliance [3] and the 5G Public-Private Partnership [4], have included the mentioned categories in their own definitions of use cases. All of them have agreed on the convergence of mobile broadband and vertical sectors onto a common physical infrastructure, accessible by means of *network slices*. A network slice [3] is referred to as a collection of core network (CN) and radio access network (RAN) functions whose settings are configured to meet the diverse requirements of given use cases in terms of functionalities (e.g., security, mobility support) and delivery performance (e.g., latency, reliability, throughput).

An operator is allowed to compose and operate different network slices in parallel (e.g., to host multiple enterprises) while guaranteeing slice *isolation* so that data communication in one slice does not negatively affect services in other slices [2].

The automotive vertical market is an undoubted key driver for 5G systems. Vehicle-to-everything (V2X) communication and its enhancement (eV2X) have been included by 3GPP in Long Term Evolution (LTE) Release 14 [5, 6] and among the 5G use cases [2, 7], respectively. The interest of mobile network operators (MNOs) in the automotive business case is also witnessed by the recent formation of the 5G Automotive Association, gathering major automobile manufacturers and information and communications technology (ICT) players with the aim to promote interoperable solutions for cellular V2X, based on 5G and on the enhancement of LTE.

The V2X umbrella term actually covers a multiplicity of use cases, characterized by single- or multi-tenancy and by diverging service requirements, spanning from a self-automated car moving in a smart city, to HD video streaming played on an in-vehicle infotainment system, to enhanced real-time navigation systems on board. The potential benefits and the related business opportunities for automotive and ICT players are still to be adequately disclosed, while network slicing for the 5G era is rapidly shaping up. Such facts motivate this article, aimed at presenting our vision of 5G network slicing as a key technological enabler of the future automotive market. After a brief presentation of the 3GPP specified V2X services and related key performance indicators (KPIs), followed by an overview of network slicing, we debate on how to adapt this concept in view of supporting V2X services. This is done by discussing technological and architectural options, concerns, and open issues, and pinpointing future research directions. Guidelines are provided on slicing solutions concerning the RAN, the CN, and the vehicular end device, with hints also on management, security, and business issues. Most of the mentioned issues have been and are currently under investigation as standalone enhanced mechanisms and solutions for V2X services. However, to the best of our knowlege, this is the first

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time that they are analyzed as crucial components of the end-to-end 5G slicing for V2X services.

V2X Services in 3GPP

So far, IEEE 802.11 OCB (outside the context of a basic service set, BSS) mode (earlier amendment *p*, now superseded and part of the IEEE 802.11-2012 standard) has been considered the de facto standard access technology for vehicular networking [4]. Despite the field trials running worldwide, it could take a decade or longer until a critical number of vehicles will be equipped with 802.11 OCB onboard devices. Meanwhile, 3GPP is defining the full set of V2X technical enablers in Releases 14 and 15.

V2X Communication Modes

3GPP identifies four types of V2X communication modes (Fig. 1, bottom): vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I), and vehicle-to-network (V2N) [6].

V2V and V2P modes cover *direct* communication between vehicular user equipment (UEs) and between vehicles and vulnerable road users (VRUs), such as pedestrians, bikers, motorcyclists, and wheelchair users, respectively. Direct links over the sidelink PC5 reference interface in Release 14 are based on the customization for the vehicular scenario of proximity services (ProSe), originally specified in Release 12. Sidelink radio resources can be allocated in:

- *Scheduled mode* (typical for in-coverage UE operations), under control of the cellular infrastructure (i.e., the eNodeB)
- *Autonomous mode*, with the UE autonomously selecting the sidelink resources from a (pre)configured pool[1] (may be required for out-of-coverage UE operations)

V2I refers to communications between vehicles and the roadside infrastructure, for example, a roadside unit (RSU) implemented either in an eNodeB or as a standalone stationary UE. A vehicular UE and the RSU exchange data over the *LTE-Uu* interface. The RSU can transmit toward multiple UEs in a given area through the evolved multimedia broadcast multicast service (eMBMS).

V2N puts vehicular UEs in communication with a server supporting V2N applications, referred to as a V2X application server (AS), which provides a centralized control and the distribution of traffic, road, and service information.

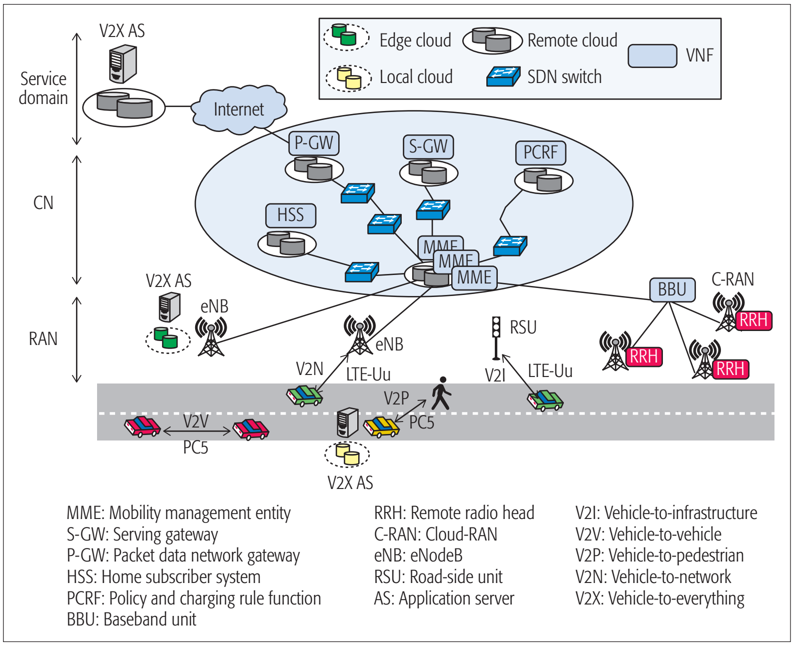

FIGURE 1. V2X communication modes and 5G slicing concept in the device, the RAN and the CN for V2X services.

V2X Use Cases and Related KPIs

The wide set of vehicular use cases (referred to as V2X in [6] and as eV2X in [7]) [2] is categorized as follows for the discussion in this article:

Safety and traffic efficiency. V2V/V2P *event-driven* and *periodic* messages carry the position and kinematics parameters of the transmitting vehicle to allow other vehicles and VRUs to sense the surrounding environment and support applications [6] such as:

- *Forward collision warning* that notifies a driver of an impending rear-end collision with a vehicle ahead
- *Cooperative adaptive cruise control* that allows a group of vehicles in proximity to share the same path (a.k.a. *platooning*)
- *VRU safety* to alert a vehicle of the presence of a VRU

Autonomous driving. Requirements in autonomous driving are stricter than those in V2V safety applications; self-driving vehicles may drive very close to each other and at higher speeds (up to 200 km/h). Moreover, an autonomous vehicle requires full road network coverage to be driverless in all geographies, with the network supporting (mainly V2V) communications under high vehicle density. In some scenarios, video/data exchange over V2N links may further enhance the autonomous driving efficiency and safety [2].

Tele-operated driving. In environments that are either dangerous or uncomfortable to human beings, such as the area of a nuclear accident, an earthquake, road construction, and snow plowing, *drones on wheels* may be leveraged with driving tasks taken over by a human driver physically located outside of the vehicle, which controls it by using camera, status, and sensor data. Such a use case, representative of *extreme real-time communications*, a.k.a. "tactile Internet," exhibits tight requirements for the network to ensure fast vehicle control and feedback [2].

Vehicular Internet and infotainment. Web browsing, social media access, files/apps download, and HD video streaming for passengers are considered a "must-have" for new cars and would become even more relevant with increased penetration of self-driving vehicles [2], in which the driver may also be engaged in media consumption.

Remote diagnostics and management. A V2X AS owned by a car manufacturer or a vehicle diagnostic center can retrieve information *periodically* sent by vehicles in V2N mode to track their status for remote diagnostic purposes [6]. Similarly, fleet management applications may track the vehicle status and position for forensic diagnostic activity and to avoid insurance fraud.

The identified categories, with relevant KPIs, are summarized in Table 1.

[1] Information regarding the out-of-coverage operation may be (pre)configured by the home public land mobile network to ensure interoperability in the case of multiple MNOs.

[2] Hereafer, for the sake of simplicity, we use the term V2X for both sets of use cases.

V2X category	Communication type	Latency	Data rate	Reliability
Safety and traffic efficiency [6]	V2V, V2P	100 ms	Not a concern	Not yet explicited
Autonomous driving [2]	V2V, V2N, V2I	1 ms	10 Mb/s (downlink/downlink)	Nearly 100%
Tele-operated driving [2] (under discussion in [7] as teleoperated support, TeSo)	V2N	20 ms (end-to-end)	25 Mb/s for video and sensors data (uplink), 1 Mb/s for application-related control and command (downlink)	99.999%
Vehicular Internet and infotainment [2]	V2N	100 ms (for web browsing)	0.5 Mb/s (web browsing), up to 15 Mb/s for UHD video streaming	Not a concern
Remote diagnostics and management [6]	V2I, V2N	Not a concern	Not a concern	Not a concern

TABLE 1. V2X categories and main KPIs.

5G Network Slicing

An Overview

The main drawback of today's networks is that multiple services are supported over the same architecture, typically conceived with no elasticity in mind, and are processed by the same network elements in the CN and by sharing the same resources in the RAN.

Network slicing logically isolates network functions (NFs) and resources that are specifically tailored to a vertical market's need on a single common network infrastructure. A slice potentially spans all 5G network domains across CN and RAN segments [3, 8].

Slicing the CN segment affects control plane (CP) functionalities, such as mobility management, session management, and authentication (as hosted in the MME and HSS), and user plane (UP) functionalities (e.g., those in the S-/P-GWs), which become programmable and auto-configurable [9].

Slicing the RAN is a less mature and challenging practice (mainly due to the shared nature of wireless resources) and encompasses various radio access technology (RAT) parameter configurations, such as time/frequency resources, frame size, and hybrid automatic repeat request (HARQ) options [9].

Although a network slice spanning both the RAN and the CN would complicate the overall slice design, we are in favor of an *end-to-end* approach that ensures higher flexibility allowing, for example, some of the CN functions to be placed in the RAN (to meet the strict latency and scalability constraints of some applications), thus blurring the boundaries between the CN and the RAN. An end-to-end slice can be composed of different slice instances in the RAN and in the CN segments with a proper binding mechanism among them to support the targeted service [8].

Technology Enablers

The most promising way to implement network slicing is by decoupling CP and UP functionalities and leveraging open application programming interface (API) principles and the programmability of network functions, provided by paradigms like network functions virtualization (NFV) [10] and software defined networking (SDN) [11].

Decoupling CP and UP functionalities allows displacing them in convenient locations. UP functions can be distributed close to the user, to reduce service access latency; CP functions can, instead, be placed in a central site, which makes management and operation less complex.

In early 3GPP attempts, network slicing was conceived to deploy multiple dedicated core networks (DÉCOR) running on purpose-built proprietary hardware hosting the related NFs to support different services. Thanks to NFV, CP and UP NFs are not tied to the underlying hardware: they can be deployed as virtual NFs (VNFs), and run independently and on different platforms (e.g., low-cost hardware, general-purpose CPU), hosted either in the remote cloud or in edge cloud facilities, according to the mobile edge computing (MEC) paradigm [12]. VNFs can be dynamically instantiated, relocated, and horizontally/vertically scaled as virtual machines (VMs)/containers according to the requirements of the services supported by a given slice, and in response to network demands and to underlying infrastructure dynamics.

An SDN controller can (i) configure VNF and physical NF (PNF) chains in a given slice and (ii) flexibly interconnect UP/CP functionalities running over distributed hardware-based or virtual SDN-enabled switches, through the setup of paths that can be automatically reconfigured either to handle traffic engineering requirements or to react to possible network failures.

Figure 1 illustrates some representative functionalities/entities in the V2X ecosystem deployed as VNFs, in the remote/edge cloud, and interconnected through SDN in the device, the RAN, and the CN domains.

5G Slicing for V2X Services

In the V2X ecosystem, network slicing can effectively cope with a wide variety of use cases with divergent demands provided over the 5G infrastructure (typically) by multiple tenants. Besides traditional Internet and service providers, new players, such as road authorities, municipalities, and vehicle manufacturers, will enter the scene. The unique, heterogeneous, and complex features of V2X services do not allow either *straightforward mapping into reference slice types* supporting *eMBB*, *URLLC*, and *mMTC* services [8] or *mapping into a single V2X slice*. Therefore, based on the main KPIs and functional requirements of the identified V2X use case categories from earlier, we propose the following set of slices (as illustrated in Fig. 2).

•The slice for *autonomous driving* and other safety-critical services (e.g., platooning) relies on ultra low-latency V2V as the prevalent RAT connection mode and on additional RAN/CN functions, such as for network-controlled resource allocation over the PC5 interface (in the eNodeB)

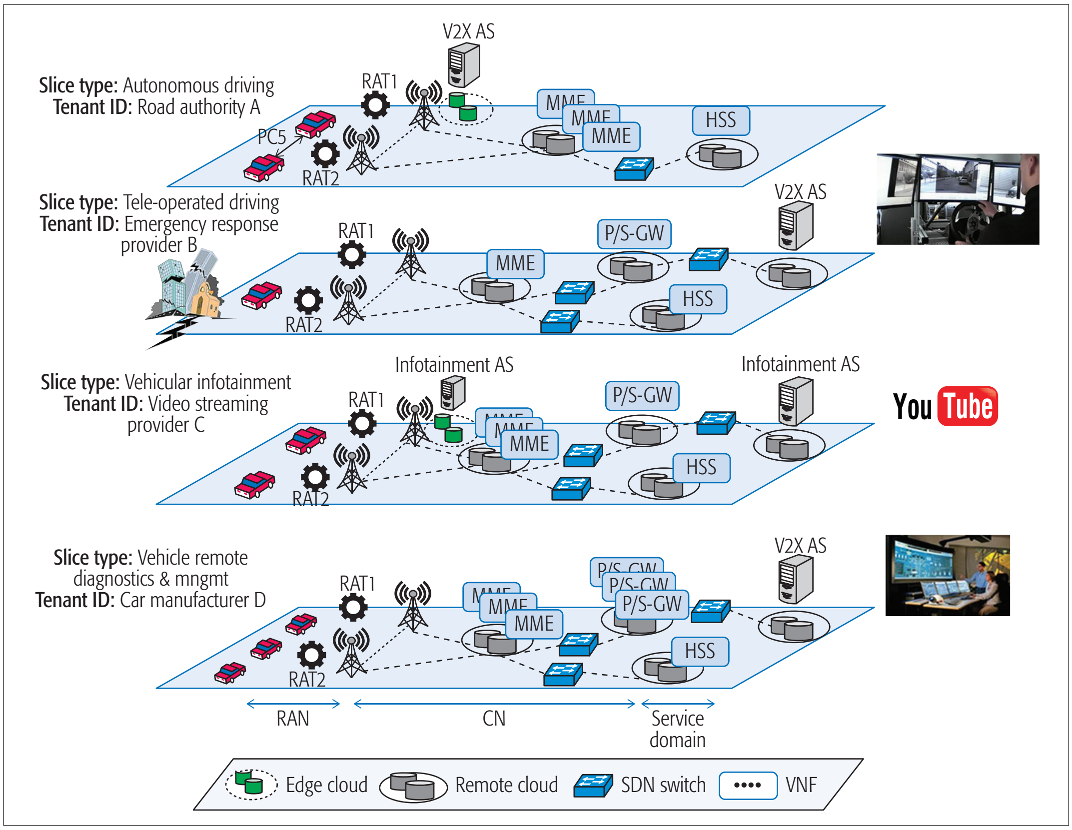

FIGURE 2. High-level overview of the proposed slices for the identified V2X service categories.

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and mobility, authentication, authorization, and subscription management (i.e., in the MME and HSS). Moreover, low-latency and reliable video/data exchange needs to be supported with a V2X AS, deployed at the network edge, that helps vehicles in 3D-map processing of the surrounding area and building an augmented vision beyond their visual perception.

•The slice supporting *tele-operated driving* should ensure ultra-low latency and highly reliable end-to-end connectivity between the controlled vehicle and the remote operator who is typically hosted outside the CN (with data flows passing through a P-GW). Unlike the autonomous driving slice, such services will be limited to a few vehicles and activated under particular circumstances only, hence resulting in a light load over CN entities (e.g., in the MME).

•The slice for *vehicular infotainment* applications is expected to use multiple RATs for higher throughput, and to host contents either in the remote cloud or close to the user (e.g., with the server co-located at the eNodeB). According to the users basin, multiple MME instances may be required.

•The slice for *vehicle remote diagnostics and management* has to be configured to support the exchange of small amounts of low-frequency data between many vehicles and remote servers outside the CN. To this purpose, UP functionalities should handle multiple interactions (e.g., through multiple S/P-GW instances) and CP functionalities (e.g., the MME) should be instantiated accordingly.

Table 2 summarizes the main configuration for the identified V2X slices, whose design is driven by the following main issues.

•The design of an *end-to-end* V2X slice should allow the dynamic composition of different slice instances in the RAN and in the CN segments. An example is given by the slice for autonomous driving, which may share a set of *common* CN functions (e.g., those related to authentication/authorization) with other slices, but entails *slice-specific* customizations over the RAN to account for V2V interactions.

•The 3GPP *multi-dimensional slice descriptor* [8] should be enriched with other parameters that better identify the slice configurations. Besides the *tenant ID* (e.g., the car manufacturer, the road authority) and *slice type* (e.g., vehicular infotainment, remote diagnostic), the slice description could also account for position/kinematics parameters so that, for example, different resource pools may be allocated to vehicles moving in opposite directions [13].

•Vehicular devices would likely be conceived as *multi-slice devices*, that is, devices able to attach to multiple slices, possibly *simultaneously*. A driver could start her self-driving car that relies on the autonomous driving slice for V2V messages exchange, whereas children in the back seat request HD streaming of a cartoon that is offered as a vehicular infotainment slice, and remote diagnosis applications are running in the background over the corresponding slice.

•*Multi-tenancy* is a typical feature of the V2X scenario: different services (e.g., V2V-based safety data exchange and HD cartoon streaming), mapped onto different slices, may be offered by different providers over the infrastructure owned by different network operators. This may, for example, complicate slice subscription and attachment operations.

	Autonomous driving	Tele-operated driving	Vehicular Infotainment	Vehicular remote diagnostics and management
RAT settings	4G/5G NR	4G/5G NR, 802.11 OCB	4G/5G NR, 802.11 OCB	4G/5G NR, 802.11 OCB
Main communication mode	V2V over PC5	V2N over LTE-Uu (for 4G/5G)	V2I/V2N over LTE-Uu (for 4G/5G)	V2I/V2N over LTE-Uu (for 4G/5G)
Main communication primitive	Broadcast	Unicast	Unicast	Unicast
QoS treatment	Additional QCIs to meet strict packet delay budget and loss	Additional QCIs to meet strict packet delay budget and loss	QCI 4	QCI 9
HARQ support	Local among UEs for V2V communications	Network-assisted	Network-assisted	Network-assisted
Scheduling mechanism	Semi-persistent	Dynamic	Dynamic	Semi-persistent
TTI length	Short	Short	Large	Short
V2X/infotainment AS placement	Not required for V2V interactions	At the remote driver premises	Edge cloud/remote cloud	Remote cloud

TABLE 2. Configuration for the main identified V2X slices.

•*Different types of UE could request the slice activation*: slice customization should also be related to the UE type; it could be, for example, a smartphone for a VRU, a transceiver unit embedded into the vehicle, or an onboard infotainment platform.

Slicing the RAN for V2X

Slicing the RAN functionalities may span from the selection of the RAT and RAN architecture and the communication mode/primitive to the choice of the radio resource allocation policy and the configuration of a subset of more fine-grained air interface parameters.

RAT selection. 5G will be deployed as a mashup of existing and novel 3GPP (4G, 5G New Radio) and non-3GPP (e.g., 802.11) access technologies. In the V2X context, cellular technologies provide nearly ubiquitous coverage, whereas 802.11 OCB, mainly conceived for localized V2V communications over unlicensed spectrum, may be desirable to offload 3GPP networks. A V2X slice configuration entails:

- The selection of the RAT (or combination of RATs) able to satisfy its KPIs
- Its modification to adapt to changing network conditions

In particular, the usage of multiple RATs may be configured to increase the V2I connectivity capacity for the vehicular infotainment slice or to provide redundant connectivity to the tele-operated driving slice.

RAN architecture. V2X slices could benefit from the on-demand deployment of RAN functions achieved through the cloud RAN (C-RAN) technology, which splits the radio and baseband processing functionalities, with the latter ones migrated to the cloud and forming a baseband unit (BBU) pool. By leveraging virtualization, C-RAN resources in the pool can be dynamically allocated to eNodeBs according to the network load. This ensures adaptability to the non-uniform traffic that characterizes vehicular scenarios (e.g., during off-peak/rush hours, in urban/rural environments). Moreover, a centralized processing of the pooled BBU functionalities, compared to distributed processing in each eNodeB, reduces the time (and the signaling) for handovers.

Communication mode and primitive selection. The V2X slice configuration requires the mapping of a traffic flow onto a communication mode (sidelink or cellular) and a primitive (unicast, multicast, or broadcast). For instance, the slice for autonomous driving may rely by default on sidelink communications for localized interactions, but mobility and time-varying density conditions could trigger the slice reconfiguration to switch from the PC5 to the LTE-Uu interface. This would be the case of safety data dissemination spanning large areas under low vehicle density. Vice versa, the interface could be switched from LTE-Uu to PC5 when vehicles, initially far and in non-line of sight, approach intersections within the reciprocal sidelink communication range. Release 14 specifies broadcast primitives to match V2V/V2P safety services; however, we believe that reliable unicast would also play a crucial role in safety-critical applications like platooning. Unicast is used for V2I and V2N uplink communications and for tele-operated driving in both directions. Multicast could be used by RSUs/eNodeBs to reach multiple UEs over a wide area (e.g., for accident/congestion warning dissemination).

Radio resource allocation. Although the scheduler of a RAT (e.g., in an eNodeB) is typically shared among multiple slices, it plays a key role since it is in charge of allocating resources to different slices (*inter-slice*) and to different UEs within a slice (*intra-slice*). Slicing of radio resources can occur in the time/frequency domains (e.g., LTE resource blocks). Geo-location-based resource assignment may facilitate intra- and inter-V2X slice isolation [13]. Additionally, slicing can be enforced by specifying a set of packet forwarding treatments (e.g., priority, throughput), as captured by the quality of service class identifier (QCI) of a bearer.

Besides the QCIs defined in [5] to meet the V2X requirements of latency (50 ms packet delay budget) and reliability (10^{-2} packet error rate) over the LTE-Uu interface, further QCIs should be conceived for V2X slices with stricter requirements (e.g., 1 ms latency for autonomous and tele-operated driving).

Among the 3GPP scheduling schemes, *dynam-*

ic scheduling, which adaptively allocates radio resources based on each UE's buffer status and channel state information, well matches the requirements of the vehicular infotainment slice. Meanwhile, *semi-persistent scheduling*, which allocates resources periodically without any additional signaling [14], is particularly indicated for traffic patterns with a predictable frequency and packet size, like for autonomous driving and remote diagnostic slices.

Numerology. V2X support will be achieved in 5G through different time/frequency numerology (e.g., flexible frame structure to match high Doppler effects under high speeds and variable transmission time interval, TTI, length) [14]. For instance, large TTI (e.g., 1 ms) may be used to deliver throughput-demanding applications mapped onto the vehicular infotainment slice, while short TTIs (e.g., 0.125 ms) can be used to provide fast feedback/retransmission for the tele-operated driving slice.

Slicing the CN for V2X

Network slicing over the CN affects the design and placement of CP/UP functionalities and servers that support V2X communications.

MME. The MME plays a key role in the CN by managing mobility, session, authentication, and authorization procedures. The high vehicle speed in *all V2X slices* may either overload the mobility management (MM) functionalities of the MME of a legacy CN, with consequent increase in latency, or inefficiently use them if configured based on the peak rate (i.e., expected at peak hours on the road). To avoid the two mentioned cases, while ensuring isolation with other (non-V2X) slices leveraging the same functionalities but less aggressively (e.g., for pedestrian/indoor UEs), the V2X network slicing design shall enable *multiple MME instances* to be flexibly deployed as VNFs and interconnected to meet the needs of the V2X slices (Fig. 2). In particular, by decomposing MME functionalities, MM functions can be co-located with the eNodeB to ensure low-latency signaling procedures, as shown in Fig. 3 for the autonomous driving slice. Such decomposition entails the design of new lightweight interfaces to let the splitted MME functionalities interact with each other and other network entities through the configuration of paths (e.g., established by an OpenFlow SDN controller). In Fig. 3, the MM is interconnected to the authentication and authorization (AU) module and to the HSS, to manage subscription/authorization procedures of devices onboard self-driving cars. The AU and HSS can be deployed as VNFs common to other V2X slices.

eMBMS. The autonomous driving slice may require the *on-the-fly* activation of multicast flows to allow the dissemination of road safety information concerning an accident. Nodes supporting eMBMS functionalities (i.e., the BM-SC, the MBMS-GW, and the MME) are typically located in the CN. The backhaul delay between the BM-SC and the eNodeB may be non-negligible. Thanks to CP-UP decoupling, the user plane of MBMS CN functions (BM-SC, MBMS-GW) can be moved closer to the eNodeB to ensure safety data to be promptly distributed over a large area, as proposed in [5] (Fig. 4), for example, by leveraging NFV techniques.

Application Servers. Typically, ASs are deployed outside the LTE network (e.g., in cloud facilities owned/rented by a transportation authority, a municipality, a car repair center, or a service provider). Thanks to the MEC enabling technology, V2X AS instances can run close to users (e.g., at the eNodeB premises) to provide services with short latency. This would be particularly beneficial in case of a traffic AS collecting sensor and vehicle-generated data, and locally processing them to track the road congestion status and promptly notify vehicles in an incident area through RSUs. A V2X AS supporting the operations of autonomous vehicles could also be preferably deployed at the network edge (Fig. 3). The placement of the V2X AS in remote cloud facilities, outside the operator's network, is still convenient, instead, for delay-tolerant services, such as remote diagnostics. Infotainment servers may also benefit from NFV and MEC solutions to move the UP functions closer to the UE. Due to vehicle mobility, a vehicular infotainment slice configured to allow caching at the edge can be more effective if coupled with *pre-fetching* strategies that let the content follow the vehicular UEs. Contents are moved from edge node to edge node (e.g., eNodeBs) to ensure service continuity. To this aim, the slicing functionalities could be enriched with vehicle mobility prediction models, as part of a large set of network data analytics tools aimed to optimize V2X resource planning and traffic engineering.

Slicing the User Device for V2X

Slicing may also encompass the configuration of some settings/functions in the vehicular device.

Vehicular and VRUs' UEs exhibit different capabilities. Thus, traffic pattern parameters should be differently configured in the two device types for the same slice supporting safety services (e.g., the frequency of exchanged messages for the VRU must be lower than in vehicular UEs).

Besides, although the network is expected to retain control over the V2V/V2P sidelink communications at least in the scheduled mode (e.g., for the autonomous driving slice instantiated in Fig. 3, the RRM module in the eNodeB decides the resource pool allocation), some control functionalities could benefit from being split between the RAN/CN and the UE. For instance:

- Retransmissions can be *locally handled* by the vehicular UEs over the PC5 links in the autonomous driving slice to match the high-reliability and ultra-low-latency requirements over V2V links (HARQ PNF, Fig. 3).
- *Adaptation of link parameters* (e.g., transmission power, modulation and coding scheme) may autonomously be performed by the UE.
- When out of coverage, the UE should be capable of *autonomously selecting the set of slice configurations*, which better matches the services of interest (e.g., it can decide which sidelink resource pools among the [pre]configured ones to allocate to different V2X services).

As a last indication, it may be convenient in some situations to extend the UP to the extreme edge of the network, up to the UE, and beyond communication procedures. For instance, 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

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Network slicing in 5G is expected to overturn traditional business models. Operators may agilely provide a tailored network slice for their customers from different vertical markets as a Service [9]. On the other hand, the business model behind 5G-based V2X for MNO is still under debate.

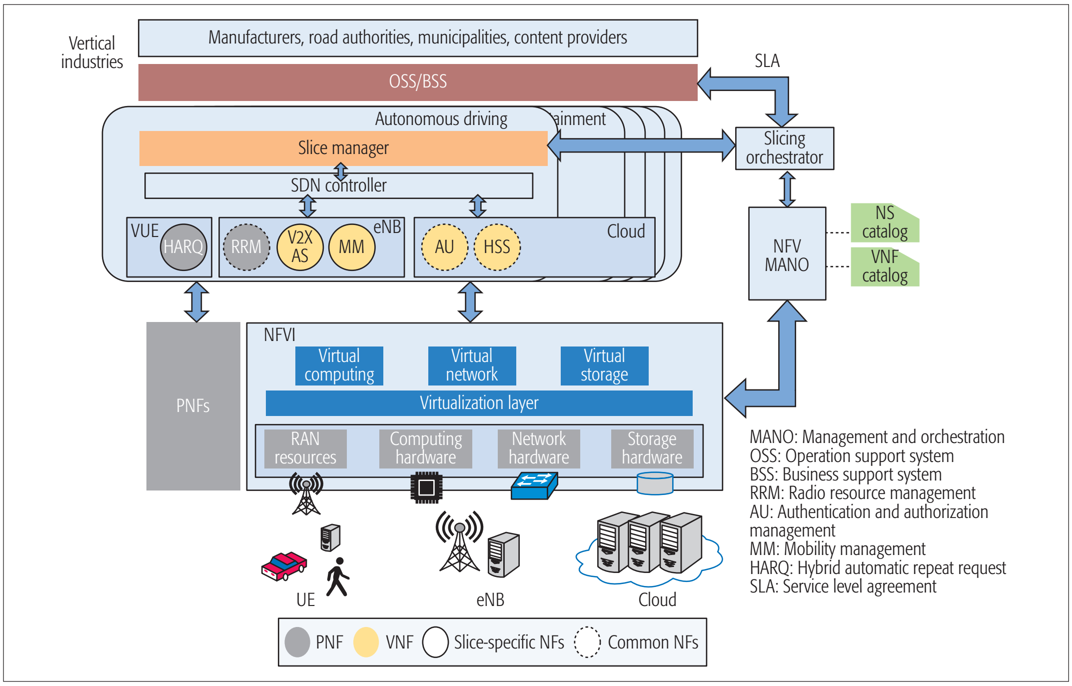

FIGURE 3. The case of autonomous driving slice: management and orchestration of V2X slices coupled with European Telecommunications Standards Institute (ETSI) NFV.

a smartphone). A slice should be able to support the operations of a vehicular UE that could alternatively act as a *storage unit*, to disseminate locally-relevant infotainment contents, and as a *processing unit*, to perform local cloud operations (e.g., data fusion and processing from multiple sensors for autonomous driving) [14].

Operational and Business Open Issues for V2X Slicing

Slicing management and orchestration require the following main capabilities:

- *Slice description*, which captures the requirements of a given service level agreement (SLA) as agreed by vertical segments, whose assurance is tracked by the operations support system (OSS)/BSS. Such a description needs to be translated to network elements;
- *Slice instantiation*, which encompasses the identification of CP/UP architecture, interfaces, sets of slice-specific and common VNFs/PNFs in the CN and their interconnection (e.g., configured by an SDN controller), and parameter settings in the RAN/device;
- *Slice life cycle management*, which entails configuration, adaptation, and monitoring to fulfill isolation constraints and agreed SLAs.

A *per-slice manager* is in charge of the two latter functionalities. It interacts with the *slicing orchestrator*, which, in its turn, communicates with the ETSI NFV management and operation (MANO) platform [10], and enables the brokering of NFV resources (hosted in the device, at the network edge and in the remote cloud) between multiple slices, as illustrated in Fig. 3.

When requesting a given service, a V2X device should be able to either select the required slice (when the slice identifier is pre-stored in the device itself), or receive from the network an indication about the activated slice (e.g., according to what is subscribed and stored in the HSS profile). As for other (non-V2X) slices, a network entity recognizes the requested slice, confirms the attachment request after checking the authentication and subscription data of the UE, and reconfigures the slice to accommodate the demands of the new attached UE [8].

Due to the high dinamicity of the reference environment, the complex nature of V2X services, and the expected edge-dominated network infrastructures, such operations will get much more complicated than in other 5G contexts. For instance, the slicing orchestrator will have to configure multiple slices per device simultaneously and to adapt a slice configuration at runtime (e.g., by moving VNFs at the edge network, not only to manage SLA degradation, but also to promptly follow a vehicular UE, through proper migration prediction mechanisms).

Network slicing in 5G is expected to overturn traditional business models. Operators may provide in an agile manner a tailored network slice for their customers from different vertical markets *as a service* [9]. On the other hand, the business model behind 5G-based V2X for MNOs is still under debate [4]. New partnerships will likely emerge between automotive players, focused on meeting the needs of a specific service without owning network infrastructure and the MNOs offering it. To this aim, suitable open APIs must be designed to offer network programmability to vertical segments.

User authentication, non-repudiation and data integrity, confidentiality, and user privacy should be guaranteed in 5G V2X with low overhead and latency [4, 6]. In addition, security threats could specifically emerge through network slicing usage in 5G V2X. Security procedures should be tailored to the needs of the different use cases, which means that network slices with different security assurance requirements may coexist, while ensur-

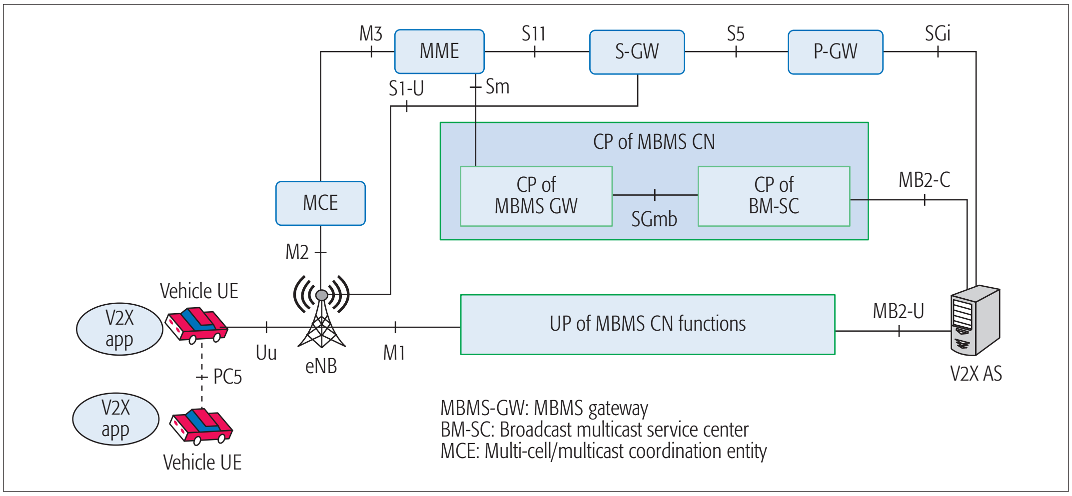

FIGURE 4. Moving the user plane (UP) of MBMS CN functions (BM-SC, MBMS-GW) close to the eNodeB (adapted from [5]).

Security procedures should be tailored to the needs of the different use cases, which means that network slices with different security assurance requirements may coexist, while ensuring adequate isolation between them. Moreover, trust relationships between the slice manager and the provider owning the infrastructure are required before any negotiation for slice instantiation may take place.

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Conclusions

This article elaborates on the role of network slicing to enable the isolated treatment and guaranteed performance of V2X services as crucial 5G use cases. Suggestions are provided to contribute to the design of dedicated V2X slices. Such a choice is meant to better address their unique peculiarities and not to create a bottleneck in existing reference slices, while specifically supporting vertical applications. However, we do not disregard the possibility of properly customizing slices belonging to a set of basic reference slices to manage them (e.g., as either subtypes or proper composition of different slice instances). In this case as well, the provided guidelines still apply.

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