Towards 5G Network Slicing for the V2X Ecosystem

Claudia Campolo, Antonella Molinaro, Antonio Iera
Università Mediterranea di Reggio Calabria
Reggio Calabria, Italy
claudia.campolo,antmolin,antonio.iera@unirc.it

Ramon R. Fontes, Christian E. Rothenberg
School of Electrical and Computer Engineering (FEEC)
University of Campinas (UNICAMP)
Campinas, Sao Paulo, Brazil
ramonrf,chesteve@dca.fee.unicamp.br

***Abstract*—The automotive vertical market is currently undergoing key technological transformations as the number of connected and more autonomous vehicles grows, thus realizing the Vehicle-to-Everything (V2X) communication ecosystem. Such a revolution raises unprecedented challenges to the ICT players that have to guarantee ultra-low latency and ultra-high reliable connectivity under high-mobility and high-density conditions. By allowing an operator to flexibly provide dedicated logical networks with customer-specific (virtualized) functionalities over a common physical infrastructure, *network slicing* candidates itself as a prominent solution to support V2X over upcoming *programmable* and *softwarized* 5G systems. In this paper, we share our vision about V2X network slicing, by pinpointing key requirements and providing a set of design guidelines, aligned with ongoing 3GPP standard specifications and network softwarization directions.**

***Index Terms*—V2X, 5G, network slicing, network softwarization.**

I. Introduction

The growth in mobile data traffic and new services is pushing Telco operators and service providers to upgrade their network infrastructures and delivery platforms, by engaging themselves in cutting-edge paradigms and technologies in order to meet the new service requirements and to satisfy their customers' demands.

Software-Defined Networks (SDN) [1], Network Function Virtualization (NFV) [2] and Mobile Edge Computing (MEC) are key enablers of such an unprecedented paradigm shift, which is impacting deeply Telecom and Information and Communication Technology (ICT) industries, also contributing to their convergence. This trend, often referred to as *network softwarization* [3], has the potential of efficiently handling heterogeneous resources, spanning networks and data center domains, and easily and flexibly deploying new services, with significant reduction in expenditure and operational costs of the next-generation, the so-called fifth generation (5G), network [4].

The 5G deployment race is accelerating thanks to the joint efforts from industries, academia and standard developing organizations, aimed to fulfill the demands of very-high data rate, ultra-low latency, fast user mobility, and ultra-reliable communications [5]. The 3rd Generation Partnership Project (3GPP) is currently carrying out the standardization of both 5G access and core network segments, to be ready for the 5G commercialization in 2020 [6].

The envisioned network softwarization will be an advantage to many new services enabled by 5G in various vertical markets, such as augmented and virtual reality, industry 4.0, tactile Internet, Internet of Things, and autonomous driving. The latter one has been identified by 3GPP [7], within the so-called *enhancement of Vehicle-to-Everything* (eV2X[1]) category, as one of the most challenging 5G use cases, which cannot be accommodated in the 4G system due to its strict latency (around 10 ms), reliability and availability (nearly 100%) demands.

Whereas the entire scope of new business opportunities opened by V2X to automotive and ICT players are still to be adequately disclosed, the interest of mobile network operators (MNOs) is growing, as witnessed by the fervent activity already underway in 3GPP. The recent efforts within Release 14 [8], [9] and Release 15 [10], [11] have provided a set of technical enablers for V2X services and designed a spectral-efficient air interface, especially targeting localized vehicle-to-vehicle (V2V) communications.

Such efforts only cannot fully tackle the complexity of the V2X ecosystem; the entire end-to-end chain of 5G radio, networks, applications and services should be tailored to meet V2X requirements. The 5G *network slicing* concept [5], [7], [12], could effectively serve the purpose, with the promise to logically isolate control plane (CP) and user plane (UP) network functions (NFs) and resources that are specifically tailored to a vertical market's need on a single common

[1]Please notice that the terms V2X and eV2X will be used interchangeably.

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network infrastructure. Network slicing requires a high degree of flexibility and programmability that can be provided by the emerging SDN, NFV, and MEC technologies, to achieve simplified orchestration, better resource utilization and cost efficiency.

Early works have been published which discuss, at a high level, how to apply the slicing concept to the V2X environments [13], [14] and some players have identified the need for a dedicated V2X slice [5]. However, the design of a network slicing framework supporting V2X is a challenging task. This article aims at dissecting the key V2X peculiarities and major requirements and investigate their impact on the high-level design of V2X network slices, with the identification of a set of valuable guidelines. Unlike previous works the analysis accounts for the latest 5G specifications as frozen in December 2017, by the System architecture milestone of 5G Phase 1.

The remainder of the manuscript is organized as follows. Section II sets the scene by presenting the 5G architecture, network slicing pillars and enablers. An overview of 3GPP V2X standardization progress and applications are presented in Section III. Section IV analyzes the key V2X requirements for the design of network slicing. A reference network slicing architecture for V2X services is proposed in Section V. Finally, Section VI summarizes concluding remarks.

II. 5G Network slicing: A primer

A. The 5G architecture in a nutshell

5G is expected to be deployed as a highly flexible and programmable end-to-end communication, networking, and computing infrastructure. As shown in Figure 1, the 5G architecture recently specified by 3GPP [6] is composed of NFs and reference points connecting them. It is natively conceived with modularization and softwarization in mind and realizes the paradigm shift from today's network of entities to a network of functions.

In the 5G architecture, the User Equipment (UE) is connected to either the Radio Access Network (RAN) or a non-3GPP Access Network (AN) like Wi-Fi, as well as with the Access and Mobility Management Function (AMF). RAN represents a base station using new radio access technologies (RATs) and evolved LTE.

The core network consists of various NFs, with a clear separation of CP functions and UP functions (UPF):

- AMF provides UE-based authentication, authorization, mobility management, etc.
- The Authentication Server Function (AUSF) stores data for authentication of UEs.
- The Unified Data Management (UDM) stores UEs subscription data.
- The Session Management Function (SMF) is responsible for session management and also selects and controls the UPF for data transfer.
- The Network Repository Function (NRF) is in charge of maintaining and providing the NF instances information when deploying/updating/removing them; it also supports service discovery function.
- The Network Exposure Function (NEF) is responsible for providing means to collect, store and securely expose the services and capabilities provided by 3GPP network functions (e.g., to third parties or amongst NFs themselves).
- The Application Function (AF) represents any additional CP functions which might be required, e.g., to implement network slicing.

B. Network Slicing: Concept and Enablers

Network slicing has been recognized by different stakeholders, e.g., 3GPP [7], the Next Generation Mobile Network (NGMN) Alliance [5], the Open Networking Foundation (ONF) [15], the GSMA Alliance [16], the European Telecommunications Standards Institute (ETSI) [17], as a key element to realize widely different services with often conflicting requirements in future 5G networks. Many 5G research and demonstration projects (especially within the 5G Infrastructure Public Private Partnership, 5G-PPP, [18] initiative) are addressing the implementation of network slicing by leveraging the synergies of network softwarization technologies.

Network slicing departs from the *one-type-fits-all* design philosophy of existing networks, by allowing an operator to flexibly provide dedicated logical networks (i.e., slices) with customer specific functionality, without losing the economies of scale of a common infrastructure.

NGMN has argued in favor of an end-to-end (E2E) scope that encompasses both the RAN and CN [5]. In particular, a slice can span all domains of the network: software modules running on cloud nodes, specific configurations of the transport network supporting flexible placement/migration of functions, a dedicated radio configuration or even a specific RAT, as well as configuration of the device.

Thanks to NFV, UP and CP functionalities of different slices can be virtualized (Virtual NFs, VNFs) and be independently scaled and displaced in convenient locations to flexibly support various services. UP functions can be distributed close to the user to reduce service access latency. Edge servers can also be exploited for storage, processing, and dynamic service creation within a given network slice by verticals and over-the-top providers, introducing another multi-tenancy dimension. CP functions can, instead, be placed in a central site, which makes management and operation less complex.

Some network functions can be *shared between multiple slices*, while others are *slice-specific*. Examples for common NFs include distributed eNodeBs or the radio scheduler in the RAN domain [19]. In the CN domain, the AMF can be shared among multiple slices. The same holds for UDM and AUSF, whereas the UPF and SMF will be dedicated per each slice.

SDN allows to remotely configure the physical network in order to reserve on demand networking resources for the slices. It can be used to steer traffic between VNFs of a given slice through the set-up of paths that can be automatically reconfigured either to handle traffic engineering requirements (e.g., load balancing, traffic prioritization) or to react to possible network failures and changing conditions (e.g., mobility).

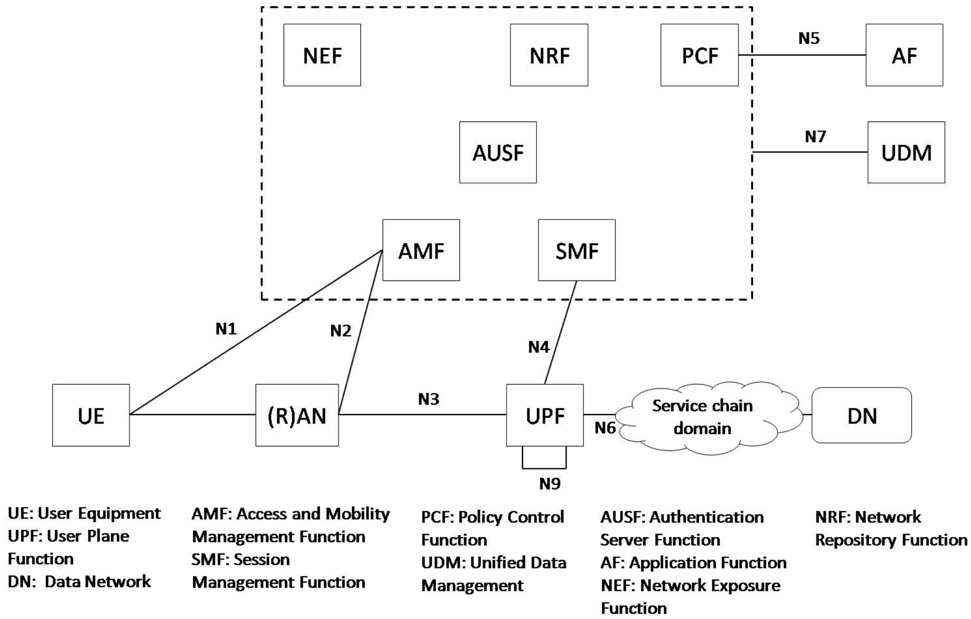

Fig. 1. The 3GPP-5G architecture adapted from [6].

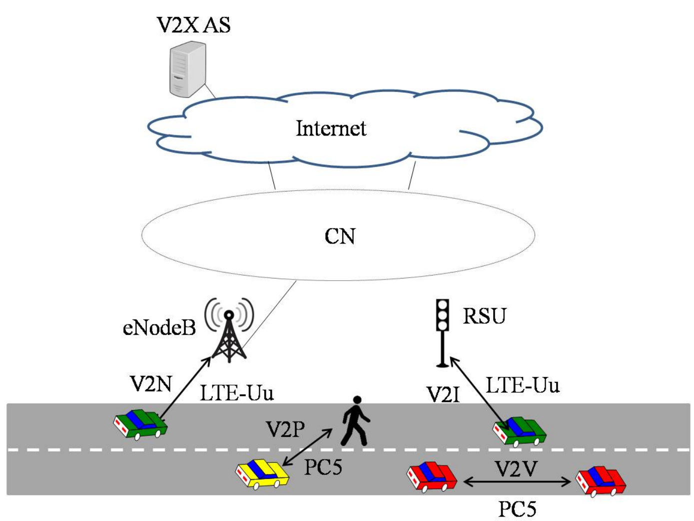

Fig. 2. V2X communication modes.

A set of references slices are typically considered, where each of them represents categories of use cases identified by the International Telecommunication Union (ITU) [20] and by the 5G-PPP [21], i.e., *enhanced mobile broadband* (eMBB), *massive machine-type communications* (mMTC), and *critical communications* (CriC), a.k.a., ultra-reliable and ultra-low latency communications (URLLC). A slice for eMBB services requires very high data rates to ensure access to multimedia content, services and data, like ultra-high definition video streaming and augmented reality. A slice supporting mMTC should sustain the traffic load generated by massively connected devices, typically transmitting a relatively low volume of non-delay-sensitive information. Common examples are those related to the Internet of Things, e.g., sensor networks deployed to enable smart home, smart buildings.

Reliability, low-latency and security will be critical for the URLLC slice to provide services that are extremely sensitive to latency such as emergency services and tactile Internet. They would greatly benefit from dedicated functions instantiated at the edge.

III. The V2X Vertical

The automotive vertical market is an undoubted key driver for 5G. The interest of MNOs in the automotive business case is also witnessed by many initiatives: the vision shared by representatives from both the automotive and the telecommunications industries in the 5G-PPP white paper [22], the recent formation of the 5G Automotive Association (5GAA) [23] gathering major automobile manufacturers and ICT players with the aim to promote interoperable solutions for cellular V2X, based on 5G and on the enhancement of LTE.

V2X communication and its enhancement (eV2X) have been included by 3GPP in LTE-Release 14 [8], [9] and among the 5G use cases in Release 15 [10], [11], respectively. In the following the main communication modes, the envisioned set of services and their requirements will be shortly discussed.

A. V2X Communication Modes

3GPP identifies four types of V2X communication modes: vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I), and vehicle-to-network (V2N) [9], as simplified in Figure 2.

V2V and V2P modes, respectively, cover direct communication between vehicular UEs and between vehicles and vulnerable road users (VRUs), such as pedestrians, bikers, motorcyclists, wheelchair users. Direct communications occur over the *sidelink PC5* reference interface in Release 14 and are based on the customization for the vehicular scenario of Proximity Services (ProSe), originally specified in Release 12.

V2I refers to communications between vehicles and the roadside infrastructure, e.g., a road-side unit (RSU) implemented either in an eNodeB or as a stand-alone stationary UE. A vehicular UE and the RSU exchange data over the LTE-Uu interface. The RSU can transmit towards multiple UEs in a given area through the evolved Multimedia Broadcast Multicast Service (eMBMS), e.g., to disseminate safety messages over a large area.

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

B. V2X Services

V2X services cover both *non-safety* and *safety* V2X scenarios. Non-safety scenarios encompass mobile high data rate entertainment, mobile hotspot/office/home, dynamic digital map update, remote vehicle diagnostics [10]. However, the focus of 3GPP specifications is on V2X safety, due to the clear impact on the road transport and challenging demands.

In [11] safety-related scenarios are classified in *vehicles platooning, advanced driving, extended sensors* and *remote driving*:

- Platooning enables vehicles to dynamically form a group travelling together and move at high speeds, while being very close to each other.
- Advanced driving enables semi-automated or fully-automated driving through the sharing of data between vehicles and/or RSUs.
- Extended sensors enables the exchange of raw or processed data gathered through local sensors, or live video data among vehicles, RSUs, VRUs and V2X AS.
- Remote driving enables a remote driver or a V2X AS to operate a vehicle, e.g., under dangerous conditions.

3GPP specifies the requirements for such services in terms of *maximum end-to-end latency*, *reliability*, *communication range*, *data rate*, *payload size*. Requirements get stricter as the degree of automation increases, with latency requirements passing from 100 ms for information sharing between UEs and RSU in case of advanced driving, to 5 ms in case of remote driving.

Although the scope of 3GPP is on ensuring connectivity, the mentioned safety applications also need cloud computing resources for developing remote vehicle control systems and for the analysis and aggregation of sensor/video data from vehicles and other sources. While data stored and processed remotely may be adequate for some use cases, it can be unreliable and slow for other use cases, due to potentially long and fluctuating delay towards the cloud. In the latter cases, a MEC approach can be leveraged to move the connected car cloud at the edge.

IV. V2X Network Slicing: requirements and design guidelines

Due to the high dynamicity of the reference V2X environment and the variety of V2X services and applications, the design of V2X slices is much more complicated than for other verticals. In the following, we will dissect how the main V2X features and requirements can be translated into network slicing design features and choices.

Multiple slices/sub-slices activation. The V2X umbrella term actually covers a multiplicity of use cases, characterized by diverging service and connectivity requirements. This unique, heterogeneous feature of V2X services does not easily allow the straightforward mapping into the ITU reference slices (eMBB, URLLC, mMTC) or the mapping into a single ad-hoc designed V2X slice. Services like autonomous driving, tele-operated driving, vehicular infotainment, vehicle remote diagnostics and management will likely be mapped onto different V2X slices (or different sub-types of the same V2X slice) [24], which may be simultaneously consumed by a single vehicle. For example, a driver starts her self-driving car relying on a specifically designed autonomous driving slice, while the babies in the back seat watch a cartoon video streaming offered as a vehicular infotainment slice, and the real-time navigation applications run in background over another slice. Thus, vehicular devices should be able to attach to multiple slices/sub-slices and, possibly, simultaneously.

Multi-tenancy management. Besides traditional Internet and service providers, new players such as road authorities, municipalities, and vehicle manufacturers, will enter the V2X scene. Network slicing can effectively cope with a scenario where (typically) multiple tenants will provide a wide variety of V2X use cases with specific demands over the same 5G infrastructure. For instance, the road municipality may offer a V2V-based safety data exchange; a vehicle manufacturer can offer a vehicle diagnostics service; a content provider a video streaming, which can be mapped onto different slices and offered over the infrastructure owned by different network operators. A proper set of *flexible slice templates* should be defined which allow the vertical to properly describe the services to be supported and the desired Key Performance Indicators (KPIs). Then, the assurance of requirements is tracked by the Operations Support System (OSS)/Business Support System (BSS) w.r.t. the template specifications agreed in the form of Service Level Agreements (SLAs).

Massive communications. The AMF may be required to sustain a high load to manage a high-density of moving vehicles. To avoid the AMF to be overloaded with consequent increase in latency, while ensuring isolation with other (non-V2X) slices leveraging the same functionalities but less aggressively (e.g., pedestrian/indoor UEs), the V2X network slicing design shall enable *multiple AMF instances* to be flexibly deployed as VNFs and interconnected to meet the needs of the V2X slices.

The instantiation of the AMFs could be boosted close to highways and urban areas to accommodate the huge density of vehicles at peak hours, although it could be flexibly scaled down at off-peak hours to avoid over-provisioning. A lighter deployment could be used, instead, in rural areas. Moreover, AMF functions can be co-located with the eNodeB to ensure low-latency signaling procedures, e.g., for autonomous driving use cases.

Transparent mobility. The high vehicle speed requires frequent interactions with the network to manage mobility procedures affecting both UP and CP operations. Mobility poses serious issues to the run-time configuration of a slice. Quick path resource allocation algorithms in the backhaul/fronthaul segments should be conceived, which allow to allocate/migrate resources in another area while reducing disruption periods. The effective and efficient instantiation of a sort of *moving slice* entails proper mobility prediction modules to trigger slice reconfiguration, while also pre-fetching UP functions close to vehicles. With the introduction of MEC cloud servers, live migration and service redirection are necessary actions which increase the complexity of mobility management and handover procedures.

Heterogeneity of originating devices. Different types of UEs can activate a V2X slice for the same type of service; the heterogeneity of the originating devices asks for *slice customization*. A V2X UE can be a smartphone in the case of a pedestrian or other VRU; a transceiver unit embedded into the vehicle; an on-board infotainment platform. The communication on the PC5 interface for example shall be optimized based on the type of UE: energy efficiency is critical for a smartphone UE engaged in V2P interactions for road safety purposes. Customization of slice on a per-device level should be enabled, for instance, by enriching the slice descriptor with information about the device type.

Out-of-coverage communications. Some critical V2X applications (e.g., cooperative driving) must be ensured even in out-of-coverage conditions, which may be frequently experienced by vehicles (e.g., inside tunnels, due to urban canyon effects and under emergency scenarios). To ensure vehicles to communicate over the PC5 interface, even without the support of the network infrastructure, the UEs should be capable of autonomously deciding which sidelink resources to use.

Isolation. The network operator should carefully avoid that an abnormal situation in other applications negatively affect the Quality of Service (QoS) of V2X safety applications [10]. 3GPP partially targets this issue by suggesting the allocation of a dedicated spectrum for V2V communications over the PC5 interface [25]. The isolation of the V2X slices from other network slices must be also supported. Limiting the number of shared CP/UP functionalities, proper scheduling algorithms over the RAN and SDN-configured paths would contribute to achieve the required degree of isolation.

Security. Safety-critical V2X applications require a special care. Indeed, V2X communications may encompass critical operations; for instance, they connect vehicles to manufacturers who can alter component settings [24], they allow a cloud server to set-up vehicle trajectories, etc. Network slices with different security assurance requirements may coexist.

V. A 5G Network Slicing architecture supporting V2X customization

In this Section, we present the main design elements of a devised 5G network slicing architecture, which is illustrated in Figure 3. Although there is no single design available of a unified framework that supports the network slicing concept, there is a wide consensus on a three-layer model plus an additional management and orchestration layer, which neatly identifies the involved players and domains. Without loss of generality, our architecture builds upon the three-layer model described in [13] and includes the following layers:

Infrastructure Layer. It encompasses all the physical resources: user devices, RAN nodes, remote and edge computing, storage and networking resources.

Service Layer. It includes the virtualized network functions and logical network behaviours that realize a slice when chained together. For instance, a slice dedicated to autonomous driving relies on V2V as the prevalent RAT connection mode and on additional RAN/CN functions, e.g., for network-controlled resource allocation over the PC5 interface (in the eNodeB), mobility (i.e., in the AMF), authentication, authorization and subscription management (i.e., in the AUSF). Additionally, a ultra-low latency and highly reliable V2N connectivity with an edge-based V2X AS is also required for video/data exchange that helps vehicles in high-definition map processing of the surrounding area and to extend the visual perception of each vehicle.

Business Layer. It resides at the top of the model and includes services and use cases of the vertical markets for which slices are designed. It encompasses the mechanisms and tools to describe the slice behavior at a high level, and to capture the requirements of a given SLA for a vertical segment, whose assurance is tracked by the OSS/BSS. Such a description needs to be then translated to the underlying layers.

A **Management and Orchestration (MANO)** transversal layer includes all the tools that allow an operator to monitor, manage, orchestrate and adapt the slice's components to fulfill the negotiated SLAs by interacting with both the Infrastructure Layer and the Service Layer.

VI. Conclusions

The interest of MNOs in the automotive vertical is surging, as testified by the plenty of initiatives promoting V2X communications and networking deployment in order to address the societal needs for smart and connected transport and high road safety.

In this paper, we discussed the opportunities and challenges related to the support of the automotive vertical over 5G networks, through the slicing concept built upon the closely-knit interactions of network softwarization technologies like SDN, NFV and MEC. A set of guidelines have been provided to inspire the slicing design for V2X services, after thoroughly analyzing their peculiarities and demands.

Then, the vision of a preliminary architecture conceived to support V2X network slices has been presented, along with the instantiation of a slice for autonomous driving services.

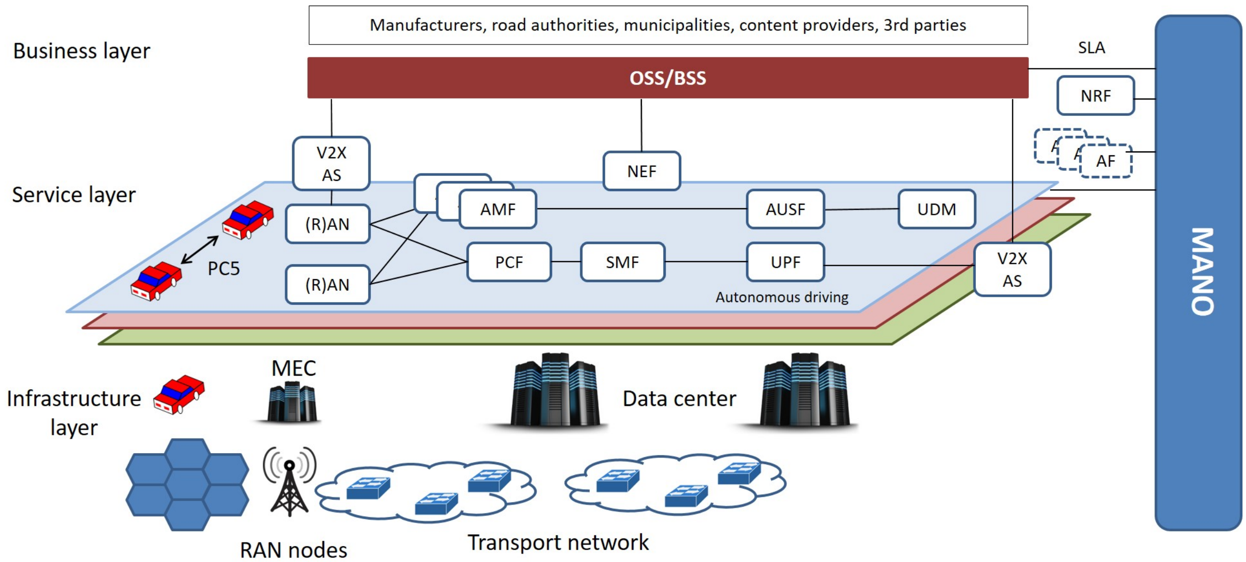

Fig. 3. Slicing architecture and slice instantiation for autonomous driving services.

Although the benefits of slicing for V2X can be sound in theory, practical validation is a necessary step that may include unanticipated critical implementation and deployment issues. So far this has not been adequately addressed and will a subject matter of our future research.

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