Fifth Generation Communication Automotive Research and innovation

Deliverable D4.2
Final Design and Evaluation of the 5G V2X System Level Architecture and Security Framework

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Abstract

Deliverable D4.2, entitled "Final Design and Evaluation of the 5G V2X System Level Architecture and Security Framework" provides a detailed description of the architectural enhancements developed by 5GCAR, which cover five areas, namely end-to-end security, network orchestration and management, network procedures, edge computing enhancements, and multi connectivity cooperation. In total, in this deliverable 14 technical components are described, considering their domain of influence on the overall end-to-end architecture together with a detailed analysis of their mapping to the 5G 3rd Generation Partnership Project (3GPP) architecture. Furthermore, this deliverable provides an analysis on the interaction among proposed technical components. Finally, it is provided a description about the benefits introduced by the technical components when it comes to improving the delivery of 5GCAR selected use cases.

Executive summary

The goal of the 5GCAR architecture work is to study and propose an evolution of the 5G Service-Based Architecture (SBA) that will be suitable to support the requirement of V2X applications. A first version of the SBA has been analysed in [5GC18-D41] which has analysed the basic aspects of the 5GCAR technical components and their mapping to the service based architecture.

Towards this direction, deliverable D4.2 further elaborates on the way the 5GCAR technical components facilitate the fulfilment the 5G V2X requirements, and captures the key features the proposed technical components address in order to facilitate the mapping of the proposed technical components to the end-to-end architecture and their possible chaining options for the realization of the use cases of interest within the 5GCAR project.

The following categories have been the focus of the architectural enhancements introduced by 5GCAR architecture technical components:

- end-to-end security, addressing security and privacy enablers
- network orchestration and management, incorporating Infrastructure as a Service (IaaS) for vehicular domain
- network procedures including Road Side Unit (RSU)-enabled Smart Zone (SM-Zone), Fast application-aware setup of unicast sidelink (SL), Location aware scheduling, Evolution of infrastructure-based communication for localised V2X traffic, Multi operator solutions for V2X communications, and, V2X service negotiation
- edge computing enhancements, incorporating edge computing in millimetre Wave Cellular V2X networks, and 5G core network evolution for edge computing-based mobility
- multi connectivity cooperation including SL and Uu multi-connectivity, Redundant mode PC5 and Uu, Use case-aware multi-Radio Access Technology (RAT), multi-link connectivity, and Dynamic selection of PC5 and Uu communication modes

Using the above grouping as reference, Deliverable D4.2, provides a coherent system architecture, which is then mapped to the reference 5G 3GPP system architecture. The 5GCAR proposed technologies are linked with the existing system using as basis the above technical families. Then network slicing is presented as a way to facilitate these enhancements.

Contents

List of abbreviations and acronyms

3GPP	Third Generation Partnership Project
5GAA	5G Automotive Alliance
5GC	5G Core Network
AF	Application Function
AMF	core Access and Mobility management Function
API	Application Programming Interface
AS	Application Server
AUSF	Authentication Server Function
B2B	Business-to-Business
BM-SC	Broadcast Multicast Service Centre
BLER	Block Error Rate
BS	Base Station
BSR	Buffer Status Report
CA	Carrier Aggregation
CAM	Cooperative Awareness Message
CHF	Charging Function
CN	Core Network
CP	Control Plane
C-V2X	Cellular-V2X
D2D	Device-to-Device
DECOR	Dedicated Core Network
DENM	Decentralized Environmental Notification Message
DL	Downlink
DN	Data Network
DNS	Domain Name Server
DSRC	Dedicated Short Range Communications
DTX	Discontinuous Transmission
E2E	End-to-End
EATA	European Automotive Telecom Alliance
eDECOR	enhanced DECOR
EM	Element Manager

eMBB	Enhanced MBB
eMBMS	evolved MBMS
eNB	evolved Node B
ETSI	European Telecommunications Standards Institute
eV2X	Enhanced V2X
ETSI	European Telecommunications Standard Institute
GMLC	Gateway Mobile Location Centre
gNB	g Node B
HD	High Definition
HO	Handover
H-PLMN	Home PLMN
HSM	Hardware Security Module
IaaS	Infrastructure as a Service
IEEE	Institute of Electrical and Electronics Engineers
IMA	Intersection Movement Assist
IMSI	International Mobile Subscriber Identity
IoT	Internet of Things
IP	Internet Protocol
ITS	Intelligent Transportation System
ITU	International Telecommunication Union
IVI	In Vehicle Signage
KPI	Key Performance Indicator
LTE	Long Term Evolution
MAC	Medium Access Control
MANO	Management and Orchestration
MBB	Mobile Broadband
MBMS	Multicast Broadcast Multimedia Service
MCH	Multicast Channel
MEC	Multi-access Edge Computing
mMTC	massive Machine Type Communications
MNO	Mobile Network Operator

MOCN	Multi Operator Core Network
MORAN	Multi Operator RAN
MPTCP	Multi Path TCP
MSP	MCH Scheduling Period
NAS	Non Access Stratum
NEF	Network Exposure Function
NF	Network Function
NFV	Network Functions Virtualisation
NFVI-PoP	NFV Infrastructure - Point of Presence
NFV-O	NFV Orchestrator
NR	New Radio
NRF	Network functions Repository Function
NSSF	Network Slice Selection Function
OEM	Original Equipment Manufacturer
ONAP	Open Network Automation Platform
OSS	Operations Support System
OTT	Over The Top
PCF	Policy Control Function
PCRF	Policy and Charging Rule Function
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDCP_RSR	PDCP Reception Status Report
PDU	Protocol Data Unit
PHY	Physical (layer)
PKI	Public Key Infrastructure
PLMN	Public Land Mobile Network
PLMNO	Public Land Mobile Network Operator
PNF	Physical Network Function
PoP	Point of Presence
ProSe	Proximity Services
PSA	PDU Session Anchor
QUIC	Quick UDP Internet Connections
QoS	Quality of Service

RAN	Radio Access Network
RAT	Radio Access Technology
RB	Radio Bearer
RBMT	Radio Bearers Mapping Table
REST	Representational State Transfer
RF	Radio Frequency
RLC	Radio Link Control
RNTI	Radio Network Temporary Identifier
RRC	Radio Resource Control
RSU	Road Side Unit
SaaS	Software as a Service
SBA	Service-Based Architecture
SBI	Service-Based Interface
SC-PTM	Since Cell Point-to-Multipoint
SDN	Software Defined Networking
SDO	Standard Development Organisation
SIB	System Information Block
SIM	Subscriber Identity Module
SL	Sidelink
SLA	Service Level Agreement
SMF	Session Management Function
SON	Self-Organizing Network
SPaT	Signal Phase and Time
SPS	Semi Persistent Scheduling
SR	Scheduling Request
SSP	Service-Specific Permission
SURB	Secondary Uu Resource Block
S-GW	Serving Gateway
TAU	Tracking Area Update
TC	Technical Component
TCP	Transmission Control Protocol
TMSI	Temporary Mobile Subscriber Identity
TTI	Transmission Time Interval
UC	Use Case
UDM	Unified Data Management
UDP	User Datagram Protocol

UDR	Unified Data Repository
UE	User Equipment
UL	Uplink
UP	User Plane
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communications
UTRAN	Universal Terrestrial Radio Access Network
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2N2I	Vehicle-to-Network-to-Infrastructure
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VIM	Virtualised Infrastructure Manager
VNF	Virtualised Network Function
VNFM	VNF Manager
VRU	Vulnerable Road User
V-PLMN	Visited PLMN
WG	Working Group

1 Introduction

The automotive sector is one of the most prominent verticals that will benefit from the upcoming 5G cellular networks. Vehicular applications cover a wide range of use cases, which will introduce strict requirements in terms of data rate, timely service delivery, and ultra-low communication latencies, just to mention a few. It is thus evident that Vehicle-to-Everything (V2X) communications will not only leverage 5G network, but will play an important role in the definition of their design. In 5GCAR, we have worked towards the definition of enhancements in terms of system architecture, security and privacy, specifically targeting automotive applications: in this document, we present the results of the studies performed.

1.1 Objective of the document

The objectives of the deliverable D4.2 *"Final Design and Evaluation of the 5G V2X System Level Architecture and Security Framework"* are to develop an overall 5G system architecture, conceived to provide optimized end-to-end V2X network connectivity for highly reliable and low-latency V2X services, including security and privacy, QoS and traffic flow management in a multi-RAT and multi-link V2X communication system.

In this document, representing the final deliverable of 5GCAR architecture, we present the final finding of the project related to the system architecture, including the definition of the end-to-end architecture paradigm, and the definition of a paradigm of network slicing for V2X. The technical contributions of the project are structured in the form of "technical components", which are introduced, described, and evaluated in this document. Technical components cover several aspects of the network architecture, including multi-link and multi-radio access technology cooperation, edge computing, security and privacy. Recommendations are then provided on how to integrate the technical components in order to satisfy the communication requirements of the use cases defined in 5GCAR.

1.2 Contributions and achievements

In this document we present an overview of the work performed in 5GCAR in the domain of 5G V2X system and architecture, including contributions in different areas of interest for architectural enhancements, among which we mention:

- The definition of an end-to-end proposition of architecture extensions for vehicular communications, based upon the 3GPP Release 15 architecture, which relies of extensions of the already standardized network functions to serve automotive applications, hence not requiring the definition of new network functions;
- The definition of a network slicing paradigm for V2X, which relies on a set of slices belonging to the types already standardized;

- Novel propositions for E2E security in V2X, and a set of recommendations concerning privacy matters, which are of particular interest on the wake of new regulations being discussed and introduced in the European Union;
- A collection of technical enhancements concerning the network architecture, belonging to the following categories:
    - end-to-end security,
    - network orchestration and management,
    - network procedures,
    - edge computing enhancements, and
    - multi-connectivity cooperation.

  Technical components are described, and evaluated; furthermore, in this document we present the interactions between technical components, and how they can be combined;
- A set of recommendations are provided in terms of which technical components could be implemented and chained to support the use cases defined in 5GCAR.

The architecture work performed within 5GCAR resulted in contributions to standardisation and pre-standardisation bodies, as shown in Annex A.

1.3 Structure of the document

This document is articulated in 4 main chapters, as described in the following.

Chapter 2 “System architecture” introduces the final architecture proposed in 5GCAR, including a definition of the end-to-end architecture itself, a description of the areas of architectural enhancements considered by the project. The contributions of the project come in the form of technical components, which is a concept defined in this section; furthermore, the reference architecture is presented, along with how the technical components map onto it.

Chapter 3 “Technical components” is dedicated to the description and evaluation of the technical components regarding the system architecture and security.

Chapter 4 “Integration and use case support” deals with the integration of technical components, presenting the ways they interact and interwork with each other, along with a set of recommendations on how to utilize them to support the requirements imposed by the use cases defined in [5GC19-D21].

Chapter 5 “Conclusions”, finally, concludes the document, and presents recommendations concerning the architecture design for V2X, the support of the vehicular use cases defined in the 5GCAR project, and finally introduces conclusions and recommendations on privacy matters, which are of particular relevance considering the regulations currently under discussion.

Furthermore, Chapter 6 contains the references utilised in the document, and Annex A summarises the contributions related to the architecture made by 5GCAR partners to various standardisation and pre-standardisation bodies

2 System architecture

The main objective of the Work Package 4 is the definition of a system architecture template designed to enhance the support of Vehicle-to-Everything (V2X) communications, tailored to support automotive applications. In this chapter, we introduce a first description in Section 2.1.1 of the architectural extensions introduced by the project, referred to as “technical components” (sometimes with the abbreviated form “TC”) which are grouped in several classes to facilitate the presentation of the areas of enhancement covered by 5GCAR. In Section 2.1.2, we introduce the 3GPP architecture considered as reference architecture in 5GCAR, and provide an overview of the mapping of 5GCAR technical components to the reference architecture. In Section 2.2 network slicing is introduced, which is a notable enabler for the network infrastructure to offer differentiated services with precise requirements in terms of Quality of Service (QoS). Further critical enablers for 5G networks, namely network function virtualisation and software defined networking, are presented in Section 2.3, along with an analysis of their impact and specific significance in V2X context.

2.1 End-to-end architecture description

In 5GCAR, we consider several flavours of enhancements which touch different features of the network architecture. In 5GCAR, we propose a collection of technical solutions, referred to as “technical components”, designed to address specific needs and requirements of automotive applications and the related V2X communication needs. As far as architecture is concerned, 14 technical components have been defined, belonging to the following areas:

- end-to-end security
- network orchestration and management
- network procedures
- edge computing enhancements
- multi-connectivity cooperation

More details on above listed areas are given in Sec. 2.1.1, with also information on the mapping of the technical components to the relevant classes. Moreover, in Sec. 2.1.2, it is provided an overview of the 3GPP 5G architecture used as reference architecture in 5GCAR and the mapping of 5GCAR components to the architecture.

2.1.1 Areas of architectural enhancements

The architectural enhancements introduced by 5GCAR can be summarized in five different areas, which are now discussed in more details.

End-to-end security

Security and privacy are two key requirements for V2X communication and applications and 5GCAR considered the impact that security and privacy might have on the communications. As an example, some concerns should be raised about some security operations that may themselves add too much latency and defeat 5GCAR use cases latency requirements. One example is signing all messages with a Hardware Security Module (or USIM - Universal Subscriber Identity Module). As a feature of enhancement for end-to-end security, 5GCAR consider, whenever possible (application specific), to establish communication sessions between vehicles and application servers, or among group of two or more vehicles, with the benefit that only initial messages are signed and all permissions verified, then a session encryption key being agreed upon, further message exchanges are only encrypted.

The proposed 5GCAR enhancement would also apply to the exchange of V2X vehicle-to-vehicle awareness messages, or other vehicle-to-infrastructure/infrastructure-to-vehicle messages, which are all signed and need to be verified by receivers in today Cooperative Intelligent Transportation Systems (C-ITS) security. UEs (vehicles or UE-type roadside units) should use certificates that comply with the European Commission ITS certificates policy, to authenticate themselves and assert their permissions.

Network orchestration and management

Network orchestration and management play a key role in order to optimize the deployment of a network and to maintain the network during its lifetime. Such aspects consequently impact network performance. From a network infrastructure point of view, it will rely on servers distributed at several locations: at the edge on the Multi-access Edge Computing (MEC) server or on local/edge cloud capabilities, at district level (big town, or group of towns), at regional level, at country level, and more centralized (at the Internet for instance). The orchestration of such infrastructure should be able to define a set of infrastructure services enabling to automate deployments, maintenance, management, configuration, upgrade, repair of each component of the system. In addition, another aspect related to network management to be considered is related to the relationship with the variation of road traffic conditions, e.g., road may experience some 10 folds increase of vehicle density compared to that of preferred road traffic situations. This brings to the need of having a network able to dynamically reconfigure itself to adapt to varying load conditions.

Benefits introduced by 5GCAR for network orchestration and management are in terms of improved orchestration capabilities able to cope with the unique requirements of vehicular use cases and with improved network management and re-configurability capabilities to cope with the dynamicity in terms of traffic demand of vehicular scenarios.

Network procedures

The delivery of a service in a mobile network involves several network procedures, spanning from network-application interaction, connectivity establishment, to mobility management, and user plane management, just to mention a few. Such procedures impact the effectiveness of service delivery (e.g., some procedures might introduce latency) and such issues are exacerbated in vehicular environments. 5GCAR identified challenges that are not only limited to vehicle mobility, but also related to roaming, exchange of service requirements which extend legacy QoS parameters, and localized traffic.

Enhancements on network procedures introduced by 5GCAR are in terms of improved management of roaming scenarios, enhancements in the awareness of service requirements and additional related information for the network when delivering a certain vehicular use case, optimization of control and user plane paths, and finally optimization of scheduling capabilities considering vehicle mobility.

Edge computing enhancements

Availability of computing capabilities at the edge of the network (i.e., edge computing) opens for several improvements in mobile networks to support vehicular use cases. To take fully advantage of edge computing, enhancements are needed from a core network perspective as well as from an access network point of view.

Benefits of edge computing enhancements introduced in 5GCAR are related to improvements in handover management and edge-computing based radio access optimization.

Multi connectivity cooperation

Vehicular services are expected to exploit infrastructure-based links (i.e., Uu) as well as direct Vehicle-to-Vehicle (V2V) links (i.e., Sidelink - SL). These two links have different characteristics and consequently are associated to different features, e.g., SL is expected to provide better resource efficiency, latency reduction and out-of-coverage support while Uu is expected to offer higher reliability and/or higher data rate. 5GCAR identified that the exploitation of only one communication mode (i.e., only Uu or only SL) might not be sufficient to meet the requirements of complex V2X environments. In addition, environments with the availability of multiple RATs could be also considered, thus extending above challenges considering that each RAT has its own features in terms of performance such as reliability, capacity, latency, etc. 5GCAR also identified the issue that the selection of a suitable communication mode or technology should not only be driven by the Quality of Service (QoS) requirements of the related traffic, as many V2X use cases (e.g., lane merge) should focus more on the completion of a certain action (e.g., a vehicle safely merging into the main road) and this should be thus reflected on the chosen communication mode/technology to allow the completion of the use case.

The benefits of approaches for multi-connectivity cooperation considered in 5GCAR are in terms of improved performance (e.g., reliability, data rate) with also higher resilience to link failure. Benefits might also be related to improved service availability by jointly using several communication modes or technologies instead of relying only on one mode/technology that might not be able to support some use cases on its own.

List of architectural technical components

The complete list of technical components related to the system architecture presented by 5GCAR is depicted in Table 2.1, wherein each component is labelled by a number, and associated to one of the areas introduced above. A more detailed description of each of the components is provided in Section 3 of this document.

Table 2.1: Architectural technical components defined in 5GCAR

#	Technical component (TC)	Area
1	RSU enabled Smart Zone (SM-Zone)	Network procedures
2	Fast application-aware setup of unicast SL	Network procedures
3	SL and Uu multi-connectivity	Multi-connectivity cooperation
4	Location aware scheduling	Network procedures
5	Infrastructure as a Service (IaaS) for vehicular domain	Network orchestration and management
6	Redundant mode PC5 and Uu	Multi-connectivity cooperation
7	Evolution of infrastructure-based communication for localised V2X traffic	Network procedures
8	Use case-aware multi-RAT, multi-link connectivity	Multi-connectivity cooperation
9	Multi operator solutions for V2X communications	Network procedures
10	V2X service negotiation	Network procedures
11	Edge computing in millimetre Wave Cellular V2X networks	Edge-computing enhancements
12	Dynamic selection of PC5 and Uu communication modes	Multi-connectivity cooperation
13	Security and privacy enablers	End-to-end Security
14	5G core network evolution for edge computing-based mobility	Edge-computing enhancements

Figure 2.1 illustrates the ensemble of the architectural technical components, organised per area, along with their domain of influence, which may include the radio access network (RAN), the core network, the application server, or combinations thereof.

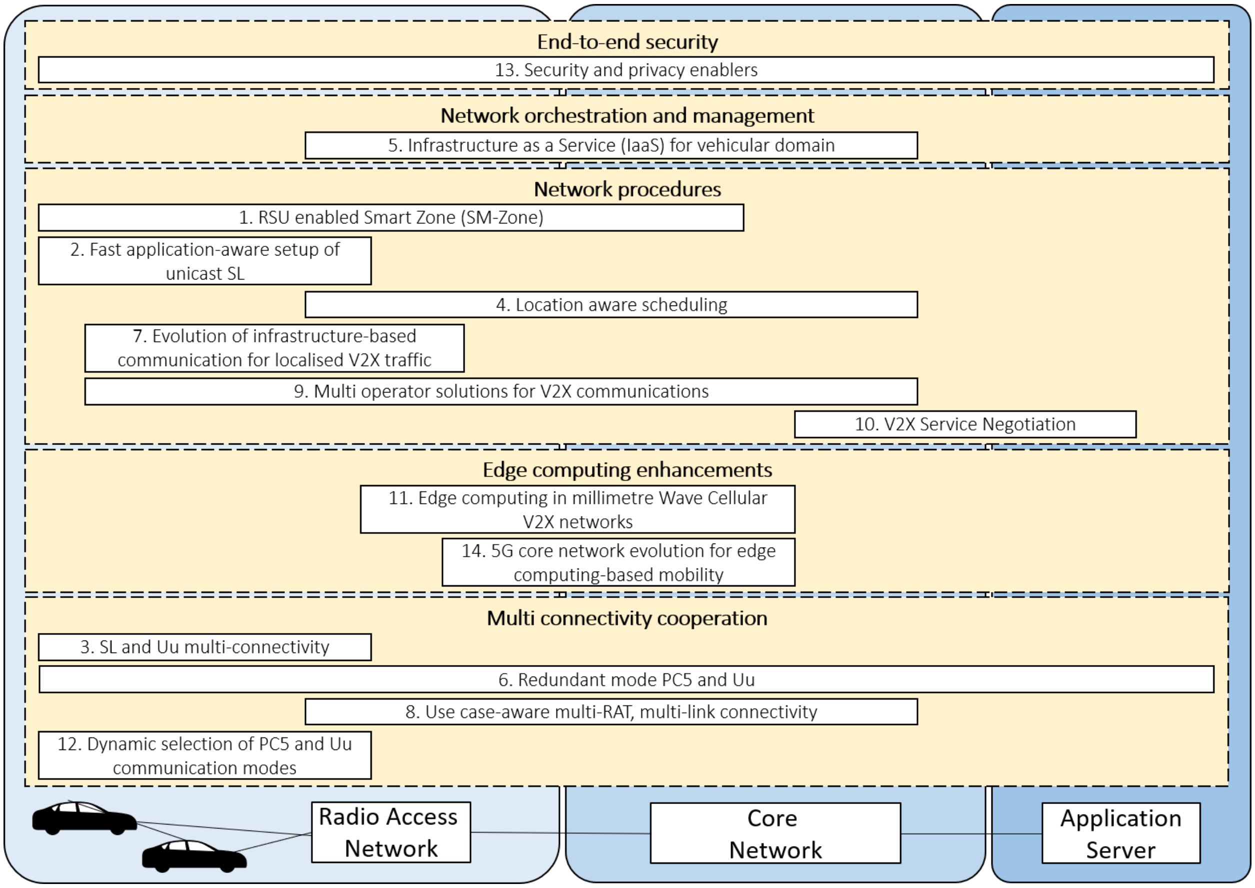


Figure 2.1: 5GCAR technical components mapped, organized per area of relevance, highlighting their domain of influence in the end-to-end architecture.

2.1.2 Reference architecture

5G networks have been designed by the 3rd Generation Project Partnership to be flexible and extensible, in order to be able to support applications, services, and vertical currently existing, and the new ones that will emerge in the decade to come. In 5GCAR, we recognized the inherent flexibility of the 3GPP Release 15 architecture design and established that the innovations proposed by the project will be based upon it, which is therefore considered the reference architecture. More details about it are provided in the next part of this section.

5G Service-Based Architecture

The 5G architecture breaks ground with respect to the previous generations by introducing the concept of Service-Based Architecture (SBA), wherein the design of the Control Plane (CP) is centred on services rather than on interfaces, and Network Functions (NFs) are defined, instead of network entities. Such 5G architecture, defined in [3GPP17-23501], currently is provided in two representations, namely the “service-based” representation and the “reference point” representation, respectively illustrated in Figure 2.2 and Figure 2.3. Both figures contain building blocks, each representing a NF. The list of NFs, along with a reference to the section in [3GPP17-23501] containing their formal definition, is provided in Table 2.2. The interested reader may also refer to [5GC18-D41], wherein a synthesised description is provided for each of the depicted network functions.

In the 3GPP Release 15 architecture, control plane functions are interconnected to each other on a service-basis: each function is provided with an interface through which it can offer services to other functions, or subscribe to services offered by other functions. These services are web-based, utilizing Representational State Transfer (REST) Application Programming Interface (APIs).

Interfaces and dedicated protocols are on the other hand still in place for the interconnection between the control plane and the user plane.

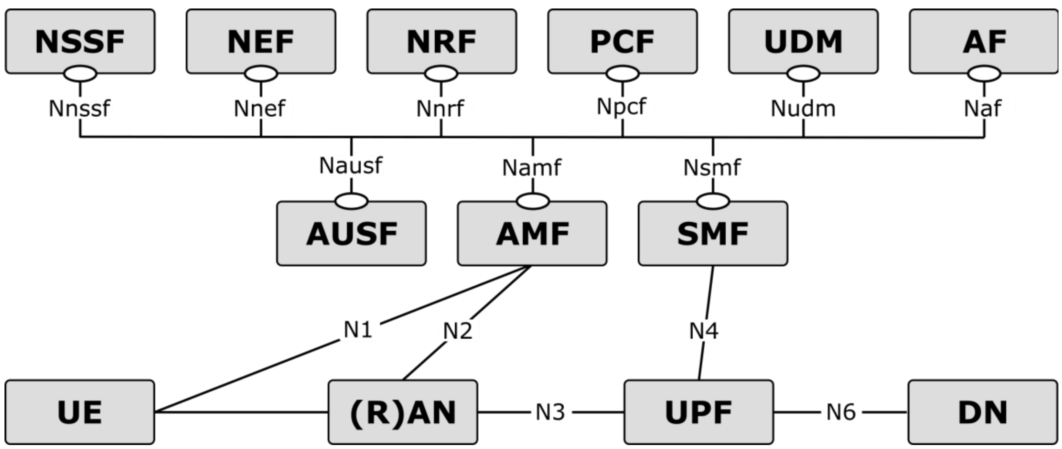


Figure 2.2: 5G System architecture

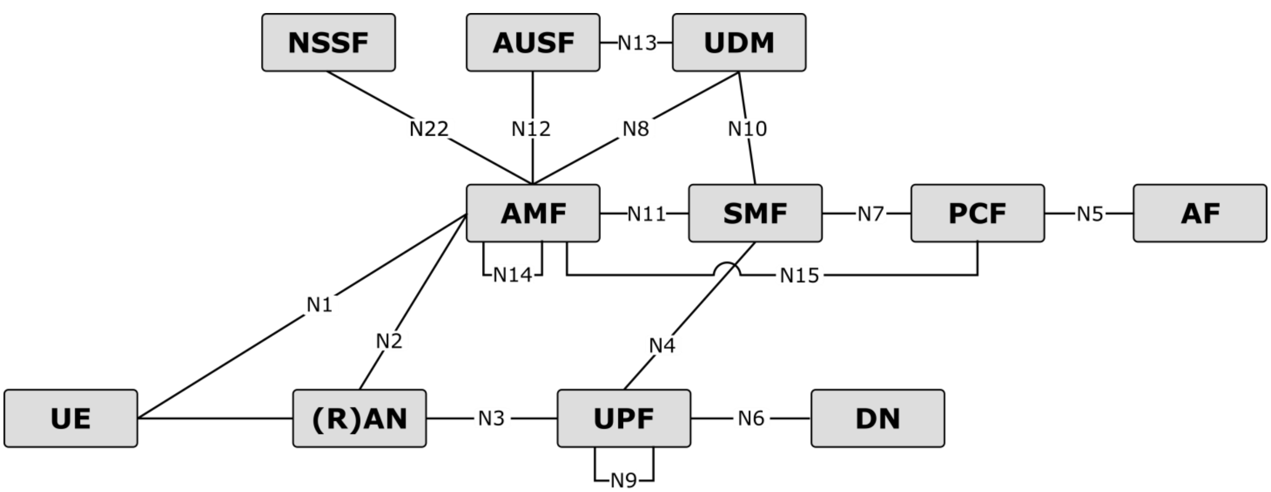


Figure 2.3: Reference point representation of the System architecture

Table 2.2: 5G Network Functions

NF acronym	NF full name	Clause in [3GPP17-23501]	
AF	Application Function	6.2.10	Control Plane (CP)
AMF	core Access and Mobility management Function	6.2.1	
AUSF	Authentication Server Function	6.2.8	
NEF	Network Exposure Function	6.2.5	
NRF	Network functions Repository Function	6.2.6	
NSSF	Network Slice Selection Function	6.2.14	
PCF	Policy Control Function	6.2.4	
SMF	Session Management Function	6.2.2	
UDM	Unified Data Management	6.2.7	
DN	Data Network	-	User Plane (UP)
UPF	User Plane Function	6.2.3	
RAN	Radio Access Network	-	UP+CP
UE	User Equipment	-	

Mapping of 5GCAR technical components to the reference architecture

The technical components developed in 5GCAR are designed to address specific features required by particular applications, use cases, and communication patterns. This results in each technical component having a different mapping to the reference architecture, which is illustrated in Figure 2.4. In Figure 2.4, the reference architecture is represented with addition of the Network Data Analytics Function (NWDAF), which is defined by the 3GPP, along with its interface to connect to the SBA, but not included in 3GPP's non-roaming reference architecture illustration. With "mapping to the architecture", we refer to the ensemble of network functions belonging to the 3GPP 5G reference architecture that require modifications and extensions to support the functionalities of a given technical component. Figure 2.4 is meant to provide a global view, for practical reason: a potential implementer may select the subset of technical components to be implemented in order to support a given use case, and identify the subset of network functions that require extensions. This possibility is enabled by the flexibility of the

3GPP Release 15 architecture, where different "flavours" of network functions can be defined, according to the specific requirements of a given use case to be supported.

Further guidelines on how to select technical components are provided in this document in Section 4, where indications are provided about which technical component are suitable to support the requirements of the use cases defined in [5GC19-D21]. Figure 2.4 represents an aggregated view, illustrating the mapping of all the TCs on the reference architecture: it does not imply that all technical components need to be simultaneously implemented. Instead, the choice of which TCs to implement is determined by the use case, and by its specific requirements. Furthermore, in Figure 2.4, two instances of the UE are depicted, in order to highlight both the Uu and the PC5 link: the impact of the technical components on those specific links is also indicated separately. More details on the realization of the technical components are given in Section 3.

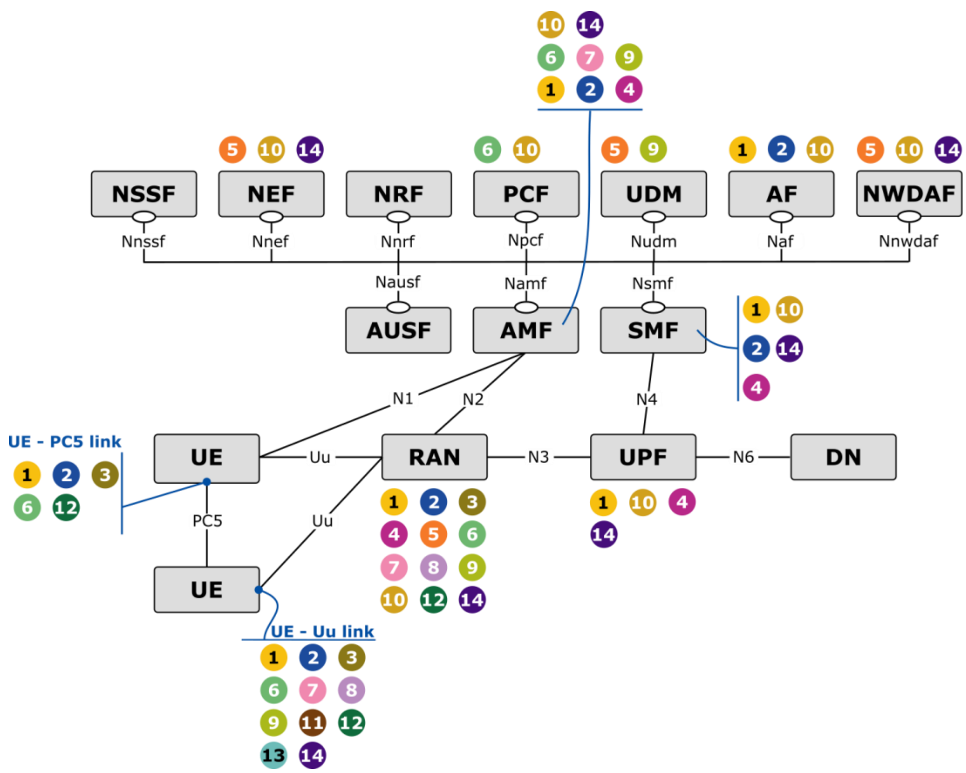


Figure 2.4: Mapping of 5GCAR architecture technical components to 5GS architecture

2.2 Network slicing

With respect to previous generations, 5G is vastly expanding the set of use cases, communication needs and traffic patterns to be supported by cellular networking. Broadly speaking, these span from enhanced Mobile Broadband (eMBB), to ultra-Reliable Low Latency

Communications (uRLLC), massive Machine Type Communications (mMTC), and any combination thereof. Globally, this results in a considerable heterogeneous set of requirements, which prove challenging to be served by a monolithic network, as conceived in previous generations.

This is where network slicing comes into play: network slicing is a novel architectural paradigm, according to which the overall communication system is composed by a collection of slices running in parallel and independently from each other on top of the same physical infrastructure. Each slice is one end-to-end logical network designed to specifically address the needs of a well-defined set of services. According to the 3GPP definition, a slice is “a logical network that provides specific network capabilities and network characteristics” [3GPP17-23501, §3.1]. For the interested reader, we provided an overview of the definitions of slices from different entities, including ETSI, ITU, and NGMN in [5GC18-D41, §A.2.1].

Network slicing, in conjunction with QoS mechanisms like dedicated bearers, provides the means to reliably deliver differentiated performance levels to different classes of services: network slicing allows optimizing the entire network, including the geographic deployment of network functions, and the selection of resources allocated for them. This is of particular relevance for automotive application, and by consequence for 5GCAR. In the reminder of this section, we will provide a brief introduction to network slicing and its challenges, and then illustrate the specificities of slicing for V2X, along with 5GCAR views and propositions.

2.2.1 Network slicing: an overview

Network slices are end-to-end entities within the 3GPP domain, controlled by the Mobile Network Operator (MNO), including the UE, the radio access network, and the control plane and user plane of the core network, this latter until the latest UPF before reaching the data network. Due to their substantial different nature of the radio access network and core network, and the different sets of challenges they introduce slicing is applied in different manners to these two parts, as described in the following of this section.

Core network slicing

Core network slicing is made possible by a multitude of network enablers being developed in recent years, including Software Defined Networking (SDN) and Network Functions Virtualisation (NFV), which are treated in detail in Section 2.3 of this document. In particular, softwarisation and virtualisation enable a major paradigm shift in networking, wherein network entities are no longer implemented by dedicated hardware running custom firmware; instead, they are implemented as software functions running on a virtualised environment hosted on physical servers. This flexibility allows the implementation of core network slices tailored to supporting the specific needs of a given use case. From a practical standpoint, it enables the following features:

- each slice will only need to implement those NFs that are necessary to support a defined set of services. In particular, some NFs may not be needed for a given service.

- only the desired "flavour" of each NFs needs to be deployed, exclusively supporting the set of functionalities strictly required by the use case: each NF instance is hence created by selecting only the required software components; furthermore, "flavour" could also mean the configuration of the NF is optimized for the use case
- each NF is assigned, in the virtualised environment, an appropriate amount of computational, storage, and networking resources to support the Service Level Agreement of the services to which it is dedicated. Slices offering higher reliability, for instance, will implement a higher degree of redundancy;
- NFs can be chained, i.e. interconnected with each other, in the most convenient way, according to the service delivery requirements
- NFs can be deployed in the most appropriate location, such as in the Public Land Mobile Network Operator (PLMNO) central cloud, the edge cloud, or intermediate data centres/aggregation points, if available: in case of edge deployment latency can be reduced for applications requiring this, such as automotive safety-critical services, wherein the delay introduced by the transport network is reduced by moving the data plane processing as close as possible to the users.

Even if virtualization is an important technical enabler for network slicing, it is not a mandatory pre-requisite. Some functions, in particular the ones that are most critical in terms of hard real time requirements, are likely to be deployed on dedicated hardware, at least in a preliminary phase.

Radio access network slicing

Network slicing the radio access network imposes a different set of challenges than the core network. The spectrum, in fact, is a limited resource that needs to be carefully managed in order to avoid spectrum inefficiencies. Slicing the RAN is equivalent to managing the limited available bandwidth among UEs requesting different kinds of services. The 3GPP standard (according to current Rel-16 status) does not add RAN slicing capabilities but assumes this to be achieved through radio resource management (e.g., Medium Access Control – MAC – scheduling), which is traditionally not standardized in 3GPP but left to implementation and configuration. 5GCAR considers three possible options for RAN slicing, which are a subset of those first identified in [5GN17-D32], represented in Figure 2.5.

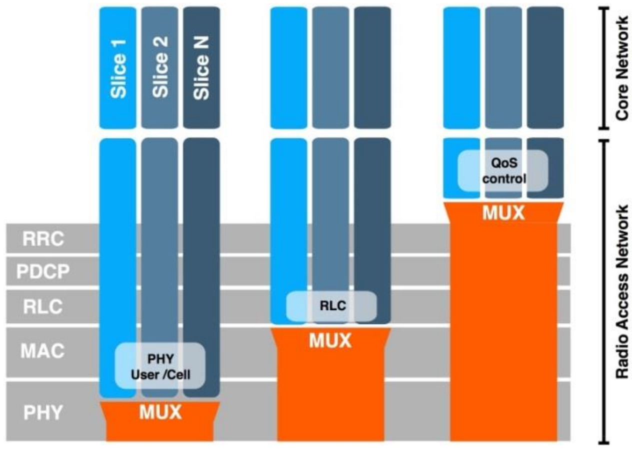


Figure 2.5: 5GCAR RAN slicing options

These options are differentiated from each other by how deep slices extend into the radio protocol stack. Starting from the left in Figure 2.5, these options are:

- Option 1: every slice has its own independent radio stack starting from above the Physical (PHY) layer. Transmission functionality is shared between all the network slices, while all other functions are slice-specific. This option can be used for mixing different radio access technologies; it is the most efficient in terms of traffic isolation between slices, but results in poor flexibility.
- Option 2: PHY and MAC layers are common to all slices, while the layers from RLC and above are slice-specific. This configuration implies there is a unique MAC-layer scheduler for all of the slices. This option can be seen as an intermediate degree of isolation and customisation.
- Option 3: implementing core network slicing with a shared RAN. It can be seen as a 3GPP multi operator core network using an advanced QoS differentiation at the RAN level. This solution is optimal in terms of multiplexing gain, but is the most challenging one when it comes to ensure traffic isolation.

The NG-RAN and 5G radio interface introduce a multitude of innovations that can be exploited in conjunction with network slicing to improve the support of diverse classes of services, including:

- flexible numerology, which enables the support within the same band of ultra-low latency services, and high throughput mobile broad band;
- mini-slots, which enable fast flexible scheduling of delay sensitive services (this concept is studied in 5GCAR for C-V2X applications)
- downlink pre-emption is a further mechanism to support ultra-low latency transmissions, by pre-empting already allocated resources used by eMBB transmissions, for utilization by urgent URLLC transmissions.
- grant free uplink, which reduces the scheduling overhead for delay-sensitive uplink transmissions: these can be performed by selected UEs without requesting a grant.

Benefits and challenges of end-to-end network slicing

End-to-end network slicing enables operators of 5G networks to provide differentiated level of service to different classes of users and services, by serving them through appropriately instantiated network slice. Furthermore, slicing provides a mean to isolate traffic flows, in that variations of traffic in a slice do not cause a violation of the Service Level Agreement (SLA) terms agreed on for other slices running on the same physical network.

Network slicing enables the concept of multi-tenancy, wherein different slices may be assigned and, to a certain extent, managed by or on behalf of a tenant. A tenant may be the PLMNO itself, another operator, a service provider, or a third company which may desire to rent a slice to offer tailored services to its clients.

There are many challenges to be solved to achieve this goal, however, including the management of the increased complexity on the core network side, and the fact that on the radio channel allocating a certain amount of resources to a slice does not necessarily equate to providing the expected throughput.

2.2.2 Network slicing for V2X

Vehicular communications represent at the same time an excellent case study and motivation for network slicing, since they involve multiple use case, traffic types, and communication paths, as illustrated in Figure 2.6.

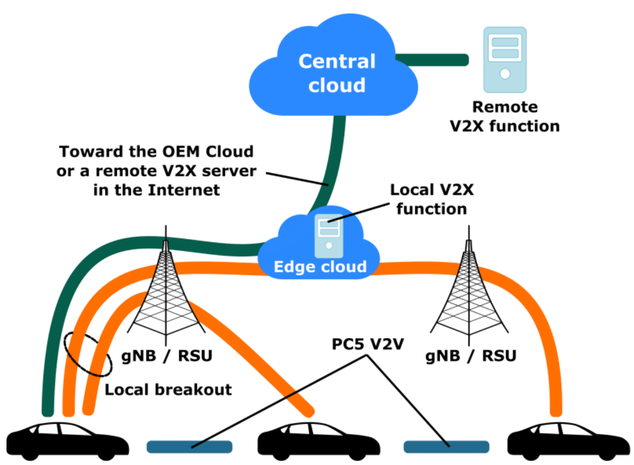


Figure 2.6: V2X end-to-end communication paths

Communications with remote servers are routed by the network via their central office clouds, whereas local servers reduce the length of the data path by being closer to the end-user. Communications between vehicular UEs in proximity may involve different path: the PC5 link can be used for direct V2V/V2P communications, whereas local breakout can be applied for V2N2V links routed through the edge network. Use cases with relaxed delay constraints may not require local breakout towards the edge, if performant transport networks are available. In special cases of local UPF or local breakout, the base station or road side unit can directly relay the messages to the UEs in proximity, and/or route them to UEs covered by neighbouring cell via short routing paths via the edge data centre.

Automotive applications include a wide set of services, offered by different providers, each imposing a specific set of requirements. For this reason, vehicles shall be served, at any given time, by a collection of network slices, each instantiated by the mobile service provider with characteristics appropriate to support the related service. This collection is composed by slices belonging to the standard types already defined by 3GPP, notably the “enhanced Mobile Broadband”, and the “ultra-Reliable Low Latency Communications”. Considered the flexibility provided by the definition of slicing, it is not necessary to define new types.

We provide an example of how to utilize a collection of slices to serve all the diverse V2X applications in Figure 2.7, where we provide an example of deployment of slices for a vehicular UE.

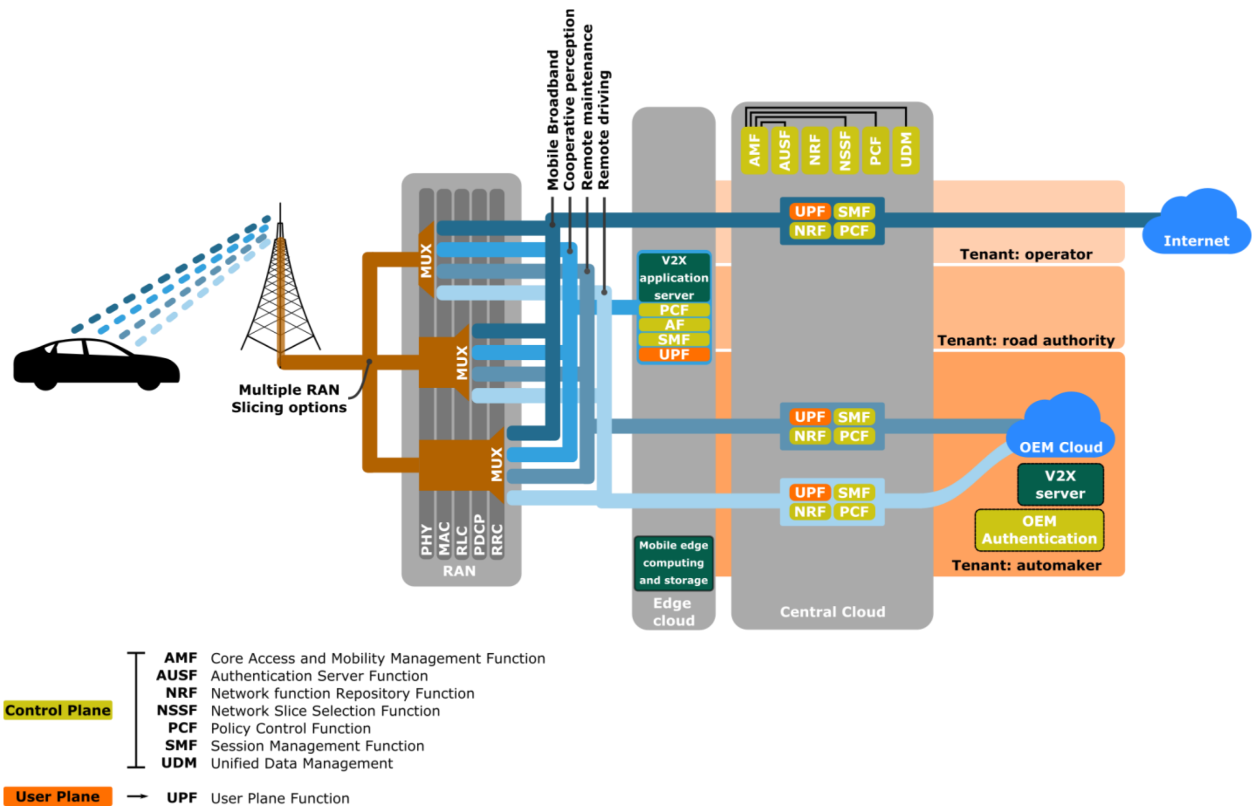


Figure 2.7: example of typical V2X network slicing configuration

The system illustrated in Figure 2.7 provides an example configuration of a sliced communication system consisting of multiple logical networks for different automotive service domains. Both the RAN and the core network domains are shown, with the latter being split into edge cloud and central cloud, to reflect the geographical locations where network functions can be deployed. The RAN illustrates the three possible option for RAN slicing we briefly introduced in this document; the edge cloud contains the network functions that may be allocated in proximity of the UEs, such as the Multi-access Edge Computing (MEC) and storage; finally, the central cloud contains the control functions common to all the slices within the same network (illustrated in the upper part of the figure), and the slice-specific NFs for use cases that require connectivity with the Internet or with a public network.

The concept of multi-tenancy is notably leveraged in vehicular applications, wherein the tenant is the subject (company, vertical, or service provider) who benefit from the services supported by one slice, or one set of slices. In this example, we consider three tenants: the Mobile Network Operator (labelled as “operator” in the figure), the road operator, and a generic automaker. All slices are deployed on the same physical infrastructure, belonging to and being managed by the Mobile Network Operator (MNO), which can also be the tenant of network slices. In the case study presented, the operator manages the Mobile Broadband slice, which supports best-effort services, such as infotainment.

Road authorities would as of today be interested in C-ITS services like hazard warning and in-vehicle signage but in the future might be interested in offering cooperative perception services, which shall be available on every road. Cooperative perception involves information that is both strictly time-sensitive and location-sensitive: in fact messages are transmitted and received by vehicles to spread and acquire information about the instantaneous traffic conditions in their surroundings. These services hence need an ultra-low latency slice with high reliability, since the successful and timely reception of these messages is safety-critical. For this reason, network resources could be mostly allocated in the edge cloud, as close as possible to the users. Alternatively, sufficient transport network resources towards the central cloud must be allocated for the slice.

Road authorities can furthermore offer cooperative manoeuvre services, such as the lane merge assistance considered in 5GCAR, which also benefit from a local edge-cloud deployment of network functions or well dimensioned transport network resources to reduce latency and increase reliability.

The automaker, also referred to as Original Equipment Manufacturer (OEM), may offer different classes of services to its client: in the case represented in Figure 2.7, these include the remote maintenance and remote (tele-operated) driving. Both these services require connectivity between the vehicle and the OEM cloud, but with completely different service level requirements.

In the former case, the slice supports machine type communications which could be delivered via an eMBB slice, used to retrieve data from the on-board sensor to forward plan the maintenance of large vehicular fleet. Remote driving, on the other hand requires low latency, high data rate, and high reliability in the uplink to provide a real-time video flow and/or instantaneous sensor data to the remote driver, and in downlink to deliver the driving commands to the vehicle. Both these slices allocate NFs mostly in the operator’s central cloud, but with completely different purposes and degrees of redundancy. In both cases, however, the OEM can implement further authentication functions beyond those offered by the network, as well as hosting the V2X application server in their premises.

Network slices natively enable the support of dedicated bearers, which can be leveraged to provide tailored QoS to specific applications. Distinct applications are assigned to specific bearers (in the radio access network), and flows (in the core network), which are treated with a different level of priority.

2.3 Network function virtualisation and software-defined networking

3GPP has described and detailed network slicing in the references mentioned in Table 2.3.

Table 2.3: 3GPP references on network slicing

3GPP	TR	[3GPP18-28801]	Network slice MANO study
3GPP	TS	[3GPP19-28531]	Network slice Provisioning
3GPP	TS	[3GPP19-28541]	Network slice IM & DM YANG

With this regards, ETSI NFV analysed the network slice data model [ETSI17-EVE012] in order to provide a unified data model which considers 3GPP Network Slices and ETSI NFV Network Services. Figure 2.8: shows the reported relationship between them. It can be observed that a Network Slice Subnet can be considered as an NFV Network Service. Moreover, 3GPP Network Functions can be described as Virtualised Network Functions (VNF) and Physical Network Functions (PNF). With regards to the NFV Management and Orchestration (MANO) framework, [ETSI17-EVE012] proposes a new element inside Operations Support System / Business Support System (OSS/BSS) in order to handle network slice lifecycle. This element shall be connected through NFV standard interfaces towards NFV-Orchestrator (NFV-O) and Element Managers (EMs).

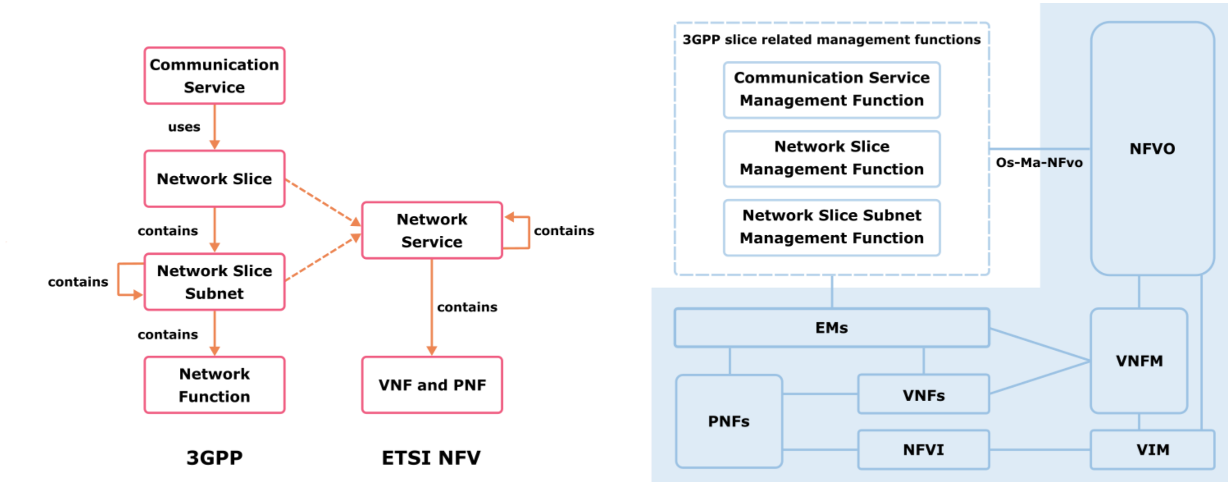


Figure 2.8: Relationship with 3GPP Network Slices and ETSI NFV Network Services.

[ETSI17-EVE012] allows us to focus on how V2X network slices shall be deployed from the NFV orchestration perspective. This is the reason why Figure 2.9 shows the location of NFV orchestrator (NFV-O) in the previously presented network slicing scenario. It is of significance to remark that a single NFV-O might be used, as it can handle multiple slice deployments as requested by OSS/BSS. Moreover, certain related topics will be later detailed, such as VNF function placement (edge or core locations), integration of Mobile Edge Computing (MEC) and mobility support for edge computing functions.

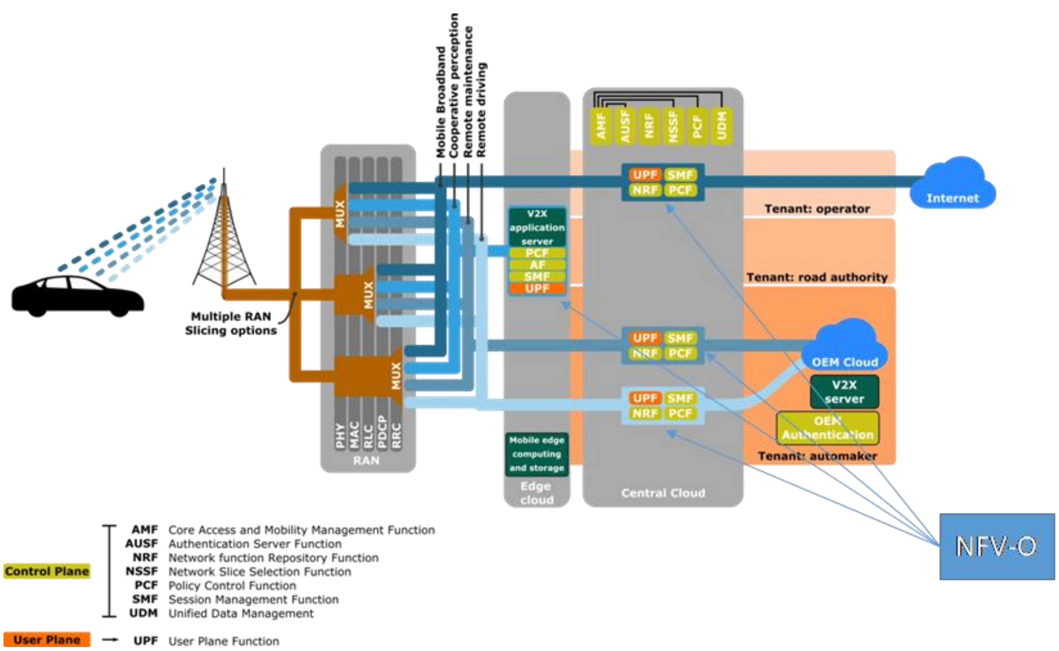


Figure 2.9: NFV and Network Slicing in proposed V2X architecture

Figure 2.10: SDN in V2X architecture shows the SDN controller and how it controls network elements that interconnect network domains. While virtualized network functions are deployed on top of NFV Infrastructure Points of Presence (NFVI-PoP), network elements need to interconnect these NFVI-PoP and provide network overlays for necessary traffic flows that are characterized in order to provide QoS.

Some of the challenges that SDN faces in V2X networks are the following:

- Necessary extensions for flow identification (e.g., GTP) in SDN switches and controllers.
- Introduction of QoS Flow Identifier. All packets are tagged.
- Extension of SDN controller hierarchy/peer for multi-domain provisioning.
- Mobility extensions for flow migration.

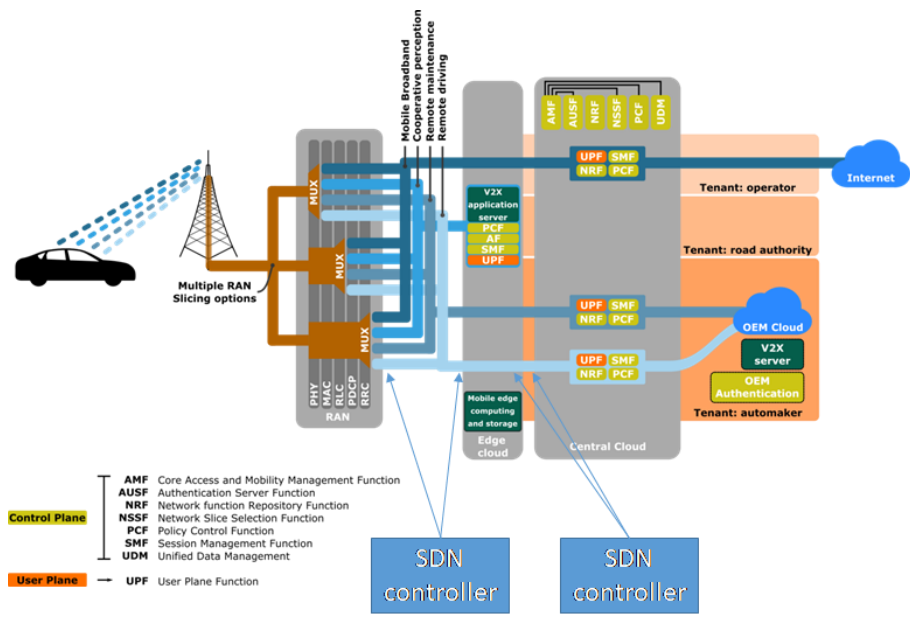


Figure 2.10: SDN in V2X architecture

Finally, Figure 2.11 shows the proposed integrated NFV/SDN architecture for V2X networks. The objective is to deploy network slices, which are tailored for specific QoS needs and use cases such as:

- Mobile broadband
- Cooperative perception
- Remote maintenance
- Remote driving

NFV Orchestrator (NFV-O), as part of a global Service Platform is responsible for the deployment of located network services over multiple NFVI-PoP which might be located at network edge or core. Moreover, the NFV-O is responsible for establishing the necessary traffic flows that conform the network slice and interconnect the deployed network services.

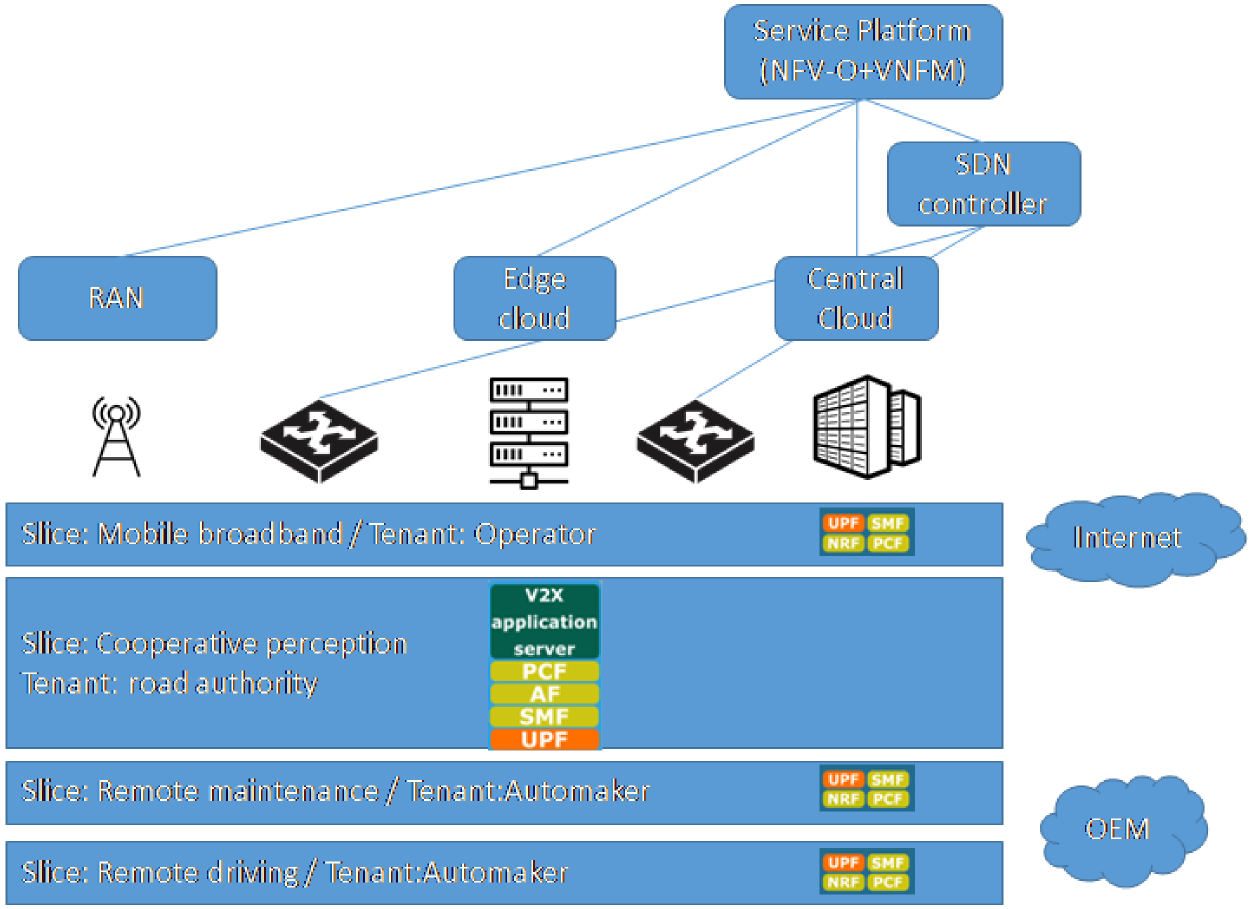


Figure 2.11: NFV/SDN integrated architecture

3 5GCAR architecture technical components

As previously mentioned in this document, many of the technical innovations introduced in 5GCAR come in the form of technical components. Specifically, 14 5GCAR architecture technical components have been defined, which are individually presented, illustrated, and evaluated in this section.

3.1 RSU enabled smart zone

3.1.1 Objectives

This TC introduces some enhancements to network procedures considering an integration of a functional architecture and a deployment architecture based on using RSUs for a flexible and effective support of V2X communications. The integration is aimed to provide smart radio access service areas, referred to as Smart Zones (SM-Zones), which are local to targeted individual roads (covering just road areas) for serving V2X communications of UEs on roads, over either SL or Uu via either UE-type RSU or Base Station (BS)-type RSU. Thus, radio transmissions as well as E2E service flows of V2X communications between UEs on roads may be kept local to individual roads which is rather desirable for an efficient utilisation of spectrum and network resources while meeting QoS requirements of advanced V2X services. This comes with the cost of deployment of RSUs along targeted individual roads, mounted on roadside lamps for instance.

Further to the introduction of the SM-Zone concept in [5GC18-D41], the objectives here include:

- To describe some technical enablers of SM-Zone in resolving certain SL related issues, assuming that broadcast-based SL without feedback control as adopted in LTE is the baseline. The SL issues include the half-duplexing problem related to SL transmission/reception, the hidden or exposed terminal problem, the collision problem in UE autonomous resource allocation for SL transmissions as well as the issue with QoS reassurance over SL.
- To describe some essential network-configuration-and-control procedures as well as UE procedures for flexible SM-Zone operations, adapted to diverse characteristics of targeted services, UE classes, road types and road traffic patterns, etc.;
- To address efficient resource allocation for SL transmissions with spatial resource reuse for SM-Zone;
- To address further QoS and congestion control using Self-Organizing Network (SON) based multi-mode RSU;
- To address multi-operator support of SM-Zone;

- To address possible supports as well as benefits of SM-Zone for 5GCAR use cases in particular.

3.1.2 Description

SM-Zone as an integrated logical entity of 5G network:
SM-Zone is physically enabled by deployment of enhanced RSUs, also referred to as 5G-RSU in [5GC18-D41], along targeted individual roads. Basically, RSU can be either UE-type or BS-type. 5G-RSU can be enhanced with flexible capabilities and network functions, adapted to best serve targeted use cases, as showed in Figure 3.1 for examples. RSUs of a SM-Zone may be interconnected to each other and connected to both cellular network and ITS network via wireline or wireless interfaces, as shown in Figure 3.2 for examples. Thus, flexible control and data forwarding between RSUs of SM-Zone, involved serving cellular network and ITS network can be enabled and facilitated.

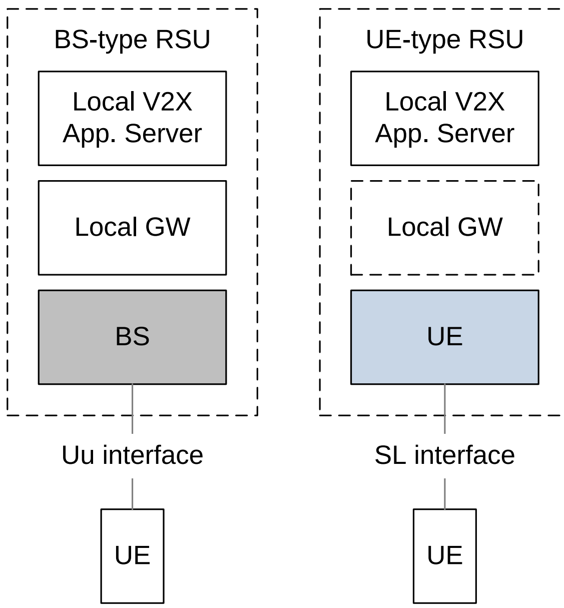


Figure 3.1: RSU with flexible capabilities and network functions

It is noted that the local GW entity is RSUs shown in Figure 3.1 is considered as generic and flexible distributed network functions of gateway functionality. This is not necessarily equivalent to a standard serving gateway of a serving cellular network but may be enhanced and adapted for interconnecting and packet forwarding needs of RSUs. It is further assumed that UE-type RSU may be connected to and served by a Public Land Mobile Network (PLMN) via a serving macro BS as a regular UE. BS-type RSU may be connected to and served by a PLMN as a regular small-cell BS. In this case, a UE which is connected to and served by a BS-type RSU might also have another connection to a macro BS (e.g., a primary connection to a controlling BS). This is presented in [5GC18-D41].

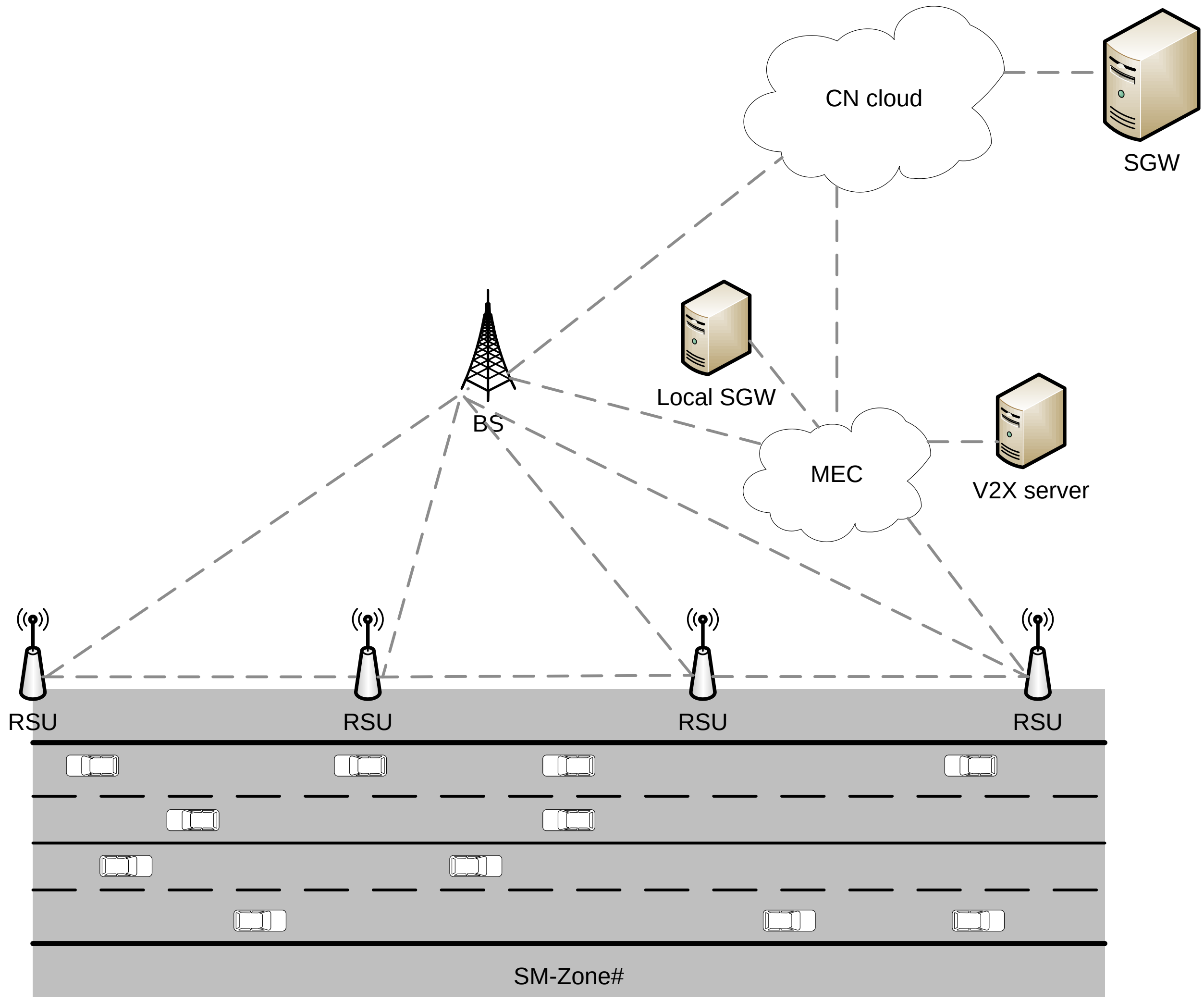


Figure 3.2: Examples of an integrated SM-Zone

SM-Zone is logically configured and controlled by a serving 5G network to provide a designated radio access service area local to targeted individual roads, as determined by the serving network. Further details on network configuration and control of SM-Zone are provided below. The radio access is assumed based on SL or Uu of LTE and NR using licensed spectrum as the baseline.

Technical enablers of SM-Zone in resolving certain SL related issues:

The autonomous UE selected mode can be applied for UE in either idle, connected or out-of-coverage state. However, this comes with some certain unsolved issues, as mentioned above and described in [5GC18-D41].

Therefore, UE type RSU of SM-Zone is enhanced to provide a smart SL relay mode for SL data transfer of targeted UEs being served by SM-Zone, in addition to or instead of the current SL direct mode between Tx UE and Rx UE(s). In the smart SL relay mode, RSU is configured to receive broadcast SL transmissions of targeted UEs and rebroadcast received messages of targeted UE back to targeted UEs over SL according to a predefined schedule. The predefined schedule is related to SL resource allocation using Semi-Persistent Scheduling (SPS) concerning both UE side and RSU side. Further details are provided below in addressing network configuration and control and resource allocation for SM-Zone. The targeted UEs can be UEs of a certain priority group, capability class, QoS class, use case or application class, frequency band for examples. Thus, depending on such characteristics, a given UE, while being served by SM-Zone, may be configured to use one of the following options: (i) only the SL direct mode as in current LTE; (ii) only the SL relay mode; or (iii) both the SL direct mode and the SL relay mode. The main difference between these options can be seen from SL reception perspective how UE needs to monitor to receive SL. In this regard, the option (ii) is the most efficient, as UE only needs to receive SL from RSU according to a predefined schedule, instead of constantly monitor and receive over the entire of configured Rx resource pool. The option (iii) can be used for enhancing reliability of SL data transfer, as duplication can be provided.

It is noted that the SL relay mode does not necessarily prolong latency of SL data transfer (which needs to be kept under the required E2E latency constraint). In the SL direct mode as in LTE SL for examples, a given Tx UE may automatically repeat transmission of the same message several times for enhance reliability. In the SL relay mode, the given Tx UE may need to transmit the message once and then listen to the relay from RSU. The relay should include the message of the given Tx UE as well as message(s) of other Tx UE(s). In this way, the given Tx UE can be reassured as well as detect whether the message of its own is transmitted successful or not. If not, then the given Tx UE may decide whether to retransmit the message or transmit a new one. The SL relay can be realized on different layers of SL protocol stack, L2 or above. Figure 3.3 [5GC18-D41] provides an illustration of the SL relay mode.

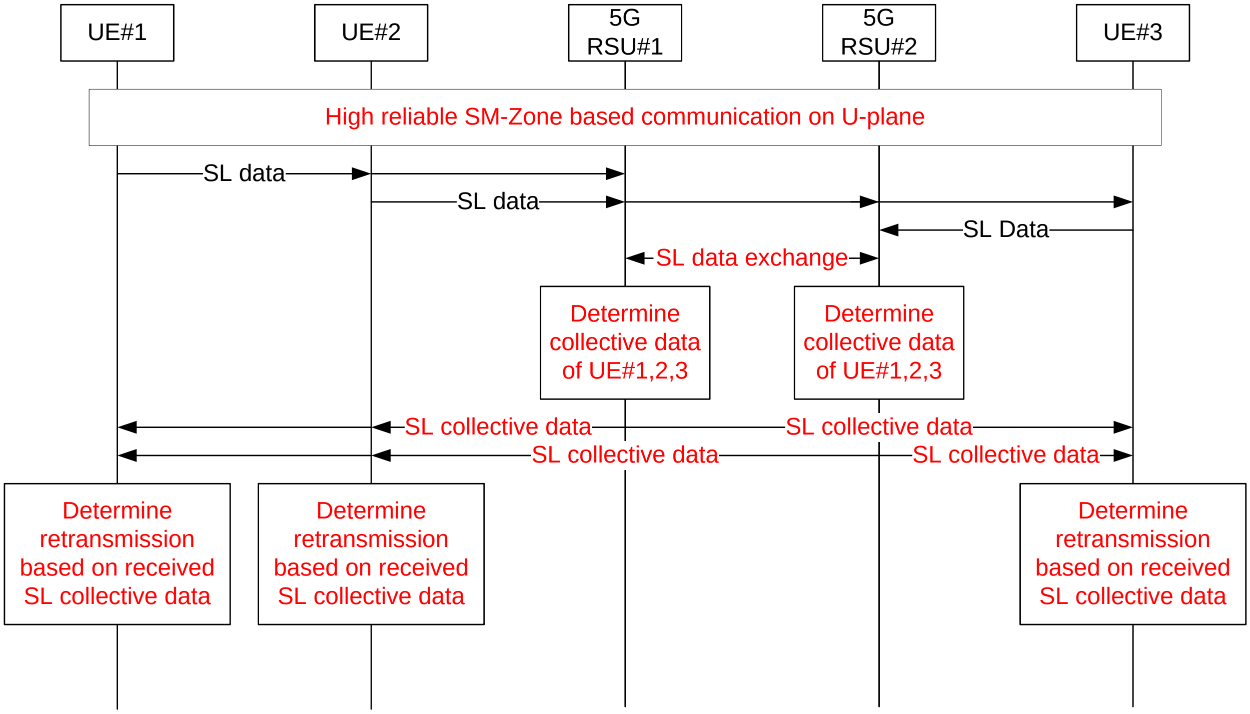


Figure 3.3: Illustration of SL data transfer in SM-Zone using UE-type RSUs

Network configuration and control of SM-Zone:

SM-Zone with specific configuration is made visible to targeted UEs, similar to the current cell or location tracking area concept. Thus, the network configuration and control of SM-Zone consist of both RSU related procedures and UE related procedures. Figure 3.4 [5GC18-D41] illustrates an overview of network configuration and control of SM-Zone for examples.

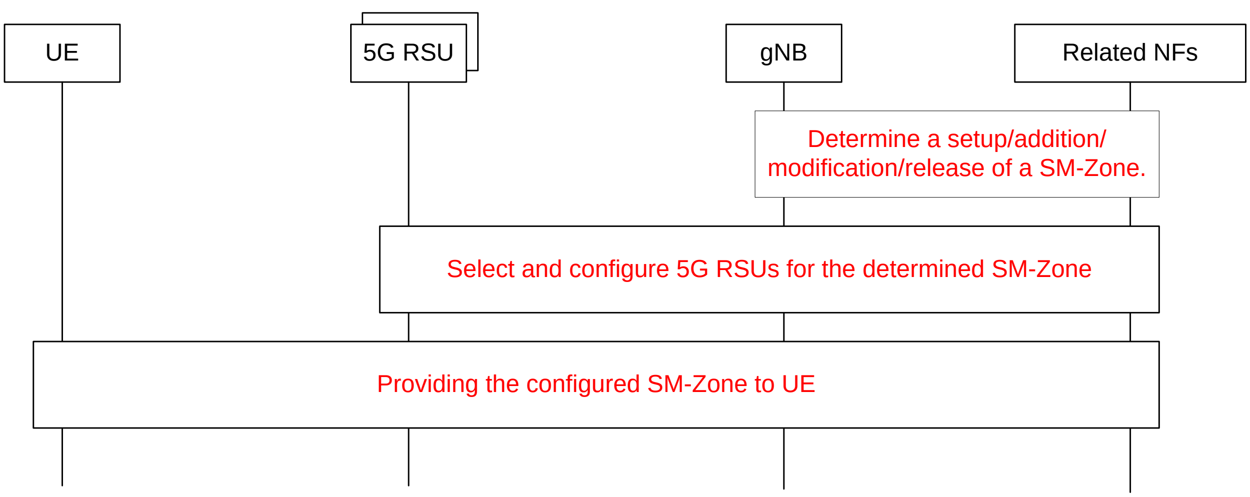


Figure 3.4: Overview of network configuration and control of SM-Zone

RSU related procedures:

SM-Zones with different profile characteristics may be configured to provide flexible and optimal supports of V2X communications. For examples, a general-purpose SM-Zone may be configured to serve all relevant UEs on road for road safety related services with minimum admission control. Then, a dedicated-purpose SM-Zone may be configured to serve a certain class or group of targeted UEs for some specific advanced services such as auto-pilot driving cars which need extended admission control.

Individual SM-Zone is assigned with a unique identity by the serving network(s) which is indicated to targeted UEs by e.g., individual gNBs of cells the configured SM-Zone is crossing as well as individual RSUs providing the configured SM-Zone. The profile configuration of individual SM-Zone may further include contexts of the serving network(s), resources such as SL resource pools specific to the SM-Zone, service and access related constraints or restrictions, etc. It is noted that individual SM-Zone may be common or shared to more than one PLMNs. This issue is further discussed below in multi-operator support of SM-Zone.

Individual SM-Zone may be semi-statically or more dynamically configured (added, modified or removed) by the serving network, reflecting variable service coverage, life-time, service and resource arrangement in order to adapt to road types and road traffic patterns, for examples.

The above SM-Zone configuration and control have direct impact on RSUs which are selected and configured to provide one or more individual SM-Zones. It is noted that RSUs located at the road entry or exist or cross section of roads or geographical border of a SM-Zone may likely be involved in providing more SM-Zones or handling more UE related procedures, compared to RSUs located in middle of a road. This can be explored for flexible and optimal differentiation and use of RSUs in terms of functionality, capability and capacity.

UE related procedures:

UE related procedures here aim for facilitating individual UE on road to discover and get access to a selected individual SM-Zone. The admission control of individual UE to get access to individual SM-Zone may be carried out at the serving network, similarly to location registration and update of the regular cellular network access.

It is noted that in case a UE is granted some dedicated resources for SL upon getting access to a certain SM-Zone, the UE may need to indicate the serving network to release the resources when living the SM-Zone.

Figure 3.5 [5GC18-D41] provides an illustration of some UE related procedures for some example. In this example, it is considered that the serving gNB carries out the admission control and release of the UE directly. There can be other options. In one example, the UE may discover and get admission control to a selected SM-Zone from a serving RSU. In another example, the UE may be allowed to access a certain SM-Zone provided by UE-type RSUs using SL and UE autonomous resource allocation without a need of an explicit admission control in real time, similarly to SL transmissions of out-of-coverage or idle UE.

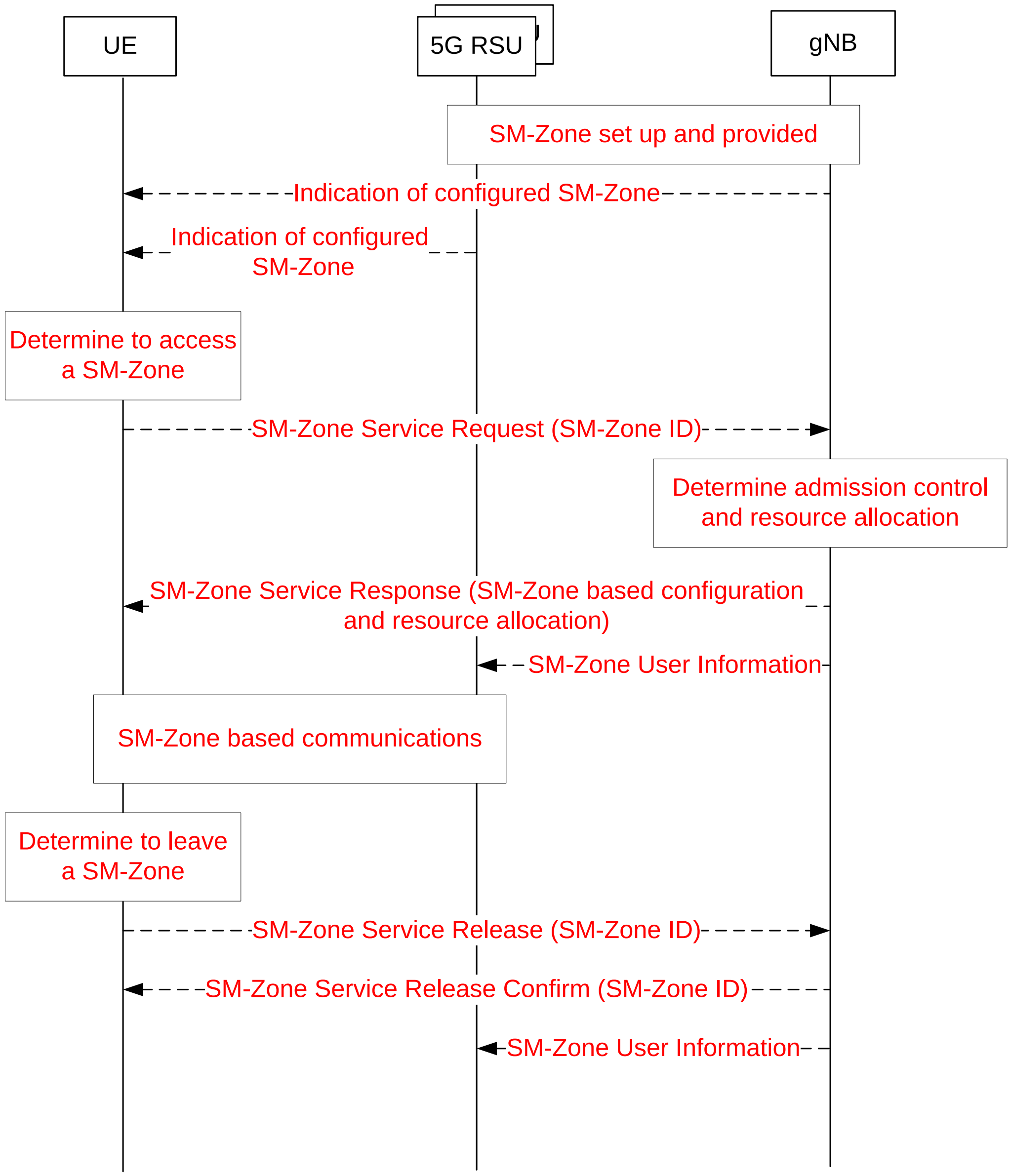


Figure 3.5: Example of SM-Zone configuration and UE access control

It is noted that UE-type RSUs may offer UE-to-Network relay services for UEs in SM-Zone. These UE-to-Network relay services may be enhanced and utilized for support of regular idle or active UE procedures of serving cellular access network for UEs in SM-Zone.

Resource allocation for SM-Zone:

RSU driven spatial-reuse SL resource allocation:
The serving network may allocate dedicated SL transmission resources in a SPS based fashion for individual RSUs of a configured SM-Zone for targeted applications and services such as the SL relay services described above for examples. This allocation may be optimized with spatial

reuse across the RSUs using some predefined reuse pattern, depending on SL range and inter-distance between neighbouring RSUs for examples. The reuse pattern as well as resource pool allocated to RSUs for SL transmissions may then be indicated to targeted UEs being served by the SM-Zone, as a part of the SM-Zone configuration information. This allows individual targeted UE to determine which resources to be monitored to receive SL from individual RSUs the UE is currently passing by along the road, as opposed to monitor the entire of the SL resource pool.

Figure 3.6 provides a close look into an example how the spatial reuse of SL resources may be provided with configuration and control from a serving gNB. In this example, the spatial reuse is based on a coupling of assigned L1 ID of RSU and SL resources, out of a preconfigured resource pool for the whole SM-Zone, to be used by RSU and UE in proximity of RSU.

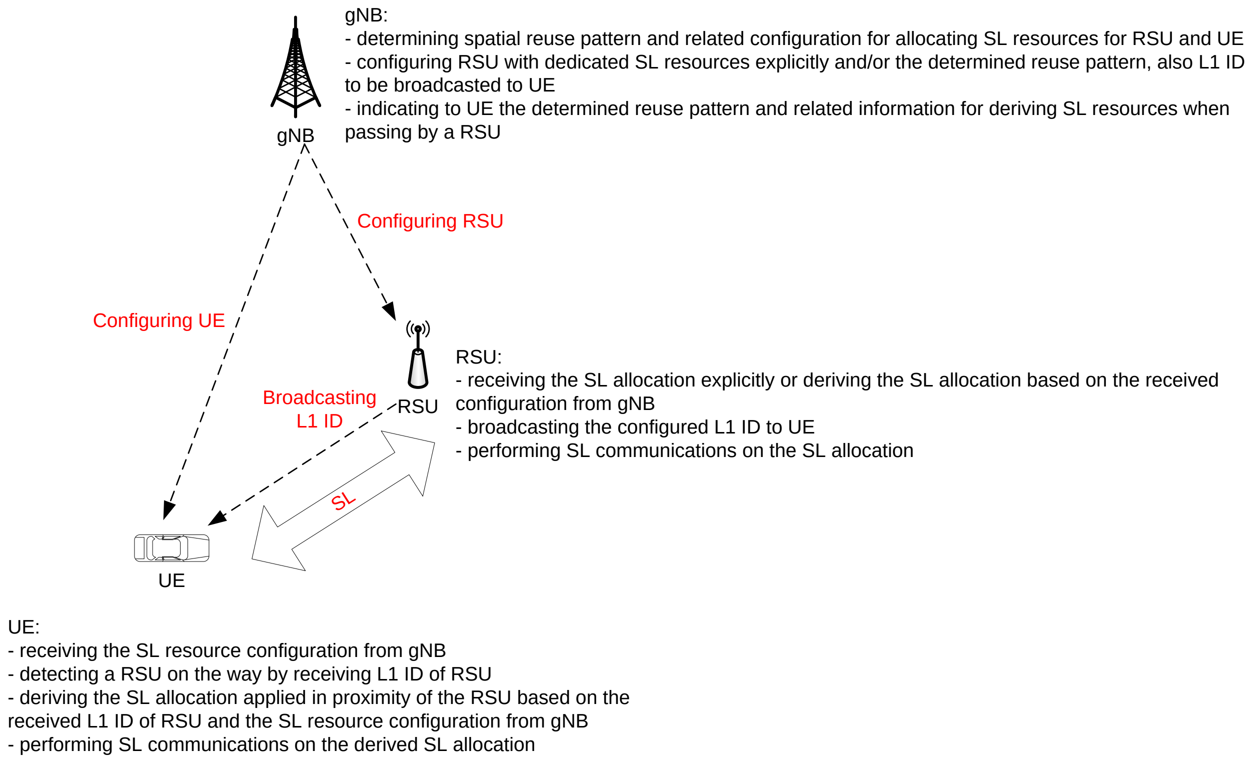


Figure 3.6: Example of providing spatial-reuse SL resources for SM-Zone

SPS based SL resource allocation for individual UE:

UE may be allocated SPS based resources for SL communications throughout the serving SM-Zone without a need of keeping UE in the connected state to the serving network for enhancing QoS as well as reducing mobility management, as the serving SM-Zone may be crossing many serving cells provided by gNBs. The main challenge is, as there can be a rather large number of UEs being served by a SM-Zone at a particular point in time (depending on the size of the SM-Zone, many thousands of UEs on the move and distributed along a route of tens of km in length covered by the serving SM-Zone), exclusive SPS resource allocation to that many UEs is not affordable. Hence, a spatial reuse of resources among constantly moving UEs, as opposed to stationary RSUs, throughout the serving SM-Zone is necessary.

Because individual SM-Zone is adapted to individual roads or specific travelling paths, mobility patterns of UEs served by the SM-Zone can be rather predictable or even regulated in normal road traffic situation, considering the SM-Zone covering a highway of 20km with speed limits between 80km/h and 120km/h for an example. Thus, in one example, the same resources allocated to UE1 upon entering the SM-Zone at a certain location (particular entry point of the highway) may be allocated to UE2 upon entering the SM-Zone at the same location but at a later time instant, by a predefined time interval, as compared to that of UE1. In another example, SPS based SL resource allocation to UE1 may be based on time-space hopping between preconfigured SPS instances. UE1 is initially given SPS#1 and SPS#2 coupled with a predefined time-space hoping rule. The rule dictates that UE1 starts using SPS#1. Then either in every predefined time interval T or every predefined traveling distance L or every predefined passing location whichever comes first UE1 switches between SPS#1 and SPS#2. The location resolution may be provided by the serving network, considering expected cell-border crossing as well as location-marking provided by using selected RSUs (those located at entries/exists of the highway and every L distance starting from a predefined reference point). The followings are considered for SPS based SL resource allocation for individual UE being served by the SM-Zone:

- UE is assigned with unique ID valid throughout the serving SM-Zone, denoted as Z-RNTI (Z - Radio Network Temporary Identifier), similar to C-RNTI or Temporary Mobile Subscriber Identity (TMSI)
- UE can be configured with SPS based SL resource allocation valid throughout the serving SM-Zone by a serving gNB
- The serving gNB may coordinate with other identified serving gNBs involved in providing and assisting the SM-Zone as well as selected RSUs of the SM-Zone (or a centralized common control NF or server of the SM-Zone if adopted) for SPS based SL resource allocation of individual UE.

Figure 3.7 illustrates signalling procedures for SPS based SL resource allocation of individual UE. The allocation (and release) of dedicated resources of individual UE, including Z-RNTI and other UE contexts related to the serving SM-Zone, may be carried out as once off upon the individual UE entering (and existing) the serving SM-Zone. The UE may be then put into idle or inactive state of the serving cellular network while being active for communications over SL in the serving SM-Zone.

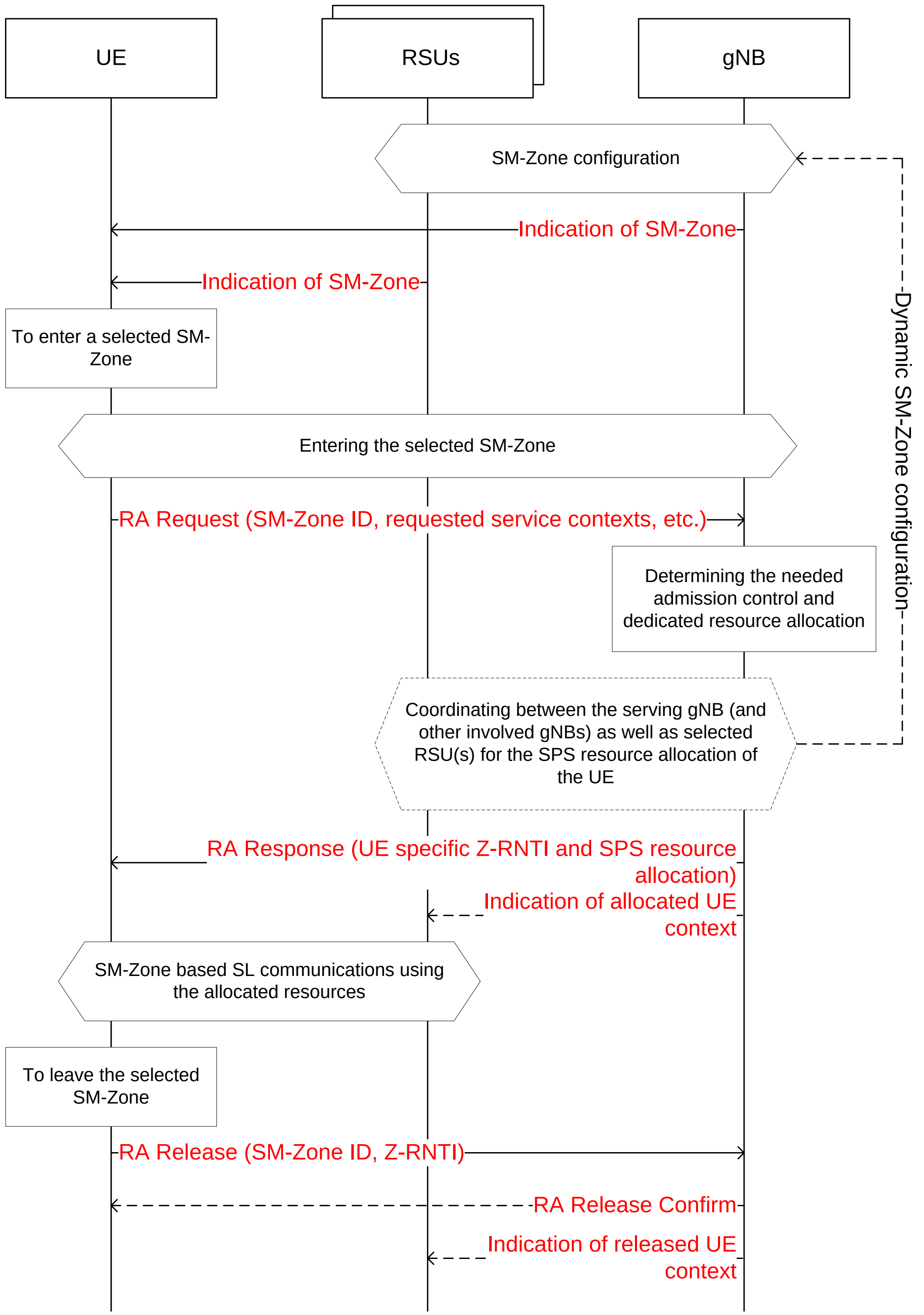


Figure 3.7: Illustration of SPS based SL resource allocation for SM-Zone UE

SON-based multi-mode RSU:

As discussed above, the RSU deployed for the SM-zone may be either UE-type of RSU operating SL interface or BS-type of RSU operating Uu interface or even a combination of UE-type and BS-type RSU to make the RSUs as multi-mode RSUs. To support V2X communications more efficiently, the SON based method may be used to configure and control the multi-mode RSUs as well as relevant vehicular UE devices on the fly based on the V2X traffic statuses. Examples for adaptive RSU mode control include: i) UE type RSU for highway or freeway in normal traffic conditions, for rural areas with less road traffic or for sub-urban or urban road during night time; ii) BS type RSU for high volume of V2X traffics due to massive number of vehicles so that high multiplexing gain of V2X traffic is achieved by BS scheduling in order to give sufficient capacity in RAN for regular Mobile Broadband (MBB) cellular access; iii) BS type RSU combined with small-cell gNB in rush hours or congestions when road traffic is slow or standing still on roads for long enough time so that the same network node can flexibly and dynamically manage the V2X and MBB traffic; and so forth.

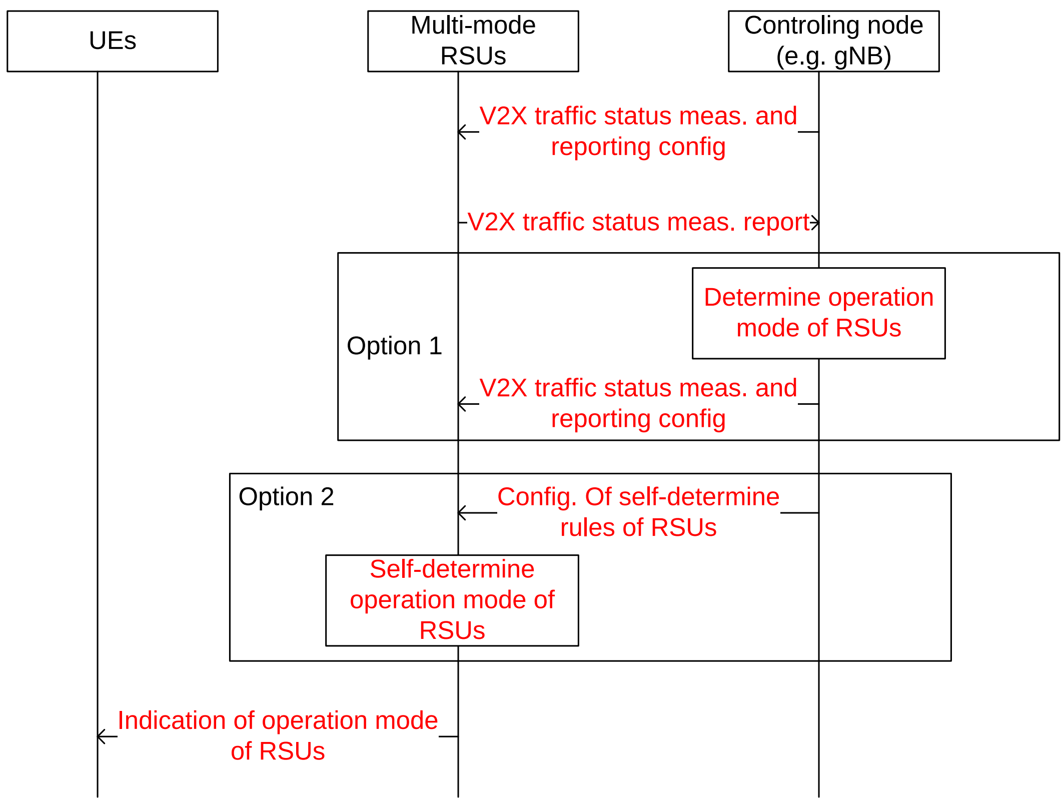


Figure 3.8: Illustration of SON based multi-mode RSU configuration

The procedure on configuration of multi-mode RSUs is illustrated in Figure 3.8. To facilitate the configuration and control of the operation mode of the multi-mode RSUs, the RSUs are configured to measure and report on designated V2X related traffic statuses to a controlling node which may be a serving macro eNB or a network server, individually as well as cooperatively (i.e. cooperative measurement and/or reporting together with targeted codeployed RSUs along relevant road). Based on RSU measurements and reports, either controlling node or individual RSUs can configure and control the operation mode of the multi-mode RSUs:

- In one option, the controlling node (re-)configures the operation modes of individual RSUs on the fly based on the received V2X related traffic status reports as well as the cellular-access traffic load statuses the macro cell is experiencing. This tight network initiated reconfiguration is preferable for urban, less predictable or frequent congested areas where eNB type RSU or combined eNB type RSU and small-cell eNB is more suitable during day time or in busy roads and either eNB type RSU or UE type RSU is during night time depending measured V2X related traffic statuses.
- In another option, RSUs are configured and controlled to determine and reconfigure the suitable operation modes themselves, either individually or cooperatively depending on pre-configured information (more static or predictable road and location specific traffic patterns in rush hours, night time, mid-day time, traffic-light control, etc.) and based on measured statuses or conditions. This option is preferable for RSUs deployed in freeways or highways, rural areas, etc., where UE type RSU operation mode may likely be sufficient for most of the time. The eNB type RSU mode or a combination with eNB is applicable around traffic light cross sections or when some unexpected events causing traffic to slow down or congestion happen.

RSUs may be configured to advertise or indicate of the current operation mode and upcoming operation mode change towards UE devices if such the transition or modification is determined.

Multi-operator support of SM-Zone:

SM-Zone, as described above, is an integrated network entity that can be physically as well as logically shared by more than one PLMN. Because SM-Zone is provided by interconnecting local RSUs deployed along targeted road, sharing SM-Zone between PLMNs may be realized similarly to the well-known RAN sharing. In accordance with RAN sharing defined in 3GPP, the following RAN sharing types are applicable for this case:

- Multi-Operator RAN (MORAN) is where only equipment is shared;
- Multi-Operator Core Network (MOCN) is where both equipment and spectrum are shared.

It is noted that the baseline of RAN sharing is said to be licensed spectrum (also for SL). Thus, the multi-operator scenario should take into considerations aspects where two vehicles from two different PLMNs exploit the same licensed spectrum in the SM-Zone.

Sharing of a SM-Zone between PLMNs can be further simplified depending on whether the SM-Zone is based on using just SL for V2X communications inside SM-Zone or Uu in addition or instead of SL. For the former case, all SL properties related to multi-operator support, as of current LTE SL or NR SL, may be inherited by SM-Zone. For the latter case, multi-operator support of SM-Zone resembles RAN sharing of local small-cell radio access layer.

It is further noted that SM-Zone may be provided and managed by a third party common to all involved PLMNs (as part of ITS infrastructure for examples).

3.1.3 Evaluation

The SM-Zone provides many benefits, including:

- SM-Zone allows for keeping local radio communications as well as local E2E communications between UEs on road local to individual roads. This helps enhance spectral efficiency as well as reduce involvement of CN for involved PLMNs.
- SM-Zone allows for enhancing reliability via RSUs also when adopting broadcast-based SL and resolving the half-duplex issue provided, as compared to current LTE SL. It is noted that SL relayed via RSU in SM-Zone does not necessarily increase E2E delays or resources needed for SL communications. This is because SL relayed via RSU may no longer need blind automatic SL retransmission or repetition, as applied for current LTE SL. Furthermore, adopting RSU allows for simple and effective spatial resource reuse. This also helps narrow down SL reception resource pool for UE, as opposed to always monitoring over the entire of preconfigured reception pool as in current LTE SL, resulting in better power efficiency for UE.
- SM-Zone allows for UE to use dedicated SL resources throughout a serving SM-Zone which may cross many cells. This helps reduce mobility management and control overhead as well as enhance QoS.
- SM-Zone allows for SON based adaptation of RSU functions and operations and therefore the local radio access layer provided by RSUs in order to provide flexible and optimal supports of V2X communications, considering diverse applications and services, road characteristics and road traffic patterns, etc.

SM-Zone is based on somewhat massive deployment of RSUs resulting in high cost, even though it is flexible to use either UE-type RSU or BS-type RSU. This is the main drawback of the SM-Zone concept.

Considerations on supports of 5GCAR use cases

SM-Zone is not designed for a specific use case but advanced V2X communications between UEs on road in general. SM-Zone may be applied for supporting all the targeted use cases of 5GCAR. More detailed assessments are provided in Section 4 for each of the targeted UCs.

It is further noted that RSU can be considered as a distributed local server of some V2X applications. In this regard, the RSU can be enhanced with MEC. RSUs of the smart zone can be interconnected to each other and to a common server, local or remote. Thus, the use of RSU in the smart zone allows for providing fast and reliable radio access connectivity not only to the local distributed server at RSU but also to the common V2X server, local or remote.

3.2 Fast application-aware setup of unicast SL

3.2.1 Objectives

5GCAR considers possible use of unicast SL to facilitate and improve the support of some use cases such as cooperative driving including cooperative perception (see-through UC) and cooperative manoeuvring (lane-merge UC) [5GC19-D21]. The communication session over SL for both the see-through UC and the lane-merge UC is in real time on the need basis of individual vehicle UE and therefore a fast and reliable setup of the communication session using unicast SL is of a great importance.

It is noted that the UEs which are involved in the see-through UC and lane-merge UC are rather random, determined on-the-fly along with the service availability, therefore a fast and reliable setup of the communication session using unicast SL is of a great importance.

Then, a unicast communication session over SL may be realized based on either L1 unicast SL or L1 broadcast SL. The latter is currently adopted in LTE [3GPP18-36300] wherein the unicast is seen on higher layer – e.g., non-access-stratum or application layer. In this option, the setup of the unicast communication session over SL relies also on non-access-stratum or application-layer signalling including the discovery phase of the involved UEs. This is rather time consuming and less efficient. It is not to mention that due to using L1 broadcast SL non-involved UEs in proximity of the involved UEs may need to receive and discard the unintended unicast communications of the involved UEs. The L1 unicast SL, on the other hand, may overcome those limitations but require that each of the involved UEs or SL(s) thereof has assigned a locally unique L1 ID. This is in order to allow that a Tx UE of the L1 unicast SL may schedule a L1 unicast SL transmission addressed to only a targeted Rx UE by indicating the locally unique L1 ID of the targeted Rx UE or SL in the scheduling assignment (SA) or SL control information (SCI) of the Tx UE sent over a Physical SL Control Channel (PSCCH). The assignment of such the locally unique L1 ID to the involved UEs needs to be reassured and therefore, in practice, is relied on assistance from a serving network. The alternative of using a globally unique UE ID such as International Mobile Subscriber Identity (IMSI) or application ID as L1 ID is not preferable if not prohibited, due to high L1 signalling overhead as well as security reason.

Hence, the objectives of this TC is to enhance the network procedures to include RAN-level enhancements for speeding up the setup of a SL based unicast communication session for the targeted use cases, In particular, this TC proposes an adaptive operation for setting up a needed SL based unicast communication session wherein the network-assisted L1 unicast SL is preferred whenever possible or otherwise L1 broadcast SL is applied. This TC also proposes that the UE which initiates the setup of the unicast SL may proactively allocate SL resources for the other involved UE for faster and more reliable SL transmissions.

3.2.2 Description

RAN-level enhancements proposed in this TC include: (i) triggers for the involved UEs to determine whether the unicast SL communication session should be based on L1 broadcast SL or L1 unicast SL; and (ii) signalling enhancements for facilitating faster and more reliable setup of the SL communication session, especially when using L1 unicast SL. These are based on exploring application contexts of the targeted use case coupled with UE contexts of the involved UEs as well as availability of the network assistance from a serving RAN of either one of the involved UEs in assigning locally unique L1 ID and, optionally, resources for the unicast SL.

The following details are described from the perspective of the UE which is initiating or requesting the setup of the unicast SL communication session, also referred to as the initiator UE. It is noted that the initiator UE may be able to discover the involved UE based on received basis safety related messages from the involved UE (or other means such as smart cameras).

Triggers for determining at the initiator UE:

1. L1 unicast SL is selected and used for the unicast SL communication session of the targeted use cases whenever possible or otherwise L1 broadcast SL is used.
2. The initiator UE determines whether L1 unicast SL can be used or not for the needed unicast SL communication session further based on one of the following conditions.
   a. In case the initiator UE is in the network coverage:
      i. If the serving RAN of the initiator UE is able to provide the needed assistance for facilitating L1 unicast SL. This is realized using some of the proposed RAN-level signalling enhancements, as detailed below.
      ii. Else, if the serving RAN of the other involved UE is able to provide the needed assistance for facilitating L1 unicast SL. This step is realized using some of the proposed RAN-level signalling enhancements, as detailed below.
      iii. Else, L1 broadcast SL is used.
   b. In case the initiator UE is out of the network coverage:
      i. If the serving RAN of the other involved UE is able to provide the needed assistance for facilitating L1 unicast SL.
      ii. Else, L1 broadcast SL is used.
3. The initiator UE determines SL resources needed for the unicast SL communication session (e,g, based on expected response message for unicast SL communication session establishment) and proactively reserves SL resources upon determining either L1 unicast SL or L1 broadcast SL is applied, before the unicast SL communication session is actually set up. This step enables actual unicast SL communication to take place as soon as possible and hence speed up the setup as well as enhance reliability of the SL communication session. This step is associated to some of the proposed RAN-level signalling enhancements, as detailed below.

RAN-level signalling enhancements:

For Uu interface:

1. The serving RAN may indicate cell-specific support for assisting the L1 unicast SL in System Information Block (SIB), the indicated assistance may include allocation of L1 ID and SL resources for L1 unicast SL with constraints such as the maximum number of unicast SLs per a SL communication session; extended support such as scheduling for intra-cell L1 unicast SL when both Tx and Rx UEs of L1 unicast SL are served by the same cell; etc.
2. L1 unicast SL assistance request from UE to the serving RAN and L1 unicast SL assistance response from the serving RAN to UE are introduced. The request can be for one or more L1 unicast SL to be set up, as indicated in the request. The request may ask for a SL resource allocation for the needed unicast SL communication session, the resource allocation may include radio resources and a set of L1 IDs or SL-RNTIs which can be used as locally unique UE IDs or SL IDs for L1 unicast SLs on at least the allocated radio resources. The response may provide a resource allocation or, otherwise, an indication that requested network assistance for the time being cannot be provided.
3. L1 unicast SL indication from UE to the serving RAN, indicating about its SL-peer UE upon establishing L1 unicast SL, at least in case SL-peer UE is being served by the same serving RAN, as determined by the indicating UE, or indicating about the unused resources out of the allocated resources, such as unused L1 IDs or SL-RNTIs out of the allocated set.

For SL or PC5 interface:

1. The initial SL unicast connection establishment request, is sent by the initiator UE to at least one involved UE, is based on using L1 broadcast SL mode as in LTE at this stage. The request may include an indication of the initial determination of the initiator UE whether the initiator UE is able to provide and enforce L1 unicast SL or not. The former may come with an indication of a global cell ID of the serving RAN and a resource allocation including a L1 ID or SL-RNTI and resources on which L1 ID or SL-RNTI is locally unique. The latter may come with an indication that the initiator UE is out of coverage or that the current serving RAN of the initiator UE is not able to provide the needed network assistance. The latter may also come with an indication of SL resources but without L1 ID or SL-RNTI. The indicated SL resources are proactively reserved by the initiator UE either autonomously or allocated by the serving RAN that can be used for the involved UE to transmit/receive SL to/from the initiator UE right away.
2. The SL unicast connection establishment response that is sent by the involved UE when responding to the received request from the initiator UE may include an indication that the involved UE is served by the same serving cell as the initiator UE or that the involved UE is able to provide and enforce L1 unicast SL. The latter

implies that the initiator UE is initially not able to provide L1 unicast SL, as determined by the involved UE based on indications in the received request from the initiator UE. The latter comes with indications of a global cell ID of the serving RAN of the involved UE and a resource allocation including a L1 ID or SL-RNTI and resources on which L1 ID or SL-RNTI is locally unique.

Figures 3.9, 3.10 and 3.11 illustrate signalling procedures over SL and Uu between the initiator UE, the involved UE and the serving RAN. Figure 3.9 is for the case with the most favourable outcomes: the serving RAN of the initiator UE is able to provide the needed network assistance for establishing and using L1 unicast SL between the initiator UE and the involved UE and that the initiator UE and the involved UE share the same serving RAN. Figure 3.10 is for the case in which the initiator UE is out of network coverage and the involved UE is able to provide and enforce L1 unicast SL. Figure 3.11 is for the case in which both the initiator UE and the involved UE are out of network coverage.

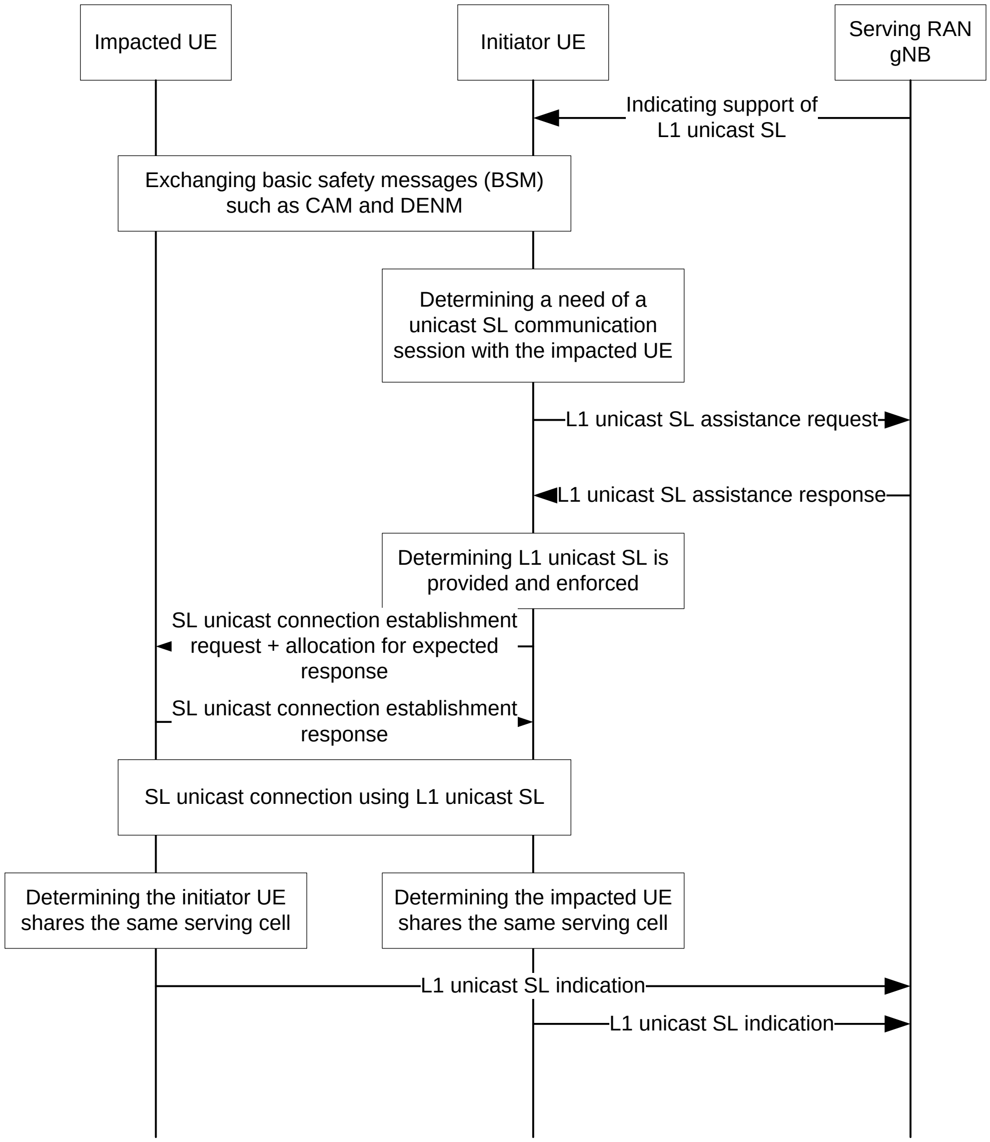


Figure 3.9: Example 1: L1 unicast SL is possible and enforced by the initiator UE

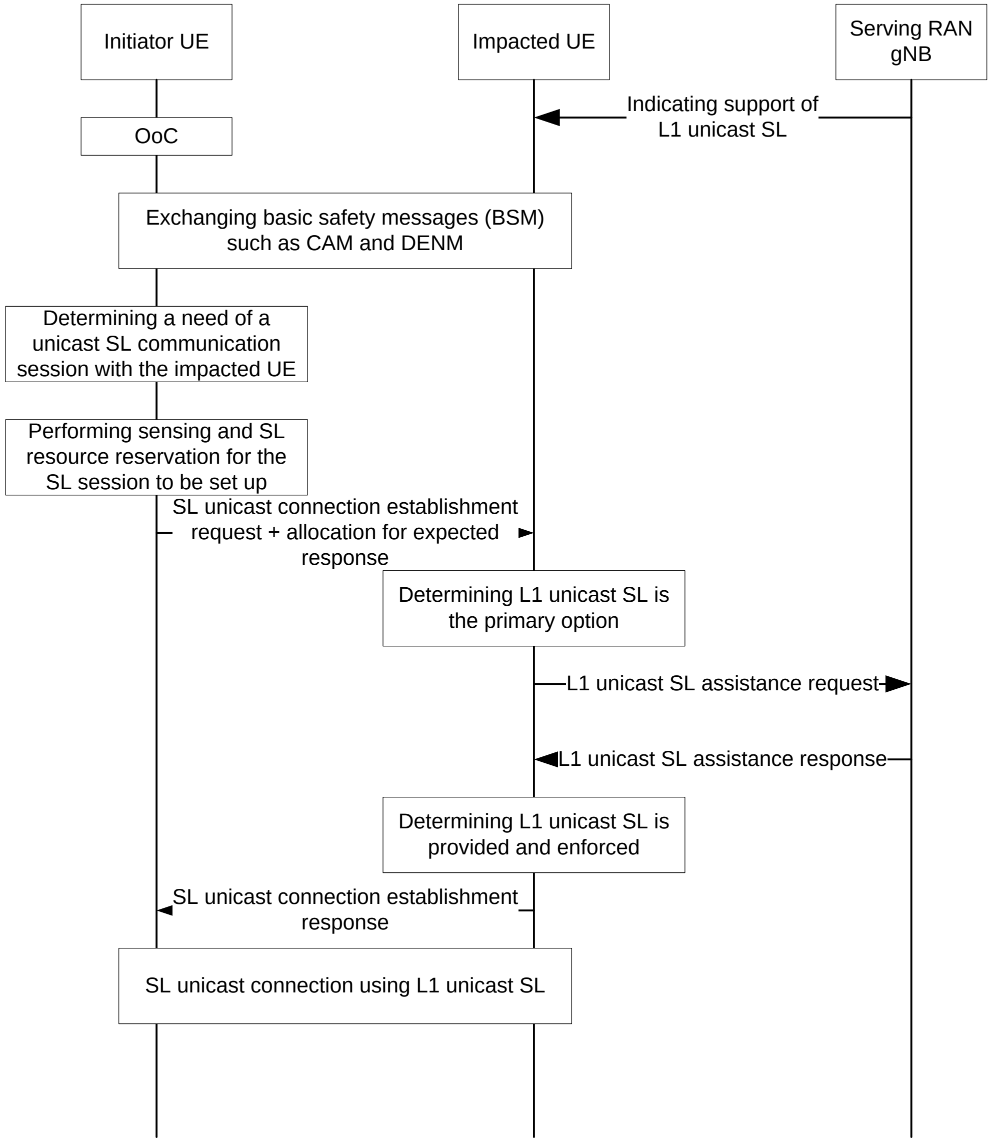


Figure 3.10: Example 2: L1 unicast SL is possible and enforced by the involved UE

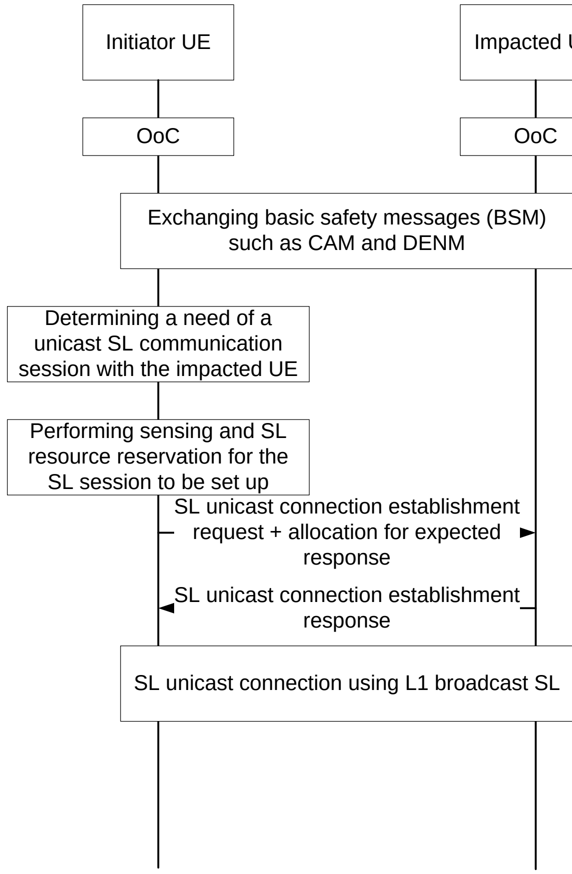


Figure 3.11: Example 3: L1 unicast SL is not possible and therefore L1 broadcast SL is used

3.2.3 Evaluation

It is shown in Figures 3.9, 3.10 and 3.11 above that the setup of unicast SL communication may be based on basic safety message (such as Cooperative Awareness Message – CAM – and Decentralized Environmental Notification Message – DENM) exchange between vehicles and therefore the discovery procedure between the involved UEs can be bypassed before the unicast SL communication connection setup is triggered. Thus the setup delay can be expected with an optimized round-trip time of the SL application-level signalling and, optionally, plus a round-trip time of the Uu access-level signalling. This setup delay can be kept as a faction of the delay requirements of the targeted use cases, e.g., the lane-merge UC and the see-through UC [5GC19-D21], provided foreseeable capabilities and constraints of NR [3GPP19-38885].

Compared to the current state of the art on SL, for examples, considering the SL specified in the current LTE [3GPP18-36300], this TC allows not only faster and more reliable setup of the unicast SL but also more efficient use of the unicast SL. This is due to the following features of this TC:

- The initiator UE may proactively reserve and allocate SL resources for the involved UE to response and transmit to the initiator right away without any further delays of the response UE requesting or selecting the resources for transmitting the response message. It is noted that in the see-through UC the initiator UE is the one which needs to receive contents (see-though assisting video streams) from the involved UE. In this case, the unicast SL communication session is a kind of receiver-initiated, from application perspective. Having the Rx UE to proactively reserve and allocate resources for the Tx UE over SL has so far not been considered in the current LTE.

- The adaptive use of L1 unicast SL and L1 broadcast SL allows for improving spectral and energy efficiency due to use of L1 unicast SL, as opposed to using only L1 broadcast SL.

Compared to the setup of network-controlled unicast Device-to-Device (D2D) communications reported in academic literatures [DRW+09] and [TTK+14], the network-assisted unicast SL considered here is notably simpler, faster and more practical for the following reasons:

- The network-assisted L1 unicast SL considered here shares all the same basic radio technologies and systems of L1 broadcast SL which have been made into 3GPP standards and thus rather practical. It is noted that L1 broadcast SL is used as the fall-back option whenever the needed network assistance is not available.
- The network-controlled L1 unicast D2D communications reported in academic literatures often do not consider aspects such as non-functional requirements of network deployments such as multi-operator support, out-of-coverage support, etc. D2D communications is considered as an optimized mode which is fully controlled by the network and applied when the involved UEs are in proximity of each other according to some optimization criteria. The setup of such network-controlled D2D communications implies a mode-switch between the regular cellular access mode to the D2D mode and requires extensive network signalling between the involved UEs and between each of the involved UEs and the serving network.

Further qualitative evaluation of this TC against KPIs of the targeted use cases, the lane-merge UC and the see-through UC, can be found in Section 4.

3.3 SL and Uu multi-connectivity

3.3.1 Objectives

This TC targets enhancements in the area of multi-connectivity cooperation and aims for enhancing reliability for use cases of 5GCAR such as the see-through UC or the lane-merge UC [5GC18-D21] which can be delivered by using SL as the primary means of communications. SL here is assumed based on 3GPP LTE PC5 [3GPP18-36300] and thus using SL alone may not be sufficient enough for meeting the required high reliability and high data-rate of some targeted UCs.

This TC considers that SL is established as the primary end-to-end (E2E) connection between a pair of impacted UEs (direct communication). In addition, a secondary connection between the impacted UEs is also established and routed via a serving base station (BS). That is, the Uplink (UL) transmission from one impacted UE is mapped onto the Downlink (DL) transmission to the other impacted UE so that the E2E communications between the impacted UE is realized over Uu interface via the serving BS. The secondary Uu connection is being used for assisting or enhancing data transmissions over the primary SL connection, e.g., with data duplication or split, respectively. It is noted that the secondary Uu connection may inherently suffer from the multi-operator issue due to the national roaming restriction applied for cellular access networks in general. That is, provided that the impacted UEs are subscribers of different operators, one impacted UE may not be allowed to access the serving network (including the serving BS) of the other impacted UE.

Hence, the objective of this TC is to provide RAN-level protocol enhancements, focusing on simplifying the operation of the secondary Uu connection as much as possible, for the proposed dual-connectivity of the primary SL and the secondary Uu connection for the impacted UEs. This is based on exploring the observation as well as the idea that, as the full radio protocol stack of PC5 (from PHY to PDCP) is enforced on the primary SL connection for SL data transmission between the impacted UEs, the secondary Uu connection may not need to adopt also the full radio protocol stack of Uu. This in turn helps reducing processing overhead as well as delay over the secondary Uu connection resulting in better performance. Furthermore, this TC also provides network enhancements to overcome the multi-operator issue concerning the secondary Uu connection.

3.3.2 Description

RAN-level enhancements proposed in this TC include: (i) introduction of Secondary Uu Radio Bearer (SURB) for realizing the secondary Uu connection as well as SURB related operation mechanisms over Uu in assisting the primary SL Radio Bearer (RB) for duplication or split of E2E data transmissions between the impacted UEs; and (ii) RAN-level authentication and admission control of an impacted UE for radio access services limited to the serving RAN and not to the CN, such that of the secondary Uu connection, based on credential of the impacted UE towards the common third-party server (ITS) connected to and served by all involved serving networks in order to resolve the multi-operator issue.

SURB and related enhancements on Uu interface:

Figure 3.12 illustrates the radio protocol stacks of the primary SL and the secondary Uu connection using SURB. In this figure, only one direction communication from Tx UE to the Rx UE is illustrated.

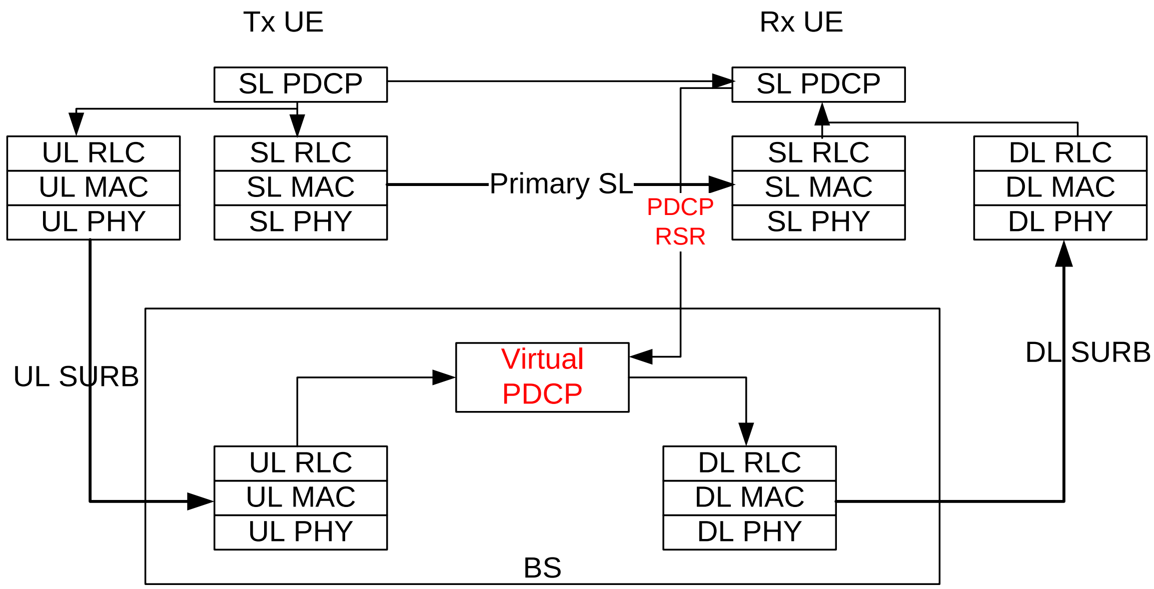


Figure 3.12: Protocol stacks of the primary SL and secondary Uu connection using SURB

SURB is provided as follows.

- Instead of having a separate Packet Data Convergence Protocol (PDCP) entity per a RB on either UL or DL as for a regular RB, a pair of UL SURB and DL SURB is provided by using a common PDCP entity (then simplifying the protocol stack structure avoiding to have two PDCP layers, one for uplink and one for the downlink) depending on, e.g., whether the primary SL connection is for one-to-one or one-to-many communications. In case of one-to-many communication over primary SL connection, the Rx UEs may be configured with the group-RNTI and use the group-RNTI to monitor and receive the multicast RB.
- The support of SURB may implicitly or explicitly indicate the multi-operator (multi-PLMN) support wherein at least one of the serving PLMNs of Tx UE and Rx UE of the primary SL allows RAN-level access for UE from other PLMN to request and use SURB. Since there can be more than one Rx UEs receiving from Tx UE, it is preferable to prioritize the serving RAN of Tx UE to provide support for SURB.

SL PDCP at Rx UE of the primary SL, in the case of unicast communication, is configured to report SL PDCP Protocol Data Unit (PDU) Reception Status Report (PDCP_RSR) to the virtual PDCP, a new layer instance introduced at the BS which is common to both UL SURB and DL SURB, at the serving BS. The PDCP_RSR may be triggered: (i) when the gap between SN of the latest received PDCP PDU from SL and SN of the latest received PDCP PDU from DL SURB is larger than a configured threshold (this trigger is mainly for data duplication over the secondary Uu connection); (ii) when a missing PDCP PDU is identified from the SL reception (this trigger can be applied for both data duplication and data split over the secondary Uu connection); and/or (iii) periodically. The PDCP_RSR may indicate either the last in-sequence received PDCP PDU or the missing PDCP PDU(s) of the SL reception.

The virtual PDCP entity at the serving BS, based on received PDCP_RSR from Rx UE, can determine to skip duplication of those PDCP PDUs over DL SURB that have been already received by Rx UE directly from the primary SL. In case missing PDCP PDU(s) are reported in the received PDCP_RSR and the reported missing PDCP PDU(s) are buffered in the virtual PDCP entity, the BS may determine to increase the scheduling priority of the DL SURB temporarily to speed up the transmission of the missing PDCP PDU(s) to Rx UE.

Figure 3.13 illustrates some RAN-level signalling enhancements of this TC for the case of data duplication over the secondary Uu connection.

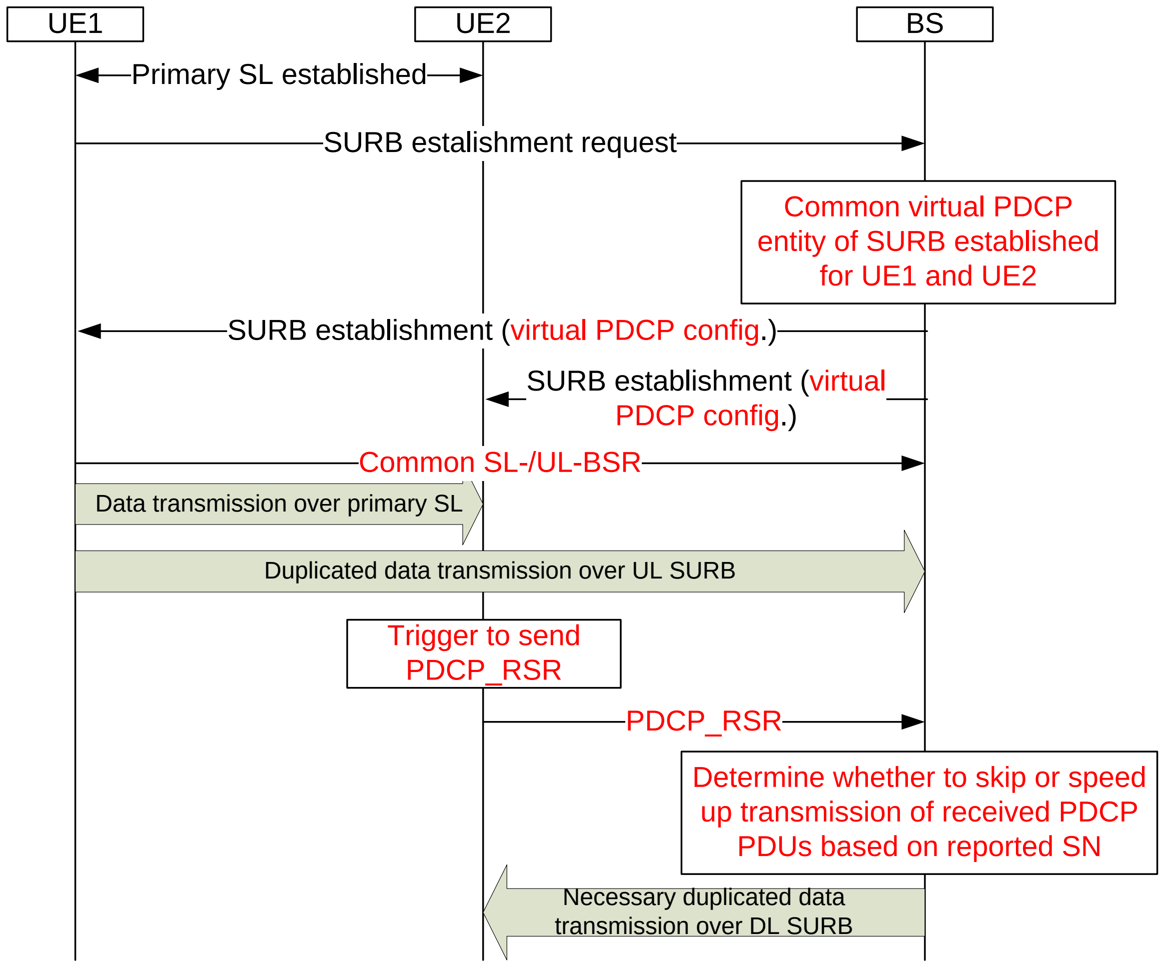


Figure 3.13: RAN-level signalling enhancements for data duplication

To reduce power consumption for Rx UE, Rx UE may be allowed for skipping to receive DL SURB if it is determined by Rx UE that there is no missing PDCP PDU as received from the primary SL. This can be applied for unicast as well as broadcast/multicast transmissions. To ensure Rx UE not to miss the chance to receive useful duplication transmission from DL SURB, Tx UE needs to have SL resources allocated (either by itself or by the serving BS) to transmit PDCP PDU over the primary SL no later than the scheduled UL transmission on UL SURB for duplication of the same PDCP PDU.

In case the BS allocates resources to Tx UE for the primary SL and data duplication is carried out over the corresponding UL SURB, the primary SL and the corresponding UL SURB may share the same Buffer Status Report (BSR). Thus, either one of SL-BSR or SURB-BSR from Tx UE to the BS is sufficient.

MEC based RAN level authentication and admission control for multi-operator support of SURB

It is described above that the serving BS may indicate, e.g., in broadcast common control signalling or SIB, the support of SURB with multi-operator support, in line with the support of the primary SL. In order to enable the BS to perform quick and reliable authentication and admission control of a UE from a different PLMN, as compared to that of the BS, the UE requesting the SURB service, the following network procedure is provided:

- The BS may indicate in SIB the support of SURB with multi-operator support.
- The UE, upon accessing and requesting the BS to provide the SURB service, may determine the implication of the SURB and multi-operator support from the BS and, as based on that, indicate to the BS the required V2X credential of the UE in the request for SURB.
- The BS, upon receiving the request from the UE including the V2X credential of the UE, may determine and authenticate the UE with the V2X server which is assumed common to all PLMNs.
- The BS then performs admission control of the UE and requested SURB.

Figure 3.14 illustrates a network arrangement for facilitating the above network procedure. It is assumed that the BS is connected to the V2X server via a local mobile edge cloud (MEC) for a fast authentication of the UE. It is noted that certain functionality of the V2X server may be distributed into RSU, including BS-type RSU.

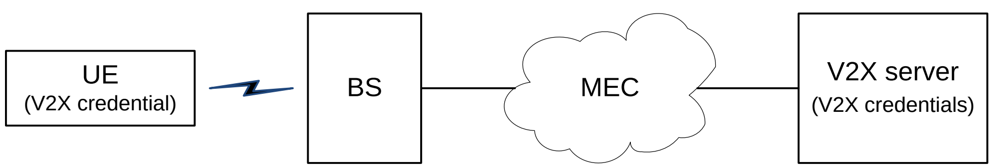


Figure 3.14: Limited RAN access of SURB based on V2X credential for multi-operator support

3.3.3 Evaluation

This TC allows for using the SL as the primary connection of communications between impacted UEs in proximity of each other while utilizing available cellular access over Uu for a secondary connection in order to ensure the required high reliability. The secondary Uu connection is based on an optimized local-breakout path which is further enhanced and facilitated by the introduced virtual PDCP and SURB with multi-operator support.

Thus, this TC inherits all the advantages of using broadcast SL without feedback control on radio access layers as specified in the current LTE [3GPP18-36300], e.g., in terms of simplicity, flexibility, low latency, and multi-operator support but, in addition, with reassured QoS in terms of high reliability. This is due to the assistance provided by using the secondary Uu connection. The TC configuration could be further updated to consider also data splitting in addition to data duplication, thus achieving also data rate improvements. In comparison with the optimized local-breakout path for D2D communications reported in prior arts [TTK+14], the secondary Uu connection based on the introduced SURB with the common virtual PDCP as well as RAN-level authentication and admission control has considerably lower protocol overhead and multi-operator support.

This TC can be applied directly to support advanced cooperative driving use cases considered in 5GCAR such as the lane-merge UC and the see-through UC which may use SL for needed communications on the fly. Further qualitative evaluation of this TC against KPIs of the targeted use cases, the lane-merge UC and the see-through UC, can be found in Section 4.

3.4 Location aware scheduling

3.4.1 Objectives

The location aware scheduling is an extension of network procedures that enhances network capabilities in managing transfer of messages with adaptive spatial/time deadlines. The aim of the location aware scheduling is to take additional V2X service information into consideration when mapping a certain service to a certain QoS. In particular, the focus is on using location information, with regards to both vehicle location information (e.g., expected/planned trajectory) and service location information (e.g., area of relevance of a certain message). This is motivated by the fact that, for some V2X applications, the requirements of the transfer of a certain message should be interpreted in terms of geographical region (e.g., the vehicle should receive/transmit the message before entering/leaving a certain area) instead of absolute latency budget. Accordingly, the transfer of the message should be optimized considering the spatial (or time) deadlines of the message, jointly with the vehicle status information (position, speed, etc.).

The location aware scheduling then targets the following objective:

- enable a dynamic adaptation of QoS parameters taking into consideration additional V2X service information instead of using static QoS mapping for services that might be sub-optimal and bring to an inefficient utilization of network resources.

3.4.2 Description

In the following, we consider that a certain message to be transferred has associated an information regarding its area of relevance that represents the geographical area the message refers to. According to the service, this implies that the vehicle should receive/transfer the message before entering/leaving the associated relevance area. An example is show in Figure

3.15 considering an High Definition (HD) map acquisition use case, where different messages (layers 1-2 and layer 3) have different areas of relevance and such messages should be received before entering the associated relevance areas. In addition to the relevance area, additional information can be associated to a message such as the message size.

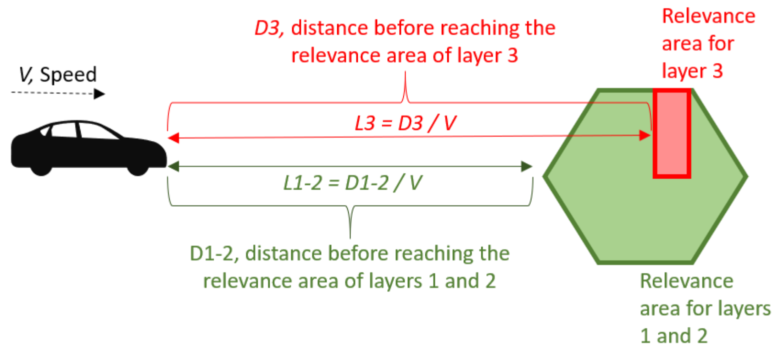


Figure 3.15: examples of different messages with different geographical area of relevance.

From Figure 3.15, considering the speed of the vehicle and its distance from the relevance areas of the messages it is supposed to receive, it can be seen that two different latency budgets for message reception can be extrapolated. Please note that in other use cases, the V2X service might provide the network directly with the information about the latency budget of a certain message instead of providing the relevance area and vehicle information. This is to consider services where for instance data transfer has an associated time deadline instead of a spatial deadline. The latency budgets associated to the messages represent an additional source of information that can be exploited by the network to optimize the message delivery.

Inputs and outputs of the location aware scheduling are depicted in Figure 3.16. The location aware scheduling receives the following inputs from the V2X service:

- Message information
    - Relevance area (or time deadline)
    - Message size
- Vehicle information
    - Location and speed (or planned trajectory with associated timestamps)

An example of source for such information in a 3GPP 5G system could be e.g., an AF interacting with a 3GPP network. According to such information, the location aware scheduling provides the following outputs:

- Scheduling information
    - Transfer planning, etc.
- QoS requirements

  - QoS Profile, etc.

Depending on the implementation of the location aware scheduling, the outputs can be delivered and used in different ways. Parts of the outputs could be delivered to the service. For instance, the service might be informed about the transfer planning to be aware when to trigger the message transfer. Other parts of the output are delivered to the network, which can use such information in several ways. For instance, information about the transfer planning can be converted by the network into target nodes involved in the message transfer (e.g., RAN nodes), which could be then informed about the upcoming message transfer. Information about the associated QoS requirements can be then used by the network to enforce the correct QoS for the message transfer. Considering the exchange of information between the service and the location aware scheduling, the service negotiation solution can be exploited for retrieving message and vehicle information, as well as to provide the service with feedback (if any) from the location aware scheduling.

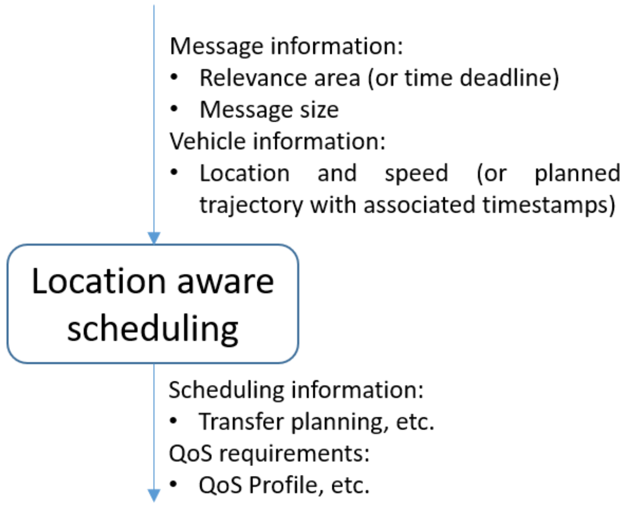


Figure 3.16: Inputs and outputs of the location aware scheduling

An example of utilization of location aware scheduling considering the messages of example in Figure 3.15 is shown in Figure 3.17. The location aware scheduling receives information about the size of messages for Layers 1-2 and Layer 3, as well as the associated geographical areas of relevance. Considering the information about the vehicle location and its speed, the location aware scheduling can schedule in an efficient way the delivery of the layers 1-2 and layer 3 messages, i.e., schedule the most suitable nodes to transfer the message according to current network conditions as well as enforce the most suitable QoS to fulfil the message transfer. In particular, given the larger size of Layers 1-2 compared to Layer 3 as well as its closer relevance area, the location aware scheduling plans the transfer of Layers 1-2 and Layer 3 in two different windows, guaranteeing the overall transfer of Layers 1-2 and Layer 3 is completed before the vehicle approaches the associated relevance areas.

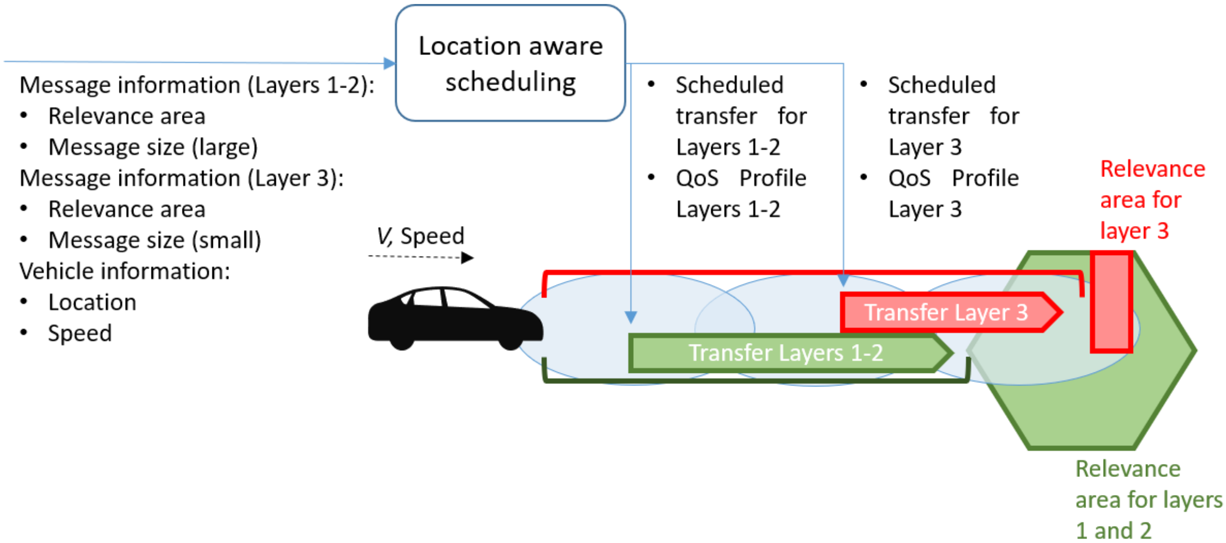


Figure 3.17: Example of utilization of location aware scheduling

3.4.3 Evaluation

The location aware scheduling is a functionality that allows to optimize scheduling operations within a network by taking advantage of additional service information. The optimization of scheduling operations can introduce the following benefits:

- Increase of the overall network capacity. This is due to a more efficient scheduling of network resources that is enabled by the knowledge of message size and associate spatial/time deadlines. This also has benefits on the overall network efficiency.

Higher service availability. In current networks, where QoS requirements do not consider service information such as vehicle trajectories and relevance area of a certain message, a service may be not available (e.g., admission control does not admit a certain flow) if the network cannot fulfil the QoS of the service. With the location aware scheduling, unnecessarily stringent QoS requirements could be avoided for services with e.g., relaxed message transfer deadlines, thus improving the overall service availability. On the other hand, for services involving message exchange among vehicles close to each other (e.g., lane merge), location aware scheduling can be used to temporally increase the service priority with respect to other services in the cell (if needed e.g., in case of network load) thanks to the fact that transferred messages will contain location information highlighting that messages are generated in a certain local area and need to be delivered within that area (this intrinsically means that messages have high priority).

3.5 Infrastructure as a service (IaaS) for vehicular domain

3.5.1 Objectives

The IaaS technical component belongs to the area of enhancements on network orchestration and management. The TC targets the following objectives: facilitating and adapting application network deployment, enabling re-deployment in near real time and finally providing a set of tools allowing at the same time independence and interdependence between ITS application layer (including service orchestration) and network control layer and user plane.

Application layer could be developed by 3rd parties (different actors than MNO, car manufactures, etc.), such as software developers, Over The Top (OTT) players. The infrastructure providers including mobile cellular network, centralized cloud, regional cloud, distributed MEC will be in charge of offering infrastructure services for the Business-to-Business (B2B) user of the service to be able to automate deployments of each software component of the system, to monitor service, to adapt service deployment to network conditions as well as server conditions in operational condition, to secure service architecture in order to achieve high level service availability.

Software components instances will be deployed at different locations: at the edge (MEC and edge cloud), at regional, or in a centralized way. The more the software component will be instantiated low in the network (closed to the vehicular UE), and the less the software component will have to take into account an important amount of practical road situations corresponding to different use cases studied in 5GCAR (for instance the amount of crossroads for lane merge use case) as depicted in Figure 3.18.

The problem of placement of components in a distributed environment is a complex problem. An orchestrator will be used to deploy the components in order to satisfy on running time SLA constraints such as latency, reliability, etc. Some open source projects such as OpenStack Tricircle [OST-TRI] deal with the problem of placement in a distributed environment. [SGH17] and [SGH18] are addressing the problem of placement of software component in a distributed environment.

3.5.2 Description

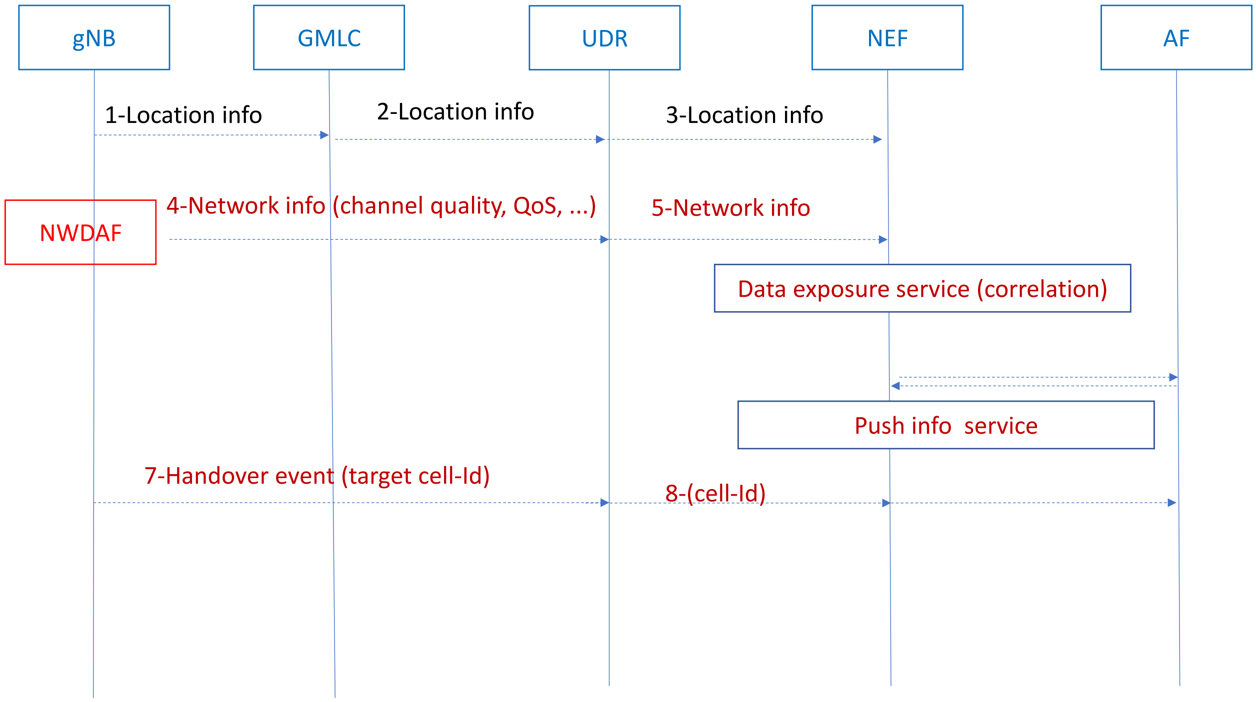


Figure 3.18: IaaS, impact over 3GPP interfaces and functional entities

At application level (see Figure 3.18) an interface will grant exchange of information between the Application Function (AF) and 3GPP functional control plane entities through the Network Exposure Function (NEF) The NEF is in charge of exposing authorized network-related information to the AF. Examples of information envisioned to the exposed might include channel quality info, UE Location, Cell-ID, Cell Load, Average Network Latency at access, core level, target Cell-ID (before handover execution).

Indeed, the knowledge in advance of the Cell-ID will be useful for instance at AF to correlate car trajectory with network trajectory, to be able to anticipate fading situation in particular area (tunnel, building shadowing). The AF could be able also to organise in advance switching from as edge server to another one if the target cell is attached to a different edge server.

The gNB will have to send information (radio layer info) towards UDR (Unified Data Repository).

Some network information would be generated by NWDAF (Network Data Analytics Function) which provides slice load information for the time being at 3GPP standards defined for 5G. The information provided by NWDAF could be extended to channel quality information for ITS domain.

GMLC (Gateway Mobile Location Center) refined in 3GPP Release 15 will push location information towards UDR. The interface between GMLC-NEF for location already exists before 5G, should have to be activated for ITS domain.

The UDR could contain network information possibly averaged on a given windows (provided by NWDAF) whose duration could be variable. Information collected at UDR could be also used to extrapolate predictive data on expected network performance. In that context, the novel report issued from 5GAA to 3GPP standardization bodies: “LS on Requirements to enable Predictive QoS for Automotive industry” [5GAA18-180265], deals with the interest of pushing predictive QoS information towards AF. Indeed, novel component network component (Prediction Function) is able to deliver value added data to application layer. Predictive QoS could be integrated as a network service by using the IaaS framework presented here.

Furthermore, Interface/API could be set between NEF and Business Support System and/or Operating Support System which will be in charge of pushing information towards service orchestration in order to be able to deploy or to re-deploy application components in an optimal way.

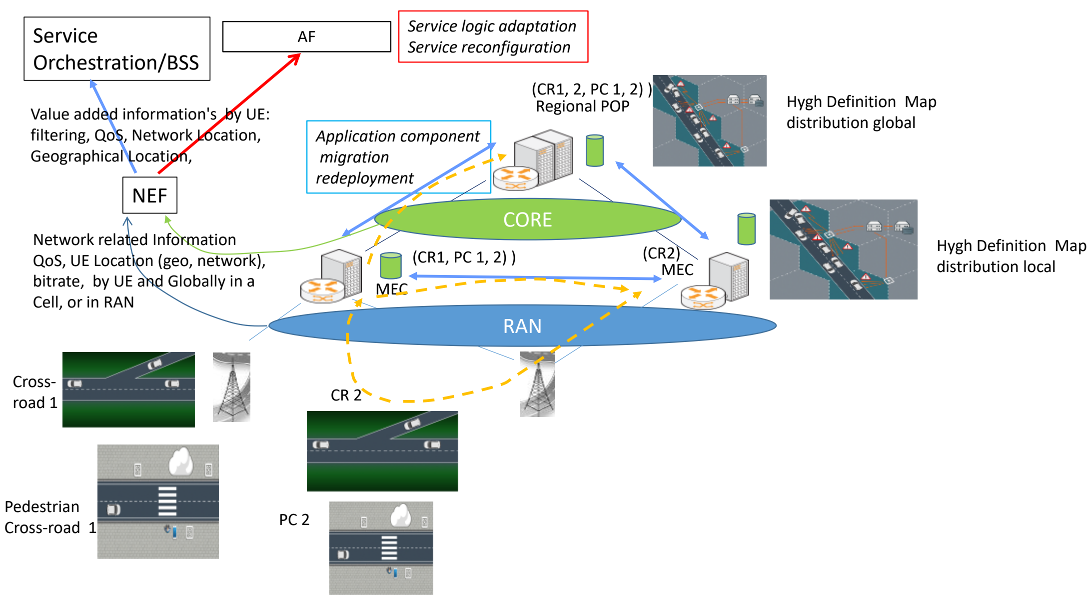


Figure 3.19: IaaS, mapping with 5GCAR use cases

3.5.3 Evaluation

This technical component has not been formally evaluated in real conditions; some possible interest for 5GCAR use cases hare presented here.

The lane merge Use Case of 5GCAR [5GC19-D21] is an interesting one. For lane merge, it would be interesting at application level to hold network indicators such as latency and packet loss ratio, etc. For lane merge, the application (i.e., traffic orchestrator) will make calculation over car trajectories for creating a gap between two vehicles on a given lane. After calculation, the traffic orchestrator will then send orders/recommendations to target cars for gap creation, e.g., speed reduction. The enhancements introduced by the IaaS framework would be that traffic orchestrator could decide eventually to cancel the manoeuver (e.g., recommending the entering vehicle to stop) in case it is detecting bad network conditions related to the merging vehicle because packet drop (or latency) is too high, and not coherent with service level requirements of lane merge.

Furthermore, for that specific use case, localisation information would be interesting at data merging/fusion level to validate the localisation information computed by cameras for each connected car.

Furthermore, let's imagine lane merge specific traffic orchestrator running in a regional data centre Service orchestrator could detect thanks to the VIM (virtual Infrastructure manager) a service latency problem (time for message processing is too high for instance) due to server high occupancy, and then decide to redeploy application component (traffic orchestrator instance dealing with lane marge use-case in a given area) to a given edge server. The service orchestration, by exploiting the information given by the NEF, will be able to estimate in advance end-to-end latency for a given service topology (service component placement) taking into account network (both radio access and core network) and service latency contributions. Thanks to IaaS framework, the service orchestrator will then be able to select the best edge server to perform the vehicle traffic orchestration for a given set of cross road in accordance to the service level requirements of lane merge.

The same principle could be applied to vulnerable road user protection use case as well as high definition map distribution for service re-orchestration and redeployment purpose. For the case of high definition dynamic map, the application could deliver a warning when network and/or service infrastructure are not good enough such as: "Pay attention, dynamical map could not be a 100% up to date". As a consequence, the speed of autonomous car could be reduced.

3.6 Redundant mode PC5 + Uu

3.6.1 Objectives

As defined previously in [5GC19-D21], 5GCAR is aiming to contribute to the 5G specification with a goal of becoming a true enabler of V2X applications that are not yet realizable with the current technologies. For this purpose we have defined several technical components that could help to achieve some stringent requirements corresponding to several use cases defined in [5GC19-D21]

Among them, a key goal of 5G is to provide ultra-high reliability close to 10^{-5} (defined as the maximum tolerable packet loss rate at the application layer) within the maximum tolerable end-to-end latency.

The technical component redundant mode PC5 and Uu is intended as enhancements for multi-connectivity cooperation, in order to improve and achieve this reliability thanks to the usage of both radio interfaces, namely the PC5 interface for Sidelink Communications and Uu interface over cellular network at the same time. It could be used for V2V services when covered by the cellular network or for V2I/V2N services when an RSU using Sidelink communications (i.e., UE-type RSU) is located close to an eNB/gNB.

This technical component differs from other proposals mainly for two reasons:

- the objective is to envision a simple algorithm without heavily relying on feedbacks from lower layers, external information sources or reports from the Rx UE to avoid situations of hysteresis or ping-pong effects when a decision should be made in a highly dynamic situation (i.e., selection of the best link between PC5 and Uu interface for a specific packet to be transmitted at a given time). However if there is no feedback at all, the “blind” duplicate transmission should be restricted to triggered messages only for a limited amount of time because the side effect will be a reduction of spectrum efficiency (i.e., more radio resources used than needed and increase of interference).
- the intention is to not only focus on lower layers and to provide an analysis of different possibilities at different levels, with always the notion of a simple redundant scheduler in mind. Among the possible options, even the solution based on Radio Resource Control (RRC) support will complement the TC “SL and Uu multi-connectivity” (presented in Section 3.3) showing a possible usage of SPS (SL and UL/DL) instead of relying on SL UE information reports from Rx UE.

Several implementation options will be described in the next section below and the evaluation sub-chapter will give an overview of pros and cons of every solution.

3.6.2 Description

For reminder, here is in the figure below from [5GC18-D41] the overall concept depicted for a V2V service example:

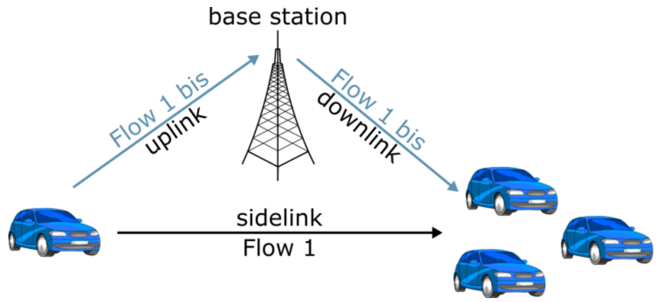


Figure 3.20: Redundant mode PC5 + Uu for a V2V service

Complementing the paper [LWH+18] showing already clear benefits from such feature, this TC focuses on “*how*” to achieve PC5/Uu redundancy. Furthermore, this TC is not only restricted to the LTE-V2X access and could be extended to the NR-V2X as well.

Several options for implementing a redundant scheduler at UE side allowing PC5 and Uu communications have been already described in Chapter 4.6 of [5GC18-D41].

Some of them may address only the C-V2X access part which is the main focus of 5GCAR project but all four options could be included in future standards of ETSI ITS as well taking into account that the C-V2X Access layer in an ITS station defined in ETSI ITS architecture is already including the LTE-V2X PC5 part as described in [ETSI18-103613].

Depending upon the layer where the scheduler is envisioned in the UE, a summary is represented below in a single figure grouping the four options already described in [5GC18-D41]:

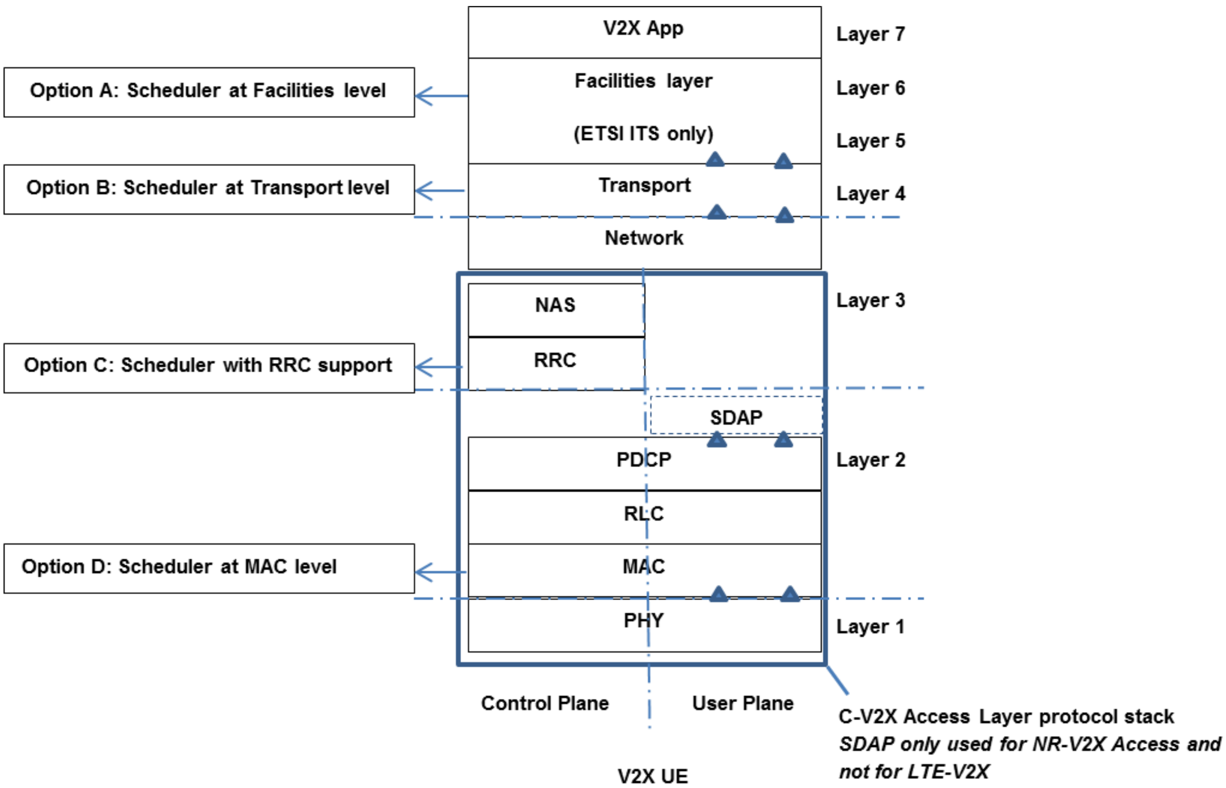


Figure 3.21: Redundant mode PC5 + Uu implementation options at UE side

From the figure above, it clearly appears that options A and B could be used with other RATs and would require modifications of ETSI ITS standards for instance whereas options C and D would involve modifications directly in the C-V2X protocol stack and therefore impacting 3GPP Technical Specifications.

To complement the description of each option already given in [5GC18-D41], some examples of possible usages of this TC are represented below depending on the intended use case.

Use Case example 1: Lane merge

This TC could help to achieve the expected reliability of 99.9% while maintaining latency under 30 ms of the Lane Merge Use Case defined in [5GC19-D21]. To do so, duplicate messages for cooperative maneuverers would be sent simultaneously over PC5 and Uu interface either with one of the four options, namely with a redundant scheduler at Facilities layer, Transport, SDAP/PDCP level with RRC support or at MAC layer of UE side.

The next figure represents the path over Uu interface for a V2V service such as a Lane merge message exchange between two vehicles (for the sake of simplicity, direct UP inter-connection between gNBs is shown). The specific case where both V2X UEs are NR/5G compliant is depicted but the same concept could be applied as well for UEs compliant with LTE-V2X (Rel.15 for instance) changing the corresponding protocol stack.

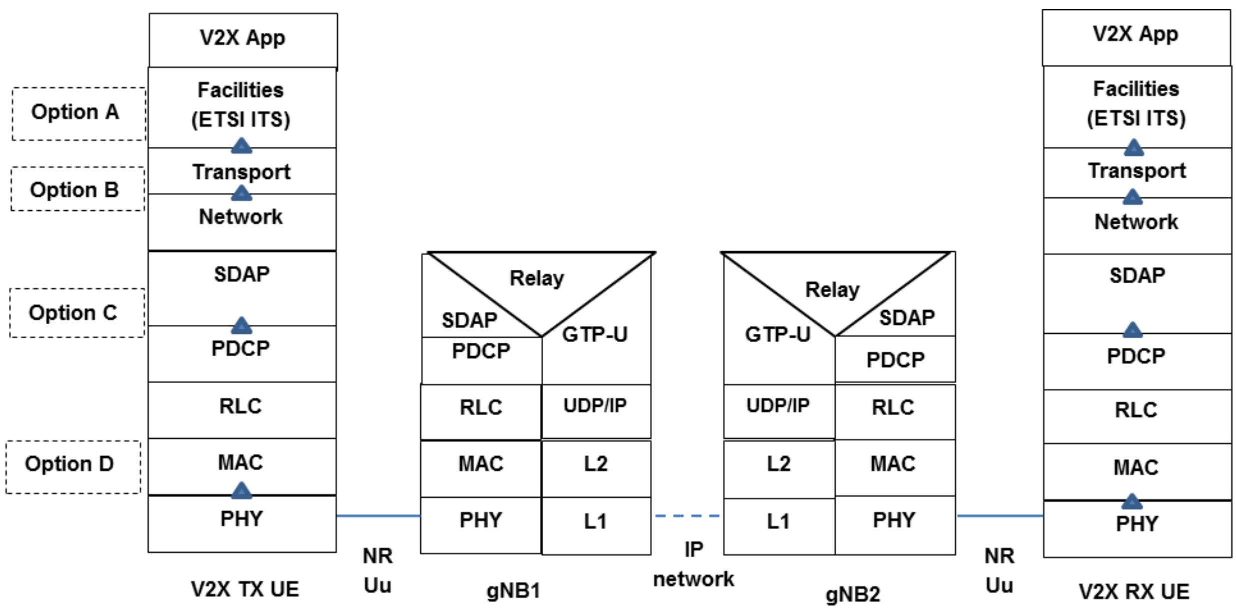


Figure 3.22: User Plane of Uu path for V2N2V service with direct UP inter-gNB connection.

The relaying part through an IP network between the two gNBs in this example could be achieved with legacy standard procedures (e.g., the deployment of local UPFs) or thanks to the TC 4.7 establishing an end-to-end Local Radio Path. Either way, it is out of the scope of this present TC. It is assumed that the E2E maximum latency could be achieved most of the time (under 30 ms with the Lane merge example) through the Uu path.

The next figure represents the path over PC5 interface for the same V2V service such as for the Lane merge message exchange between two vehicles with the four options envisioned for duplicate message transmission.

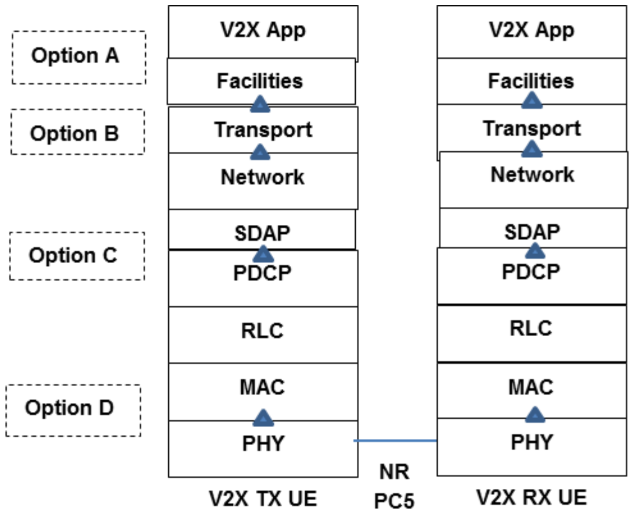


Figure 3.23: User Plane of PC5 path for V2V service

__Use Case example 2: Remote driving for automated parking__

This TC could help to achieve the expected reliability of 99.999% while maintaining latency between 5 ms and 30 ms of the remote driving for automated parking Use Case defined in [5GC19-D21]. The next figure represents the path over Uu interface for the V2N2I service such as the sensors feedback from the vehicle remotely driven through a V2X Application Server (AS).

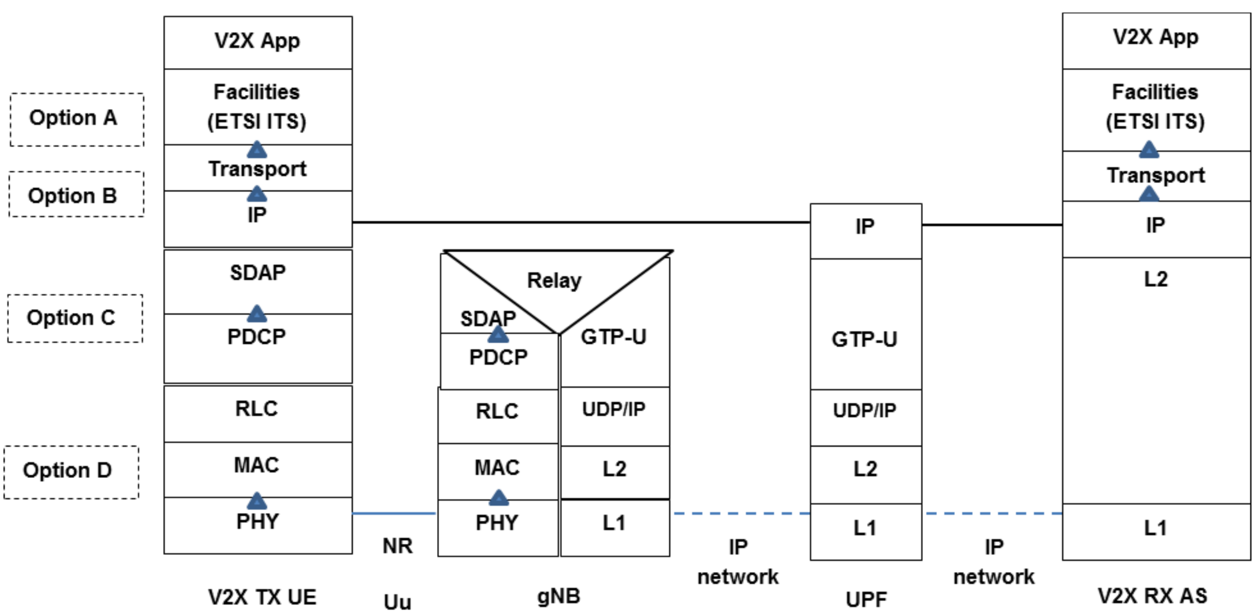


Figure 3.24: User Plane of Uu path for V2N2I service

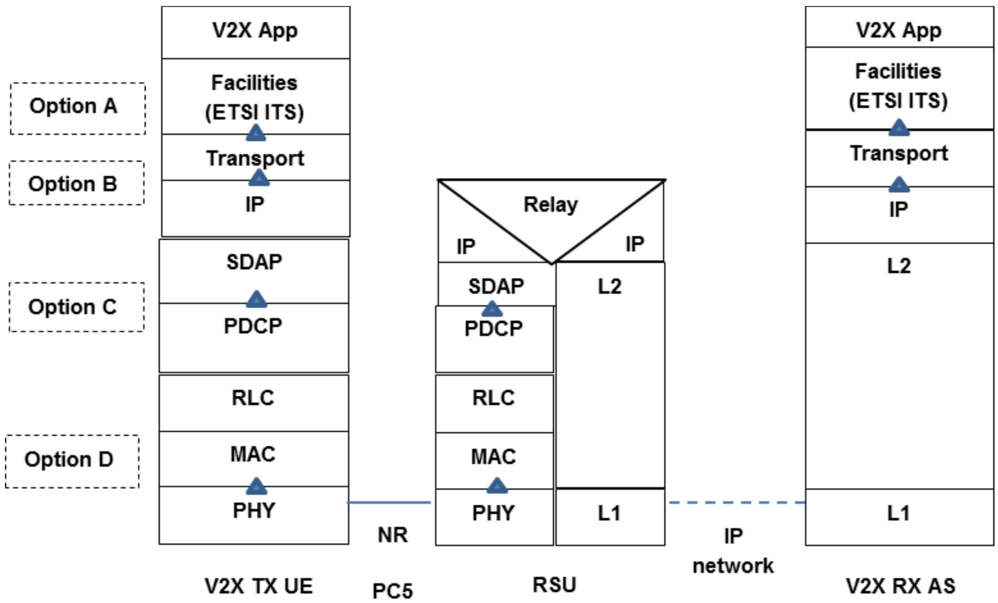


Figure 3.25: User Plane of PC5 path for V2I service

It appears that options A and B would impact mainly the protocol stacks of UE and V2X Application server like with the Lane merge Use Case. However for a V2N2I or V2I service, options C and D would impact the protocols stacks of UE and RSU but not the V2X AS.

If options C or D are applied, the consequences are the following:

- If the RSU and gNB are independent each other, then the V2X AS will receive potentially the same message twice, from two distinct IP addresses (one from the UPF linked to the UE and one from the RSU). The V2X application will need to deal with and it may not so easy to manage.
- In order to achieve the expected goal of reliability focusing on duplicate usage of radio links, the RSU should be linked with the gNB such as the TC "RSU enabled Smart Zone (SM-Zone)" proposal. In this way the mixed gNB/RSU could manage the duplication of messages in a smarter way and only forward to the V2X AS the relevant single messages with one source IP address.

3.6.3 Evaluation

The four implementation options described in Chapter 4.6 of [5GC18-D41] have the following pros and cons.

Option A: Redundant scheduler at Facilities level

Pros:

- A redundant scheduler at Facilities Layer level should be easier to implement and test
- This feature could be applied to specific applications types only
- The message duplication could also be performed for other types of RATs (not necessary PC5 and Uu interface of C-V2X technology)
- Communication interface selection, global messages management, support of repetitive transmission and relevance checking is already under the responsibility of the Facilities Layer according to the ETSI ITS standards
- For a V2N service such as the Remote Driving Use case, the V2X AS could manage duplicate messages if it is also compliant with those ETIS ITS standards and include a specific management for the same message coming from two different sources

Cons:

- The V2X UE and V2X AS are required to be fully compliant with ETSI ITS specifications that should evolve as well to include this concept at Facilities layer
- The Receiving UE needs to listen on both interfaces concurrently (not all UEs may have such capability)
- Defining a redundant scheduler at Facilities layer is more relevant for broadcast/group cast messages than unicast messages when a specific and low E2E reliability is expected.
- There is less interaction with lower layers and it is a paramount of importance to restrict the duplicate usage of interfaces very carefully and for a limited time in order to avoid unnecessary congested situations.

Option B: Redundant scheduler at transport level

Pros:

- Protocols at transport level enabling multi path are already developed
- Multi Path TCP (MPTCP) can rely on different RATs easily with legacy well known TCP connections
- MPTCP redundant scheduler code is already available for testing purposes as well as other policies
- Multipath Quick UDP Internet Connections (QUIC) is an extension to the QUIC protocol that enables hosts to exchange data over multiple networks over a single connection [MQUIC].
- If another application needs also redundancy, it can rely on the same scheduler

Cons:

- For MPTCP, it needs an E2E TCP connection between Transmitter and Receiver UE adding more delay than connectionless communications such as UDP
- Multi Path transport protocols work only in IP connectivity (excluding non-IP messages such as CAM/DENM)
- Needs that both Transmitter and Receiver UE implement the same protocol
- It will create network load all over the E2E path and not only the radio part that requires specifically the redundancy.
- Like for the Facilities layer, there is less interaction with lower layers and it is a paramount of importance to restrict the duplicate usage of interfaces very carefully and for a limited time in order to avoid unnecessary congested situations.

Option C: Redundant scheduler with RRC support

Pros:

- RRC is already integrating in Release 14 Semi Persistent Scheduling configuration for Sidelink communication over PC5 interface and UL transmission over Uu interface.
- Mode 3 in Rel14 can already allow cross-carrier scheduling for V2V communications over PC5 interface
- Could benefit from an enhanced Mode 3 eNB scheduler proving the interest in combining both interfaces for the same V2V service

Cons:

- It is not yet clear what are the required modifications of RRC elements to allow redundant flows for same V2V application
- it is required that the V2X UE is compliant with this functionality
- it is required that the RSU and eNB/gNB are linked together to allow efficiently the duplicate usage of both interfaces for a V2I or V2N2I service.

Option D: Redundant scheduler at MAC Level

Pros:

- V2X Concurrent inter-band configuration for Uu+PC5 communication is already defined in Release 14
- A new UE Mac entity performing Scheduling and Multiplexing could be added like for UL Carrier Aggregation

- Scheduling at this level would allow other policies allowing better performances than a simple redundant approach

Cons:

- Certainly the most complex solution to implement
- It is not yet clear how to disable/allow redundancy for specific flows
- It is not yet clear if this feature at MAC level is worth just for adding a simple redundant scheduler.
- it is required that the RSU and eNB/gNB are linked together to allow efficiently the duplicate usage of both interfaces for a V2I or V2N2I service.

3.7 Evolution of infrastructure-based communication for localised V2X traffic

3.7.1 Objectives

In many V2X use cases (e.g., cooperative manoeuvres, sensor information sharing, video sharing, intra-platoon communication) the data traffic that is exchanged among vehicles (V2V) has localized significance. This means that the communicating vehicles that participate in the same use case are located in the same geographical region and there is no need to access a remote server, (e.g., V2X Application Server, ITS cloud server), while multiple transmission modes (unicast, broadcast, multicast) might be required. For localized V2X communications, either the cellular (Uu) interface or the sidelink (PC5) interface could be used considering the radio conditions and the environment where the V2V use case takes place. Specifically, the NR-Uu interface could provide guaranteed QoS (i.e., high reliability, low latency) especially in the case of, e.g., no line-of-sight among communicating vehicles, poor PC5 radio conditions or high PC5 interference due to vehicles' high density.

Nevertheless, existing cellular solutions, based on the Uu interface, may need some updates for supporting in a more efficient way the challenging performance requirements that localised V2X services have, which include the need for fast and guaranteed transmission of localized data.

This TC targets enhancements of network procedures through the formation of local end-to-end (E2E) radio data paths over the Uu interface, proposed to enable the fast and guaranteed transmission of localized data traffic among the involved devices, satisfying their QoS requirements and the features of the V2X services, as initially presented in [KZ18]. The "end-to-end" term denotes that the (user plane) radio data paths are established among the involved communicating end devices (i.e., vehicles), while the "local" term denotes that the paths are established via the BSs. Instead of using solutions such as local UPFs providing a local UP end-point instead of reaching the UPF within the core, the focus of this TC is that the nodes of the core network do not participate in the user plane transmissions, since the data traffic is localized and handled directly among involved BSs. Local e2e paths via the BS can support different communication modes (unicast, multicast, broadcast) without the need to interact with other entities such as MBMS. Although, according to the proposed solution the data traffic does not pass through core network nodes, online and offline charging methods could be used and specifically with the support of the Charging function (CHF) of the 5G system architecture. For instance, the SMF that could be used for the establishment of the local e2e paths could also trigger the appropriate event and support the collection of charging required charging information [3GPP15-32255].

3.7.2 Description

Localised communication through the Uu interface requires the introduction of a data routing/forward function at the BS (e.g., gNB) that transmits the data packets, e.g., among vehicles in a fast and guaranteed way without traversing any core network entity (i.e., user plane). This routing table in the BS maps and connects the uplink (UL) and downlink (DL) radio bearers of different UEs for the formation of the local radio paths and consequently the faster forwarding of localized V2X traffic (user plane latency reduction). According to the type of the traffic, the routing table at the BS undertakes to forward the data packet to one or more UEs in the same of neighbouring cells (e.g., multicast, unicast transmissions). In case UEs are attached to different cells, a possible solution which requires further investigations is to use Xn interface for path establishment and for data packet exchange. Figure 3.26 provides an overview of the involved entities and interfaces.

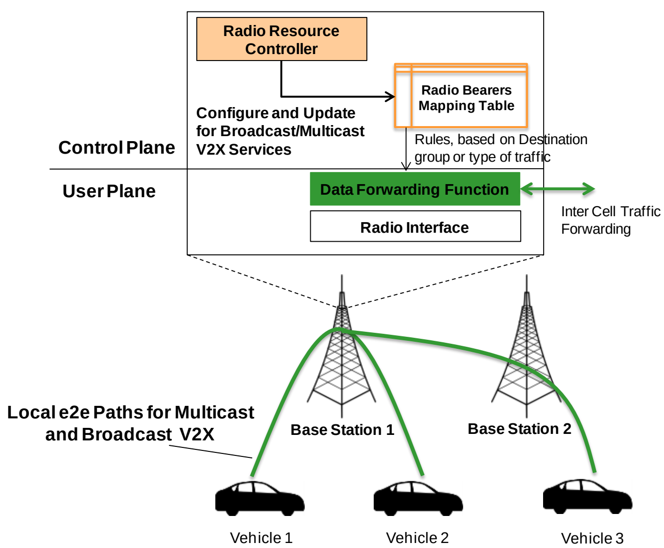


Figure 3.26: concept of fast V2V paths via the cellular interface

A UE requests the establishment (or update) of the local cellular V2V paths using Radio Resource Control (RRC), Non Access Stratum (NAS) protocols, for localised V2X traffic and to transmit/receive data packets over a local e2e path. The type of the service and the identifiers of other involved UEs in the corresponding V2V service are information that the initiating UE should provide and is used for the establishment of the paths as well as for the configuration of the routing tables. RRC and NAS protocols need extension to support establishment, update and release of local cellular V2V paths between the UEs over the gNB(s) as well as to update and configure the routing table needed for the forwarding of localised data traffic. Based on these RRC or NAS messages, core access and mobility management function (AMF) and session management function (SMF) functions can control the establishment, modification, and release of this new type of link (i.e., local cellular V2V paths) as well as to update and configure the routing tables that are introduced at the BSs in order to form V2V paths for localized V2X traffic over the Uu interface.

3.7.3 Evaluation

A performance analysis is provided in this section using analytical method to present the benefits of the proposed local cellular V2V path solution for user plane latency, comparing to baseline technologies for the single cell cases. It should be also noted that at the above examples an LTE configuration has been considered (e.g., 1 ms Transmission Time Interval - TTI) in order to have a fair comparison with an LTE system. For 5G communication systems, the achieved user plane latency will be much lower, using 5G New Radio (NR) numerology and configuration schemes (e.g., 0.25 ms TTI, faster Xn interface).

According to the proposed scheme, the core network is involved in the establishment of the local cellular V2V paths. Hence, improvements of the control plane latency are not expected. An analysis of the control plane latency issue can be found in [KZ18], where the option RAN-based establishment is considered.

Considering the operation of existing multicast and broadcast schemes, the overall E2E latency for the transmission of a data packet via the cellular interface, from a source to a destination vehicle is calculated as follows:

$$\text{E2E latency} = \text{L-RAN\_UL} + \text{L-CN} + \text{L-RAN\_DL}$$

and includes the following latency components:

- L-RAN_UL: the time duration from the time the vehicle has a V2X message to send over the uplink to the time the BS successfully receives the V2X message (i.e., 17.5ms+Scheduling Request (SR) period+(1+8*Target block error rate (BLER) %/100) in the case that dynamic scheduling with a separate buffer status report (BSR) is used [3GPP16-36881]).
- L-CN: the time duration the V2V message is travelling from the BS of the source vehicle to the BS of the destination vehicles with passing through core network nodes (e.g., S-GW/P-GW, and BMSC in case of multicast/broadcast services) centrally located, which is estimated around 20 ms [3GPP14-36868].
- L-RAN_DL: the time duration from the time BS has V2X message to send and to the time the vehicle receives the V2X message via unicast DL (4ms+8*Target BLER (%)/100, [3GPP16-36881]).

Firstly, we assume that the source and destination vehicles are located at the same BS and dynamic scheduling with a separate BSR is used. For a SR period=1ms and a BLER=10% the total e2e latency for a unicast communication, using the existing LTE scheme through the P-GW (L-RAN_UL+ L-CN+ L-RAN_DL) is larger than 45ms (Figure 3.27). Using the local e2e radio data paths the latency that is introduced by the core network entities centrally located (e.g., MBMS, S-GW) is avoided and the user plane latency for the exchange of unicast V2V packets is in the order of 25ms, showing an improvement of 45%.

In the case of multicast or broadcast communications there are two baseline technologies that could be used: a) MBMS and b) SC-PTM. On both cases, the L-RAN_UL and the L-CN latency components are also involved. The L-CN includes the network latency for the V2V message from the BS of the source vehicle to the BS of the destination vehicles with passing through the Broadcast Multicast Service Centre (BM-SC), which is estimated around 20ms in case of central deployments [3GPP14-36868]. The difference between MBMS and SCPTM lies in the time from when a V2V message arrives at the BS (of the destination vehicles) to the time when the vehicles successfully receive the V2V message. In the case of MBMS (L-RAN_MBMS-DL) the total latency includes the waiting time for the Multicast Traffic Channel opportunity for transmission, the DL transmission and the UE processing time. The L-RAN_MBMS-DL (equal to 3.5+ multicast channel (MCH) scheduling period (MSP)/2+ upper layer processing, [3GPP16-36881]). In the case of SCPTM (L-RAN_SCPTM-DL) the latency depends on the SCPTM scheduling period (SSP) (equal to 2.5+max (SSP/2+1,2)+upper layer processing, [3GPP16-36881]), which is shorter comparing to the MSP.

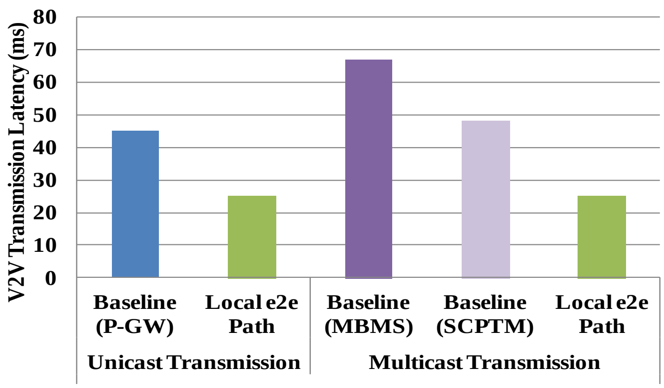


Figure 3.27: Local e2e Path User plane Latency - Single Cell.

Figure 3.27 presents the e2e latency for multicast communication, comparing the baseline multicast schemes (with MSP=40ms and SSP=1ms) with the proposed local e2e paths scheme. Due to the larger MSP the average e2e latency of MBMS is 67ms, while using SC-PTM the average e2e latency is 48ms. The e2e latency of multicast transmissions of the proposed local e2e path is the same as the corresponding latency for unicast transmission (25ms), and it is better comparing to the baseline multicast schemes (52% improvement comparing to the SC-PTM scheme and 73% comparing to the MBMS scheme). The reason is that the proposed scheme treats both unicast and multicast data packets with the same manner. In case of a multicast transmission the BS undertakes to forward (via the RBMT) the packets directly to the corresponding DL unicast bearers (or via a SC-PTM bearer) that have been formed during the establishment of a local e2e path for a multicast service. Hence, the introduction of the RBMT at the BS provides the benefit of the faster user plane transmission of the localized V2X data traffic, without the need of IP protocol procedures and without any interaction with the MBMS entities for multicast transmissions.

In the case that the source and destination vehicles are located at the neighbouring BSs (multi-cell case) the latency that is introduced by the inter-BS interface should be added for the communication over the local cellular V2V radio data paths (i.e., 7 ms according to [3GPP14-36868]). However, even in this multi-cell scenario there is substantial improvement comparing to the baseline LTE-based schemes and centrally located UP nodes. For both cases, the improvement of the latency via the local e2e paths solution allows the realization of V2V services that more demanding in terms of latency and reliability requirements (e.g., cooperative manoeuvres, sensor data exchange, cooperative perception, see-through).

3.8 Use case-aware multi-RAT, multi-link connectivity

3.8.1 Objectives

Use case-aware multi-RAT, multi-link connectivity is a multi-connectivity cooperation functionality that is proposed to enhance delivery of the use-case service requirements, which is usually known and formulated as QoS. Successful QoS delivery for some V2X use-cases, such as cooperative safety, is specifically challenging because of high mobility as well as latency/safety-critical nature of those use-cases, an example of which is lane merge manoeuvre. Therefore, it is very important for the service provider to guarantee persistent coverage for V2X communication for the duration of the use-case. On the other hand, some other use-cases, such as cooperative safety, requires persistent high data rate for a specific period of time, while vehicles' high mobility and congestion in the network hinders guaranteeing such requirements.

Use case-aware multi-RAT, multi-link connectivity is a technical component introduced for the aforementioned problem. When necessary, assignment of more than one radio resources to one UE via simultaneous connection to different BSs or via connection to more than one link of a BS, is a promising technique to mitigate impairments of only one link. In addition, in case of using only one link (for example, when multi-connectivity is not possible or not supported), selecting the best possible link among all the available options provides diversity gain and link quality improvement. In other words, the capability of actively selecting one or multiple links and/or RATs, based on network conditions and the use-case, would increase service availability for V2X use-cases. As a summary, the objectives of use case-aware multi-RAT, multi-link connectivity are:

1) To guarantee delivery of the use-case QoS by
    a) Exploiting diversity gain among different available links either by choosing the best one or by transmitting the same data over more than one link/RAT simultaneously.

   b) Exploiting multiplexing gain by splitting the data between different available links/RATs.

2) To avoid over-provisioning by carefully considering the use-case requirements (use case-aware consideration) and examining if a specific link/RAT connectivity is enough for the use-case. Otherwise, allocating more links/RATs to the UEs involved in the use-case.

3) To reduce network congestion by off-loading data from more congested networks to a more available one by choosing the less congested BS and/or RAT among all.

3.8.2 Description

To be able to use this TC, one should assume:

1) Vehicles/UEs capability of simultaneous connection to more than one link either within one RAT or to different RATs.
2) Communication network support of multi-link/RAT connectivity through information exchange and coordination between protocol stacks of different RATs e.g., LTE, NR.
3) A coordinator entity, located within the domain of the MNO the UE is attached to and managing available links/RATs, is responsible for determining the type of multi-link/RAT connectivity for the involved vehicles/UEs.

To evaluate each combination of links/RATs for each use case, in the first step, the “action” should be defined as a series of V2X communications with pre-defined QoS requirements to enable successful delivery of the use-case. In this context, “completion of action” refers to successful delivery of the use-case. Therefore, the evaluation should be based on completion of action rather than per packet analysis of QoS. For instance, a specific type of connection may fail to deliver QoS requirements for some periods of time during the manoeuvre, but it may still be able to provide enough resources for the manoeuvre completion since small periods of service un-availability would not cause a serious problem.

The second step is to consider the “completion time” of the action. There are two scenarios in this step:

1) The use-case requires V2X communication of a pre-defined period of time.
2) Completion time of the use-case depends on some parameters such as current location and speed of vehicles as well as the intended type of multi-link/RAT connectivity. However, there is probably an upper bound limit for the completion time defined by the use-case. If none of the available multi-link/RAT connectivities is able to complete the action before the deadline, the use-case will be declared as unavailable by the coordinator.

In case of the first scenario, the coordinator does not need to compute the time to completion and thus, can proceed to the third step. However, in the case of the second scenario, the coordinator needs to compute the completion time for each multi-link/RAT connectivity based on automotive conditions as well as the intended method of data splitting between links e.g., exploiting diversity via coding or aggregating bandwidth to increase data rate.

In the third step of the evaluation process, the coordinator decides which links/RATs to attach to for each of the involved vehicles/UEs. Taking into account the following parameters which are assumed to be known or predicted by the coordinator, the coordinator would be able to predict the resulted QoS of each combination of multi-link/RAT connectivity. Those parameters include:

1) Geographical area of relevance and the related information such as buildings topology (to find the most fitting path-loss model) as well as locations and height of BSs.
2) Expected trajectory of all the vehicles in the area of relevance.
3) Data type (e.g., video, status information, warning messages, etc) and its related properties such as packet size, arrival distribution, etc.
4) Relative priorities among different use-cases and/or vehicles.
5) Expected congestion and number of available resources for each RAT based on current waiting time of queues in bottlenecks and number of connected UEs.

Then, the coordinator compares the expected QoS for the whole action duration against the required QoS of the use-case and reports the promising candidates for the connection of each vehicle/UE. The final decision between those candidates is made with the aim of congestion control via traffic off-loading to the less-congested networks, while avoiding over-provisioning and waste of resources.

3.8.3 Evaluation

Use case-aware multi-link/RAT connectivity is a solution proposed to increase availability for V2X use-cases. For instance, in safety-critical driving use-cases, using only one link for connecting the vehicles may not provide high reliability, since the wireless channel may go to deep fade and fails to deliver the packets. Therefore, multi-connectivity solution can provide a backup link for those types of application when necessary.

The main benefits of this TC are:

1) Supporting better QoS management for V2X use-cases,

2) Dynamic selection of connectivity mode based on the use-case demands as well as network efficiency,

3) Consideration of additional use case specific information such as action completion rather than only looking into instantaneous QoS.

3.9 Multi operator solutions for V2X communications

3.9.1 Objectives

It is a valid assumption that V2X communication is going to be a multi-operator environment since it cannot be guaranteed that only one operator is going to coordinate the vehicular interactions in the overall area. This assumption has been accepted by various organizations [5GAA19-WP] [EATA] and is the working assumption in order to make a V2X system operating, under the considered V2X requirements. Multi operator V2X has implications in the communication via both PC5 and Uu interfaces, as well as in the use of edge computing.

Multi operator V2X Communication using PC5 may happen using:

1) Mode 1/3 by applying
    a. **Shared carrier**, which may face synchronization problems (can be handled with global clock such as GLONASS) and resource overlap. Resource overlap can be solved by applying resource split in TDM way.
    b. **Separate carriers**, which does not face resource collision between different PLMNs but requires carrier switching (with Interruption and delay) or multiple Rx Chains (which increases the cost).
2) Mode 2/4 by applying
    a. **Shared carrier**, which also may face synchronization aspects which can be handled by applying a global clock such as GLONASS. In this case static configuration is used requiring updates in special cases such as the cross border situations or when the spectrum pools are reconfigured.
    b. **Separate carriers**, which is based on static configuration – updates may be required in cross border cases. Carrier switching in this case is needed a well (with Interruption and delay) or Multiple Rx Chains (costly)

Above cases should also include the case of PC5 in unlicensed or licensed spectrum (which would need agreements among MNOs in case of shared carrier). In any case the configuration should be static or updates every time a reconfiguration occurs are needed. Also it has to be stated that the reconfigurations, and the carrier switchings come with delays that may hinder meeting the requirements in particular cases. It has to be noted that in case of shared carrier in licensed spectrum agreements between operators are needed.

Multi operator V2X Communication using Uu may happen using:

1. Typical Uu communication through normal UPF functions (i.e., home routing)
2. Local Breakout Schemes to communicate with vehicles of the other operator. This solution requires implementations with local breakout dependent on the topology (e.g., gNBs in the highway should have access to it) thus increasing the complexity

When using Uu interface, Edge Cloud Schemes used for processing the data need to provide this information to vehicles of the other operator (e.g., in the case of HD maps use case and vehicles that are associated with different Edge Clouds owned by an operator). This requires MECs sharing the same schemes with Local Breakout solutions described above to reduce the time for sharing this information. Additionally, multicast/groupcast requires duplication of the messages in the two (or more) operators' spectrum.

The previous analysis shows that enhancements are required for dealing with the proper (in terms of delay and reliability) communication of the vehicles belonging to different operators if we want to avoid complex deployments.

Additionally, we should consider the case of the cross country border crossing, where interruptions are going to occur since the UE should register to the other country's operator. The latter procedure requires a significant amount of time (i.e., at least some seconds; it has to be noted that the registration/attach procedure is in the range of 330ms [TGV+15]), and thus a significant interruption in the service, which is not acceptable according to 3GPP requirements, where it is mentioned that "Regardless of actual scenarios in place, from passenger experience point of view, automated driving should not be interrupted even when the vehicles cross borders as long as automated driving is permitted by regulation" [3GPP18-22886]

3.9.2 Description

The aforementioned challenges related to increased delays or limited reliability can be solved if the multi operator problem may be simplified to single operator based on agreements among operators for a regional split. Splitting the overall area in regions where only one operator is responsible simplifies the multi-operator environment and enables efficient V2X communication. Additionally, new ways for charging and to split the costs and the investments fairly or proportionally among involved operators could be envisioned. PC5 communication is efficiently handled by one operator without requiring complex coordination among multiple operators. Also the edge cloud solutions do not require any further enhancements since a single operator offers such service. The rationale has also been described in details in [5GC18-D41].

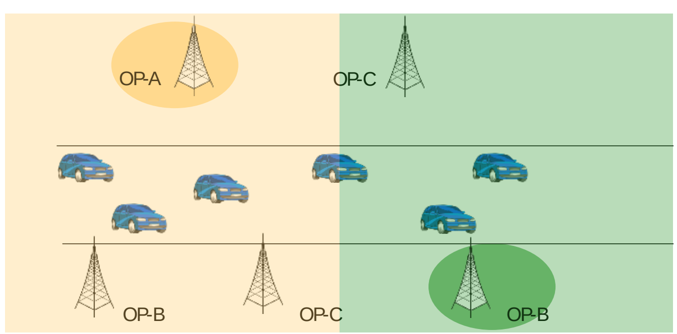


Figure 3.28: Regional Split of a highway

In order to minimize the transition time from one operator to another, when crossing the boundaries of an area, the devices will be registered in advance to all available operators. For example, in the case of a vehicle while performing a typical attachment to its HPLMN, the Subscriber Server of the HPLMN triggers through the core network the attachment (i.e., registration of the same vehicle) in all other available operators. Upon attachment to all the networks, a device is considered to be “connected” to only one of them while being in an “idle” state in the others. To which operator a UE should be connected is dictated by the network; this may be done by direct indication form the operator or via pre-configurations, or the Tracking Area Updates (TAUs).

One key requirement of this solution is to enable the vehicles (i.e., UEs) to transit smoothly from one operator’s area to the other. Thus we define the transition areas (Grey Areas). For a UE to be able to listen to messages (e.g., emergency notification messages), three options are possible (described in Figure 33):

1) The UE turns to CONNECTED for both operators: In this case the UE is connected to both operators and listens to both operators signalling channels and he can be scheduled to receive and transmit to both of them. In this case the UE should have two independent reception chains; thus increasing the cost.
2) The UE is CONNECTED to the one operator and IDLE to the other but listens to the downlink signalling channels with higher frequency.
3) The UE is IDLE in both operators but listens to the downlink service requests of both operators with higher frequency compared to that of the standard operation.

In case the UE participates in an active communication it should not switch operators directly, because this will interrupt the communication on the one hand and it is not ensured that the other UEs (i.e., vehicles) that participate in the collaborative manoeuvre will change operator at the same time. Thus certain coordination is required among the vehicles that participate in active communication the before switching to the new operator.

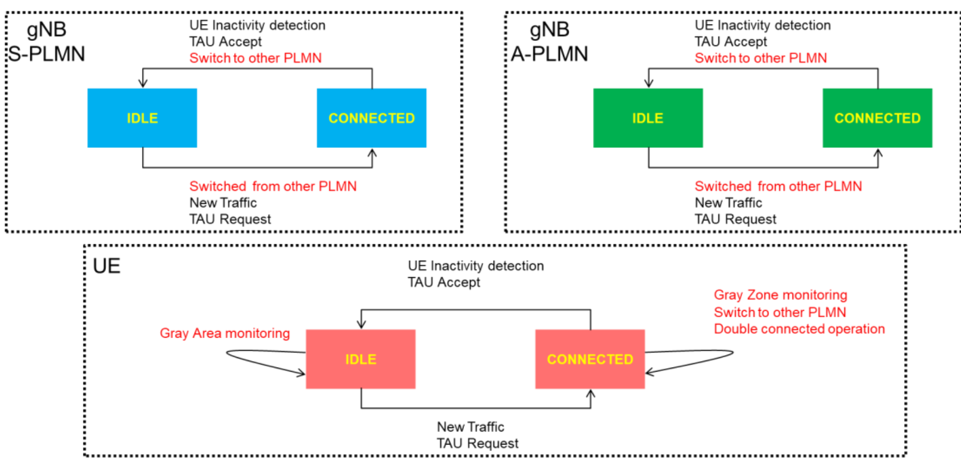


Figure 3.29: RRC State transitions with two PLMNs

3.9.3 Evaluation

For the evaluation of the proposed scheme we have used only communication via Uu interface since this is the most demanding when it comes to transition from one regional operator to the other and to transition from one country to the other. PC5 communication is demanding in cases where updates are required in the spectrum configuration, which is harder to be quantified when they will occur and how they will be implemented.

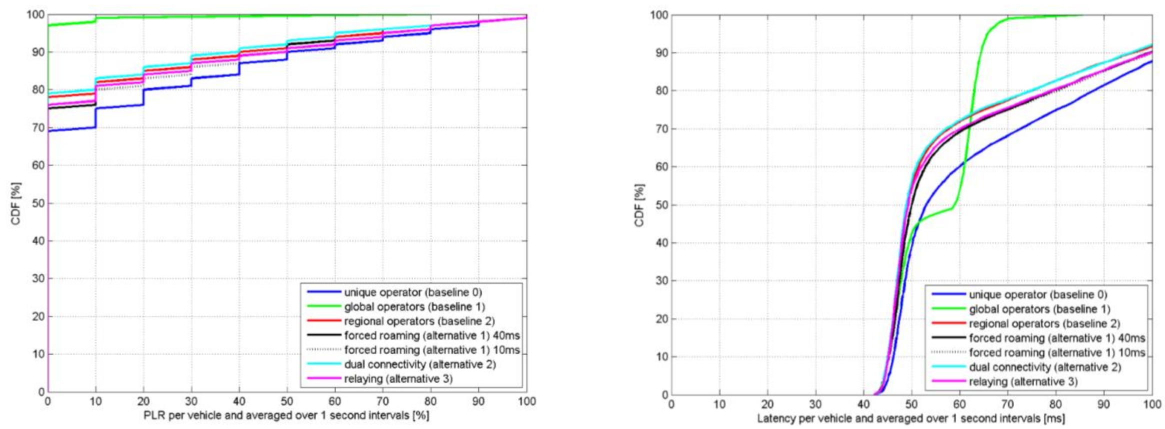
The considered alternatives are:

- Single radio with dual RRC state and forced roaming in border area. In this case a single Radio Frequency (RF) unit is available in the car. Before and inside the gray area, the UE is RRC CONNECTED in OpA and RRC IDLE in OpB. In IDLE connection the UE listens only to synchronization, Sys Info, and Paging Channel every certain times (40, 10 ms). Every time that the UE switches from CONNECTED in OpA to IDLE to the OpB it needs a certain time to synchronize (~1 ms). The same time is considered for switching back to CONNECTED to OpA.
- Dual connectivity in border area. In this case each car has two RF units (which increases the cost). Before the gray area the UE is RRC CONNECTED in OpA and RRC IDLE in OpB, whereas when entering the gray area, the UE gets RRC CONNECTED to both operators (after some delay to pass from IDLE to CONNECTED in OpB). It is assumed that it can listen simultaneously to both operators.
- Unique operator scenario. In this case we assume half of base stations as compared with the other alternatives.
- Multi-operator scenario (this scenario is referred to for simplicity as global operators). In this case two operators coexist and approximately 50% cars are assumed to be served by each operator.
- Multi-operator scenario with regional split but without enhancements. In this case the cost delay cost is 1 sec to transit from one operator to the other; the 1 sec assumption comes from the 330 ms needed for the attach adding a certain penalty for detecting the link failure, and the scanning, considering though that the UE is configured to scan for a certain PLMN (in field studies the delay to attach to a vising operator is up to 100 sec because of the sequential process and the context transfer procedure; whereas to home PLMN can be up to 9 second). This case is applicable in the situations when the UE crosses the border of one country.

For completion purposes we have included the use of relays in the transition region which replicate the other operators' messages.

The considered traffic comprises CAM messages of 300 bytes, transmitted periodically every 100 ms, and relevant to all the vehicles within 100 m range of the originator with a maximum end to end (E2E) delay of 100 ms [3GPP-36885] and Platoon messages of 450 bytes, periodicity of 100 ms, and the maximum acceptable E2E delay for these packets of 100 ms. All the messages are transmitted via the Uu interface. Platoon messages are originated in one vehicle and must be received by only one destination whose IP is known by the transmitter. Therefore, these packets are sent by the transmitter in uplink towards the UPF of its operator where the packets can be sent in downlink to the destination or can be transmitted to the UPF of other operator, in case the destination is connected to another operator. CAM messages follow a different path that platoon messages, since CAM messages need to reach the remote ITS server to update the location database of the server and to be transmitted to all the vehicles located less than 100 m away from the message originator.

Global operators perform better because this solution has double resources than the rest of configurations; it can be observed that in the global operators' case a "step" appears in the graph. This stands for the delay due to the increased core network delay required to traverse the other operators. Dual-connectivity in the transition area achieves best results because it does not require Inter-ITS-server communication. However it requires two reception chains. This is avoided with the regional operators and the results with forced roaming with Discontinuous Transmission (DTX) periodicities of 40, 10 ms are acceptable since delay is better than compared to the baselines except of that of the Global operators (with double the resources) and that of the dual connectivity (with dual reception chains). On the other hand unique operator approach has the worst performance since it has a half amount of resources than the rest of alternatives. The PLR as shown in the figure is significantly better in the case of Global operators case whereas the other alternatives move in acceptable levels – with the Unique operator case having the worse performance due to the resources' shortage. Considering the emergency messages, it has to be noted that due to the interruption time, regional operators without enhancements will not manage to meet the delivery requirements.



(a) (b)

Figure 3.30: (a) PLR and (b) latency CDF for the platooning case

3.10 V2X service negotiation

3.10.1 Objectives

The V2X service negotiation is a network procedure that is introduced to enhance the network awareness of service requirements, which is usually referred to QoS only. For instance, spatial/time information represents an important information associated to a V2X service, as well as information about receiver (i.e., vehicle) status, such as its location, speed, intended trajectory, etc. Such information can be exploited by the network to optimize the delivery of the service. On the other hand, the service might benefit from additional information coming from the network, e.g., network capability in fulfilling QoS in a certain area, network capability for message transfer within a certain deadline. As an example, the service can select the most appropriate vehicle driving status (e.g., speed, route) thanks to its increased network awareness. To recap, the objectives of the V2X service negotiation are:

- Support a more dynamic network-service negotiation, extending current QoS-based negotiation procedures. This has two further benefits:
    - Increase network awareness on V2X service features. The network receives additional service information (application, message, vehicle, etc.) which can be used e.g., to optimize the service delivery. Increase service awareness on network capabilities. If required by the service, the V2X service negotiation can provide the service with information about e.g., its capabilities on delivering a certain service.
- Facilitate the introduction of V2X-specific network features. The V2X service negotiation can be exploited by other solutions (e.g., location aware scheduling) to collect additional information from the service.

3.10.2 Description

The V2X service negotiation is a solution that enables a more dynamic and tuneable network-service interaction. The interaction happens between a V2X service and the V2X service negotiation component. In a 5G 3GPP system, the V2X service can be an AF connected to a 5G core network, while the V2X Service negotiation can be an enhanced network functionality of e.g., a NEF or of a PCF. In this case, the V2X service negotiation uses the already available protocols and interfaces for network-service interaction.

The V2X service provides the network with the V2X Service Descriptor, which contains the following information:

- Application information. This contains information that are relevant to the application object of the negotiation. Example of such information are:
    - Application type (video, voice, remote control, etc.). Different solutions can be used to identify applications, as for instance ITS-AID or PSID in 3GPP systems.
    - QoS. This field is tuneable and might be used for several purposes. In one example, the field indicates a desired QoS by the application (e.g., a certain 3GPP QoS Profile). In another example, it might be used to send a request by the service to be informed about the QoS (e.g., a certain QoS Profile or some QoS characteristics such as achievable bitrate) the network is expected to support in a certain location.

    - Message size. For service such as HD map acquisition, software updates, etc., this field can be used to indicate the size of the message to be transferred.
    - Spatial/time constraints. This field might be interpreted in several ways: relevance area (e.g., a certain message should be transferred before the vehicle leaves/enters the relevance area, or the application is happening in a certain location, for instance for a lane merge); message time deadline (the message should be transferred within the deadline); application completion time (the time interval within which the application is expected to be completed).
- Vehicle information. Such information could be provided for each vehicle involved in a certain service.
    - Location (e.g., current location of the vehicle).
    - Speed (e.g., in the form of current vehicle speed, or vehicle speed averaged over a certain window).
    - Planned trajectory (e.g., waypoints and associated timestamps).

The V2X Service Negotiation, according to the information received by the service, maps the V2X service descriptor to the relevant network function(s) and forwards the descriptor (or part of it) to it. This mapping might depend on several aspects, for instance the application type, whether the service descriptor includes only information or also a request of a response, etc. If the V2X service descriptor included a request, the V2X service negotiation provides a feedback once received by the relevant network function(s). The content of the feedback varies depending on the V2X service descriptor, examples of feedback are:

- If the descriptor included a request for information about the QoS the network is expected to support in a certain location, the feedback includes the requested information.
- If the descriptor indicates that a certain message should be delivered within a certain time/spatial deadline, the feedback might indicate whether the network expects that the message transfer will be completed by the deadline.
- If the descriptor indicated that a desired QoS should be maintained for a certain time interval equal to the application completion time (for instance, in case of a lane merge), the feedback might indicate whether the network is expected to fulfil the desired QoS for indicated application completion time.

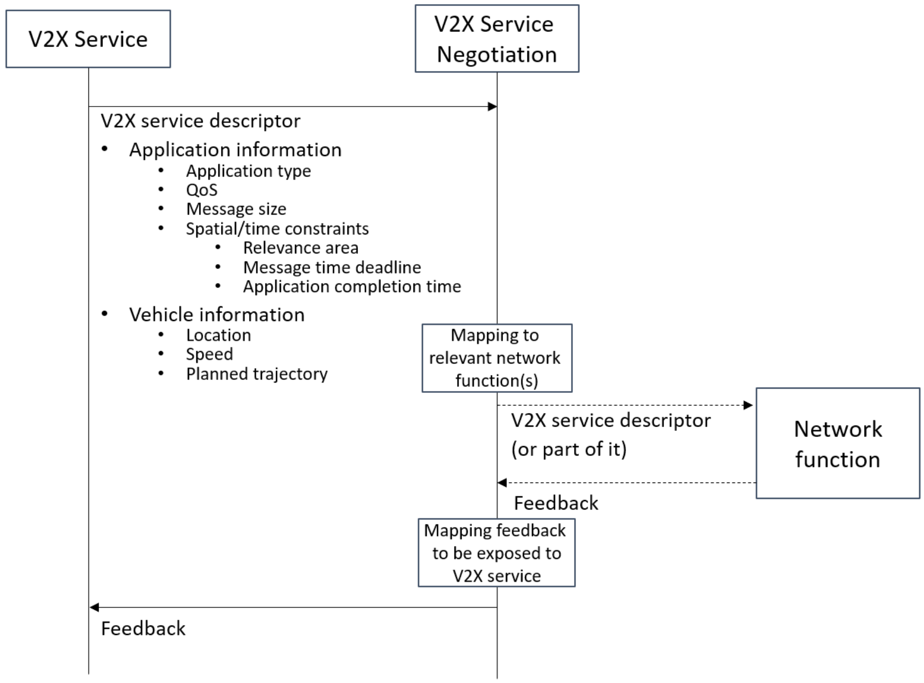


Figure 3.31: The V2X Service Negotiation with an example of information exchanged between the network and the service.

Additional and ad-hoc information exchanged can be considered as well, depending on specific features of V2X services as well as specific functionalities supported by the network.

3.10.3 Evaluation

The V2X service negotiation is a functionality that allows network to collect additional information including application, message, and vehicle features. Accordingly, the network can also provide a feedback to the service on its network capabilities. The availability of such information, at both network and service sides, brings the following benefits:

- Network awareness. The network becomes aware of V2X-specific features, to be re-used by other V2X-specific features to support V2X services in a more enhanced way as well as to optimize service delivery. Examples of network-related benefits are increase of the overall network capacity, and higher service availability.
- Service adaptation. For instance, if the service is aware that a certain QoS cannot be fulfilled by the network in a certain area (or a message cannot be delivered within the associated time/spatial deadline), the service can adapt as follows: (i) use another configuration (set of sensors to enable, number of cameras to use, etc.) requiring a less stringent QoS; (ii) send a warning notification to driver/vehicle; (iii) change message format/content.

3.11 Edge computing in millimetre wave cellular V2X networks

3.11.1 Objectives

Merging edge computing and millimetre wave technologies brings up some new benefits as well as new challenges. Edge computing provides many benefits such as reducing energy consumption at the vehicles/UEs and enables fast and low latency computation capabilities. In addition, by running some computation tasks on the edge near to the vehicles/UEs in a cellular network, network congestion would be reduced.

There are many computation-sensitive use-cases among V2X services, for instance, cooperative perception, local HD map acquisition, and cooperative manoeuvres. Taking lane merge scenario as an example of cooperative manoeuvre, for successful and safe lane merge, vehicles in the area of relevance may send their status information (e.g., location, speed, etc) to the associated access nodes (e.g., UE/eNB-type RSUs or eNBs/gNBs) enhanced with edge computing capabilities and then the access node computes and recommends a trajectory and some additional safety comments. In the next step, the access node informs the involved vehicles about the result of computations.

Using millimetre wave as the radio access technology for offloading the computation tasks to the -access node, can provide higher data rates as well as lower latencies as a result of higher data rates and lower scheduling delay in millimetre wave (since millimetre wave band is assumed to support higher capacity).

In this Section, the technical component “edge computing in millimetre wave” targets the following edge-computing enhancements:

1) Reduce end to end latency of sophisticated computations.
2) Reduce energy consumption of the vehicles/UEs by offloading complicated tasks to the edge cloud via access nodes. Therefore, enabling low cost smart vehicles and increasing batteries lifetime.
3) Reducing cellular network congestion because of undertaking the computation tasks by the edge cloud.

3.11.2 Description

In the following, we consider a millimetre V2X network as shown in Figure 3.32 where V2V and V2I communications exist. This scenario has been considered and optimized in [ZWW+18] and here we will explain the proposed algorithm for using this TC.

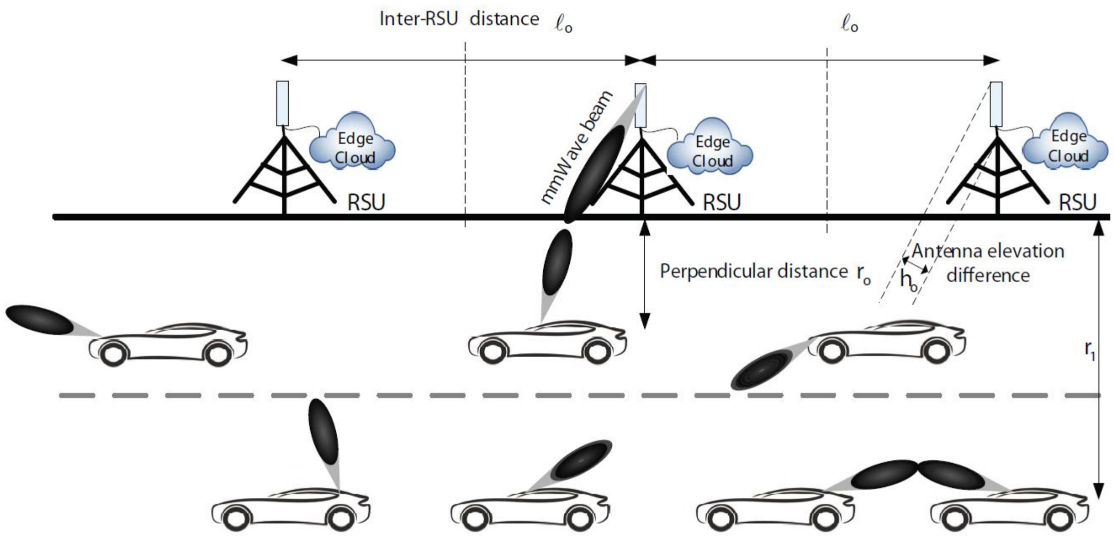


Figure 3.32: an illustration of edge computing using millimetre wave in cellular V2X networks [ZWW+18]

In this scenario, it is assumed that BS-type RSUs are responsible for edge computing and they have its required capabilities. In addition, it is assumed that RSUs and vehicles have sectored beam pattern antennas. RSUs can get limited information about road traffic, such as traffic density, from external application servers. RSUs and vehicles are equipped with sectored beam pattern directional antennas to be able to communicate in millimetre wave.

To optimize scheduling and resource allocation of offloading tasks from the vehicles to the associated RSUs, the following procedure is repeated whenever a vehicle triggers off-loading process by sending a request to the RSU. The associated RSU is considered as a controller which is responsible for making optimization decisions.

1) A vehicle randomly (according to a distribution) generates computing tasks, some of which are scheduled for offloading. The possible reasons for offloading include vehicle's hardware limitations, lack of real-time traffic and road data at the vehicle, etc.
2) The vehicle's computing tasks' queue is updated with new arrivals and the amount of tasks scheduled for offloading.
3) Dynamic channel model between the vehicle and the RSU is estimated, taking into account the vehicle's speed and distance from the RSU at each time.
4) The total computing latency (for tasks to be offloaded) which consists of the following parts, is estimated.
    a) Latency of task uploading from the vehicle to the RSU (uplink transmission)
    b) Task execution time at the RSU
    c) Latency of downloading the computing result from the RSU to the vehicle (downlink transmission)

Uplink and downlink transmission latencies depend on the dynamic channel model estimated in the previous step, millimetre bandwidth, transmit powers of the vehicle and the RSU, uplink interference, and noise power.

It is assumed that there is no cooperation between RSUs, so the computation result has to be received by the vehicle before leaving the coverage area of the RSU. Therefore, total latency estimated in the previous step must be less than a certain amount to make the vehicle's reception possible before leaving that area.

5) A model is considered for the total communication and computing energy consumption by RSU and the vehicle.
6) An optimization model is considered with the objective of minimizing the average energy consumption and some constraints including latency constraint, maximum transmit powers and stability conditions of the vehicle's computing queue. The variables to be optimized are RSU and the vehicle's transmit power as well as the amount of tasks scheduled for offloading.

The output of the optimization problem determines whether a certain amount of tasks can be offloaded to a certain RSU or not.

3.11.3 Evaluation

Edge computing in millimetre wave is a solution proposed to mitigate computing limitations at the vehicles while keeping the total latency low enough so that the vehicle can receive the output of computing before leaving the coverage area of the access node (which is responsible for edge computing). Since this TC helps to cope with vehicle's computing limitations, simpler and cheaper devices can be used at vehicles. In addition, due to lower energy consumption at the vehicle by offloading complicated tasks, prolong battery lifetime is expected. Moreover, by processing and computing vehicles' offloaded tasks at the edge of the network, congestion is reduced at the core network because the tasks are not carried out through the core.

3.12 Dynamic selection of PC5 and Uu communication modes

3.12.1 Objectives

This TC targets enhancements in the area of multi connectivity management. Considering that the intrinsic spatiotemporal dynamics of communication networks and other parameters (e.g., vehicles' density) affect the QoS that a communication interface (either via the cellular (Uu) interface or via the sidelink (PC5) interface) can provide, the focus of this TC is on the dynamic selection and switching of the most suitable communication mode/interface to support the QoS requirements (e.g., delay, throughput, reliability) of a specific service. This will allow to utilize the benefits that each communication interface can provide at a specific point of time and/or location. The scope of this solution is to enable communication systems (e.g., 5G systems) to select, combine and dynamically switch the best communication interface in order to support the QoS requirements of demanding services.

3.12.2 Description

This technical component proposes that the selection of the most appropriate interface is computed by the RAN when a vehicle requests the establishment of a V2X service (Figure 3.33), instead of being a decision based on application configuration. For this selection the BS considers information about the requested QoS for specific service, the preferred mode, the involved vehicles as well as the current network and road conditions. More specifically, the BS can request additional radio (e.g., sidelink radio measurements) and application layer information (e.g., trajectory, direction, location) from the initiating and/or other involved vehicle, for example a measurement request message. The measurement report is provided by the corresponding vehicles. All this information will help the BS to calculate e.g., the coverage levels, the current and/or expected QoS that could by supported by any available individual communication interface (cellular, sidelink) and/or combination of communication interfaces (both cellular and sidelink).

The communication interfaces that are decided for each vehicle for the specific V2X service are provided via an RRC Connection Reconfiguration message. The communication interfaces that could be used between two or more vehicles include: cellular interface (Uu), sidelink interface (PC5), both interfaces (Cellular and Sidelink). After the reception of the decided configuration by the network the vehicles undertake to apply the configuration of the communication links and inform the network for the completion of the configuration.

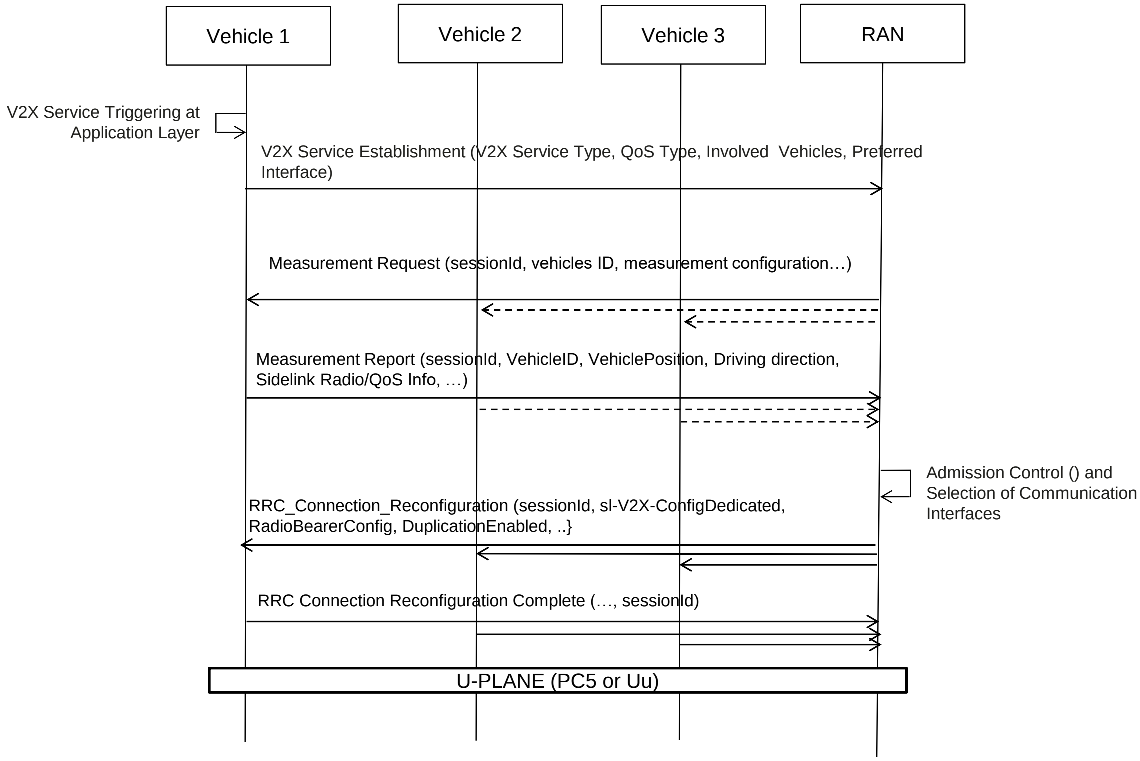


Figure 3.33: flow Chart for Interface Selection process

As mentioned above, the spatiotemporal dynamics of communication networks and other parameters (e.g., vehicles' density, vehicles mobility) affect the QoS that a communication interface can provide. As a consequence, the achieved QoS of a link between two or more vehicles (either via the cellular (Uu) interface or via the sidelink (PC5) interface) may change during the lifetime of a service e.g., due to radio conditions, vehicles' mobility etc. In this case, in addition to the selection step, a dynamic switching to a more suitable communication interface or a combination of interfaces could be used to support the QoS requirements (e.g., delay, throughput, reliability) of a specific service and hence utilize the benefits that each communication interface can provide at a specific point of time and/or location. The dynamic switching could be initiated either by the network or by a vehicle.

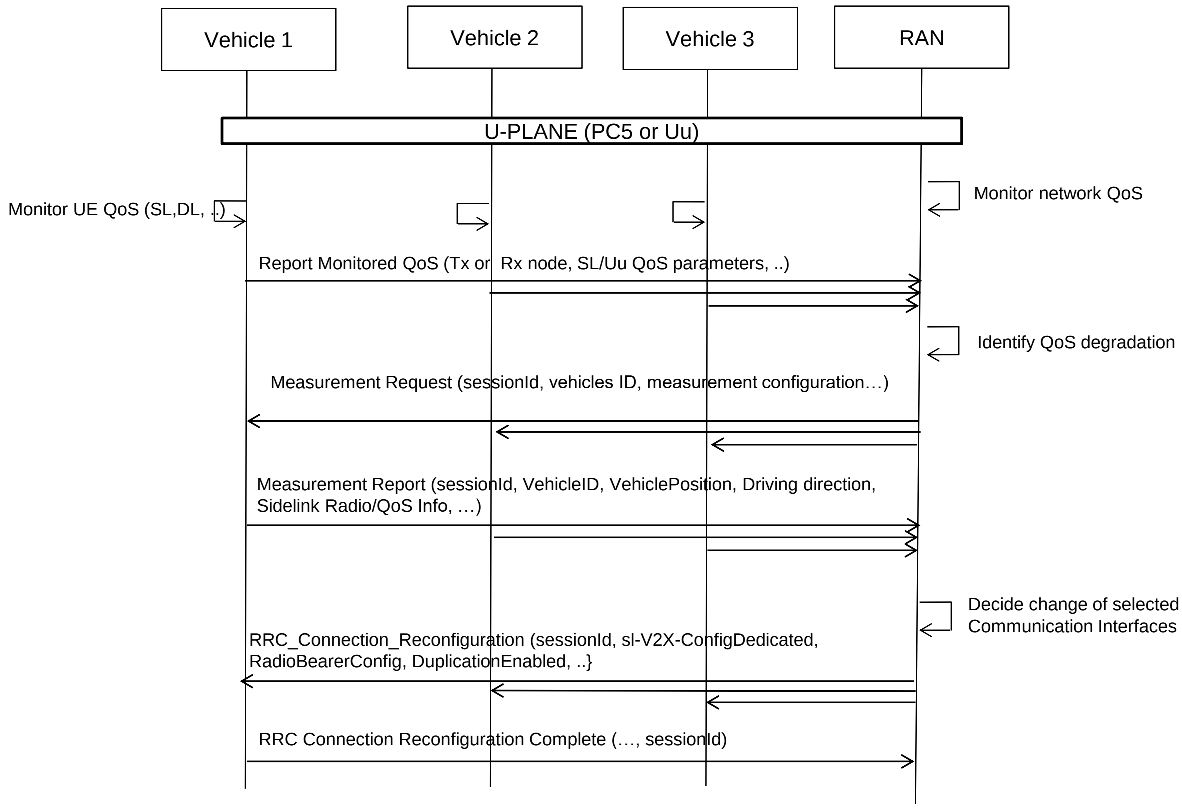


Figure 3.34: Flow Chart for Dynamic Interface Switching (Network-Initiated)

Figure 3.34: presents the flow chart for a network-initiated switching of initially selected network interfaces. In this case, the BS identifies the QoS degradation of one or more communication links, based on information collected by vehicles, the BSs and other involved entities. In this TC, signalling from the UEs towards the BS is extended to allow vehicles to report the monitored and perceived QoS (e.g., e.g., latency, reliability, data rate of sidelink interface) for the established data links with other vehicles (reception and/or transmission side). The QoS reporting can be either periodic or event-triggered e.g., when one or more KPIs (e.g., latency) cannot be supported by the used communication interface. The BS can decide on communication interface switching, based on the detected QoS degradation, with additional measurements from vehicles and resource availability information. The type of QoS degradation will help the BS to decide on the type of required interface update. For instance, if low reliability has been monitored for a specific link between two vehicles then the BS may decide to enable both interfaces (Cellular and Sidelink) for the specific pair of vehicles, where links redundancy type of communication is used (Packets Duplication). The updated communication interfaces are provided via RRC Connection Reconfiguration messages, as happens with the initial selection.

Alternatively the UE can initiate the change of initially selected interfaces. In this case, the UE detects a degradation of one or more QoS parameters (e.g., latency, packet loss), and triggers the interface switching process at the network. The UE indicates the preferred communication interface option (e.g., change from SL to Uu, change from SL to Both Modes -Duplication, enabling links redundancy).

3.12.3 Evaluation

The dynamic selection of the appropriate interface for the V2X services that can be realised with both communication interfaces could provide several benefits: increase flexibility of communication networks and V2X services, better coordination of available Uu and Sidelink resources utilizing all communication interfaces, increase throughput via link aggregation, reduce latency via optimal link selection, increase reliability via link redundancy, maintain and guarantee the expected QoS by selecting (or switching to) the appropriate interface(s) and communication link(s).

3.13 Security and privacy enablers

End-to-end security and privacy are key requirements for V2X communication and applications.

Security is a challenge because it has some impacts on bandwidth and latency. For Authentication, Authorization and Accounting purpose, a signature and its associated certificate need be attached to some messages, if not all. They can add a couple hundred bytes to a message, hence a significant bandwidth impact. Signing or verifying a signature, encrypting or decrypting a message, also requires CPU-intensive cryptographic operations that negatively impact latency, even though cryptographic hardware accelerators and Hardware Security Modules (HSMs) are used.

To mitigate such impacts, session-based communications must be preferred: authentication and authorization are performed once, at the beginning of the session; then session keys are exchanged and/or derived to encrypt all of the remaining exchanges. Such a scheme works fine for V2N (UE to V2X server application), or one-to-one V2V/I2V applications. It does not work for one-to-many V2V or I2V applications (for instance, for exchanging awareness messages).

- One approach is to sign every message, as currently done over ITS-G5 for CAM, DENM, MAP, SPaT, or IVI messages. It has two drawbacks: signing every message with an HSM has latency penalty; and it also implies that every receiving UE needs to go through all consistency and relevance verification checks.
- Another approach is to rely on a central entity to perform authentication and authorization checks, and to provide a session key for the group of communicating UEs. Note that this is (logically) the overall approach used by 3GPP for ProSe one-to-many security communication.

  As an alternative, the central entity may be replaced by one UE that plays a specific role in the scope of one specific V2X application (such as the lead vehicle in a platoon).

  This is addressed by the Technical Component described hereafter in this section.

In both cases, it must be possible to retain the utilisation of pseudonyms whenever required by the V2X service.

3.13.1 Objectives

The purpose of this Technical Component is to allow secured and anonymous communication between a group of UEs (one-to-many V2V or I2V applications), while not requiring signing all messages with a strong (but costly) cryptographic signature (and possibly encryption, depending on the use case) algorithms.

The principle is to perform (strong) authentication and authorization against a central entity in the back office, the main principles are:

- Each V2X application wanting to join the service will need a group of keys devoted to the specific application considered
- To get this group of keys the UE must be successfully authenticated from the central entity.
- This application-specific shared key can be then used to derive signing and/or encryption keys, depending on the application security needs, for somewhat weaker, but way more efficient from a bandwidth or latency standpoint, cryptographic algorithms.

Possession of the shared key from the back office is proof that the sending UE can be trusted.

3.13.2 Description

The two following figures describe the overall proposal.

The proposal relies on a central entity in the back office called “Key Manager”. This approach is agnostic of who is responsible of this entity (MNOs, public administrations, OEMs, OTT-like entity, etc.). Multiple Key Managers may be deployed, each one operating in a given geographical area.

The first figure describes how the Key Manager generates a high number of keys, called Z, to be used as shared secret keys by all UEs wishing to participate in a given V2X service. For security purpose, such Z keys have a short validity period. Trust is based on the knowledge of such shared secret key during its validity period.

The connection to the Key Manager is secured by using the UE pseudonym certificates which could be provided in the same way as it is done in the current ITS solution. The requirements are: a secure process for the UE certificate enrollment and the trust of the the authority chain by the back office entity.

To compute the shared keys, an elliptic curve is used defined by a base point G and a prime p, z is a ramdon value, Z keys are curve points computed from a random number z: $Z = G^z \bmod p$. The 3 elements (G, p, z) are specific to the V2X service and the backend entity.

UEs need to regularly connect to the Key Manager to download batches of signed tuples containing the curve specifiers G and p, a key Z and its associated validity period. Multiple batches may be downloaded, on per requested V2X service. Requesting and downloading such batches are performed over a secured connection, typically TLS based: the UE and Key Manager authenticate each other using their respective ETSI V2X certificates (pseudonym certificate for the UE). The Key Manager may also verify whether the UE pseudonym certificate holds permissions to request a batch for a given V2X service.

The validity of Z key may be inversely proportional to the number of UE in the group that shares the same key Z. Further discussion and service adaptation will be needed to define Z keys validity duration, and how far in the future a UE can request and download Z keys batches.

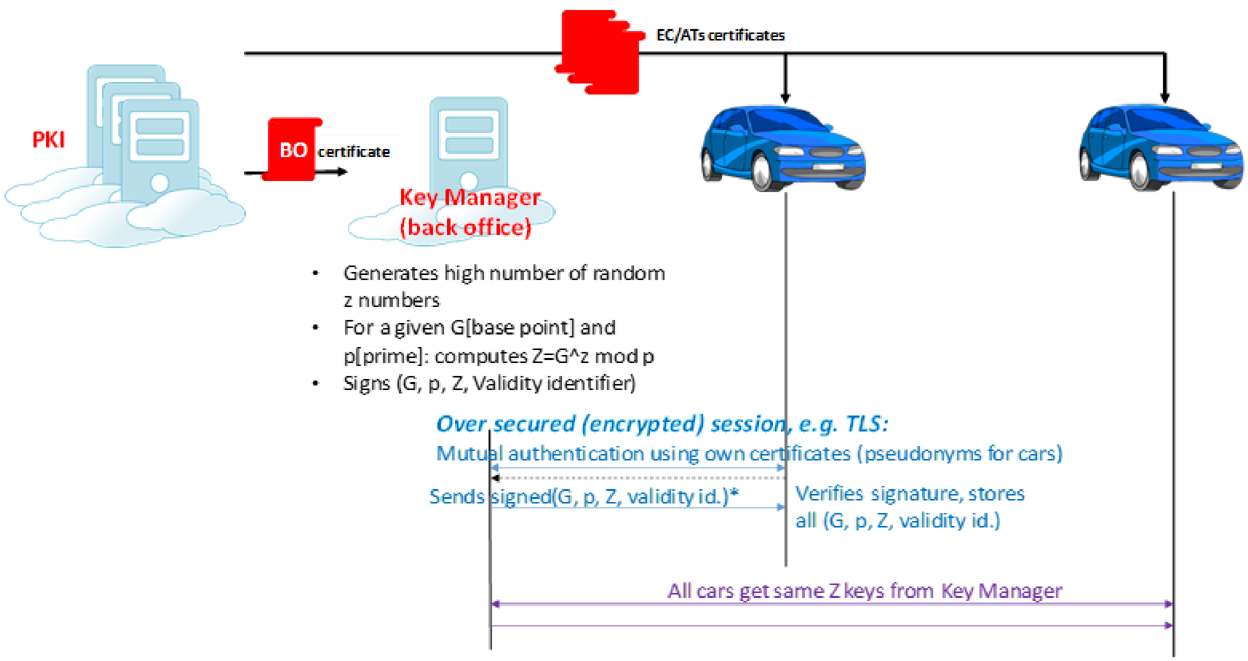


Figure 3.35: UE gets shared keys from back-office Key Manager

The second figure describes how the shared secret key Z is used during its validity period, when one UE sends a message to all other UEs participating to the V2X service for which key Z has been obtained. Key Z is used to derive another key Kaz that may be used to

- Encrypt the message payload, and compute a hash for integrity purpose.
- Encrypt only the hash for integrity purpose.

For these cases, the UE generates a random number “a” which is used to derive the encryption key Kaz. For Non-repudiation purposes, UE may calculate A = $(g)^a$ [mod p] and upload the result to any entity responsible for traceability.

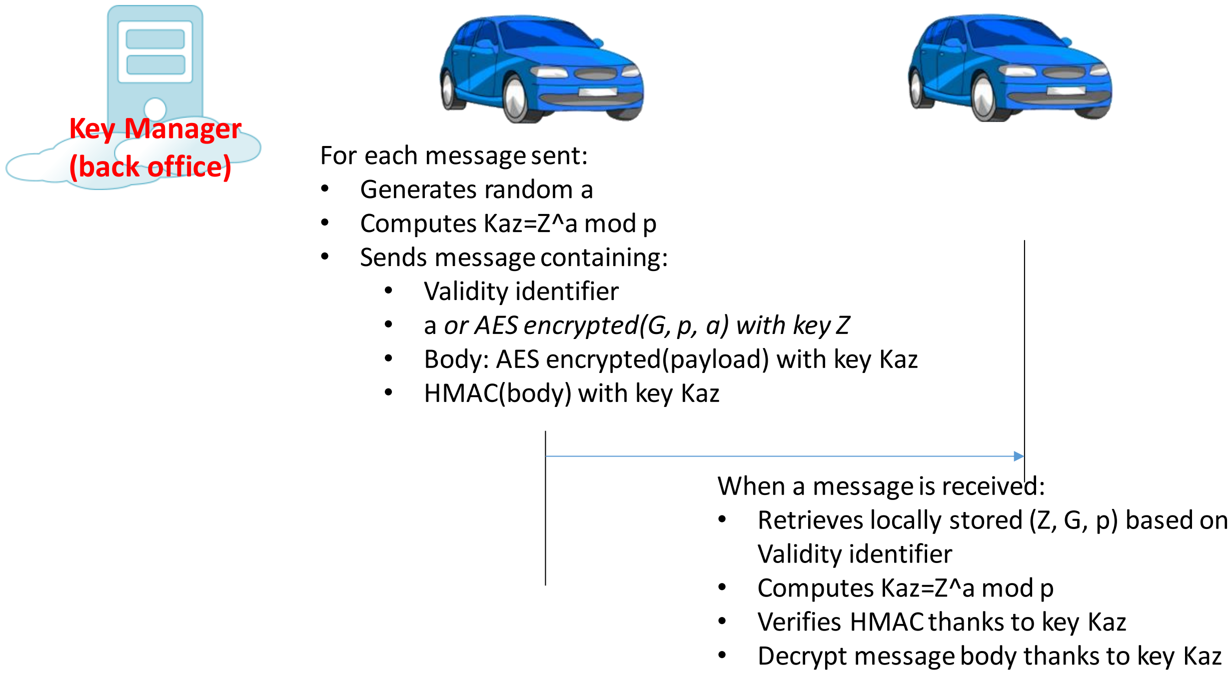


Figure 3.36: Anonymous messages exchange between UEs

It is important to highlight that the header of the message, will be encrypted by Z and then all the UEs can decode it and obtain the a and p needed to obtain Kaz

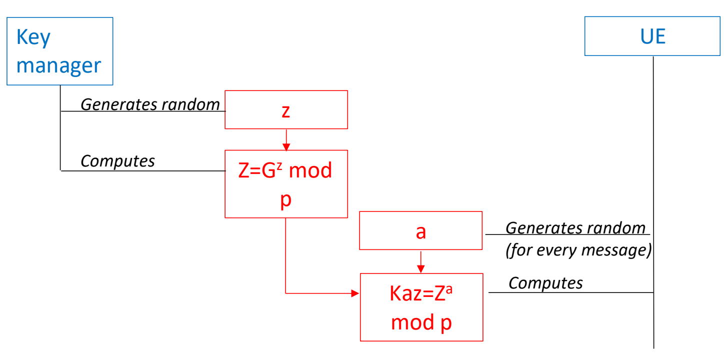


Figure 3.37: Key dependencies

3.13.3 Evaluation

This Technical Component seeks to reduce the latency, bandwidth and processing of secured messages exchanged between a group of UEs participating to given V2X services.

It will also reduce the cost by not requiring as many pseudonym certificates per UE as currently envisioned. Indeed, based on current E.U. policies, up to 100 pseudonym certificates may be required for every UE, every week (each pseudonym certificate has a validity period of at most one week). The cost of generating, and especially downloading to the UE, that many certificates cannot be ignored by an OEM when considering millions of vehicles being deployed.

3.14 5G core network evolution for edge computing-based mobility

End-to-End Network Slicing is the cornerstone of the 5G architecture and it allows the operator to provide dedicated logical/virtual networks for specific requirement and functionality each having their own unique properties.

3GPP has defined three broad use case families of Network slices, according to their requirements:

- Enhanced Mobile Broadband (eMBB),
- Massive Machine-type Communications (mMTC) or Massive Internet of Things (mIoT),
- Ultra-Reliable Low Latency Communications (URLLC).

The eMBB slice has high requirement for bandwidth and will be supported by a physical infrastructure capable of high computations (for entertainment, etc.). URLLC is highly sensitive to network latency and adapted for services like self-driving. Those 2 slices could be used simultaneously for V2X.

Focusing on URLLC slice, Edge Computing is a component of paramount importance in 5G networks, especially when dealing with use cases pertaining to the Ultra-Low latency requirements like automotive domain. EC does in fact enable the deployment of computing and storage resources close to the final users, in those locations where they are most needed. In this way, the length of data path between the UE and the server is reduced to a minimum, contributing to reducing the communication latency inside the dedicated URLLC slice.

Automotive Services typical issue:
Vehicles are by definition highly mobile terminal, which require frequent handovers when moving at high speed on a highway, for instance. Due to its local nature, EC infrastructure is hosted on local, small size data centres, designed to serve a relatively limited set of base stations in its proximity. This means that vehicle may handover multiple times within a single journey, within access points connected to different EC infrastructures, hosted on different locations. These specific scenarios require particular attention, since when migrating from one EC server to the other, the application need to be migrated accordingly, and be updated with the appropriate internal state before the vehicle completes the handover phase.

Multi-access Edge Computing (MEC) is a component of paramount importance in 5G networks, especially when dealing with use cases pertaining to the automotive domain. MEC does in fact enable the deployment of computing and storage resources close to the final users, in those locations where they are most needed. In this way, the length of data path between the UE and the server is reduced to a minimum, contributing to reducing the communication latency.

The EC infrastructure could host and run applications, provided either by first or third party, meant to serve vehicles, resulting in a constant information exchange. At any given time, it is reasonable to assume that the EC applications will contain an internal state dependent on the preceding history, and fundamental for the application itself to run correctly.

3.14.2 Objectives

The solution upon which this technical component is based aims at minimizing the latency that is introduced when a vehicular UE hands over from one source base station connected to a given EC server to a destination base station connected to a different EC server. In this scenario, and without applying any optimization, applications running on the source EC server and their related state need to be migrated to the destination EC server; this mechanism is triggered by the handover procedure itself. This results in application-level delay, as the migration procedure extends in time for a certain interval after the handover is completed. Furthermore, since 5G specifies soft handovers, there will be no network-level delay perceived by the UEs and is hence important for the application-induced delay to be reduced to a minimum.

3.14.3 Description

We consider a system with two network slices, one eMBB (evolved Mobile Broad Band), and one URLLC (Ultra Low Latency and High Reliability).

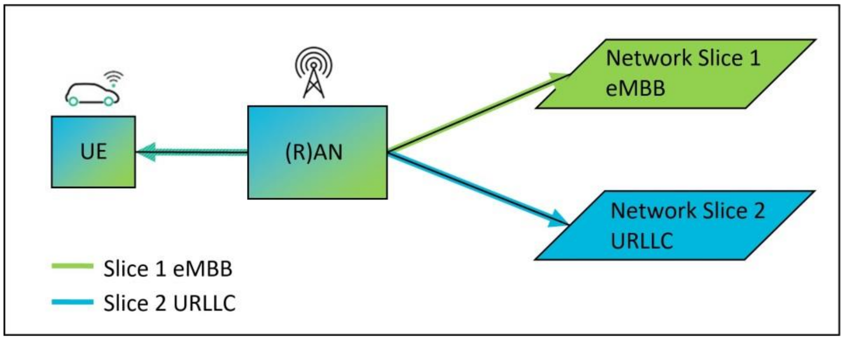


Figure 3.38: network slices - eMBB and uRLLC

The reason of having these two slices is that vehicle-related services can be divided, according to their urgency and QoS requirements, into different sets: basic roadside services, value-added services, and fixed roadside services. Their tasks correspond to high priority tasks and low priority tasks.

Basic roadside services are supposed to have high priority, since they are used to ensure driving safety, such as forward collision warning, road hazards notifying, traffic congestion avoiding, etc. These services are delay-sensitive and need highly localized information; this is why they should be efficiently performed by EC servers instead of the remote Cloud Centres.

Some Fixed roadside services are delay-tolerant or difficult to implement locally, however, the core network is obviously advantageous to deal with them. As a typical example, vehicle paging function is still supposed to reside in core network elements so that it could take advantage of the global network information.

In addition to the basic and fixed roadside services, there are a variety of innovative value-added services and applications toward Vehicular Clients (VCs) created by application developers and content providers, such as parking location, augmented reality and other entertainment services (e.g., video distribution).

In order to fulfil all of these service's requirements, the deployment of the two slices, eMBB and URLLC, is a promising option. The eMBB slice will provide high throughput, while the URLLC slice will provide reduced latency and increased reliability.

In the 5G definition, we consider the following V2X architecture:

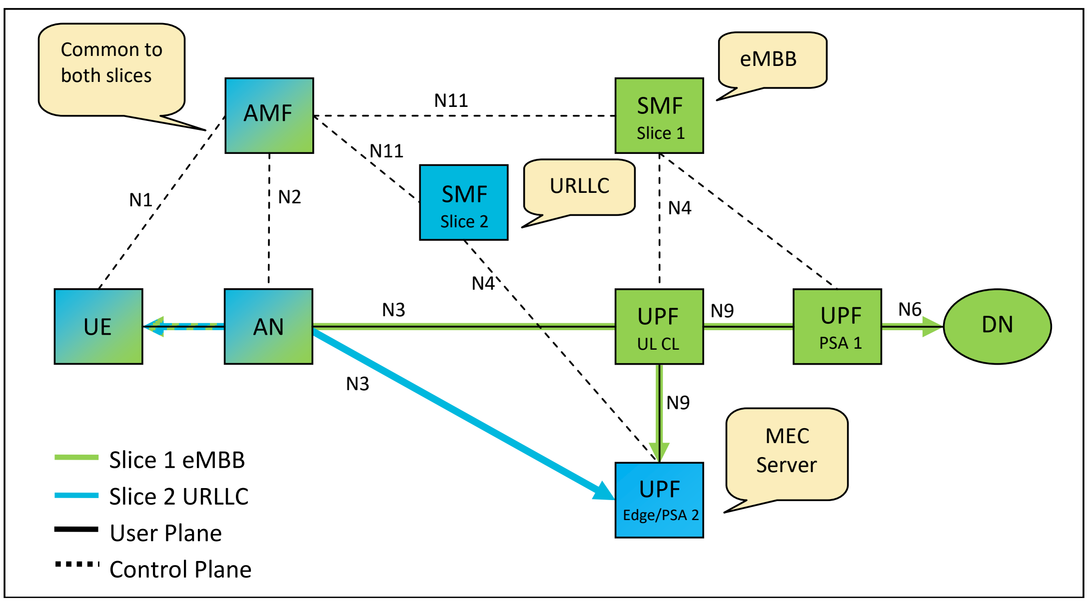


Figure 3.39: V2X Simplified Core Architecture with Network Slicing (Reference Point Representation)

This Figure shows as well the deployment of two network slices: eMBB (slice 1 green) and URLLC (slice 2 blue). It is important to point out that the AMF instance serving the UE, logically belongs to each of the Network Slice instances serving the UE, since the AMF instance is common to the Network Slice instances serving a UE. On the other hand, there are two SMFs (one per slice) because if a UE has multiple sessions, different SMFs may be allocated to each session to manage them individually and possibly provide different functionalities per session

The UPF supports the Uplink classifier functionality in order to route traffic flows to an instance of a data network. Different types of UPF are used: Intermediate UPF (I-UPF) which is the UPF Uplink Classifier (UPF UL CL) and UPF Edge collocated to the UPF Edge, a dedicated Edge computing function (EC Server) is embedded providing Software as a Service (SaaS) to V2X UE.

As mentioned before, the main V2X services issue to resolve is linked to the way for migrating from one EC server to another, the application needing to be migrated accordingly, and be updated with the appropriate internal state before the vehicle completes his Mobility phase.

The following is a proposition of solution resolving this point.

A 3GPP procedure is used to hand over a UE from a Source AN (Access Node) to a Target AN when the AMF is unchanged and the SMF decides that the UPF Edge (EC node) must be changed.

The procedure is shown in the figure below:

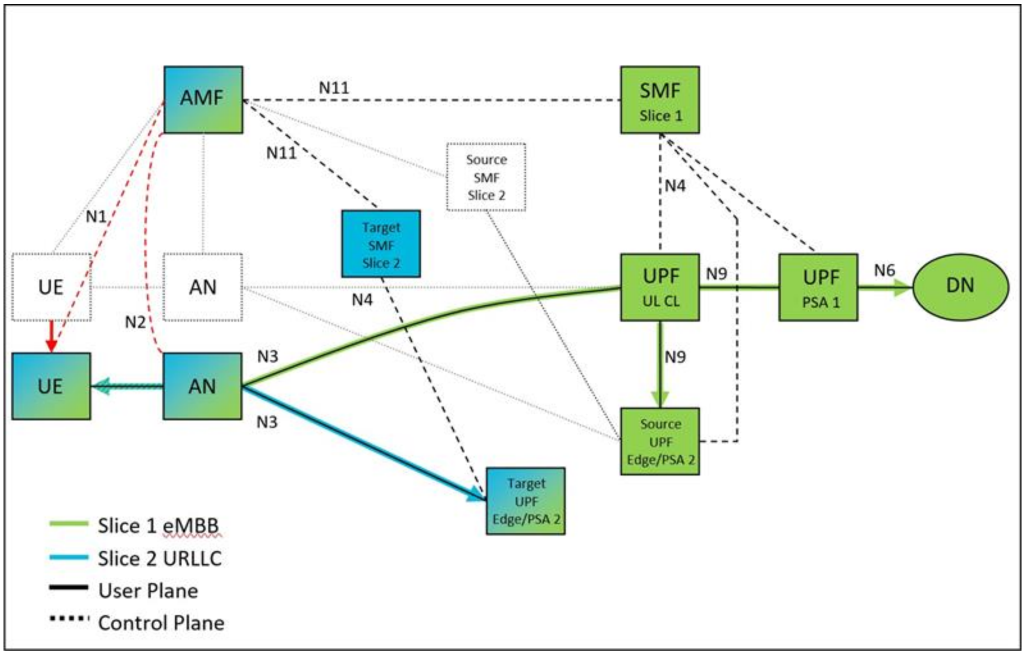


Figure 3.40: UPF switching procedure

The 3GPP procedure must be combined with the 5GCAR procedure (see Figure below). In this process, it can be seen that the UE is constantly sending its information to the AN and, when there is a signal power decrease and UE handover towards a target AN, the AN sends this information (that the UE has moved to a new target cell) to the AMF which starts the process of choosing a target SMF and this one triggers the process of choosing the target UPF Edge (and consequently the EC node) together with the reservation of resources and transfer of data between the source and target elements.

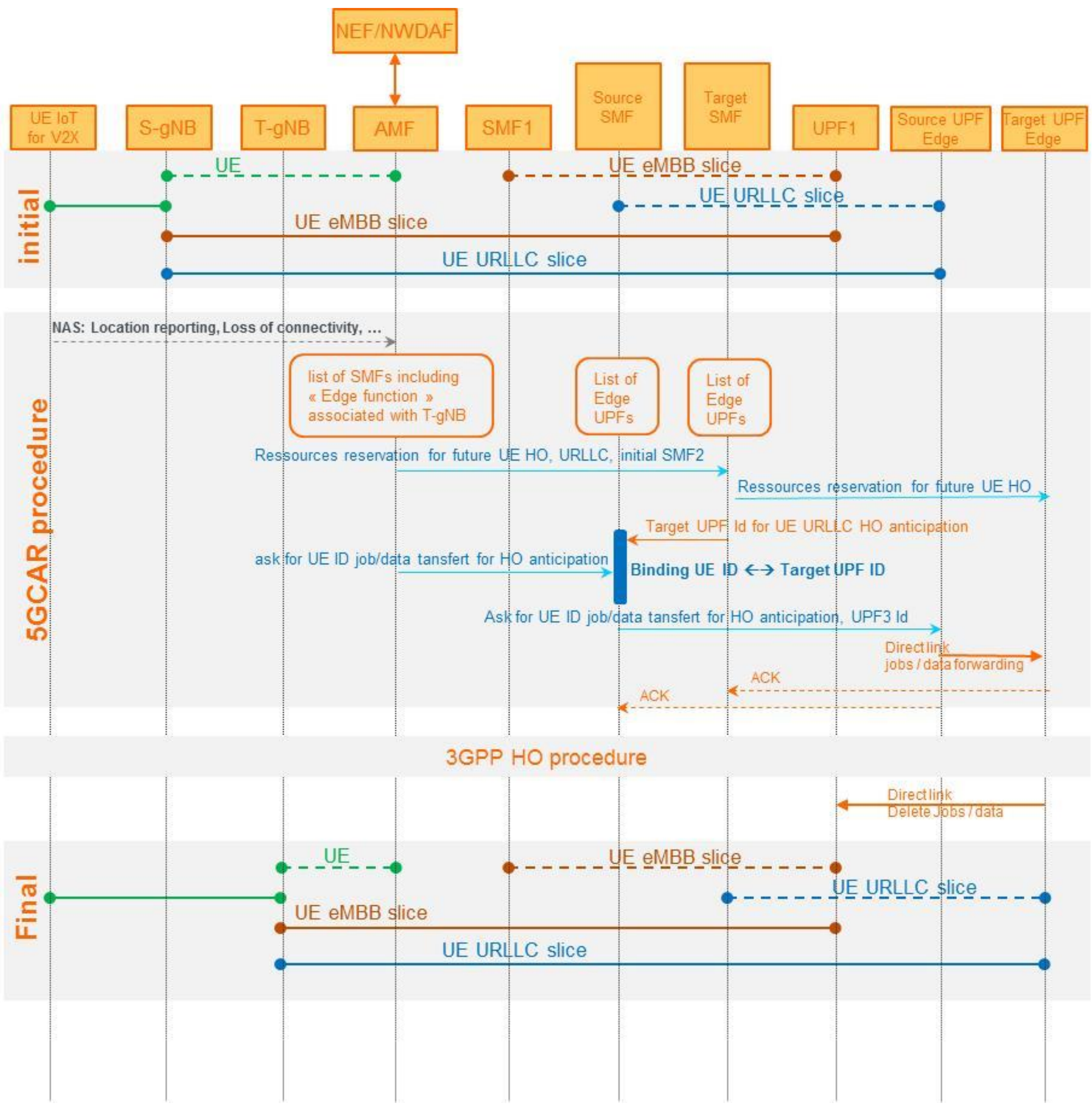


Figure 3.41: 5GCAR enhanced handover procedure

This anticipation allows having a more simplified 3GPP procedure afterwards, for instance, the SMF Selection and UPF selection phases could be perform in less time, having a lower latency, ideal for vehicular applications.

3.14.4 Evaluation

This anticipation allows having a more simplified 3GPP procedure afterwards, for instance, the SMF Selection and UPF selection phases could be perform in less time, having a lower latency, ideal for vehicular applications.

Edge computing- based mobility Technical Component will allow reducing communication latency which may be useful in use case of Ultra Reliable Low Latency communication. The best way to evaluate this Technical Component is to compare the latency in 5G V2X architecture without edge computing- based mobility with one 5G V2X architecture implementing this feature.

4 Integration and 5GCAR use case support

The focus of this section is on the use cases defined in 5GCAR, and on how the solutions can be integrated in order to support their requirements. In the remainder of this section, we consider the five use cases one by one, recall the communication requirements they impose, and present in detail how technical components introduced in 5GCAR can contribute in supporting them.

In this section, for each use case a synthesis of the requirements defined in [5GC19-D21] is provided: the interested reader is invited to refer to it for more details concerning the computation of the values associated to each key performance indicator.

4.1 Interaction and flows between 5GCAR architecture technical components

Technical Component	Direct link with other TCs #	Description
1 – RSU enabled Smart Zone (SM-Zone)	#1 can be used in combination with other TCs	This TC, with flexible use of either UE-type or BS-type RSUs, has no specific interaction with other TCs and may incorporate or jointly cooperate with any other TCs.
2 - Fast application-aware setup of unicast SL	#2 can be used by #3, #6, #8, #12 to setup unicast SL	This TC is used for unicast SL with or without network assistance. This TC therefore may be used for other TCs which consider unicast SL, such as: • SL and Uu multi-connectivity • Redundant mode PC5 + Uu • Use case-aware multi-RAT multi-link connectivity • Dynamic selection of PC5 and Uu communication modes
3 - SL and Uu multi-connectivity	#3 is an addition/alternative to #6. #3 is in line with #8, #12	This TC can be considered an addition or alternative to Redundant mode PC5 + Uu. This can be kept in line with Dynamic selection of PC5 and Uu communication modes and Use case-aware multi-RAT multi-link connectivity.

4 - Location aware scheduling	#4 receives inputs from #10	This component interacts with other components (e.g., inputs from V2X service negotiation) to receive inputs to run its scheduling tasks. The component interacts with other network functionalities (e.g., RAN scheduler) to enforce its outputs (e.g., UE or traffic priority).
5 - Infrastructure as a Service (IaaS) for vehicular domain	#5 interacts with #10, #14	This component has a relationship with • V2X service negotiation TC in a sense that for IaaS, network layer will provide information to service layer thanks to NEF (network exposure function). This possibility of providing information from network could be seen as enabler for providing feedback from service negotiation entity (as defined in V2X service negotiation TC) to V2X service. Thus we could make the assumption that service negotiation could be implemented in NEF. • 5G core network evolution for edge computing-based mobility TC will have to be coordinate with infrastructure as a service TC principle. Indeed, when the AMF is detecting that the signal strength is becoming too low (see edge computing-based mobility TC), AMF anticipates a handover by selecting appropriate SMF in advance. Migrating the application from an edge cloud server to another will be in charge of application layer using IaaS principle. The two mechanisms will have to be coordinated, for instance by the NEF.
6 - Redundant mode PC5 and Uu	#6 is an addition/alternative to #3 #6 can be used in combination with #2, #7, #12. #6 can receive input from #4	Redundant mode PC5 and Uu is applied in those situations wherein both the Uu and the PC5 links are available, in order to increase reliability. It operates in a similar way to #3 ("SL and Uu multi-connectivity"), and could be combined with other technical component that exploit multi-link with different approaches. Furthermore #6 may receive input from #4 ("Location aware scheduling") and #10 ("V2X service negotiation"), to establish under which conditions the vehicle is authorized to access multiple links at the same time.
7 - Evolution of infrastructure-based communication for localised V2X traffic	#7 can be combined with #3, #6, #12 #7 can be jointly used with #9	This component can be combined with other multi-link technical components and provide an additional option of a Uu type communication link that could be selected/used ("SL and Uu multi-connectivity", "Redundant mode PC5 + Uu", "Dynamic selection of PC5 and Uu communication modes", "Use case-aware multi-RAT multi-link connectivity"). "Multi operator solutions for V2X communications"

		component could allow the usage of this solution in a multi-MNO environment.
8 - Use case-aware multi-RAT, multi-link connectivity	#8 gets input from #10 #8 can drive configuration of #3, #6 and #12	"use-case aware multi-RAT, multi-link connectivity" gets input from "V2X service negotiation" to choose the type of multi-link, multi-RAT connectivity to deliver use-case QoS. Outputs from "use-case aware multi-RAT, multi-link connectivity" can drive the configuration of other TCs "SL and Uu multi-connectivity", "Redundant mode PC5+Uu", and "Dynamic selection of PC5 and Uu communication modes".
9 - Multi operator solutions for V2X communications	-	The objective of the TC is to handle the multi operator problem, by simplifying it to single operator. It may coordinate with other TCs where the same carriers are used between operators for the PC5. Additionally, in cases where Uu interface communication is used requiring core network interactions it can reduce delay.
10 - V2X service negotiation	#10 can provide inputs to #1, #4, #5, #7, #8, #14	This component has the following interactions with the other components: • Provide "RSU enabled Smart Zone (SM-Zone)" with information about services expected to enter a certain SM-Zone • Provide information regarding UE location, expected trajectory, geographical area of relevance of messages, amount of traffic to be transferred to "location-aware scheduling" • Provide service-specific information to "Infrastructure as a Service (IaaS) for vehicular domain" to be used as inputs by the component to optimize the deployment • Provide "Evolution of infrastructure-based communication for localised V2X traffic" with information whether a certain service requires "localized V2X traffic" by using information about involved UEs and their trajectories • Provide information regarding UE location, expected trajectory, service geographical area of relevance, service requirements, expected service duration to "Use case-aware multi-RAT, multi-link connectivity" • Provide "5G core network evolution for edge computing-based mobility" with information about expected UE trajectory to be used by the component to optimize the tasks regarding mobility

11 - Edge computing in millimetre Wave Cellular V2X networks	-	This TC provides fast and low latency computation capabilities while reducing energy consumption at the UEs via offloading computing tasks to the edge. It has no direct interaction with other 5GCAR architecture technical components.
12 - Dynamic selection of PC5 and Uu communication modes	#12 can be combined with #3, #6, #8	This technical component could be combined with ("SL and Uu multi-connectivity", "Redundant mode PC5 + Uu", "Use case-aware multi-RAT multi-link connectivity") to enable the multi-connectivity framework and specifically to provides the capability to dynamically select/switch between communications interfaces and use them concurrently.
13 - Security and privacy enablers	#13 can be facilitated by #9, #10	This Technical Component really addresses end-to-end security and privacy at the application level, between a group of UEs and for specific V2X services. As such it has no interaction with other Technical Components specified in that deliverable. However, Technical Components such as "Multi operator solutions for V2X communications" and "V2X Service Negotiation" may impact and/or facilitate the way this Technical Component is deployed.
14 - 5G core network evolution for edge computing-based mobility	#14 interacts with #6, #10 It can optimise the operations of #11	The action of technical component #14 may conveniently be combined with #5 ("Infrastructure as a Service for vehicular domain"), coordinating their actions related to the handover of applications running on servers located at the edge. This action can be based on information performed by #10 ("V2X service negotiation"). Furthermore, this technical component can be applied to edge-computing based TCs (such as #11 – "Edge computing in millimetre wave cellular V2X networks"), in order to optimize its performance when user are handing over from one base station to another served by different MEC servers.

4.2 Use case 1: lane merge

4.2.1 Use case description and requirements

The "lane merge" use case is a prominent representative of the class of cooperative manoeuvre use cases, wherein the system aims at automating the process of insertion of new vehicles into a highway, as illustrated in Figure 4.1. Vehicles are connected via Uu link to a traffic orchestrator, which determines which are the vehicles involved in the procedure (in the illustrated instance, "Veh1" and "Veh2" are, whereas "Veh3" is not), and instructs those involved with instructions on speed, and trajectory to optimise the insertion manoeuvre. The requirements of the “lane merge” use case are summarized in Table 4.1.

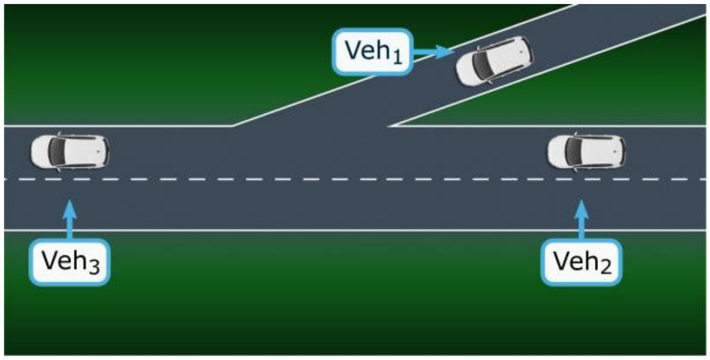


Figure 4.1: use case 1 - "lane merge" [5GC19-D21]

Table 4.1: requirements for use case 1 - “lane merge”

Requirement Label	Requirement value and Requirement Unit
Automotive requirements	
Localization accuracy	4 m at 3 σ (standard deviations) along the driving direction in the main lane for driver-assist driving.
Manoeuvre completion time	4 s, assuming a lateral speed of 1 m/s
Minimum car distance	2 s between vehicles, with the possibility of reducing it down to 0.9 s for a maximum of 3 seconds. Note that this is a regulatory definition.
Mobility	0 to 150 km/h
Relevance area	250 m to 350 m
Network requirements	
Availability	99%
Communication range	at least 350 m
Data rate	1.28 Mbps per vehicle (if trajectory messages are transmitted)
Latency	lower than 30 ms

Reliability	99.9%
Service data unit size	messages not containing trajectories: 800 bytes messages containing trajectories: 16 000 bytes
Transmission rate	10 packets/s
Qualitative requirements	
Cost	Medium
Power consumption	Low
Security	Privacy: High. Confidentiality: Low. Integrity: High. Authentication: High.
Resiliency	Human driven vehicle: the driver must be warned through HMI that the system is not working. Autonomous driven vehicle: connectivity will be used to facilitate the insertion, if it does not work the AD vehicle, will modify the driving conditions according to the on-board sensors and if the conditions are not respected a lower AD level will be proposed or even the car will do a stopping manoeuvre.
Multi-operator support	Vehicles connected to different operators shall be able to interwork to ease the insertion of vehicles in the motorway

4.2.2 Use case support

The “lane merge” use case can be supported as described in Table 4.2 by the 5GCAR architecture technical components.

Table 4.2: support to use case 1 - "lane merge"

#	Technical component
1	If the lane merge area is served by RSUs, “RSU enabled Smart Zone” can be used while delivering the service to improve the service stability by defining a Smart Zone covering the geographical area of interest of the lane merge.
2	In case a setup of a SL unicast link is necessary during the delivery of the service, “Fast application-aware setup of unicast SL” can be used to guarantee a quick setup to

	guarantee SL unicast availability during the lane merge.
3	"SL and Uu multi-connectivity" can be used to improve reliability
4	"Location aware scheduling" can be used during the service delivery, especially in situations of congestion or high load, to guarantee that UEs involved in the lane merge (being already in a geographical area where the information they send/receive refer to) are treated with higher priority compared to other UEs in the cell which are not involved in the lane merge (and thus, outside the area of interest of the lane merge).
5	"Infrastructure as a Service (IaaS) for vehicular domain" service logic (traffic orchestrator) will receive location information of vehicles, and will be able to correlate/merge/fuse that information with information coming from camera. Vehicle traffic orchestrator will be aware of bad network conditions, adapting the computed gap between vehicle for instance
6	"Redundant mode PC5 and Uu" can be used to improve reliability
7	Evolution of infrastructure-based communication for localised V2X traffic can be used in case a vehicle-to-vehicle communication is needed via Uu (i.e., a lane merge use case implemented without lane merge coordinator) as a solution to establish a local path among vehicles involved in the lane merge.
8	Use case-aware multi-RAT, multi-link connectivity can be used by the network to map the service delivery to the most suitable RAT/link configuration to guarantee a successful delivery. The output of this selection can be for instance enforced by the "Dynamic selection of PC5 and Uu communication modes" component.
9	"Multi operator solutions for V2X communications" can be used in the case of country borders crossing for the reduction of the delay while crossing the borders. Additionally, in case regional split is applied, the solution can benefit for the reduction of the delay when switching from one operator to the other.
10	V2X service negotiation can be used by the service right before starting the service (e.g., when vehicles are at short distance from the lane merge area) to provide the network with information regarding which UEs are involved in the lane merge, the geographical area of relevance of the lane merge, the service requirements, and the expected duration of the lane merge. Above information can be used to optimize the service delivery, or to inform the service about the service unviability (or expected interruption/degradation) if the network expects to not being able to support the service for the whole duration of the lane merge.
13	Security and privacy enablers, may be used to provide privacy and security for all UEs (connected vehicles) involved in lane merge operations.
14	5G core network evolution for edge computing-based mobility can provide seamless operations for those scenarios wherein the merging area is covered by multiple cells attached to different MEC servers.

4.3 Use case 2: cooperative perception based on see-through

4.3.1 Use case description and requirements

The “see through” use case belongs to the class of cooperative perception use cases, wherein vehicles share among them and with the infrastructure information concerning object detected in their surroundings, with the purpose of easing the completion of manoeuvres. Notably, the “see-through” use case is an overtake assistant that intervenes in situations such as the one illustrated in Figure 4.2, wherein a vehicle “Veh1” needs to overtake another vehicle (“Veh3”) that obstructs its view on other vehicles coming the other way, in the specific instance “Veh2”.

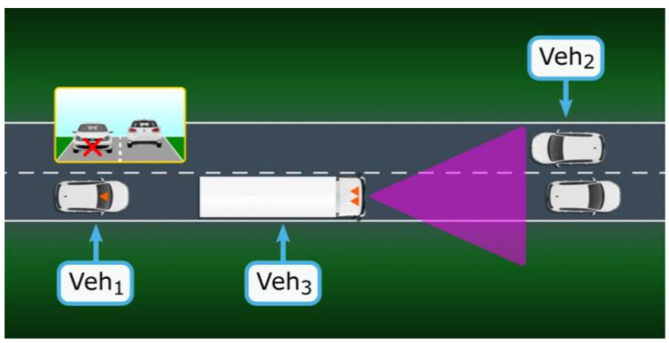


Figure 4.2: use case 2 - "cooperative perception based on see-through" [5GC19-D21]

In such situation, a real-time hig resolution video stream is started from the camera installed in Veh3 (whose field of view is illustrated in the figure by the purple area) towards Veh1. The requirements for this data rate intensive and delay sensitive use case are summarized in Table 4.3.

Table 4.3: requirements for use case 2 - “cooperative perception based on see-through”

Requirement Label	Requirement value and Requirement Unit
Automotive requirements	
Localization accuracy	10 m
Manoeuvre completion time	2 s, assuming a lateral speed of 2 m/s and considering the 2 lane changes required to complete the overtake
Minimum car distance	0.9 s at the start of the overtaking

Mobility	0 to 30 km/h (both vehicles at the same speed)
Relevance area	300 m to 500 m (for a soft overtake)
Network requirements	
Availability	99%
Communication range	50 m to 100 m
Data rate	14 Mbps (if motion-compensation codes are applied to video), or 29 Mbps (if motion-compensation codes are not applied)
Latency	lower than 50 ms
Reliability	99%
Service data unit size	41700 bytes per video frame
Qualitative requirements	
Cost	Medium
Power consumption	Low
Security	Privacy: Medium Confidentiality: Low. Integrity: High. Authentication: High.
Resiliency	Human driven vehicle: the driver must be warned through HMI that the system is not working. Autonomous driving vehicle: connectivity will be used to facilitate the overtake manoeuvre; if it does not work, the vehicle will engage or not the overtaking manoeuvre based on the on-board sensors and according to the decision making process
Multi-operator support	Vehicles connected to different operators shall be able to interwork to ease the overtaking manoeuvre

4.3.2 Use case support

The “cooperative perception based on see-through” use case can be supported as described in Table 4.4 by the 5GCAR architecture technical components.

Table 4.4: support to use case 2 - "cooperative perception based on see-through"

#	Technical component
1	In case the cooperative perception is served by RSUs, “RSU enabled Smart Zone” can be used while delivering the service to improve the service availability and stability.
2	In case a setup of a SL unicast link is necessary during the delivery of the service, “Fast application-aware setup of unicast SL” can be used to guarantee a quick setup to guarantee SL unicast availability during the lane merge.
3	The service can be delivered directly between a requesting UE and a requested UE in proximity by using “SL and Uu multi-connectivity” to improve service reliability and “Dynamic selection of PC5 and Uu communication modes” to select appropriate interface or combination according to sidelink radio conditions.
4	“Location aware scheduling” can be used during the service delivery, especially in situations of congestion or high load, to guarantee that UEs involved in the lane merge (being already in a geographical area where the information they send/receive refer to) are treated with higher priority compared to other UEs in the cell which are not involved in the lane merge (and thus, outside the area of interest of the lane merge).
6	“Redundant mode PC5 + Uu” can be used as fallback option when “Dynamic selection of PC5 and Uu communication modes” or “SL and Uu multi-connectivity” encounters a failure, thanks to a redundant scheduler working in a blind mode (without relying on RRC measurement reports or reception status reports from the Rx UEs).
7	“Evolution of infrastructure-based communication for localised V2X traffic” can be used in case cooperative perception is provided via Uu e.g., to support data rate, reliability requirements of see-through use case.
8	Use case-aware multi-RAT, multi-link connectivity” can be used to define link/RAT configuration for V2X communication required for cooperative perception to deliver a successful service. In case of network support for multi-RAT, multi-link connectivity, service reliability and availability can be improved.
10	“V2X service negotiation” can be used to gather information about service level requirements and expected service duration, and provide feedback about service availability for the completion of the service.
13	The “Security and privacy enablers” Technical Component may be used to provide privacy and security for both UEs (connected vehicles, one ahead, one following) involved in see-through operations.

4.4 Use case 3: network assisted vulnerable road users protection

4.4.1 Use case description and requirements

“Network assisted vulnerable user protection” is an interesting use case belonging to the cooperative safety use class, wherein road users leverage the network infrastructure to detect and protect the safety of the most vulnerable classes of roads occupants. Specifically, this use case makes use of advanced signal processing to detect pedestrians and share their position with vehicles approaching them and send information about vehicles approaching to the VRUs. The requirements for such application are summarized in the following in Table 4.5.

Table 4.5: requirements for use case 3 – “network assisted vulnerable road users protection”

Requirement Label	Requirement value and Requirement Unit
Automotive requirements	
Intersection crossing time	7 seconds are needed with 5km/h speed
Localization	25 cm expected localization accuracy
Mobility	Relative speed up to 100 km/h
Relevance area	40 m – 70 m in the city 400 m on the country roads at night
Network requirements	
Availability	99.99%
Communication range	At minimum equal to the relevance area
Data rate	128 kbps.
Latency	lower than 60 ms
Reliability	99.9%
Service data unit size	1600 bytes (if pedestrian trajectories messages are sent) 50 to 100 bytes (if trajectories are estimated by the network)
Transmission rate	10 packets/s

Qualitative requirements	
Cost	Medium to high depending on the environment.
Power consumption	Low
Security	Privacy: High. Confidentiality: Low. Integrity: High. Authentication: High.
Resiliency	Human driven vehicle: the driver must be warned through HMI that the system is not working. Autonomous driving vehicle: connectivity will be used to facilitate the RU detection and warnings; if it does not work, the vehicle will engage or not the overtaking manoeuvre based on the on-board sensors and according to the decision making process
Multi-operator support	Vehicles and VRUs connected to different operators shall be able to detect each other

4.4.2 Use case support

The “network assisted vulnerable road users protection” use case can be supported as described in Table 4.6 by the 5GCAR architecture technical components.

Table 4.6: support to use case 3 - "network assisted vulnerable road users protection"

#	Technical component
1	“RSU enabled Smart Zone” with RSUs deployed along roads and multi-operator support can provide and enhance availability of access points, RSUs, for the required high-accuracy location measurement of VRU which is essential to enable the service.
4	Information about vehicle position and VRU position can be used by the “location-aware scheduling” to prioritize the exchange of traffic from/to involved vehicle(s) and VRU(s).
5	IaaS could help service logic to be adapted to network conditions (for instance probability of temporary unavailability of service). The service could take some precaution, by asking for reducing speed of cars when pedestrian is approaching the road at a given distance which could be increased compared to situation when network condition are better.
6	In case the Network assisted vulnerable road users protection can be served by RSUs

	deployed along roads, “Redundant mode PC5 + Uu” can be used to improve specifically the reliability. • If the redundant scheduler is implemented either at Facilities or Transport layer from both sides (vehicle/pedestrian and network server) it could be managed without other requirements at a cost of duplicate load on radio and backhaul side. • If the redundant scheduler is implemented at C-V2X Access layer, the RSUs will need somehow to be connected to the eNB/gNBs managing the Uu interface. “RSU enabled Smart Zone” could be used for that purpose.
7	“Evolution of infrastructure-based communication for localised V2X traffic” can be used in case cooperative perception is provided via Uu e.g., to support data rate, reliability requirements of see-through use case.
8	To ensure fast and reliable delivery of notification to VRU and approaching vehicles, “Use case-aware multi-RAT, multi-link connectivity” configures the type of connection required for the safety-critical use-case of “Network assisted VRU protection”, in case of network support for multi-RAT, multi-link connectivity.

4.5 Use case 4: high definition local map acquisition

4.5.1 Use case description and requirements

High definition local map acquisition will be a critical enabler for highly autonomous driving, hence they are a relevant use case pertaining to the autonomous navigation class. In this use case, an off-board system gathers all the information from different sources, including static objects and moving ones, to build an optimal route map. This information is subsequently organized and disseminated to the vehicles by the application server, as illustrated in Figure 4.3. The requirements for this use case are summarized in Table 4.7.

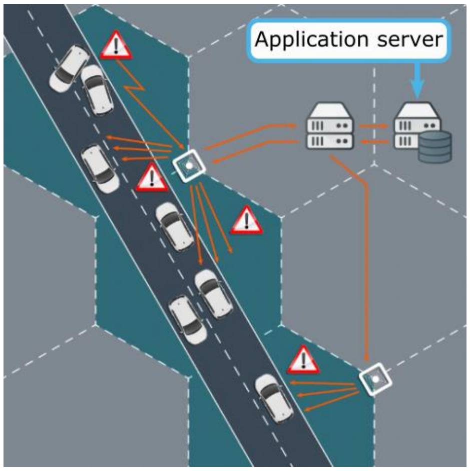


Figure 4.3: use case 4 - "high definition local map acquisition" [5GC19-D21]

Table 4.7: requirements for use case 4 – "high definition local map acquisition"

Requirement Label	Requirement value and Requirement Unit
Automotive requirements	
Localisation	10cm
Minimum car distance	2 s between vehicles, with the possibility of reducing it down to 0.9 s for a maximum of 3 seconds. Note that this is a regulatory definition.
Mobility	0 km/h – 250km/h
Relevance area	At least 5 s horizon (or more than 250m)
Take over time	10 seconds until safe stop
Network requirements	
Availability	99%
Communication range	A few kilometres
Data rate	2.88 Mbps, derived as follows: 1.920 Mbps for objects closer than 100m to the vehicle, plus 960 kbps for objects farther away than 100m from the vehicle
Latency	Lower than 30 ms

Reliability	99.99%
Service data unit size	12000 bytes, derived as follows: 200 object samples per SDU, each occupying 60 bytes
Transmission rate	20 packets/s for objects closer than 100 m from the vehicles, plus 10 packets/s for objects farther than 100 m from the vehicle
Qualitative requirements	
Cost	Medium to high.
Power consumption	Medium to high.
Security	Privacy: High. Confidentiality: High. Integrity: High Authentication: High.
Resiliency	Human driven vehicle: no major immediate impact for the human driver Autonomous driving vehicle: driving conditions will be adapted or vehicle will stop itself, depending on the age of information and the driving scenario. It will not be the same for the line-marking information or for the dynamic object detection.
Multi-operator support	Vehicles and VRUs connected to different operators shall be able to detect each other

4.5.2 Use case support

The "high definition local map acquisition" use case can be supported as described in Table 4.8 by the 5GCAR architecture technical components.

Table 4.8: support to use case 4 - "high definition local map acquisition"

#	Technical component
1	"RSU enabled Smart Zone" with RSUs deployed regularly along roads (e.g., one RSU mounted on every second roadside lamp post), fast and reliable local connectivity to local server and multi-operator support can be enhanced to provide (distribute) HD local map to vehicle UE in need, comparable to the MEC option considered in "Edge computing in millimetre Wave Cellular V2X networks" below.

4	"Location-aware scheduling" can be used to optimize the data transfer of the HD map by exploiting information about amount of data to be transferred, vehicle trajectory, geographical area of relevance for HD map data. The scheduling can be optimized to reach the overall goal of meeting transfer deadlines, but also to achieve improvements such as reduction of cost for data transfer by exploiting windows where the network is less loaded.
6	In case the high definition local map acquisition can be served by RSUs deployed along roads, "Redundant mode PC5 + Uu" can be used to improve specifically the reliability. • If the redundant scheduler is implemented either at Facilities or Transport layer from both sides (vehicle and server) it could be managed without other requirements at a cost of duplicate load on radio and backhaul side. • If the redundant scheduler is implemented at C-V2X Access layer, the RSUs will need somehow to be connected to the eNB/gNBs managing the Uu interface. "RSU enabled Smart Zone" could be used for that purpose.
7	"Evolution of infrastructure-based communication for localised V2X traffic" can be used in case cooperative perception is provided via Uu e.g., to support data rate, reliability requirements of see-through use case.
9	The "multi operator solution for V2X" can be used in order to simplify the problem to single operator. It facilitates faster Uu communication; thus ensuring operation under delay limits.
10	"V2X Service negotiation" can be used to gather information from the service about amount of data to be transferred, vehicle trajectory, geographical area of relevance for HD map data. In addition, the TC can provide feedback to the service whether the network expects to successfully deliver the data within the transfer deadline. This helps the service to e.g., adapt the amount of data to be transferred (e.g., reduce amount by transferring only high-priority information) if case the deadline is expected to do not be met.
11	The "Edge computing in millimetre Wave Cellular V2X networks" can be used to reduce latency of HD map acquisition by shortening the data path (due to provision of computing capabilities near the edge and using milimeter wave for fast data exchange), as well as to increase computing capability by offloading computing tasks to a centralized and more powerful computer e.g. at RSU, while making it possible for the RSU to extract information from offloaded data to update dynamic map of the road.

4.6 Use case 5: remote driving for automated parking

4.6.1 Use case description and requirements

"Remote driving for automated parking" reflects a meaningful sub-case of the wide class of remote driving use cases. Specifically, this use case considers a scenario wherein a vehicle is remotely conducted in the last mile towards the parking spot, and the parking manoeuvre is completed. It requires two critical information flows: a high resolution, low-latency video stream from the vehicle to the remote driving server, and a ultra-high reliability low-latency flow of trajectories (driving instructions) from the server to the vehicle. The requirements for such use case are summarized in Table 4.9.

Table 4.9: requirements for use case 5 – "remote driving for automated parking"

Requirement Label	Requirement value and Requirement Unit
Automotive requirements	
Localization	5 to 50 cm
Minimum car distance	2 s between vehicles, with the possibility of reducing it down to 0.9 s for a maximum of 3 seconds. Note that this is a regulatory definition.
Mobility	30 km/h to 50 km/h
Relevance area	100 m to 1000 m (urban environment)
Network requirements	
Availability	99,999%
Communication range	A few kilometres
Data rate	Uplink video flow: 14 Mbps (if motion-compensation codes are applied to video), or 29 Mbps (if motion-compensation codes are not applied) Downlink driving instructions flow: 1.28 Mbps
Latency	Uplink video flow: 300 ms (200ms for the server processing plus 100 ms for telecommunications) Downlink driving instructions flow: 5 ms
Reliability	99.999%

Service data unit size	Uplink video flow: 41700 bytes per frame. Downlink driving instructions flow: 16000 bytes per frame.
Qualitative requirements	
Cost	Medium to high.
Power consumption	Low
Security	Privacy: Medium. Confidentiality: Low. Integrity: High Authentication: High
Resiliency	Temporary interruption of the system will affect the maneuver depending on the use case, but the complete system failure will provoke a controlled stopped.
Multi-operator support	This is a unicast use case, which is not affected by multi-operator issues

4.6.2 Use case support

The “remote driving for automated parking” use case can be supported as described in Table 4.10 by the 5GCAR architecture technical components.

Table 4.10: support to use case 5 - " remote driving for automated parking "

#	Technical component
1	“RSU enabled Smart Zone” with BS-type RSUs and multi-operator support may be deployed locally over the parking area to provide fast and reliable local connectivity between vehicle UE and the application server of automated parking.
6	In case the remote driving for automated parking can be served by RSUs, “Redundant mode PC5 + Uu” can be used to improve specifically the reliability. • If the redundant scheduler is implemented either at Facilities or Transport layer from both sides (vehicle and server) it could be managed without other requirements at a cost of duplicate load on radio and backhaul side. • If the redundant scheduler is implemented at C-V2X Access layer, the RSUs will need somehow to be connected to the eNB/gNBs managing the Uu interface. “RSU enabled Smart Zone” could be used for that purpose.
10	“V2X Service negotiation” can be used to gather information from the service about the

	service level requirements associated to the remote driving for automated parking and provides feedback to the service whether the requirements are expected to be met by the network. This helps the service to receive enhanced information about service availability.
11	Since a cloud server could be supposed to replace human driver in some realizations of remote driving, edge in the TC “Edge computing in millimetre Wave Cellular V2X networks” can act the role of remote cloud i.e. computing trajectory and controlling the automated manoeuvre, with the benefit of proximity to the vehicle.

5 Conclusions

In this document, we presented the findings and the solutions introduced by 5GCAR related to the system architecture, privacy, and security matters. Technical components have been developed covering the domains of network orchestration and management, end-to-end security, edge computing enhancements, multi connectivity cooperation, and network functionalities. In this section, we summarize the recommendations resulting from the 5GCAR architecture work, respectively related to the architecture design, the use case support, and privacy considerations, which are increasingly relevant on the wake of the newly established European regulations.

5.1 Architecture recommendations

Network and service architecture will play a fundamental role in the delivery of V2X communications, and in making them capable of providing and sustaining QoS tailored to advanced vehicular applications. In particular, an ensemble of notable feature is highlighted in 5GCAR as critical for V2X communications.

Multi operator support is necessary to enable seamless and low latency communication between vehicles and road users in general, regardless of the MNO each single actor is subscribed to. In 5GCAR, approaches and related procedures have been proposed to address the issue.

To support enhanced service delivery, 5GCAR has envisioned an exchange of information among the applications, the network, and the vehicles. In this way, at any moment in time, applications will be aware of the QoS they can be provided, and the network will be capable of optimizing the resource usage to optimally serve applications under any traffic and load condition. In addition, the utilization of RSUs has been considered, which in 5GCAR are considered from an architectural perspective as either UE-type or BS-type RSUs integrated within the mobile network to further enhance the delivery of V2X services. The integration of RSUs with road side infrastructure has been considered from an architecture perspective, while deployments options should be evaluated case by case considering local road infrastructure configuration in terms of available cabinets together with computation/capacity capabilities, available connectivity options, etc.

Multi-link multi-RAT joint exploitation is a key feature to be exploited in order to support and facilitate vehicular communications in multiple different ways, including providing enhanced reliability exploiting multiple links, increased data rates, and enabling the network to selectively offload different traffic flows on the appropriate links based on the application needs and on the network load. On this topic, 5GCAR has proposed several enhancements covering optimized network-driven multi-link multi-RAT selection including flexible configurations for data duplications or data splitting between PC5 and Uu.

Network slicing is a key technology for 5G networks, enabling the network to provide stable and differentiated performance to different actors, leveraging on a shared network infrastructure. In 5GCAR we concluded that it is not necessary to define a novel type of slice with respect to those defined by 3GPP, the enhanced Mobile broadband, ultra-Reliable Low-Latency Communications, and massive Machine-Type communications. Road users are on the other hand served, at any given time, by several slices belonging to these base types, each serving a specific application, such as the remote driving, high definition maps distribution, or on board infotainment.

5.2 Use case support recommendations

The technical components and system enablers defined in 5GCAR have been designed with the intent of supporting next generation automotive applications, which are a wide domain including diverse and complex use case classes. In 5GCAR, five use cases are considered, selected because of the way they cover different types of requirements and different paradigms of V2X communications. These use cases provide a comprehensive and relevant representation of Day-2 vehicular applications; however, their practical implementation will be deeply influenced by the local road configuration, regional driving patterns, local regulations, and by the business models chosen by the involved actors. These factors introduce a variability of scenarios not only from the economic standpoint, but will also have an impact on their technical realization.

In 5GCAR, we hence developed our solutions in form of technical components, which are modules designed to address a specific challenge imposed by V2X communication. Hence, in order to address a specific scenario, a potential implementer needs to select the optimal subset of components to implement, based on their specific requirements. In this document, an entire section (Section 4) has therefore been dedicated to the integration of technical components, and to showing how they can contribute to satisfying the requirements of each of the use cases. Furthermore, the links between technical components are provided, along with insights on how to chain them to achieve the required performance to support each use case.

5.3 Privacy considerations and recommendations

The European Commission draft Delegated Act has a section about “Fundamental Rights”, which emphasizes that C-ITS services must comply with the E.U. law on the protection of personal data, in particular the General Data Protection Regulation (GDPR).

Personal data are not only those that obviously allow identifying a person, such as a driver, a passenger or a vehicle’s owner: person’s name, phone number or e-mail address, or vehicle’s plate number or serial number.

Personal data are also geographical location data, mileage, driving style or other vehicle’s technical data.

Indeed, GDPR does not apply to truly anonymous data. Provided that the anonymization mechanism cannot is not reversible, and that a person cannot be identified by cross-referencing multiple data sources. In that context, positioning data are challenging: for instance, someone doing the same journey from home to work every day may be identified.

In that context, which data are requested, whether they are stored, and if they are, how long, needs careful consideration. Data Minimization principle shall be enforced: for instance, an accurate position is not needed for a weather forecast application or map distribution application.

Data shall not be stored unless required to provide a service. Data shall not be shared with other entities unless explicit consent by the data's subject.

V2X protocols and messages that have been standardized so far support the adoption of pseudonyms: all protocols identifiers and addresses, as well as security certificates, cannot be linked to a person or vehicle. Furthermore, standards require V2X devices for which privacy is required (such as privately-owned vehicles or smartphones) to regularly change identifiers, addresses and certificates. Such as IPv6 addresses and/or sidelink layer-2 addresses for 3GPP-based access technologies. The draft Delegated Act annex about security policy proposes an algorithm for triggering such identity changes.

Utilisation of pseudonyms and anonymization are not quite the same: for misbehaviour reporting purpose, there must exists some entity that can link a pseudonym to its enrolment certificate (i.e. true identity). So that this enrolment can be revoked and not further pseudonym certificates allocated for and assigned to the misbehaving device. I.e. the adoption of pseudonyms needs be reversible, by some authority of the Public Key Infrastructure (PKI).

It must be noted that the draft Delegated Act does not address how V2X devices, protocols and applications may comply with GDPR. It merely states that they must comply with GDPR. As a consequence, vehicles manufacturers may have to provide the ability for a driver to disable V2X. GDPR applicability to V2X should therefore be clarified, and for the sake of safety-related applications, regulation should allow a minimum set of information to be always sent by devices installed in vehicles or other road user equipment. Such that a minimum set of safety critical services can be operated.

For instance, the CAM awareness message, one of the C-ITS messages that are referenced in the Delegated Act, will be critical for many Day-2 safety applications. Still its content has been met with some reserves by the European Commission, and it is not clear whether it complies with GDPR, even though pseudonyms are utilised. The next-to-come CPM message will most likely raise similar concerns.

On the other hand, other V2X services (such as lane merging, remote parking, etc.) may require explicit consent from the vehicle's owner or driver.

The 5GCAR project is therefore recommending that V2X be always enabled for sending a minimum set of safety-critical data.

6 References

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A Contributions to standardisation

In this section we summarise the inputs to standardization bodies based on technical contributions concerning the architecture introduced by 5GCAR.

A.1 3GPP

R2-1900606 - Mobility challenges for NR V2X platooning

This Tdoc analysed challenges of supporting V2X platooning with high mobility in 5G system, which called for enhanced mobility management focusing on service continuity and interruption avoidance.

R2-1900604 - Validity area for NR Sidelink resource allocation in V2X communications

This Tdoc discussed the different type/level of validity area (which can be considered as smart zone in 5GCAR concept) for keeping the SL resource unchanged for more stable V2X communication performance and low latency while vehicles are moving within certain area.

R2-1817681 - Discussion on Connection-based versus Connectionless NR Sidelink

This Tdoc compared connection-based and connection-less SL design in 5G system and concluded to support connection based SL in 5G for unicast and groupcast SL communication in network coverage scenario.

R2-1817680 - NR Sidelink resource allocation for V2X communications

This Tdoc discussed the SL control message transmission for e.g., setup SL unicast and/or groupcast session and proposed to support SL resource allocation from sending UE to the receiving UE so that receiving UE may send feedback control message to the sending UE using the allocated resources.

R2-1814465 - Various approaches to SL QoS support in NR V2X

This Tdoc discussed per-packet based SL QoS scheme as in LTE SL QoS design and the per-flow based SL QoS scheme as in NR Uu based QoS design t. The former is simple, but may not be sufficient to support all advanced V2X services and the latter may enable SL and Uu duplication more easily. Therefore SL QoS design in 5G should be more adaptive depending on the supported use cases.

S6-180782 - New key issue on interaction between V2X application and 3GPP system for V2X application and QoS adaptation

Proposal of a key issue for studying the interaction between the V2X application and the 3GPP system, which is currently focusing only on QoS demand by the V2X application and QoS capabilities and monitoring by the 3GPP system. The aim of the key issue is to enable the exchange of additional information regarding the V2X service which might be beneficial for the 3GPP system to better understand the demand of the V2X application.

S6-181048 - Solution proposal for key issue #13 communicating application requirements from the V2X application server

It is proposed a protocol where the VAE server provides the network with information about application features, vehicle information and application requirements. Above information from the VAE server are enriched with indications about the desired time intervals constraints for the network to interact with the VAE server. In the proposed protocol, the network provides a feedback to the VAE server indicating the network capabilities in supporting the application requirements considering the additional information regarding the application features and vehicle information.

S6-181352 - Procedures for service negotiation

Detailed description of the procedure for communicating of service requirements from V2X AS, with list of information associated to the procedure.

A.2 5GAA

5GAA has released the “White Paper on C-V2X Conclusions based on Evaluation of Available Architectural Options”. This white paper analyses the architectural options for C-V2X communication and summarizes the considerations for the ability of the current networks to handle vehicular services by evaluating them against two particular use cases of interest, the Intersection Movement Assist (IMA) and the Vulnerable User (VRU) Discovery. The considered approaches in this study relate to PC5, Uu, and MEC architectural options. Additionally, multi operator aspects are being analysed in details. The architectural options and solutions of the white paper relate to and have been influenced from the solutions developed in 5GCAR project.