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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) IPv6 Enhanced innovation (IPE).

Modal verbs terminology

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Executive summary

The mobility sector is undergoing a phase of rapid development, driven by the new capabilities and services offered by Autonomous Driving, electrification and sharing economy. In this context, protocols and technologies enabling connectivity between vehicles and with infrastructure - an essential requirement for most applications and use cases - are being heavily studied, tested and deployed.

In the field of vehicular connectivity, 5G and IPv6 are considered to be two core technologies. 5G guarantees a high data throughput and low latency, two fundamental properties for exchanging high volumes of data in real time. IPv6 ensures a sustainable increase in the number of electronic modules with a wireless interface present in the vehicles, as well as a smoother change of their IP addresses across different scenarios and locations.

In the present document, the properties and use cases for Connected and Automated Mobility (CAM) enabled by 5G and IPv6 are described. Furthermore, the connectivity handover between operators and vendors in cross-border cases is addressed, and the technological and regulatory challenges posed by these scenarios within the EU are discussed.

Introduction

Mobility is in a phase of intense transformation. The evolution of the sector is being driven by three major forces:

1) **Autonomous Driving -** As technology advances in external sensing, route planning, vehicle control, and other areas, innovations in Connected and Automated Mobility (CAM) are increasingly penetrating the market as active safety, driver assistance systems, and limited automated driving features. The advancements of autonomous vehicles have the potential to fundamentally alter how the current transportation system operates by actively reducing traffic congestion and increasing the overall safety.

2) **Electrification** - In recent years, the environmental impact of fossil-fuel-based transportation infrastructure, as well as disruptions in supply chains caused by the escalation of geopolitical tensions, has fueled a growing interest among governments, businesses, and the general public in reducing Green House Gas (GHG) emissions.

3) **Sharing Economy** - While car ownership was a common goal for most people in the industrialized world in the 1900s, in the last two decades the desire to own a car has given way to creative leasing models, fractional ownership, and other forms of on-demand transportation.

While these three macrotrends address different needs and technologies, they all require connectivity. Connected vehicles are becoming more common, to the point that it is predicted that by 2030, 96 % of new vehicles shipped globally will have built-in connectivity [i.29]. Connected vehicles generate massive amounts of data from multiple sensors, including radar, LIDAR, cameras, etc., thus providing rich information about the vehicle and its surroundings to other vehicles and to infrastructures.

To power automotive Internet of Things (IoTs), data from connected cars can be transmitted via embedded modems or SIMs. The data needs to be processed and analysed using a combination of edge computing and cloud computing, as well as to be sent to centralized data hubs. Vehicle-to-Everything (V2X) technologies allow vehicles to exchange data with other vehicles (V2V), infrastructure (V2I) and even pedestrians (V2P).

Automotive data can be used for smart cities to power their intelligent transportation systems, as well as a variety of other use cases that improve the customer experience. External data, including data from other vehicles, can help Connected Automated Vehicles (CAVs) see farther than the range of their own sensors and improve accuracy in inclement weather conditions where the vehicle's sensors may be compromised. For instance, V2I will be fundamental in communicating critical information, such as whether a traffic light has changed from red to green or if a dynamic sign has changed the speed limit. As a result, V2X connectivity is necessary in assisting the vehicle in making critical decisions. The ultimate goal is to provide better traffic management and road safety response times.

Autonomous driving is expected to have the greatest impact in the automotive sector, and the success of the deployment of these technologies is heavily reliant on connectivity. The present document focuses on CAM.

1 Scope

The present document outlines the motivation for the deployment of IPv6-based 5G Mobile Internet, the objectives, the technology guidelines, the step-by-step process, the benefits, the risks, the challenges and the milestones.

5G is the latest generation standard for broadband cellular networks, which meets the strict requirements of latency and bandwidth imposed by autonomous vehicles, as well as allowing a higher number of users per squared km, necessary for urban deployment. Secondly, contributions that may bring IPv6 to the automotive sector are presented, focusing on the advantages of a large IP addressing space and easy management of IP addresses in dynamic contexts.

There is particular focus on the handover of 5G and IPv6 between different Mobile Network Operators (MNOs) and vendors in cross-border corridors. Such scenarios are not only challenging from a technological standpoint but also from a legal persepective due to national regulations and policies.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

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3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

3GPP	Third Generation Partnership Project
4G	4th Generation
5G	5th Generation
5GAA	5G Automotive Association
5GCAR	5G Communication Automotive Research and Innovation
5G-DRIVE	5G HarmoniseD Research and TrIals for serVice Evolution
5GMED	Sustainable 5G deployment model for future mobility in the Mediterranean Cross-Border Corridor
5GNR	5G New Radio
ACCA	Anticipated Cooperative Collision Avoidance
ADAS	Advanced Driver Assistance System
AG	Aktiengesellschaft
AI	Artifical Intelligence
AT	Austria
BSS	Business Support System
C-ADAS	Cooperative-ADAS
CAM	Cooperative Awareness Message
CAV	Connected Automated Vehicles
CoA	Care-of Address
COVID	Coronavirus Disease
DE	Germany
DHCP	Dynamic Host Configuration Protocol
E2E	End-to-End
ECU	Electronic Control Unit
EE	Estonia
ES	Spain
FI	Finland
FR	France

GHG	Green House Gas
GR	Group Report
GSM	Global System for Mobile communications
GTP-U	General Packet Radio Service Tunnelling Protocol User
HA	Home Agent
HD	High Definition
IAB	Internet Architecture Board
IANA	Internet Assigned Numbers Authority
ICT	Information and Communications Technology
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IoT	Internet of Things
IP	Internet Protocol
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
ISO	International Organization for Standardisation
IT	Italy
ITS	Intelligent Transport Systems
ITU	International Telecommunication Union
LAN	Local Area Network
LIDAR	Light Detection And Ranging
LT	Lithuania
LTE	Long-Term Evolution
LU	Luxembourg
LV	Latvia
MANET	Mobile Ad-hoc NETworks
MCoA	Multicast Care-of-Addresses
MEC	Mobile Edge Computing
MHMP	Multi-Homing, Multi-Prefix
MN	Mobile Network
MNN	Mobile Network Node
MNO	Mobile Network Operator
MR	Mobile Router
NAT	Network Address Translation
NCC	Network Control Center
NEMO	Network Mobility
OBU	On-Board Unit
OCB	Outside the Context of a BSS
OEM	Original Equipment Manufacturer
PPP	Public-Private Partnership
PT	Portugal
QoS	Quality of Service
RAW	Reliable and Available Wireless
RIPE	Reseaux IP Europeens
RSU	Road Side Unit
SDA	Strategic Deployment Agenda
SDO	Standard Development Organization
SIM	Subscriber Identity Module
SLAAC	StateLess Address Auto-Configuration
SMF	Session Management Function
Std	Standard
TG	Task Group
ToD	Tele-operated Driving
TR	Turkey
UE	User Equipment
ULA	Unique Local Address
UPF	User Plane Function
URLLC	Ultra-Reliable Low-Latency Communications
V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrians
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything

VITAL	Validation of Integrated Telecommunication Architectures for the Long term

4 5G for Connected and Automated Mobility

4.0 Introduction

This clause handles three topics:

- Properties and advantages of employing 5G in CAM, with a focus on cross-border scenarios.
- Three approaches for handling the handover between MNOs and vendors across the borders.
- The main EU-funded trial projects for 5G cross-border are compared to highlight challenges and solutions to deploy effectively such approaches in the continent.

Real-time Vehicle-to-Vehicle (V2V) connections are now possible due to the low latency and high speeds offered by 5G networks. Furthermore, in-car applications and software can now be updated wirelessly. The incorporation of 5G connectivity into infotainment systems makes it possible to transmit video and audio without interruptions or delays, and it also enables the integration of weather predictions and traffic information.

The shift to 5G showcases the progress that has been made in vehicular communications. 5G is commonly defined as a system that satisfies three fundamental requirements:

i) peak data throughput faster than 10 Gbps;

ii) device density larger than 1 million per km²; and

iii) latency less than 1 ms.

5G is defined as any system that uses 5GNR (5G New Radio) technology by the 3rd Generation Partnership Project (3GPP), which is the industry collaboration that develops the specifications for 5G. The International Telecommunication Union (ITU) is responsible for establishing the baseline criteria.

The 5G cellular networks are able to partition the service area into several small geographical units referred to as cells. Every single 5G wireless device within a cell establishes a connection with a base station by way of radio waves and fixed antennas, using frequency channels that are assigned by the base station. Through either optical fiber or wireless backhaul connections, the base stations, which are referred to as gNodeBs, are connected to telephone network switching centers and routers for the purpose of gaining Internet access. A mobile device that is being transferred from one cell to another is seamlessly transferred to the cell that is currently active.

5G networks have the potential to support up to one million devices per km². In addition to the low-band and medium-band frequencies that were utilized by earlier cellular networks, the newer cellular networks make use of higher-frequency radio waves. This helps to attain the faster speeds. On the other hand, higher-frequency radio waves have a restricted useful physical range, which necessitates the use of more compact geographic cells. In order to provide extensive coverage, 5G networks can operate on up to three frequency bands:

- low;
- medium; and
- high.

5G can be implemented in millimeter-wave bands with frequencies ranging from 24 GHz to 54 GHz, either in the low-band, the mid-band, or the high-band.

Low-band 5G makes use of a frequency range that is comparable to that used by 4G handsets, namely 600 MHz to 900 MHz, in order to deliver download speeds that are marginally superior to those offered by 4G: 30 Mbit/s to 250 Mbit/s. In terms of range and coverage, low-band cell towers are on par with their 4G counterparts. Mid-band 5G makes use of microwaves that operate at frequencies ranging from 1,7 GHz to 4,7 GHz, which enables download rates of 100 Mbit/s to 900 Mbit/s and service coverage that extends for several kilometers. Since there are locations that do not implement the low band, the service level that provides the bare minimum is the mid-band. The frequencies used by high-band 5G range anywhere from 24 GHz to 47 GHz. Nevertheless, greater frequencies may be utilized at some point in the future.

4.1 5G in cross-border corridors

One of the problems that Original Equipment Manufacturers (OEMs) are facing is guaranteeing that CAM services, which require real-time reaction and ultra-high reliability, can be given across multiple countries as cars cross multiple borders. The continuity of the service should be ensured, and service quality should not be compromised when crossing borders. The situation is made more difficult by diversity in terms of operators, vendors, and OEMs that a cross-border scenario deployment entails.

When used in environments that span international borders, services that are based on V2X communications have a number of distinctive characteristics. These characteristics present a challenge for the design and implementation of the Information and Communications Technology (ICT) infrastructure as well as specific new needs to meet.

The first distinguishing feature is that many V2X applications have a narrow scope of interest. Information is frequently required only near the source from where it was generated, e.g. an alert of a traffic jam or accident may should be required to be communicated only to other vehicles near the area of the occurrence. It makes no difference to a conventional mobile radio network that provides services such as phone and data communication that peering connections between MNOs, vehicle clouds, and public data networks are placed far from the "edge". This problem should be solved in a V2X architecture with Mobile Edge Computing (MEC), and the answer cannot be having only one MEC supplier.

The presence of a multi-OEM, multi-MNO and multi-vendor interoperability problem is the second distinguishing feature [i.21]. Some CAM services, for example, may necessitate real-time response and ultra-high reliability when vehicles manufactured by different OEMs cross various national borders and should roam between different MNOs operated under different regulations, as well as using telco equipment provided by different vendors. Even in these cases, the continuity of the service should be preserved, and service quality should not be compromised when crossing borders [i.22]. In the event that connectivity quality is degraded, it is essential to anticipate this degradation in order to take appropriate countermeasures. This can be achieved by decreasing the amount of driving automation with sufficient foresight or simply stopping a driverless vehicle until the quality of the connectivity is restored to a level that allows safe operation.

The third distinguishing feature is the role that the road authority has as a source and sink of information [i.23]. The result of this is that the ICT systems, which are frequently closed and sometimes even proprietary, will need to be integrated into a distributed computing V2X architecture that supports MEC. Because of this, there is a special difficulty caused by the fact that crossing national boundaries, and in certain cases also regional borders, results in a new road authority becoming liable. This road authority will have its very own ICT infrastructure.

The fourth distinguishing feature is the availability of data regarding the vehicle's motion, which can be received from its navigation system. Many past and current research endeavors, for example, focus on using route data and position to improve Quality of Service (QoS) or, at the very least, make delivering a guaranteed QoS easier [i.24] and [i.25]. Most of these systems fail in practice due to a lack of exact routing information. Although this is technically achievable in a vehicle environment, security, privacy, and design issues have not yet been addressed [i.26].

V2X services can be divided into two categories:

1) **Utility and infotainment:** these services include, for example, HD maps, multimedia services, entertainment, weather forecast, etc. From a network standpoint, such services may be delivered from a centralized location.

2) **Assisted and cooperative driving:** this second group includes tele-driving, cooperative collision avoidance, V2I, etc. These apps require MEC or similar support.

The first group of services pose minimal requirements to service continuity at the IPv6 layer, while the second imposes higher requirements to service continuity.

Below the three core services, HD Mapping, Tele-operated Driving and Cooperative Collision Avoidance are described, that should the smooth handover between different networks and infrastructures in cross-border scenarios.

4.2 High Definition Mapping

An accurate, up-to-date map that is also seamless and in high definition is one of the essential components of autonomous driving. The primary function is to identify the location of the vehicle, including the road and lane in which it is traveling, in addition to providing information on traffic regulations, such as speed limits, or more dynamic conditions, such as construction zones or road closures. Users of high-definition maps expect an uninterrupted availability of the map content, including in situations that straddle international borders. Nonetheless, autonomous vehicles necessitate the map to be updated at all times; hence, the map would be updated whenever the underlying reality undergoes a shift.

There should be as many automobiles participating in the process of updating the map to ensure a high information reliability. Generally speaking, the vehicles utilize their on-board sensors to collect data about their surroundings, and then they use their wireless interfaces to transfer sensor data to a backend routine in the cloud. At this point, the received data and the existing map are compared to one another; if any discrepancies are identified, the map may be modified. It is also possible that the data originates from somewhere other than vehicles, such as Road Side Units (RSUs).

In addition, the high-definition map can serve as the foundation for the storage of information that is more dynamic in nature, such as reports of accidents. All of these processes have to be able to work without any problems in international borders. For instance, map updates originating from vehicles on one side of a border should be also transmitted to vehicles on the opposite side of the border. These vehicles would be served by a different operator, and their backends should run on a distinct Mobile Edge Computing (MEC) architecture.

The high-definition map is transmitted to the vehicle, where it is then kept in a local cache. This is necessary for autonomous vehicles, which require to always include the most recent changes and be available at all time. This demands pervasive and seamless connectivity. The necessity for autonomous driving not to be halted at country borders by the border operators presents an extra hurdle that should be overcome. Therefore, there is necessity for continuous communication at all times, even if the vehicle is moving between various MNOs. In addition, the sensor data that is collected on each side of the border should be made accessible to the corresponding other side in a manner that is prompt, effective, and uninterrupted. In the case the map service backend employs the MEC provided by the network operator rather than third-party servers, it should be possible to communicate with potentially diverse MEC architectures on each side of the border.

The data that needs to be transported from the vehicle to the backend of the map service might be pretty substantial and demanding of a significant bandwidth, depending on the type of sensor that is being used. In other circumstances, a low latency is essential so that modifications can be made accessible to other automobiles in the shortest amount of time possible.

A further prerequisite is the necessity of providing an accurate forecast of the intervals during which the desired communication quality is unavailable. In the basic approach, the map is loaded onto the car as it travels, covering the distance of a few kilometers ahead of the vehicle. However, depending on the specifics of the circumstance, it may be more prudent in certain cases to download a greater portion of the map in advance. An example of this would be a network that has a high level of usage in a metropolis but a significant amount of unused capacity in less populated areas that surround the city. A car that is traveling toward that city should thus download the entire map of the city before it enters the areas that have the most congested network. Because of this, the network needs to be able to make an accurate forecast on the level of service that the vehicle will experience in the immediate future. In conclusion, the network should be able to accommodate a large number of connected devices in both the uplink and the downlink directions. This is especially important in places that have a high population density.

The seamless availability of the capabilities of autonomous driving is a critical factor in determining the level of acceptability of such capabilities. This is particularly relevant in the case of a fully autonomous vehicle, in which passengers who are unable to drive the vehicle themselves might become stranded in the event of a malfunction in its performance. It is important to have accurate maps available available at all times and in all locations in order to achieve such seamless availability. In particular, the availability of maps is important in scenarios that are dynamic and rapidly changing, such as accidents and road closures, among other things. Because modern communication networks do not provide coverage throughout the entire area, it is impossible to attain such a high order of magnitude of availability with them. In a similar vein, there is a significant absence of seamless connectivity across national borders or operator boundaries in the networks of today.

5G will provide strategies for the management of its resources that are more intelligent and optimal. Another aspect that is lacking in today's networks is predictable connectivity. It is vital to have a capability such as Quality of Service Prediction, which is now being studied for incorporation into 5G, in order to constantly provide availability anywhere and at any time.

It is possible that future traffic scenarios will feature an extremely high concentration of driverless cars, and it is possible that high-definition map updates will need to be delivered for a large number of vehicles all at once. This results in new requirements for high-capacity or unique data distribution capabilities in the downlink, which are not accessible in 4G or below.

In addition, the number of connected vehicles that contribute to the development of the high definition map has a significant impact on the quality of the map, which may be understood as referring to the degree to which it is both geographically precise and up to date. This means that, while the volume of data for individual vehicles could be small enough to be addressed by 4G networks, the number of electronic units with wireless interfaces will almost certainly generate data traffic that exceeds the capacity of today's networks.

4.3 Tele-operated Driving

The existence of CAM vehicle prototypes demonstrates that fully connected and driverless cars are technically possible. There will always be exceptional circumstances that call for the intervention of human drivers, therefore Tele-operated Driving (ToD), can be utilized as an enabler to make this transition easier.

To facilitate ToD, an interface that operates via the mobile 5G network and enables a human to exercise remote control over a vehicle has been developed. Sensor and vehicle data, such as video feeds and velocity, are transferred from the V2V control center using an interface of this kind. At that point, the data are presented to the human operator, who is the one who provides control directives, such as the appropriate speed or steering wheel angle. After that, these instructions are sent back to the vehicle to be carried out. The technology of remote-controlled driving faces a variety of obstacles, each of which needs to be tackled. A report from Continental AG provides a reference for those who are designing Tele-operated Driving (ToD) hardware and software by the presentation of a system design for remotely controlled road vehicles [i.25].

Latency is s introduced when signals are transmitted over mobile networks. This might be problematic if the vehicle is being remotely controlled at the stabilization level, which means that the teleoperator is producing direct steering orders. If the latency is too great, it may be necessary to employ alternative control concepts. One such notion is the trajectory-based control scheme that was introduced in [i.26]. The limits that are created by network latency are, however, liable to alter as a result of the development of 5G technology. The difficulties associated with teleoperated driving from a general and technical standpoint as well as when traveling across international borders in terms of the requirements placed on the automotive industry and the telecommunications industry will be addressed below.

The functionality of ToD technology is heavily reliant on mobile network connectivity. In a nutshell, there are three primary needs to fulfill. First and foremost, the mobile device needs to have a bandwidth that is sufficient for the car and the vehicle control center to be able to communicate and share the necessary quantity of data with one another. An objective measurement for this is the level of situational awareness possessed by the tele-operator, who should feel at ease when directing the vehicle from a remote location. Second, it is essential that the information that is passed around is actual when it is finally received. Therefore, a small network latency is another demanding condition that should be met in addition to the minimal delays in the vehicle that were discussed previously. In conclusion, the dependability of the network is an important factor in functional ToD. For the tele-operator to have complete control over the vehicle, it is necessary to minimize the amount of vital information that is lost during the encoding process, specifically the number of crucial frames that are lost during the process.

If the car is going to cross a country boundary, there is a possibility that all of the above essential conditions will be compromised. In an ideal scenario, the handoff from one MNO to another would be imperceptible or only barely noticeable to the teleoperator. In the event that this criterion is unable to be satisfied, the vehicle may be required to come to a complete stop before the MNO handover may take place in a secure manner.

Because errors created by the autonomous vehicle system could potentially cause damage to passengers as well as other users of the road, ToD has stringent criteria regarding the functional safety of the system. The current notions for functional safety, such as the one that is primarily stated in the ISO 26262 [i.31], do not take into account the possibility that essential components of the system could be designed without taking into account the specified rules [i.31].

In order to preserve the ability to deliver a functional and secure ToD, it is necessary to establish concepts that allow a the presence of system elements that are not developed in accordance with ISO 26262 [i.31], while at the same time keeping functional safety fully under control [i.31]. Important needs include functional safety and reliable End-to-End (E2E) quality of service communication requirements. When data is being handed off from one MNO to another, cross-border operations present new and substantial problems that should be overcome to ensure lag-free transmission.

In addition, for tele-operation to be safe, the information that is sent to the tele-operator should be of a high quality. This can be accomplished by installing cameras inside the vehicle, for example. The information from the cameras, together with the data from the other sensors, needs to be transmitted to the remote operator as quickly as possible, while maintaining a high quality and regular update rate. The latency of mobile networks that use 4G or LTE can be unpredictable and can reach peaks of several hundreds milliseconds at their worst. Consequently, the implementation of a buffer is required to eliminate jitter in video streams. This makes the data provided to the tele-operator even more outdated than it already was. The deployment of 5G technologies, such as network slicing or Quality of Service (QoS) prediction, contributes to the improvement of the ToD technology in this regard.

4.4 Anticipated Cooperative Collision Avoidance

Car manufacturers are embracing and creating sensors that will enable vehicles to perceive their surroundings and take control of themselves as part of the transition to autonomous vehicles. A wide variety of sensors, including cameras, radar, LIDAR, and others, are utilized by driving automation systems.

The car's perception of its surrounding environment is still limited, despite the growing number of sensors that are integrated into the vehicle. Standard, stand-alone sensor systems may locate potentially hazardous events on the road with an adequate level of anticipations in some contexts.

In these kinds of circumstances, the recognition of a potentially hazardous incident too late will result in a sudden application of the brakes, a possibly hazardous movement, or perhaps a crash.

The Anticipated Cooperative Collision Avoidance (ACCA) allows to anticipate certain potentially critical events and, thus, to reduce the probability of collisions in scenarios in which typical sensors have a short detection range (a few hundred meters) or no visibility [i.27] and [i.28]. This is done in order to reduce the likelihood of collisions occurring.

In order to deliver MEC features, the infrastructure of a telecommunications operator is required. This infrastructure is necessary because it enables the usage of standardized ITS geo-positioning through a direct connection to the base station.

In addition, the infrastructure needs to be able to give service assurances to a cloud-based ITS system, which is typically offered by a third party such as a road operator.

Functionalities such as slicing have the goal of ensuring that there is a seamless connection between the ITS provider and the cloud infrastructure, which is necessary in order to meet standards pertaining to reliability and delay. This is necessary in order to orchestrate and disseminate discovered dangers among a number of geoservers that are housed at MECs.

These slices should take into consideration infrastructures that span international borders through internet exchange points. The MEC capability should be able to support virtualization to extend and coexist multiple geoservice solutions without requiring any changes to be made to the operator's underlying infrastructure.

It is of the utmost importance to enable effective exchange of information when dealing with a situation that spans international borders, in which only a portion of the information is being managed by the geoservices that are operating at the various MECs that are being hosted by different MNOs. When it comes to managing the connections between MNOs, the 5G network architecture plays a crucial role in this particular scenario.

According to the information presented in the preceding subsections, there are particular necessities and functions that are reliant on the network infrastructure and should be supplied by the telecom operator.

The capability of the infrastructure to respond in "real time" is a primary requirement. This means that it should be able to receive events that are indicated by vehicles, process them, and then signal them back to other vehicles that are located in the same geographic position. This capability requires constrained latency and reliability assurances, which cannot be delivered by existing 4G infrastructures. As a result, 5G support for Ultra-Reliable Low-Latency Communications (URLLC) traffic is projected to be crucial in the near future.

In addition, taking into account the fact that essential geoservices need to be processed as close to the vehicles and potential hazards as it is physically possible, it is necessary to allow a 5G MEC capability in order to support the following needs:

- Highly reliable connectivity between the vehicle and the off-board geoservice distributed across the edge cloud.
- Low and guaranteed latency of the connectivity between the vehicle and the off-board geoservice distributed across the edge cloud.
- A backend communication between the central cloud and the distributed edge cloud to ensure a seamless service connectivity under handover conditions or roaming.

4.5 5G Cross-Border Trials

With financing from the EU totaling 105 million euros, the European Commission has issued two calls aimed at cross-border corridors in order to meet the political priorities associated with 5G for CAM.

Concretely, the goal was to engage the constituency, to identify gaps, to build consensus, to suggest answers and, mostly important, to test and evaluate these solutions in the field.

By tackling rigorous border circumstances, they identified and overcame technological and institutional difficulties and provided answers that will have consequences on 5G as a whole, thus enabling and speeding the development of advanced services and applications [i.1].

The first call for 5G for CAM was issued at the tail end of 2017, and its purpose was to "identify the problems and barriers and provide a blueprint towards accelerating the deployment of 5G for CAM in cross-border scenarios, and in general in areas where there would be no business case and therefore deployment would not happen, or where there are identified mild market failures and therefore deployments risk being substantially delayed".

In November 2018, the EU decided to fund three different cross-border corridor projects with a total of 63 million euros:

- 5G-MoBiX: corridors connecting Porto (PT) and Vigo (ES) as well as Thessaloniki (EL) and Istanbul (TR) [i.4].
- 5G-CARMEN: Brenner corridor: Münich to Bologna (DE-AT-IT) [i.3].
- 5GCroCo: Metz (FR) - Luxembourg (LU) - Saarbrücken (DE) triangle [i.2].

The involved corridor portions are highly distinct, as they span over a thousand kilometers of roadways and eight different countries' borders [i.19].

In the year 2020, a second call for 5G for CAM was issued, with the intention of targeting cross-border rail and automotive corridors, with a total funding of 42 million euros.

The following three initiatives, the primary focus of which was on road transport, were chosen and inaugurated in September 2020:

- The 5G-Blueprint for the North Sea corridor (Belgium to the Netherlands) [i.5].
- 5G-ROUTES - Baltic corridor (FI-EE-LV-LT) [i.6].
- 5GMED - Mediterranean corridor (ES-FR) [i.7].

In November 2020, a fourth one called 5G rail was introduced, and its primary concentration was on rail [i.8].

All seven initiatives have the same overarching goal, which is to demonstrate sophisticated CAM use cases in the field that are enabled by 5G and take place in actual cross-border segments. Furthermore, they do an excellent job of illustrating the many different corridor scenarios that can be found all around Europe.

In addition to the projects described above that concentrate specifically on cross-border corridors, there are a number of 5G PPP phase-3 projects that address, at the very least to some degree, issues that are relevant to CAM, with some of these projects covering Rail-related components.

The projects focus primarily on technology factors, with some also tackling application aspects and platforms for the delivery of services, [i.9], such as 5G-DRIVE, 5GCAR, 5G-HEART, and 5G-IANA (CAM); 5G-MoNArch and 5G Solutions (ports); 5G-PICTURE and 5G-VICTORI (Rail); VITAL-5G and 5G-Loginnov (logistics).

Despite being affected by COVID-19 confinement measures, the solutions implemented and evaluated, and the systematic testing in the field of various CAM use cases constitute unique contributions to the advancement of 5G for CAM.

4.6 Requirements, regulations and funding in the EU

The white paper on 5G CAM Trials produced by the 5G PPP offers a comprehensive overview of the accomplishments that have been made by the initial CAM call projects as of this point [i.10]. The authors began by determining the obstacles that stand in the way of deployment of 5G, which extend far beyond technology or equipment. Investigating the continuation of service across international borders was given top importance in order to achieve the goal of presenting demonstrations that span international borders.

Critical factors include cross-border connection breakouts, inter-operator agreements, and the requirement for nearby mobile e-communications centers.

Table 1: Challenges towards deployment of 5G for CAM [i.20]

Technological	Issues related to the network- 5G Radio, Core and MEC; 3GPP releases and equipment
	Issues related to legacy vehicles
	Instrumentation and ITS functionalities related to Road Infrastructure and Operators
Business Models	Change of paradigm from Competition to Cooperation
Legal and Regulatory	From rigid data protection to the sharing of data across borders

The ability to attract the necessary capital in expanding and improving the infrastructure is also of the utmost importance and it is undoubtedly unique to the case involving the border that is being considered. It will be necessary to involve several funding agencies.

Table 1 summarizes the main challenges to be addressed for the effective deployment of 5G for CAM.

The aforementioned study was later used as a basis for a recent white paper written by the 5GAA, where market problems and technical requirements, in particularly in cross-border regions, are identified [i.11]. In the present document, 5GAA has also addressed the requirement for support from regional and national authorities in order to facilitate deployment. This includes coordinating with authorities on the other side of the border, reducing bureaucracy, and providing access to public infrastructure in areas where it is applicable. Finally, bearing in mind that the ultimate goal is deployment on a massive scale, the initiatives made a significant contribution to the 5G PPP 5G for CAM Strategic Deployment Agenda (SDA) [i.12].

The present document was carried out within the framework of the 5G PPP automotive working group, in conjunction with other pertinent initiatives, particularly those concerned with V2X, and in collaboration with important stakeholders including the 5G Automotive Association (5GAA) and the GSM Association:

- Defining deployment priorities and roadmaps.
- Identifying effective cooperation models and appropriate investment strategies.
- Advising on most suitable regulatory incentives The SDA's goal is to accelerate and maximize investment, both public and private by:
    i) defining deployment priorities and roadmaps;
    ii) identifying appropriate cooperation models and investment strategies; and
    iii) advising on most suitable regulatory incentives.

This is done with the intention of maximizing societal benefit and more specifically advancing the digital transformation of downstream and upstream industries.

Table 2 reports the main aspects that EU countries are jointly considering for the deployment of 5G for CAM infrastructures.

Table 2: EU shared vision for the deployment of 5G for CAM [i.20]

Development	Highly adaptable, evolvable, and secured
Should provide	Unlimitedconnectivity
	Maintaining continuity of service across all vendors and Original Equipment Manufacturers (OEMs), borders, Mobile Network Operators (MNOs), service providers, traffic managers, and road operators
Relies upon	Planning that is carried out in collaboration and coordination with both public authorities and private entities
	Platform that supports multiple services and applications simultaneously and makes use of standardized protocols or data interfaces

The following factors have been recognized as key drivers for expediting the adoption of new infrastructure:

- standards;
- spectrum;
- network segmentation;
- regulatory innovation;
- access and sharing of data; and
- cybersecurity.

In order to maintain economic competitiveness on a global scale the EU needs to develop a complex ecosystem that involves all relevant stakeholder communities, reflecting the need for a system's approach on an EU level. This is necessary in order to keep economic competitiveness as the political driver behind the decision to deploy 5G for CAM across Europe.

In this regard, the necessity of achieving synergies with the many policies and processes already in place in the EU becomes particularly crucial.

5 IPv6 in 5G for CAM: challenges and opportunities

5.0 Introduction

In this clause, IPv6 is introduced and the challenges and advantages related to its adoption in CAM is discussed. The steps required to handle the handover in case of cross-border scenarios are described.

Internet Protocol version 6 (IPv6) is a version of the Internet Protocol (IP), described in IETF RFC 8200 [i.32]. It was planned to replace Internet Protocol version 4 (IPv4) [i.13]. IPv6 offers various benefits that cover critical demands in cooperative vehicular communication. In particular, it solves the problem caused by the exhaustion of the IPv4 address space, which threatens the expansion and continuity of the internet by offering a broad space of addressing.

As a matter of fact, the majority of electronic modules in vehicles will not be able to connect to the IPv4 Internet without employing an intermediate technology known as Network Address Translation (NAT) [i.14]. This technology makes it possible for one or more public addresses to serve a large number of private IP addresses in an effort to conserve addresses. Because of this, it is essential to make use of IPv6, which expands the addressing capacity from 32 bits to 128 bits.

The IPv6 protocol also brought a plethora of other benefits, including the enhancement of mobility and security services, as well as the addition of node auto-configuration mechanisms, which makes it easier to configure linked equipment. As a matter of fact, the capability of an IPv6 node to be setup when it is joined to a network through the utilization of router discovery messages is one of the primary features that it possesses.

This type of auto-configuration is referred to as stateless because nodes can be configured without the need for manual configuration or the assistance of a server like Dynamic Host Configuration Protocol version 6 (DHCP v6). This auto-configuration is essentials in V2I networks because it allows quick connectivity with other ITS stations and reduces latency.

5.1 5G Handover

During its movement along its journey, a vehicle connects to different cells, each covering a selected geographical area. A L2-handover happens whenever the vehicle moves from a cell to the next one. During handover, session continuity is maintained if the session's anchoring point, represented by a User Plane Function (UPF), does not change, as depicted in Figure 1.

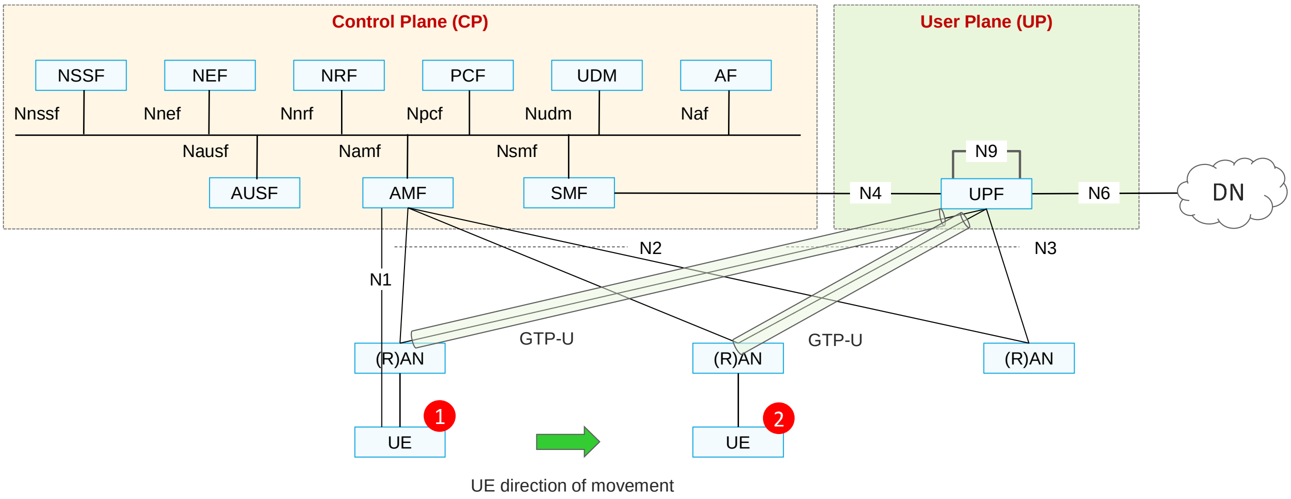

Figure 1: 5G Handover

Initially, the vehicle, represented by the box UE, is connected to the cell on the left (position 1). The GTP-U tunnel carrying the user's sessions is anchored at the UPF located in a centralized location; the UPF forewards the session to the relevant destinations (e.g. the Internet or any other applications in the same data center).

The movement of the UE to the next position 2 determines a change of cell. The coordination with the Session Management Function (SMF) enables the sessions to be moved on the GTP-U connecting the second cell to the same UPF. During handover the UE retains its IPv6 address so that session continuity is maintained.

A different case is represented by the movement of a vehicle along a path where multiple anchoring point are located, Mobile Edge Computing (MEC) represents such a case, as shown in Figure 2.

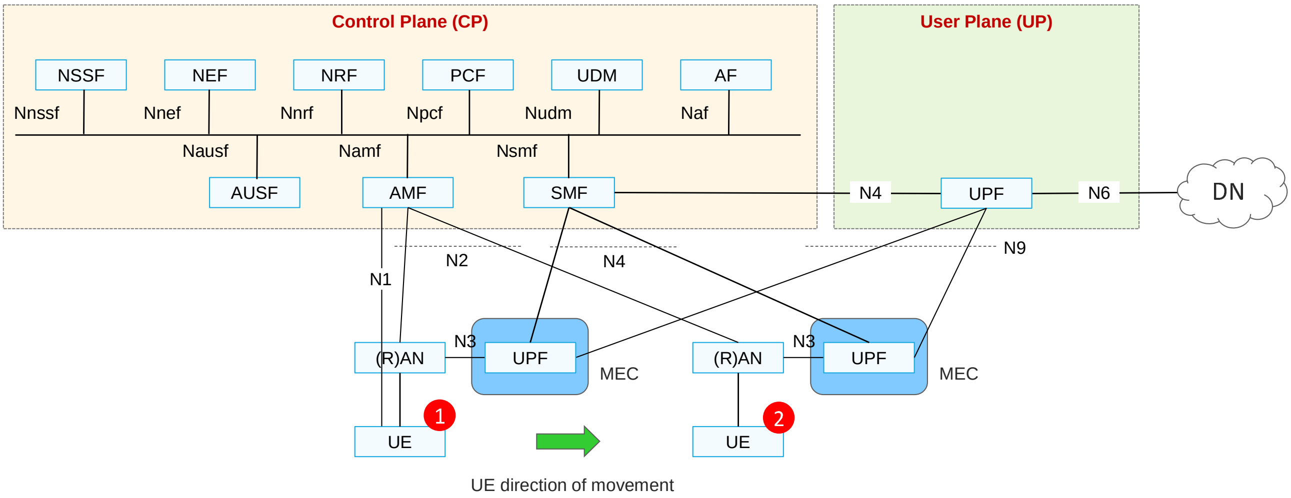

Figure 2: Distribution of UPFs in MEC architecture

The UPF deployed at the first cell, corresponding to position 1 of the vehicle, acts as the session anchor point. Until the vehicle is within the cell, it is able to use the relevant UPF for accessing local content or workloads. The proximity to the localized computing resources enables low latency communications for advanced driving related functions.

When the vehicle leaves the area covered by the first cell and reaches the area of the second one, corresponding to position 2, the process for attaching to the UPF localized there triggers a new session setup phase, incolving the 5G core (in particular, the SMF function).

Session continuity is lost for some time, even if it may be computed in the order of hundreds of milliseconds. Mission critical applications may be then impacted and ave to rely on the support of more centralized UPF serving as a backup during handover.

5.2 IPv6 Service continuity

IPv6 service continuity is ensured by the IPv6 mobility support, which comprises mechanisms for maintaining IPv6 global addressing, Internet reachability, session connectivity and media-independent handovers (handover between different access technologies) for in-vehicle networks. The foundational technologies are Network Mobility Basic Support (NEMO) and Multiple Care-of Addresses Registration (MCoA) [i.14] and [i.15].

NEMO extends Mobile IPv6 to provide continuous Internet connectivity to an entire network (associated with one or more network prefixes) instead of a single node [i.17]. The border of the Mobile Network (MN) is represented by a Mobile Router (MR) corresponding, for example, to the car's On-Board Unit (OBU). Mobility is handled transparently to the nodes located behind the MR, called Mobile Network Nodes (MNNs).

A MN has at least one MR serving it. A MR maintains a bi-directional tunnel to a Home Agent (HA). When connected to its home network, the MR establishes a network relationship with the HA based on standard routing mechanisms and the HA sends the packets destined to a MR through direct forwording.

When the MR moves away from the home network and attaches to a different one, it acquires a Care-of Address (CoA) from the visited network. As soon as the MR acquires a CoA, it sends a Binding Update to its HA. Upon receiving this Binding Update, the HA creates a cache entry binding the MR's HA to its CoA at the current point of attachment. A bi-directional tunnel is established between the HA (the Home Agent's address) and the MR (CoA).

This also allows a node in the vehicle network to remain reachable at the same IPv6 address as long as the address is not deprecated.

NEMO Basic Support is recommended in for Cooperative ITS services complying with the ITS station reference communication architecture [i.16].

MCoA is a further extension to Mobile IPv6 and NEMO Basic Support [i.14] and [i.17]. It allows a MR to register multiple CoAs with its HA. As a result, a MR may use multiple connections simultaneously, for example for redundancy purposes or to grant access to the services of different service providers.

5.3 IPv6 for CAM

The emergence of automotive Ethernet for in-vehicle communications and variations of Wi-Fi® designed to operate outside of the context of a Business Support System (BSS) (IEEE Std 802.11™ [i.13] OCB and new work from TG 802.11bd) naturally brings in the need for IP communications. IP enables to leverage:

a) ICT technologies such as Internet access;

b) AI and big data for applications such as video, LIDAR, and traffic-sign recognition inside the car;

c) Connectivity-based services such as remote diagnostics, location based services, autonomous vehicles and Cooperative-Advanced Driving Assistance Systems (C-ADAS).

While it seems simple to design a model for IP subnets inside the vehicle that connects and isolates functions and ECUs as required, the connectivity to the outside appears a lot more problematic:

- IP addresses are normally assigned to fixed locations around an abstract link where a subnet resides. Subnets are then aggregated by routers in larger and larger aggregations that are finally advertised in the Internet default-free zone. This is what routable addresses mean. But the vehicle and the prefixes within are mobile, and a technology such as Network Mobility (NEMO) is required to maintain IP connectivity and session continuity from the inside to the outside of the vehicle at all times.

- Cars may be moving together and may need to maintain connectivity within the platoon whether connectivity to the larger internet is available or not. Depending of the type of swarming (relative movement inside the platoon) and the size of the platoon (average number of relays), one of the possible Mobile Ad-hoc Network (MANET) technologies may be more appropriate than another.

- IPv4 addresses are running out; RIPE NCC ran out on November 25th, 2019. With millions of cars produced each year and several subnets inside each car, it makes sense to leverage IPv6 and IPv6-specific types of addresses such as Unique Local Addresses (ULAs) to design the networks inside the cars and define their interconnectivity at Layer-3. While it is possible to tunnel the traffic to the outside in IPv4 tunnels or to apply NAT64 techniques, vehicle communication will hugely benefit from a pervasive native IPv6 access.

- As the vehicle moves, it may be connected to the Internet, other vehicles or the infrastructure with one or more of 3GPP networks (LTE, 5G), Wi-Fi® hotspot (e.g. with openroaming), and specialized V2X communication such as OCB. Each of these communication methods has its own challenges in terms of geographical availability and bandwidth. Selecting a technology or a set of technologies at every point of time and deciding whether to leverage redundant transmissions is now being discussed in the context of Reliable and Available Wireless (RAW) networking.

- Wireless LANs in particular present unique challenges for IP communications, that are not fully resolved at the IETF. As unrelated cars move in and out an access location, which ones are members of a local subnet and for how long? When should a vehicle form an address and for how long should it retain that state? Should that address be preserved for that vehicle and for how long? Indeed, what is the Link model for IPv6 in that case?

Due to the fact that vehicular networks are considered to be a new network pattern in the global Internet, IPv6-only should be stimulated to be the main IP based approach for V2X, while other transition should be considered as auxiliary. This is due to the following reasons:

1) IPv6 has replaced IPv4 for new protocol compatibility and optimization. On 7 November 2016, the Internet Architecture Board (IAB) of IETF advised its partner Standards Development Organizations (SDOs) and organizations that networking standards need to fully support IPv6. The IAB expects that IETF will stop requiring IPv4 compatibility in new or extended protocols. Future IETF protocol work will then optimize for and depend on IPv6.

2) New "CAR" should not be configured with old "WHEELS". Similarly, Vehicular Networks should not be configured with old protocol. As a new generation of IP protocols, IPv6 has been designed and polished by global Internet community, and it has gained technical advantages over IPv4 protocol, in terms of address space, forwarding efficiency and routing efficiency, etc.

3) Compared with dual-stack, IPv6 single stack approach will make V2X more concise and economically reasonable. The industry should be encouraged to use IPv6-only for V2X development, construction and operation.

5.4 IPv6 in cross-border corridors

Clause 5.2 has discussed how session continuity can be maintained in 5G Core. The current 5G state of the art allows to maintain session continuity when the anchoring UPF does not change, so that the IPv6 prefix(es) assigned to the vehicle by the SMF does (do) not change during the trip.

Considering this limitation, the scenario discussed in this clause follows the architecture shown by Figure 1. It is assumed that a centralized UPF serves as the anchoring point for the users' sessions. As a result, the applications supported likely belong to the group of information or multimedia entertainment (e.g. HD maps, wheather forecast, video streaming).

As described in clause 5.3, the Mobile Router supports Network Mobility [i.14] and [i.15].

The different steps described hereafter can be considered as the most likely and are useful to describe the role of IPv6 networking to support service continuity as well as other functions, such as enhanced resilience or multi-homing connectivity.

Step 0 - The car's V2X system connects to the carrier's 5G infrastructure.

The car starts its journey. The V2X system, from now on referred to as the Mobile Router (MR), receives its initial configuration, which includes an IPv6 network prefix from the mobile carrier it is connected to (carrier A in this example).

Depending on the preferred addressing scheme, the devices that are part of the Mobile Network (MN) may receive indication to auto-generate the IPv6 addresses they need through SLAAC [i.30]. As an alternative option, the MR may further delegate a sub-prefix to the connected devices.

This process allows the user devices (e.g. smartphones) of the passengers to connect to the Wi-Fi vehicular network and have access to the external services (e.g. Internet connectivity or other online services) provided by carrier A.

If the MR is within the area of a V2X-enabled element (e.g. a 5G cell or any other types of ITS road infrastructure run by carrier A), some localized content may be accessed. In such a case, the support for advanced application as assisted driving may be temporarily enabled.

From a networking standpoint, mobile connectivity is enabled by the use of the (mobile) network prefix assigned to MR by carrier A. This prefix will remain stable along the trip, no matter of the handovers performed along the path [i.14].

Forwarding of the traffic flows to MR follows the common routing policies active on carrier A's network.

Step 1 - Cell handovers are performed within the same carrier's network.

In its trip, the car crosses several areas covered by different 5G cells, all managed by the same mobile carrier (again, carrier A).

When leaving a cell's area and entering the next one, a L2 handover is performed. The process has been described previously and is handled by the 5G systems involved (cells and relevant control functions).

At the networking layer, service continuity is fully maintained. The MR handles two L2 connections, one with the existing cell and another with the newly connected one. The radio levels trigger the switch-over at L2.

The 5G Core (SMF) informs the User Plane (UPF) of the users' session moved onto a different GTP-U tunnel.

At L3 the traffic flows are normally routed across carrier A's network.

Both the MR's network prefix and the different addresses in the vehicular network are maintained.

Step 2 - Multiple V2X networks are available.

In some cases, infrastructures from multiple provides may be present in the same area. For example, in addition to the 5G cells operated by carrier A, ITS equipment run by municipalities or third-party agencies may be available. These networks may also be based on technologies different from 5G. For example, an ITS network based on 802.11 OCB may be run by carrier B and be available in the same area where the 5G network of carrier A is also present.

While this case is not likely to happen in the short term, it is described here as a case of IPv6 Multi-Homing, Multi-Prefix (MHMP) connectivity, where the MR may connect simultaneously to all of the available networks [i.18].

In essence, each newly added connection is handled as in Step 0. The MR may use the new wireless connection to connect to carrier B. After carrier B provides a mobile network prefix, traffic may be exchanged across carrier B's network.

The availability of two or more networks provides additional advantages. For example, resilience is achieved: in case of failure on one of the uplink connections, traffic may be diverted to the surviving network. For some applications, throughput may be increased exploiting the two simultaneously available connections.

From the mobile networking standpoint, multiple HAs (and CoAs when the MR moves to a foreign network) are made available [i.14] and [i.15].

Step 3 - National borders are crossed.

When crossing a national border the MR switches from its 5G home network, run by carrier A to a 5G foreign network, run by carrier Z (visited network, in 3GPP terminology).

As of today, the attach procedure of a terminal to a foreign mobile network creates service disruption. The 5G core of the visited network needs to authenticate the users against its home network, check its profile and the allowed services. Once this process is completed, the terminal can activate its data sessions, handled by a UPF in the visited network.

In the case of V2X applications in a cross-border corridor, the service interruption caused by the attach process to the new network has to be taken into consideration. The interruption time is hard to be quantified, but even in the case of a few seconds most applications may experience loss of continuity (for example, a stremed video may undergo buffer emptiness). The process of recognizing a roaming V2X user by the foreign network also implies specific agreements between the two service providers, at the technical and service level.

After the MR enters carrier Z's network and it is recognized as a V2X user, it is assigned a Care-of Address (CoA). The CoA address grants the network reachability through carrier Z's domain and access to the previous services.

The CoA addres is reported by the MR to its Home Agent, triggering the set-up of the tunnels through which traffic is forwarded to the vehicular network. From the 5G user plane perspective, the communication takes place between two UPFs, one located in the home network and the second one in the visited network. As such, some non-optimized path may be established. IPv6 mobility allows some further optimization mechanisms to provide optimized routing directly across carrier Z's network.

If multiple networks are available, the sequence of steps may be repeated to provide again multi-homing support. The mechanisms to enable Multiple CoAs are described in [i.15].

6 Conclusion

In the present document, the main challenges and advantages of employing 5G and IPv6 for Connected and Automated Mobility have been presented and discussed.

The necessity of adopting 5G to meet the tight constraints of autonomous driving regarding bandwidth and latency have been investigated, and the need for IPv6 to ensure an effective attribution of IP addresses to all in-vehicle sensors in highly dynamic scenarios have been shown. The criticalities of managing the handover of 5G and IPv6 at, respectively, L2 and L3 in countries cross-borders corridors due to the presence of multiple MNOs and multiple vendors were also addressed.

For 5G, three issues of autonomous vehicles, namely Tele-operated Driving, High Definition Mapping and Anticipated Cooperative Collision Avoidance, in countries' cross-border scenarios were analysed. Furthermore, the trials addressing such scenarios in Europe were presented. Following the technological advancements proved by these trials, a discussion regarding the current state of the policies and regulations in the EU is enabled. The conclusion is that to maintain economic competitiveness on a global scale, the EU should enable the creation of an ecosystem involving all relevant public and private stakeholder at a continental level.

Regarding IPv6, the present document highlighted the necessity of extending the IP address space to meet the largely increasing number of in-vehicle sensors with internet connectivity, as well as ensuring a smoother management and attribution of IP addresses in highly dynamic vehicular scenarios. Also for IPv6, the constraints and requirements to handle the handover in cross-border scenarios are tackled. A strategy to ensure the handover at L2 among multiple MNOs based on three points is introduced.

In conclusion, the present document highlights the need to design and deploy CAM networks that are inherently based on IPv6 and 5G, in order to ensure a sustainable growth of the vehicle capabilities and use cases.

Annex A:
Change History

Date	Version	Information about changes
January 2023	1.1.1	First publication

History

Document history		
V1.1.1	January 2023	Publication