5GMOBIX

5G for cooperative & connected automated MOBIlity on X-border corridors

Report on the international cooperation and results

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ABBREVIATIONS

Abbreviation	Definition
3GPP	3rd Generation Partnership Project
5GAA	5G Automotive Association
5GIA	5G Industry Association
5GMF	Fifth Generation Mobile Communication Promotion Forum
5G-PPP	5G Infrastructure Public Private Partnership
CBC	Cross Border Corridor
CAM	Connected and Automated Mobility
CAPEX	Capital Expenditure
CATT	China Academy of Telecommunications Technology
CAV	Connected and Automated Vehicle
CU	Central Unit
DoA	Description of Action
DU	Distribution Unit
EC	European Commission
ETSI	European Telecommunications Standards Institute
FIRE	Future Internet Research and Experimentation
GA	General Assembly
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Communication Union
JCT	Yeoju Junction
Jinan-1-SDAS	Shandong Academy of Sciences
Jinan-2-SDHS	Shandong Binlai Expressway
KATECH	Korean Automotive Technology Institute

KPI	Key Performance Indicator
MNO	Mobile Network Operator
MoU	Memorandum of Understanding
NR	New Radio
OBU	On-Board Unit
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
QoS	Quality of Service
RSU	Roadside Unit
SDO	Standards-Developing Organization
StVZO	Road Traffic Licensing Regulations
TS	Trial Site
TSDSI	Telecommunications Standards Development Society, India
TSL	Trial Site Leader
WP	Work Package
WPL	Work Package Leader
X-border	Cross-border
V2X	Vehicle-to-Everything

EXECUTIVE SUMMARY

Through the joint effort of 58 partners from 13 countries, 5G-MOBIX evaluated the added value of 5G technology for advanced Connected and Automated Mobility (CAM) use cases and the viability of the technology to bring automated driving to the next level of vehicle automation (SAE L4 and above). To do so, 5G-MOBIX executed trials along two cross-border corridors (Spain-Portugal and Greece-Turkey) and 6 pre-deployment urban trials (France, Germany, Netherlands, Finland, China and South Korea), using 5G core technological innovations to qualify the 5G infrastructure and evaluate their benefits in the CAM context. The Project defined critical scenarios and the required features needed to enable advanced CAM use cases needing advanced connectivity provided by 5G, e.g. tethering via vehicle, CAVs cooperative collision avoidance, emergency trajectory alignment, etc. Based on these evaluations and international consultations with the public and industry stakeholders, 5G-MOBIX proposed recommendations for the deployment of 5G-enabled CAM.

D7.6 - Report on the international cooperation and results, describes the actions undertaken to support the cooperation with international consortium partners and 5G organisations as well as other 5G for CAM projects, in order to compare and harmonise results between 5G and V2X industries in the EU and beyond.

5G-MOBIX sees international cooperation as a key asset to promote the rapid development of the automotive and telecommunications industries: it allows different sets of knowledge or complementary capabilities to flow among different manufacturers, operators and public agencies to increase the speed of testing, development, standardization and deployment.

First of all, the Project has ensured a presence at relevant global events such as IEEE 5G World Forum to get 5G Fora and 5G for CAM active stakeholders and projects on a yearly basis to present their strategies, activities and outcomes, including 5GAA, 5GIA, 3G-PPP, and 5G-ACIA (for Europe) and 5G Americas, IMT-2020 (5G) (China), 5GMF (Japan), TSDSI (India) and 5G Brasil. This has allowed 5G-MOBIX to capture active as well as non-active or hidden stakeholders in the sector and to create a core community around 5G for CAM deployment and the evaluation of its potential in the real world.

The collaboration amongst European automotive projects, namely 5GCroCo and 5G CARMEN, but also 5GMED, 5G-Blueprint, 5G-ROUTES, 5GRAIL, and global partners has been namely ensured through the 5G for CAM Summits, organised by Latif Ladid, 5G-MOBIX UNI.LU representative and 5G Initiative Co-Chair, and Jorge Pereira, Principal Scientific Officer of the European Commission, in the framework of IEEE 5G World conferences.

The 5G for CAM Summits served as a forum for EU-funded projects related to CAM to share experiences, report findings, and talk about the next steps towards deployment, with stakeholders from the United States and Canada. This activity, initiated and developed under the 5G MOBIX project, has contributed to creating synergies and building an international community that exchanges best practices, ideas and innovation in the field of 5G.

The 5G-PPP Partnership has also provided a platform for the European automotive projects to share vision, approach and outcomes and facilitated their cooperation within its thematic Work Groups or through cross project joint events and publications.

The report also describes the contributions of the Korean and Chinese trials of the 5G-MOBIX project and their significance for possible future collaboration between Asia and Europe. The project provided the opportunity to build solid research relationships between EU and Asian partners and to share respective experiences and innovative findings in developing and testing the 5G CAM use cases and 5G-enhanced technology.

Finally, the report describes current policies and regulations in European (Belgium, Estonia, France, Germany, Greece, Italy, Luxembourg, Poland, Spain) and non-European (China, Japan, South Korea, US) countries actively involved in CAM trials and deployments. For each country, the requirements for conducting tests on public roads are described and/or the current status of regulations for the commercialization of CAVs. The aim is to draw attention on the challenges and opportunities of homogenizing and standardizing regulations at an international level.

In conclusion, Deliverable D7.6 acknowledges the necessity to strengthen international cooperation in key fields such as automation, interconnection, transportation information services, intelligent city transportation, freight transport and logistics industries by fostering exchange activities in global conferences, demonstrations, seminars, technical visits, etc., but also through organising within EC-funded projects international trials, in non-EU countries or in corridors that transcend international borders.

D7.6 also sheds light on the open issue of interoperability and harmonisation with respect to 5G standards[1], as well as the lack of an international regulatory framework on CAM research, development, testing and commercialization. This heterogeneity can be the cause of inefficiencies and delays for the widespread adoption of 5G for CAM.

Based on the demonstrated benefits of international cooperation within the project, 5G-MOBIX recommends to keep working closely on both technological/operational as well as regulatory aspects of 5G for CAM to speed up the adoption of this technology which is essential for the future of a seamless mobility that takes full advantage of what 5G technologies have to offer.

[1] UNI.LU (Latif Ladid is IEEE Industry Editor and the chair of ETSI IPE ISG) has also submitted two papers to the IEEE Industry Newsletter, with the contribution of the European Commission (Jorge Pereira) and a standardisation paper to ETSI IPE ISG, both listed in annex.

1. INTRODUCTION

This section introduces the 5G-MOBIX project by describing in brief its aims and objectives. It also specifically presents the objectives of this deliverable, D7.6 - Report on the international cooperation and results.

1.1. 5G-MOBIX concept and approach

5G-MOBIX aims to showcase the added value of 5G technology for advanced Connected and Automated Mobility (CAM) use cases and validate the viability of the technology to bring automated driving to the next level of vehicle automation (SAE L4 and above). To do this, 5G-MOBIX demonstrates the potential of different 5G features on real European roads and highways, while creating and using sustainable business models to develop 5G corridors. 5G-MOBIX also utilizes and upgrades existing key assets (infrastructure, vehicles, components) and the smooth operation and co-existence of 5G within a heterogeneous environment comprised of multiple incumbent technologies such as ITS-G5 and C-V2X.

5G-MOBIX executed CAM trials along cross-border (x-border) and urban corridors using 5G core technological innovations to qualify the 5G infrastructure and evaluate their benefits in the CAM context. The Project also defined deployment scenarios and identified and responded to standardisation and spectrum gaps.

5G-MOBIX defined critical scenarios needing advanced connectivity provided by 5G, and the required features needed to enable some advanced CAM use cases, including tethering via vehicle, CAVs cooperative collision avoidance, emergency trajectory alignment etc.

Through the joint effort of 58 partners from 13 countries, 5G-MOBIX developed and evaluated automated vehicle functionalities using 5G core technological innovations along two cross-border corridors (Spain-Portugal and Greece-Turkey) and 6 pre-deployment urban trials (France, Germany, Netherlands, Finland, China and South Korea).

The trials also allowed 5G-MOBIX to conduct evaluations and impact assessments and define business impacts and carry out cost/benefit analysis. Based on these evaluations and international consultations with the public and industry stakeholders, 5G-MOBIX identified new business opportunities for the 5G-enabled CAM and proposed recommendations and options for its deployment.

Through its findings on technical requirements and operational conditions, 5G-MOBIX actively contributed to standardisation and spectrum allocation activities. The details regarding these activities are contained in D6.7.

1.2. Purpose of the deliverable

This deliverable outlines the activities undertaken to support the project consortium cooperation and collaboration with the international 5G organisations and other 5G for CAM projects in order to compare results and achieve interoperability and harmonisation of the work and end results among these partners. We have used the IEEE 5G World Forum platform to get all 5G Fora and 5G for CAM active stakeholders and projects on a yearly basis in-person and later online to announce openly their national strategies and concepts. As a matter of fact, it took three years for all organisations to clearly open up to each other and announce their results and plans in full confidence. This has allowed the 5G-MOBIX project to capture active and apparent and non-active and hidden stakeholders in the sector in an effective way, as well as creating a core community around 5G for CAM.

1.3. Intended audience

The audience targeted with this Report are international 5G Fora, 5G for CAM projects, Standardisation bodies and institutes such as ETSI, ITU and IEEE.

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2. DISSEMINATION ACTIVITIES

One of the objectives of 5G-MOBIX is to disseminate systematically its activities and results, to increase its impact and visibility across the EU and worldwide.

In this section, we present the actions that have been undertaken by 5G-MOBIX and its members to promote the outcomes of its activities among communities of experts and relevant stakeholders, as well as its initiatives to foster collaboration amongst European and global partners in this field. In the following section, we present the main events organized by 5G-MOBIX in this context.

2.1. Worldwide 5G Industry Fora Sessions

The Worldwide 5G Fora sessions [2] are events that have been organized and co-chaired yearly by Latif Ladid, 5G-MOBIX UNI.LU representative and 5G Initiative Co-Chair, since 2018.

The goal of these fora is to promote the sharing of information and ideas among various industry associations that are primarily focused on 5G. The attendees were asked to describe their endeavors, visions, roadmaps, trials, and pilot projects related to the deployment of Full 5G and the evaluation of its potential in the real world.

In particular, session discussions during the Worldwide 5G Industry Fora focus on the following three primary subjects:

- **Regional visions:** The 5G standards process should assure interoperability and ubiquity by including regional perspectives and the participation of vertical industries. However, because of the many ecosystems and approaches that exist across the world, various concepts of 5G may emerge. As a matter of fact, operators analyze their spectrum portfolios and build 5G experiments, pilots, and use cases with verticals taking into consideration the particularities of their position in the respective region.
- **Roadmap for Full 5G vision, including spectrum, standards, and deployments:** the discussions enabled in the forum aimed at answering to four fundamental questions: i) what are the available target spectrum and candidate bands and when and how would the allocation happen, ii) what does the current image of 5G deployments look like (dense urban, rural etc.), iii) what is the roadmap of 5G for automotive, and what can be done to ensure its success, iv) how are different industries, or verticals, contributing to the standardization and development of 5G.
- **Industry international cooperation**: the sessions that focus on this topic aimed to investigate the ground for joint inter-regional projects and cross-continental collaborations towards the success of 5G. Specifically, the goal of these sessions was to investigate how 5G can be used in developing countries.

Notable guests of the latest edition (2021) were Wang Zhiqin, Chair IMT-2020 Promotion Group (China); Yoshinori Ohmura, Secretary General 5GMF (Japan); Pamela Kumar, Director General TSDSI (India); Dong Ku Kim, Chair Executive Committee 5G Forum (South Korea); Colin Willcock, chairman 5G-IA (Europe); José Marcos Brito, Secretary General 5G (Brazil); Chris Pearson, President 5G Americas (Americas); Dr. Mitch Tseng, Senior consultant "Next Generation Communication Technology Office" (European Commission); Bernard Barani, Deputy Head of Unit DG CNECT, IEEE; Ashutosh Dutta, Chair IEEE Future Networks Initiative; Tao, Project Manager, EU-China 5G-DRIVEChen; Andreas Mueller, Chairman, 5G-ACIA; Maxime Flament, CTO 5GAA; BCG: Heinz Bernold, Partner & Director, BCG; Wanshi Chen, Chairman TSG RAN, 3GPP.

2.2. 5G for CAM Summit 2021

The 5G for CAM Summit 2021 [3] served as a forum for participants from a wide range of EU-funded projects related to CAM. Sharing experiences, reporting findings, and talking about the next steps towards deployment were the goals of this event. It was co-chaired by Latif Ladid, 5G-MOBIX UNI.LU representative and 5G Initiative Co-Chair, and Jorge Pereira, Principal Scientific Officer of the European Commission.

The 5G for CAM program initiative quickly evolved into a gathering spot for all European teams conducting research in the cross-corridors mobility scenarios, in addition to bringing stakeholders from the United States and Canada to the 2021 IEEE 5G World conference event. This dual strategy has tremendously eased the communication between them, and it has created synergies in their collective efforts to work together under the neutral umbrella of the IEEE 5G Initiative. This activity, initiated and developed under the 5G MOBIX project has greatly contributed towards building an international community that needs to meet and exchange best practices, ideas and innovation in the field of 5G.

The topics that were discussed at the conference were related to all of the mobility verticals that were targeted by the European 5G Action Plan within the scope of the European Single Digital Market. These mobility verticals included roads, rails, water ways, and coastal maritime, along with a multi-modality component of the discussion. In addition to discussing a wide variety of infotainment-related themes, the conference's primary emphasis was on the primary societal goals of CAM.

The participants had a common objective: to lay the groundwork for a complete ecosystem focusing on infrastructure, equipment, and services that were built on top of 5G advanced connectivity, while also defining the responsibilities and resources (in terms of technology and investments) that were necessary for the development of mobile and fixed broadband. In this context, the work and financing from EU Horizon 2020 of 5G in cross-border stretches of Trans-European Transport Network (TEN-T) was regarded as the beginning point for the large-scale deployment of 5G in Europe. Even though the EU-funded initiatives were the primary topic of discussion at the 5G for CAM 2021 conference, participants from other regions of the world were welcome to attend in an effort to foster transcontinental collaboration.

Notable guests of the latest edition (2021) were Maxime Flament, CTO, 5G-AA; Magnus Frodigh, Vice President and Head of Ericsson Research; Peiying Zhu, Senior Vice President of Wireless Research, Huawei; Chih-Lin I, Chief Scientist, Wireless Technologies China Mobile Research Institute; Riccardo Calabro, Director Product Marketing Qualcomm CDMA Technologies GmbH; Coen Bresser, Senior Manager I&D at ERTICO – ITS Europe, 5G-MOBIX Project Coordinator; Uwe Herzog, Programme Manager at Eurescom GmbH and 5G-DRIVE Project Coordinator; Eusebiu Catana, Senior Manager, ERTICO.

2.3. Other EU projects liaison activities

The collaboration with other European projects, and in particular with the other two automotive projects selected for funding in the 5G-PPP ICT-18-2018 Call, 5GCroCo and 5G CARMEN (and later with the projects selected for funding in the 5G-PPP ICT-53-2020 Call, 5GMED, 5G-Blueprint, 5G-ROUTES, 5GRAIL), has also been the focus of many different events in the course of the project, some organised by 5G-MOBIX itself, to foster collaboration and harmonisation between these initiatives:

- Workshop organised in 2019 by the European Commission, on the 5G Strategic Deployment Agenda for Connected and Automated Mobility (5G SDA CAM);in 2020, on "5G for CAM: Preparing for cross-border deployment", and in 2022, on 5G-MOBIX, 5GCroCo and 5G CARMEN respective deployment studies and the preparation of a "5G for CAM: A Deployment" Metastudy;

- Co-organised sessions / workshops at the EUCNC Conference 2019, 2021 and 2022;

- Workshops organised during the ITS European and World Congresses 2019, 2021, 2022;

- Joint webinars on '5G Trials for Cooperative, Connected and Automated Mobility along European 5G Cross-Border Corridors' in 2020, and on CAM deployment challenges in 2021.

Other dissemination activities of these projects included joint white papers [4] under the umbrella of 5G-PPP, which was namely responsible for coordinating joint opportunities for 5G projects dissemination and liaison.

3. COOPERATION WITH THE INTERNATIONAL COMMUNITY

To incentivize knowledge transfer and disseminate the activities of 5G-MOBIX worldwide, the members of the consortium have been in direct contact with international stakeholders in the fields of telecommunications, information and communications technology (ICT) and automotive.

3.1. 5G-MOBIX International Partners

Several organizations have been officially involved in 5G-MOBIX activities. In Table 1, we describe the main partners of the project.

Table 1: Partner organizations of 5G-MOBIX

Organization	Description
5GAA	The 5G Automotive Association (5GAA) is a global organization that was established in 2016 in Munich, Germany, by eight founding members - AUDI AG, BMW Group, Daimler AG, Ericsson, Huawei, Intel, Nokia, and Qualcomm Incorporated [5]. The 5GAA's primary objective is to allow businesses in the automotive, information technology, and telecommunications industries to collaborate with one another. Since its inception, 5GAA has experienced rapid expansion, extending its membership to include 130 companies in a variety of industries, including but not limited to Tier-1 suppliers, automotive manufacturers, mobile operators, infrastructure vendors, and chipset/communication system providers. The ultimate objective is to make use of the various areas of knowledge held by its members in order to design and create the next generation of connected mobility and automated vehicle solutions. In this context, the 5GAA endorses the use of 5G as the best possible platform to carry mission-critical communications for safer driving, as well as to assist the development of Vehicle-to-Everything (V2X) and, consequently, connected mobility solutions. The contributions made by 5GAA focus on the following topics: i) defining use cases and deriving technical requirements and Key Performance Indicators (KPIs), ii) defining, developing, and recommending system architectures and interoperable solutions for the use cases, iii) evaluating and validating the solutions through the testbeds, iv) standardizing the solutions that have been presented, v) defining business models and go-to-market strategies for industrial adoption.

	Involvement with 5G-MOBIX 5GAA is an Advisory member of 5G-MOBIX.
5G-IA	The 5G Infrastructure Association, also known as 5G-IA, is the private counterpart to the 5GPP (being the European Commission its public side) [6]. The 5G-IA is dedicated to the continued development of 5G in Europe as well as the formation of a global consensus around 5G. In order to accomplish this objective, 5G-IA brings together a global industry community of telecoms and digital actors. These actors include MNOs, manufacturers, universities, research centres, and small and medium-sized enterprises. 5G-IA engages in a wide variety of activities in strategic areas such as standardization, frequency spectrum, research and development projects, technology skills, international cooperation, and collaboration with industry sectors, especially for the development of trials. Through a partnership Board, the 5G-IA formally engages in conversation with the European Commission. Additionally, the 5G-IA closely coordinates the activities of its Policy Work Groups with those of the 5G Initiative Projects and Technical Work Groups. The 5G-IA emphasizes its goals and action plan, which are as follows: • Communicating with vertical industry sectors and ensuring that the EU will support and enforce the necessary policies and regulations in order for 5G to be adopted in the many different vertical industries throughout Europe. • Steering the implementation of the 5G PPP program through cross-project cooperation in Europe and targeting the utilization of the achievements of the 5G PPP in a consistent manner. • Increasing the amount of radio spectrum that is available for use while also developing an all-encompassing standardization roadmap with the end goal of creating a 5G communications standard that is internationally interoperable. • Defining its "5G trials roadmap strategy" for the implementation of advanced pre-commercial and pan-European trials to be launched in key sectors, with the goal of ensuring a clear European voice on 5G around the world.
	Involvement with 5G-MOBIX

	Other than being the private counterpart of 5G PPP, many members of 5G-MOBIX (e.g. ERTICO) are part of the consortium and of its follow up, 6G-IA.
3GPP	Founded in 1998 in Sophia Antipolis, France, the 3rd Generation Partnership Project (3GPP) provides a stable environment for the production of specifications that concerning mobile telecommunications technologies, namely radio access, core network, and service capabilities [7]. This project brings together seven international standards-developing organizations (SDOs) in the field of telecommunications: ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, and TTC. It is currently focusing on LTE and 5G. Making these systems both backward- and forward-compatible is one of the primary priorities of the 3GPP, as this helps to ensure that the usability of user equipment is not disrupted in any way. 3GPP is working on "forward compatibility" into Non-Standalone NR equipment in this scope since several operators are working on dual connection between LTE and 5G NR equipment employment the Non-Standalone NR equipment. In addition, the 3GPP specifications take into account interoperability with networks that do not use the 3GPP standard as well as non-radio access to the core network.
	Involvement with 5G-MOBIX All operators involved in 5G-MOBIX fed results to 3GPP as part of their standardization process.
CATT	The China Academy of Telecommunications Technologies (CATT) is a research institute affiliated to the Ministry of Industry and Information Technology (MIIT) of China. It is considered a "think-tank for the government and an innovation and development platform for the industry". Since its foundation in 1957, CATT has provided strong support for major strategies, plans, policies, standards, tests, and certification for the development of the national ICT sector and IT application. For this reason, CATT is an essential player in the development and innovation of the Chinese ICT sector. In recent years, CATT has expanded its innovation efforts to reach a broader research landscape. It has conducted in-depth research and foresighted planning in 4G/5G, smart manufacturing, Internet of Things (IoT), V2X, cloud computing, blockchain, etc. national activities.

	Involvement with 5G-MOBIX CATT conducted the 5G-MOBIX pre-deployment China trial which is described in Section 5.2.2.
KATECH	The Korean Automotive Technology Institute (KATECH) is Korean a government-funded research institute that operates on a not-for-profit basis. In addition to providing support for the automotive R&D policy of both the central and local governments, KATECH is also responsible for the planning of large-scale projects for the national government and assumes the responsibility of evaluating and certifying automotive parts. It is involved in the Korean automotive industry in a number of different fields, such as CAM, EVs, advanced materials, reliability, and hydrogen mobility [8]. KATECH, in its role as leader of the Korean TS, provided the most important findings of the remote-controlled vehicle under SAE L4.
	Involvement with 5G-MOBIX KATECH coordinate the 5G-MOBIX pre-deployment Korean trial site, which is described in Section 5.2.1.

3.2. Organizations of interest for 5G-MOBIX

Table 2 lists the associations, coalitions and consortia which similarly to 5G-MOBIX, aim at investigating the potential of 5G and/or other technologies for the automotive sector, as well as standardization and promotion of individual or joint activities of the members to external stakeholders.

These associations that were thus of interest for the vision and the activities of 5G-MOBIX, have been invited to the events described in Section 2, thus allowing a continuous interaction, and sharing of information and ideas with 5G-MOBIX.

Table 2: Organizations of interest for 5G-MOBIX

Organization	Description
5G-ACIA	5G-ACIA is a working group of the Electro and Digital Industry Association, a global forum to allow diverse sets of stakeholders from a diverse set of industries to cooperate for the

	creation of a new ICT ecosystem and define frameworks for the CAM market [9]. 5G-ACIA has its headquarters in Frankfurt-Am-Main, Germany. Stakeholders in 5G-ACIA include academic institutions, research institutes, government bodies, industrial automation enterprises, Mobile Network Operators (MNOs) and chips manufacturers. The ultimate objective of 5G-ACIA is "to maximize the use of 5G in industrial applications." Furthermore, 5G-ACIA determines the spectrum requirements for 5G networks used in industry.
5G Americas	5G Americas is a trade group for the telecommunications industry that has its headquarters in Bellevue, Washington. Its membership includes prominent telecoms service providers and manufacturers, including AT&T, CISCO, Ericsson, Intel, Nokia, and Samsung [10]. The mission of the organization is to foster the advancement of LTE wireless technologies and their transition to 5G throughout the ecosystem's networks, services, applications, and connected devices in the Americas and overseas. In particular, 5G Americas investigates i) communications based on satellites, ii) communications via cellular networks, and iii) data protection.
IMT-2020 (5G)	On the basis of the original IMT-Advanced Promotion Group, the IMT-2020 (5G) Promotion Group was established in China 2015 [11], with the support of three ministries. It is the most important venue in China for advancing research and development of 5G technology. The most influential MNOs, vendors, academic institutions, and research organizations in the field of mobile communications are among its members.
5GMF	Founded in 2014 by a consortium of public and private players in Japan, the Fifth Generation Mobile Communication Promotion Forum's (5GMF) aims at conducting research and development concerning 5G to achieve early realization of those systems, with the intention of contributing to the healthy growth of the use of telecommunications in the process [12]. The goals of 5GMF can be summarized as it follows: • Engaging in research and development of 5G systems, as well as in studies pertaining their standardization.

	• Collecting information on 5G and exchanging it with other organizations.
TSDSI	The standardization of telecom and ICT goods and services in India is the mission of the Telecommunications Standards Development Society of India (TSDSI) [13]. TSDSI is a nonprofit organization, whose declared goals are i) the development and standardization of telecom and ICT requirements and solutions that address the Indian ecosystem, ii) The dissemination of Indian requirements and initiatives to the rest of the globe, iii) The contribution to the development of manufacturing skills in India In recent years, TSDSI has been actively promoting the adoption of 5Gi, which is an extension of 3GPP 5G standards. This has been done in order to meet the critical rural coverage requirements that are necessary in India. This particular set of guidelines has resulted in the collaborative creation of intellectual property with enterprises based in both Europe and China.
5G Brasil	Telebrasil is a private organisation with 65 institutions as members. Its primary mission is to support the growth of the telecommunications sector in Brazil [14]. 5G Brasil is a private autonomous project of Telebrasil. Its primary objective is to foster the growth of a 5G ecosystem in Brazil by facilitating and creating contacts between the country's ICT industry, the Brazilian government, and the regulatory body in the country. 5G Brasil promotes national and international cooperation agreements for the development and adoption of 5G technology, represents the members' common interests in national and international forums related to 5G, and fosters 5G technology development and adoption.

4. LIAISON AGREEMENTS WITH SIMILAR PROJECTS

In this section we present the liaison agreements established between 5G-MOBIX and entities conducting similar tests in the field of 5G for CAM.

4.1. China: Memorandum of Understanding between ITS China and ERTICO – ITS Europe

ERTICO organized the Europe-China ITS Summit in September 2018 with the goal of boosting ERTICO's international cooperation. The summit was held in Shanghai, China. During the course of the Summit, the two organizations came together to inaugurate a new Joint Innovation Centre as well as sign a Memorandum of Understanding (MoU) [15]. Figure 1 shows the celebration of the MoU signature.

The exchange of information on ITS and mobility among ITS partners from the two continents is essential to the development of technology in the transportation sector. In this regard, Jacob Bangsgaard, who was serving as the CEO of ERTICO at the time, stated: "We have been working with China for 20 years and seen the relationship change, the integration of our organisations is more complex and deeper than ever before, and it will increase. This new centre will facilitate these efforts".

Figure 1: Celebration of the Memorandum of Understanding between ERTICO ITS and CHINA ITS

This collaboration and the Joint Innovation Centre served to speeded up the cooperation between enterprises, authorities, and research institutes in both Europe and China. This promoted a series of cooperation activities between the companies which are part of ITS China and ERTICO. Some of these activities include the promotion of ITS standards, the creation of cooperation projects, the exchange of knowhow, and the organization of networking events and site visits in Europe and China.

The expansion of China's and ERTICO ITS-collaborative Europe's efforts in the development of ITS and services is a goal that both organizations have in common. Both Europe and China are experiencing similar difficulties in the field of ITS, and as a result, both regions are working to increase their level of collaboration in ITS research and development, as well as their efforts to promote the flow of knowledge.

Additionally, both parties acknowledge the benefits of advancing global ITS standards that are consistent with one another. In this regard, both ITS China and ERTICO ITS-Europe are aware of the significance of consolidating their connection and the establishment of more intimate kinds of collaborative working relationships. The collaboration focuses on the following three primary points:

- Regularly share and exchange information of mutual relevance and provide information services for the industries and members of both Europe and China.
- Encourage the development of policies and technologies within the intelligent transportation industry, cooperate in the creation of intelligent transportation standards, technological research and development, and hold cooperation meetings within the framework of the ITS World Congress.
- Strengthen cooperation in important areas such as automation, interconnection, transportation information service, intelligent city transportation, freight transport and logistics, and organize exchange activities in the intelligent transportation industry. These activities include establishing together the China-Europe ITS Joint Innovation Centre, co-organizing conferences, demonstrations, seminars, and technical visits, etc., as well as building a platform for cooperation of the members of both sides and fostering a more rapid expansion of the industry.

The MoU was signed to formalize existing collaboration between the ERTICO Partnership and the European ITS Community and that of China. Taking advantage of the collaboration, 5G-MOBIX has benefitted from this collaboration by having access and a direct link to Chinese partners in the project who were interested and able to work on the same objectives of the project.

The outcome of this collaboration resulted in the opportunity to be able to cross-check ideas and operational practices in testing 5G applications cross-border and thus ensure alignment with the approach and technologies that our counterparts in Asia are using. Cross-checking with the pilots in Asia, on the performance of the relevant 5G systems and services, and the ability to enhance the exposure of EU projects, partners and knowledge in Asia has greatly contributed towards building a truly international community that cooperates on the topic of 5G benefits on transport.

Thanks the MoU, ERTICO had the possibility to involve the China Academy of Telecommunications Technology(CATT) in 5G-MOBIX (see Section 5.2.2). In particular:

- In June 2019, ERTICO co-organised the EU-China ITS Forum at the World Transportation Convention in Beijing.

- In June 2020, ERTICO participated in the Belt and Road International Transport Alliance Board Meeting, at which the 5G MOBIX project was presented as open for collaboration.
- In September 2020, ERTICO had planned a business delegation to China which was to include a 5G Workshop at the Huawei headquarters, to include 5G MOBIX Chinese partners, as well as visits to multiple 5G V2X demonstration sites, however due to the COVID-19 crisis this was delayed to 2021.

4.2. Other Liaison Agreements

The 5G-PPP Partnership is a joint initiative between the European Commission and European ICT industry aiming to reinforce the European industry leadership on global markets and open new innovation opportunities. 5G-PPP provides a platform to share vision, approach and outcomes and to facilitate cooperation (within the task forces of the 5G-PPP - the collaboration between EU cross-border projects is further discussed in Section 5.1).

Though the 5G-PPP Phase 1 projects contracted a specific collaboration agreement [16] under the 5G-PPP program, 5G-PPP Phase 2 projects (including 5G-MOBIX) grant agreements contained an extra provision obliging "cross project joint actions, 5G Global Events, Work Groups, KPIs progress evaluation and the granting of complementary access rights by acceding to the 5G PPP collaboration agreement". No supplementary MoUs between European projects were thus required.

Regarding 5G Fora from other world regions, they expressed a strong interest to work with us and they did (namely through those IEEE World 5G Industry Fora described in Chapter 2), but formally they just signed MoUs with other 5G Fora.

5. COMMON INTERNATIONAL AND GLOBAL VISION FOR 5G CAM DEPLOYMENTS

Although Europe was a driving force and a leader in the creation of 4G, the continent's rollout of the 5G technology was beset with problems, including significant delays. This ultimately resulted in Europe being put at a disadvantage in comparison to global competing powers.

During his State of the Union (SoU) speech in 2016, the European Commission President Jean-Claude Juncker (2014-19) set as an European Union objective "to completely deploy 5G, the fifth generation of mobile communication networks, across the European Union by 2025" [17].

In a socioeconomic study, it was determined that the rollout of 5G would result in the creation of millions of jobs and billions of euros in economic benefits [18]. To put this into perspective, investments totaling approximately 57 billion euros are expected to result in the creation of 2.3 million jobs in Europe, and the benefits derived from the introduction of 5G could generate 113 billion euros annually in just four key industries (automotive, healthcare, transport, and utilities).

However, in order for 5G for CAM technologies to be advanced and implemented on a broad scale, not only a standardized strategy to research and development, testing, deployment, and market penetration is required on a global level but also international cooperation. This is especially relevant for corridors that transcend international borders [19]. The 5G MOBIX project aim to advance international cooperation is an action supporting the European Union objectives, as these were set in the SoU referred to above, thus contributing to the creation of jobs and economic benefits for both Europe and globally.

This section analyzes the most relevant trials for cross-border CAM in the EU, South Korea, and China, that were used as pilots within 5G MOBIX, but also contributed to the project international cooperation efforts towards a 5G for CAM technologies standardized strategy for research, testing, deployment and market penetration at a European and global level.

5.1. Cross-border trials within EU

Within the context of Horizon 2020, the European Commission launched a 5G Public-Private Partnership (5G PPP), with EU funding of 700 million euros, in collaboration with 5G-IA [20].

5G PPP brings together a diverse collection of stakeholders from the field of communications technology and from its extended value chain. These stakeholders include user industries as well as players from the fields of microelectronics and information technology.

The 5G PPP welcomes participants from all over the world and it was designed to be carried out in three stages, beginning with the demonstration of basic technologies and progressing on to proof-of-concept tests and trials involving vertical industries (in this case, CAM). It also encompasses investigations into longer-term developments beyond 5G.

A long-standing legacy of experimentation for the purpose of testing and validating new technologies, services, and applications can be found in Europe. However, the realization that end-to-end systems are now too complex and too heterogeneous to be analyzed or even simulated, highlights the need for extensive testing and validation on prototypes. In particular, end-to-end systems, as well as individual (sub-) systems, need to be tested in the real world, in actual situations, with real traffic/loads, and with real users. In addition, it is impossible for anyone, even for the wealthiest organizations, to have the financial means to assemble and run an entire proprietary system.

Based on this concept, 5G PPP provides first trial platforms and, subsequently, conducts the trials themselves. For CAM, the approach was slightly different because the platform is actual infrastructure in a specific section of each considered corridor, which has its unique characteristics. In the case of 5G-MOBIX, for instance, the trial between Greece and Turkey had to take into account aspects such as rigorous border checks, customs etc., which were, instead, absent in the Spain-Portugal corridor trial.

In support of the 5G for CAM strategic priorities as they were stated in the SoU referred above, the European Commission launched two Calls targeting cross-border corridors, with 105M€ EU-funding. The aim was concretely to engage the constituency, identify gaps, create consensus, propose solutions, and, most importantly, test and validate in the field.

A first 5G for CAM Call was launched at the end of 2017. The objective 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."

Three cross-border corridor projects with 63M€ EU-funding were selected and launched in November 2018:

- **5G-MOBIX**: Kipoi (GR) - Ipsala (TR) and Vigo (ES) – Porto (PT)
- **5GCroCo**: Metz (FR) - Luxembourg (LU) - Saarbrücken (DE) triangle [21]
- **5G-CARMEN**: Münich (DE) – Innsbruck (AT) - Bologna (IT) [22]

The collaboration of the three projects aimed at achieving the following objectives: i) to have a comprehensive overview of the most prominent requirements and applications expected for 5G in cross-border environments; ii) to analyze the key challenges that need to be addressed for CAM support in cross-border environments, based on the work of the three projects; and iii) to provide a list of candidate technological enablers and solutions to be investigated within the projects, which may potentially mitigate or resolve the key challenges.

The projects also jointly assessed the CAM connectivity demands and the corresponding 5G infrastructure investment delta in different European cross-border corridors, in the "5G for CAM Deployment Metastudy".

A second 5G for CAM call was launched in 2020, aiming both at automotive and rail cross-border corridors. Three projects, mainly with road transport focus, were selected and launched September 2020:

- **5G-Blueprint** - North Sea corridor (BE-NL) [16]
- **5G-ROUTES** - Baltic corridor (FI-EE-LV-LT) [23]
- **5GMED** - Mediterranean corridor (ES-FR) [24]

A fourth one, focusing on rail, was launched November 2020: **5Grail** [25]. The total EU-funding was 42M€.

5G-MOBIX and 5G-Blueprint have been involved in each other activities since the launch of 5G-Blueprint since they share a pilot site in the Netherlands.

The trials conducted by the seven projects did not only provide insights from a technological perspective, but also served to investigate the economic challenges and opportunities of adopting 5G tools in cross–border transport and logistics, as well as in passenger transport: bringing capital expenditure (CAPEX) and operational expenditure (OPEX) into view, both on the supply (telecom) side and the demand (transport and logistics) side, leading to the transformation of current business practices as well as new value propositions [19].

The experiences and results of the ICT-18 projects, namely 5G-MOBIX, are re-used as a basis by the ICT-53 (2020-Call) projects.

5.2. International cross-border trials of 5G-MOBiX extra-EU partners

Within the 5G-MOBIX project, two trials were conducted by KATECH and CATT, the extra-EU partners of 5G-MOBIX, in controlled environments to emulate the cross-border scenarios in, respectively, South Korea and China.

In this section, we describe the trials and discuss the reached achievements, as well as discussing possible future collaboration between the Asian partners and the EU.

5.2.1. The Korean trial

The South Korea trial conducted by KATECH addressed two of the five use cases identified by the 5G-MOBIX project, namely Remote Driving and Vehicle QoS (Quality of Service) Support, by using mmWave communication.

KATECH was in charge of the 5G-MOBIX Korean Trial Site (TS) and collaborated closely with a variety of technical partners like ETRI, SNETICT, and Renault Samsung Motors. The two use cases chosen for the trials served as investigation ground for remote controlling a vehicle through the use of mmWAVE communication. The collaboration of KATECH to 5G-MOBIX precisely matched its own objectives, which are to foster the innovation of CAM technology and to harmonize all of the stakeholders' strategic technologies related to 5G.

The Korean TS utilized two separate testing locations, primarily the testing grounds at KATECH and the testing site along Yeoju Highway.

KATECH's own testing ground was used to test the use case of remote-controlled vehicles, and it offered two different types of closed test roads: a 1 kilometer patch of different types of test roads (such as a pavé road, straight lane, and braking track), and a road emulating an urban environment composed of multiple intersections and a roundabout.

The Yeoju Highway test was constructed in parallel to the main highway and is located between the Yeoju junction (JCT) (shown in Figure 2) and the Gamgok interchange (IC).

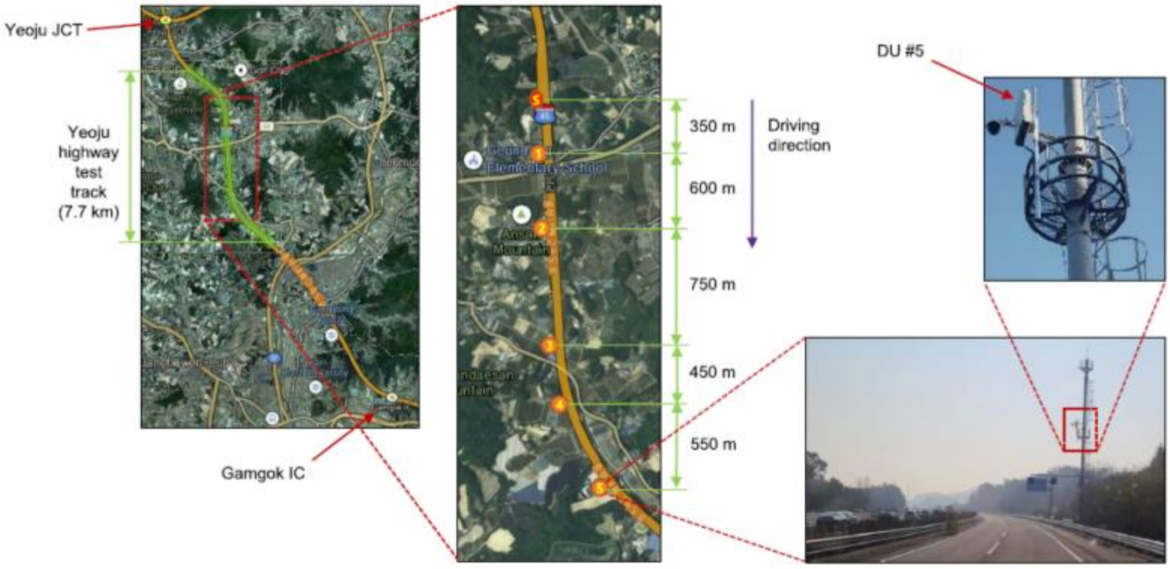

Figure 2: Celebration of the Memorandum of Understanding between ERTICO ITS and CHINA ITS DU deployment [26]

At the Korean TS, ETRI and SNETICT were in charge of the mmWAVE (SA) network (base station and 5G Core network), whereas KATECH is in charge of the remotely-controlled vehicle, a Renault Arkana, that is based on mmWAVE, and Renault Samsung Motors was responsible for providing the necessary technical support. The mmWAVE OBU was installed in a L4 autonomous vehicle. Inside of the test car, there were a total of eight cameras ready to transmit real-time footage to a distant server using mmWAVE communication. The mmWAVE base station as well as the core network were both mounted in the moving base station vehicle, which was a Renault Master van equipped with a remote control station.

The primary features, including real-time video streaming and control RCV through mmWAVE communication, were put through their paces during the field trial in order to be tested and validated. Figure 3 illustrates the field trial conducted on the target vehicle with the base station being located in the Renault Master van in the front of it.

Figure 3: Field trial of the remote controlled via mmWAVE communication

After successfully developing, testing, and validating the mmWAVE network system and integrating it into the remote control vehicle, KATECH also tested it in the closed ground with predefined scenarios such as high-speed maneuvering with the remote-controlled vehicle and various other maneuvers such as lane changing and avoiding a sudden obstacle. KATECH's testing ground was equipped with predefined scenarios such as high-speed maneuvering with the remote-controlled vehicle.

Additionally, KATECH contributed to 5G-MOBIX by dealing with one technical problems specific to the cross-border sites; mmWave applicability, and have analysed the cross-border issues related to Korean user stories.

Overall, with its activities and findings, KATECH has contributed to the deliverables from WP2 to WP6, in particular D2.2, D2.3, D2.4, D3.2, D3.3, D3.4, D3.5, D4.1, D4.2, D5.1, D6.3, which cover 5G-enabled CAM use cases, 5G architecture and technologies, vehicle adaptation, corridor infrastructure, and the KR site's roll out plans.

5.2.2. The China Trial

In accordance with the goal of the 5G-MOBIX project, the China trial conducted by CATT contributed to dealing with two technical problems specific to the cross-border sites: Low coverage Areas and Session & Service Continuity by emulating a 5G cross-border scenario at the Jinan location [27].

Collaboration with 5G-MOBIX benefits the requirement to accelerate the Chinese pace of 5G application and strengthen the construction of new infrastructure, industrial Internet and Internet of Things. To match the main objective of 5G-MOBIX, the Dalian University of Technology (DUT) 's and the related stakeholders, researchers made a series of trials on the quality of autonomous driving and 5G communication services for cross-border scenarios. Doing so, they tried to explore the potential and commercial value of Cross-Border 5G technology for advanced CAM. These collaborations focused on the technical issues involved in 5G-MOBIX for achieving roaming and inter-working between various MNOs, and other service providers, which is helpful to improve the performance in 5G deployment under Chinese MNOs.

In order to replicate the relevant scenarios, it was proposed to make use of a number of different 5G MNOs, e.g. China Unicom and China Mobile. As a result, they set up the multiple 5G SA network within the enclosed portion of the Shandong Academy of Sciences (Jinan-1-SDAS, urban road), in addition to selecting the Shandong Binlai Expressway as their preferred location (Jinan-2-SDHS, highways), which is shown in Figure 4.

The purpose of this simulation was to validate essential technical performance of 5G, including cloud-assisted advanced driving, cloud-assisted platooning, and remote driving. Three user stories were devised to accomplish this.

Figure 4: Jinan-2-SDHS field trial

Also, taking into consideration the needs of the 5G-MOBIX project, the partner built a 5G shared MEC framework in Jinan-1-SDAS in collaboration with China Mobile and a 5G SA framework in Jinan-2-SDHS in collaboration with China Unicom.

In addition, by adhering to the XBI-CS list of the 5G-MOBIX, they constructed the MEC cloud, produced the 5G V2X apps with the Roadside Unit (RSU) and On-Board Unit (OBU) equipment from ZTE, DATANG, and other manufacturers in order to evaluate the 5G performance indexes, and developed the CAM application on this server. Figure 5 shows the equipment mounted on the target vehicle in both trials.

Figure 5: In-vehicle equipment in the two trials

The China partners shared the results of the tests from CN user stories and built three use cases for each US to validate 5G performance in China in accordance with the need of the 5G-MOBIX project.

Additionally, the findings demonstrated that a complete 5G SA wrapped in SDIA improved the Quality of Service (QoS) of the transmission sent from the car to the cloud server.

These China trial contributed to 5G-MOBIX deliverables D2.2, D2.3, D2.4, D3.2, D3.3, D3.4, and D3.5, as well as D4.1, D4.2, D5.1, and D6.3.

To express the impact that this 5G-MOBIX trial had on the Chinese 5G ecosystem, we report the words of Dr. Yanjun Shin from Dalian University of Technology: "During the COVID-19 pandemic, major emergencies require advanced mobile communication technology represented by 5G, furtherly 5.5G and 6G, to achieve close coordination and flexible scheduling of social resources in a more inclusive, intelligent and efficient cross-regional coordination. We expect to make further cooperation among the Chinese partners and the EU partners. Also, we thank the 5G-MOBIX project for providing the DUT the chance to build solid research relationships with the EU partners and share our experiences in developing and testing the 5G CAM. Furthermore, we are glad to share more innovative findings concerning the CAM use cases on 5G and future 5G enhance technology among China and Europe partners".

5.3. Analysis of government policies

In the prior sections, we discussed the technological and operational efforts that have been carried out by 5G-MOBIX and other HORIZON 2020 EU projects for CAM regarding CAM cross-border scenarios both inside and outside of Europe.

However, the widespread implementation of CAM in public road networks provides national regulators and road operators with a new dilemma regarding the relationship between infrastructure and road users. Even though it is anticipated that the norms and context of vehicle operation will remain the same, the automation of driving tasks shall contain all of the safety and compliance demands that a human driver ought to adhere to. Some laws are amenable to being modeled using computation, while others belong more squarely within the realm of behavior and culture.

The road network has become more complicated as a shared space resulting in the higher multiplicity of the stakeholders active within the road network ecosystem of products and services and users. Road Operators are dedicated to the implementation of high-level automation in cars as well as in the infrastructure, but they pay top attention and concern to any issues that have an impact on road safety.

In light of the regulatory concerns that could have a significant impact on supporting CAVs crossing international borders that could be implemented to support them, the existing national policies and regulations need to be taken into consideration and harmonized.

In this section, we present the regulations and policies adopted by European and extra-European countries actively involved in the CAM trials and deployments. The 5G MOBIX project consortium aims, with this listing, to raise awareness of the diversity of regulations and the need for a more harmonised approach in testing CAM on public roads, and for EU regulatory bodies to accelerate the adoption of common policies regarding CAM, so that interoperability can be promoted and a more seamless cross-border transport achieved.

5.3.1. EU

Table 3 presents the policies of the EU countries mostly involved in CAM testing, deployment and regulation. For each country we describe the requirements for conducting tests on public roads and/or the current status of regulations for the commercialization of CAVs.

Table 3: Regulations and Policies in EU countries actively involved in CAM testing and deployment

Country	Policy
Belgium	According to Belgian authorities, the steps to be followed to test CAM on public roads are the following [28]:

	• Discussion with the relevant organizations; • Completion of the application form, including all required papers; • Agreement on how to communicate with the other drivers on the road; • Notification to the police; • Allow the authorities, such as the administrations and the police, to assist with the testing; • After the testing is complete, a test report should be given to the authorities so that it can be discussed. Documentation needed: • Auditing record maintained by the test's organizer that demonstrates that the internal tests have yielded adequate data to enable testing to be carried out on the public road network without putting road users in any additional danger as a result of the testing; • Risk assessment; • Training plan for test drivers; • Copy of an insurance policy for the tested vehicle; • Copy of the roadworthiness test certificate; • Copy of the appropriate driver's license for every test driver; • A picture of the vehicle
	Main organizations in charge: The organizations involved in the process depend on the region where the testing takes place. They are: • Federal Public Service Mobility and Transport • Flemish Ministry of Mobility and Public Works • Brussels Regional Public Service Mobility • Walloon Regional Public Service
Estonia	Testing of CAM are permitted on Estonia's public highways and streets beginning in March of 2017.These vehicle can undergo testing in either public or off-road environments [29]. In order to successfully complete those tests, it is necessary for it to conform to the following requirements: • Not exceed SAE L3;

	• Have a driver who is either physically present in the vehicle or is able to take charge of it remotely in the event that this becomes necessary. Because the driver is the one who is legally accountable for the vehicle, he or she needs to have a license that lets them drive that particular kind of vehicle; • The vehicle needs to comply with the most relevant portions of EU Directive 2007/46. Furthermore, it is asked to realize a trial plan, which shall include the following points: • General description of the trials; • Technical specifications of the vehicle; • Information of the road area where the trials will be conducted; • Proof of insurance cover for third-party liability; • Description of measures to ensures road safety; • Require a test plate certificate. For its application, manufacturer shall describe how has trained or will train its stewards/safety drivers; • In the event of an accident, the only person who may be held criminally liable is the driver; the liability does not extend to the manufacturer or to any other legal body. In October 2019, the conclusion that was reached during discussion at the E-Estonia Council was that, despite the presence of a working legal framework for testing CAM vehicles on public roads, an algorithmic-liability law should first come into effect.
	Main organizations in charge: Estonian Road Administration.
France	The standards that shall be met for CAVs to be used on French roads were established by Decree n° 2021-873 on June 29, 2021. This Decree encompasses all levels of automation up to and including completely automated systems, under the condition that those systems are deployed in pre-defined courses or zones and are supervised by a remote operator [30]. The provisions and requirements, among other things, specify responsibility principles that were established in ordinance 2021-443 dated 14 April 2021 and will go into effect on 1 September 2022. This will allow to deploy automated passenger transport services beyond a framework that is considered experimental.

	The following are the files that shall be submitted in order to obtain the certificate WW DPTC in order to carry out the test:
	
	• Design file – Technical system
	  ◦ Declaration of functionality and safety, which summarises the characteristics and conditions of use of the vehicles;
	  ◦ Capabilities of the technical system: manoeuvring, perception;
	  ◦ and localisation capabilities, remote intervention capabilities;
	  ◦ Types of routes or areas covered by the technical system;
	  ◦ System requirements for testing and facilities outside the vehicle.
	
	• Preliminary safety file – In project phase
	  ◦ Routes or areas identified for the circulation of the system;
	  ◦ Characteristics of the service;
	  ◦ Proposed operational safety management system;
	  ◦ Proposed layout of the technical and safety installations located outside the vehicles;
	  ◦ Responses to the technical system requirements for technical and safety facilities;
	  ◦ Characteristics and level of service of the road, its facilities and the technical and safety installations necessary to achieve the safety level;
	  ◦ Test and trial programme.
	
	• Safety file – Commissioning decision
	  ◦ Verification that the technical and safety facilities and installations outlined in the preliminary safety file have been effectively implemented;
	  ◦ Final version of the safety management system that is now in use;
	  ◦ Presentation of the Agreements Reached Between the Road Managers and the Service Organizer;
	  ◦ Give a report on the experiments and testing that were carried out.

	Main organizations in charge: • Ministry of Ecological Transition and Solidarity (in charge of Transport) • Ministry of domestic affairs (in charge of Traffic Safety) • Ministry of Economy and Finance

	• Ministry of Energy and Climate
Germany	The Road Traffic Licensing Regulations (StVZO in German) is the document that contains the pertinent regulations [31]. The vehicle that is required to pass the dynamic driving tests may be eligible for an individual operating permit under section 19.6 of the StVZO. In the event that the vehicle will be testing functions that are not permitted by the law as it stands, there is a requirement for an exemption approval (70 StVZO): In addition, the law may demand that a particular permit be obtained in order to comply with the regulations of the road. The EU regulation UN-ECE-R79 on steering systems places a significant restriction on the range of automation functions that can be utilized. According to this regulation, a long-term automated steering intervention is only permitted for speeds of less than 10 kilometers per hour. By June of 2018, the regulation was in the process of being revised. The following steps are recommended for the owner of the vehicle in order to receive the admission: • Describe the modifications that have been made to the vehicle's technical components (the differences from the serial type). To the greatest extent possible, make use of references to preexisting standards and laws; • Create a Failure Modes and Effects Analysis FMEA and/or other failure analysis models that are comparable for either individual system modules or the entire system itself; • Explain what technical countermeasures are and the best approach to keep them under control; • Define organizational guidelines for the research and development staff as well as the technical personnel. These guidelines should address questions such as how to obtain the keys, who among the employees has the internal permission to develop and download code on the system, how you will (long-term) educate your employees, how you will prevent misuse, and so on; • After the previous documentation is completed, choose an independent testing institution and enter into a contract with it and prepare an assessment report concerning the technical modifications made to the vehicle, its level of safety, and any organizational issues or countermeasures. This evaluation

	report can include some new requirements that you have to fulfill in order to move forward; • Supply the independent testing organization with the documentation that you have developed in advance of the procedure, and organize a demonstration with the vehicle in which you exhibit the driving features in a variety of scenarios.
	Main organizations in charge: Federal Motor Transport Authority
Greece	The following is an outline of the most important aspects for testing that shall be adhered to in Greece [32]: • Operation is only allowed in a dedicated bus lane; • The lane of use should be adequately marked while signs identifying the operation of the autonomous cars should be put in place; • The vehicle should have labels inside and outside indicating the absence of a driver; • The remote operator shall have the ability to stop the vehicle in the event of an emergency, in the event that they lose visual communication with the vehicle, or in the event that the maximum number of passengers allowed is exceeded; • The maximum operating speed is set to 25km/h. The procedure for granting the licence to operate is broken up into two discrete sub-periods, which are as follows: • the testing phase, during which there shall always be an operator on board who is able to perform emergency braking; • the operating time, during which, under certain circumstances, the operator may be moved to a remote control center.
	Main organizations in charge: Greek Ministry of Transport, Infrastructure and Networks

Italy	According to the Decree 28/2/2018 issued by the Ministry of Infrastructures and Transport, a Ministry authorization is required in order to test autonomous vehicles on public roads [33]. The authorization is only valid while the test is being conducted inside of the stated testing region. In order for vehicles to pass inspection, they need to be able to record comprehensive technical data at a frequency of at least 10 hertz. Testing is permitted so long as the vehicle supervisor satisfies a list of prerequisites, stays in the test vehicle at all times, and maintains a state of readiness to respond to any potential hazards. The certification of a new transportation system is something that a local authority, such as a municipality or the authority responsible for the infrastructure, shall request from the fifth division of the Italian Ministry of Transport. For the purpose of conducting a risk assessment research, it is necessary to compile a dossier in accordance with the EN 50126 technical standard. The technicians of the Ministry will add their views and suggestions to the project, which will then need to be adjusted properly. When they are satisfied, a commission of national specialists reviews the dossier and gives a temporary certification to operate in dry run mode. This commission is generally chaired by a high ranking official of the Ministry, such as a vice minister or someone along those lines. The results of the dry runs are reported, and if they are successful, the certification to open to the public is granted.
	Main organizations in charge: Ministry of Infrastructures and Transport
Luxembourg	To conduct a CAM trial on public roads it is necessary to Make a formal application to the Ministry of Sustainable Development and Infrastructure in Luxembourg, including the following information [34]: • A report of a technical service for non-type approved vehicles and the original certificate of conformity for type approved vehicles with any modifications made to the vehicle;

	• A description of any error prevention procedures that have been implemented; • An explanation of the technique for entering the safe state in the event of any errors; • The route that was intended to be taken for the trip; • The anticipated duration of the trip in hours; • Documentation regarding the training that the driver of the vehicle received; • A technical assessment of the vehicle will be carried out by the Société Nationale de Circulation Automobile in order to confirm that none of the alterations pose any potential threats to safety, and a report on the inspection's findings will be sent to the Ministry; • In the event that the Société Nationale de Circulation Automobile does not identify any technical problems and that all other provisions are satisfied, the Ministry will provide a permission for the period of time that has been specified; • Throughout the entirety of the trip, the car is required to have a label that reads "Essai scientifique" affixed to either the front or the back of the vehicle.
	Main organizations in charge: • Ministry of sustainable development and infrastructure Luxembourg • Société Nationale de Circulation Automobile
Poland	The procedure for testing automated vehicles was included in the Act on Electromobility and Alternative Fuels (Dz. U. 2018 poz. 317), which provides an update to the Traffic Law Act. This law was passed in Poland in 2018. According to the documentation available, the testing can take place if and only if certain safety constraints are met, as well as if the relevant testing authorization is obtained [35]. The permission can be obtained from the authority responsible for road control. It is granted on the basis of the formal application, which needs to include the following information in order to be considered valid: • The applicant's name, including their surname, as well as the name of their company and their address; • Information on the location of the test, including the beginning and ending dates; • The planned testing route; • A list of the people responsible for securing the testing route;

	• The signature of the person in charge of organizing the test. A copy of a professional vehicle registration should also be attached to the permit in addition to the following: • A confirmation of signing a compulsory liability insurance policy on the possible damages incurred during the test; • A confirmation of paying the insurance fee; • A copy of the insurance policy By posting the application on its website for a predetermined amount of time, the organization responsible for road supervision facilitates public conversations with the surrounding community (not shorter than 7 days). An objection can be lodged by the owner of a structure or plot of land that is situated along the proposed testing path. After receiving the positive decision of the relevant road supervisory entity and the opinion of the Voivodeship police commander about the potential testing disruptions on traffic flow and safety, the final permit is given. During the testing, the organizer of the tests is obliged to: • Provide the Police with the possibilities to ensure the traffic safety, life and health protection of people and property; • The person in charge of organizing the tests has a responsibility to submit an official report to the organization in charge of transportation technical supervision no later than three months following the conclusion of the tests; • The report is required to be formatted in accordance with the template that was presented in an applicable Ordinance issued by the Minister of Infrastructure.
	Main organizations in charge: • Voivodeship police commander
Spain	The purpose of Instruction 15/V-113 is to create a framework for the regulation of the granting of special authorizations for testing and research tests that are carried out on roads open to general traffic using automated vehicles with an SAE L3 rating or above. Before granting an exemption, the instruction stipulates a number of standards that shall

	be met about the vehicle, the driver, and the application [36]. These requirements are as listed in the following. • A current insurance policy; • A proof that they have satisfied basic standards of both safety and performance, including an examination on a test track; • An independent and accredited laboratory is required to carry out the tests in order to determine whether or not the vehicle satisfies the safety criteria; • Driver qualifications should include a current and valid driver's license for each individual driver. Even if they are not physically present in the cabin at the time of the request, they will be liable for driving and controlling the vehicle in accordance with the request; • The applicant is required to provide proof in the form of a statement of responsibility that the driver is familiar with or has been trained in the operation of the automated vehicle; • It is essential to have at least one person behind the wheel of the car at all times; • The applicants need to meet the eligibility requirements (be they OEMs, Tier1s, researchers, or something else) and supply the documentation that is needed in the instructions. This paperwork, among other things, has to describe the cars that are being tested as well as the description, location, and schedule of the tests that are desired; This license is good for a period of two years after it has been issued, and it can be used anywhere within the DGT's jurisdiction. Any driving that takes place outside of the specified testing zones should be completed in manual mode.
	Main organizations in charge: • General Directorate of Traffic

5.3.2. Extra-EU

Table 4 summarizes the policies and regulations of a few extra-EU countries which are at an advanced stage of CAM testing, deployment and commercialization. By providing a global perspective of the differences, challenges and opportunities concerning CAM policies in other countries, 5G-MOBIX aims at fostering discussions on the topic between national and EU regulatory bodies.

Table 4: Regulations and policies in extra-EU countries actively involved in CAM trials and development.

Country	Policy
China	In accordance with the law of the People's Republic of China that currently in effect, the testing of CAVs is permitted on public roads in China. However, the road testing for CAVs is restricted to specific areas of regular public highways that are chosen by the competent departments and notified to the public [37]. In addition, road tests for CAVs should comply with numerous stringent regulations, including (but not limited to) the following: • The test applicant shall be an independent legal person registered in the PRC that is capable of manufacturing, research and development, and testing of CAM-related vehicles and components • The test applicant should also have sufficient financial capability to make civil compensation for likely personal or property damages caused by CAM tests; • The test applicant shall be capable of conducting distance-monitoring, recording, analysis, and reproduction of the tested CAVs • There shall be personal qualification requirements placed on the test driver; • There should be technical requirements placed on the tested • A formal application for road testing, which needs to be accompanied by extensive documentation including proof that the CAV being tested is covered by insurance for more than RMB 5 million.
	Organization in charge: • Ministry of Industry and Information Technology • Ministry of Public Security • Ministry of Transport
Japan	On public roads, testing of automated driving systems may take place in accordance with the Guidelines for Public Road Testing of Automated Driving Systems, another procedure

	that does not comply with the Guidelines, always with the preliminary advice of the police or a combination of both of these [38]. The following are the fundamental requirements for carrying out these tests: • The driver should always be able to operate the vehicle; • The driving session should meet the rules of the Road Traffic Act; • The Safety Regulations for Road Vehicles (Ministry of Transport Ordinance nr 67 of 1951) are met by the test vehicle. A substantial amount of driving testing should first be carried out in test facilities before it may be undertaken on public roads. • Testing on public roads should begin in an environment where there are relatively few elements that cannot be anticipated; • Implementing Entities are obligated to conduct a pre-trip inspection of the traffic conditions on any public roads they intend to use; • In order to properly supervise the autonomous driving systems, there needs to be a second person present in the test vehicle; • The test driver is required to possess the valid driver's license that corresponds to the used car being evaluated; • The test driver is solely responsible for all aspects of legal driving; • The individual is not required to handle the steer but is expected to monitor the traffic in the surrounding area; • The individuals or organizations that are responsible for the planning and execution of public road testing are referred to as "implementing entities"; • They need to establish a plan for testing public roads and take appropriate precautions to protect everyone's safety. In addition, the entities in charge of implementation are responsible for the following: • The required qualities of the test driver; • An appropriate level of cybersecurity when testing on public roads; • The recording of various data regarding driving and the condition of the vehicle; and the required qualities of the test driver. Public highways, as specified in article 2(1)-1 of the Road Traffic Act (= statute nr 105 of 1960), and private testing facilities are both acceptable options when it comes to testing infrastructure.

	Organizations in charge: • National Police Agency • Ministry of Land, Infrastructure, Transport and Tourism
South Korea	The Ministry of Land, Infrastructure, and Transport of the Republic of Korea, which is the government agency in charge of the regulation of motor vehicles, has the authority to designate testing zones after examining proposals submitted by local governments [39]. Within these testing zones, a variety of restrictions that normally need to be followed in order to operate an autonomous car in Korea will not be enforced. This is because the Act on Motor Vehicle Management is the law that regulates the safety of motor vehicles in Korea. In addition, the Ministry of Land, Infrastructure, and Transport of the Republic of Korea has the authority to designate some public roads as "safety zones" for CAVs. Continued investment in infrastructure such as road facilities and ITS which support CAM, is intended to make such safety zones more reliable in the future. If market participants in the autonomous vehicle industry first anonymize and process any personally identifiable information collected into non-personally identifiable information, then the collection and use of big data would be exempted from the laws aiming at protecting privacy, such as the Act on Personal Information Protection. The Ministry of Land, Infrastructure, and Transport amended the Rules on the Performance and Standards of Automobiles and Automobile Parts (the "Safety Standards") in order to implement new safety standards for autonomous vehicles on the 31st of December, 2019, prior to the enactment of the Automated Vehicles Act. On January 1, 2020, the amended laws that are relevant to SAE L2 went into effect. Although the Act on Motor Vehicle Management, which is a statute that governs the Safety Standards, already contains a provision that conceptually defines a 'autonomous vehicle,' the amended Safety Standards introduces the definition of 'autonomous driving system,' which encompasses all equipment, software, and other devices that are directly related to autonomous driving. In addition, the Safety Standards adopt the concept of an operable area (similar to the Operational Design Domain outlined in SAE J3018). According to this concept, the OEM is required to designate a particular area in which the CAV system can be operated normally

	and safely. The Safety Standards do not, however, impose a requirement on such a producer to advice customers of the area in which the product can be operated.
	Organization in charge: • Ministry of Land, Infrastructure and Transport
US	The regulatory framework for testing CAM on public roads in the United States does not follow a uniform standard throughout all of the states [40]. There are certain states in which the governor has issued executive directives concerning autonomous vehicles. In the following, we list the main • **California**: the first protocols for testing autonomous vehicles were developed after the Bill 1298 in the year 2012. Other laws detail the authority of law enforcement agencies to confiscate autonomous vehicles that have been wrongly licensed, the authority of local municipalities to levy special fees on driverless taxi services, and a variety of other aspects that are associated with autonomous vehicles. • **Colorado:** The state of Colorado has passed legislation that lays out the legal standards for automated driving systems and specifically enables citizens to drive self-driving cars, providing that such vehicles conform to the laws of both the state and the federal government. • **Florida:** in 2012, it became the first state to enact legislation that would allow for the safe testing of technologies related to self-driving cars. Additionally, the legislation made it clear that the state of Florida does not prohibit the testing or operation of autonomous vehicles in any capacity. Later legislation that was passed in 2016 expanded on this overarching concept and even prepared the path for the testing of fully automated vehicles that did not require the presence of a human driver. • **Kentucky:** Although Kentucky has a law that regulates autonomous platoons of commercial vehicles, the state does not have any legislation on the books that pertain to self-driving cars that are not used for business purposes. Because of this, there is currently no law that expressly prohibits self-driving cars. • **Nevada:** In certain situations, it should be illegal for a person to use a portable wireless communications device or a cellular phone while they are behind the wheel of a motor vehicle. The bill should also include provisions for sanctions and any other issues that are pertinently related to the issue.

	• **Pennsylvania:** The state of Pennsylvania does not have any rules that apply to autonomous vehicles used for non-commercial purposes. There have been two laws issued that are related to autonomous vehicles. One of these laws allots funds for the development of autonomous vehicle technology, while the other law defines the parameters for platoons of commercial vehicles that operate autonomously. • **Texas:** has passed legislation that not only specifies a range of terminology related to autonomous vehicles but also makes it clear that the operation of self-driving vehicles is not illegal in the state. The legislation also prohibits local governments from passing laws against self-driving vehicles and allows for the use of completely autonomous vehicles—vehicles that have no human operator at all—under certain conditions. However, these provisions are only applicable in certain settings.
	Organizations in charge: • Department of Transportation • National Highway Traffic Safety Administration • Each respective Federal State

5.3.3. Conclusions

As highlighted by Table 3 and Table 4, regulations and policies adopted by governments with regards to testing and trialing of (5G for) CAM appear extremely fragmented and heterogeneous not only around the world, but also within the EU, in particular for what concerns high level of automation for CAVs.

Since 2019 the European Commission has passed a number of relevant implementing regulations that address the various driver assistance measures that were included in the General Safety Regulation. Along with the publication of the EU's strategy on automated mobility, the Commission's proposal for the revised General Safety Regulation was also released at the same time. This strategy outlines a comprehensive set of actions that the EU is planning to take in order to facilitate the deployment of CAM systems. These envisioned steps including the deployment of important technology and infrastructure, putting in place the appropriate legal framework for the EU internal market, and ensuring that automated mobility offer considerable benefits to the population of Europe, such as road safety, better access to mobility, lower greenhouse gas emissions, etc.

The European Commission plans to adopt technical rules for automated and connected vehicle based on the General Safety Regulation. These rules will focus specifically on automated vehicles that replace the driver on highways (SAE L3), as well as on fully driverless vehicles such as urban shuttles or robotaxis (SAE

L4). Before fully automated vehicles may be sold in the EU, they will need to be first evaluated thoroughly for their level of maturity and safety in accordance with the established technical rules encompassing testing processes, regulations for cybersecurity, rules for data recording, as well as requirements for monitoring the safety performance of completely driverless vehicles and reporting incidents by manufacturers.

In Europe, there have been significant efforts to promote interoperability and harmonization of CCAM technologies. The European Commission has established several initiatives to promote the development of CCAM, including the European Green Vehicles Initiative and the European Truck Platooning Challenge. Additionally, the European Union has set up the European Data Task Force to develop a common data sharing framework for CCAM technologies.

In China, the government has made significant investments in CCAM technologies, with a focus on developing intelligent transportation systems and promoting the adoption of electric vehicles. In 2018, China established a national-level intelligent connected vehicle (ICV) industry innovation center, which aims to accelerate the development and deployment of CCAM technologies in China.

In South Korea, the government has also invested in CCAM technologies, with a focus on developing advanced driver-assistance systems (ADAS) and autonomous vehicles. In 2020, the Korean Ministry of Land, Infrastructure and Transport launched a project to test self-driving cars on public roads in Seoul and other major cities in South Korea.

While there are some differences in the approaches taken by each region, there are also efforts to promote interoperability and harmonization of CCAM technologies. For example, the EU-China Cooperation on Intelligent Transport Systems (ITS) has been established to promote the exchange of information and expertise in the field of CCAM. Additionally, the Korea-EU Joint Research Center has been established to promote joint research and development of CCAM technologies between South Korea and the EU.

6. CONCLUSION

International cooperation has been a key asset for an impactful completion of the 5G-MOBIX project. Since its launch in 2018, 5G-MOBIX has been actively promoting its results to international key actors in the public and private sectors and the automotive and telecommunications industries, with the aim to strengthen cooperation in key fields such as automation, interconnection, transportation information service, intelligent city transportation, etc.

To stimulate long-term EU and global cooperation and innovation initiatives, 5G-MOBIX has been facilitating the exchange of knowledge and experience between 5G industry and V2X industry researchers in the EU and beyond via dedicated events and dissemination of results both online and offline. The deliverable presents international organizations of interest for the activities and vision of 5G-MOBIX, with which exchanges were established during such international events.

Finally, the deliverable looks into the regulations and policies in the EU and abroad regarding CAM trials and commercial adoption, highlighting that, despite being a mature technology, highly diverging views on 5G for CAM, for both trials and commercial deployment, coexist in different EU and non-EU countries. Given the complexity of harmonizing the communication between different national bodies, MNOs and vendors, the lack of a harmonized regulatory framework at an international level is especially affecting cross-border scenarios.

However, while there are some differences in the approaches taken by Europe and other regions, namely China and South Korea, there are also efforts to promote interoperability and harmonization of these technologies. This is important for ensuring that CCAM technologies can be deployed and used seamlessly across different regions, promoting their widespread adoption and maximizing their potential benefits.

Having shown the clear benefits of international cooperation, we recommend European countries to keep working closely on both technological/operational aspects of 5G for CAM, as well as jointly converging on regulations and policies to speed up the adoption of this technology which is essential for the future of a seamless mobility that takes full advantage of what 5G technologies have to offer.

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ANNEX I – CONTRIBUTION TO IEEE INDUSTRY NEWSLETTER, JORGE M. PEREIRA, EUROPEAN COMMISSION

5G FOR CONNECTED AND AUTOMATED MOBILITY (CAM) IN EUROPE: TARGETING CROSS-BORDER CORRIDORS

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(THE OPINIONS HEREIN ARE THOSE OF THE AUTHOR, AND DO NOT REFLECT ANY OFFICIAL POSITION OF, NOR DO THEY COMMIT, THE EUROPEAN COMMISSION.)

ABSTRACT

Confronted with the patchy, slow deployment of 4G in Europe, the European Commission (EC) President Jean-Claude Juncker recognized that, in spite of being strong in research, Europe "needs a more aggressive infrastructure roll-out". He called for coordinated action "to make 5G a reality for all citizens and businesses", to reap the benefits that would accrue and achieve the European Digital Single Market. However, coverage of sparsely populated areas, in particular rural ones and those near the borders, remains a challenge. Similarly, Connected and Automated Mobility (CAM) adds taxing real-time requirements. By focusing on these exacting scenarios, aiming at continuity of service across the continent, and addressing the broad scope of issues involved, which go well beyond technology, we are aiming for large-scale deployment across Europe as early as 2025.

INDUSTRIAL POLICY, DE FACTO

Europe certainly played a driving and leading role in the development of 4G, but its deployment in Europe sputtered, suffered considerable delays and ended up putting Europe at a disadvantage relative to its competitors in the world scene. In his 2016 State of the Union address [1], the European Commission (EC) President Jean-Claude Juncker (2014-19), set as an objective "to fully deploy 5G, the fifth generation of mobile communication systems, across the European Union (EU) by 2025."

One of the main benefits of 5G is the "mutualization" of costs between various services and sectors using the same basic infrastructure, improving the overall economic case. A preparatory socio-economic study [2] had identified millions of jobs and billions of euros of benefits arising from 5G deployment. Concretely, investments of approximately 57B€ are likely to create 2.3 million jobs in Europe, and benefits from the introduction of 5G capabilities could reach 113B€ per year in four key sectors (automotive, healthcare, transport and utilities) alone.

This has been recently confirmed by an Ericsson study on 5G for business [3]. Namely, 5G-enabled 1.5 trillion USD in revenue are forecast to be captured by 5G in 2030, including 700 billion USD of new, additional revenue streams beyond enhanced-mobile broadband (eMBB).

In the context of the 2016 Telecom Package, the EC set two important, closely related goals: the Gigabit Society [4] and 5G for Europe [5]. In fact, 5G requires broadband, namely pervasive fiber availability, but can also competitively provide broadband.

The 5G Action Plan aimed at full deployment by 2025, in particular everywhere people live and pass by: all urban areas as well as all major transport paths should have uninterrupted 5G coverage. The objective is to accelerate deployment in those areas where the market would be too slow to act, but not in urban areas where the market is expected to deliver full coverage through strong competition. Focusing on Cross-border sections of Trans-European Transport Network (TEN-T) corridors, mostly in rural, less populated areas, does make sense. In fact, in the context of the 2018 Mobility Package, while setting the EU Connected and Automated Mobility (CAM) vision, the CAM Communication [6] called for working with Member States and stakeholders toward large-scale testing and pre-deployment of 5G cross-border corridors[1], addressing these challenging deployment scenarios while fully taking into consideration 5G licensing coverage conditions and local deployment constraints.

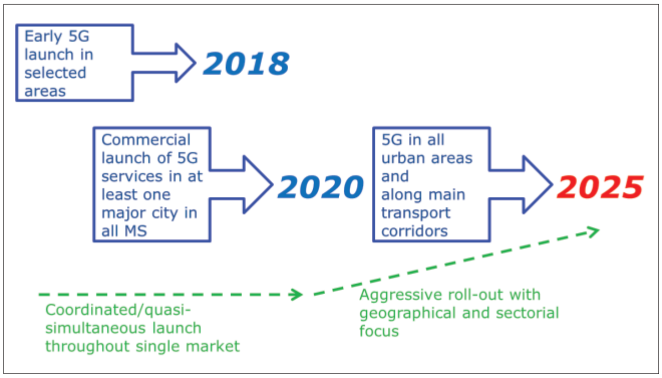

FIGURE 1. Committing to coordinated EU-wide deployment.

The communication sets out the requirement for seamless roaming of CAM services, on top of other data services, including eMBB and IoT. Some critical CAM services require real-time connectivity, so best-effort is not enough! Unfortunately, the majority of current deployments was not designed with that in mind. Furthermore, uninterrupted coverage of sparsely populated areas to deliver high data rate (in the order of Mbit/s per vehicle) and Ultra Reliable, Low Latency (URLLC)-type services (sub-1ms delay) will require dense deployment of cells with the supporting fiber infrastructure along at least the major highways, not to mention close proximity to Multi-access Edge Computing (MEC) resources.

This fiber deployment will be extremely expensive[2], and it is difficult to see return on investment. On the funding side, co-investment by relevant stakeholders seems essential to share the burden. On the connectivity side, solutions like (various degrees of) infrastructure sharing, potentially extending to the MEC, as well as national roaming[3], are being considered.

R&D WITH A TRIAL FOCUS

The European Horizon 2020 (H2020) program was the framework for R&D in the period 2014-20[4], with 80B€ of EU-funding for a broad scope of activities. To address 5G, the EC established a 5G Public-Private Partnership (5G PPP) [7], with 700M€ EU-funding, with the 5G Industry Association (5GIA). The 5G PPP brings together a broad range of stakeholders from the communications technology sector and from its extended value chain including the user communities and actors from the microelectronics and IT sectors. 5G PPP is open to international participation, and was structured in three phases, from core technologies to proof-of-concept to trials involving verticals, and namely CAM. It includes as well research on long-term evolution beyond-5G.

In Europe, there is a long-standing tradition of experimentation for testing and validation of technologies, services and applications [8]. The realization that end-to-end systems are now too complex, too heterogeneous, too "connected" to be analyzed or even simulated, and that therefore they need to be "prototyped" to be tested and validated, led to the launch

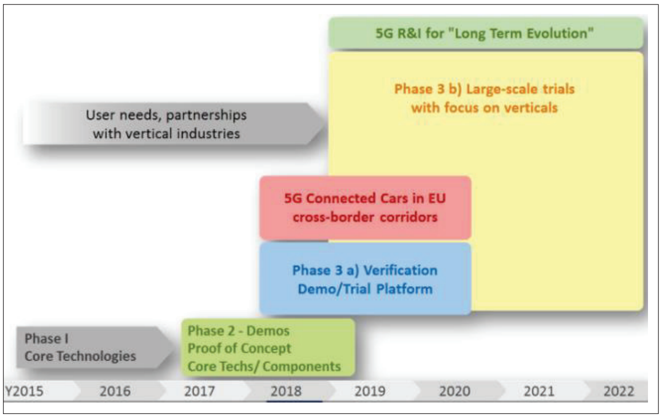

FIGURE 2. 5G PPP three-phase structure.

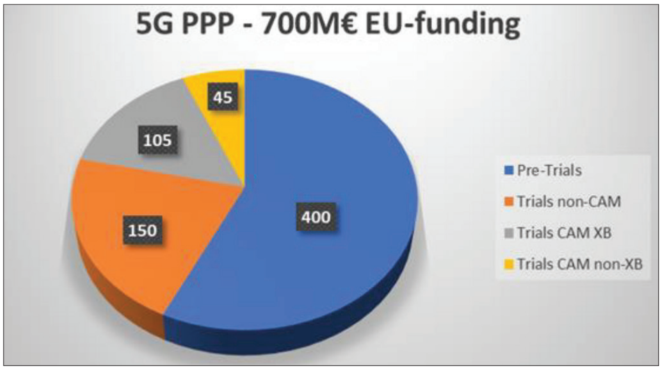

FIGURE 3. Funding allocation in 5G PPP.

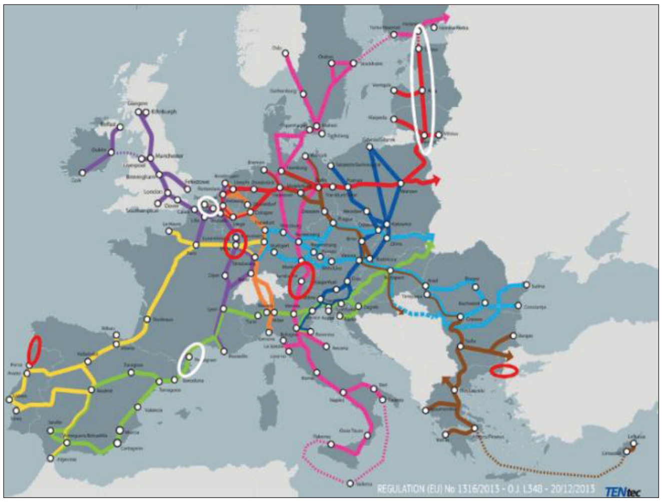

FIGURE 4. Cross-border Corridors in the TEN-T network (first CAM call in red, second CAM call in white)

of experimentally-driven research with over 200M€ funding under Future Internet Research and Experimentation (FIRE) [9,10], moving from experimental platforms and facilities to open experimentation, even remote, on top of them.

End-to-end, and even individual (sub-), systems need to be experimented with in the real world, under real conditions, with real traffic/loads and real users [11]. Also quite pragmatically, no one, not even the largest corporations, can afford to assemble, much less operate, the "entire" system to be able to test/assess their solutions, developments, and improvements.

5G PPP built upon this approach, calling first for demonstration and trial platforms, and then for trials on top. For CAM, the approach was slightly different, as the "platform" is actual infrastructure in specific sections of a corridor, with unique characteristics. It is important to understand the amounts engaged, reflecting the political importance of the different areas. From the 700M€ envelope of the 5G PPP, the Commission reserved 300M€ for trials (43 percent), with around 150M€ of these for CAM (50 percent), of which 105M€ is specifically for cross-border corridors.

5G for CAM Cross-border Corridor Projects

In support of the 5G for CAM political priorities, the EC launched two calls targeting cross-border corridors, with 105M€ EU-funding. The aim was concretely to engage the constituency, identify gaps, create consensus, propose solutions, and, most importantly, test and validate in the field. By addressing stringent "boundary" conditions, they will identify and resolve problems, both technological and institutional, offering solutions with repercussions on 5G at large, empowering and accelerating novel advanced services and applications [12].

A first 5G for CAM call was launched end-2017; the objective was to "identify the problems and barriers and provide a blueprint toward 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."

Three cross-border corridor projects with 63M€ EU-funding were selected and launched in November 2018:
- 5GCroCo: Metz (FR) - Luxembourg (LU) - Saarbrücken (DE) triangle [13]
- 5G-CARMEN: Brenner corridor: Munich-Innsbruck-Bologna (DE-AT-IT) [14]
- 5G-MoBiX: Porto (PT) - Vigo (ES) and Thessaloniki (EL) - Istanbul (TR) corridors [15]

The involved corridor segments are quite distinct, stretching over 1000km of highways, and crossing eight borders.

A second 5G for CAM call was launched in 2020, aiming both at automotive and rail cross-border corridors. Three projects, mainly with a road transport focus, were selected and launched in September 2020:
- 5G-Blueprint - North Sea corridor (BE-NL) [16]
- 5G-ROUTES - Baltic corridor (FI-EE-LV-LT) [17]
- 5GMED - Mediterranean corridor (ES-FR) [18]

A fourth one, focusing on rail, was launched in November 2020: 5GRAIL [19]. Their total EU-funding was 42M€. The seven projects above aim at demonstrating 5G-enabled advanced CAM use cases in the field, in actual cross-border segments. They also illustrate well the variety of corridor scenarios across Europe.

Other Relevant Projects

Besides the above projects focusing specifically on cross-border corridors, a number of 5G PPP phase-3 projects address, at least to some extent, CAM-relevant issues, some of them covering rail aspects. The EU-funding associated with the focus on Mobility in general (persons and goods), on Logistics, and also on Ports, is approximately 45M€. The projects cover mainly technological aspects and a few address application aspects and platforms for service provision. Non-exhaustive examples [20] are: 5GCAR, 5G-DRIVE, 5G-HEART and 5G-IANA (CAM); 5G-PICTURE and 5G-VICTORI (Rail); VITAL-5G and 5G-Loginnov (logistics); 5G-MoNArch and 5G Solutions (ports).

Achievements and Contributions

Even if affected by COVID-19 confinement measures across Europe, the identification and characterization of currently deployed infrastructure and connectivity, the solutions implemented and their assessment, the lessons learned, and the sys-

Technological	Telecom/Network issues - 5G Radio, Core and MEC; 3GPP releases and equipment
	Road Infrastructure/ Road Operator - instrumentation and ITS functionalities
	Automotive issues - Equipped and legacy vehicles; Various levels of automation
Business Models	from Competing to Cooperating
Legal and Regulatory	from GDPR to access to data across borders
Security and Privacy	
Reliability and Availability	
Liability	

TABLE 1. Challenges toward deployment of CAM.

Development	Flexible, adaptable and evolutionary
	with very high level of cybersecurity
Must provide	Boundless connectivity
	Continuity of service across borders, across MNOs, across vendors/OEMs, across service providers, as well as across traffic managers and road operators
Relies upon	Cooperative planning
	Coordination with public authorities and relevant private actors
	Multi-service/multi-application platform using standardized specifications and/or data interfaces

TABLE 2. Shared vision for 5G CAM infrastructure.

tematic testing in the field of various CAM use cases, constitute unique contributions to the advancement of 5G for CAM. The 5G PPP white paper on 5G CAM Trials [21] provides a detailed analysis of the achievements thus far of the first CAM call projects. They started by identifying challenges toward deployment, which go beyond technology, telecommunications, and even equipment.

Driven by the objective of delivering cross-border demonstrations, the first priority was to investigate continuity of service across borders. Understanding the constraints of current and planned network implementations was just the first step. Aspects like cross-border connectivity breakouts, inter-operator agreements and the need for close-by MECs become critical. Equally critical is conjuring the necessary investments in infrastructure extension and upgrade. It is a difficult, complex challenge, and certainly specific of the border scenario under consideration. Funding agencies will need to be involved.

The projects addressed cooperative business models to enable and even drive the necessary investment. By identifying market failures and technical requirements, specifically in cross-border regions, their work informed a recent 5GAA white paper [22]. They have also addressed the need for institutional support from National and Regional authorities, to facilitate deployment: coordinating with authorities across the border, reducing bureaucracy and, where applicable, providing access to public infrastructure and right-of-way.

Finally, keeping in mind that the end game is large-scale deployment, the projects contributed decisively to the 5G PPP 5G for CAM Strategic Deployment Agenda (SDA) [23]. The work was done in the context of the 5G PPP automotive working group, involving also other relevant projects, namely those dealing with V2X, and in cooperation with key stakeholders such as the GSM Association (GSMA) and the 5G Automotive Association (5GAA).

The SDA aims at accelerating and maximizing investment, both public and private, by:
- Defining deployment priorities and roadmaps,
- Identifying appropriate cooperation models and investment strategies
- Advising on most suitable regulatory incentives

with a view toward maximizing societal benefits[5], and concretely toward accelerating the digital transformation of upstream and downstream industries.

Key Drivers for accelerating infrastructure rollout were identified as: Standards; Spectrum; Network slicing; Regulatory innovation; Access and data sharing; and Cybersecurity. On the other hand, in order to retain economic competitiveness at a global scale, the political driver behind the decision to deploy 5G for CAM across Europe, we need to shape a complex CAM ecosystem involving all relevant stakeholder communities, reflecting the need for a system's approach on an EU level. Here is where the need for synergies with other EU policies and mechanisms becomes important.

Articulation with Other Policies

A specific element of the Gigabit Society is the provision of extremely high data rate connectivity to all "main socio-economic drivers (SED)", such as schools, universities, research centers, transport hubs, hospitals, public administrations, libraries, museums, business parks, and enterprises relying on digital technologies. The idea is now to provide wireless broadband connectivity to SEDs and surrounding areas under the 5G Communities initiative.

This initiative will expand upon WiFi4EU [24], a 130M€ initiative (2018-20) to promote access to wireless connectivity for citizens and visitors in public places via free public Wi-Fi. The funding came mainly from the Connecting Europe Facility (CEF) Telecom program. It operates via a system of 15.000€ vouchers per qualifying municipality.

Obviously, the broadband infrastructure needed to provide service to SEDs in remote/rural, low population density areas will be of good use to provide CAM to the crossing transport paths (roads, railways and waterways). To render more economical, and ultimately feasible, the coverage enhancements to deliver both CAM and connectivity to SEDs, exploiting this synergy is critical [25].

Another important focus, arising already under the Ursula von der Leyen Commission, spearheaded by Commissioner Thierry Breton, has to do with European data spaces [26,27]. Here again, the synergies with the investments to bring MEC closer to the borders to enable CAM service continuity is of paramount importance; in fact, many such facilities could in principle be shared with, or made available to, operators, and, conversely, operators could open their MECs to other uses and players, with all necessary security and isolation caveats.

Next Steps

From large-scale testing and pre-deployment in H2020, we now need to move toward large-scale deployment, in the context of CEF2-Digital. In March 2019, the Council and Parliament provisionally agreed on a Regulation to extend the Connecting Europe Facility (CEF becoming CEF2) and adapt it to the needs of the Gigabit Society, namely supporting Member States in addressing existing funding gaps with strategic projects.

The main objective in the new digital focus, CEF2–Digital, is "to contribute to the development of projects of common interest relating to the deployment of safe and secure very high capacity digital networks and 5G systems, to the increased resilience and capacity of digital backbone networks on EU territories by linking them to neighboring territories, as well to the digitalization of transport and energy networks."

The European Commission proposed, in this context, a major public financing support action for accelerating private investments in 5G infrastructure along sections of TEN-T corridors known as "5G Corridors", to enable 5G for CAM solutions. The focus will be put on cross-border and "challenge" areas, in support of growth and cohesion and for a better integration of the Digital Single Market.

It is expected that EU-funding for the 5G corridors will amount to 0.9B€, a significant part of the 2B€ proposed by the Commission for CEF2-Digital. This represents an almost one order of magnitude increase relative to the preparatory work in H2020, even more if one considers other sources of funding, at regional, national and EU levels.

In what concerns R&D, a Smart Networks and Services (SNS) partnership [28] has been agreed in the context of the Digital, Industry and Space cluster, of the Global Challenges and European Industrial Competitiveness pillar of Horizon Europe [29], with 0.9B€ EU-funding to continue work on 5G evolution, with a longer-term focus on 6G. 5G Corridors will be implemented in coordination with SNS, which will also articulate with the Digital Europe Program [30] (in areas like Artificial Intelligence and Cybersecurity), structural funds and InvestEU [31].

Conclusions

Challenges as well as gaps, technological and otherwise, have been identified and are being addressed by a number of 5G for CAM cross-border projects with substantive funding. A broad constituency has been engaged, spanning Telecom MNOs; Automotive OEMs; Rail, Ferry, and Road operators; as well as as Local, Regional and National authorities. A number of solutions have been proposed and are being tested and validated in the field, in spite of COVID-19 pandemic restrictions, with a view toward delivering cross-border demonstrations from the second half of 2021.

We are now at a critical juncture, where we need to start planning for large-scale deployments of 5G for CAM in pan-EU corridors. In order to address the variety of challenges involved, including the critical one of syndicating the necessary investments, we need to engage a broad ecosystem. Only so will we be able to deliver on the promise of CAM for all.

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Biography

JORGE M. PEREIRA has been with the European Commission since September 1996, becoming Principal Scientific Officer in 2005, dealing with ICT Research and Policy, covering a broad variety of areas, with a focus on networking, devices, applications and services, testing and validation, as well as deployment. Since 2016, he has been in the Future Connectivity Systems unit, focusing on 5G and beyond. He is responsible for the areas of Advanced Spectrum Management; Optical/Wireless Convergence; Connected and Automated Mobility (CAM); and Public Protection and Disaster Relief (PPDR). Prior to that, he was responsible for re-structuring the area of Future Internet Research and Experimentation (FIRE). He is a Member of the IEEE, where he is an associate editor for Mobile Radio, including Vehicular Communications, for the *IEEE VTS Magazine*, and a member of the IEEE 5G Summit Steering Committee of the IEEE Communications Society. He also served as an associate editor for *ACM Transactions on Sensor Networks*. He has been involved in the organization of major IEEE conferences, namely PIMRC, WPMC, VTC, ICC, ICT, GLOBECOM and 5G Summits in various positions, including TPC, Panel and Special Session co-Chair. He obtained the Engineering and Master degrees in electrical and computer engineering from Instituto Superior Técnico, Lisbon Technical University, Portugal, in 1983 and 1987, respectively. He received the Ph.D. in electrical engineering-systems from the University of Southern California, Los Angeles, in 1993. He received the Industry Achievement Award of the Software-Defined Radio (SDR) Forum in 2003, in recognition of his "outstanding contributions, research and development in the field of SDR", and was inducted as a life-member of the Wireless Innovation Forum. He was inducted in the IPv6 Hall of Fame at the IPv6 Forum Summit in Nanjing, China, in October 2019.

Footnotes

[1] A set of cross-border corridors have been identified to foster large-scale testing and deployment of 5G for CAM, following the letter of intent of 23 March 2017 signed by 26 Member States, plus the UK, Switzerland and Norway.

[2] A 250B€ funding gap has been identified to provide Broadband in rural areas.

[3] National roaming is already enshrined in the 5G licencing conditions of a number of EU Member States, e.g., Germany, at least for new operators, e.g., Portugal.

[4] Many projects will extend into the next framework program.

[5] Namely, Safe ride (zero deaths in road accidents); Efficient ride (reduced travel times; automated driving; no traffic jams; zero pollution); and Connected ride (HD infotainment).

ANNEX II – ETSI IPV6-BASED 5G FOR CONNECTED AND AUTOMATED MOBILITY

ETSI GR IPE 007 V1.1.1 (2023-01)

IPv6 Enhanced innovation (IPE); IPv6-based 5G for Connected and Automated Mobility

Disclaimer

The present document has been produced and approved by the IPv6 Enhanced innovation (IPE) ETSI Industry Specification Group (ISG) and represents the views of those members who participated in this ISG.
It does not necessarily represent the views of the entire ETSI membership.

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Intellectual Property Rights

Foreword

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

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

"**must**" and "**must not**" are **NOT** allowed in ETSI deliverables except when used in direct citation.

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.

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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.

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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.

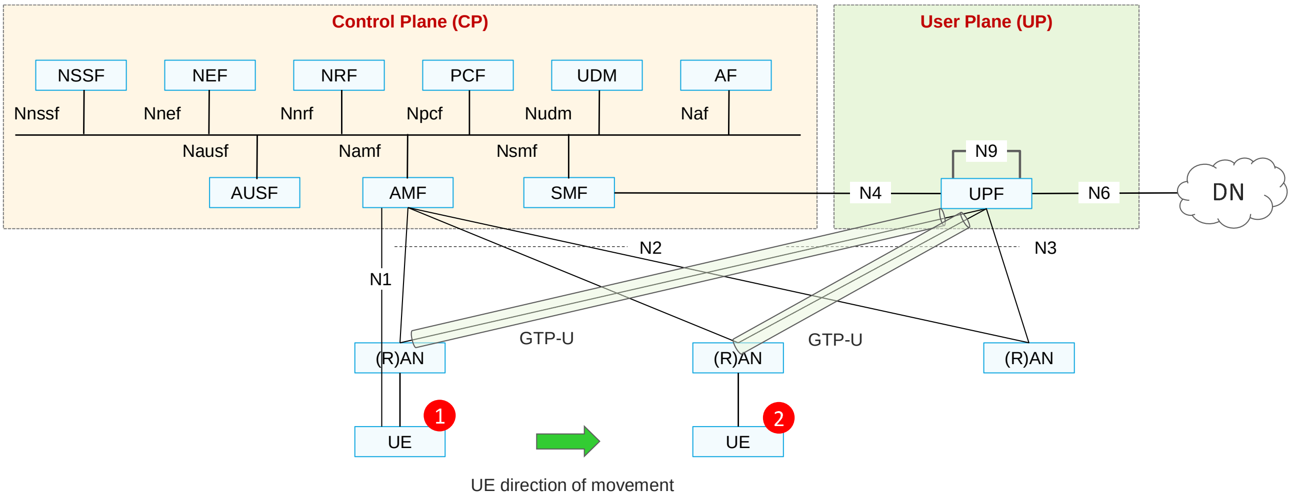

Figure 1: 5G Handover

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.

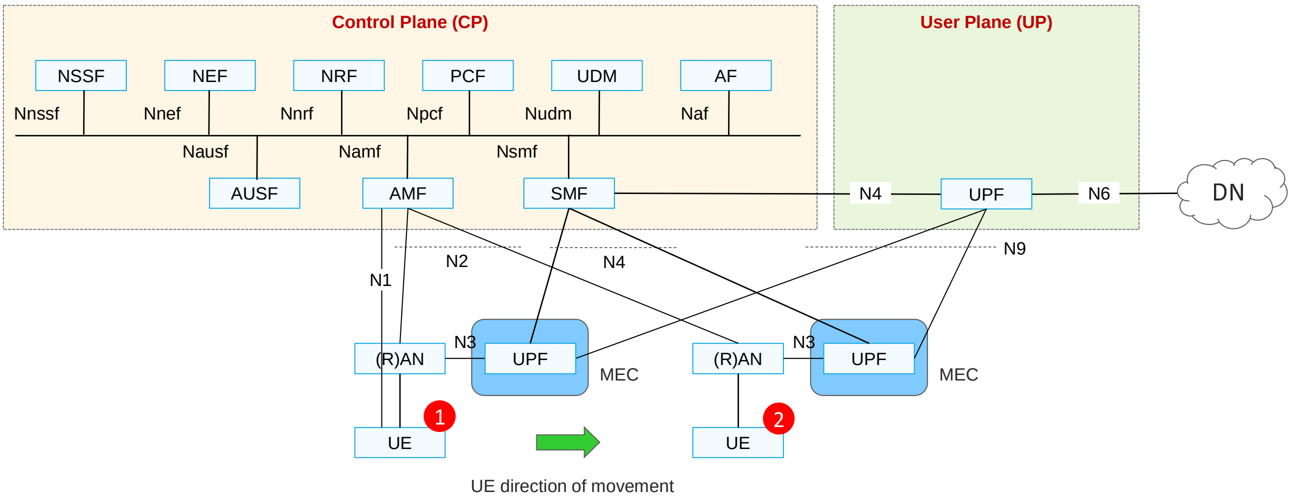

Figure 2: Distribution of UPFs in MEC architecture

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