5G Vehicle-to-Everything (V2X) services in cross-border environments: Standardization and Challenges

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Abstract— **Vehicles will be wirelessly connected in the future and they will be able to exchange information with other vehicles and their surroundings for safer and more efficient driving. 5G communication systems have introduced advanced functionalities and radio solutions to support connected, cooperative, and automated mobility (CCAM) services with demanding Quality of Service (QoS) requirements. However, interoperability among involved stakeholders, seamless connectivity and the uninterrupted delivery of real-time services across borders are issues that should be carefully analyzed for the realization of cross-border CCAM services. This paper provides an overview of key standardization bodies by analyzing recent work on key technologies to provide cross-border connectivity services for CCAM. Standardization gaps and regulatory barriers that may affect fast and efficient adoption of 5G-enabled CCAM services, are also discussed.**

Index Terms—**5G, vehicle-to-everything, V2X, connected and automated driving, QoS, MEC, cross-border.**

I. Introduction

Vehicles of the future will be more automated and wirelessly connected to cooperate with each other and with their surroundings, e.g., road infrastructure, pedestrians, etc. Wireless communication among vehicles can complement the on-board sensors by extending detection ranges even when visual line-of-sight is not available. Wireless communication is important also for cooperative manoeuvres among vehicles. Both features can contribute to safe and efficient driving, especially for higher levels of driving automation, where no or limited human interaction is needed.

Cellular V2X (C-V2X) communication enables the provision of both driving support and other broadband services that create added value for the end users. Connected driving support can be enabled through long-range connectivity, i.e., using the Uu interface between the network infrastructure and the end user equipment, that can bring information and thereby awareness from far away to the vehicle, and through short-range connectivity, i.e., using the PC5 interface between devices without routing data through the network infrastructure, allowing the local exchange of information in the immediate surroundings of the vehicle. Hence, C-V2X removes the limitation of vehicles to only rely on on-board sensor information. However, for reliable and safe V2X communication services, both connectivity and QoS shall be properly predicted so that vehicles can plan ahead, anticipating the future quality of connectivity as well as any potential network downtime periods. In this context, two additional important features leveraged by 5G technology are Mobile Edge Computing/Cloud (MEC), which brings cloud service computations to the edge of the network to enable flexibility and the opportunity to reduce latency when needed, and enhanced accurate positioning to, e.g., protect Vulnerable Road Users (VRUs). It should be noted that in this paper the Mobile Edge Cloud enables Mobile Edge Computing, so the expansion of the acronym depends on the sentence. The "M" should not stand for "Multi-access", since this would point at just one subset of MEC-related specifications i.e., the European Telecommunications Standards Institute (ETSI) ones. "Mobile" is used instead to stress the relation to mobile radio networks as specified by 3GPP.

Due to introduction of CCAM, the business models for the automotive industry are about to change. 5G could be a catalyst

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to enable new features in the CCAM services as well as new value chains. More specifically, the value chains will change from the traditional customer/supplier roles, towards a more dynamic and network-oriented paradigm. For the success of such an evolution and specifically for the faster adoption of V2X, the cooperation between the telecom and the automotive industry can help to address all challenges and open issues of CCAM services.

Overall, the deployment of a complete V2X infrastructure is a complex task with several standardization, regulatory and legal issues that involve various stakeholders (e.g., Mobile Network Operators (MNO), transport authorities, road operators and service providers). The provision of CCAM services across different countries in Europe need harmonized solutions to support cross-border traffic, when vehicles drive through various national borders. There are technical and regulatory challenges due to the need for seamless connectivity and uninterrupted delivery of real-time services across borders. Taking into account the multi-operator, multi-country multi-car-manufacturer, multi-telco-vendor and cross-generation scenario of any cross-border then it is evident that the situation becomes more challenging.

In this paper we present an overview of the current status of key standardizations activities as well as potential gaps (i.e., standardization, regulatory, business and legal) that should be taken into account for the successful realization of 5G-enabled cross-border CCAM services. In particular, in Section 2, we describe the current activity status of related standards and the maturity level of available communications technology. Section 3 dwells on regulation aspects, while section 4 provides a business case perspective. Section 5 concludes the paper.

II. Standardization And Technology Status

From a technical perspective, different entities shall interact to deliver CCAM services enabled by 5G across borders. On a high level, four tiers can be identified:

1) The vehicle tier, which comprises cars and other road vehicles,
2) the network tier, which comprises cellular networks and Intelligent Transportation Systems (ITS) infrastructure,
3) the cloud tier, which comprises clouds that form back-end systems, and
4) the application tier, which comprises applications to support CCAM services.

Figure 1 presents the technical entities, technologies, and standardization bodies that are involved in the provision of 5G-enabled cross-border CCAM services. In particular, it is worth highlighting the following technologies and features which are discussed in this paper:

- Handover between borders and/or MNOs
- MEC
- Slicing and
- Service Continuity.

The current standardization status as well as potential gaps are analyzed in the following.

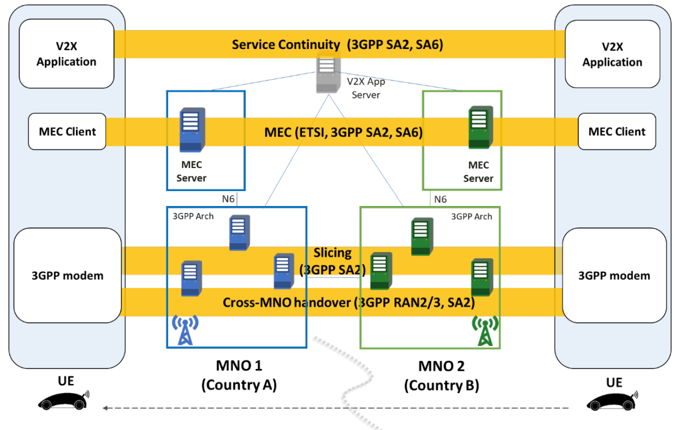

Figure 1. Overview of technologies and entities required to deliver 5G-enabled cross-border CCAM services

A. *Handover across borders and/or MNOs*

Cross-border/-MNO handover, which is called “Inter Public Land Mobile Network (Inter-PLMN) handover”, has been a requirement even for 4G LTE networks. But today’s networks usually do not allow cross-MNO handovers. As it is analyzed below, there is an initial technical solution but the required links for interfaces across MNOs are not in place, mainly due to the introduced complexity since each country has several MNOs that might need to be interconnected. However, it is needed to evaluate the solution as decision basis to deploy the links for cross-MNO interfaces, determine the QoS requirements for these links and also to investigate further enhancements, considering the demanding QoS requirements that many V2X services have (e.g., low latency).

The network that a user is a subscriber to is called home network, while the network to which the UE roams to when leaving the home network, is called visited network. Experience shows that when leaving a country, a user equipment (UE) will stay connected to the network of the previous country (home network) until it is so far away that it loses synchronization to the last serving cell in the home network. For many seconds, or even minutes, radio link quality can be very low making even simple Mobile Broadband (MBB) services and voice calls infeasible. After loss of synchronization, the UE will perform a scan and attach to a new network in the new country (visited network). It will then establish a new connection usually resulting in a new Internet Protocol (IP) address, being served by a different network than the home one. This process is called “roaming”.

Analysis performed for the delay of the registration procedure indicate that this roaming procedure is time consuming and introduces delays in the range of seconds or even longer [1]. The analysis in [1] shows that the attachment latency to a visited network may require few tens of seconds due to the sequential process and the context transfer procedure, while towards the home network it may require up to 9 seconds. The required attachment time can be affected by various factors e.g., roaming agreements, load of base stations or core networks. In a roaming procedure [2], interaction between the Access and Mobility Management Function (AMF) in the visited network, Unified

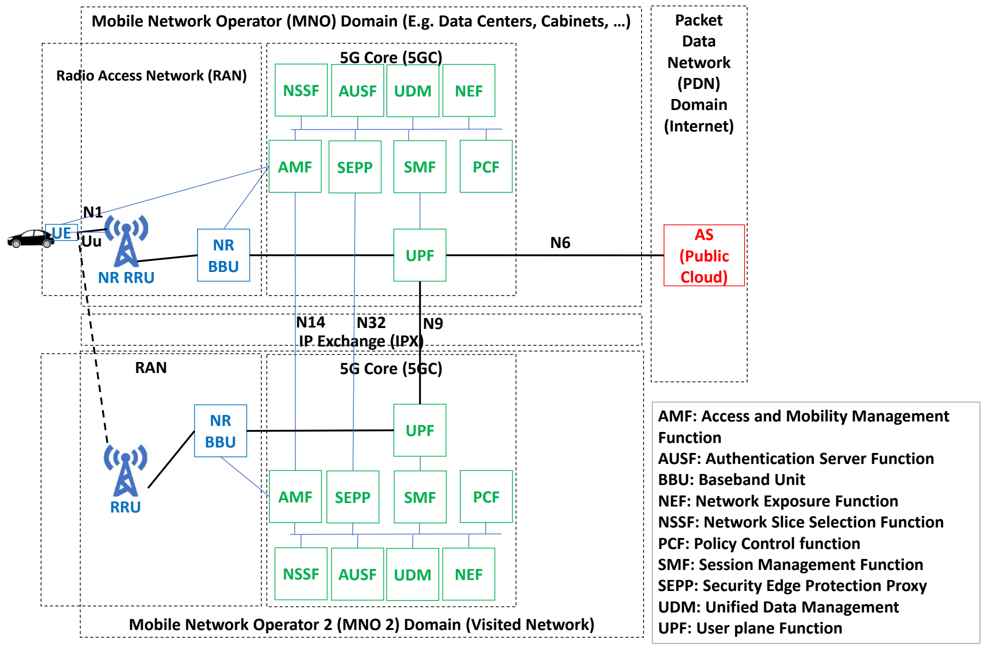

Figure 2. Standalone 5G New Radio home-routed roaming architecture with N14 interface between AMFs

Data Management (UDM) functions in the visited and home networks, and the Policy Control Function (PCF) in the home network is needed. According to [3], the time required to perform a single attachment procedure (without considering roaming delays) is in the range of hundreds of milliseconds (~330 ms), which is unsuitable for many time-critical V2X use cases e.g., cooperative manoeuvres, tele-operated driving that have latency requirements of less than 50ms [4].

In 5G communication systems, local breakout or home-routed roaming schemes could be used to reduce these delays. In local breakout, the user plane traffic is routed directly from the visited network to the data network, while authentication and handling of subscription processes take place at the home network. In home-routed, the visited network user plane traffic is routed to the data network via the home network. Figure 2 shows the home-routed roaming architecture using a standalone 5G core communication system. In 5G, Security Edge Protection Proxies (SEPPs) are used to secure the connection between the home and visited networks.

5G communication systems can enable cross-border / -MNO radio handover by deploying the N14 interface between the AMFs of the involved operators (Figure 2). As a result, same handover procedures as within the same network with AMF change apply. Such a solutions requires agreements between the MNOs and the deployment of particular interfaces. In this case the User Plane Function (UPF) could remain unchanged in order to provide session continuity; however, the details of such operation have to be defined. It should be noted that even in the LTE communication systems the inter-MNO handover can be enabled, by employing the S10 interface between Mobility Management Entities (MMEs), across different MNOs [5].

In any of the two cases, cross-MNO handover using either N14 (5G communication systems) or S10 (in LTE communication systems) aims at keeping session continuity and minimizing interruption time. However, even though this is supported by the 3GPP specifications, to the best of our knowledge, it is not deployed in current 4G or 5G networks, due to the need for interfaces across networks managed by different MNOs. Also, cross-vendor interoperability tests are necessary. According to [5], in a cross-MNO handover, the home and visited networks have to interact in order to exchange the following information:

- Static information, for example, neighbor cell lists, interconnecting traffic and signaling links.
- Dynamic information, for example real-time signaling information related to target cell selection.

For the reduction of the required time for the exchange of the information mentioned above, some particular actions (e.g., context transfer, proactive registration) can be performed in advance, i.e., before the actual handover process is triggered. Nevertheless, to the best of our knowledge, this feature has been rarely evaluated in a systematic manner. However, it is important to evaluate the performance of cross-border/-MNO handover in commercial networks if CCAM services, which require uninterrupted service provisioning, are to be offered.

B. *Mobile Edge Computing/Cloud (MEC)*

MEC is a key technology to meet end-to-end latency requirements introduced by novel 5G services and aims at improving the efficiency of the whole network operation through the deployment of computing and storage resources at the edge of the network, closer to mobile users. The exploitation of edge resources offers the possibility to execute computing tasks in a distributed manner directly at the edge of a network, reducing the traffic load on the core of the infrastructure and guaranteeing faster service responses. The adoption MEC technologies is particularly suitable for V2X use cases due to its intrinsic characteristics such as the proximity to the end device as well as the ultra-low latency and availability of high bandwidth.

With respect to MEC integration into 5G systems, the 3GPP has defined a list of enabling functionalities that are provided in [6], where a basic Application Programmable Interface (API) for application function influence on traffic routing is specified. Further key issues and potential solutions are being studied in a corresponding Release 17 Study Item [7].

One feature, especially useful in automotive context, was introduced in the 5G Core in Release 15. It enables a seamless change of session anchors (5G Core Protocol Data Unit Session Anchor – PSA – UPF) to have a short route between vehicle and MEC-hosted application servers (AS). This includes mechanisms within the 3GPP core domain like Session and Service Continuity mode 3 of the 5G Core [6]. Further adjustments might be needed for improved end-to-end solutions where challenges like server discovery, IP address changes, and connection-oriented transport layer protocols, e.g., TCP, must be supported. Even though not all of these are within 3GPP specification domain, the 3GPP might provide solutions supporting this.

The ETSI Multi-Access Edge Computing initiative, provides further specifications in the context of MEC; e.g., APIs allowing applications and the network to exchange information [8]. Following this approach, applications deployed in MEC environments can benefit from a real-time access to network-related context information, which can also support automotive use cases [9].

To date, one of the major challenges in the management of MEC applications remains the application portability among different platforms (i.e., technical solutions). From a commercial point of view, each MNO is offering its own solution; this requires the adaptation of the application format each time, thus limiting the possibility of deploying distributed services across different administrative domains unless recurring to custom solutions. ETSI MEC ISG has specified a MEC application data-model and Lifecycle Management APIs with the purpose of defining a general and standardized approach for the orchestration of MEC application. A further important aspect is related to the dynamic and transparent management of Service Level Agreements (SLAs) between service providers and customers, which represents a key asset towards the adoption of federated MEC ecosystems for running end-to-end services. In this direction, the TM Forum alliance is working on the specification of business-oriented API, with several provided specifications e.g., on SLA management [10].

Currently, we have no reason to believe that further essential standardization effort for the MEC is required, focusing on cross-border V2X services. Instead, solutions specified in 3GPP and other fora need to be profiled. This could be firstly done for specific V2X use case, due to the use-case-specific service continuity requirements and then it could be merged to a common profile or set of profiles suitable for all a larger set of V2X use cases.

C. Network Slicing

Network Orchestration aims at providing functionalities and mechanisms for managing end-to-end network slices to support automotive services deployed across different geographical, administrative and technological domains. In such a context, different challenges have to be taken into consideration for orchestrating end-to-end services and instantiating the associated slices. In particular, the end-to-end service must be decomposed into multiple service components to be instantiated in the underlying single administrative domains, where the different Virtualized Network Functions (VNFs) and ASs composing the end-to-end service chain can be either placed in a centralized public Cloud or the MEC. For instance, depending on the specific service, the service decomposition can result in a set of centralized management functions plus several distributed functions running in MEC hosts for data processing in proximity to the vehicles.

Network slicing is a feature of 5G networks to provide different specific networks to different types of uses and users (e.g., end users, enterprises, public safety). It is considered a key mechanism of 5G in order to serve vertical industries with different service needs, depending on latency, capacity or reliability. Network slicing was introduced in 3GPP Release 15 and a V2X slice suitable for the specific requirements of V2X services has been specified [6].

Road authorities are interested for V2X services e.g., hazard warnings and in-vehicle signage, as well as coordinate cross-border services. An ultrareliable low latency communication slice is required for fast and reliable reception of safety-related messages. In order to support these requirements, network resources could be allocated at the edge cloud, as close as possible to the users, or adequate transport network resources towards the central cloud should be allocated for the slice.

According to [11], a network slicing is composed by a service profile, which models the characteristics of the mobile traffic, and a network slice subnet that contains/refers NFV applications' elements, i.e., network services and virtual network functions. In addition, a network slice subnet can potentially contain several other network slice subnets, enabling a recursive model, where a network slice is then composed by one or more subnets. From a cross-border scenario point of view, this recursive modelling is an important enabler for the definition of end-to-end network slices where subnets are indeed "nested" network slices provided by different operators in different administrative domains, including the possibility of sharing subnets for running services belonging to different tenants. ETSI NFV proposed integration of NFV data model in 3GPP network slice data model [12].

Some of the challenges that network slicing will face are related to the introduction of trusted and isolated smart connectivity services. It is envisaged that network slicing will be used end-to-end, considering core and RAN. The on-demand capacity broker has been introduced by 3GPP to further improve RAN sharing flexibility. It is envisioned that in networks it can be performed by the user requesting the network slice, evolving the concept towards a smart connectivity service [13]. Cross-border scenarios also represent a research challenge for network slicing. Network slice stitching refers to a management operation consisting in creating an end-to-end network slice or a larger network slice subnet, by interconnecting a set of network slice subnets together, through

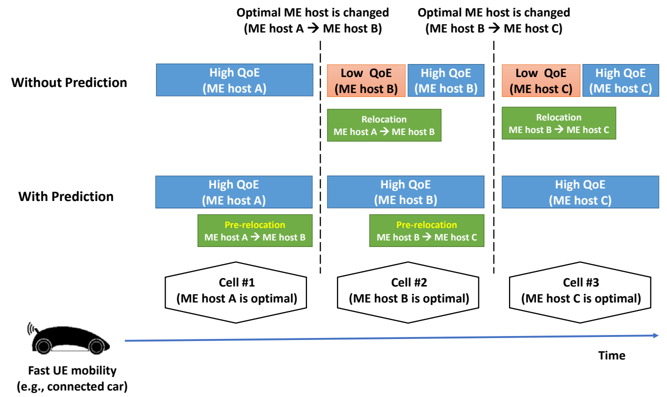

Figure 3. Pre-relocation of application state information [9]

interconnection anchors, which represent cross-domain end points. Furthermore, in research on the relationship of network slicing and network monitoring with analytics is an ongoing work. To provide autonomous smart connectivity services, several autonomic network architectures have been considered so far.

D. *Quality of Service (QoS) Tools for Application Adaptation*

Service adaptation to achievable performance is an important requirement for critical V2X services (e.g., safety, autonomous driving), especially in cross-border environments. On the other side, many V2X applications can use different application-layer configurations (e.g., speed video configuration), depending on the achievable communication performance, which might be mapped to different QoS levels. This is a very useful feature, since the applications can operate with alternative QoS profiles (e.g., even lower QoS) that could be selected instead of the initial QoS profile.

The V2X AS can provide a list of alternative service requirements to the 5G System (5GS), for the V2X applications that can operate with different configurations (e.g., different latency requirements). This allows the 5GS to support alternative service requirements and apply them for the extended NG-RAN notification, as described in [6]. An improved service adaptation and the avoidance of a session interruption due to QoS degradation are the key benefits that the support of Alternative QoS profiles can provide to a service.

In addition, the experienced QoS may be affected by various parameters (e.g., mobility, roaming and channel conditions). Harsh application adjustment, due to a QoS degradation, is not appropriate and may affect the V2X services performance, since this might lead to service discontinuity and impact traffic efficiency. Hence, an application may have to adjust its configuration (e.g., increase inter-vehicle gap), according to the QoS that can be delivered. To each application-level configuration a different QoS level (e.g., data rate, latency) may be associated. V2X application can be timely notified of predicted change of the QoS before the actual change takes place, allowing thus the application to gracefully adapt its behavior and configuration to the expected achievable performance.

3GPP has been introduced an architectural solution about the notifications on potential QoS change [14]. The goal is to enable 5G communication systems to provide analytics information regarding potential QoS change upon request from a V2X AS. The procedure for QoS prediction is provided by Network Data Analytics Function (NWDAF). The V2X AS can provide the notification to the vehicle side, if needed in case adjustment of application behavior is handled by in-vehicle application.

Predictive QoS support has also been identified as one of the key solutions for mobility and Quality of Experience (QoE) support issues, described by ETSI, in the context of the MEC framework [9]. One key example is illustrated in Figure 3, where the relocation of application state information to the target MEC host is completed before connecting to the MEC host.

The above-mentioned solutions of alternative QoS profiles as well as QoS prediction analytics have been currently standardized only for the Uu interface, while further analysis is required for Cross-border/-MNO interactions, where both could be useful to improve service adaptation capabilities and to maintain a V2X service operational regardless of a QoS degradation.

III. Regulation Aspects Status

Besides the technical challenges analyzed in the previous section, there are also many regulatory topics that should be addressed for realization of 5G-enabled cross-border CCAM services and ensure their successful mass market adoption. Certification, liability, safety, security, as well as data management and ownership are some of the challenges of CCAM services at cross-border areas that are analyzed below.

A. *Certification, Liability and Safety*

The need for certification (homologation) and specification of testing procedures of standalone automated vehicles has already been identified as a real problem, especially for vehicles controlled by artificial intelligence. Currently, there is not such a regulation defined for the autonomous vehicles moving on the roads. This testing and certification framework should consider future connected vehicles with 5G connectivity capabilities, together with the impact on V2X infrastructure. Certification of an automated vehicle will require the homologation of the whole technical chain that includes vehicle, network, cloud, and application side. Moreover, the regulation of homologation is necessary to avoid incompatible testing and certification schemes at different countries or the need for different certification processes at specific countries.

It would be more difficult to identify the responsibility in the case of an accident where involved connected vehicles are relying on an external communication infrastructure, than for an automated vehicle without the usage of connectivity service. For instance, when a 5G infrastructure is used then the responsibility of an MNO or of a CCAM service provider could be invoked. How the responsibility will be shared between an MNO and a vehicle Original Equipment Manufacturer (OEM) is an open challenge. Higher levels of automated driving and tele-operated driving will make more challenging the liability

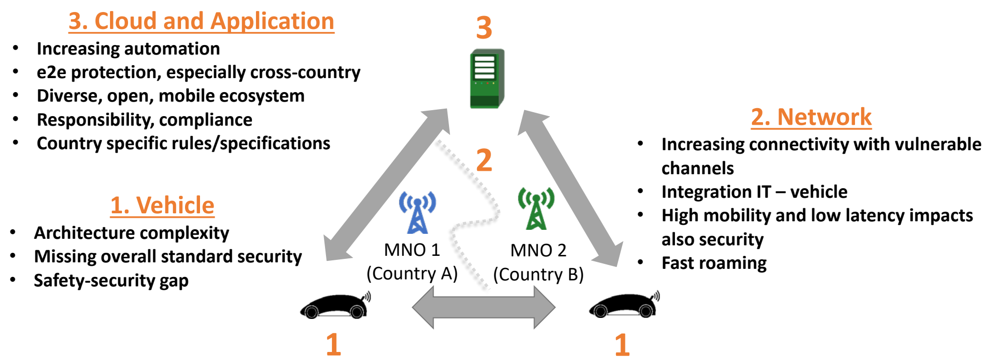

Figure 4. Root causes for security challenges

management. New laws are needed to regulate the distribution of responsibilities, while methodologies are needed to assess the validity of the claims.

A connected vehicle is a cyber-physical system leading to interaction vulnerabilities between safety and security, while threats (malicious) and failures (accidental) have been so far handled separately, leading to a safety-security gap. Figure 4 presents root causes of security challenges, while a non-exhaustive list of challenges at different involved entities is presented below:

- **Vehicle security**: Electronic control unit (ECUs) should be isolated for trusted execution of computations. In vehicle violations of isolation should also be detected, with early remediation. Secure over-the-air (OTA) updates of software and firmware should be guaranteed as well.
- **Network security**: Network connections should be strongly isolated end-to-end. Anomalies regarding network isolation should also be detected and mitigated. High mobility imposes security mechanisms to be compatible with low-latency constraints, to manage handover efficiently, and to consider roaming challenges.
- **Application and ecosystem security**: Cyber-resilience is needed to guarantee safety of a distributed decision-making layer highly vulnerable to attacks. Vehicle and passenger data must also be protected end-to-end in terms of confidentiality, integrity, authenticity and privacy, while being compliant with regulations, especially among different countries.

To address this type of challenges, a holistic vision of protection is required. A regulation for the uniform provisions concerning the approval of vehicles related to cyber security and cyber security management system is under definition by United Nations Economic Commission for Europe and will be applied in the framework of EU Regulation, starting from July 2022 for all new vehicle models.

B. Data management

Vehicles are the most essential part of a data-shaped CCAM ecosystem. Vehicle and passenger-data will be collected, stored, analyzed, and shared with different stakeholders using multiple channels. Difficult trade-offs must then be found between integrity of information, safety of vehicles, and privacy of drivers and passengers.

The different CCAM stakeholders are responsible only for a part of the data, while the privacy of the vehicle driver is of utmost importance. Data ownership, data sharing and data exchange are very important procedures. For instance, practical issues arise when video sensors capture private and sensitive data. The real time data generated by different actors or sub-systems (e.g., by the vehicular control application running at a cloud server) together with operational logs of the infrastructure (e.g., MNO) will be stored at data repositories and could be used to estimate the load in the road infrastructure among other derived applications. Other stakeholders may be interested to use the stored data, such as insurance or third party companies that aim to exploit mobility patterns to derive other businesses (e.g., smart parking). Considering the criticality of the infrastructure and the generated data, regulators should clearly define protective laws and enforce that the storage of this data must be subject to privacy frameworks such as the General Data Privacy Regulation (GDPR).

Regulation and protection of data ownership is needed. For instance, vehicle's data can be used for safety purposes based on agreements that will be signed between the vehicle owners and OEMs. Also, the data that is sent from the vehicle and is stored by the road or telecom operators should preserve the highest level of privacy, as defined by the GDPR. Authorities should regulate its use enforcing privacy at all times.

At another example, road operators that are in charge of traffic management, have the mission to inform all road users when an event occurs e.g., an accident to protect the incident zone from any secondary incident, manage the issues related to the incident, and clean the road after the incident is closed. For that reason, interfaces for data exchange between road operators with telecom operators, service operators and vehicles are needed. The definition of data sharing agreements among involved stakeholders e.g., MNOs, road authorities, vehicle manufacturers, map providers etc is needed to enable various CCAM services. This will allow the monitoring, evaluation and testing of the entire data exchange. However, the authorities responsible for the orchestration of nationwide infrastructures have not been identified yet.

Nationwide data should be exchanged between neighboring countries, to support cross-border CCAM scenarios and to enable international support to V2X technologies. Once the regulation authorities of a country are defined, those will need to define the agreement policies for transnational information exchange. The cross-border data exchange becomes more challenging considering counties that use different privacy frameworks.

IV. Business Case Perspective

The development of the 5G technology, therefore, needs to be sustained by economic models that can pay back the capital expenditure required to materialize the 5G deployment and ensure that its operation is maintained thanks to regular incomes. The cost of 5G technology deployment can be divided in the following three fractions:

- instalment costs of hardware and software for the communication components of the vehicles (CAPEX)
- infrastructure cost in terms of 5G network deployment (CAPEX)
- maintenance costs in terms of the system operation (OPEX).

These costs related to building and maintaining the system need to be compensated for, e.g., by regular subscriptions of the customers/users or by inclusion in vehicle's selling price. The key motivation for customers to pay and contribute to the Capital Expenditures (CAPEX) and the Operating Expenses (OPEX) relies on the expected benefits of innovative features and services which allow to enhance safety, improve traffic efficiency, and provide real time awareness and infotainment services.

The identification of the appropriate billing models for CCAM services is an open issue. For example, the services used to enable C-V2X capabilities, and thereby the corresponding data bits used to enable those services, could be seen as more advanced specialized bits than the more regular broadband bits providing e.g., internet access. In a pricing model, it could be thus reasonable to charge a premium fee for more advanced specialized bits compared to regular broadband bits, e.g., when cross-border uninterrupted service provision with guaranteed QoS is needed.

Different roads have different characteristics; while network coverage in urban and inhabited areas most likely provides sufficient coverage and capacity for roads, the same cannot be taken for granted in rural or cross-border areas, where either coverage or capacity might not be sufficient to support uninterrupted 5G V2X services, also considering that different countries have different road and network infrastructure deployed. In very rural areas (e.g., where roads may have very few vehicles per day) or remote cross-border areas, it is expensive to build out a full fetched 5G coverage; therefore, there is a need to find incentives and define cooperation models to ensure that 5G-enabled CCAM services can be delivered. For this particular reason, together with urban areas, densely vehicle-populated highways are foreseen to be locations where

TABLE I
List of identified gaps for 5G-enabled CCAM deployment

Topic	Identified Gaps and Challenges
Roaming and inter-MNO interaction	• Test and evaluate inter-MNO handover interfaces, including cross-vendor interoperability tests to identify issues that harmonization and further standardization is needed. • Investigate whether proactive actions (e.g., context transfer, proactive registration) are needed before the inter-MNO handover, to further reduce the time required for the exchange of this information. • Roaming schemes improvement for the reduction of roaming latency and determination of more detailed SLA handover, ensuring the maintenance of SLAs.
Predictive and e2e QoS	• Specification of QoS prediction functionality in a multi-operator environment, to receive QoS prediction notifications before the handover from one MNO (home country) to another MNO (visited country). • Service and session continuity at country borders when switching gateways and/or MEC hosts (e.g., server discovery, IP address changes, and connection-oriented transport layer protocols).
MEC	• Inter-MEC communication, considering different architectures and MEC deployment strategies in different countries by the MNOs.
Network slicing	• Slice selection impact during the transition from one operator to another, when accessing a service in the visited network. • Impacts when registering and performing slice selection in the visited network, during the transition from one MNO to another, considering that 3GPP has defined a V2X slice type that could serve as common ground for MNOs to define slices with same QoS for certain V2X services in different networks, even when roaming.
Data Management	• Regulation and protection of data ownership. • Definition of data sharing agreements among involved stakeholders e.g., MNOs, road authorities, vehicle manufacturers, map providers etc to enable various CCAM services. • Cross-border data exchange should be regulated to enable cross-border V2X services to retrieve and process data from different countries.
Liability, Security and Privacy	• Homologation (certification) of several hardware and software components involved in V2X services is needed and also the regulation of homologation among different countries. • Define the regulatory and legal framework for the sharing/identification of responsibilities among V2X stakeholders (liability management), within one country and across borders. • Define how e2e protection of information (vehicle, network, cloud) could be provided. Considering also that different security and privacy frameworks (GDPR) may be utilized by different countries.
V2X Applications and Traffic Management	• Standardization of advanced V2X services (e.g., cooperative manoeuvres, automated intersection management) allowing cross-OEM, cross-vendor and cross-MNO realizations is needed to accelerate development of V2X, services avoiding proprietary or localized solutions. • Define and standardize interfaces between traffic management centers and cloud platform (e.g., MEC) for collecting and sharing road and traffic information (e.g., road warnings, road status), also across different countries.

early roll out will take place, given that these networks will deliver V2X services along with regular services, such as voice and broadband data.

The identification of appropriate cooperation models between road authorities and MNOs is an important factor that can enable the deployment and use of 5G infrastructures for CCAM. A cooperative planning model can create synergies for connectivity deployment along CCAM corridor networks in a cost-effective manner. The 5G Strategic Deployment Agenda (SDA) for CCAM services in Europe is an initiative to provide a common ground among different stakeholders [15].

V. Conclusion

The provision of cross-border CCAM services creates many business opportunities. On the one hand, there are technical challenges (e.g., seamless communication and uninterrupted real-time services across different countries) that can be addressed via 5G technologies. But on the other hand there are several legal, regulatory and business issues that should be considered. Table I provides a summary of barriers, requirements and gaps from standardization, regulatory, business, and legal perspective, which have been discussed in this paper and should be addressed for fast and efficient adoption of 5G-enabled CCAM services, especially in cross-border environments. For the majority of the identified technical issues there are either initial solutions or proposed enhancements that could be adopted. At this stage, the evolution of the regulatory framework and the coordination among involved stakeholders (e.g., for liability management, data management, security and privacy issues) constitute probably the most important factors for the development of a consistent ecosystem that is needed for cross-border CCAM services.

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