5G Connected and Automated Driving: Use Cases and Technologies in Cross-border Environments

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***Abstract*— The vision of cooperative, connected and automated mobility (CCAM) along Europe can only be realized when harmonized solutions that support cross-border traffic exist. The possibility of providing CCAM services along different countries when vehicles traverse various national borders has a huge innovative business potential. However, the seamless provision of connectivity and the uninterrupted delivery of real-time services along borders also pose technical challenges which 5G technologies promise to solve. The situation is particularly challenging given the multi-country, multi-operator, multi-telco-vendor, multi-car-manufacturer, and cross-generation scenario of any cross-border layout. Motivated by this, the 5GCroCo project, with a total budget of 17 million euro and partially funded by the European Commission, aims at validating 5G technologies in the Metz-Merzig-Luxembourg cross-border corridor, traversing the borders between France, Germany and Luxembourg. 5GCroCo validation will focus on three use cases: 1) tele-operated driving, 2) high definition map generation and distribution for automated vehicles, and 3) Anticipated Cooperative Collision Avoidance. The results will help reduce the uncertainties associated with eV2X communications across borders in Europe in preparation of commercial 5G deployment.**

Keywords—5G, connected and automated mobilty, V2X, automotive use cases, cross-border, CCAM, trials, QoS.

I. Introduction

The automotive industry is evolving towards a vision where cars are becoming more automated and wirelessly connected to cooperate with each other for a safer and more efficient driving. Connectivity offers a good complement to the on-board sensors by extending vision and detection range even when visual line-of-sight is not available. In addition, connectivity is key to cooperative functions. For the success of such a revolution, it is necessary that both the telecom and the automotive industry cooperate together to shape the future by addressing all the challenges that connected, cooperative and automated mobility (CCAM) brings into the innovation arena. Different standardization organizations (3GPP [1], ISO [2], ETSI ITS [3]), associations (e.g. 5GAA [4]), and research projects around the world (e.g., 5G PPP [5]) have been working on CCAM services and V2X communications in particular.

One of these challenges consists in ensuring that CCAM services, which require real-time response and ultra-high reliability, can be provided along different countries when vehicles traverse various national borders. Service continuity must be guaranteed and the quality of services must not be degraded when crossing borders. The situation is particularly challenging considering the multi-country, multi-operator, multi-telco-vendor, and multi-car-manufacturer scenario that a cross-border deployment brings into place.

This is the motivation for 5GCroCo [6], where key European partners from both the telco and automotive industries join efforts to trial and validate 5G technologies at large scale in a cross-border setting with the mission to reduce uncertainties before CCAM services running on top of 5G communication infrastructures are offered to the market. 5GCroCo also aims at identifying business opportunities and defining new business models for disruptive CCAM services which can be possible thanks to 5G technology, as well as ensuring the appropriate impact into relevant standardization bodies both from the telco and automotive sectors.

The aim is to define a successful path towards CCAM services in cross-border scenarios and to reduce the uncertainties of a real 5G cross-border deployment. 5GCroCo aims at trialing 5G technologies in the Metz-Merzig-Luxembourg cross-border corridor, traversing the borders between France, Germany and Luxembourg. The objective is to validate advanced 5G features in the cross-border context, such as New Radio, Mobile Edge Computing (MEC), distributed computing, predictive Quality of Service (QoS), Software Defined Networking (SDN), Network Slicing, and improved positioning systems, all combined together, to guarantee that innovative use cases for CCAM can be enabled. In addition, 5GCroCo aims at defining new business models that can be built on top of this unprecedented connectivity and service provisioning capacity, also ensuring that relevant standardization bodies from the two involved industries are impacted. 5GCroCo validation will focus on three use cases: 1) tele-operated driving, 2) high definition (HD) map generation and distribution for automated vehicles, and 3) Anticipated Cooperative Collision Avoidance (ACCA). Moreover, it will also provide general recommendations for any other CCAM use cases.

The remainder of the paper is organized as follows: Section II highlights the key objectives of the 5GCroCo project. The use cases that will be evaluated in 5GCroCo are presented in Section III. Section IV describes the key technologies as enablers for CCAM that will be validated. Section V presents the trials that will be conducted at both small and large scales. Business models and cost/benefit analysis are discussed in Section VI. Finally, Section VII concludes the paper.

II. 5G CroCo Project OVerview

5GCroCo is an innovation action partially funded by the European Commission (EC) under the umbrella of the 5G Public Private Partnership (5G-PPP). 5GCroCo is devoted to conduct large-scale trials of 5G technologies for CCAM in the European 5G cross-border corridor connecting the cities of Metz (in France), Merzig (in Germany), and Luxembourg. In addition to the large-scale trials in the 5G corridor, 5GCroCo will also conduct small scale pilots in Barcelona, Montlhéry, Munich, and the German A9 5G-ConnectedMobility testbed.

5GCroCo has a total budget of close to 17 million euros and counts with a contribution from the EC close to 13 million euro, with a planned duration of 3 years, running from 1st of November 2018 until end of October 2021. The project is coordinated by the Centre Tecnològic de Telecomunicacions de Catalunya (CTTC, in Castelldefels, Barcelona, Spain), and gathers 24 partners from 7 European countries comprising key organizations in the intersection of both the telecom and the automotive worlds. 5GCroCo coordinates the contributions from leading car manufacturers, tier-1 suppliers, road authorities, mobile network operators, telecom vendors, SMEs, and academia.

The trial of 5GCroCo will be focused on three use cases related to CCAM services will be tested: tele-operated driving, HD map generation and distribution for automated vehicles, and ACCA. The next section describes them into further detail.

III. 5GCroCo Use Cases

5GCroCo aims at validating 3 key CCAM services: 1) Tele-operated driving, 2) HD map generation and distribution for automated driving, and 3) ACCA. While the actual trials and validations in 5GCroCo will be focused on these particular use cases with envisioned high potential market opportunities, the activities of 5GCroCo aim at deriving recommendations and insights which can be valid for a wider set of CCAM use cases

A. Tele-operated driving

Tele-operated driving is defined as remote control of automated vehicles by a human or by an artificial intelligence over mobile radio networks. The emphasis in 5GCroCo is set to remote control by a human. Tele-operated driving in context of automated driving can be deployed in different traffic situations, such as:

- Remotely-initiated lane change or speed adaptation on highway: a remote driver can take over control of the vehicle from a tele-operated command center in cases where it can be anticipated with sufficient time horizon that a driver over a Level 3-4 autonomously driving vehicle needs to regain control of the vehicle.
- Transfer from urban to highway: A car could be capable of highly-automated and even autonomous driving on highways but not on urban roads (Level 4). Rather than having the driver to take over control of the vehicle, tele-operated driving can be used to reach the final destination. This also enables journeys without presence of people legally permitted to drive the car, e.g. minors.
- Not responding driver: even though Level 4 automated driving vehicles are not able to handle every situation, the driver is not either required to be always ready to regain control as with Level 3 autonomous driving. In case the driver does not respond to the request of taking over control, an operator in a teleoperated driving command center can take over control.
- Undefined traffic situations: In the unlikely event of a fully autonomously driving enabled vehicle (Level 4-5) not capable to handle a certain traffic situation, tele-operated driving can remotely involve a human operator to solve the situation. This could happen through providing additional information to the vehicle, enabling it to correctly perceive its situation. It can also include shortly taking over control to resolve the situation or proposition of a new route.

Several challenges on the network arise from this use case, starting with high bandwidth demands for uplink video streaming and the need to provide the capacity to control several vehicles in an area. An extra challenge arises from the fact that there is a high risk of correlation of requests for remote drivers to take over control. This is caused by previously described situations for tele-operated driving, making it likely that if one vehicle requests the service, other vehicles in the same area will act the same way. Furthermore, involved network infrastructure, as well as backend servers running the application services required for this use case, will likely belong to different domains, e.g. different Mobile Network Operators (MNOs). If communication or service orchestration is required across those domains, QoS requirements must still be met end-to-end. This also applies when country borders are crossed. The network should be designed in a way to provide the required QoS with very high reliability. Predictive QoS is required to issue warnings towards the people in the vehicle and the remote driver in the tele-operated command center when QoS degradation is expected. Possible consequences depend on previously described situations and automated driving levels, but may include reducing speed, changing the route towards one where the network can support the service, or safely stopping the car. On-top of QoS prediction, which is an important base requirement for tele-operated driving, the safe remote control of a vehicle requires an overall functional safety concept. This concept development needs to consider the in-vehicle architecture, the 5G communication network architecture with its advanced features, and the backend architecture.

B. High definition (HD) map generation and distribution for automated driving

Intelligent and dynamic HD maps provide highly accurate position and traffic information of dynamic and static objects which enable optimal route and lane selection by an autonomously or semi-autonomously driven vehicle. Such maps could be constructed by smartly fusing all the available data from different sources at and along the roads, e.g. the sensor data shared by the vehicles, the data shared by the road infrastructure, or by the map content providers, among others.

5GCroCo will develop a common understanding on how the data required to generate the HD maps shall be exchanged between the vehicles, data servers, and map providers, and how it shall be structured. The focus will be on three particular scenarios and applications:

1) Large scale optimal route selection for automated vehicles: a detailed route planning capability is a mandatory part of an automated vehicle that includes large scale planning to estimate optimal route from the starting point to the destination.
2) Small scale maneuver planning and execution, e.g. selection of correct lanes. Some places on the roads such as roundabouts, tunnels, or bridges require special consideration due to the specific geographical needs, and road conditions. HD maps shall be able to work well in these special situations in terms of route and maneuver planning with good position accuracy.
3) Updating routes in hazardous situations: automated driving vehicles should avoid getting stuck in queues due to accidents, traffic jams or any other hazard, by switching to alternate routes before getting there, which requires the map to be up-to–date. That can be achieved by utilizing environment or hazard notification information shared by vehicle sensors or road infrastructure in order to recompute optimal routes.

C. Anticipated Cooperative Collision Avoidance (ACCA)

At high speed, a typical stand-alone sensing system (e.g., radars, cameras, lidars) will not have sufficient and safe means to detect and localize dangerous events on the road in all situations and with sufficient level of anticipation. In such situations, too late detection of a dangerous event will trigger a hard braking and possibly a collision depending on friction conditions.

5GCroCo will define and trial cooperative solutions to anticipate the detection and localization of such dangerous events and to facilitate smoother and more homogeneous vehicle reaction. This is called the ACCA and can be useful in a number of situations, such as:

- Temporarily static events like traffic jams.
- High deceleration, emergency breaking, or unexpected maneuver of vehicles in front (with or without visibility for the ego vehicle).
- Cut-in anticipation, e.g., when a vehicle suddenly comes in from another lane.

The cooperative vehicles (or the road side infrastructure) will upload a set of information such as status (position, speed, acceleration), detected events, and some sensors data (camera/radar streams, or any other information based on a standardized methodology, e.g. Cooperative Perception Messages) towards specific servers. This data will be used by local servers (e.g. Mobile Edge Computing – MEC - servers) to create an off-board dynamic map which handles and consolidates all collected information based on a known road topology. The off-board distributed service is used to:

- Aggregate and consolidate data received from vehicles with data coming from e.g., road operators.
- Manage independently (on a per-vehicle or on a per-geographical area) dynamic information, especially in traffic congestion areas.
- Extrapolate from the distributed dynamic map the relevant content for a specific user.
- Ensure the hand-over towards neighboring MECs.
- Ensure the roaming between different countries and MNOs.

IV. 5G TECHNOLOGIES IN 5GCROCO

5GCroCo has identified a set of key 5G technologies which will become enablers for CCAM. They have all been thoroughly evaluated in previous and ongoing research and innovation projects. Some of them are even commercially deployed already. The motivation of 5GCroCo is to evolve them to also fulfill their purpose and role in overall QoS fulfillment in cross-border, cross-MNO, cross-vendor, and cross-OEM deployments. Service continuity is a particular goal in this context. The key identified technologies are:

- MEC-Enabled Distributed Computing.
- Predictive QoS.
- E2E QoS with Network Slicing.
- Mobile Network Supported Precise Localization.
- Security.

The V2X services that will be studied and trialed in 5GCroCo for the use cases described in the previous section have unique characteristics which make the use of these technologies particularly interesting.

First, a limited area of interest. Information is often only needed close to the source where it was generated. This is true for many, but not all applications. It particularly applies to the use cases of HD maps generation and ACCA. Direct communication omitting the cellular network and MEC-enabled cellular networks must be, therefore, part of the V2X architecture.

The second unique property is the multi-OEM and multi-MNO challenge. This one is tightly coupled with the first one. For typical mobile radio network services like voice and data communication, it does not matter that peering points between MNOs, vehicular clouds and public data networks are located far from the “edge”. In a MEC-enabled V2X architecture this problem must be solved, and the solution cannot be to have just one MEC provider.

The third unique property is the role of the road authority as another source and sink of information. This comes along with often closed, sometimes even proprietary, IT-systems needing integration in a MEC-enabled distributed computing V2X network architecture. A particular challenge arising from this is that crossing national, in some cases also regional, borders results in a new road authority with own IT infrastructure becoming responsible. With these technologies, 5GCroCo will address the gap of existing cellular V2X technologies (such as LTE Release 14) by enhancing a number of Key Performance Indicators (KPIs) in the 5G network, such as latency, reliability, packet error rate, etc., even under cross-country, cross-MNO, cross-OEM and cross-vendor operations.

In the following sub-sections, we further elaborate on the challenges to be solved by each of these technologies.

A. MEC-Enabled Distributed Computing

Mobile Edge Computing/Cloud and Multi-Access Edge Computing/Cloud are all terms referred to by the acronym "MEC" often associated with computational resources collocated with one or more base stations. The MEC definition used for the 5GCroCo project is not strictly bound to geographic location of the MEC, but to the fact that applications running on such MEC instance experience very low delay to and from the base stations the MEC is related to. A local MEC instance serving a limited geographic area in combination with vehicle mobility, results in frequent change of the MEC instance handling the particular vehicle (i.e. MEC handover). For this and other MEC-related challenges, 5GCroCo will define generic MEC-enabled distributed computing architectures and best practices to deploy the micro-services required for the services forming the three project use cases and further ones typically encountered in V2X context. The goal is to reach an optimal trade-off between network performance and deployment complexity and cost.

B. Predictive QoS

Safety of life can often be traded for availability or degraded performance. Brought into V2X context, it can for example mean increasing inter-vehicle distance and therefore reducing traffic throughput, or even stopping the vehicle. For that, the state of the communication system must be monitored, failure must be detected, and the application/service must be informed. Previous research activities (e.g., [6]) have shown that instantaneous information of network failure is often not enough to guarantee functional safety. The vehicle might require time to enter a safe state and might need to rely on communication while doing this, e.g. to inform surrounding cars or query application services about the best possibility to reach a safe state in the current situation.

5CroCo ambition regarding predictive QoS is to broaden the scope from pure Radio Access Network (RAN) to end-to-end evaluation. Redundancy, as key for reliable communication, will be evaluated for RAN, core and backend, with particular focus on how MEC-enabled distributed computing can assure redundancy, failover and fast recovery mechanisms. 5GCroCo will extend the network with very reliable prediction of QoS at a given location. Within the project we will determine the performance and applicability of existing predictive QoS algorithms by evaluating them in realistic scenarios and evolve underlying interfaces and architectures to enable cross-border and cross-MNO predictive QoS.

C. E2E QoS with Network Slicing

Network Slicing is a technique opening a magnitude of options for MNOs to instantiate one or more virtual networks, including for V2X. While different standards (e.g. 3GPP Rel. 15, ETSI-MEC) and data center technologies pave a way to a convenient and interoperable flexible and controlled instantiation of multiple logical networks on top of a shared infrastructure, it is naturally not standardized how many and which kind of slices should be deployed and when.

5GCroCo will address this question by considering the entire solution space, i.e. starting with an assumption of no dedicated V2X slice at all (very unlikely) and going to a very fine-grained differentiation resulting in one or more dedicated slices for almost every service, like for each of the three use cases described. The truth will lie in the middle and will depend on current and planned infrastructure deployments of each MNO.

D. Mobile Network Supported Precise Localization

The advanced Intelligent Transportation System (ITS) services for connected and automated cars developed in 5GCroCo require delivering cm-level accurate positioning to moving vehicles. This accuracy cannot be supported today with GNSS (Global Navigation Satellite Systems), especially in urban environments (e.g. urban canyons). 5GCroCo will design and validate innovations to deliver cm-level positioning supported by the 5G network.

5GCroCo will approach the positioning problem from a holistic perspective, considering approaches dependent and independent from the Radio Access Technology (RAT), and also hybrid approached. As RAT-dependent approaches, 5GCroCo will study PHY layer extensions to 5G NR (new radio) that allow a User Equipment (UE) to obtain the required accurate position.

E. Security

It is a key goal of 5GCroCo to guarantee that state of the art security standards are met throughout all areas of the involved information technology (IT) infrastructure. The overall architecture, communication protocols, software and hardware should have appropriate measures implemented that assure the maintenance of the security goals, including confidentiality, integrity, availability, and authenticity. Strict adherence regarding data privacy in accordance to the General Data Protection Regulation (GDPR) is also an integral part.

Along the different stages of the project, security aspects including privacy, confidentiality, integrity, availability, and authenticity will be evaluated. Special focus will be put onto the first one, privacy, since here we expect most V2X (vehicle to anything) specific challenges. Existing 3GPP security mechanisms will be evaluated and gaps will be identified. Solutions to close them will be defined, preferably relying on standard Internet or C-ITS specific mechanisms defined in IETF, ETSI-ITS and other SDOs.

V. 5GCroCo Test Sites

Trials at both large and small scales will be conducted in 5GCroCo to validate the 5G technologies described in Section IV for the three use cases described in Section III, especially in cross-border, cross-vendor, cross-OEM and cross-MNO environments.

A. 5GCroCo Cross-Border Corridor

5GCroCo will concentrate its large-scale trials in the 5G European corridor which connects cities of France, Germany, and Luxembourg, and is part of the pan-European network of 5G corridors facilitated through several regional agreements (see Figure 1). These agreements allow Europe to count with hundreds of kilometers of motorways where tests can be conducted up to the stage where a car can drive autonomously with a driver present under certain conditions (third level of automation). These corridors count with the support of the European Commission as part of its 5G Action Plan, which aims at ensuring commercial deployment of 5G technologies by the end of this decade.

Figure 1 Map of the 5G Corridor where 5GCroCo will conduct transnational CCAM 5G-enabled trials

B. 5GCroCo Pilots

In addition to the large-scale trials in the corridor, 5GCroCo also plans to deploy local pilots, as a step before large-scale deployment in the corridor. These pilots will be deployed in Montlhéry (South of Paris, France), two in Germany (in a section of the motorway A9 and a test-site in the Munich city center), and one in the city of Barcelona (Spain) where a cross-border city setting will be emulated. These pilots will allow testing 5G functionalities locally (geographically close to the different involved partners), and possibly in restricted closed areas, so that the complexity of doing the trials in the large scale corridor can be managed. These trials will allow selecting and fine-tuning the 5G capabilities that will be then integrated in the large scale trials, thus reducing the uncertainties associated to their deployment and trial.

C. Key Performance Indicators (KPIs)

The approach in 5GCroCo will be to continuously monitor and evaluate the performance of the proposed 5G innovations in the trials based on the measurement of KPIs. On the one hand, KPIs related to telco operations will be considered. These include throughput, latency/delay, packet error rate, reliability, call drop in case of handover, packet error rate, maximum speed supported by user equipment, etc. In addition, there will be also KPIs associated to the specific use cases, from an application-oriented perspective, such as braking time, anticipation time, service interruption time, etc.

VI. Business Innovations in New Ecosystems for Automated Driving

In addition to the 5G trials for CCAM, the study and definition of new business models and cost/benefit analysis is a fundamental part of 5GCroCo to understand the business possibilities that emerge from CCAM services which can operate across borders. The possibility of having advanced 5G functions operating in a cross-border, cross-telco-vendor, cross-car-OEM, cross-MNO fashion generates a new arena for innovation. 5GCroCo will analyze the cost/benefit relationship of deploying 5G in such a complex scenario and develop tools which can allow for the definition of valid business models. This process will be done in parallel with the deployment of the trials, learning from the experience acquired, understanding the needs of all stakeholders, and reducing the uncertainties of deploying a 5G infrastructure to offer unprecedented 5G-enabled services for CCAM.

VII. Summary

5GCroCo is an Innovation Action partially funded by the European Commission where key European partners from both the telco and automotive industries join efforts to trial and validate 5G technologies at large scale in a cross-border setting with the mission to reduce uncertainties before CCAM services running on top of 5G communication infrastructures are offered to the market. 5GCroCo also aims at identifying business opportunities and defining new business models for disruptive CCAM services which can be possible thanks to 5G technology, as well as ensuring the appropriate impact into relevant standardization bodies both from the telco and automotive sectors. 5GCroCo is an important element of the 5G IA Trial Roadmap Strategy v2.02, being directly aligned with the 5G Action Plan for Europe and planning to contribute to and synchronize with the overall 5G Public Private Partnership (5G-PPP) ecosystem.

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