(INVITED) 5GCroCo: Use Cases, Challenges, and Solutions for Cross-border Trials

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***Abstract*—This paper presents an overview on the recent activities carried out by the 5GCroCo (5G Cross Border Control) project with a particular focus on (i) its three automotive-related use cases and associated challenges, (ii) the different solutions proposed at project level to address them, (iii) the project experience related to encountered interoperability issues, and (iv) the deployed architecture to conduct tests and trials together with a summary of the first experimental results. The paper will conclude by assessing that the obtained results indicate that the minimum requirements from the different use cases are met by the deployed 5G networks.**

Keywords—5G, V2X, connected and automated driving, QoS, trials, cross-border.

I. INTRODUCTION AND OBJECTIVES

The 5GCroCo project (http://5gcroco.eu), aims at validating 5G technologies in the Metz-Merzig-Luxembourg cross-border corridor, traversing the borders between France, Germany and Luxembourg. 5GCroCo is an Innovation Action partially funded by the European Commission where key European partners from both telco, road operations and automotive join efforts to trial and validate 5G technologies at large scale in a cross-border setting with the mission to reduce uncertainties before Connected and Automated Mobility (CAM) 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 CAM 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 remainder of the paper is organized as follows: Section II presents the three 5GCroCo use cases and the challenges associated with their related CAM services. Section III provides an overview of the solutions considered in 5GCroCo to address the challenges. Next, in Section IV issues related to interoperability across different domains are analysed in detail and, in Section V, the resulting deployment architecture and the related test and trial activity is succinctly presented. Section VI concludes the paper.

II. USE CASES AND CHALLENGES

In 5GCroCo, three use cases have been identified to be representative for the automated driving application domain: 1) Tele-Operated Driving (ToD), 2) High Definition (HD) map generation and distribution for autonomous driving (HD Mapping), and 3) Anticipated Cooperative Collision Avoidance (ACCA). The three use cases have been already specified in detail together with the requirements that are imposed by them [1]. An animation showing all use cases and their user stories can be found in [2].

As it was concluded in [3], to allow a successful deployment of 5G-enabled CAM services, some 5G performance requirements are mandatory to be met. In that context, the 5GCroCo use cases listed in the previous paragraph are defined to validate these required performances, in particular: high reliability and very short latency with ToD, asymmetric communication (high data rate in uplink, lower data rate in downlink) with ToD, high throughput with HD Mapping, short latency in both uplink and downlink with ACCA, QoS prediction with HD Mapping and ToD.

It is also key that CAM services do not suffer from any performance degradation of the service during mobility across countries and do not suffer from a service discontinuity when crossing a border. For this reason, 5GCroCo use cases are also defined to validate the service continuity at border crossing or at MNO handover and validate the performances when the vehicle is under the coverage of a visited MNO.

One of the major challenges imposed by the selected use cases on the radio networks is that the different defined performances need to be available jointly and at any-time. In today's networks, there is often good performance only at specific areas while other areas suffer from a degradation of the service performance. In addition, some KPIs are fulfilled while others are not. Such degradations are not acceptable anymore for CAM services and failure of the communication would lead to a standstill of the vehicles or even generate serious dangers to other road users. It is the intent of the 5GCroCo use cases to demonstrate that CAM services can be safely deployed because 5G features have the required performances.

III. KEY 5G CROCO SOLUTIONS

The 5GCroCo project considers input from different standardization bodies to propose its solution architecture for CAM in cross-border environments [4]. The 3GPP 5G New Radio specifications are considered the main set of input documents. Some key aspects are widely considered being a part of 5G but are not within the scope of 3GPP specifications. For these, other standardization bodies, as well as best practices from open-source communities, are considered instead.

The baseline for the project is, therefore, the state of the art of technologies implemented and integrated today in 5G networks that are currently being deployed. This includes Physical and Virtual Network Functions (PNFs and VNFs) and Software Defined Networks (SDN) to interconnect them. For the baseline, 3GPP 5G New Radio Access Network (RAN) with a 4G LTE EPC are considered. This is referred to as non-standalone 5G New Radio. This deployment is being rolled out in most parts of the world today, including Europe.

Experience from previous network generation rollouts shows that this deployment could remain in place for several years. Some, but by far not all, 5G Core features are also available with 4G EPC since the LTE specifications are also being evolved. According to this baseline, all use cases will benefit from the increased capacity, reduced latency and improved reliability offered by design by 5G.

On top of this baseline, components are added, and/or their configuration is optimized to serve the challenges of cross-border CAM. The three use cases defined in the previous Section allow to discover the different facets of those challenges more systematically in order to design a network capable of supporting a wide range of advanced use cases.

QoS prediction has been identified as one key solution. Its baseline is the 3GPP QoS framework currently mostly used for voice calls. For this rather simple application, the current way of describing QoS requirements by delay budgets, packet loss rates and throughputs is enough. More advanced use cases have more complex requirements. A first version of Generic Network Slice Templates (GSTs) was defined by Global System for Mobile Communications Association (GSMA) [5] and we consider them a solution to describe service requirements across MNOs and country borders. Their generic principle is equally applicable to 4G and 5G core networks, but the respective document [5] explicitly references the 5G Core specifications [6]. Furthermore, the standalone 5G New Radio with its defined Slice/Service Type (SST) for Vehicle-to-Everything (V2X) will allow better integration with the vehicle and backend, especially for identifying the right slice.

Besides information on instantaneous QoS, looking ahead in time and allowing selection of alternative QoS is being studied in 3GPP (QoS Sustainability Analytics [7]). The required new interfaces and/or changes to existing ones might only become available for the 5G Core. For the project trials and intermediate deployments and tests, proprietary interfaces can be used but those always come at the risk of cross-telco-vendor issues towards the backend and cross-car OEM ones on the vehicle and modem side (see further next Section for additional details). Interfaces proven to be beneficial can be proposed for standardization.

For a special subtopic of prediction allowing to deliver large data volumes at reasonable monetary price, the Background Data Transfer (BDT) functionality was identified as a candidate to support the HD Mapping use case. The currently specified interface might need to be improved or replaced because it is intended for communication (e.g., software update) with usually geographically static Internet of Things (IoT) devices. Also, here QoS prediction is needed to identify the best times and/or places to download HD map updates.

3GPP specifications only allow QoS management within the RAN and core domain. End-to-end performance guarantees are difficult or even impossible to fulfil with one end of the communication in the public Internet. MEC enables operators to deploy backend applications within their domain. This often requires the so-called Local Breakout through additional gateways. The capabilities of the 4G EPC to dynamically select and especially switch the gateway to reach the closest or otherwise best suitable MEC host are very limited. The 5G Core adds capabilities for more dynamic and seamless gateway selection. EPC and 5G Core are currently not capable to provide this in a cross-MNO environment as experienced across country borders, but also within the same country where usually multiple MNOs are present. Within 5GCroCo, solutions are being studied for addressing these aspects.

Handover from one MNO to another one across country borders is technically feasible but rarely enabled and the required links for the interfaces across MNOs are not present. The project is working to demonstrate the benefit of such interfaces for enabling and improving handover between different MNOs. Today, roaming is usually realized with Home Routed Roaming using the packet gateway in the home network. Particularly in context of MEC, it is preferable to use gateways in the visited network. As of today, no solution allowing service continuity across country borders (cross-MNO handover) and using a gateway in the visited network is specified. In 5GCroCo we are now evaluating if and how the capabilities of the 5G Core for more dynamic and seamless gateway selection can be applied across MNOs.

IV. INTEROPERABILITY ISSUES

This section identifies interoperability issues for the different solutions described in Section III. It divides the issues into the categories of cross-telco-vendors, cross-MNOs and borders, and cross-car-OEMs.

A. Across Telco Vendors

It is common that mobile radio networks consist of software and hardware components from different vendors. With the introduction of All-IP networks any network company became a potential vendor. Furthermore, the Information Technology (IT) industry was added to the set of potential vendors with introduction of virtualization in 5G. In broader sense open-source communities also qualify as "vendors". In this context, interoperability issues related to cross-border, MANO & SDN, radio schedulers, and cloud/MEC between different products from telco vendors are listed and discussed below:

- In [4], it is proposed to deploy the S10 interface across different MNOs to enable cross-MNO radio handover. Ericsson has successfully tested this with its MME products [8] but this does not guarantee it is also possible with MMEs from other vendors. This also includes cross-vendor interoperability tests that sometimes reveal issues that were not detected during single-vendor testing. To the best of our knowledge cross-vendor tests of the S10 interface where the MMEs serve different networks are not common and therefore undetected issues might exist.

- Although often based on the same open-source components, MANO and SDN solutions are usually not compatible across vendors due to e.g., customization and packaging that tightly couples the different components forming the overall MANO and SDN solution. For example, the carrier-grade MANO and SDN solutions come with a set of installation templates tailor made for certain high-performance hardware configurations that were tested and certified.

- The radio schedulers in the gNBs are the key components to deliver the requested QoS according to CQI/5GI class. Their algorithms and implementations are vendor specific. This is a minor problem if the respective QoS is fulfilled but products from different vendors might show different behaviour and therefore different behaviours and / or performance in case of congestion and insufficient resources to fulfil the QoS requirements of all subscribers.

- With different cloud management systems in place, migrating a MEC application from a cloud managed by a system from one vendor to another one managed by a different vendor might become complex.

B. Across MNOs and borders

MNOs are typically active within one country and even ones active in several countries typically act separately per country. One of the reasons is the spectrum licensing per country. Crossing a border and driving a certain distance into a visited country will therefore eventually result in a change of serving MNO. Besides country borders, further cross-MNO topics exist. Within one country it cannot be expected that all vehicles are served by the same MNO. Vehicles might also be allowed to roam into different networks within one country.

As pointed out previously, in [4], it is described how deploying the S10 interface between MMEs in different mobile networks operated by different MNOs can enable cross-border / -MNO radio handover. In reality, IP connectivity between different data centers across borders must be established and each MME might have to be connected to several MMEs in the other network. Furthermore, complexity is added since each country has several MNOs that might need to be interconnected. Using IPX networks to reach the HSS in the home network is a well-established enabler for roaming. For the S10-interface, performance is currently not known when deployed over an IPX network and the influence of S10-interface performance on cross-border / -MNO handover performance is also not known. Besides that, security topics like authorization and authentication must be evaluated for such setting, including their potential influence on performance, e.g., when Virtual Private Network (VPN)-tunnels are applied on the path.

Also, [4] presents how this service continuity concept could evolve with standalone 5G New Radio and beyond. These enhancements relate to interconnecting AMFs of different MNOs, similarly to the previous inter-MME connections. Furthermore, it includes proactive registration to the operators of the neighbouring countries. Such solutions however need additional study and are the focus of 5GCroCo.

Additional considerations to consider regarding cross-MNO and cross-border issues pertains to the fact that an SLA with an MNO usually only applies when connected to the home network, not when roaming. Even when extended to visited networks one would have to guarantee that the agreement is identically interpreted by the visited network providing same performance or at least the one agreed for roaming case. The QCI/5GI classes only give an indication of what QoS to expect. Thus, besides the cross-vendor issues described in Section IV.A, diverging behaviour can also result from different parametrization of the schedulers. SLAs might require more information than what is provided in the QCI/5QI tables. A potential solution is to use Network Slice templates, which support a common, machine readable understanding of QoS requirements across MNOs. A challenge arises if a prediction for a different than the currently serving network is needed. This can be particularly true when crossing a country border. Furthermore, the reliability of the prediction or other parameters defining its confidence might be different for different MNOs. In the worst case, involved MNOs do not offer a QoS prediction service. Furthermore, a common method to identify and address the PF offered by an MNO is required to continue using a PF after being handed over to a different MNO.

Finally, the issue of having different, potentially not compatible, cloud management systems is discussed in [4]. If MNOs have customized management systems, third party software MEC application server providers face the challenge of having to customize their software images for the different systems. A P-GW in the home network is always used in case of home-routing. Local Breakout for MEC is therefore prohibited. Network supported APN configuration might not be possible in a visited network or the APN configuration from the home network might not be accepted by the visited one. MNO-dependent server discovery mechanisms might also differ in different networks. The above examples mostly refer to non-standalone 5G New Radio where certain customization on the client side might be required for certain use cases. MEC-related mechanisms in standalone 5G New Radio are, as far as we evaluated them by now, designed in a way to be transparent for the client application in the vehicle. MNOs can therefore apply different solutions and still achieve the same goal, e.g. seamless gateway switching and end-to-end service continuity when switching the MEC-hosted application server. Many of the 5GCroCo use cases require information exchange between neighbouring MEC hosts. Within one MNO this is possible through the transport network outside of the 3GPP domain but doing this across MNOs might be more challenging.

C. Across Car OEMs

Vehicles from different brands are considered in the project and in reality, there are even more brands and each brand has different models with different series. Even within the same series the software and hardware can change, so a huge set of different components must be considered for interworking. Thus, different than for the previous sections, this section is focused on issues resulting from the modem and antenna as the interface of the vehicles towards the network. Some aspects of service quality are beyond network influence and depend on the modem, antenna type and antenna placement. These can be different for different car brands and even within the same brand. The network relies on support from the UE for channel estimation in order to perform link adaptation and handover. Procedures are mostly specified and unified, but per-modem performance differences can exist. End-to-end performance can be different even if everything is identical except for modem and/or antennas.

Although standardized and best practice open-source interfaces for interaction with the modem exist, behaviour can differ across different modems. This is particularly true when querying channel quality parameters. Experience shows that general availability, sampling rate, range, and quantization differ across modems. It cannot be precluded that two different modems report different values for the same channel quality.

Moreover, it must be taken into account that the realization of the vehicle application is tightly coupled with the MEC realization, for example in 5GCroCo's ACCA use case [9]. This includes e.g., server discovery, description of geographical regions and realization of geocasting. Some vehicle OEMs already have systems in place for other or similar services with certain solutions that might be intended for reuse. This can result in the desire to not have identical, and therefore naturally interoperable vehicle applications, but allow a certain degree of customization as long as interoperability through the backends is assured.

V. DEPLOYED ARCHITECTURE, TEST AND TRIALS

Taking into account what has been described in the previous sections and all the accumulated experience related to it, 5GCroCo is conducting 5G large-scale trials on cross-border roads at the French-German and German-Luxembourgish borders since the end of 2020. The different use cases of 5GCroCo were rolled out in this large-scale corridor as described in [10] and the deployed architecture for, e.g., the HD Mapping use case is depicted in Fig. 1.

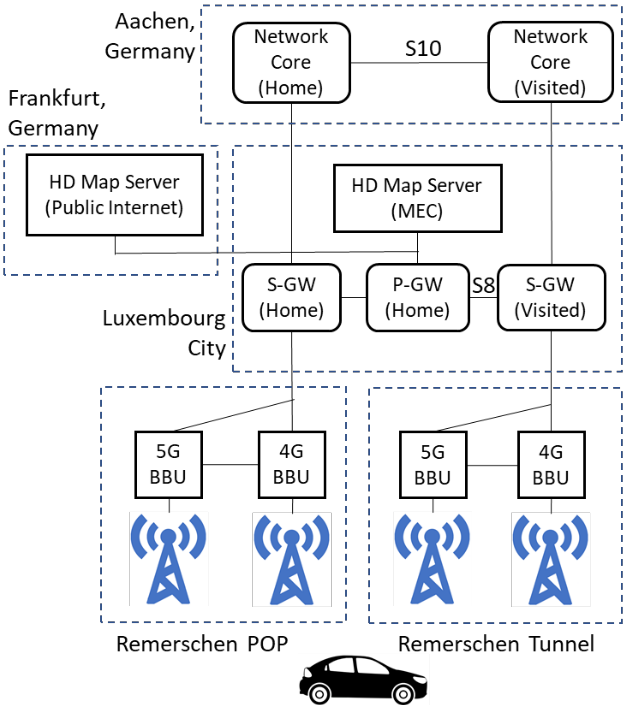

Fig. 1. Architecture of Deployed Networks for Trials

As a first step towards our large-scale tests, small-scale test site deployments in France, Sweden, Germany, and Spain have been carried out, despite the difficult situation imposed by COVID-19. All use case implementations planned for this first round of trials were finished and have been validated from a functional perspective. The tools to measure the KPIs have been set up and the components that need to report their measurements were also properly validated. As a summary, all small-scale test and trial sites are finished and almost all intended tests and trials were successfully completed. The obtained results for all small-scale and the German-Luxembourgish part of the large-scale test and trial site are reported in [11] and summarized below:

- **Cross-border / -MNO handover** works and no substantial impact on use case performance was observed.
- The maximum **downlink throughput of the 5G network oberating at 40 MHz with 4:1 downlink/uplink ratio for Time Division Duplex (TDD) is 306 Mbit/s** and therefore higher than for 4G (46 Mbit/s) but also the area where it can be achieved is smaller, due to the much higher frequency band (3.7 GHz for 5G, 700 MHz for 4G) and therefore higher radio attenuation over distance.
- The maximum **uplink throughput is** almost the same **for 5G (31 Mbit/s)** and 4G (24 Mbit/s) due to the TDD pattern mandated for the 5G network (downlink has four times the resources of the uplink).
- **RTTs under static conditions are 8.2 ms** on average with 90 % within 11 ms and 98 % within 13 ms for small packets like 56 Byte emitted by the Ping application. Larger packets, e.g. 500 Byte, require 5 ms more on average.

VI. CONCLUSION

With the main results presented in the previous section, it can be safely concluded that the latency requirements of the ACCA use case can be fulfilled leaving plenty of delay budget for processing in the backend. The throughput requirement for HD Mapping is fulfilled and map downloads finish within 10 s. ToD was not yet trialled in Luxembourg due to travel restrictions, but it is already obvious that the optimal uplink throughput of 50 Mbit/s will not be available, but still more than the minimum required throughput of 10 Mbit/s can be achieved allowing to execute the use case as planned. The one-way latency requirement for ToD should be satisfied.

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REFERENCES

[1] 5GCroCo D2.1, “Test Case Definition and Trial Site Description Part 1”, July 2020.
[2] 5GCroCo: Use Cases and Users Stories Animations Video. Available online: https://www.youtube.com/watch?v=1v1i2vp8cEQ&t=2s
[3] 5GCroCo D2.2, “Test Case Definition and Test Site Description for Second Round Tests and Trials”, November 2020.
[4] 5GCroCo D3.2, “Intermediate E2E, MEC & Positioning Architecture”, January 2021.
[5] GSMA, “NG.116 v3.0 Generic Network Slice Template,” 2020
[6] 3GPP, “TS 23.501 v16.1.0 System architecture for the 5G System (5GS),” 2019.
[7] 3GPP, “TS 23.288 Architecture enhancements for 5G System (5GS) to support network data analytics services,” 2020.
[8] Tomas Nylander, Roland Gustafsson, Daniel McGillivray, Henrik Sahlin, “Keeping vehicles connected when they cross borders”, 2019, https://www.ericsson.com/en/blog/2019/5/connected-vehicle-cross-border-service-coverage
[9] 5GCroCo D3.1, “Final Application Architecture”, January 2021.
[10] 5GCroCo D4.1, “Report Validating Development and Integration in Network, Vehicle and Backend on Small- and Large-Scale Trial Sites”, January 2021.
[11] 5GCroCo D4.2, “First Phase Trial Execution Report and Analysis of 5GCroCo KPIs”, April 2021.