Connected and Automated Mobility Services in 5G Cross-Border Environments: Challenges and Prospects

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Connected and automated mobility services in 5G cross-border environments: challenges and prospects

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The next generation of mobile networks, namely 5G, promises significant qualitative and quantitative advances for multiple vertical domains. However, most studies and investigations assess these advances under the implicit assumption of a single network service provider, with typical national coverage. In this paper, we take a close look at the automotive sector and highlight a series of challenges emerging in the context of its inherent (inter-)national mobility and the corresponding importance of cross-border and/or multi-operator environments. Our target is to pinpoint the key influential factors affecting the transition towards seamless (cooperative) connected and automated mobility services within and across national borders. To this end, we identify and analyse a series of challenges in the areas of, networking, application, security and regulation. We further present and discuss a series of corresponding solutions investigated in the pragmatic context of our experimental activities.

Introduction

The advent of 5G is expected to bring significant advances to the world of mobile communications. The support for substantially increased data rates e.g., in the order of up to 1 Gbps/user, only a few milliseconds latency, and the ability to host massive numbers of IoT devices e.g., 1 million/km^2, signify the ability of 5G to support a plethora of new demanding services in various domains i.e., the so-called verticals.

The automotive sector presents particular interest in this context. A series of advanced (cooperative) connected and automated mobility ((C)CAM) solutions [1], ranging from autonomous or remote driving, to extended sensor-based environmental perception and platooning, present stringent performance requirements to be met by 5G networks e.g., latency below 5ms for platooning, or below 10 ms for cooperative manoeuvres [2]. Such applications are expected to bring significant improvements on mobility, including commuting, travelling, as well as goods transportation and logistics. For instance, the more than 1,500 billion tons-km of freight traffic via road in EU-28[1] reflect the importance of advanced (C)CAM services across Europe e.g., reducing fuel consumption with truck platooning. In this context, the EU has set the target for "all urban areas and major terrestrial transport paths to have uninterrupted 5G coverage by 2025" [3].

However, reaping the benefits of (C)CAM services faces a series of challenges that clearly go beyond infrastructure deployment costs, and all relate to the support of service continuity i.e., the uninterrupted user experience of a service [4]. At the core of these challenges, lays the extended scope of mobility in the automotive sector i.e., extending from typical urban environments to rural ones, further reaching transportation at an (inter-)national level e.g., transnational commerce. In such environments, satisfying the aforementioned performance requirements, while ensuring service continuity, is exceedingly challenging, especially if viewed in the light of the cross-border environment diversity; which is shaped by a series of factors: 5G deployment options and roll-out stages, edge computing and application-level mobility, spectrum and automotive regulation, to name a few. What is more, the progressive deployment of and transition to 5G, render these challenges of particular importance even in the context of national roaming. In the example application shown in Figure 1, data, such as sensor readings e.g., high resolution video, collective perception messages (CPM), and cooperative awareness messages (CAM), from vehicles and road-side infrastructure, are fused, and information is extrapolated at the edge computing nodes, which are responsible for quickly and reliably delivering notifications e.g., lane change advice via manoeuvre coordination message (MCM), to nearby vehicles. Seamless service delivery is challenged as the computing and communicating end points change due to the vehicle mobility across the border.

This paper sets out to identify and explore key challenges towards the support of seamless 5G cross-border (C)CAM services. Our work focuses on the intersection of 5G deployment/roll-out, (C)CAM service specificities and mobility challenge areas, with the purpose of identifying key influential factors affecting the transition towards seamless (C)CAM services within and across borders. This work brings together and analyses the views of a large set of telecom operators, major European vendors, automotive OEMs, IT and

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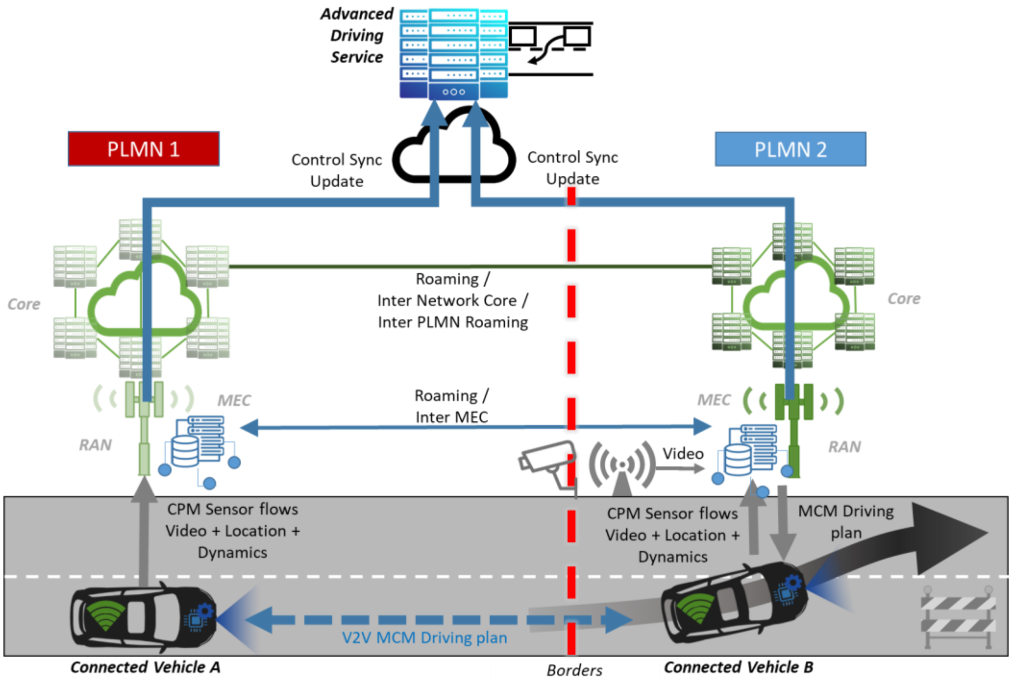

Figure 1 *Example (C)CAM application Infrastructure-assisted advanced driving. A Mobile/Multi-access Edge Computing (MEC) node, located at the Radio Access Network (RAN), collects sensor and CPM data from vehicles and roadside infrastructure, fuses them, analyses collision risks, and safely guides vehicles, using MCM. MEC nodes, particularly those installed in different Public Land Mobile Networks (PLMNs) cooperate with each other and with the central entity to ensure service continuity at the cross border.*

(C)CAM application developers, services industries, research institutes, as well as road operators/local authorities, from across Europe, as an outcome of 5G-MOBIX, a large EU-funded Innovation Action project focused on experimentation [5]. We identify and analyse a series of challenges, categorizing them in four categories, namely: Networking, Service Layer, Security and Regulatory. Focusing on the most challenging issues, we discuss their impact on seamless (C)CAM service support, as well as the respective solutions investigated in our experimental activities. An overview of identified challenges and solutions is provided in Table 1.

In contrast to previous work [6][7], and to the best of our knowledge, this is the first attempt to both (i) pinpoint these challenges taking into account the migration path towards 5G deployment, and (ii) report on experiences and insights from practically dealing with the identified challenges, and applying the corresponding solutions at a scale of two international and four national 5G trial sites. Our experimental approach complements numerical/simulation based investigations on individual challenges e.g. [8]. Also our holistic perspective, covers cross/application-layer aspects, going beyond 5G NR-specific issues and solutions [9].

In the following, we first present the technological context of this work including the 5G architectural environment and the (C)CAM applications at hand. Then the identified cross-border issues and solutions are detailed across the four identified categories. Finally, the work is concluded.

5G for (C)CAM Context

Our investigation takes an experimental approach in identifying the key challenges in the context of 5G infrastructure deployment and trial activities at two cross-border corridor (CBC) sites i.e., at the Greek-Turkish (GR-TR) and Spanish-Portuguese (ES-PT) borders, and four multi-PLMN national trial sites (TS) namely in Germany (DE), Finland (FI), France (FR) and the Netherlands (NL). This further gives ground to the design, implementation, deployment and eventual evaluation of the corresponding solutions in real environments. Focusing on the migration path to 5G, the CBCs are deploying their networks based on a common basic 5G NSA architecture, entailing a direct interconnection of the neighbouring Public Land Mobile Network (PLMNs) (see Figure 2). MEC and cloud functionality is available at both CBCs based on a distributed cloud architecture [11]. 5G SA deployments at national TSs e.g., FI and NL, provide the context for the investigation of issues and solutions in future deployment environments, as discussed below. Our effort to identify the key challenges for (C)CAM applications goes through a series of Use Cases grouped in five main Use Case Categories (UCC) [1]: 1) Advanced Driving, 2) Vehicles Platooning, 3) Extended Sensors, 4) Remote Driving and 5) Vehicle QoS support. The variety of (C)CAM applications at hand, gives ground to the identification of challenges associated to different performance requirements e.g., latency for Remote Driving vs. Advanced Driving.

Category	Issue Title	Overview	Considered solutions
Networking	Inter-PLMN handover	Insufficient network and UE steering capabilities for HO; local UE behaviour not tailored for service continuity.	Smart UE HO steering; multi-SIM/multi-modem UEs.
	Service/Session Continuity	Early roll-out phases will not support make-before-break (SSC Mode 3).	Application function interacting with both UE and the Core, steering UE session establishment.
	Routing	Home Routing vs. Local Break-Out: service/session disruption vs. service degradation.	Network dimensioning with experimental assessment of trade-off in both SA and NSA deployments; direct (leased line) interconnection.
Service Layer	Handling communication disruption	Need for application-level support against service disruption.	Non-connection-oriented protocols; service discovery and resilience; state management; predictive QoS
	Accurate Geo-positioning	Limited number of reference points; lack of coordination framework across PLMNs.	Compressed sensing; channel estimation; angle-of-arrival/departure.
	Geo-Constrained Information	Scoping the delivery of information subject to location/context of the vehicle.	Publish/subscribe inter-PLMN broker topology; *quadtree* tiling.
Security	Data Privacy and GDPR	Data privacy through anonymization or other mechanism, data ownership, personal data processing under different regulations, common data processing procedures.	GDPR enforcement through common EU procedures, end-to-end data privacy protection at service layer; TLS connections; DPIA
	Trusted and secure communications	Confidentiality, authenticity and authentication features. Lack of trust domain definition results in non-authenticatable information exchange.	3GPP security features; service-level MQTT solution using TLS to support message exchange between domains.
Regulation	Geo-dependant spectrum	Differences in radiofrequency spectrum availability.	Multi-SIM/multi-modem UEs; fall-back PC5 and/or satellite connectivity.
	Law enforcement interaction	Communication procedures and protocols needed for law enforcement across countries.	Integration of hard border customs.

***Table 1** Overview and classification of challenges and potential solutions for 5G supported cross-border (C)CAM functionality.*

Networking Issues

The most prominent issues to be resolved for (C)CAM service continuity relate to mobility management and broader inter-PLMN handover (HO) implications. These implications are shaped by the migration path towards 5G deployment, which passes through intermediate stages and deployment options combining 4G/LTE components i.e., Non Stand Alone (NSA) deployments [12].

Inter-PLMN Radio Handover

When a user equipment (UE) e.g., an automated vehicle, crosses the country borders, switching to another PLMN, operated by another Mobile Network Operator (MNO), a radio HO needs to be performed in a way that fulfils the aforementioned strict performance requirements of the corresponding services/applications. Currently however, the UE tries to stay at the network it is connected to, resulting in connection losses of minutes. This is because 1) the UE keeps the current connection, only searching for other networks after the connection is lost; 2) the UE performs a full network search before selecting a new operator; 3) most operators have steering on roaming enabled, however steering the UE subject to roaming agreements and not radio conditions. In essence, current roaming network selection is practically controlled by the UE and the network lacks fine-grained control.

CONSIDERED SOLUTIONS: 5G-MOBIX investigates *short-term solutions* by implementing a smart steering algorithm on the UE, which triggers regular searches and forces the UE to do a handover when needed. The algorithm continuously measures the signal strength of the available networks. If values fall below a certain threshold and there are other networks with a better signal, a reconnect is triggered. To prevent unnecessary switching between networks a centralized Prediction Function helps to make the best selection depending on the current location of the UE. As current UEs simply stay connected until the signal is lost before looking for a new network an application running in the vehicle is needed, to steer the modem to the best network based on measurements and a central function. Tests show that this mechanism reduces connection loss duration, from a few minutes, down to between 1 second and 10 seconds. To achieve however the sought after performance, in the short term, we further consider multi-modem / multi-SIM card solutions. In this approach, one modem can already connect to the new network before the old connection is broken. In a comprehensive development, the in-vehicle application or multi-SIM router making the HO decision, considers the network better meeting QoS requirements in terms of latency, bandwidth or a combination.

We further explore *mid-term solutions* to enable an S1 (4G Core) / N2 (5G Core) handover between bordering PLMN networks. To enable a handover between bordering PLMNs, the S10 (4G Core) / N14 (5G Core) interface is added next to the regular interfaces. These are existing and standardized interfaces, normally only used in a single network to connect different Mobility Management Entities (MMEs) or Access and Mobility Management Functions (AMFs). In single-PLMN environments, the operator code stays the same, hence no PLMN selection is needed during the handover and the UE simply scans the same frequencies looking for the current PLMN. The current base station knows what other base stations are in range and can direct the UE to the best new base station. As shown in Figure 2, we extend this functionality to inter-PMN scenarios, linking the S10 / N14 interface over an IP/MPLS direct connection between the PLMNs. Base stations are configured with information about other base stations in bordering PLMN's. Only then the current base station can direct the UE to the base station of the other PLMN. Tests have shown that this approach reduces connection loss duration to around 200-300ms. However, the solution requires the details of neighbouring networks to be collected, kept up to date and programmed in the base stations at the borders. This is a challenging factor for the scalability and complexity of this approach, not to mention the trust that is required between the neighbouring operators.

Our investigation and experience, reveals that *longer-term solutions* will need to carefully take into account the following considerations: 1) the home PLMN should have influence on the actual network selection to select a suitable network; 2) the home PLMN has insight in the actual resource availability of the potential visited network; 3) a minimal level of integrations and special configurations are needed to enable a scalable solution. This requires changes in the current roaming procedures, UE behaviour and network functions.

Service/Session Continuity

In addition to network selection and the triggering of a radio HO event, minimizing service disruption during cross-border mobility further depends on the actual sequence followed to establish a new or maintain the existing communication session. This sequence has important implications on connectivity after a radio HO event. In understanding these implications, it is important to first distinguish between service continuity and session continuity. While the first refers to service-level user experience, session continuity considers preservation of network attachment parameters, such as the IP address, during a HO process.

3GPP has defined three Session and Service Continuity (SSC) modes for protocol data unit (PDU) sessions in 5G Stand Alone (SA) [4]. With SSC mode 1, the User Plane Function (UPF), that plays the role of a packet gateway (GW) for UE traffic, gets selected once at the PDU Session Establishment and is maintained throughout session lifetime regardless of UE mobility. The UE's PDU session IP address does not change, even after mobility. However, maintaining the UPF instance may come at a performance cost i.e., increased delays on the sub-optimal UE-UPF path (see also *Routing* next). In SSC mode 2, the network may trigger the release of the PDU session and instruct the UE to establish a new PDU session from its new location. In this scenario, the IP address changes and a new PDU Session Anchor UPF may be selected. Finally,

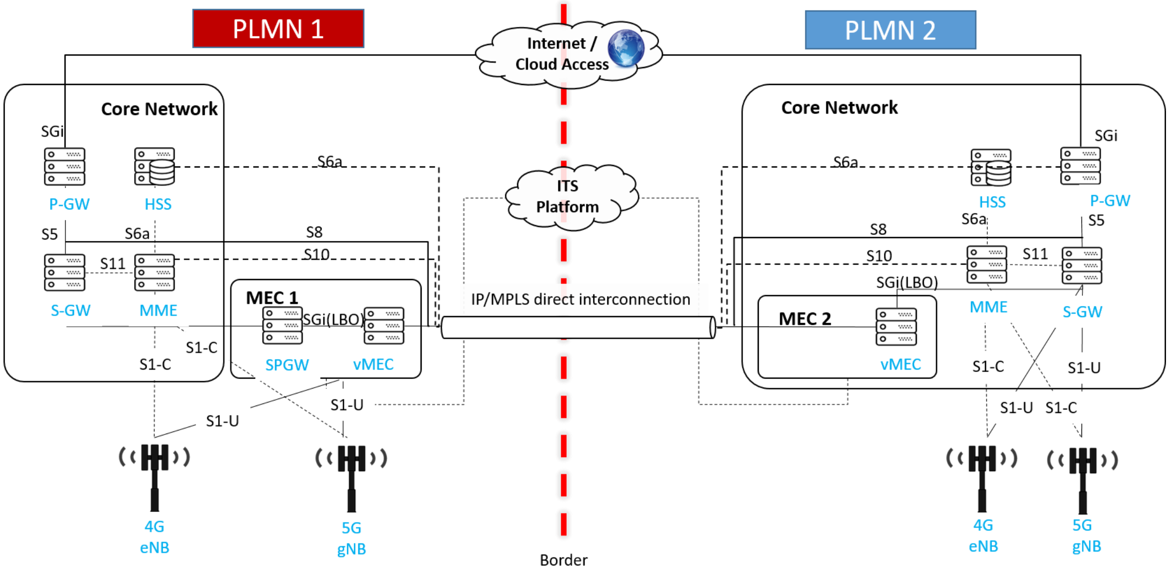

Figure 2 *5G-MOBIX common basic architecture for inter-PLMN connectivity in the GR-TR and ES-PT cross-border corridor testbeds. S10 interface is extended across for the support of inter-PLMN HO.*

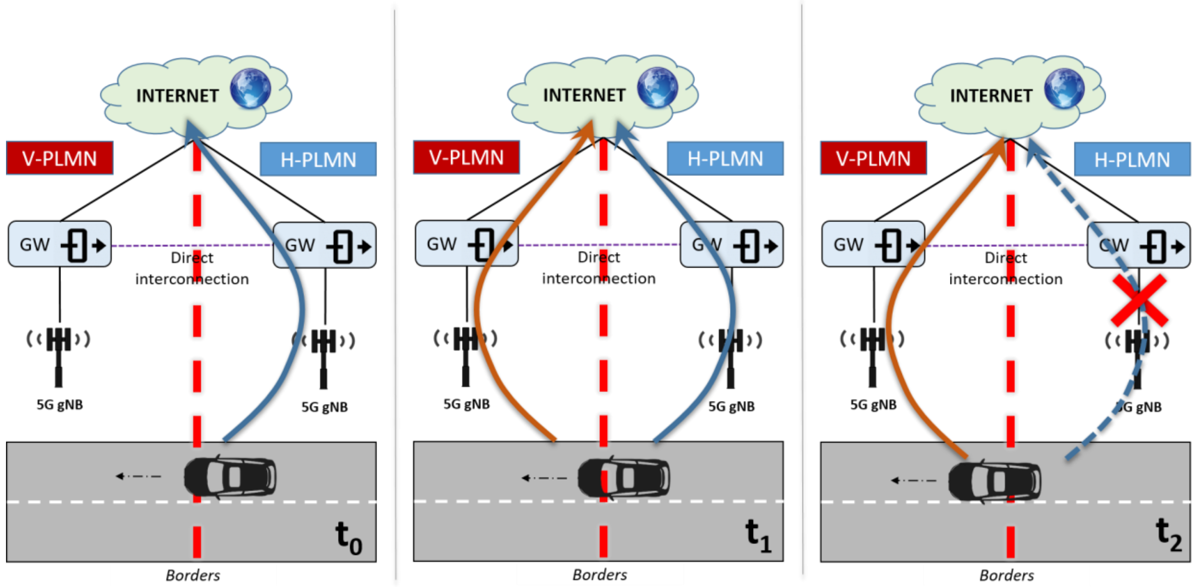

Figure 3 *Make-before-break in SSC Mode 3. The UE (a vehicle in the considered environment) establishes a PDU session with the visiting network before breaking the existing one at the home network.*

SSC mode 3 employs a make-before-break approach, where the network ensures that there is no loss of connectivity (see Figure 3). The network allows the establishment of UE connectivity via a new PDU Session Anchor UPF before connectivity between the UE and the previous PDU Session Anchor is released. SSC mode 3 involves changing the IP address but supports service continuity through the make-before-break approach. Although the mode is defined considering connectivity through the same Data Network, the signalling procedure can be also applied in the case of inter-PLMN handovers, with different Data Networks involved, i.e., switching from a home routed data connection to a local breakout connection (see *Routing* next). SSC mode 3 has not been implemented so far by any vendor nor is it seen on vendor roadmaps, while it also requires specialized UEs (with multiple Tx-Rx chains). As a result, the solution space appears unclear, especially in view of the evolutionary path from 4G to 5G NSA and eventually 5G SA deployments.

CONSIDERED SOLUTIONS: Supported by our 5G SA deployments, our work here focuses on the support of SSC in the particular context of edge computing, employing a mixture of techniques, as also indicated, though not fully specified, in [4] (Section 5.13). The solution is based on the development of an application function (AF) which interacts with the mobile core via the network exposure function (NEF) and controls the UE behaviour. Via the NEF the AF receives a location update when the UE enters a region covered by a new edge. The AF instructs the in-vehicle application to setup a PDU session to the new edge before breaking the old PDU session. For this, the in-vehicle application needs to keep connected to the AF. This has the advantage that both the in-vehicle application and the UE can be steered to the closest edge node and also that the application is triggered in time to set up a new connection. In cross border environments, the AF triggers this behaviour without the need of special integrations of the neighbouring PLMN's to facilitate SSC between both networks.

Routing

Roaming places significant challenges relating to the routing of the traffic and associated performance. When roaming traffic is Home Routed (HR), subscribers always obtain service from their home network i.e., traffic is routed to their current location through a packet gateway at their home network (see Figure 4). As the service is always managed through the same gateway (Packet Gateway (PGW)/UPF), service continuity, while roaming, is facilitated. However, this comes at the cost of increased latency due to the user plane traffic being routed from the visited network to the home network, typically through the GRX (GPRS Roaming Exchange)/IPX (IP exchange) networks. On the other hand, Local Break-Out (LBO) (see Figure 4) allows the optimization of the roaming traffic path through the visited network PGW/UPF, at the cost of potential service disruption since a new PDU session needs to be established at the visited network.

CONSIDERED SOLUTIONS: The selection of roaming network mode obviously depends on 1) the latency and service continuity requirements of the services at hand i.e., sensitivity to latency and/or disruption e.g., LBO service disruption may be prohibitive for remote driving operations, but tolerable by cooperative manoeuvre traffic flows, and 2) the actual latency or disruption delivered by each mode. The latter depends on the overall topology and dimensioning of the network. HR is in principle associated with the delay penalty of inefficient

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routing, but the exact penalty size depends on the performance of the intermediate GRX/IPX. Direct inter-PLMN connections i.e., through high performance leased lines, appear as a potential approach, promising the benefits of HR at a low latency cost, although such a solution might not be (financially) cost effective. Towards the experimental assessment and *quantification of the latency (HR) vs. disruption (LBO) trade-off* presented above, tests have shown that LBO disruption can reach several seconds revealing the need for optimization, as well as standardization, of the IP session restoration triggering mechanism. HR avoids this disruption, however yielding E2E latencies in the order of 60ms, against 40ms values exhibited in LBO.

Service Layer Issues

Handling Communication Disruption

As previously discussed, a HO event can imply the change of network address with impact on running UDP/TCP communications and service disconnection. Moreover, a change of MNO in a roaming situation can imply a different set of protocols used in each domain e.g., IPv4 vs. IPv6. All this becomes especially evident in the case of edge computing, where latency requirements impose a switch to a different instance of an edge-supported application server i.e., both ends of a communication session may change. In several cases, this may correspond to the need for state/session and/or data transfer between the involved edge nodes. Under these circumstances, the end-to-end nature of the transport layer in the TCP/IP protocol stack becomes problematic in delivering a stable communication substrate to the applications. As such, the applications' ability to adapt to underlying network changes becomes increasingly important, so as to reduce the impact of mobility and ensure service continuity.

CONSIDERED SOLUTIONS: In this context, our solution set leverages: 1) non-connection-oriented protocols such as UDP, when possible, which facilitates resuming data flows when communication is available again; 2) resilience features related to connectivity management e.g., service discovery, for solving the uncertainty about the network address that each entity is reachable by; and 3) disruption tolerant behaviour in what concerns state management e.g., stateless applications, context migration of state-full applications, that allows to resume applications after an interruption without any dependency to the past, or by recovering these dependencies. Application-level solutions further encompass techniques such as imminent HO detection, pro-active IP change notification and DNS updates. At the same time, application design is further enhanced with pro-active communication or caching of static information where applicable e.g., border area events, ensuring information and resource availability before the vehicle reaches the area where it may lose connectivity. Finally, solutions further consider predictive QoS principles [12], where the expectation of service degradation triggers proactive actions e.g., state transfer between edge node application instances, across borders, vehicle data rate adaptation. During our experimentation and trialling activities, a large amount data from vehicles,

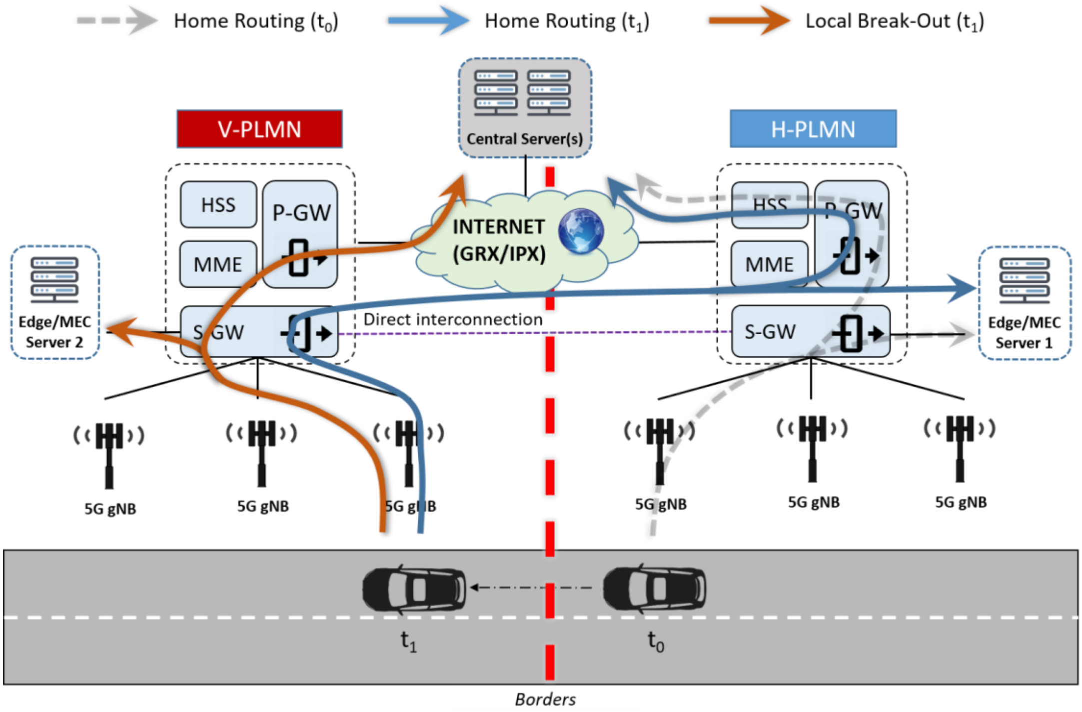

Figure 4 *Home Routing vs. Local Break-Out for two neighbouring 5G NSA networks.*

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applications, and networks is collected at a central QoS prediction module. An example of such data includes vehicle position, velocity, direction, future trajectory, application requirements, link quality, throughput, latency, frequency, uplink/downlink bandwidth, and cell occupation. Data is fed to a supervised machine learning module trained to predict communication quality for vehicles at their near future position. The prediction is conveyed to consuming entities e.g., vehicles, via so-called In-Advance QoS Notification (IQN) messages [12].

Accurate Geo-Positioning

Current autonomous vehicles heavily rely on positioning e.g., for steering and navigation or during manual or automated remote driving. Global Navigation Satellite Systems (GNSS) positioning cannot meet the requirements of these applications, i.e., down to 20-30 cm accuracy, cannot be used while indoors (for example in tunnels, indoor parking/garages or lower decks of multi-level bridges), and have strong limitations in dense urban environments. GNSS also lacks a refresh rate high enough to be used in safety critical applications. Without accurate geo-positioning, (C)CAM applications that require external information based on absolute position cannot merge this information onto local maps with relative positions (distance to other vehicles/obstacles, lane position, etc.). In addition to employing in-vehicle and road side equipment, such as radars, currently envisioned solutions focus on 5G mmWave band characteristics, allowing, together with network densification, for a higher precision and refresh rate [14]. Nevertheless, cross-border environments challenge the applicability of such solutions as they present limited reference (base) stations, potentially larger delays/distances to the nearest edge and a lack of coordination across (PLMN) borders.

CONSIDERED SOLUTIONS: 5G-MOBIX investigates augmenting positioning through the use of compressed sensing techniques on the OFDM signal. Estimated channel improves localization accuracy where only few reference (base) stations are available and only line-of-sight and few multi-path components contribute to the received signal. At the same time, taking advantage of known angle-of-arrival/departure and the sparsity of mmWave channels in the angular domain, substantially improves downlink positioning. The improved performance with few reference (base) stations and potential independence of PLMNs allows accurate positioning at and across borders.

Geo-Constrained Information

A connected vehicle usually needs to receive traffic information directly related to its surroundings, not the whole flow of (C)CAM messages exchanged through the edge computing node it is connected to. When it is travelling close to the border, it might also want to receive some data from neighbouring geographical areas covered by an edge node located in another PLMN. Also in this situation, not all (C)CAM information exchanged through the neighbouring edge node is of interested to that specific connected vehicle. For instance, in a platooning application, the connected and autonomous members of the platoon solely need to exchange data with the platooning vehicles and possibly with some other vehicles and sensors in the vicinity. As a result, geo-constrained information dissemination schemes should be devised in order to disseminate the relevant CCAM data to the appropriate vehicles.

CONSIDERED SOLUTIONS: We handle this problem through a Message Queue Telemetry Transport (MQTT) broker publish/subscribe architecture based on *quadtree* tiling schemes for the geo-localized dissemination of standard ETSI C-ITS messages and also other relevant CCAM information, such as HD-Maps updates. The MQTT protocol provides a common communication layer between users, allowing one-to-one, one-to-many or many-to-one transfer of information. Adopting a bridging approach [15], the solution exploits a direct interconnection of the MQTT brokers instantiated in the edge computing nodes of the different MNOs. This is extended by the tiling scheme that handles communications in a geo-located manner, so that only the (C)CAM information related to the geographical areas on the border is exchanged between the edge nodes from distinct MNOs.

Security Issues

Cross-border mobility inherently relates to the traversal of administrative and authoritative borders, both on a (network) service provisioning level, and on the road and national authoritative level. As such, a series of security and privacy issues emerge.

Data Privacy and GDPR

Legal issues arise due to the enforcement of the European General Data Protection Regulation (GDPR)[1] to the automotive sector and (C)CAM services in particular. Without proper legal basis, as for instance demonstrated by explicit user consent, lawful processing of personal data cannot be achieved. For example, CAM and DENM messages are considered personal data but are required for the normal functioning of (C)CAM systems. Compromising the confidentiality of personal data (location, car identification, etc.) is expected to hinder the deployment and sustainability of the corresponding services, both in terms of compliance to the law, but also in terms of user acceptance. In parallel, different data protection regulations may apply in neighbouring countries e.g., between Greece and Turkey. In all, different levels of data protection may cause services to become unavailable across borders.

CONSIDERED SOLUTIONS: The enactment of a legal instrument in the European Union and in other involved

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[1] General Data Protection Regulation: https://gdpr-info.eu/ [Last accessed:September 20, 2022]

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countries is necessary, so as to define the entities and the measures to be used in order to guarantee fair, harmonized and lawful processing of personal data in the context of (C)CAM. The solution adopted in 5G-MOBIX relies on assuring at least end-to-end data privacy using Transport Layer Security (TLS) connections, to avoid data disclosure at intermediate points between the user and the edge/cloud processing nodes.

Trusted and Secure Communications

Confidentiality and integrity of messages exchanged by vehicles and roadside infrastructure must be assured when involving critical services such as safety-of-life applications. However, security features and their configuration parameters could be provided in a local basis, within a known “trust domain”. This raises a critical issue when involving different network operators and/or countries. Without a common network domain in which communications can be trusted, secure communications among vehicles and the protection of the privacy of data subjects cannot be assured.

CONSIDERED SOLUTIONS: 5G-MOBIX first considers the adoption of base 3GPP security and authentication features to assure essential secure communications. In an attempt to further harmonize the secure exchange of data between different domains, a service-layer security approach is followed. Hence, the MQTT solution adopted for message exchange between MEC servers and ITS centres is secured using TLS, as indicated above. However, in the long term, it is understood that international agreements between different trust domains must be established to address co-existence issues e.g., using cross-certification or federating credentials at a larger scope e.g., European level, that assure the application of privacy preservation mechanisms.

Regulatory Issues

Regulation becomes important when it comes to supporting the smooth operation of services across administrative and national borders. At the same time, smooth services are required to enable regulated operations by authorities across borders.

Geo-Dependent Spectrum Regulation

Neighbouring countries can have different radio-frequency spectrum allocations. If the frequency used by the on-board connectivity systems is not available on the destination country, then connectivity functions might become unavailable. Therefore, service might not be available in the visited country and can even break the law if it transmits on an unauthorized frequency.

CONSIDERED SOLUTIONS: Multi-SIM/multi-modem approaches may help solving this problem, considering that different modems could support distinct spectrum bands. Alternatively, fallback solutions relying on PC5 technology or satellite communications can be also considered to assure connectivity when crossing the border

Law Enforcement Interaction

As automated driving technology becomes widely adopted, law enforcement entities must be able to interact with automated vehicles. For instance, one can envision situations in which police officers may need to force a vehicle to stop if there is suspicion that it is carrying a wanted individual. Dedicated communication procedures and protocols will need to be in place to ensure that authorities can communicate with vehicles, even if they originate from a different country being generally served by a foreign network provider.

CONSIDERED SOLUTIONS: The procedures to handle these situations should be standardized, granting agents on both sides of a border the possibility to interact with the vehicle. A common (internationally agreed) communication standard for law enforcement interaction could be a solution for this issue. In the scope of 5G-MOBIX, a specific use case targeting hard border customs verification is deployed, enabling customs agents to obtain a real-time overview of the driver and the cargo as the vehicle approaches the borders and to request autonomous vehicles to stop whenever needed. The solution involves machine learning techniques for risk assessment, predictive handover and application migration between multiple edge computing nodes and the cloud environment in an inter-PLMN scenario.

Summary and Conclusions

Advanced (C)CAM applications come with strict performance requirements, rendering 5G as a necessary key enabler. However, mobility inherently puts emphasis on aspects related to service continuity, which become of paramount importance when it comes to (inter-)national borders. Reflecting the results of a detailed investigation by major European MNOs, vendors, automotive OEMs, local (road) authorities, and technology developers participating in the 5G-MOBIX EU project, this article identified and shed light on a series of emerging challenges towards seamless (C)CAM services using 5G networks, within and across borders. The article highlighted the effects of spatiotemporal diversity in the technological and regulatory environment, as shaped by the gradual transition towards 5G and the local regulatory frameworks, and the importance of standardization.

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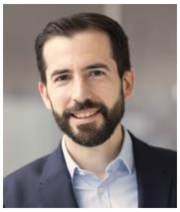

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