The 5G Route to Connected and Automated Mobility: the 5G-ROUTES Project

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***Abstract*—The motivation behind the development and deployment of connected and automated mobility (CAM) applications embraces clear environmental, demographic, and social-economic aspects including improved traffic efficiency, road safety, and driving comfort to name a few. However, the 5G communication networks will be challenged by the deployment of CAM services, as such services need to work seamlessly across borders, their delivery should be multimodal, and regardless of whether passengers or cargo are involved. The overall objective of the H2020 ICT-53-2020 5G-ROUTES project is to accelerate the widespread deployment of 5G end-to-end interoperable CAM ecosystems and services by validating key 5G features and the latest 3GPP specifications in large-scale trials in a designated 'Via Baltica-North' 5G cross-border corridor. This paper is aimed at providing a broad perspective on the 5G-ROUTES project's scope, objectives and use cases. It also offers an insight into the on-going innovation activities and contributes with an initial version of a cross-domain integration fabric designed to seamlessly support CAM services across borders.**

Keywords*—*5G networks, CAM services, cross-border, MNO, use case validation, zero-touch management, automation, AI, ML, distributed MEC, network slicing, spectrum use, positioning.

I. Introduction

The European Commission (EC) has the ambitious goal to make the mobility and goods in the European Union (EU)[1] more safe, clean, efficient, accessible, and user-friendly. The 5G communication networks are expected to contribute to the realization of this bold vision through the support and provision of innovative connected and automated mobility (CAM) applications. The overall goal of the 5G-ROUTES project [1] is to accelerate the widespread deployment of 5G end-to-end (E2E) interoperable CAM ecosystems and services in motorways, railways and waterways throughout Europe. To attain this objective, the 5G features and latest 3GPP specifications will be validated under realistic conditions in the 5G-ROUTES project. In particular, large-scale field trials of some of the most innovative and representative CAM applications will be conducted in a designated 'Via Baltica-North' 5G cross-border corridor[2] that spans 3 EU member state borders, namely Latvia-Estonia-Finland.

The H2020 ICT-53-2020 5G-ROUTES is an Innovation Action project, initiated in September of 2020 by a 21-partner consortium that is driven by industry heavyweights (involving telecom operators and vendors, CAM service providers, car manufacturers, railway, logistical and shipping companies) and renowned research and technological organizations. Such amalgam of partners from diverse sectors ensures that all distinct stakeholders' perspectives are considered and holistically addressed. This paper offers a high-level overview of the 5G-ROUTES project's main scope, primary objectives (Section II), selected use cases (UCs) (Section III), and on-going innovation activities (Section IV). We also contribute with the initial version of a cross-domain integration fabric designed to seamlessly support CAM services across EU country borders.

II. 5G-ROUTES Objectives

The acceleration of the widespread deployment of 5G E2E interoperable CAM services will be fulfilled in 5G-ROUTES by accomplishing 8 specific interdisciplinary implementation objectives. These are listed below.

- To develop innovative and commercially exploitable CAM UCs defined together with key experts and stakeholders.
- To analyse the technical and business requirements for the selected vertical UCs.
- To advance and optimize the enabling technologies using Artificial Intelligence (AI) / Machine Learning (ML) for delivering reliable, seamless, and uninterrupted CAM services across borders.
- To develop a 3GPP compliant 5G infrastructure by upgrading key previous assets, integrating technological enablers in an E2E CAM ecosystem, and setting up the 5G cross-border corridor.
- To demonstrate the potential and user value of CAM services by validating applicable standards and target Key Performance Indicators (KPIs), aimed at boosting the confidence for their wide adoption in Europe.
- To develop and validate business models of advanced CAM UCs in cross-border 5G operator environments, demonstrating benefits from potential operational cost reductions and new revenue generation streams; to protect EU IP and ensure long-term economic sustainability.
- To contribute to standardisation and the opensource community by validating applicable standards.
- To ensure long-term success through wide dissemination of the project's results, to exploit synergies with other 5G-PPP projects and 5G CAM initiatives; to actively contribute to the 5G Action Plan[3] strategic initiative for the benefit of the European 5G industries, university education and training.

III. 5G-ROUTES Cross-Border CAM Use Cases

The CAM UCs are the main focus of the 5G-ROUTES project. They have been carefully selected to cover Vehicular-to-Vehicular (V2V), Vehicular-to-Infrastructure (V2I), Vehicular-to-Network (V2N) and Vehicular-to-Pedestrian (V2P) scenarios under all weather conditions, daytime and nighttime, and will be validated in extended large-scale trials, preceded by lab and localised field trials. The selected UCs are well-aligned with the work of the CAR2CAR Communication Consortium[4] and 3GPP related to service

[1]https://ec.europa.eu/transport/themes_en
[2]https://digital-strategy.ec.europa.eu/en/policies/cross-border-corridors
[3]https://digital-strategy.ec.europa.eu/en/policies/5g-action-plan
[4]https://www.car-2-car.org/about-c-its/

requirements for enhanced vehicle-to-everything (V2X) scenarios TR22.186, 5G V2X services and enablers for network automation for 5G TR23.791 and the EC 5G Strategic Deployment agenda for CAM. The challenges in supporting CAM services and UCs across borders are primarily due to the expected service interruption during inter-Public Land Mobile Network (PLMN) handover (HO) and roaming among other aspects. The UCs will allow not only technological validation but better understanding of the roles, relations and responsibilities of market players and public authorities within the CAM ecosystem. The 5G-ROUTES UCs have been grouped into 5 categories. For each UC, the network, service-level and business perspectives will be validated against target KPI values during the trials.

A. Automated Cooperative Driving

Automated driving involves an increased level of automation of the vehicle's functions and a reduction of the involvement of the driver. To achieve the vision of fully automated driving, several key enabling capabilities need to be implemented both in vehicles (AI-based On-Board Units (OBUs), V2V communications and LIDAR detection system among others) as well as in communication networks (5G connectivity for V2X, accurate positioning, Multi-access Edge Computing (MEC) enabled 5G RAN nodes enhanced with AI to name a few).

1) Dynamic vehicle platooning on highways ending in cross-border junctions will be explored as a means for mitigating traffic congestion (increased traffic efficiency).

2) Cooperative lane change to enhance road safety and help to get through difficult traffic situations even when crossing EU borders.

3) See-through view for safe automated overtake for provisioning of enhanced visibility of road conditions to prevent catastrophic head-on collisions during an automated overtake maneuver (i.e., for enhancing the road safety).

B. Awareness Driving

Awareness driving is aimed at ensuring safe passing, collision avoidance and user comfort provision in traffic jams during automated driving. A reliable exchange of road traffic status data, such as enhanced real-time traffic video feeds, and control in complex intersections via V2X communication is required. Information about the position, speed, and driving trajectories of vehicles together with similar information from Vulnerable Road Users (VRUs) plays an essential role.

1) Real-time traffic information and cooperative intersection collision control for enhanced visibility in intersections, for safe automated passing, improved decision making, and avoidance of potential collisions, that is, improved road safety and traffic efficiency.

2) Traffic jam chauffeur for providing automated driving functionality (vehicles with SAE level 4 automation) in traffic jams even at EU borders. It will relieve the driver from traffic jam anxiety leading to increased user comfort and opportunity for the users to employ their travel time more efficiently. Other expected benefits are collision avoidance, increased fuel economy, and reduction of CO_2 emissions.

C. Sensing Driving

The primary objective of this UC group is to enable connected vehicles to share advanced environmental information and observations gathered by sensors; to provide situational awareness, especially awareness of presence of non-communicating VRUs, who are beyond the direct line of sight of drivers; to create a preventive maintenance framework with predictive analytics, to enable long-term maintenance and repair services throughout the lifetime of vehicles. With sensing driving other traffic participants may be warned in advance against dangers they could not perceive themselves and VRUs can be protected in different traffic situations.

1) Sensor info sharing for cooperative situation awareness: connected vehicles can provide holistic view of the local situation well beyond what the sensors of a single vehicle can detect. The expected outcomes relate to efficient management of roadways and development of more reliable self-driving vehicles that can run in motorways even when crossing borders (road safety objectives).

2) Connected maintenance: the automated, life-long monitoring of vehicle's operational status will increase driver safety even when crossing EU borders through remote assessment, real-time alerts and early detection of faults. Other expected benefits include improved customer satisfaction, and reduction of service and maintenance costs.

3) Vulnerable road user collision avoidance aims at extending the safety protection of VRU by enabling reliable interaction between the active vehicle and the surrounding passive VRUs. Expected benefits are reduced number of traffic accidents especially at cross walks and spots without line of sign and at guaranteeing the safety of pedestrians, disabled people, pets, cyclists and motorbike drivers.

D. Uninterrupted infotainment passenger services on the go

The objective of the UCs falling into this group is to allow and enable multimodal passengers to exploit the high-performance capabilities of 5G networks while on-route and when crossing EU member states borders. The expectation is to have uninterrupted user experience for services used by passengers whilst crossing borders and means of transport, both for productivity and for entertainment purposes.

1) 360^o Immersive multi-user gaming on the go is aimed at achieving and validating Ultra-High Definition continuous collaborative Augmented Reality (AR) gaming experience across borders and across different means of transport with content adapting to the user's ambient environment.

2) 3D real-time virtual collaboration on the move. Similar to the previous UC, the goal is to provide seamless and uninterrupted Virtual Reality (VR) experience throughout the entire journey. The focus is on 3D virtual (business) collaboration when crossing borders and when changing different means of transport.

E. Multimodal services

Uninterrupted, seamless service delivery to passengers and visibility of tracked goods throughout the entire journey regardless of the mode of transport is of special interest to the 5G-ROUTES project, too. In particular, the objective is to maintain the quality of experience (QoE) unaltered during the entire journey, irrespective of the change of transport means (QoE should remain the same when changing vehicles or trains to onboard ship liners), 5G network provider (terrestrial and/or satellite), and country (telecom provider).

1) Goods tracking visibility in multimodal cross border logistics: seamless HO and 5G performance between different Mobile Network Operators (MNOs), including terrestrial and satellite.

2) 5G-based proactive and multimodal management of passengers and freight for ensuring the continuation of the communication sessions in the destination network after crossing borders and to automate the inspection of goods/freight towards zero-touch custom inspection and to provide a notification system that informs the authorities at the cross border for anticipated freight and passengers.

3) FRMCS telemetry operation is aimed at improving service availability and performance for telemetry operation of railways through the Future Railway Mobile Communication System (FRMCS).

IV. 5G-ROUTES Innovation Streams

The connected autonomous driving vehicles bring a whole new ecosystem with some of the most demanding requirements, such as high throughput and ultra-low latency. Furthermore, the delivery of CAM services should be seamless, multimodal (that is, independent of the mode of transport) and transparent to both passengers and cargo. To overcome the technological challenges and to fulfill the demanding CAM requirements, several key technological enablers need to be implemented, advanced and optimized. Furthermore, as broadly acknowledged nowadays, supporting the diverse mosaic of connected devices, the exponential volumes of data generated by them in real-time, and the ever-increasing complexity of the underlying communication systems is beyond our human ability to fully comprehend and hence to efficiently control them. Therefore, AI is at the heart of any contemporary network management and an integral part of the on-going 5G-ROUTES innovation activities. The work on the required enablers has been organized into five innovation streams within the 5G-ROUTES project.

We continue with the main contribution from the innovation stream aimed at defining the interaction between different MNOs across borders as it lays the foundation for the implementation of other technological enablers.

A. Multi-operator, multi-vendor, multi-domain interaction across borders

The 5G-ROUTES project aims to deliver seamless cross-border CAM services by proposing a new approach, termed the *integration fabric*. It is based on the ETSI Zero-touch network and service management (ZSM) [2] specification. The integration fabric [2] provides the flexibility to: a) integrate and compose cross-domain management services and b) build closed automation loops that span different (MNO) domains. The ETSI ZSM architecture [2] follows the principles of modularity, scalability, resilience, simplicity, automation, and support of stateless management functions among other.

The 5G-ROUTES multi-domain architecture, illustrated in Figure 1, is based on 3GPP SA2 specifications (following the forthcoming R.16 & R.17 5G releases), as well as the ETSI Network Function Virtualisation (NFV) and MEC specifications. MNOs will deploy in each domain an ETSI compliant NFV Infrastructure (NFVI) with a Management and Orchestration (MANO) stack at the Core data center, and ETSI ISG MEC compliant edge data centers. CAM E2E services will be delivered in a tailored slice that complies with a set of requirements defined in a Network Slice Template (NST) to configure and instantiate the required artefacts in the network infrastructure (Core, RAN and Transport).

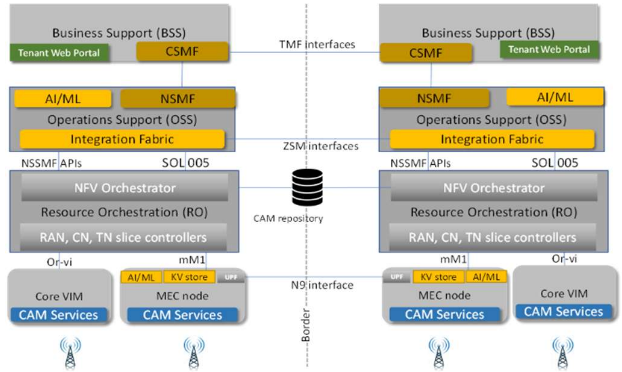

Figure 1. The proposed 5G-ROUTES architecture with cross-domain integration fabric for CAM services delivery across borders

In multi-domain/MNO scenarios, 5G-ROUTES will offer a novel approach for CAM service orchestration via Application Programming Interfaces (APIs) for multi-domain service ordering and onboarding, and via ETSI ZSM runtime APIs for AI driven closed-loop operations across domains. Cloud and network resources (and correspondingly network slices) will be managed independently by each MNO, but the integration fabric will allow the coordination of CAM service delivery across domains. Network Slice Instance (NSI) is provisioned in the E2E MANO layer with three logical Management Functions (MFs): Communication Service (CSMF), Network Slice (NSMF) and NS Subnet (NSSMF) to manage the lifecycle of the NSI. Furthermore, to harmonise automated cross-domain orchestration, 5G-ROUTES will support the exposure of management data (such as related to topology and telemetry), which can be leveraged by the relevant network and service management orchestrators of each domain without resorting to a monolithic/centralised system. In particular, a CAM repository will be implemented for network service sharing among MNOs.

The depicted 5G-ROUTES architecture introduces a high-level separation of blocks that interact together via the integration fabric for the cross-border scenario, in order to enable the E2E CAM services that will be tested and validated in the project. However, these blocks are further composed by loosely coupled blocks, which split responsibilities and tasks for a more agile and easier to update process. This microservice-type architecture highly depends on the existence of well-known and standardized APIs, which expose services from one block to be consumed by another. Design work on the outlined building blocks is on-going and at present a high-level list of APIs is being defined. The next iterations of this work will produce the required modules.

Figure 1 also makes reference to the technological enablers that will be developed within the 5G-ROUTES project and outlined in the following subsections.

B. AI-based network slicing and optimisation for CAM services

The complexity of CAM network slicing stems mainly from the highly dynamic vehicular environment, and the diverse variety of CAM UCs with different service and connectivity requirements. In addition, when attempting to provision CAM services at border areas, resource allocation needs to be extremely efficient in order to achieve inter-MNO transparent mobility. In 5G-ROUTES we will develop *holistic* AI solutions for automated creation and management of *multiple* E2E network slices tailored for CAM services. Currently, predictive models are developed to support the pro-active creation of CAM network slices and their dynamic Life Cycle Management (LCM). Predictive models are essential for capturing the extremely variable vehicular environment. The predictive algorithms are data-driven (that is, ML based) and will combine the diverse (and often big) network data with the vast amount of context-aware data generated by vehicles sensors and RSUs, available (historical) traffic data from highways, railways or water paths, road maps, transport timetables, etc. Intelligent LCM is especially relevant in cross-border scenarios as these impose additional challenges and requirements due to inter-PLMN HO and cross-domain aspects. Furthermore, 5G-ROUTES will develop and implement different layers, from coarse-grained high-level slices that satisfy the operator SLAs (e.g., NEtworks Slice Type (NEST) templates [3]), to fine-grained AI-based slicing techniques that go even up to the application level. We also aim to optimise the slice creation as a means for overcoming resource overprovisioning (the latter is often used as a tool to address high volumes of sporadic but critical traffic).

C. Distributed multi-access edge computing for V2X applications

Another major task in 5G-ROUTES is to advance and optimise distributed MEC for V2X through ML techniques. In particular, the goal is to retain an ultra-low latency link between the user and the infrastructure by moving the services as close to the user as possible at any given time. The initial, high-level versions of fully automated closed-loop ML algorithms have already been designed. Deep Learning (DL) solutions for predicting mobility, incoming traffic and network load are studied at present with the aim to aid the task of pro-active placement and migration of relevant Virtual Network Functions (VNFs). Deep Reinforcement Learning (DRL) algorithms are devised for making placement and migration decisions, which aim to decrease the service latency and to distribute optimally the load in the network. Furthermore, a positioning service placement algorithm that uses vehicular localisation is researched too. Two other mechanisms that address the cross-border scenario are also under development. A low-latency synchronisation mechanism is proposed for seamless CAM service delivery across borders, and an AI assisted CAM service HO mechanism for meeting the SLAs when crossing borders is outlined too. A MEC assisted real-time data sharing between vehicles for safety applications is another aspect addressed in 5G-ROUTES. Our ambition, when developing the outlined technological enablers is to reach an optimal trade-off between network performance, deployment complexity and deployment and operational cost.

D. Innovative spectrum usage for 5G CAM services

A robust, UC-agnostic AI based mechanism for the efficient management of radio resources for supporting CAM services and slice types is in its design phase. The DL algorithm will perform the interrelated tasks of spectrum resource allocation and spectrum scheduling. In contrast to short-sighted algorithms that consider only instant resource demand and availability, the developed approach will address the resource allocation task over a time horizon. The developed solutions aim at overcoming some potential problems, associated with a predicted heavy use of 5G applications, such as lack of radio resources, traffic congestion and interference. Potentially, 5G-ROUTES might investigate the impact of radio resources especially in cross-border areas and the impact of 5G New Radio (NR) especially on critical services requiring high throughput.

E. AI-based positioning enhancements for cm-level accuracy for V2X/3D positioning

The 5G-ROUTES ambition is to develop a highly accurate 3D location algorithm with a target positioning accuracy of less than 10 cm as there are several expected location-based UCs that could benefit from an accurate positioning solution. The localization algorithm is envisioned to be used for the dynamic vehicle platooning, cooperative lane change, and see through view for safe automated overtake UCs. Radio-signal based positioning in 5G NR mobile cellular systems has been examined until now mainly through simulations. Hybrid positioning solutions using RTK and 5G network capabilities have already been empirically evaluated as a tool for high-precision positioning. Different AI/ML algorithms will be tested and developed next based on the observed outcomes.

F. Field Trials for 5G CAM validating R16 and beyond 5G features and capabilities

5G-ROUTES ambition is to go beyond prior 5G V2X trials by addressing not only the cross-border, cross-MNO, cross-telco-vendor, cross-car-manufacturer issues, but also UCs for demonstrating the uninterrupted delivery of CAM services for passengers and cargo traffic, as well as telemetry operation based on FRMCS. Target KPIs addressing technical, service-level and business aspects will be validated for each UC over two forthcoming 3GPP releases (R.16 and R.17). Furthermore, a novel integration scenario of satellite-terrestrial 5G integration will be trialed, to demonstrate service continuity.

V. Conclusion

The 5G-ROUTES project will conduct advanced large-scale field trials of 13 innovative CAM UCs across the designated "Via Baltica-North" 5G cross-border corridor spanning 3 EU state borders Latvia-Estonia-Finland. The UCs will be implemented and supported through several technological enablers, which will be enhanced and optimized first. The research objectives and on-going innovation activities on adapting these core technologies to CAM services have been outlined too. The 5G-ROUTES activities and key milestones are to be continuously documented on the project website.

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