15th ITS European Congress, Lisbon, Portugal, 22-24 May-2023

Paper ID 62

5G Architecture for Cross-border Mobility Services: The 5G-Routes Project Approach

Jose Rodriguez[1*], Guillermo Gomez[2], Jordi Baranda[3], Arturs Lindenbergs[4], Mattias Manni[5]

1. jose.rodriguez@swarco.com*, SWARCO, Italy
2. guillermo.gomezchavez@atos.net, ATOS, Spain
3. jbaranda@cttc.es, CTTC, Spain
4. arturs.lindenbergs@lmt.lv, LMT, Latvia
5. mattias.manni.ext@telia.ee, TELIA, Estonia

Abstract

Data travels across multiple system architectures to supply Cooperative, Connected and Automated Mobility (CCAM) services. The latter arrives to road users as a notification or warning message as *"Reduce the speed, accident at 500 meters*", for example. 5G-Routes project approach aims at delivering Use Cases (UC) in multi-administrative domain scenarios where a UC 5G deployment can be transferred from one Mobile Network Operator (MNO) domain to another as the users moves. The present paper analyses the use of the 5G-Routes Project Architecture for the deployment of the UC 2.1 CCAM services to be tested in a cross-border environment in the countries of Latvia and Estonia. 5G and UC2.1 CCAM Services used to improve road users' safety through traffic light maneuver (TLM), road and lane topology (MAPEM), collective perception (CPM), cooperative awareness (CAM), decentralized environmental notification (DENM) services.

Keywords:

5G Architecture, CCAM

Introductory Technology Overview

Between the multiple uses given to the 5th Generation of communication technologies (5G) is the improvement of road users' safety through CCAM services. Therefore, 5G and CCAM services are being analysed in urban, interurban and corridor scenarios and field trials (e.g., 5G-Carmen, 5G-CroCo, 5G-Drive projects, etc.) to solve flaws in communication. Flaws that can emerged from either, the use of new communication technologies (i.e., 5G) as well as the adaptation of the systems and architectures to work seamlessly between the actors involved. 5G and CCAM entail actors such as MNOs, Original Equipment Manufacturers in the automotive industry (Auto OEM), Road Traffic Authorities (RTA), Service Providers (SPs), Connected and Automated Vehicle (CAV) owners, Vulnerable Road Users (VRUs), among others.

These actors can be global or local. Such global actors go from governments working on the definition of directives, regulating, and selling the spectrum, to MNOs which are the mobile network carriers that own or control access to a radio spectrum license from a regulatory or government entity (e.g., AT&T Inc, Vodafone, etc.), to Auto OEMs which deliver vehicles worldwide (e.g., Ford, BMW, Chevrolet, etc.). While local actors can be public authorities defining guidelines for states and cities, RTA managing state roads and provided funding to local councils for regional and local roads, and SPs creating products or services to end users, CAV owners and VRUs.

The final users, so, VRUs (e.g., pedestrians, cyclists, motorcyclists, persons with disabilities or reduced mobility and orientation) are the main actors to protect due to their vulnerability. Therefore, global, and local actors are pushed to use 5G and CCAM services to improve road safety. 5G used to create mobility applications that will be benefited from the adoption of recent technological paradigms such as softwarization and virtualization introduced to enable flexible, and dynamic architectures for the automated management and orchestration architectures of the 5G infrastructure, which will count with distributed computing locations to host vertical applications. While CCAM services take advantage of the data exchange to inform and warn any road user about a potential risk, including CAVs that will require to be adapted to react to a danger situation.

Multiple factors influence actors' relationship, the communication interface used (e.g., cloud, inter-MEC communication, client applications) to exchange the information, the willingness to collaborate in a specific situation, etc. As example, Figure 1 helps to visualize the relation between an MNO, RTA, OEM, and SP which are using an application server on the cloud. Whereas single applications are utilized by VRUs, RTAs and in vehicles.

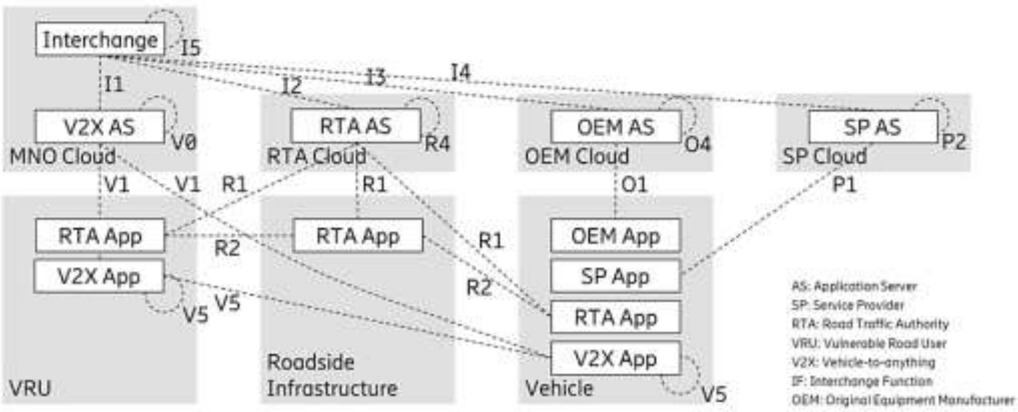

Figure 1. Deployment View with MNO Stakeholder for V2X AS and Interchange Function [1]

MNOs Spectrum and Multi-domain

Spectrum is acquired by an MNO from national authorities. This constrains the former to the provision of mobile communication services to certain areas resulting on agreements between MNOs when a specific digital service is required under some circumstances (e.g., when vehicles cross frontiers between countries, etc.). Such situations lead to the deployment of a multi-domain scenario to assure an uninterrupted service as shown in Figure 2 in which two mobile network operators use the network resources of their domains to create a multi-domain deployment to provide an end-2-end service (E2E).

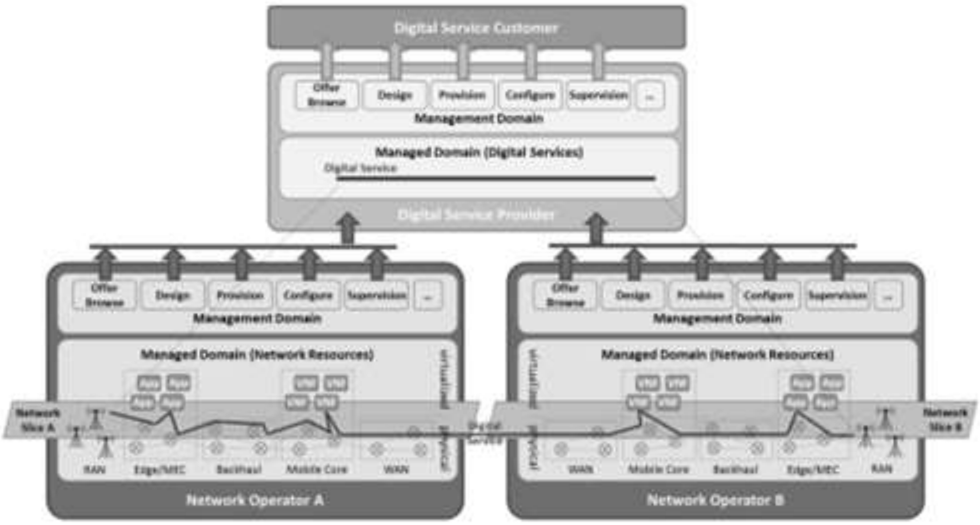

Figure 2. Multi-domain Management for E2E Service [2]

5G communication use heterogeneous network access technologies to support Mobile Nodes (MNs) with multiple services and different Quality of Service (QoS) constraints. In a 5G architecture, an MNO can use Massive Multiple Input Multiple Output (MMIMO) antennas to increase telecommunication resources. A key issue is the need to support service continuity of the MNs. Therefore, it is required an efficient design of mobility management schemes for 5G infrastructures. MNOs work on the top creating tailored slices with specific functionalities to serve clients at the bottom (e.g., road and traffic authorities, vehicle manufacturers, etc.).

Network requirements for mobility applications

Communication is critical for applications in traffic safety and control. CAVs demand extreme user proximity to guarantee ultra-low latency, high bandwidth, real-time access to radio network and context information, and location awareness. Cloud computing focuses on a client-server model, using a client-side to start server requests and a remote server-side to process and respond to those requests. This schema can be replicated at the edge, thus transferring computing and storage out of the remote cloud (public or private) and closer to the source of data to experience reduced latency.

Vehicle-2-Everithing (V2X) applications requires the use of computing technologies between MNOs, RTA, Auto OEM, and SPs to provide services. This considers that from the client side, application instances can run at VRUs, roadside infrastructure, and in vehicles and on the server side, the clouds (edge/remote) host application backend instances.

5G-Routes Project

5G-Routes project [3] is sustained in pillars going from the formulation and validation of a set of advanced use cases relevant to CAM in cross-border environments, to the provision of technological enablers, to the execution of the field trials, to the alignment with the latest 3GPP standardization releases.

A modular architecture has been devised for the deployment of the 5G infrastructure and CAM ecosystem. This to integrate the 5G mobile infrastructure, CAM network services and defined technological enablers on top of the infrastructure and assisting CAM network services via open interfaces and APIs to ease the orchestration of virtualized CAM Services across Point of Presence and administrative domains as well as to ease the collection and visualization of KPIs of the use cases. This architectural approach involves MNOs deploying an independent 3GPP-based 5G network and an ETSI compliant NFV Cloud solution with a Management and Orchestration stack (MANO). The latter supports the automatic lifecycle management of cloud-native Network Functions (e.g., CAM Services) deployed within the MNOs infrastructure. Key elements of the architecture consider a 5G deployment with dynamic Network Slicing support, a distributed virtualized infrastructure (Edge/MEC and Core Point of Presence –Pop-), an integrated terrestrial-satellite 5G connectivity, and a set of orchestrated elements also in the form of cloud-native Network functions (i.e., technological enablers) for supporting the deployment and operation of CAM Services which include an inter-domain integration fabric, and the Tenant Web Portal to automate the execution of the use cases and the KPIs analysis. The project foresees pilots and field trials that involve automotive and maritime transport modes.

Through the 5G-Routes project architecture, this paper describes the connection between the technological elements (e.g., enablers, ETSI messages, etc.) needed to provide CCAM services using 5G in a cross-border environment for the UC2.1 real-time traffic information and cooperative intersection collision control. In 5G-Routes project, UC2.1 is categorized as an awareness driving UC which combines Vehicle-2-Vehicle (V2V), Vehicle-2-Infrastructure (V2I) and Vehicle-2-Network (V2N) technologies to enable a reliable exchange of road traffic status data (e.g., position, speed, driving trajectories, VRUs). UC2.1 uses enhanced real-time traffic video feeds to control complex intersections via V2X communication resulting in safe passing on crossings, collisions avoidance, as well as supplying user comfort in traffic jams during automated driving. Its architecture is based on ETSI specifications [4] and DATEX II [5] for the traffic information and data. The cross-border environment used for UC2.1 CCAM services testing considers the cities of Valka and Valga, as depicted in Figure 3.

Figure 3. Field Trials Location - UC2.1

Therefore, considering the 5G-Routes Project Architecture [6] for the development of the UC 2.1 CCAM services, this paper starts describing how information is collected and transformed to standardized ETSI messages. Followed by the explanation of the 5G-Routes project architecture and the technological enablers that allow the transmission of data in a multi-domain scenario. To finally provide conclusions about the architecture and the CCAM services.

Detection and Processing

A CCAM service reacts to a traffic anomaly to improve safety or comfort of vehicles and/or VRUs. Road infrastructure (i.e., cameras, traffic light controllers, traffic lights, roadside units) are calibrated to detect road users. So, when an issue is perceived, infrastructure-related messages are generated and distributed to connected users. The specifications used for the set of applications for vehicular communications on the Intelligent Transport Systems (ITS) consider the ETSI Standards [4]. Therefore, UC2.1 is focused on the provision of the following services:

Traffic Light Maneuver (TLM) Service supports traffic participants (e.g., vehicles, pedestrians, etc.) to execute safe maneuvers in an intersection area. The TLM service uses the Signal Phase and Timing Extended Message (SPATEM) to disseminate the status of the traffic light controller, traffic lights and intersection traffic information. It transmits continuously in real-time the information relevant for all maneuvers in the area of an intersection [7].

Road and Lane Topology (RLT) Service includes the lane topology for e.g., vehicles, bicycles, parking, public transportation and the paths for pedestrian crossings and the allowed maneuvers within an intersection area or a road segment. The RLT service uses the Map Extended Message (MAPEM) [7].

Collective Perception (CP) Service shares information about other road users and obstacles detected by local perception sensors such as radars, cameras and alike. The service defines the Collective Perception Message (CPM) [8].

Cooperative Awareness (CA) Basic Service within road traffic means that road users and roadside infrastructure are informed about each other's position, dynamics, and attributes. The information to be exchanged for cooperative awareness is packed up in the periodically transmitted Cooperative Awareness Message (CAM) [9].

Decentralized Environmental Notification (DEN) Basic Service constructs, manages and processes the Decentralized Environmental Notification Message (DENM). DENM contains information (i.e., related to a road hazard or an abnormal traffic condition such as type and position) used to alert road users of a detected event [10].

Once the issue is detected, infrastructure services react accordingly. With that purpose, two functional blocks of the ITS Reference Architecture (Figure 4) are used: The Applications Block focuses to road safety, traffic efficiency and/or other ITS applications which are provided as an ITS service to a user of ITS. This can be complementary, multiple classes of ITS applications can be supported. The Facilities Block supports the data exchange between ITS applications. This manages the generation, transmission, and interchange of infrastructure-related messages from the infrastructure (Cooperative ITS-Station (C-

ITS-S) or Roadside ITS Station (R-ITS-S)) to Vehicular and personal ITS Station (V-ITS-S) or vice-versa. Within the infrastructure services, the facilities layer interacts with the other interfaces. This supplies APIs to applications for the processing of the payload at the transmitting ITS-S and the receiving ITS-S.

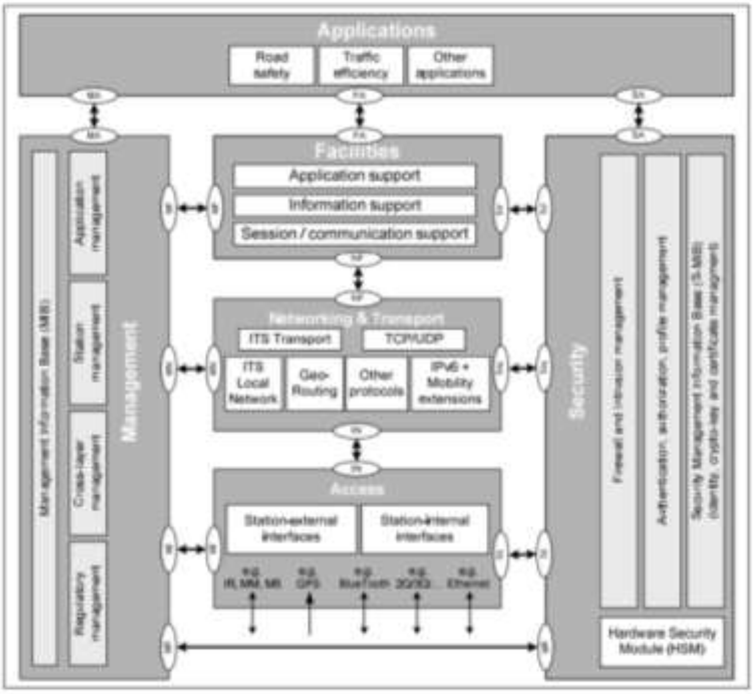

Figure 4. ITS Station Reference Architecture - Example of Elements [11]

UC 2.1 relies on ITS sub-systems such as: Roadside ITS sub-system (i.e., installed on poles), central ITS sub-system (e.g., part of an ITS central system).

Enablers and the 5G-Routes Architecture for the Multi-domain

The cross-border case raises technological challenges to assure a seamless provision of CAM Services in a multi-domain scenario, where different MNOs on each side of the border are involved. On top of background mobile network configuration to supply enhanced handover and roaming functionalities from the 5G core (5GC) perspective, it can also imply the transference of information between different MNOs across the equipped intersections in Valka and Valga cities at the UC application level. Therefore, 5G-ROUTES project foresees different enablers to habilitate UC2.1 functionalities in collaboration with the 5G mobile network infrastructure. The 5G-Routes deliverable D2.9 [9] defines the CAM Services Platform (Figure 5) as a multi-cloud system (i.e., considering multiple Points of Presence (PoPs) at the core and edge) built as the combination of innovative technological enablers developed within the project to comply with the needs of CAM UCs both, from the user perspective thanks to the Tenant Web Portal, and from the CAM Services themselves thanks to the functionalities exposed by the enablers.

Core PoP: The Tenant Web Portal and the enablers integrated here mainly supply CAM Service orchestration capabilities for the UCs to be deployed for executing experiments in the field trials. These enablers will be co-located with the 5GC as they do not have stringent requirements in terms of communication latency with UEs because they are not involved in the operation of the CAM service and will have network connectivity to the User Plane Function (UPF) entity of the 5GC. They will also have network connectivity to the MANO stack (e.g., ETSI OSM) as they will actively use it to onboard, instantiate and decommission CAM Services.

Edge PoP: In this case, the enablers integrated here are those needing a more frequent interaction with UEs and CAM Services and thus have the intention to be deployed as close as possible to the UE to support its functionality achieving low latency communications. These enablers will have network connectivity to the UPF. Contrary to CAM Services, which are deployed on demand by SPs, enablers will always be available in suitable PoPs during the integration of the CAM Service Platform in the MNO's infrastructure.

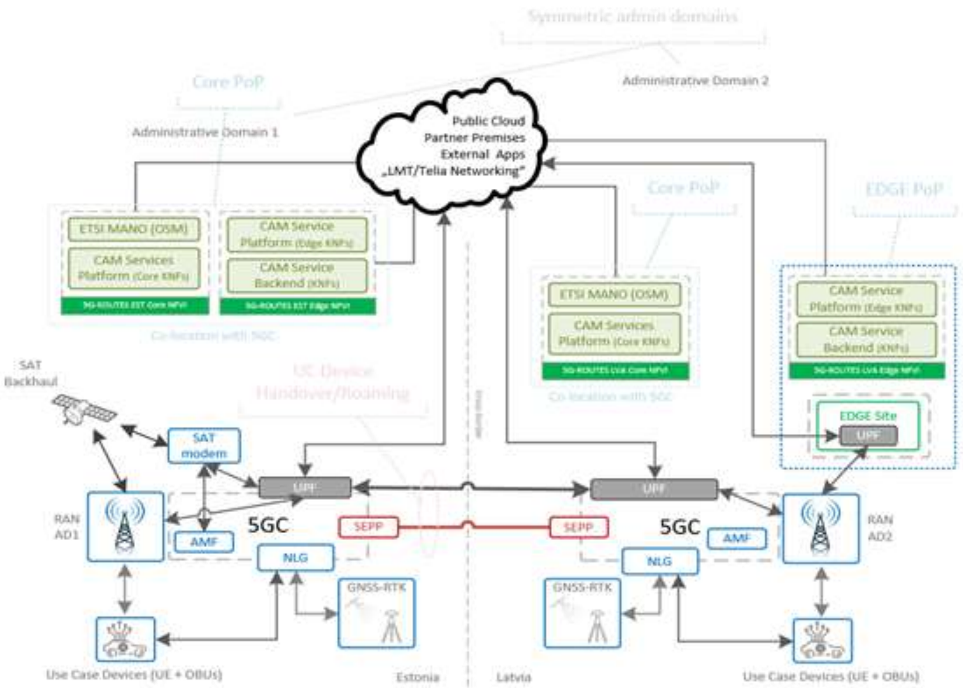

Figure 5. 5G-ROUTES Project Architecture and its deployment in field trials [6]

Figure 6 illustrates the relationship between the Core/Edge and the three categories of enablers being developed in the 5G-ROUTES project. These are AI Assisted Cross-domain MEC and Integration Fabric for CAM Services, E2E Slicing Optimization and Innovative Spectrum Usage for CAM Services, AI-based Positioning Enhancements for V2X.

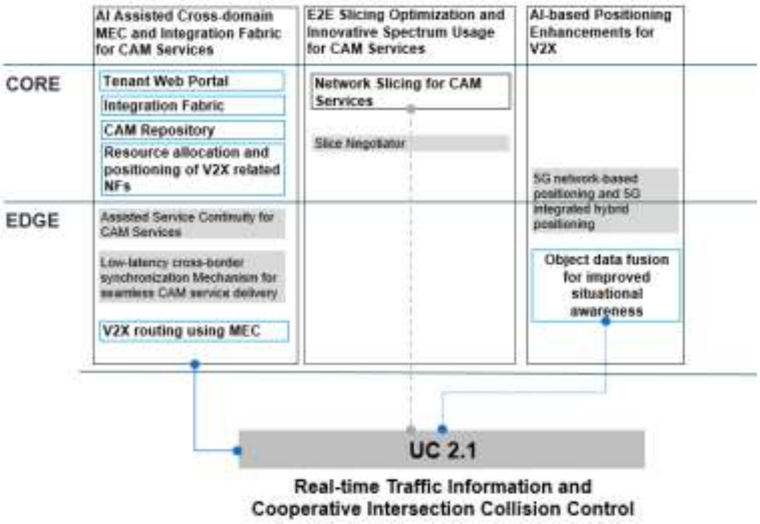

Figure 6. UC2.1 – Specific Enablers Utilized

Virtualized CAM Network Services (NSs) deployed closer to the users rely on enablers at the Edge to favor low latency delivery. In this case is possible to refer:

V2X Routing Using MEC enabler is aimed to support the communication architecture between vehicles and service providers to share the vehicle position. The latter can make use of edge computing to put applications closer to the vehicle. Hence, the information path may be either direct to the application back office (ITS center back office) or through the MEC.

Object Data Fusion for Improved Situational Awareness enabler performs track-level fusion using the low-level fused data from the RSUs, the vehicle OBUs and other actors that are interconnected in a ETSI defined collective perception system (CPS). The system depends on the V2X Routing using MEC enabler for the participation in the CPS system, by subscribing to the proper MQTT topics provided by the V2X enabler. This enabler could be used by the UC backend (ITS system) to transfer information of cars among countries.

Several computing capabilities are reached at the Core, so UC 2.1 requires relying additionally on the following enablers:

Tenant Web Portal (TWP) enabler is a web-based solution which will be the main User Interface (UI) and a visualization environment for the UC owners to launch and setup information about their UCs, and scenarios but also to enable the monitoring and real-time graph data presentation, of the experiment's execution while the CAM service is running.

Cross-Domain Integration Fabric enabler considers the implementation of a set of APIs, aimed at allowing the real-time exchange of data, analytics and orchestration operations across borders and MNOs. This exchange of data, analytics, and orchestration operations have the final goal to ease the CAM service delivery and application continuity across MNOs. Communication with the other country domain is devised through Message Queue Telemetry Transport (MQTT) messages, where one MQTT broker is deployed at each domain. The MQTT brokers are bridged, so that messages can be transmitted across domains.

CAM Repository enabler is the storage solution adopted in 5G-ROUTES for the artefacts1 required to instantiate a CAM Network Service (NS) in the virtualized infrastructure of an MNO. It mainly takes part in the UC registration phase when a new CAM Service is being configured through the Tenant Web Portal. This means that the CAM Repository takes part in the execution of all UCs in the project that require a CAM Service to be instantiated within the infrastructure of an MNO. The CAM Repository is presented to the rest of the CAM Services Platform as a multi-domain services catalogue that keeps consistent and synchronized information of the artefacts of UCs (CAM Services). Operationally, this repository will hold the collection of OSM descriptors, Helm charts and docker images required to instantiate a CAM service. It will be connect to the relevant MANO stack layers of the field trial infrastructure (NFVOs and VIMs) so that users/vehicles can seamlessly move from one domain to the gneighboring one while the CAM Service Platform orchestrates the instantiation of the relevant CAM Services in the optimal location to maintain the lowest latency possible.

Predictive Resource Allocation and Positioning of V2X related NFs enabler pre-emptively allocates the resources needed for the optimal functioning of the CAM service NFs according to the user movements. Additionally, it decides the requisites of re-location and proper positioning of V2X VNFs in the Edge Cloud and MEC network components. If the mechanism finds that cross-border re-location is required, it relies on/interacts with the Cross-Domain Integration Fabric and the Assisted Service Continuity mechanism to perform suitable orchestration operations.

Conclusions

CCAM services can benefit from the capabilities of next generation mobile networks. This paper presents an ongoing use case related to real-time traffic information and cooperative intersection collision control and its mapping with the architecture proposed by the 5G-ROUTES project. This architecture considers the automated management and orchestration of virtualized CAM network services that are assisted by defined technological enablers on top of the mobile infrastructure. Hence, this will enable the flexible and dynamic deployments of such CAM Service using the available MNO infrastructure consisting of geographically distributed points of presence and considering multi-domain scenarios involving different MNOs under cross-border situations with the final goal of increasing the safety for all road users.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement No 951867.

[1] In 5G-ROUTES, an artefact is a release of a software component containing all of the required information to execute it. It includes Network Service and Virtual Network Functions descriptors, Helm charts and docker images.

References

[1] 5GAA, “5GAA WG2 work item ‘V2X Application Layer Reference Architecture (V2XSRA).”

[2] 5G PPP Architecture Working Group, “View on 5G Architecture,” vol. Version 3., 2019.

[3] 5G-Routes Project, “Home - 5g routes project.” [Online]. Available: https://www.5g-routes.eu/. [Accessed: 31-Jan-2022].

[4] ETSI, “ETSI - Welcome to the World of Standards!” [Online]. Available: https://www.etsi.org/. [Accessed: 23-Sep-2022].

[5] “About | DATEX II.” [Online]. Available: https://www.datex2.eu/datex2/about. [Accessed: 22-Nov-2022].

[6] G. Gomez and E. Jimeno, “5th Generation connected and automated mobility cross- border EU trials D2.9 Report on integration and testing of technological,” 2021.

[7] MTR, “Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Facilities layer protocols and communication requirements for infrastructure services,” 2020.

[8] ETSI, “TR 103 562 - V2.1.1 - Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Analysis of the Collective Perception Service (CPS); Release 2,” 2019.

[9] ETSI, “EN 302 637-2 - V1.3.2 - Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service,” 2014.

[10] ETSI, “EN 302 637-3 - V1.2.1 - Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service,” 2014.

[11] ETSI, “EN 302 665 - V1.1.1 - Intelligent Transport Systems (ITS); Communications Architecture,” 2010.