5GMED Architecture for Automotive and Railway Communication Services in Cross-Border Scenarios

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***Abstract*—Cooperative, Connected and Automated Mobility (CCAM) and Future Railway Mobile Communications System (FRMCS) use cases present strict requirements in terms of service end-to-end latencies, data-rates, reliability and service availability, posing challenges in the design of 5G network architectures for cross-border scenarios, where current roaming mechanisms introduce large latencies and service disruption times. The 5GMED project proposes a novel 5G network architecture for the Mediterranean corridor cross-border between Spain and France, where the challenges imposed by CCAM and FRMCS in cross-border scenarios are addressed. In this paper, we describe cross-border challenges and present the 5GMED network architecture that will be deployed and evaluated in large-scale trials.**

Keywords*—*5G, cross-border, architecture, CCAM, FRMCS.

I. INTRODUCTION

Fifth-generation (5G) and beyond mobile networks will offer a set of capabilities that are crucial in high mobility and densely connected scenarios, such as ultra-low latency, very high data rate, very high reliability, etc. Recently, the European Union has envisioned the application of 5G networks to Connected, Cooperative and Automated Mobility (CCAM) scenarios [1][2]. This will enable novel mobility-related use cases with the potential to contribute to reducing the number of fatalities on the road, curbing carbon emissions, and improving traffic efficiency. In addition, the application of 5G to Future Railway Mobile Communications System (FRMCS) will provide a foundation for the design of a common network infrastructure to support railway services, as envisioned by [3][4]. Furthermore, Mobile Edge Computing (MEC) plays an essential role in enabling novel CCAM and FRMCS applications. By placing processing, storage and networking capabilities closer to the end users, the above set of requirements can be more easily met.

Nonetheless, CCAM and FRMCS use cases present strict requirements in terms of service end-to-end latencies, data-rates, reliability and service availability. In addition, future CCAM and FRMCS services will rely on a broad range of technologies beyond 5G, require novel multi-stakeholder approaches to service delivery, yielding a complex ecosystem that includes mobile network operators (MNOs), road and rail infrastructure operators, neutral host operators, and end users. This ecosystem becomes even more complex in cross-border sections [5], where these roles exist at both sides of the border. Although these requirements and complexity are considered in the design of 5G networks in general, they pose challenges for the cross-border scenarios. In these scenarios, the current roaming mechanisms yield long reconnection times, resulting in large end-to-end latencies and service disruption times that render the provisioning of novel, advanced CCAM and FRMCS services unfeasible.

In this context, the 5GMED project [6][7] aims to build a 5G-based multi-stakeholder network and computing infrastructure to enable advanced CCAM and FRMCS use cases implementation along the Mediterranean cross-border corridor. To this end, the 5GMED architecture is composed of six layers (i.e., network infrastructure layer, MEC layer, orchestration layer, slice management layer, cloud layer, and data analytics layer) and four cross-border interfaces. In this manner, the challenges imposed by cross-border scenarios are addressed holistically across the 5GMED architecture layers.

This work presents the specific challenges in deploying CCAM and FRMCS services in cross-border scenarios, in addition to the proposed 5G network architecture for the Mediterranean cross-border corridor between Spain and France envisioned by the 5GMED project to address these challenges. This paper is an extension of the poster paper presented by the authors in [7]. The remainder of this paper is organized as follows. An overview of the 5GMED project and use cases are presented in Section II and Section III, respectively. Section IV elaborates on the main challenges faced on cross-border mobility scenarios. The 5GMED network architecture is described in Section V, where relevant, novel cross-border interfaces at each layer are described. Finally, conclusions are provided in Section VI.

II. 5GMED PROJECT OVERVIEW

The 5GMED project is an innovation action funded by the European Commission's Horizon 2020 research and innovation programme (H2020-ICT-53-2020). The aim of 5GMED is to evaluate the capabilities of 5G technologies (3GPP Rel.16) to meet the requirements of CCAM and FRMCS use cases in cross-border scenarios. 5GMED will conduct large-scale trials of 5G for CCAM and FRMCS in the European cross-border corridor between the cities of Figueres (Spain) and Perpignan (France). To this end, 5GMED is deploying a 5G Stand-Alone

(SA) network infrastructure in Spain and France to provide 5G coverage along 65 km of the E-15 highway and high-speed rail track, including a railway cross-border tunnel. In addition to the large-scale trials in the cross-border corridor, 5GMED will conduct small-scale trials in automotive testbeds deployed in Castellolí (Spain), Paris-Satory (France) and Paris-TEQMO (France), as well as in a rail track segment of the cross-border area using a low-speed maintenance train. The small-scale trials will be used for functional verification and validation of the services and 5G network architecture prior to the large-scale trials in the cross-border corridor.

The 5GMED project focuses on four use cases related to both CCAM and FRMCS. These use cases are: *1)* remote driving; *2)* road infrastructure digitalization; *3)* future railways mobile communications; and *4)* follow-me infotainment. The next section describes the 5GMED use cases.

III. 5GMED USE CASES

This section describes the main characteristics of the four use cases that will be deployed, validated and demonstrated in both small-scale and large-scale trials of 5GMED.

A. Use Case 1: Remote Driving

The aim of the remote driving use case is to provide remote assistance to an Autonomous Vehicle (AV) running into a complex traffic situation that is out of its operational design domaim, such as bad weather, car accidents, transfer from highway to urban roads, or undefined traffic conditions, among others. In any of these situations, the AV makes a request for remote assistance to a tele-operation center and a remote driver will tele-operate the AV until it reaches a safe position, from which the vehicle will continue driving autonomously.

During tele-operation, video images and data from vehicle's sensors (e.g., LIDAR, 360º camera, etc.) are transmitted in the uplink from the AV to the remote station, and commands are transmitted in the downlink from the remote station to vehicle's actuators. To provide full control of the AV during tele-operation, the images and data from sensors must be perceived with sufficient quality and short delay by the remote driver, and the actuators must execute commands with very low latency and high reliability. The 5G network must be designed to provide these Quality-of-Service (QoS) requirements, which especially apply when the AV is crossing country borders. In addition, predictive QoS [8] mechanisms are needed in order to anticipate a potential degradation in the QoS, and then reduce speed, stop the AV, or even drive the AV to another route where the 5G network can support the service.

B. Use Case 2: Road Infrastructure Digitalization

The purpose of the road infrastructure digitalization use case is to create an intelligent traffic management system that ensures safe and efficient mobility in highways where Connected Vehicles (CVs) coexist with legacy non-connected vehicles. The intelligent traffic management is based on cooperative sensing. It aggregates data provided by CVs' sensors (i.e., LiDAR, radar, GPS, etc.) and data from other heterogeneous information sources, such as traffic cameras and roadside sensors. A Traffic Management Center (TMC) processes these data and generates intelligent traffic management strategies that are transmitted to the CVs through the 5G network. Two types of traffic management strategies have been considered: warning traffic strategies, and global traffic strategies.

The warning traffic strategies focus on the detection of road hazards (e.g., accident, stopped vehicle, etc.) and low-latency distribution of warning notifications from the TMC to those vehicles that are approaching at high speed to the risk area. The road hazards can be detected by vehicles' on-board sensors or by roadside sensors installed on the infrastructure. In the global traffic strategies, the TMC analyses the traffic status in the highway to detect abnormal behaviors (e.g., traffic jam, vehicle at abnormal reduced speed), generates a traffic strategy, and transmits regulation commands (i.e., change lane, adjust speed) to groups of vehicles driving near the risk area.

C. Use Case 3: Future Railways Mobile Communications

FRMCS is the future worldwide train telecommunication system designed by the International Union of Railways (UIC) in cooperation with different stakeholders from the rail sector [4]. FRCMS services are divided into three different categories: *i)* critical services, to control and monitor train movements and safety, e.g., emergency communication, shunting, presence, Automatic Train Control, etc.; *ii)* performance services, to improve the performance of the railway operation, e.g., train departure, telemetry, etc.; and *iii)* business services, to support the railway business operation in general by offering several types of services to passengers, e.g., wireless internet, voice calls, etc. The 5GMED project focuses on performance and business services that introduce strict QoS requirements to the train-to-ground connectivity based on 5G as well as other specialized radio access technologies dedicated to railways, such as the 70 GHz IEEE 802.11ad and satellite.

The FRMCS performance services of 5GMED are the following: *1)* advanced sensors monitoring on-board, to monitor the status of non-critical systems of the train by facilitating data communication between on-board sensors, the train control information systems on ground, and the railway staff; *2)* railway track safety, to detect hazards on the rail tracks by using a LIDAR sensor on-board and AI-based processing on the MEC; and *3)* passengers safety and comfort, to detect dangerous situations on-board (e.g., fights, etc.) by using video cameras and AI-based processing on the MEC. The FRMCS business services of 5GMED are the following: *1)* Wi-Fi for train passengers, to provide high-performance and seamless Wi-Fi access on the whole corridor segment, including the tunnel and cross-border section; and *2)* multi-tenant mobile service that uses 5G small cells on-board the train to provide high-bandwidth and low-latency access to a MNO service.

D. Use Case 4: Follow-Me Infotainment

The purpose of the Follow-Me Infotainment use case is to distribute several types of high-quality media contents (e.g., live-streaming of 360º video, video-conferencing, and virtual reality video), synchronously and keeping high Quality-of-Experience (QoE) and QoS levels, to passengers travelling at high speed by car or train along the cross-border corridor. To this end, innovative streaming and interactive technologies will be integrated on top of an orchestrated 5G network infrastructure to create new and enhanced end-user experiences to be consumed while travelling, being reactive to user requirements as well as environmental and platform-specific aspects. The target is to optimize the media contents distribution, resulting in a high-quality reception and avoiding service disruptions even when crossing the border.

This use case is based on the "Follow-Me" concept [9], which consists on moving Virtual Network Functions (VNFs) of media services accessed by end-users along different Edge nodes as these users move across the corridor, so that the VNFs are always located in data centers in the vicinity of the users' position. Aligned to the MEC concept [10], challenges arise in terms of service continuity, even when the associated VNFs are being migrated to follow the user's movements, achieving very low-latency and high data-rate at all times.

IV. CROSS-BORDER CHALLENGES

5GMED aims to design and implement a 5G network architecture for cross-border scenarios that meets the strict performance requirements of CCAM and FRMCS use cases in terms of service end-to-end latency, data-rate, reliability, and interruption time, providing continuous and seamless service experience. Providing continuous and seamless services for road and railway communications through a common network architecture is a challenging problem by itself, due to mobility problems and the huge differences between the two types of communication systems. The problem gets even more complex when considering that users might be crossing the border between two countries, and therefore changing their serving Public Land Mobile Network (PLMN). PLMNs in different countries are normally managed by different operators, and in current deployments, cooperation and information exchange between PLMNs is very low and specific to roaming procedures. In the following, we discuss the different challenges and highlight the particular problems related to cross-border scenarios.

1) Heterogeneous and challenging environment: The 5GMED network will be deployed in the Perpignan-Figueres cross-border corridor, which contains areas with irregular orography and rural areas with dense vegetation. In addition, the cross-border area for the railway is the Perthus tunnel of 8 Km. In order to solve the coverage problem resulted from this environment, a special network infrastructure has been deployed in order to hide the complexity of the radio environment from the higher layers. This infrastructure includes, in addition to the 5G network, other radio access technologies to provide services in the coverage holes of the 5G network. i.e., C-V2X for the automotive scenario and 70 GHz IEEE 802.11ad and satellite for the railway scenario.

2) Multi-connectivity and heterogeneous radio access network: As explained in the previous point, different radio access technologies will be present in the infrastructure. This will generate two problems. The first is related to the end users that can be using this infrastructure. These users might be connected through their user equipment (UE) that only supports 5G technology. Therefore, the infrastructure should provide a solution to isolate the end users from this heterogeneous network. In this case, a multi-connectivity gateway is used to move between the different technologies in a transparent way to the end users. In the case of vehicular communications, a Telematics Control Unit (TCU) is developed to communicate with 5G and C-V2X. In the case of railway, an Adaptive Communication System-Gateway (ACS-GW) was developed to switch between 5G, 70 GHz, and Satellite systems. The second problem is related to the handover between the different technologies that may generate some delay. Therefore, the multi-connectivity gateway was developed to proactively move between technologies without inducing significant delays.

3) Mobility and interruption time: For both CCAM and FRMCS use cases, the connected elements will be dynamic and move with high speed, generating a plethora of connectivity problems that are solved by 5G networks when the UE is moving inside the coverage area of its home PLMN. Unfortunately, no efficient solutions for the problem of roaming with high mobility have been developed yet. The roaming process normally induces relatively large service interruption time and latency that are not acceptable for the emerging 5G services. In fact, current roaming process requires several time consuming steps after the UE is detached from its home PLMN. More specifically, the UE has to scan the radio frequencies to search for a PLMN where it can attach, and the latter should exchange information with the home network for user authentication and service continuity. This is translated into a service interruption time of at least hundreds of milliseconds, which is not acceptable by most of the services. This interruption time can be larger inside the train, as it is moving with very high speed and holding many connected users that will perform the roaming process in a short period of time. In the 5GMED architecture, different solutions at 5G core and RAN level have been considered and will be tested.

4) Virtualization: 5G networks are designed to enable and empower service and network function virtualization, which requires the presence of an orchestrator for each PLMN. This orchestrator should manage and monitor the virtualized elements and their lifecycle. In the cross-border scenario, a UE using a virtualized service might need to change its PLMN when crossing the border, which requires provision of resources and configuration of the same service in the visited PLMN. Therefore, it becomes mandatory to have an interface between the orchestrators of the two PLMNs.

5) Latency and Edge computing: Many 5G services require extremely low latency (in the order of ms) as in the case of ultra-reliable low latency communications (URLLC). Hence, 5G networks were designed to provide services with very low latency. In addition, edge computing is a main building block of these networks to reduce latency and provide computing resources near to the users in a distributed way. The deployment of edge computing in a mobile environment such as CCAM and FRMCS poses many challenges related to the migration of the resources from one MEC to another to follow the user, which also lead to a change in the IP address of the application server and may require a restart of user session. In 5GMED, we are relying on deploying instances of the User Plane Function (UPF) in the MEC nodes. In addition, several solutions and interfaces are investigated to solve the problem of service continuity when migrating from one MEC to another. The problem of latency becomes more crucial at the border because legacy roaming, i.e., home routed (HR) roaming, exhibits high latency due to the fact that all user data are routed to the home UPF even if the UE is in a visited PLMN. The HR roaming generates another challenge related to the use of edge computing. In fact, as all user data are routed to the home UPF, using nearby MECs will loose its function when the UE is not connected to its home PLMN. Therefore, Local BreakOut (LBO) roaming is required in this case. However, the use of LBO will generate different types of

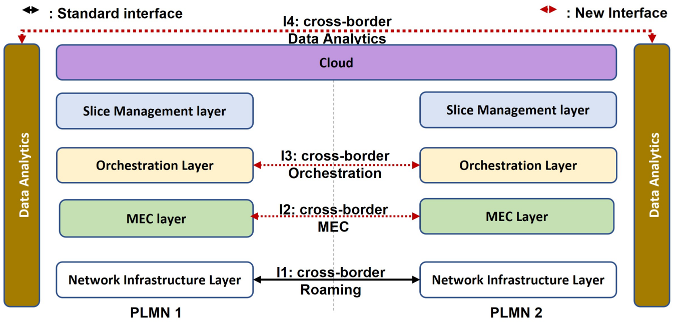

Fig. 1: High-level functional view of the 5GMED cross-border network architecture.

technical problems such as the need to change the IP address of the UE.

6) Network slicing: It is one of the main features in 5G networks. It allows different tenants to have their isolated slices with specific QoS requirements. The standard for network slicing in 5G network is stable and has been tested in several research projects. However, network slicing should be also implemented at cross-borders. The main problem is that different operators may have different slicing policies, configuration, and availability. So, moving a slice from one PLMN to another is a challenging problem.

7) Artificial intelligence: AI will be used in 5G networks to optimize both user experience and network configuration. In this sense, some operator could provide some AI functions as services that can be used by the applications. This will allow the applications to use information collected by the network to optimize its performance. In addition, if the AI modules are provided by the telecom operator with standardized interfaces to applications, information can be collected from third party applications and tools (e.g. road operators) to optimize the network and application. To conserve the continuity of this service in cross-border scenarios, the AI module decision should be available to the UEs even when changing the PLMN, which will be a problem especially that different PLMN may not have the same AI modules and normally they do not exchange information about their networks. Therefore, the 5GMED project proposes to have an AI layer with standardized interface between the cross-border layers.

V. 5GMED Cross-Border Network Architecture

In order to overcome the challenges described in Section IV, the 5GMED project has designed the network architecture depicted in Figure 1. The architecture includes six layers (i.e, network infrastructure layer, MEC layer, orchestration layer, slice management layer, cloud layer, and data analytics layer) and four cross-border interfaces to account to the fact that different network operators may exist at the both sides of the borders. Figure 2, shows a more detailed view of the architecture, where the building blocks of each layer are represented. More details about each layer are provided in the following subsections.

A. Cloud Layer

The cloud layer encompasses all back-end applications running in a centralized fashion, including applications hosted by a private cloud and third-party applications that can be hosted in public clouds. In the case of 5GMED, the applications of use case 1 and use case 2 are hosted in public platforms such as Amazon Web Services (AWS), and the applications of use case 3 and use case 4 are hosted in the private cloud located in the Cellnex testbed in Castelloli. It should be noted that the application instances in the 5GMED cloud are created and managed by the orchestrator. Furthermore, the cloud layer includes all control plane core elements and it can also include a centralized UPF. Finally, it includes a general dashboard that can be used to create and configure network slices, and to monitor network and service KPIs.

B. Slice Management Layer

By enabling the creation of logical networks under a common shared physical network infrastructure, network slicing provides some critical 5G functionalities such as resource isolation, a high level of reliability, and an optimized topology with dedicated resources to support specific services and applications. This is critical, for example, in the remote driving use case. In 5GMED, the slice management layer lies above the orchestration layer.

In the 5GMED architecture, the slice management layer provides all the necessary mechanisms for the management of end-to-end network slice instances (NSI) to support the various use cases. These NSI can be of different granularity, ranging from protocol data unit (PDU) session slices, to service-type slices, e.g., for the support of enhanced Mobile Broadband. Network slicing is provided in the transport network, in the core, and in the RAN. In the 5GMED approach, network slices are statically deployed at both sides of the border, and cross-border mobility is not managed at the slice management

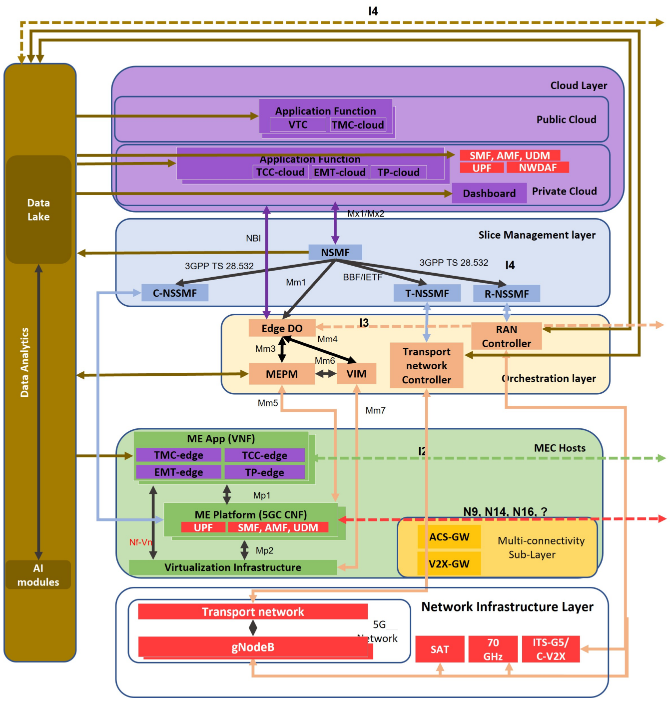

Fig. 2: Detailed functional view of the 5GMED cross-border network architecture. Only one PLMN is shown in this figure.

border, as indicated in Figure 1.

As network slicing is an already standardised feature of 5G networks, standard slices are the same in all PLMNs and have the same Single Network Slice Selection Assistance information (S-NSSAI). In case a service provider would like to have a customized slice, it should use the same S-NSSAI in all networks in all PLMNs where its service will be deployed. Therefore, there is no business model to create an interface between the slice managers.

C. Orchestration Layer

Network and service orchestration is an essential concept in cross-border scenarios to allow seamless data flow and to guarantee end-to-end service quality and continuity among different administrative domains. The orchestration layer in 5GMED is built around the NearbyOne orchestrator [11], which is a Domain Orchestrator (DO) capable of managing the lifecycle of applications and network cloud-native network functions (CNFs).

More specifically, with regard to *network orchestration*, the NearbyOne orchestrator incorporates the Network Slice Management Function (NSMF) and communicates through Southbound Interfaces (SBIs) with three elements inside the slice management layer to communicate the QoS requirements and any other required information: *i)* the core slice manager, *ii)* the transport slice manager, and *iii)* the RAN slice manager. It is worth noting that 5GMED adopts a service-based architecture, enabling NearbyOne to act as core slice manager and perform actions like 5G core lifecycle management and distributed UPF deployment.

With regard to *service orchestration*, the NearbyOne orchestrator integrates with novel 5GMED services that are placed along the compute continuum (i.e., having components from the Edge of the network to the Cloud) and require proactive migrations of services in automotive scenarios.

Network and service orchestration of different administrative domains is one of the main challenges in cross-border scenarios. To this end, the orchestration layer of 5GMED will federate the different instances of the DOs (i.e., I3 interface in Figure 1) following the specifications of the Operator Platform Group (OPG) [12]. OPG, which is driven by GSMA and major telco operators, aims at providing application developers, enterprises and other potential customers, with a common way of accessing key network capabilities towards building and enhancing services in the 5G era.

D. MEC Layer

5GMED proposes the inclusion of AI-based capabilities in the Multi-access Edge Computing (MEC) layer. The MEC layer will be based on a distributed compute platform that enables AI-powered services. 5GMED envisions a unified computing resource pool that can sustain novel CCAM/FRMCS services powered by AI, by pooling edge computing resources from different networks. For example, 5GMED demonstrates how distributed edge computing resources can be used to host AI functions that perform object detection or CCTV video analysis for high-speed trains, or steer highway traffic. The proposed multi-stakeholder MEC-enabled 5G infrastructure allows the deployment of services that leverage on AI mechanisms to deliver highly reliable and fast responsive end user applications for CCAM and FRMCS, including the previously presented use cases.

Moreover, 5GMED considers cross-MNO handover not only from a radio perspective but also from an edge computing perspective, by introducing MEC-MEC handover optimisation (c.f.r., I2 interface in Figure 1). An example is the Mobile Edge (ME) App migration when it is requested to migrate across operators. In Figure 2, a detailed architecture of a single MEC node is depicted, where a multi-connectivity sub-layer allows that both in-vehicle and high-speed train entertainment applications include additional challenges in mobility and communications intensity with moving recipients and originators of media content. Dynamic service migration from MEC to MEC (Follow-ME function) requires smart placement decision and migration triggers, according to a multi-dimensional problem.

E. Data Analytics Layer

The data analytics layer is proposed to transform the 5GMED architecture into an AI-enabled architecture to fulfill requirement 7. It contains a data lake and a set of AI modules that are managed by the network operator. The data lake will be responsible of collecting and storing all network and service KPI measurements, in addition to other information collected from sensors and third-party applications, that can be used by the AI modules or by the operator. The AI modules are generic modules with open interfaces that can be used by applications or slices that are subscribe to them. As these modules have access to all types of information and to any type of infrastructure managed by the operator, the application performance can be better optimized. In addition, the AI modules hide all the network information, which the operator wants to protect, from the applications. The AI modules can use information directly collected from the networks or the services, or can use some historical data that can be fetched from the data lake. Furthermore, the data analytics layer will contain an AI catalogue with AI modules descriptor files used by the applications as deployment templates for the AI.

For the specific case of cross-border, an interface between the data analytics layers of different operators shall be available (depicted as I4 interface in Figure 1). This interface will be used to reduce the impact of roaming on application performance. There are two possibilities in this case: *1)* the AI module is a standard AI module deployed by all operators with specific information that can be shared between operators. As most of the operators would not exchange information about their networks, information about edge cells can be the only information to be exchanged. This information exchange can be forced by regulation. In addition, application-related information and third-party information such as road information can be also exchanged. When the roaming process is performed, the orchestrators of both PLMNs should exchange information to instantiate the same AI module in the visited network; and *2)* the AI module is not standard one. In this case, the AI module will be running in the home network and information from the visited network will be sent to this module. This case can work only if the AI module requires non-sensitive information (i.e., not related to the visited network) and is not delay-sensitive. An instance of the AI module will be created for each application either in the MEC or in a centralized server, depending on application preference. The specification of the AI module and its lifecycle will be configured by the

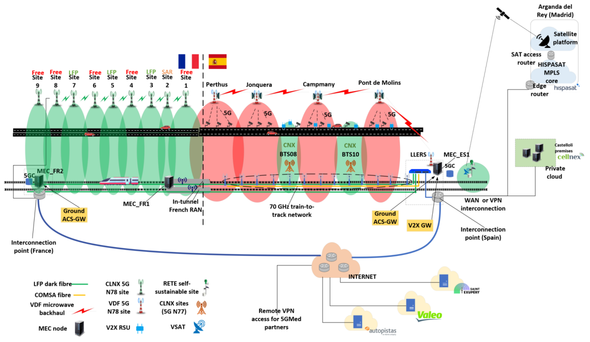

Fig. 3: 5GMED network infrastructure in the cross-border corridor.

NSF through the orchestrator.

F. Network Infrastructure Layer

5GMED aims to create a homogeneous network infrastructure, with the goal of covering both sides of the Mediterranean corridor in a holistic manner, providing a means to reach the expected KPIs of the selected CCAM and FRMCS use cases in a cross-border scenario. For this purpose, 5GMED integrates a set of different data transport technologies as well as radio access, cloud and edge computing resources. The main parts of the network infrastructure layer in the cross-border corridor are described next.

1) Radio access: Available radio nodes in the 5GMED radio access network include 5G NR gNBs, 70 GHz IEEE 802.11ad access points, Roadside Units (RSUs), i.e., dual radio ITS-G5 and C-V2X, and very-small aperture terminals (VSATs) for satellite communications.

2) Transport network: It enables the communication between the radio access nodes and the core network, and it includes microwave point-to-point connectivity, fibre optic links and a satellite backhaul.

3) Core network: Two different 5G Cores are deployed, one in France and one in Spain. 5GMED will validate enhanced roaming mechanisms to reduce the signaling latency experienced by terminals and ensure cross-border service continuity.

4) Multi-connectivity gateways: These gateways allow user devices to dynamically select alternative wireless access technologies to support 5G, based on network conditions and on specific QoS requirements dictated by the application. In 5GMED, two different solutions will be developed and validated: (i) ACS-GW, which will manage 5G NR, 70 GHz IEEE 802.11ad and VSAT for train-to-track communications, and (ii) a V2X gateway will handle 5G NR and ITS-G5/C-V2X connections for vehicular communications.

The 5G network employed in 5GMED is structured as follows. On the Spanish side, the network has a dedicated 5G Core connected to the following radio access networks: (i) Vodafone 5G RAN comprising four gNBs in the stretch between Figueres and the French border, (ii) Cellnex 5G RAN comprising two gNBs in the stretch between Figueres and the French border, required to fill the regions not covered by the Vodafone RAN, and (iii) Cellnex 5G small cell deployed at a self-sustainable site to provide extra coverage in an area not served by the 5G gNBs (i.e., the macro-cells). On the French side, the network has a dedicated 5G Core connected to the following radio access networks: (i) Cellnex France 5G RAN comprising eight cell sites in the stretch between the Spanish border and Perpignan, and (ii) Cellnex France in-tunnel 5G RAN comprising a number of sites inside the Perthus railway tunnel.

VI. CONCLUSIONS

In this paper, 5GMED's novel 5G network architecture for the Mediterranean corridor cross-border between Spain and France has been presented. 5GMED addresses the challenges imposed by cross-border scenarios in CCAM and FRMCS in a holistic manner. For this purpose, 5GMED proposes an architecture with six layers (namely, network infrastructure layer, MEC layer, orchestration layer, slice management layer, cloud layer, and data analytics layer) and four dedicated interfaces for the management of cross-border connectivity. In addition, 5GMED's CCAM and FRMCS use cases were introduced, along with some details about 5GMED's future large-scale trials.

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