MEC Federation for Seamless Service Continuity in Cross-Border Mobility Scenarios

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***Abstract*—In cross-border mobility scenarios, interactions between mobile network operator (MNO) infrastructures and multi-access edge computing (MEC) systems across international borders are required at both the control and data planes to provide seamless and uninterrupted services to users transitioning between two MNOs. However, the exchange of information between MEC systems faces numerous challenges as it necessitates the exposure of data regarding resources, network information, and application instances. This paper proposes a MEC federation architecture based on the use of an open platform and an Open Gateway network-as-a-service (NaaS) model to facilitate cross-MNO MEC service orchestration and inter-MEC communication for connected and automated mobility (CAM) services when crossing international borders. The proposed architecture is validated using an infotainment use case in a cross-border scenario with two 5G standalone (SA) networks. The evaluation results show significant improvements in service continuity, with short interruption times and high reliability, highlighting the practical benefits of MEC federation in real-world applications.**

***Index Terms*—5G, CAMARA, MEC Federation, Open Gateway, cross-border**

I. Introduction

Fifth-generation (5G) and beyond mobile networks will provide essential capabilities for highly mobile and densely connected scenarios, and facilitate the deployment of innovative mobility-related use cases and vehicular services with the potential to reduce road fatalities, enhance traffic efficiency, and improve driving comfort. Multi-access edge computing (MEC) plays an essential role in enabling novel Connected and Automated Mobility (CAM) applications by placing processing, storage, and networking capabilities closer to end-users, greatly reducing the end-to-end latency. MEC systems provide management and orchestration capabilities, thereby optimizing application deployment and enabling efficient resource allocation to ensure that applications are given the required computational resources. However, cross-mobile network operator (MNO) mobility scenarios present specific management and orchestration challenges, as users move across international borders and transition between 5G networks of different MNOs, leading to unacceptable service interruption times [1]. In addition to the different network optimization techniques, required computational resources should be readily available at the visited MEC when user equipment (UE) crosses the border to avoid long service interruption times. Therefore, it is necessary to provide interoperability mechanisms to support interactions between MEC systems of different MNOs.

Some recent works tried to address the problem of service continuity in cross-border environments by establishing direct information exchange interfaces between the home and visited MEC systems. In [2], this was achieved through message queuing telemetry transport (MQTT) messaging. The work in [3] proposed the establishment of MEC federation as a standardized way of defining control plane procedures, signaling, and data communication interfaces to allow CAM users to seamlessly access services and applications hosted at a visited MEC. The authors proved that the concept of MEC federation is well suited to support the specific challenges of cross-border environments, as it can support advanced CAM services with stringent latency requirements. The work in [4] proposed a multi-MNO MEC federation proof of concept based on East/West-bound interfaces (EWBI) to interconnect multi-MNO MEC systems, giving users the ability to access a CAM application client running at a visited MNO infrastructure. The work in [5] presented an orchestrated and federated MEC platform for supporting service continuity during cross-border mobility, based on a programmable data plane for traffic steering and orchestration capabilities for performing service relocation decisions. However, these prior works did not provide standardized application discovery interfaces or brokerage functions between MEC systems, which are necessary to ensure seamless migration in cross-border scenarios. Although ETSI developed some specifications on MEC federation [6], this does not provide a standardized framework for MNOs to expose their system capabilities. Thus, it is necessary to investigate novel frameworks to provide universal and standardized exposure of network resources, in a network-as-a-service (NaaS) fashion, to allow application providers to access and use the visited exposed MNO's resources.

The motivation of this paper is to enable enhanced orchestration capabilities, such as the discovery of the most suitable MEC in the visited network, ensuring the feasibility of deployment of services in this MEC. This paper proposes a MEC federation architecture based on an open platform (OP) and Open Gateway NaaS model for cross-MNO MEC orchestration and data communication. The proposed framework enables the shared use of CAM MEC services and applications in cross-border scenarios, as those developed in the European project 5GMED [1]. The MEC federation architecture is implemented and evaluated using an infotainment use case on two private 5G standalone (SA) networks in the cross-border corridor between Figueres (Spain) and Perpignan (France).

The remainder of this paper is organized as follows. Section II discusses the OP and NaaS approach to MEC federation. Section III describes the proposed MEC federation architecture, including cross-MNO orchestration and inter-MEC data communication solutions. Section IV evaluates the MEC federation architecture in a cross-border mobility scenario. Finally, Section V concludes the paper.

II. OP and NaaS Approach to MEC Federation

The ETSI MEC architecture [7] provides a standardized computing platform independent of, but synergic with the underlying communication infrastructure that executes on-demand applications. ETSI MEC also defines a set of services, such as the location service, among others, that can be consumed by third-party applications. This renders the ETSI MEC architecture an ideal candidate for hosting CAM applications, which can benefit from receiving updates provided by the MEC services. Moreover, MEC systems provide management and orchestration capabilities enabling the ability to meet quality of service (QoS) requirements of CAM applications.

Most research works on CAM applications consider single MEC environments, which limits the use of CAM applications only to subscribers of the same MNO [8]. However, in cross-border scenarios, users move across international borders from one MNO to another. In this regard, ETSI conducted a study on inter-MEC systems and MEC-cloud systems coordination [9], where three main high-level requirements were identified: *(i)* MEC platforms should be able to discover other MEC platforms in other MEC systems and exchange information securely with them; *(ii)* MEC applications should be able to exchange information with other MEC applications in different MEC systems in a secure manner; and *(iii)* the MEC system and MEC host levels require discovery and communication mechanisms to enable inter-MEC communication. In this regard, ETSI has proposed the introduction of a federation manager and a broker in the MEC architecture to enable cross-MEC discovery and service exposure functionalities [9].

In this light, ETSI follows the GSMA operator platform (OP) approach [10] as a baseline for defining the requirements and standards for MEC federation systems and procedures, aiming to facilitate interoperability and coordination between MEC systems of different MNOs. The application of GSMA OP helps to align diverse industry efforts, thus avoiding fragmentation and potentially enabling the seamless integration and operation of MEC systems across different organizations and networks [9]. While ETSI has developed some initial specifications on operations, data models, and APIs to support MEC federation [6], this is still a limited effort that does not go far enough in providing a standardized framework for MNOs to expose their system capabilities, thus increasing the risk of ecosystem fragmentation, as MNOs might need resort to exposing their capabilities in a proprietary, non-standardized manner.

Alternatively, considerable efforts are currently being devoted by the GSMA Open Gateway to the development of an industry-wide NaaS ecosystem [10]. Under the NaaS model, the network infrastructure of an MNO is abstracted and provided as a service, allowing customers to access and use network resources without having to own or manage the underlying infrastructure. The NaaS model is becoming increasingly popular as it provides flexibility, scalability, and cost-effectiveness to stakeholders that require network services. Moreover, the Open Gateway NaaS ecosystem is supported by the GSMA exposure gateway [10] and CAMARA [11]. The GSMA exposure gateway serves as the interface through which external stakeholders, such as third-party developers and application providers, can access and utilize the network infrastructure and services provided by MNOs. Conversely, CAMARA is a project that focuses on defining, developing, and validating standardized service APIs for external consumption. In other words, the exposure gateway acts as the entry point for external entities to access network services, while CAMARA is instrumental in defining and standardizing the APIs that enable this access (see Fig. 1).

This work proposes an architecture that combines both MEC federation and the Open Gateway NaaS model to facilitate the orchestration and deployment of CAM applications on MEC systems in cross-border scenarios, ensuring seamless service continuity. In this manner, CAM applications can consume CAMARA APIs to discover available MEC nodes to instantiate services along cross-border scenarios.

III. Proposed Architecture

In cross-border scenarios, MEC federation refers to the interconnection of MECs of different MNOs to ensure a consistent delivery of services across international borders. It allows different MNOs to collaborate seamlessly and share resources, enabling a more efficient and scalable MEC ecosystem. This section introduces a novel architecture for cross-MNO MEC federation, which includes: i) a framework based on Open Gateway NaaS for standardized network capability exposure, as described in Section III-A, which leverages CAMARA APIs to simplify the interaction between service providers and MEC systems, facilitating scalable and agile service deployment across different MNOs; and ii) an Operator Platform (OP) implementation for cross-MNO orchestration, detailed in Section III-B. This implementation utilizes an East-Westbound Interface (EWBI) to enable communication and collaboration between MNOs, allowing for the deployment and management

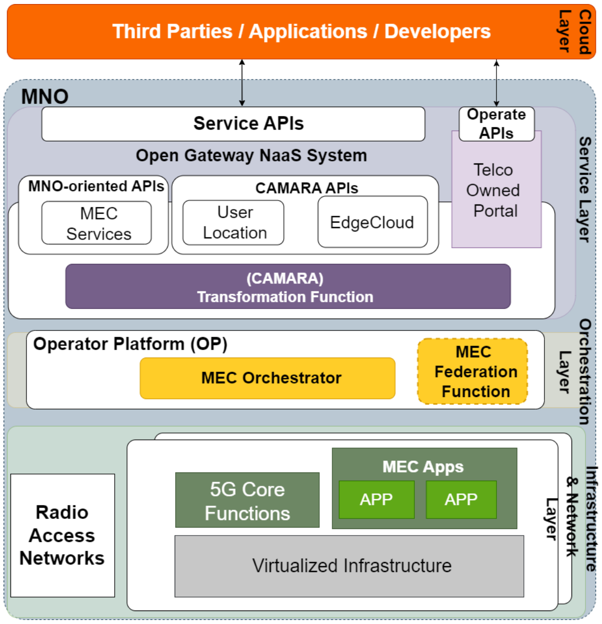

Fig. 1. Architectural framework to federate and expose network resources

of applications across MEC systems in visited networks. The interplay between these components is represented in Fig. 1.

A. Network Exposure/CAMARA

This section explains the use of the Open Gateway NaaS model for exposing network capabilities to externals consumers by using the CAMARA APIs. In this approach, CAMARA APIs serve as a facilitator for enabling consumption and the provision of federation functionalities in the scope of cross-border mobility use cases. Here, it is detailed how service providers aiming to instantiate distributed services on computing platforms belonging to different MNOs will benefit from interacting with standarized-oriented interfaces exposed by these MNO platforms. From the service providers' perspective [10], this approach enhances the scalability of service provisioning in geographically distributed zones in an agile and extensive manner (See Fig. 1).

These standardized-oriented interfaces enable enhanced service provisioning procedures, such as the application lifecycle manangement, selection of the best edge location to place, migrate and replicate applications, and traffic influence based on the user needs or on the quality of performance of the services. In this context, NaaS system can be used to apply service configurations across different MNOs, providing an abstracted orchestration capability over the MEC systems belonging to different MNOs. In other words, by using the NaaS system, service providers can avoid the complexity of the orchestration mechanisms of MEC applications in multi-operator and cross-border scenarios, minimizing the need for them to interact with vendor or operator-specific interfaces, thus fostering interoperability.

From a top-down view, the Open Gateway NaaS system, referred to as Service Layer in Fig. 1, embodies the role of capability exposure defined by GSMA [10]. It encompasses the CAMARA API group, the Operate APIs group and MNO-oriented APIs group, such as customized MEC service APIs. The CAMARA API group abstracts and exposes the network resources and infrastructure capabilities of the MNOs to external users, applications, and MNOs in a standardized manner. The Operate APIs group facilitates the operation, administration, and management capabilities of each MNO's infrastructure and resources, as well as functions for registration, publication, and application lifecycle management. The MNO-oriented APIs group could be any customized API exposed as a service by the MNOs. Additionally, the service layer incorporates the transformation function that is responsible for mapping both API groups to the internal MNO orchestration interfaces, such as the one provided by the MEC Orchestrator. Therefore, by applying Open Gateway NaaS system, the federation capabilities are enhanced as follows:

- *Cross-border distributed service deployment among MEC systems*: To avoid interacting directly with the interfaces of each MEC system, service providers can use the CAMARA EdgeCloud API for two main purposes: (i) discovering available edge nodes, and (ii) managing the lifecycle of applications. Once the resource federation process is completed, as explained in Section III-B, the combined information can be provided by MNOs through the CAMARA API. This allows for easy discovery of edge nodes and efficient on-boarding, deployment, and removal of applications. This method simplifies the interaction process and improves the efficiency and scalability of service deployment in diverse MEC environments.
- *CAMARA API for MEC Node Discovery*: By leveraging CAMARA APIs, the application or user can identify the nearest MEC when the user has performed cross-border roaming or handover. Specifically, the Edge Discovery API of CAMARA provided by one of the MNOs will expose the list of available MEC nodes it has registered. This enables seamless relocation of MEC applications to a more suitable MEC platform, such as the one closest to the user, to minimize the latency. The process of registering MEC nodes and relocating applications is carried out through the federation mechanism described in Section III-B.

In this approach, CAMARA APIs serve as a facilitator for enabling the consumption and provision of federation functionalities in the scope of cross-border mobility use cases.

B. Cross-MNO MEC Orchestration Federation

The proposed approach is based on the use of an OP, as per GSMA's definition [10], acting as a central MEC orchestrator (see Fig. 1), thus facilitating control procedures, such as application onboarding, application lifecycle management and network information acquisition through ETSI MEC APIs, among others. In addition, this layer can potentially enable the communication between two MNOs (or two OPs) through an East-Westbound Interface (EWBI), using a REST API model [12]. The EWBI defines a set of essential resources for specifying and deploying cloud-native applications across diverse

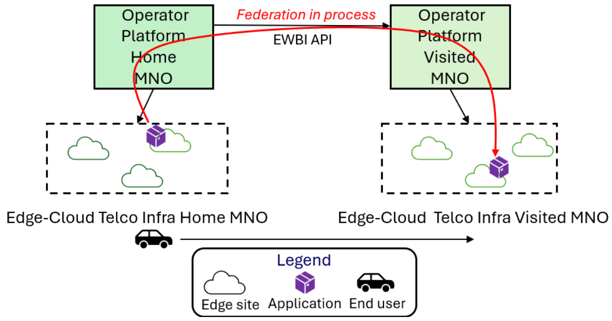

Fig. 2. High-Level Architecture of Cross-MNO Orchestration Federation

MEC sites [13]. Standardized API resources include operations related to federated processes involving the aforementioned OPs and infrastructure hosting applications, operations focusing on the infrastructure, specifications about the application, and operations for onboarding and deploying applications. These resources can relate to the infrastructure, applications, or the MECs and the infrastructure hosting applications. In a nutshell, the EWBI facilitates communication between both MNOs' MEC systems, enabling collaborative operations on available edge nodes, sharing application specifications, and performing deployment operations.

A realistic use case for the application of federation through the EWBI is depicted in Fig. 2. In this scenario, we assume that a user connected in the home network consumes an application that is deployed in the home OP, while the user is moving towards a new location that is under the coverage of another MNO (visited network). As the application will eventually need to be deployed in the new edge location, the visited MNO can share information about its infrastructure with the home MNO through the EWBI, so that the latter can deploy applications and services on the former's infrastructure in the form of containerized microservices. Hence, when the end users reach the network of the visited MNO, the required services are readily available to be consumed in the edge infrastructure of the visited MNO.

The process of MEC federation between two orchestration platforms can be divided into three phases: *(i)* federation setup, *(ii)* federation in process, and *(iii)* federation termination. It is worth noting that *federation setup* and *termination* are phases that take place offline and involve also business agreements between the operators, while the *federation in process* is the actual phase where all the orchestration action can take place. More specifically, during the *federation setup* phase, the visited MNO adds the home MNO to its database. This action generates a pair of credentials for authentication, which are shared with the home MNO. Then, using this credentials, the home MNO adds the visited MNO to its database and federation is established between the home and visited MECs. During the *federation in process* phase, the home MNO can deploy an application on the MEC of the visited MNO, an action that can be done either manually or be triggered automatically through external calls, e.g., by AI-driven decisions. This phase ensures the smooth operation of the federation and monitors its performance. Finally, in the *federation termination* phase, the home MNO can undeploy the federated service and terminate the whole federation session.

The EWBI and, consequently, the three phases of federation described above, are implemented by means of a REST API that handles a set of HTTP requests, as shown in Fig. 3. Through this interface, the home and visited MNO administrators can initiate the federation establishment process by triggering a set of API calls, including enabling the federation (setup phase), referencing the application images and manifests, as well as automatically triggering the onboarding and deployment of the application on the shared MEC site (federation in process phase). It is worth noticing that, during the deployment process, the home MNO informs the visited MNO about the location and the main requirements of the application images, while the application deployment/undeployment through the MEC orchestrator's Southbound Interface (SBI) is responsibility of the visited MNO.

IV. Implementation and Evaluation

The proposed MEC federation solution has been implemented, validated, and evaluated with an infotainment use case deployed on two 5G SA networks across the Spanish-French cross-border corridor of the 5GMED project [1].

A. Follow-me Infotainment Use Case

The Follow-me Infotainment use case aims to provide high-quality multimedia content to users travelling at high speeds and crossing international borders. When the user is in Spain, the UE is connected to the infotainment service deployed in the MEC of the Spanish 5G network. When crossing the border, the MEC orchestrator must deploy a new instance of the service in the MEC of the French 5G network (i.e., service migration), for which it follows the EWBI-based cross-MNO orchestration federation workflow described in Section III-B. When the user crosses the border, the UE makes a seamless roaming from the Spanish to the French 5G SA network, and it then connects to the infotainment service in the French MEC.

The Follow-me Infotainment use case comprises two services: Enjoy Media Together (EMT) and Tour Planning (TP). The EMT service creates a virtual "video sharing room", enabling synchronized viewing of high-definition media content for users in the corridor. It supports various formats and devices, offering both video-on-demand and real-time streaming. The service leverages a virtual content delivery network architecture and adaptive streaming technology, along with the low-latency capabilities of the 5G network, allowing users to establish peer-to-peer social networks through web real-time communication. The TP service provides a multimedia application for trip planning with access to 360-degree videos and virtual reality content. It enhances the user's experience by delivering information about surroundings, points of interest, and tour planning functionalities. The service allows users to select predefined tours or customize their own, suggesting highlights and promoting "ready-to-follow" tours.

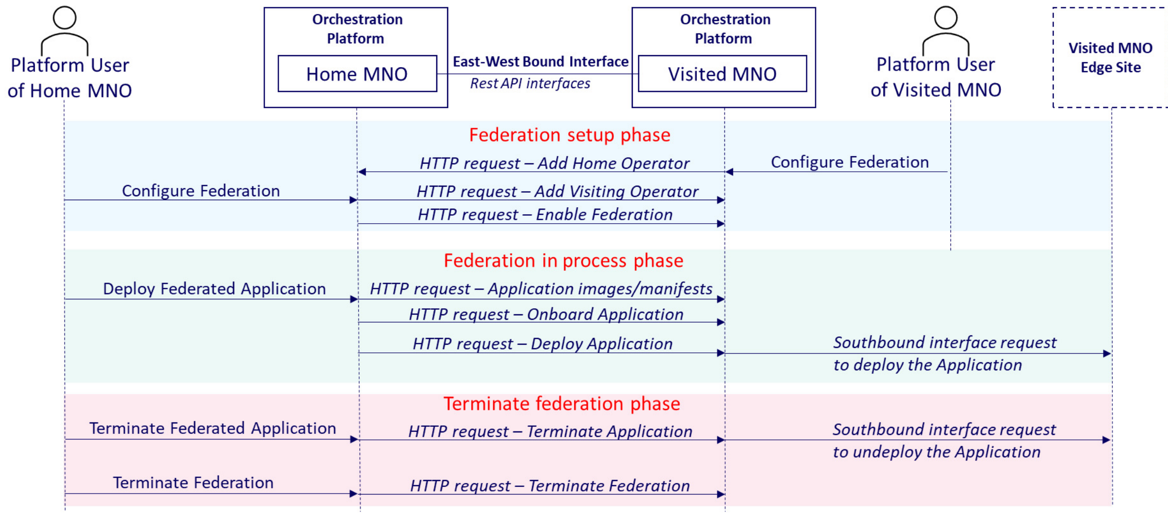

Fig. 3. EWBI API requests between Home and Visited orchestrators to enable MEC federation

Fig. 4 illustrates the functional architecture of the use case, which includes both EMT and TP services within the high-level cross-border 5G network architecture designed in 5GMED. The EMT and TP services are divided into two main components: one operates in the cloud, as a centralized coordinator and content storage; and the other operates at MEC locations to serve as an application anchor point close to users, offering low latency and reducing cloud-bound traffic. The UE on the ground layer supplies metrics (e.g., location, round-trip time, etc.) to a data analytics module (DAM). While the UE is moving, the DAM processes the collected information and detects if MEC service migration is needed. The decision can be taken using QoS predictions or less computation-intensive methods, such as geofencing, where boundaries are created around a physical location to trigger a migration. If this is the case, the DAM requests the orchestrator to deploy a new service instance at an alternative MEC location.

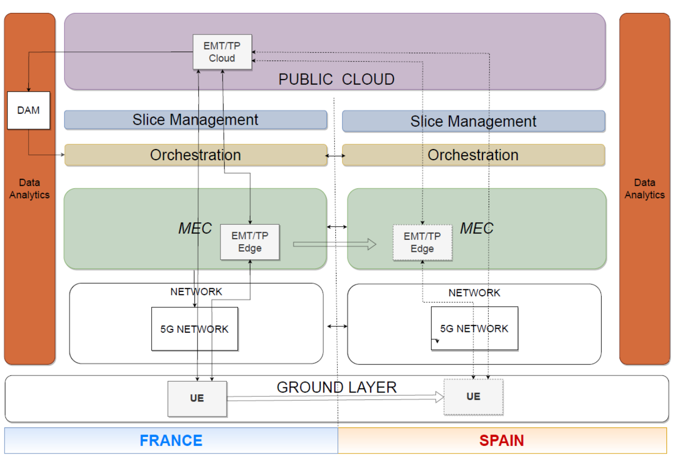

Fig. 4. High-Level Functional Architecture for the Follow-me Infotainment Use Case

B. Testbed Setup in Cross-border Scenario

We have conducted field tests within the 5GMED project on the E-15 highway of the Mediterranean cross-border corridor. The tests involved the deployment of two 5G SA networks, each equipped with a 5G core, federated MEC and orchestrator, and twelve gNodeBs, with six Ericsson gNodeBs deployed in Spain and six gNodeBs from Nokia situated in France. To enable federation, the role of the orchestrators was fulfilled by the NearbyOne orchestrator [14]. Two instances of NearbyOne were deployed with an EWBI.

Since with Home-Routed Roaming (HRR) all user data is routed through the User Plane Function (UPF) of the home network, HRR limits the effectiveness of MEC in reducing latency when the UE is connected to a visited network. In contrast, with Local Break-Out (LBO) roaming, data traffic is not sent to the home UPF. Instead, the UE connects to the nearest UPF in the visited 5G network, reducing latency. For this reason, we have implemented LBO roaming. Furthermore, to reduce the long interruption time (minutes) induced by roaming, we have implemented several roaming optimization techniques that were presented in [1], i.e., reduction of network attachment time with equivalent PLMN, idle mode roaming with AMF relocation and RAN assistance, and inter-PLMN handover. With these optimization techniques, the interruption time is expected to be lower than two hundred milliseconds.

C. Results

To validate the MEC federation solution with the Follow-me Infotainment use case, we considered two users, equipped with one UE (Samsung Galaxy S21). The users interacted with the EMT service through an internet browser, and with the TP service via an Android application showing a virtual reality video. In each experiment, the users travelled on a vehicle across the corridor, traversing the border from Jonquera (Spain) to Perthus (France), and vice versa, doing roaming between the 5G SA networks, and triggering the MEC service migration every time that the UE crossed specific locations. We conducted 20 experiments in total for both directions. In each experiment, we measured several Key Performance Indicators (KPI) for both EMT and TP services. A summary of the results

TABLE I
RESULTS OF EMT SERVICE KPIS

Service KPI	Average values
Round-trip time Latency	53 ms
Data-rate	43.52 Mbps
Jitter	92 ms
Framerate	30 fps
Reliability	99.8%
Interruption time	0 ms
Service Migration time	20 s

TABLE II
RESULTS OF TP SERVICE KPIS

Service KPI	Average values
Round-trip time Latency	90.32 ms
Data-rate	50.78 Mbps
Jitter	60 ms
Framerate	29.62 fps
Reliability	99.93%
Interruption time	0 ms
Service Migration time	18 s

obtained is provided below, along with their impact on both EMT and TP service performances.

1) EMT Service Results: Table I shows the average values of the KPIs obtained for the EMT service. The round-trip time, data-rate, framerate, service migration time, and interruption time met the desired targets, indicating robust network performance and user experience. However, there were some specific areas where the KPIs did not fully meet the target criteria due to coverage gaps in the challenging orography of the corridor, but not due to the cross-border operation. The jitter value of 92 ms exceeded the acceptable limit for video conferencing, and the reliability slightly missed the 99.9 % target, achieving 99.8%. Despite these minor deviations, the overall performance remained satisfactory, and the impact on user experience was minimal. Throughout the cross-border tests, the service encountered no interruptions and maintained seamless service continuity.

2) TP Service Results: The TP service maintained uninterrupted on the French side. While some instability was encountered in the Spanish segment due to coverage gaps, the overall user experience remained positive. Table II shows the average values of the KPIs obtained for the TP service. The framerate achieved was 29.62 fps, slightly below the target of 30 fps, yet still providing a satisfying experience. Reliability was 99.93%, surpassing the target of 99.9%. The data rate was 50.78 Mbps, above the target of 20 Mbps for video streaming, demonstrating robust performance. Latency and jitter, while not fully meeting the stringent KPIs of less than 80 ms and 10 ms, respectively, remained within acceptable bounds to ensure a seamless user experience. The latency was recorded at 90.32 ms and jitter at 60 ms, both slightly higher than desired but not significantly impacting the service quality. The service migration time was 18 seconds.

V. CONCLUSIONS AND FUTURE WORK

This paper proposed a solution for cross-MNO MEC orchestration in cross-border scenarios based on the concepts of MEC federation, OP and Open Gateway NaaS. The proposed architecture addresses the problems encountered in deploying mobility services in MEC servers when users move across international borders transitioning between 5G networks of different Mobile Network Operators (MNOs). The architecture was implemented and evaluated using an infotainment use case on two 5G SA networks deployed in a real cross-border scenario. Evaluation results showed that the proposed solution enables successful service deployment between MECs of different MNOs and ensures seamless service continuity during cross-border transitions. As future work, the MEC federation mechanisms will be optimized in terms of service discovery, resource allocation, and application deployment processes to further reduce cross-MNO service deployment time.

VI. ACKNOWLEDGEMENTS

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