Multi-Domain Architecture for CAM Service Delivery Across Borders

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***Abstract*—Connected and Automated Mobility (CAM) encompasses different driving (automated, awareness, sensing, tele-operated), multimodal and infotainment on the move services. These services have been defined with the objective to increase the road safety, improve the traffic efficiency, reduce the environmental impact of transportation and bring travel comfort to passengers and drivers. Relevant technological tasks, stemming from the highly dynamic vehicular environment, need to be solved in order to deliver seamless CAM services with the expected QoS. The cross-border scenario brings the additional challenge of supporting uninterrupted CAM services in a multi-domain environment, namely when the user leaves the serving mobile cellular network to join the newly visited one. We define a multi-domain architecture with an ETSI Zero-touch networking and service management compatible integration fabric to facilitate cross-domain service management and CAM service roaming.**

Keywords—5G, CAM services; zero-touch management; automation; AI; ML; distributed MEC, network slicing.

I. Introduction

The mobile communication networks have evolved from offering only voice to the 5th generation (5G) of mobile communication systems, which are expected to dynamically adapt to and support the diverse needs of many different industrial sectors (called verticals). At a similar pace, the automotive industry has been moving towards a more autonomous and connected vision, where vehicles can cooperate to ensure a higher level of road safety and traffic efficiency, and to become more environmentally friendly. The synergy between the telecommunications and automotive industries has led to the concept of Connected and Automated Mobility (CAM) that encompasses services such as *automated cooperative driving* (for coordinated driving between vehicles with increased level of automation), *awareness driving* (for ensuring safe passing and collision), *sensing driving* (for sharing advanced environmental information and observations gathered by sensors with the purpose of increasing situational awareness), *tele-operated driving*, *infotainment services on the move*, and *multimodal services* (such as goods tracking in multimodal logistics, management of passengers and freight) among other.

The vision of more safe, clean, efficient, accessible, and user-friendly mobility of people and goods comes with its own challenges. The connected autonomous driving vehicles bring a whole new ecosystem with demanding requirements such as high throughput and ultra-low latency. Furthermore, the delivery of CAM services should be independent of the mode of transport and regardless of whether passengers or cargo are involved. In addition, CAM services need to seamlessly function throughout all terrains, during all weather conditions, daytime and night-time. Importantly, CAM service support needs to be provided also when crossing country borders. Our focus is on the latter setting as it presents additional interesting technological challenges (some of which are discussed in [1]) that need to be overcome so that CAM services can be delivered in practice when traversing countries borders. In this paper, we address multi-operator, multi-domain CAM interaction across borders from architectural point of view.

Cross-domain service management has been previously explored in other research initiatives such as [2] and [3]. X-MANO [2] is a cross-domain solution for network orchestration that comprises an inter-domain confidentiality preserving federation interface and an information model for multi-domain network service life-cycle programmability. The 5G-Transformer [3] is aimed at enabling mobile communication networks to simultaneously support various vertical industries by tailoring the infrastructure to the verticals' needs. A Network Function Virtualization (NFV) compliant architecture, which incorporates the concept of network service federation, is proposed in [3]. The concept refers to the end-to-end deployment of parts of a network service (NS) in multiple administrative domains (AD) with each AD consisting of management and orchestration (MANO), computing and transport resources. In particular, a service orchestrator enables an end-to-end orchestration of services as a composition of Virtual (Network) Functions (V(N)Fs) across a single or multiple ADs.

The 5GROUTES project instead proposes to adopt an integration fabric compatible with the ETSI Zero-touch network and Service Management (ZSM) specification [4] for providing cross-domain service management and CAM service roaming. An overview of the ZSM reference architecture is provided in Section II, whereas the proposed 5G-ROUTES architecture is explained in Section III. The paper is concluded in Section IV with an outlook on the future development and application of the 5GROUTES architecture.

II. The ETSI ZSM Reference Architecture

The ETSI ZSM specification [4] defines a reference architecture that enables closed-loop automation at the network and service management levels. The defined there *integration fabric* provides the flexibility to integrate and compose cross-domain management services and to build automation loops that span different (Mobile Network Operator, MNO) domains. The ETSI ZSM architecture [4] follows the principles of modularity, scalability, resilience, simplicity, automation, and support of stateless management functions among other. It is a service-centric model consisting of distributed management and data services, organized into Management Domains (MDs) and integrated through a fabric.

The MDs abstract technology or ADs for the purpose of separating management concerns within a ZSM deployment based on deployment related, functional, operational, and governmental constraints. The decoupling between MDs and end-to-end (E2E) cross-domain service management is aimed at reducing service complexity and enabling the independent design of MDs and E2E management (that is, at avoiding monolithic design). The ZSM reference architecture also supports functionality for storing of and common access to up-to-date collected data across MDs, aggregation and pre-processing of the collected data (such as telemetry, logs from system, training data for Machine Learning (ML) models, etc.).

III. 5G-ROUTES MULTI-DOMAIN ARCHITECTURE AND INTEGRATION FABRIC FOR CROSS-BORDER CAM SERVICES

We propose an architecture that relies on 3GPP SA2 along with ETSI NFV and MEC specifications (following R.16 [9] and the forthcoming R.17 [9] 5G releases). The proposed architecture guarantees seamless CAM service delivery and continuity across borders. The MNOs of each domain, will deploy independently 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 services will be modeled as VNF chains that share NFVI resources with the 5G Network Services and will be managed by the NFV Orchestrator (NFVO). Moreover, we will provide a novel approach for CAM service federation via “day 1” APIs for multi-domain service ordering and onboarding, and via ETSI ZSM "day 2" runtime APIs for AI-driven closed-loop operations across domains. “Day 1” are operations responsible for starting the provision of the expected service. In contrast, “Day 2” operations are aimed at re-configuring the service when its behavior needs to be modified, and can scale or run other closed-loop operations over it. The integration fabric, following the ETSI ZSM specifications, will allow the coordination of CAM services across domains so that they can be delivered seamlessly across borders.

Figure 1 summarizes the overall 5G-ROUTES multi-domain architecture. It makes reference to the basic tiers and the technological enablers that will be developed within the project and outlined in the following subsections.

A. Business Support System (BSS)

The BSS is responsible for managing the vertical applications and CAM services of a 5G network, along with their business requirements and SLAs. Its main architectural modules are the CSMF (Communication Service Management Function), and the Tenant Web Portal. The CSMF module will map the CAM service requirements (encoded in Generic Slice Templates, GSTs) into domain-specific network requirements (encoded in Network Service Templates, NSTs) so that these can be understood by the respective management system (OSS). Coordination across domains is ensured via “day1” interfaces. The Tenant Web Portal, will conduct the analysis, benchmarking and presentation of technical KPIs from cross-border field trials, collecting the data feeds from the 5G nodes and leveraging big-data analytics for rapid and automated processing of the vast amount of data obtained from the trials. The portal interacts with the 5G enabling technologies through open, standards-based APIs.

B. Operations Support System (OSS)

The OSS implements the management functions of the MNO 5G network (for example those related to slice provisioning, network inventory, and fault management). Based on ETSI ZSM specifications, the OSS functionality could be defined through the following enablers:

- A new *integration fabric* enabler, which enacts ETSI ZSM “day 2” APIs, in order to ease unified and automated service management in multi-domain and multi-MNO scenarios. The integration fabric will follow the publish/subscribe (pub/sub) pattern, leveraging on Message Queuing Telemetry Transport (MQTT) brokers at each domain linked with a cross-domain event bus (“day 2” interfaces).
- A novel AI/ML module for closed-loop automation of CAM service management across domains, based on the inter-domain sharing of data through the integration fabric. This information exchange is relevant to V2X related data analytics, SLA requirements, vehicle mobility patterns, etc. QoS and SLA assurance satisfaction will be guaranteed via the communication of the OSS/BSS with the NFVO and the Network Slicing subsystems.

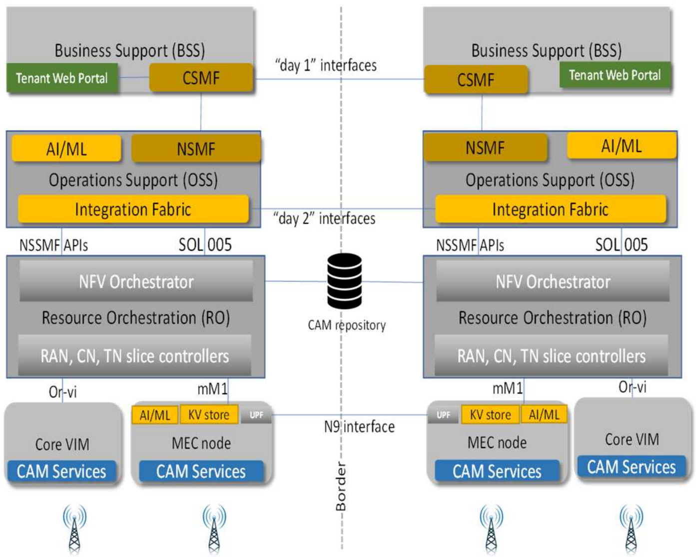

Figure 1. The proposed 5G-ROUTES multi-domain architecture with integration fabric for CAM service delivery across borders

C. Resource Orchestration (RO)

The RO is a fundamental tier, which consists of the NFVO and the Network Slice Subsystem functions. Its role is to steer the underlying 5G network resources (for example Network Services and Network Slices at the RAN, Transport and Core

Network domains). Based on ETSI NFV, Network Services (NS) are composed of one or multiple VNFs, which in turn are composed of one or several Virtual Deployment Units (VDU) or Virtual Machines (VMs). During the NS onboarding process, the NS descriptor along with the VNF Forwarding Graph (VNFFG) is procured to the NFVO, followed by a VNFFG embedding process. The goal is to assign VNFs to the Core and Edge hypervisors at the Infrastructure Tier. The CAM repository is envisioned to provide resources across MNOs, while the communication between MANO and NFVI will be conducted through the NBI SOL-005.

D. *Edge and Core Computational Infrastructure*

The virtualized computational infrastructure is composed of Edge and Core hypervisors, whose role is to host Network Functions, 5G services (for example those related to CAM), and vertical applications. Edge sites are saturated by a limited number of hypervisors (typically 10-80), while a typical 5G network could be composed of up to 100 such Edge sites. The Core site could contain hundreds of hypervisors. Edge hypervisors have a higher operational expenditure (OPEX) than the core tier hypervisors, thus, typically only a limited number of edges VNFs are deployed at the MEC. The proposed 5G-ROUTES multi-domain architecture, based on ETSI GR MEC 017 specifications [5], will adopt ETSI NFV functionality also at the Edge clouds, which will allow similar MANO workflows in both domains. Consequently, CAM services at the Edge can also be modeled as VNFs. Based to the aforementioned, the infrastructure tier could be summarized into the enablers as follows:

- A distributed Key Value store ("KV Store") will be responsible for state management and distributed storage. A data storage paradigm can be achieved through the association of unique keys with arbitrary data structures (or records) that consist of various data fields. Consequently, the user profile could be stored in such kind of records and easily migrated during vehicle handover. Through this process, with respect to ETSI MEC requirements [6] and [7], service continuity across MEC nodes and across MNO domains is guaranteed. A remarkable advantage of this approach is that it is much more efficient than solutions which involve VM migration (for example [8] [10]) and are deemed inappropriate for time-critical scenarios where handover time requirement is less than 100 ms.
- An AI/ML engine will be deployed in order to improve data consistency and service continuity based on novel predictive techniques. Typical consistency models (e.g., eventual consistency) are not appropriate for the V2X domain, where CAM services require strong consistency guarantees and there are strict time constraints. Thus, the user roaming profile (or state) needs to "follow" the vehicle such that it can be served by CAM services deployed at the closest MEC node. The ML engine will be part of the MEC host, so that local decisions can be made, which will decrease reaction time.

E. *Integration of APIs*

The integration of the different APIs has an essential role in the 5G-ROUTES multi-domain architecture. It enables the interaction with the management functions of the offered services while guaranteeing the cross-domain MNO communication. Such way of defining interfaces and APIs constitutes a modular approach which will allow the interconnection and information sharing between the modules. This process will lead to management and synchronization among the operations performed in the platform, with respect to the requirements of the service deployments. Moreover, as our proposed architecture is composed of a set of separate blocks, APIs integration is vital for displaying services consumption between blocks.

IV. Conclusion

CAM service delivery across borders brings several networking challenges related to the interaction between the management domains belonging to different MNOs. In this paper, we have presented our architectural vision on how to ensure a seamless CAM delivery in such multi-domain scenario. In particular, we suggest each MNO to manage their network and cloud resources independently yet to collaborate with neighbouring MNOs through the defined integration fabric in order to guarantee smooth and uninterrupted CAM service to their customers even when they roam to the visited MNO. In the upcoming versions of the integration fabric we will define the needed APIs and architectural building blocks in detail so that these can be implemented in practice.

Acknowledgement

This work has been supported by 5G-ROUTES (GA 951867), research project. The 5G-ROUTES project has received funding from the EU Horizon 2020 Research and Innovation programme.

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