Leveraging Mobile Edge Computing to Improve Vehicular Communications

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***Abstract*—Due to the varying conditions in traffic and resource availability in networks nowadays, maintaining continuity of network service and satisfying QoS and QoE requirements became a challenging task. If considered in a highly diversified environment in terms of technology and administration, it gets even more complicated, and appropriate service and resource management solutions are mandatory. Thus, the aim of this paper is to present our specific perspective of the ongoing European H2020 5G-CARMEN project, addressing the importance of proactive reconfiguration of network services and their migration between different domains. Leveraging on 5G technology and MEC platform, our management platform for automated low-latency-aware VNF placement and migration will enable orchestration of network services and resources across different administrative and technology domains.**

***Index Terms*—VNF placement/migration, 5G, MEC, edge computing, resource utilization, service continuity, cross-border, 5G-CARMEN**

I. Introduction and Motivation

The fluctuating nature of available resources and traffic, altogether with highly stringent requirements for network services, impose rigorous conditions for operation in communication networks nowadays. It is of paramount importance to proactively react to upcoming network service requests, and yet an appropriate network management regime is necessary in order to satisfy users' requirements and expectations.

However, the aforementioned constraints are even emphasized in case of vehicular communication networks, where each vehicle becomes a frequent participant in communication [1]. Thus, such collection of challenging network conditions and strict service requirements urgently presses to deploy the 5th generation of communication networks (5G). The plethora of benefits such as greater coverage, accessibility, and higher network density, brought by 5G technology, can be enabled by the technology pillars — Software Defined Networking (SDN) and Network Function Virtualization (NFV), to create a flexible, scalable, and programmable network [2].

The resource-hungry network service becomes a Service Function Chain (SFC), which consists of the Virtual Network Functions (VNFs), loosely-coupled via interconnecting virtual links in a specific order. Such SFC is configurable upon the changes in traffic and Key Performance Indicators (KPIs) (e.g. latency, bandwidth, etc.), making it suitable for achieving low latency and high resource utilization. The aforementioned process of VNF chaining is a service composition phase, which is then followed by corresponding embedding of the generated SFC to appropriate nodes in the substrate network. Paving the way toward programmable and virtualized future communication networks, the incorporation of Mobile Edge Computing (MEC) platform into the SDN/NFV-based 5G networks brings flexible support to applications with diverse and stringent requirements, in terms of extremely low latency, very high data rate, and high reliability [2–4]. Furthermore, with the ubiquitous support of SDN and NFV, MEC converges communication networks toward providing cloud-computing and diverse resources closer to the end-users, i.e. at the edge of Radio Access Network (RAN) [4].

Within the scope of 5G-CARMEN project[1], we are developing a multi-tenant platform that supports the automotive sector transformation towards delivering safer, greener, and more intelligent transportation with the ultimate goal to enable self-driving cars. In particular, the 5G-CARMEN Cooperative, Connected and Automated Mobility (CCAM) platform, consisted of distributed and multi-layer network-embedded cloud, will be deployed across the corridor between Bologna and Munich, spanning three different countries, i.e. different administrative and technology domains. The main goal of 5G-CARMEN is to maintain the service continuity in a cross-border scenario, which is a grand challenge that goes beyond a simple roaming/handover between different operators, in the sense that it includes also the migration of the application

[1] https://www.5gcarmen.eu/

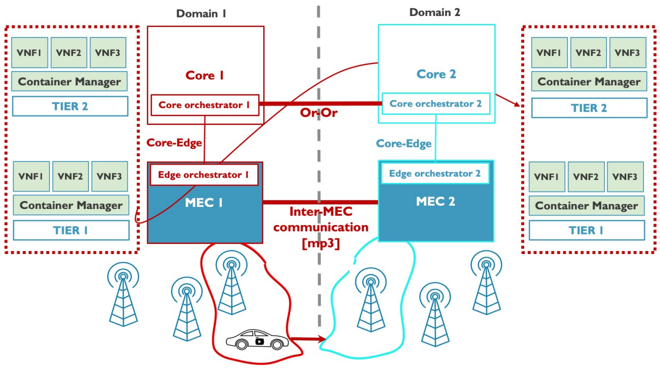

Fig. 1: 5G-CARMEN CCAM architecture: An automated low-latency-aware VNF placement and migration perspective

and services from one cloud to another. Thus, our management platform will offer on-the-fly service provisioning and orchestration by: 1. composing a network service as soon as the network request arrives, based on the specific network service requirements and resource availability, and 2. proactive preparation for migration of ongoing services when possible crossing from one administrative and technology domain to another is recognized.

II. A Low-latency VNF Placement and Migration Management in 5G Networks Based on MEC

In this section, we briefly present the high-level view of our management platform for automated VNF placement and migration in 5G-CARMEN. We also discuss the main features of VNF placement and migration, in order to better tackle their joint impact on Quality of Service (QoS), Quality of Experience (QoE), and costs, for the scenarios of vehicle crossing the border between two technologically and/or administratively separate domains.

A. High-level overview of the management platform

A simplified overview of 5G-CARMEN CCAM platform is presented in Fig. 1, and it consists of distributed and multi-layer network-embedded cloud architecture. The main cloud is deployed in the core network, while core orchestrators run on the top of it, leveraging on a global view of the infrastructure to decide on which edge cloud a certain network service should be deployed. Our management platform for automated VNF placement and migration will run in core orchestrators. The MEC platform has an embedded MEC orchestrator, which is a crucial functionality in MEC system level management [5]. Therefore, this MEC orchestrator will communicate with core orchestrator, in order to provide input for our automated VNF placement and migration algorithms, and to minimize orchestration latency and service disruptions. The use of federation interfaces is envisioned in order to avoid introducing a single entity responsible for cross domain orchestration. Such federation interfaces will allow the various domains involved in the lifecycle management of the cross-border network services to carefully control which information is disclosed to the other domains.

Thus, our management platform comprises: 1. automation algorithms that run in the orchestrators and define the logic behind VNF placement and migration, and 2. inter-MEC communication, which is based on mp3 reference point in ETSI Framework and Reference Architecture [5]. The latter should enable: 1. communication interfaces in cross-operator, cross-country/border, and cross-vendor scenarios, 2. effective exchange of inter-vehicle and vehicle-network warning and alert messages, and 3. decision upon physical interface, protocol stack, message formats, and logical mechanisms.

B. VNF placement management

The VNF placement process consists of the two following phases: 1. the composition of SFC, and 2. the SFC embedding to the substrate network which consists of the physical hosts. Although the phases are executed in a sequential manner, they cannot be detached and the overall process of VNF placement has to be coordinated. Regarding more efficient resource utilization, the VNFs can be shared among different SFCs, depending on the VNF functionalities and specific limitations which are mostly defined for the security reasons. The resource management task is to determine the amount of resources which will be enough to obtain satisfactory level of resource utilization. Thus, in order to maximize the resource utilization efficiency, VNF placement management should exploit the VNFs sharing potential. Although VNF placement raised a significant awareness about reducing utilization of resources, now with the edge computing it is even more interesting to inspect the impact of network conditions. In particular, Cziva et al. [6] define edge VNF placement as a problem of allocating VNFs to a distributed edge infrastructure, minimizing end-to-end latency from all users to their associated VNFs. Authors present the dynamic re-scheduling the optimal placement of VNFs based on temporal latency fluctuations using optimal stopping theory [6].

C. VNF migration management

The VNF migration in the 5G-CARMEN context implies relocation of network services i.e. VNF chains, from MEC servers in one domain to corresponding MEC servers in another. The enabler for such relocation will be inter-MEC communication Application Programming Interface (API), which we are currently working on. In general, the VNF migration should be invoked anytime Service Level Agreement (SLA) for the network service is not ensured. To be more specific, this type of migration has to be real-time in order to avoid potential disruptions in service continuity, which will result in undesirable effects—degradation of the QoS and QoE. Therefore, the migration of the VNF chain is necessary when resource requirements of VNF exceed the threshold of either the physical node or the physical link where VNF is deployed to [7]. In the scope of 5G-CARMEN, exceeding of the aforementioned thresholds usually happens in a cross-border scenario, with vehicles crossing the border between two operators/vendors/countries. Hence, despite the additional costs caused by the VNF migration, it is utmost important to trigger it timely and proactively. Within the confines of 5G-CARMEN, it means that corresponding resources for the re-embedded VNF chain have to be ensured in the second MEC domain prior to the migration. The allocation of such resources can be triggered based on the prediction of whether the vehicle will cross the border or not. Interestingly, the migration algorithm proposed by Tang et al. [7] predicts the future resource demand utilizing the neural network technology, which is able to extract information from resource requirements and to consider the cost during VNF reconstruction and the duration of VNF migration to the other domain.

D. Automation algorithms for on-the-fly VNF placement and migration

Our automation algorithm will enable efficient placement - in terms of latency and resources, and proactive VNF migration by leveraging MEC and 5G technology. We have considered two solutions for implementing VNF migration: 1. stateless, which means that the state of the service is not migrated, while 2. stateful migration implies that service application reserves internal state data which is then transferred from one domain to another, thus resuming the service exactly where it stopped before the migration [8]. Due to the strongly diverse domains that our management platform has to reconcile in order to maintain service continuity with low-latency, our decision is to embrace the stateless solution. This diversity includes not only different resource availability, but administrative regulations and frameworks, which are all observed through the lenses of security-related awareness. With the stateless migration, our management platform will migrate the whole or partial VNF chain to the corresponding MEC domain. A simple showcase of such automation algorithm is illustrated in Fig. 2. First, we have to scrutinize the pool of available resources and to monitor the resource utilization, in order to properly allocate resource for embedding SFC and its re-embedding in the other MEC domain. Second, in order to proactively start the migration, we will utilize Artificial Intelligence (AI) based algorithm to predict whether vehicle will cross the border or not. Third, the observation of network conditions and traffic is necessary in order to achieve low-latency, and the monitoring tool incorporated within MEC server will be used for this purpose.

Accordingly, our algorithm is going to provide an optimized SFC as an output, with the satisfactory values of QoS and QoE that can be achieved after crossing the border.

III. Evaluation of Virtualization and Orchestration Enablers

As VNF placement and migration management represent an integral part of the overall service and resource orchestration, in this section we define the set of criteria based on which the corresponding orchestration solution will be adopted. Thus, we present the existing solutions in Table I and briefly review the existing orchestration solutions based on the following four criteria.

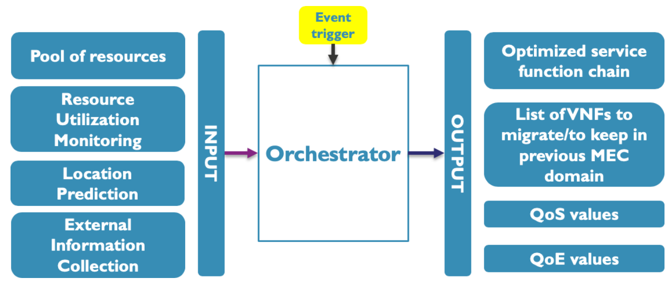

Fig. 2: A showcase of an automated on-the-fly VNF placement and migration algorithm

a) The compliance to NFV Management and Orchestration (MANO): The compliance to NFV MANO is important due to the fact that standards in multi-domain scenarios are the key factors to provide communications capabilities to heterogeneous domains.

b) Supported Virtualized Infrastructure Managers (VIMs): Two types of the supported VIMs are: Virtual Machine (VM)-based and container-based. Currently, the most popular virtualization technology is the VM [11], but due to the capability to share the host kernel with user-space isolation, the container-based virtualization is gaining momentum. While the main cloud in our architecture (Fig. 1) relies on data-centres grade virtualization and management solutions, incorporating the MEC framework into the CCAM platform requires the lightweight virtualization and orchestration solutions for small-size programmable devices. Allowing a lightweight deployment of services and applications, containers are the best candidates for deployment of emerging 5G technologies such as NFV and MEC [2].

c) Standards for VNF descriptors: Standards for VNF descriptors support the exchanging information about slices between different domains. These standards provide a broader communication compatibility among operators, and the three well-known standards for VNF description are: Topology and Orchestration Specification for Cloud Applications (TOSCA), Yet Another Next Generation (YANG), and Heat Orchestration Template (HOT). The TOSCA is a standard used to specify services and their relations on a cloud computing view. The YANG is a data modeling language for configuration and state data manipulated by the network configuration and was designed by IETF. Similarly to TOSCA, HOT can describe the resources to be deployed and the relationship among them but it is much more generic and able to automate any application production process, while HOT aims to replace the Cloud Formation syntax having in mind the creation of infrastructure. In our evaluation table, we are going to accept any solution which utilizes any of the three presented standards.

d) Multi-domain capabilities: Last but not least, the Multi-domain capabilities represent a strong contributing factor to filter the orchestration solutions. Multi-domain orchestration is characterized by having the capabilities to establish a connection with other domain using technologies such as OpenVPN, and to enable communication among the resources

Orchestrators	MANO Compliance		Support	VNF Descriptor	Multi-Domain
	NFVO	VNFM	Container as VIMs		
X-MANO [9]	✓		✓	TOSCA	✓
ONAP	✓	✓	✓	HOT, TOSCA, YANG	✓
LightMANO [10]	✓	✓	✓	TOSCA	✓
ESCAPE	✓			Unify	✓
XOS		✓		-	✓
Open Baton	✓	✓	✓	TOSCA, Own	
Tacker	✓	✓	✓	HOT, YANG	
Cloudify	✓	✓	✓	TOSCA	
Gohan	✓	✓		Own	
OSM	✓	✓		YANG	
TeNOR	✓		✓	ETSI	

TABLE I: NFV Orchestrators Overview

in both domains. Based on the criteria presented above, we down-sized our list of possible orchestrators to the three following solutions: ONAP, X-MANO [9], and lightMANO [10]. These solutions have different characteristics when considering the minimum requirements, or the time required to deploy a certain service.

Having filtered the aforementioned solutions according to the criteria, we aim to benchmark the candidate solutions and to use one with the best set of characteristics as a part of our management platform for automated low-latency-aware VNF placement and migration. The experimentation is being performed in the SmartHighway testbed, presented in [12]. The Antwerp SmartHighway testbed is designed for experimentation and evaluation in real-life scenarios, consisting of cloud-based backend, Road Side Units (RSUs), and vehicles with on-board units (OBUs). It supports short-range V2X communication (5.9 GHz) based on ITS-G5, and C-V2X (PC5 interface) between the vehicles and the roadside infrastructure. Our testbed is being equipped with Software Defined Radio (SDR) modules, which heavily increase the technical capabilities and enable its evolution towards 5G.

IV. Conclusion and Future Work

In this paper we have presented our work in progress on the development of the management platform for automated low-latency-aware VNF placement and migration within the European 5G-CARMEN project. We have depicted the main ideas and motivation for such challenging approach, recognizing the importance of an end-to-end service and resource management for vehicular communication networks based on 5G and MEC. Our paper provides a baseline for the automation algorithms that will run on the top of the edge cloud within 5G-CARMEN CCAM architecture. The main goal of our future work is to ensure the service continuity and efficient resource utilization among diverse administrative and technological domains, via on-the-fly VNF placement and migration algorithms.

V. Acknowledgements

This work has been performed in the framework of the European Union's Horizon 2020 project 5G-CARMEN co-funded by the EU under grant agreement No. 825012. The views expressed are those of the authors and do not necessarily represent the project. The Commission is not liable for any use that may be made of any of the information contained therein.

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