

An End-to-End Carrier Ethernet MEF enabled 5G network architecture

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Abstract—5G introduces new paradigms that enable communication networks to become more flexible and handle a wide variety of network services from various vertical domains. Small cell deployment exploiting virtualization techniques as envisaged by 5G, allows enhanced mobile edge computing capabilities, thus enabling flexible network service deployment and slicing support near the end user. This paper presents a cloud-enabled small cell architecture for 5G networks developed within the 5G-ESSENCE project. The paper also presents the implementation and deployment of an Ethernet Virtual Connection service over a 5G-enabled infrastructure.

Index Terms—Network Function Virtualization, Software Defined Networking, Edge Cloud Computing, 5G, Monitoring, Telemetry.

I. INTRODUCTION

The proliferation of mobile data networks and various virtualization paradigms has created the need for novel network environments in support of service management from an operator’s perspective. The continuous evolution and growth of mobile network data traffic implies a trade-off between increased capacity and cost reduction for the provider (i.e. CAPEX, OPEX). An initial approach to addressing this challenge was investigated by the EU H2020 funded SESAME project [1]. A solution based on a flexible Radio Access Network (RAN) enhanced with Network Function Virtualization (NFV) capabilities was developed by the project. The joint radio-cloud architecture realized the concept of placing intelligence at the network edge, using NFV as an enabler, to build a cost effective and energy-efficient RAN [2]. The ongoing EU funded 5G-ESSENCE project continues to evolve the small cell concept, by integrating compute capabilities at the edge and as a result is able to execute applications and network services, in accordance to the Mobile Edge Computing (MEC) paradigm [3-6]. Network Function Virtualization (NFV) [7] serves as a key enabler to this paradigm, as it can provide flexible methods on network service management.

This paper centers on an evolved Cloud Enabled Small Cell [8] (CESC) architecture as proposed in 5G-ESSENCE, aiming to enhance the processing capabilities for data that have immediate value beyond locality. Each CESC is comprised of a Small Cell enhanced with a low-cost

computation resource. The challenges of managing processing-intensive management functions, such as Radio Resource Management (RRM)/ Self Organizing Network (SON) on small cells is also addressed by the project. The approach being investigated is also expected to improve network resiliency, and to provide substantial capacity gains at the access network for 5G related applications. To achieve these goals, a distributed edge cloud environment (designated as ‘Edge Data Centre’ -Edge DC-) is under development [9], [10], [11], based on a two-tier architecture. The first tier, i.e., the Light DC, will be distributed among the CESC, in order to provide latency-sensitive services to users directly from the network’s edge. The second tier will be a more centralized, ‘high-scale’ cloud, namely the Main Data Centre (Main DC), which will provide higher processing capabilities for computing intensive network applications.

At the network’s edge, each CESC is able to host a number of VNFs comprising a service, which is available to users of a specific operator. Similarly, VNFs can be instantiated inside the Main DC as part of a Service Function Chaining (SFC). The Light DC can be used to implement different functional splits within the Small Cells as well as supporting end user mobile edge applications. At the same time, 5G-ESSENCE proposes the development of small cell management functions implemented as VNFs, which run in the Main DC and coordinate a fixed pool of shared radio resources, instead of considering each small cell as a set of unique and dedicated resources.

It should be noted that this paper does not only propose the development and adaptation of a multitenant CESC platform. It also addresses several current aspects that affect dynamic service deployment over 5G infrastructures. The paper presents the implementation of a Carrier-Ethernet Service, compliant to the Metro Ethernet Forum’s (MEF) specifications, which realizes a mobile hospital unit scenario.

Last but not least, it is worth noting that the two-tier architecture proposed in this manuscript is well aligned with the current views on 5G architecture as described by the 5G-PPP in [12], where infrastructure programmability and the split between the control and user planes are identified as two key logical architecture design paradigms for 5G. Additionally, the implemented management

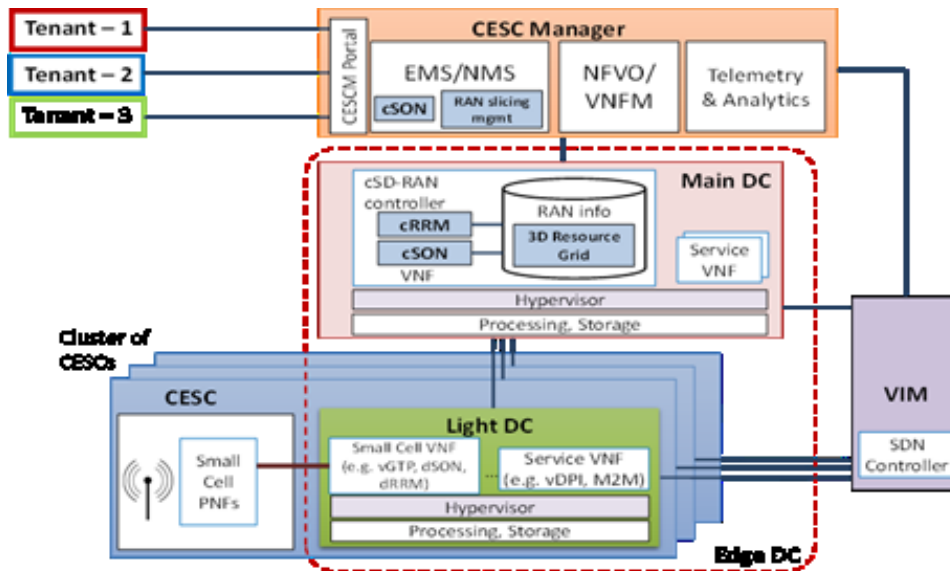


Fig. 1 - 5G ESSENCE High Level Architecture

extensions to MEF specifications create an upper layer management for the provision of market-ready network services.

The remainder of the paper is organized as follows. Section II describes the overall 5G-ESSENCE architecture and focuses on the two-tier virtualized execution environment. It also proposes an integrated management solution, and finally specifies the tier, in which a VNF should run, in order to achieve better performance. Section III describes the implementation steps in complying to MEF standards, and the development of the proposed use-case. Finally, Section IV concludes the paper and draws future research lines.

II. 5G-ESSENCE OVERVIEW

This section, firstly, details the overall 5G-ESSENCE architecture, and then, reviews the definition of a network service in the context of the project.

A. 5G-ESSENCE Overall architecture

In the 5G ESSENCE approach, the Small Cell concept is evolved not only to provide multi-operator radio access[13], but also, to achieve an increase in the capacity and the performance of current RAN infrastructures, and to extend the range of the services provided while maintaining its agility. To achieve these ambitious goals, 5G ESSENCE leverages the paradigms of RAN scheduling and additionally provides an enhanced, edge-based, virtualized execution environment attached to the small cell, taking advantage and reinforcing the concepts of MEC and network slicing.

The 5G-ESSENCE architecture is shown in Figure 1. It combines the current 3GPP framework for network management in RAN sharing scenarios and the ETSI NFV framework for managing virtualized network functions[14]. The CESC offers virtualized computing, storage and radio resources and the CESC cluster is considered as a cloud by the upper layers. This cloud can also be ‘sliced’ to enable multi-tenancy. VNFs which implement the different Small Cells features, as well as supporting end user mobile edge

applications are supported by the execution platform.

As shown in Figure 1, the 5G-ESSENCE architecture allows multiple network operators (tenants) to provide services to their users through a set of CESC s deployed, owned and managed by a third party (i.e., the CESC provider). In this way, operators can extend the capacity of their 5G RAN in areas where the deployment of their own infrastructure could be expensive and/or inefficient, as would be the case (e.g., highly dense metropolitan areas) where massive numbers of Small Cells would be required to provide expected high quality services within a given geographical area.

In addition to capacity extension, the 5G-ESSENCE platform is equipped with a two-tier virtualized execution environment, materialized in the form of an Edge DC, which supports the provisioning of MEC capabilities for mobile operators [15-17], in order to provide an enhanced user experience and agile service delivery. The first tier, i.e., the Light DC hosted inside the CESC s, is used to support the execution of VNF s for carrying out the virtualization of the Small Cell access. Finally, backhaul and fronthaul transmission resources are part of the CESC, allowing for the required connectivity.

The second cloud tier, i.e., the Main DC, will host more computation intensive tasks and processes that require centralization in order to have a global view of the underlying infrastructure. This includes the cloud-enabled Software Defined – Radio Access Network (cSD-RAN), controller which provides the control plane decisions for all the radio elements within the geographical area of a CESC cluster, including the centralized Radio Resource Management (cRRM) over the entire CESC cluster. Other potential VNF s that could be hosted by the Main DC include security applications, traffic engineering, mobility management, and in general, any additional network E2E services that can be deployed and managed on the 5G-ESSENCE virtual networks, effectively and on demand.

The management modules for the operation of the CESC platform and service provisioning within the CESC framework are shown in Figure 1. The following

subsections provide a more detailed description of each architecture component in Figure 1.

B. Main Architectural Components of 5G ESSENCE

In our scope, a CESC consists of a Multi-RAT 5G small cell with its standard backhaul interface, standard management connection (TR069 interface for remote management) and with the necessary modifications to the data model (TR196 data model) to allow Multi-Operator Core Network (MOCN) radio resource sharing. The CESC is composed by a physical small cell unit attached to an execution platform based on x86 processors. Edge cloud computing and networking are realized through sharing the computation, storage and network resources of the micro servers present in each CESC and from the Light DC. Therefore, the CESC becomes a neutral host for network operators or virtual network operators that want to share IT and network resources at the edge of the mobile network.

1. The Edge DC encompassing Main DC and Light DC

The proposed architecture is combining the concepts of MEC and NFV with Small Cell virtualization in 5G networks and enhancing them for multi-tenancy support. The purpose of the Edge DC will be to provide Cloud services within the network infrastructure and also to facilitate, by promoting and assisting, the exploitation of network resource information. To this end, all the hardware modules of the Light DC and the Main DC will be delivered as abstracted resources using novel virtualization techniques. Both networking and computing virtualization extensions will be developed using open frameworks such as OPNFV. The combination of the proposed Edge DC architecture coupled with the concepts of NFV and SDN will facilitate greater levels of flexibility and scalability.

As seen in the architecture presented in Figure 1, the Main DC will be able to execute different Small Cell and Service VNFs under the control of the CESC. In particular, the Main DC hosts the cSD-RAN controller which performs cRRM decisions for handling efficiently the heterogeneous access network environment composed of different access technologies such as 5G RAN, LTE, and Wi-Fi. These radio access networks can be programmable and under the supervision of the centralized controller. The cSD-RAN controller updates and maintains the global network state in the form of a database called "RAN Information", which includes, among other elements, an abstraction of the available radio resources in the CESC cluster.

The cSD-RAN controller can also host centralized Self Organizing Network (cSON) functionalities that are required for coordinating multiple small cells. These types of functionalities are not appropriate to run in the Light DC, as for example, InterCell Interference Coordination (ICIC) functions. Other distributed (dSON) functions and/or distributed RRM (dRRM) functions that are of low complexity and that do not involve the coordination of multiple small cells will run at the Light DC. For example, this could be the case of an admission control function that only takes decisions based on the current load existing at a given cell.

2. The CESC

The CESC Manager (CESCM) is responsible for coordinating and supervising the consumption, performance, and delivery of radio resources and services. It controls the interactions between the infrastructure elements (CESCs, Edge DC) and network operators. From an architectural perspective, the CESCM encompasses telemetry and analytics as fundamental capabilities to enable efficient management of the overall infrastructure landscape and network. The Virtualized Infrastructure Manager (VIM) is responsible for controlling the NFV Infrastructure (NFVI), which includes the computing, storage and network resources of the Edge DC.

Management and orchestration of the proposed uniform virtualized environment, which is able to support both radio connectivity and edge services, is a challenging task by itself. Management of the diverse lightweight virtual resources is of primary importance, in order to enable a converged cloud-radio environment and efficient placement of services, enhanced packet processing capabilities, and extend current solutions in the NFV field [18-20]. For this purpose, the CESCM is the central service management and orchestration component within the architecture. Generally speaking, it integrates collectively the traditional network management elements, and the new functional blocks necessary to realize NFV operations. A single instance of CESCM is able to operate over several CESC clusters at different Points of Presence (PoP), each constituting an Edge DC through the use of a dedicated VIM per cluster.

III. IMPLEMENTATION OF A CARRIER ETHERNET SERVICE OVER 5G

The main goal of this section is to describe in detail the implementation process and challenges of an Ethernet Virtual Connection (EVC) E-Line Service over a 5G enabled infrastructure. The service will provide connectivity service for between the Hospital and a mobile clinic. In order to host an EVC service over a 5G ready mobile network a set of implementation and adaptation steps need to be taken from the orchestrator point of view, in our case the CESCM. Firstly, an integration of the MEF LSO Presto Network Resource Provisioning (NRP) API to CESCM's endpoints was implemented. This modification enabled CESCM to act as a management interface and dynamically provision the components of the EVC Service. The EVC Service consists of various components both on the NFV/SDN layer and the LTE one. The CESCM is responsible for the management and the orchestration of the different layers.

In regard to the upper network service orchestration layer the LSO Presto API is used. The LSO Presto API belongs to the family of LSO Reference Points as defined in MEF 55 [21]. It defines the network management reference points needed to manage the network infrastructure, including network view management functions. Consequently, it offers the upper management layer for CESCM to manage and orchestrate accordingly the underlying network elements.

Figure 2 illustrates the described scenario and the specific network and management elements that comprise

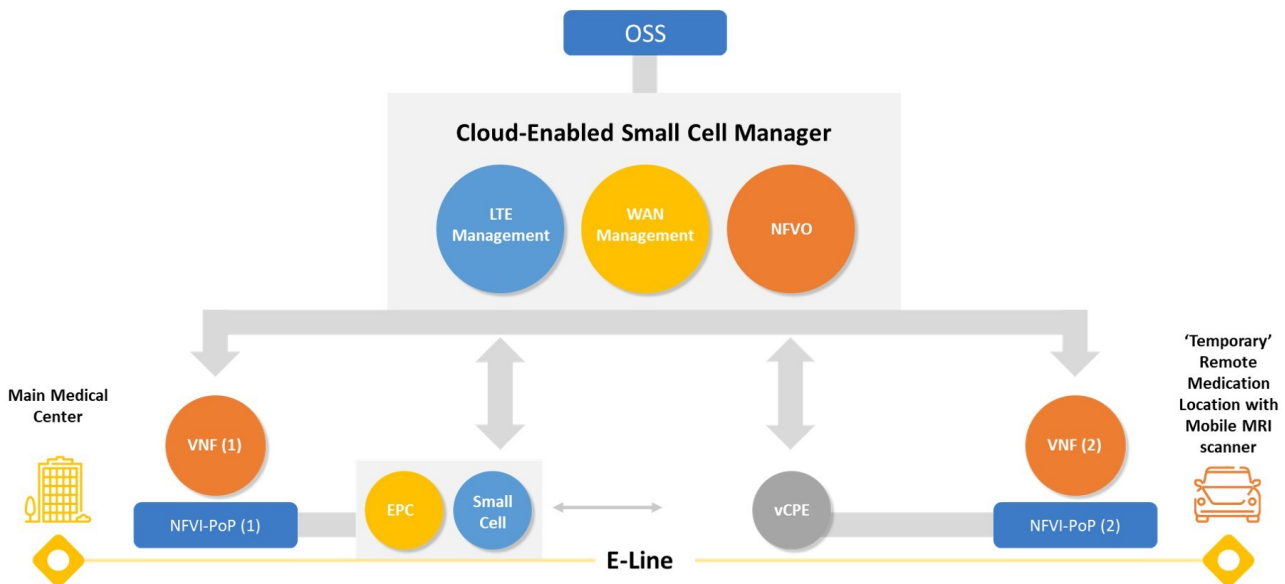


Fig. 2 – Overview of the End-to-End Carrier Ethernet Service over a 5G ready mobile network.

the system. As it can be seen CESCSCM interacts with an upper layer management entity, which initiates the service request with specific requirements (i.e. endpoints, bandwidth, traffic type etc.). By receiving the request in LSO Presto format CESCSCM provisions the required resources on the network and the NFV domain.

One of the key challenges addressed in the presented implementation was the transmission of Ethernet frames over a 5G ready network. 5G networks are based upon the LTE technology, which means that IP packets exchanged between the EPC and the Small Cell are traversed over a GTP tunnel. In our setup the packets exchanged between the two endpoints of the service are Ethernet frames, which in our case use the QinQ (802.1ad) protocol. This generates the challenge to forward QinQ frames over a GTP tunnel. As the LTE endpoints would not process correctly ethernet frames, the solution of encapsulating (using tunneling techniques) was implemented in order to allow seamless L2 connectivity between the end points.

The tunneling technology selected for this scenario was the Geneve tunneling protocol. The Geneve and QinQ functionalities were implemented in the form of VNFs that are hosted in the corresponding edge NFVI-PoPs. Each VNF serves as the edge Carrier Ethernet Enabler, its tasks include:

- Encapsulation and De-capsulation of the QinQ packets. QinQ packets are basically double tagged VLAN packets.
- Geneve tunnel establishment.

Additionally, a generic Neutron plugin was developed in order to facilitate QinQ frame switching inside the Openstack networking environment. The QinQ frames entering the NFVI-PoPs needed to be able to reach the appropriate VNFs and be processed accordingly. The performance assessment process of the EVC network service consisted of measuring the additional delay inserted by the deployed service over a generic network environment. In Figure 3 the Round-Trip Time (RTT) is calculated for the 2 test cases. In the first one the data packets are not being encapsulated (no processing is

imposed) thus traverse through the cloud and LTE environment from one endpoint to the other with the minimum possible latency. This latency is considered as baseline and is measured at 34 ms on average.

In the second case where the EVC service is deployed

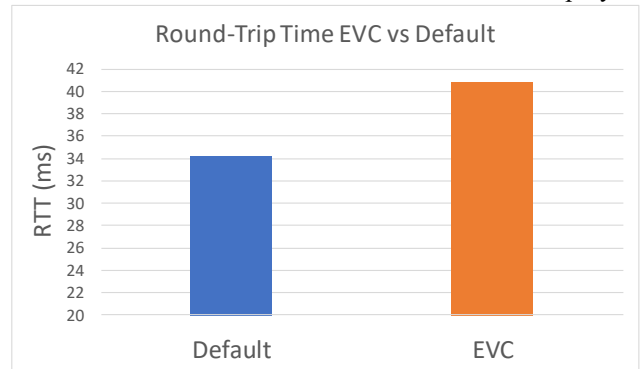


Fig. 3 – RTT times for EVC enabled and not enabled deployment setups.

and the packets are encapsulated in order to be forwarded by the LTE domain. The latency is expected to be increased due to the processing that occurs at the demarcation locations (i.e. at the end-points). The measured additional latency for the round-trip is 6 ms on average. As it can be deducted the overhead delay generated by the EVC service is acceptable, as the system can now support instantiation of EVC services over an heterogeneous underlying 5G enabled environment, exploiting the bandwidth enhancements and slicing capabilities available.

In the next step of the evaluation process, the experimental setup was tested under the scenario of multiple simultaneous flows, in order to assess its scalability.

In Figure 4, the jitter for a number of simultaneous flows is measured. As it can be seen for each additional parallel flow jitter is increased up to the point of 15 flows, where is stabilized to 14 ms. Each flow had a throughput of 10Mbps, so the total throughput in the last case is approximately 150 Mbps, which is the bandwidth limit of our LTE testbed.

Finally, the network service deployment time was

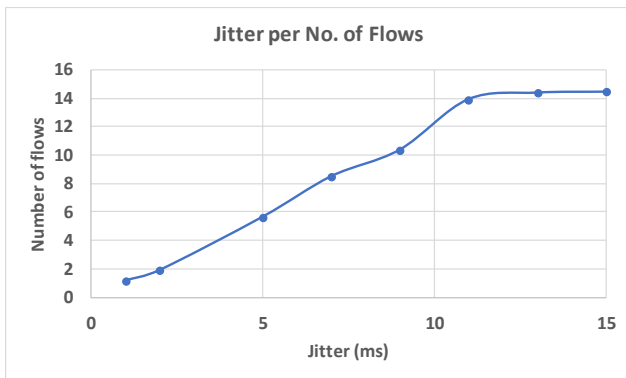


Fig. 4 – Packet jitter per number of simultaneous flows.

measured, meaning the transition from the default setup to the EVC realization. The deployment process includes the instantiation of the corresponding VNFs, and timely SFC operations on the LTE and NFVI networks. The results showed that the average deployment time of the EVC service is approximately 30 seconds. The deployment time refers to the time passed from the reception of the service request (by the CESC) till the moment the EVC service is available (counting the time required for the VNF deployment and configuration).

IV. CONCLUSIONS

This paper presented an NFV enabled Small Cell architecture for 5G systems, which aims to evolve and improve the performance of existing RAN infrastructures. The manuscript not only presented the current issues in the related field, but also proposed a reference 5G-PPP reference architecture based on the 5G-ESSENCE project.

Furthermore, the paper investigated the deployment of a Carrier Ethernet network service over a 5G network infrastructure. It also presented various challenges and solutions on the integration of this type of services over an NFV-enabled 5G-ready environment and measured the introduced delay of the proposed implementation.

As the 5G-ESSENCE project progresses additional use cases will be investigated in the context of 5G. More specifically, the concept of cSON small cells will be investigated in terms of its relevance to RRM and its potential to enhance 5G in terms of performance and efficiency.

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