Experimental SDN Control Solutions for Automatic Operations and Management of 5G Services in a Fixed Mobile Converged Packet-Optical Network

(invited paper)

Ricardo Martínez, Ricard Vilalta, Manuel Requena, Ramon Casellas, Raül Muñoz and Josep Mangues
CTTC – Communication Networks Division
Av. Carl Friedrich Gauss, 7, 08860 Castelldefels, Spain
ricardo.martinez@cttc.es

***Abstract*— 5G networks will impose network operators to accommodate services demanding heterogeneous and stringent requirements in terms of increased bandwidth, reduced latency, higher availability, etc. as well as enabling emerging capabilities such as slicing. Operators will be then forced to make notable investments in their infrastructure but the revenue is not envisaged to be proportional. Thereby, operators are seeking for more cost-effective solutions to keep their competitiveness. An appealing solution is to integrate all (broadband) services including both fixed and mobile in a convergent way. This is referred to as Fixed Mobile Convergence (FMC). FMC allows seamlessly serving any kind of access service over the same network infrastructure (access, aggregation and core) and relying on common set of control and operation functions. To this end, FMC leverages the benefits provided by Software Defined Networking (SDN) and Network Function Virtualization (NFV). First, we discuss some of the explored FMC solutions and technologies, from both structural and functional perspectives Next, focusing on a Multi-Layer (Packet and Optical) Aggregation Network, we report two implemented and experimentally validated SDN/NFV orchestration architectures providing feasible FMC to address upcoming 5G challenges.**

Keywords— FMC, 5G, SDN and NFV, Multi-Layer Networks.

I. INTRODUCTION

The upcoming *5G networks* will bring advanced services with stringent requirements: increased data rate (100x compared to 4G data rates at cell edge), enhanced end-to-end latency (10 ms or less), enhanced energy efficiency, massive connectivity with strict quality of service (QoS) levels, etc. [1]. 5G services are sorted into three main communications types: i*) enhanced mobile broadband* (eMBB), ii) *massive machine type communications* (mMTC) and iii) *ultra-reliable low latency communications* (uRLLC). Fig. 1 (a) qualitatively illustrates the heterogeneity and impact on different requirements of such service types. The service being more bandwidth-hungry is eMBB; uRLLC requires connections with extremely low latencies used for delay-sensitive applications, such as gaming or automotive services. Finally, mMTC will impose handling a high connection density, that is a very large number of connections need to be handled in a reduced area.

The above connection types and service requirements of 5G will notably challenge network operators at the time of accommodating them in their infrastructures in a cost-effective manner. That is, operators are seeking for strategies aiming at reducing both CapEx (i.e., investments) and OpEx (control functions and operations). To do that, it is widely agreed that 5G services must be supported over the same infrastructure and managed by a common pool of control elements and functions (e.g., unified control and management, authentication, authorization and accounting, etc.). In light of this, converging (mostly mobile) 5G services with traditional broadband fixed services (like FTTH) is seen as a very plausible scenario. The rationale behind this is that despite operators see that fulfilling 5G service requirements entail a notable network transformation, the expected revenue for doing that will not be proportional. Thereby, the most economically-viable solution is to lower the Total Cost of Ownership (TCO) to keep operator's competiveness. Integrating all 5G, and especially broadband mobile and fixed services is essential and this is referred to as *Fixed Mobile Convergence* (FMC) [1][2].

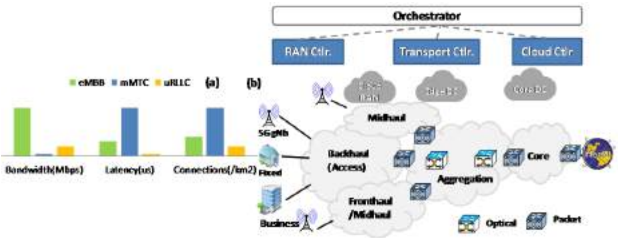

Fig. 1. (a) 5G service requirements; (b) FMC infrastructure supporting 5G

FMC embraces two convergence types: i) unifying their equipment and technologies in the different network segments (i.e., access, aggregation and core) and, ii) integrating the management as well as operations and business systems [3]. Both *convergence* approaches were recently explored and validated in the context of the EU FP7 COMBO project [4]. In this project, the first convergence type was termed as *structural convergence,* whilst the second one was named as *functional convergence.* Both FMC solutions can leverage the appealing features in terms of flexibility, agility, cost-efficiency, etc. brought by current networking trends (envisioned as essential for the 5G), such as the Software Defined Networking (SDN) and the Network Function Virtualization (NFV) [3].

SDN deals with a logically centralized control (relying on standard open interfaces) of the data plane infrastructure, i.e., Radio Access Network (RAN), Passive Optical Networks

978-3-903176-07-2

(PON) solutions, packet and optical switches, etc. This provides automatic and unified programmability of the underlying network relying on abstracted data plane information. Thus, the traditional lack of interaction between different network segments and technologies such as mobile and transport layers can be overpassed [5]. Indeed, mobile, fixed and transport layers has traditionally evolved independently which in turn does increase the TCO. Additionally, the cumbersome vendor lock-in can be removed favouring multi-vendor network scenarios.

On the other hand, NFV relies on exploiting cloud/IT virtualization techniques to enable network functions such as the mobile Evolved Packet Core (EPC), Border Network Gateway (BNG), Central Unit (CU), etc., which typically are allocated in dedicated hardware, to be run on the cloud as Virtual Network Functions (VNFs) [6]. This concept also favours reducing the TCO. Specifically, VNFs can be executed within Data Centers (DCs) (in Virtual Machines, VMs, or containers) and may be applicable to any data plane packet processing as well as control function comprised in fixed and/or mobile infrastructures [7][8].

Both SDN and NFV concepts allow operators offering emerging 5G capabilities, such as the *network slicing* [9][10]. Slicing provides, on the one hand, network virtualization, which exploits SDN abstraction capabilities to partition the physical infrastructure and compose multiple (logical) and isolated infrastructures (i.e., *multi-tenancy*). On the other hand, slicing also offers the allocation, tailoring and configuration of (virtualized) network functions required for a specific service relying on NFV. Required VNFs for a service could be deployed in DCs located at different FMC infrastructure locations depending on the service requirements. Therefore, slicing is also an enabler of FMC to accommodate over a common infrastructure heterogeneous services such as Mobile (Virtual) Network Operators (MVNO) or those related to the vertical industries (e.g., eHealth, Industry4.0, etc.) [11].

Herein we report some implementations and experimental validations we conducted addressing specific 5G and FMC objectives within an aggregation (backhaul) network segment. We consider a multi-layer network (MLN) infrastructure formed by both packet and optical switching and controlled by a transport SDN instance. This allows coping with both the envisaged tremendous growth of data traffic (specially eMBB), exploiting packet statistical multiplexing and huge optical capacity, as well as the expected high dynamicity and stringent requirements of both eMBB and uRLLC leveraging SDN flexibility and programmability. Finally, slicing is also explored where the abstraction and virtualization of the MLN is combined with NFV to specifically offer dynamic deployment of virtual backhaul transport for multiple MVNO demands.

The remainder of this paper is as follows. In Section II, we present a general FMC network architecture for 5G with special focus on access and aggregation segments, which will be the most impacted by 5G requirements. Section III addresses an implemented SDN-based orchestrator for dynamically serving both fixed and mobile broadband communications within an aggregation MLN. In Section IV, it is detailed an SDN/NFV orchestration solution providing dynamic composition of virtual backhaul infrastructures over a MLN for different MVNOs along with deploying VNFs (e.g., for EPC functions) at DCs. Finally, Section V concludes this work.

II. FMC Architectures in Support of 5G Services

Figure 1 (b) depicts a general SDN/NFV network architecture conceived to face up the challenges imposed by 5G. As mentioned, the goal pursued by network operators is to adopt a sufficiently flexible network solution satisfying both the dramatic growth and extreme dynamicity of 5G data traffic whilst reducing the TCO. In this scenario, FMC becomes very relevant, providing the integration of broadband communications via structural and functional convergence approaches. In the following, structural FMC solutions and technologies within both access and aggregation networks are reported. Next, SDN and NFV control and orchestration systems are discussed, paving the way not only for supporting 5G operations but also for addressing functional FMC approaches.

A. Access and Aggregation Networks for FMC

In the access domain, one of the most appealing convergence strategies relies on leveraging existing FTTH. Traditionally, such a deployment (in addition to the fiber to the cabinet, FTTC) were/are rolled out for delivering fixed broadband services. Nonetheless, to address the expected increase of densification of macro and small cells along with coping with the growth of 5G data traffic (eMBB, uRLLC and mMTC), the existing FTTH/FTTC infrastructure can be reused to foster structural FMC [3][12]. In this context, different RAN architectures (e.g., traditional backhaul, fronthaul, midhaul) have been proposed presenting their own functional split between Distributed Unit (DU) and CU This in turn impacts on the necessities (e.g., data rate and delay) to be dealt with by the optical fiber connectivity [13]. In all these RAN architectures, the purpose is to rely on FTTx technologies. Two of the most promising technologies to achieve that rely on the Wavelength Division Multiplexing (WDM) systems. This allows leveraging intrinsic WDM advantages, such as good scalability, low latency and commercial availability. Specifically, the current solutions being proposed are NGPON2 (using point-to-point WDM links) and wavelength-routed (WR) WDM PON [3].

In the aggregation domain, the primary objective is to aggregate and transport traffic towards adjacent network segments or DCs (Edge DC in Fig. 1 (b)). Aggregation decisions must be made considering not only the efficient capacity usage, but also the service needs (e.g., latency). From the data plane perspective, an interesting aggregation approach is based on MLN. MLN takes advantage of both worlds: packet switching (e.g., MPLS) providing finer granularity and statistical multiplexing, and optical networks (fixed or flexi-grid WDM networks) offering huge transport capacity. Thus, packets flows arriving from mobile or fixed access networks are groomed and transported over a common aggregation infrastructure [14]. Consequently, detailed MLN capabilities lead to attain an efficient use of all the network resources (packet ports, link bandwidth, optical transceiver and spectrum) which in turn enables relaxing the increasing pressure to operators for accommodating the expected traffic growth.

B. SDN/NFV Control and Orchestration for FMC

Both SDN and NFV lead to speed up and to attain the functional FMC objectives, i.e., defining a set of generic network functions being applicable regardless of the access connectivity. Such functions cover [16]: i) a common mechanism to authenticate users / subscribers by managing the session regardless of the access network; ii) advanced interface selection and routing to provide enhanced data path decisions for controlled offloading, load balancing on multiple data paths and smooth handover between access technologies. The EU FP7 COMBO project [4] studied both functional FMC solutions, which were validated under the concept of the Universal Access Gateway (UAG) [16]. The UAG is a functional element (defined within the COMBO project) that allows terminating data flows from different access technologies. The implementation of the UAG used both SDN and NFV. Specifically, the unified authentication was deployed as a VNF hosted in the UAG cloud and referred to as universal authentication. Other instantiated UAG's VNFs supported multiple virtual EPC (vEPC) implementations addressing slicing capabilities. Finally, all flows in the UAG were programmed by an SDN controller.

In general, SDN/NFV control and orchestration provides the required framework to automate network service management involving heterogeneous physical and virtual functions and resources throughout different domains and technologies, as depicted in Fig. 1 (b). That is, a unified and coordinated system (relying on common interfaces and APIs) can dynamically accommodate any type of 5G service over the underlying FMC and Cloud infrastructure. To this end, the orchestration follows a modular *tree structure* (or hierarchical) where a dedicated controller programs a set of resources (network and cloud) within a domain [17]. The orchestrator using an abstracted view of the underlying resources commands those controllers to, from an end-to-end perspective, create, update and release services. Controllers are assigned on per segment/domain or technology basis [16]. In Fig. 1 (b), a dedicated controller handles separately the RAN, the MLN aggregation / transport, and the DCs (Cloud RAN, Edge and Core). This architecture is highly scalable and flexible and allows supporting cross-domain strategies for functional FMC goals: traffic offloading, re-optimization, load balancing. In the next two Sections we report two experimental validations led by CTTC demonstrating the feasibility of applying SDN/NFV orchestration to attain: i) unified transport of fixed and mobile data flows over an aggregation MLN; ii) dynamic deployment of virtual backhaul tenants in support of 5G slicing for MVNO demands.

III. SDN ORCHESTRATION OF AGGREGATION MLN FOR FIXED AND MOBILE SERVICES

This section addresses an implemented SDN orchestrator to automatically and seamlessly configure an aggregation MLN. First, it is presented the targeted scenario and how FMC objectives are achieved. Next, it is detailed the designed and deployed SDN orchestrator with the conducted validation.

A. Targeted Scenario

Figure 2 illustrates an FMC scenario focusing on an SDN-orchestrated aggregation MLN. Fixed and mobile services arrive to the access-aggregation bordering nodes. According to their service requirements (bandwidth and latency), they are groomed and transported towards either the core (e.g., Core DC) or forwarded to VNFs running at the Edge DC. In the example, both (blue) mobile and (green) fixed services, assumed to need similar requirements in terms of bandwidth (e.g., eMBB) are grouped and jointly transported over an optical tunnel towards their respective gateways (i.e., vEPC and vBNG) located at the Core DC. On the other hand, (red) mobile service with stringent latency requirement (uRLLC) is forwarded towards the gateway and application (vEPC and CDN) at the Edge DC exploiting the advantages of Multi-Access Edge Computing (MEC) [18].

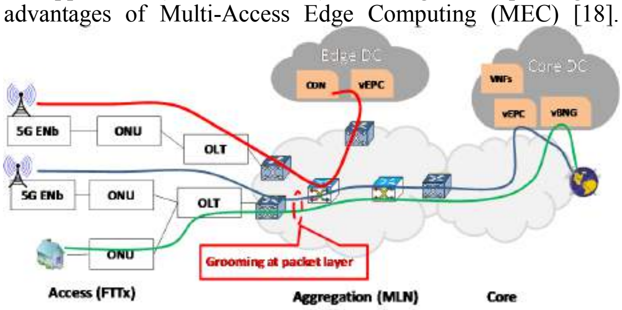

Fig. 2. Multiple fixed and mobile services in a converged MLN

To do the above in a dynamic fashion, the SDN orchestrator coordinates the configuration of all the network technologies forming the MLN. This requires awareness of: i) (abstracted) view of the resource status (i.e., packet ports, topology, optical link bandwidth, virtual packet link bandwidth); ii) the service requirements. Thus, the SDN orchestrator can accommodate and re-optimize requested and exiting services favouring grooming strategies to attain the most efficient use of all resources.

B. Deployed SDN Orchestrator

The architecture of the SDN orchestrator within the aggregation MLN is shown in Fig. 3 (a). The key architectural element is the Application Based Network Orchestrator (ABNO) [19]. The ABNO coordinates the set of controllers assigned for each technology (packet and optical) to provide end-to-end connectivity. Thus, the ABNO operates as a front-end for receiving and processing incoming (fixed or mobile) service requests. This element then coordinates/triggers the rest of the involved functions to eventually come up with the computation and programmability of the MLN [20].

In the example, the EPC's Mobility Management Entity (MME) after negotiating (out-of-band) the establishment of a new mobile service (Bearer), commands via a REST API the request for backhauling the service between the 5G ENb and the core gateway (SGW/PGW). The REST API message contains:

- *Endpoints*: IP addresses of both ENb and SGW/PGW
- *Transport Layer*: the requested packet service (MPLS)
- *Service Requirements*: bandwidth (bit/s) and latency (ms)
- *Tunnel Endpoint Identifiers* (TEID) identify the mobile service (Bearer) between the ENb and the core gateways.

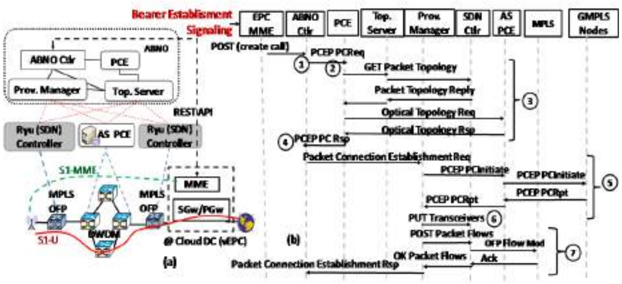

Fig. 3. (a) SDN orchestrator architecture for MLN supporting FMC services. (b) Workflow for dynamically creating a new mobile service.

The ABNO's Path Computation Element (PCE) computes MLN paths. As said, besides dealing with the demanded QoS requirements of the bearers the path computation is done to attain the most efficient use of network resources via grooming strategies. This requires the PCE having a (abstracted) view of network resources and topology being gathered by the Topology Server. This information is retrieved using a REST API for the packet domain and TCP/BGP-LS for the optical domain.

The Provisioning Manager coordinates via REST API the SDN controllers for each domain. In our setup, two SDN packet controllers (relying on Ryu implementation) and an Active Stateful (AS) PCE are used for handling packet and optical domains, respectively. The SDN controllers for the packet domains use OpenFlow protocol for the configuration. On the other hand, the optical domain is controlled combining the AS PCE (for computing and instantiating the connection) with a distributed GMPLS control plane. Last but not least, the Provisioning Manager also configures the optical transceivers (XFPs) at the MPLS nodes via a REST API selecting the nominal DWDM frequency. The experimental setup uses the LTE/EPC network provided by the ns-3 LENA emulator [21].

C. Experimental Validation

To create a new mobile service (Bearer), first the EPC's MME allocates the TEID and provides it to the 5G ENb in the connection establishment. This TEID carried into the GPRS Tunnelling Protocol (GTP-U) identifies a particular Bearer. In our approach, we associate the Bearer's TEID to a particular and unused MPLS tag at the packet nodes connected to both the cell site and the core gateways. The selected MPLS tags allows steering the traffic towards the Bearer's termination: Edge DC or Core DCs hosting vEPC user plane functions. For instance, for uRLLC services data traffic is forwarded to the Edge DC leveraging the MEC advantages.

Fig. 3 (b) depicts the workflow of the exchanged messages among: ABNO functions, packet SDN controllers, AS PCE and GMPLS control instances. The outcome is the end-to-end configuration of the whole MLN to carry a new mobile service. The triggering message (with the allocated TEID) is sent by the MME via a REST API (step 1 in Fig. 3 (b)). The message exchange is shown in Fig. 4. The message is processed by the ABNO controller which requests to the PCE (*PCEP PCReq*) the MLN computation (step 2). To do that, the PCE retrieves an updated view of the whole network (packet and optical layers) using the Topology Manager (step 3). If a feasible path is found fulfilling connection demands, a response (*PCEP PCRsp*) is returned to the ABNO controller (step 4).

The computed MLN path establishment is then triggered by the ABNO controller sending the *Packet Connection Establishment Req* message (REST API) to the Provisioning Manager. This message carries the computed path (i.e., nodes, links and resources) along with specific mobile service information, namely, the 5G ENB and SGW/PGW IPv4 addresses and TEIDs. In the MLN, the resulting packet paths transporting the mobile service may require first the establishment of optical tunnels to connect bordering MPLS switches. In this situation, an optical tunnel is configured (step 5) by combining the AS PCE and the distributed GMPLS control plane governing each involved optical node. Additionally, the optical transceivers at both endpoint packet nodes of the optical tunnel are configured (step 6) via REST API. Conversely, if the establishment of a new MPLS packet connection does not need to set up firstly an optical tunnel, the packet connection reuses existing optical tunnels with available bandwidth which favors grooming objectives. In other words, the path computation resorts on the virtual network topology derived from previously created optical connections. Consequently, steps 5 and 6 are not conducted. Finally, the computed MPLS path is established configuring the respective MPLS switches via OpenFlow [20].

Fig. 4. Captured set of control messages exchanged between EPC and ABNO.

IV. SDN/NFV Orchestration Supporting Dynamic Deployment of MVNO

5G slicing allows operators owning the physical infrastructure to dynamically offer isolated and tailored tenants over it to accommodate a myriad of heterogeneous services such as, vertical industries or MVNO. In this section, it is described an SDN/NFV orchestration which processes, computes and deploys virtual packet backhaul networks for supporting MVNO's infrastructure. Each virtual backhaul is independently controlled by a virtualized SDN (vSDN) controller deployed in the cloud. The system is completed enabling the deployment of MVNO's EPC functions as VNFs into the Cloud DC.

A. Targeted Scenario

Figure 5 depicts an example of the targeted deployment of multiple independent (virtual) backhaul tenants over a common physical aggregation MLN. The virtual backhaul connects both the MVNO's RAN to the Core DC domain where VNFs for both vEPC and vSDN are instantiated. We assume that each MVNO owns its RAN, i.e. it is not part of the conducted slicing.

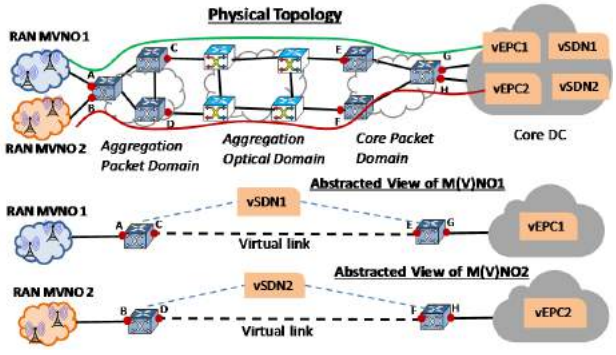

Fig. 5. Physical MLN connecting RANs and Core DC and abstracted view of backhaul network per MVNO.

An MVNO dynamically requests the creation and/or updating of its backhaul tenant according to the mobile traffic demands (e.g., envisaged eMBB) specifying the EPC needs deployed as VNFs. Besides computing and deploying that, a vSDN controller is instantiated enabling the requesting MVNO to control Bearers between the RAN and the vEPC. The vSDN controller has an (abstracted) view of the resulting backhaul tenant. The virtual backhaul is formed by a set of (virtual) packet nodes interconnected by virtual links on top of the physical MLN. In the example, for the MVNO1 its backhaul topology is made up of two virtual MPLS packet nodes (abstracted from the aggregation and core packet domains) which are connected by a virtual packet link over the physical aggregation optical domain.

B. Deployed SDN/NFV Orchestrator

The main building blocks forming the SDN/NFV orchestrator to automatically roll out MVNO's backhaul tenants with their respective DC's VNFs is represented in Fig. 6 (a). The NFV Orchestrator (NFVO) as front-end receives and processes MVNO requests. Such requests, as mentioned above, specify the requirements in terms of: network resources (link bandwidth and connectivity) as well as computing resources (VNFs for vEPC). Accordingly, the NFVO triggers the operations to allocate the demanded resources at both the cloud (DCs) and the MLN. In [6], such resources are aggregated and referred to as NFV Infrastructure (NFVI). For the cloud resources, when a VNF needs to be deployed, the NFVO requests it to the VNF Manager [6] which takes over the VNF lifecycle.

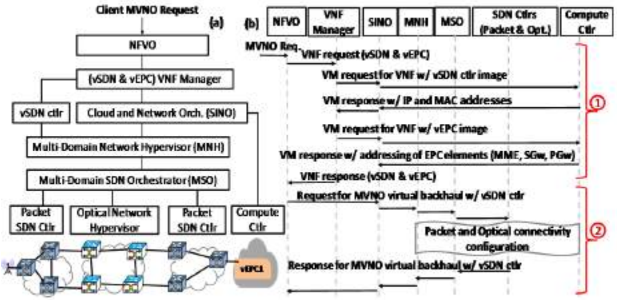

Fig. 6. (a) SDN/NFV orchestration for MVNO backhaul tenants; (b) Workflow creating both backhaul tenant and required VNFs (vEPC and vSDN).

In Fig. 6 (a) (bottom) there are the Core DC and the physical MLN. Observe that dedicated SDN controllers are deployed to configure the network elements of each particular domain: packet and optical and cloud/compute. Specifically, three network controllers are considered: 1) an SDN controller for the (MPLS) packet domain connected to the RAN; 2) an Optical Network Hypervisor (ONH) used for configuring the optical network; 3) an SDN controller for the packet network connected to the DC. Additionally, a Compute Controller is the responsible to create the VMs at the DC where the VNFs will be hosted. These controllers form part of the Virtual Infrastructure Manager (VIM) defined in the ETSI NFV architecture [6].

The Multi-Domain SDN orchestrator (MSO) is a unified network operating system enabling the end-to-end service provisioning across multiple domains. The MSO uses an abstracted view provided by each domain SDN controller. Thus, the MSO operates in a hierarchical way, as controller of controllers following the ABNO architecture (Section III.B).

The Multi-Domain Network Hypervisor (MNH) [22] partitions and aggregates the physical domain resources (i.e., nodes, links, optical spectrum, etc.) into virtual packet resources. Such resources are then interconnected to compose the MVNO's backhaul. Furthermore, the MNH provides to the vSDN controller the topology of each MVNO's backhaul.

The Cloud and Network Orchestrator handles the management of both cloud (VMs) and network resources. It uses a southbound interface (REST API) to basically retrieve (abstracted) network topology, serve connectivity requests, and perform end-to-end path computations. For the cloud resources (VMs and VNFs), the Cloud and Network Orchestrator communicates with the Compute controller. The Cloud and Network Orchestrator is aligned with the functionalities supported by the VIM in the ETSI NFV architecture [5] and hereink is termed as the SDN integrated IT and Network Orchestrator (SINO) [22].

C. Experimental Validation

Figure 6 (b) shows the implemented workflow among the functional blocks constituting the SDN/NFV orchestrator (SINO). The process is divided into two macroscopic steps:

Step 1: The NFVO requests the VNF creation of the vSDN controller (to control via OpenFlow protocol the backhaul tenant) and the vEPC within the DC. These VNF requests are handled by the VNF manager. The VNF Manager communicates with the DC's Compute controller via a REST API, requiring the creation of the VMs (specifying CPU and memory) with the respective operating system image of the VNF implementations. The response determines the IP and MAC addresses of the involved elements and functions: vSDN and vEPC (including PGW, SGW, and MME).

Step 2: The backhaul tenant creation entails both allocating the network resources and enabling the connectivity to the created vSDN (in step 1). To do that, the MNH receives and processes the request (including the IP address of the vSDN). The MNH computes, using the abstract packet view of the MLN, the domain sequence to interconnect both the MVNO's RAN and vEPC within the DC. To this end, the service requirements (peak data rate or maximum tolerated latency) are considered. In the physical MLN, it is first necessary for the traversed packet domains to be interconnected via an optical connection triggered by the MSO. That is, the MNH computes a sequenced set of virtual packet nodes that in the physical infrastructure are connected via an optical domain. This configuration is coordinated by the MSO. When the optical connection is set up (using ONH controller), at the packet level, all domains are interconnected. For those packet domains the MSO subsequently requests packet flow provisioning specifying the ingress/egress links to derive the abstracted (virtual) packet node forming the virtual backhaul. This process is performed twice to support bidirectional packet communications within the backhaul tenant. Finally, a notification is sent to the NFVO. At that moment, the vSDN has a view of the virtual backhaul used to transport both mobile control and user plane traffic between the RAN and the vEPC.

Figure 7 (a) depicts the conducted validation through interconnecting (via OpenVPN tunnel) CTTC SDN/NFV orchestrator located at Barcelona, Spain, and the ADVA ONH in Meiningen, Germany. This work was reported in [23]. For the sake of completeness, the validation is only carried out at the control plane level. The SDN controllers for the packet domains were provided by CTTC as well as the vEPC implementation based on the ns-3 LENA emulator [21], whilst ADVA provided the controller (ONH) for the optical domain.

A capture of the exchanged messages following the workflow detailed above is illustrated in Fig. 7 (b). This set of messages starts with a CLIENT MVNO requesting (using a REST API) to the SINO the allocation of two VMs for hosting vEPC and vSDN VNFs. Once both VNFs are instantiated, another REST API message sent to the SINO-MNH triggers the virtual backhaul network computation and deployment which is then served by the MSO. In this message the IP addressing of both the vEPC and the vSDN within the DC are passed.

The MSO coordinates among the different packet and optical domains the end-to-end connectivity between both the MVNO RAN and the vEPC and the vSDN controller with the SINO-MNH. The connectivity entails the establishment of an optical tunnel between the two packet domains which is handled by the ADVA ONH (simply labelled ADVA in the following). Next, it is necessary to create the packet flows from the MNO's RAN and the deployed vEPC. To do that, the MSO entity communicates with the packet domains' controllers (SDN-CTL-1 and SDN-CTL-2) relying on REST API.

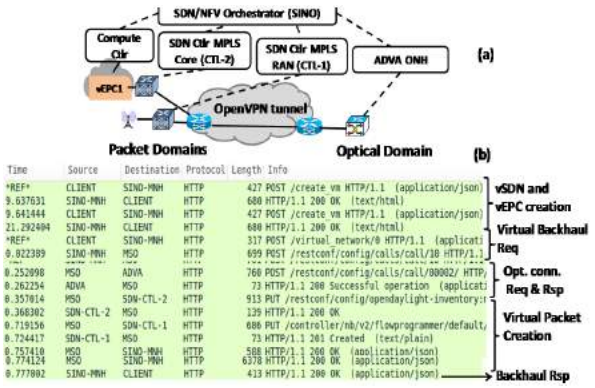

Fig. 7. (a) Setup between CTTC SDN/NFV orchestrator and the ADVA ONH.; (b) Capture of the control messages for setting up the VNFs and backhaul.

V. CONCLUSIONS

This work has reported and justified candidate strategies within the FMC concept as a mean to reduce both CapEx and OpEx investments to efficiently address/support the upcoming and stringent requirements (increased bandwidth, short latency, etc.) as well as the expected requirements imposed by 5G services. FMC is basically attained using both a common infrastructure (specially on the access and aggregation segments) for seamlessly transporting any service type (fixed and mobile) and, adopting generic and unified control and operation functions. To this end, SDN and NFV appear as fundamental enablers. Focusing on an aggregation convergent MLN, we report two implemented SDN/NFV orchestration architectures. The first one allows the automatic accommodation of mobile (and fixed) data flows over the MLN exploiting the advantages of packet statistical multiplexing and optical transport capacity. The second implementation addresses the 5G slicing capability where the physical MLN can be partitioned to compose isolated backhaul tenants used for different MVNOs.

ACKNOWLEDGMENTS

This work has been partially funded by the Spanish Ministry MINECO projects DESTELLO (TEC2015-69256-R) and 5G-REFINE (TEC2017-88373-R), and the EU H2020 5G TRANSFORMER project (grant no. 761536).

REFERENCES

[1] NGMN Alliance, "5G White Paper", February 2015

[2] S. Gosselin, et. al., "Fixed and Mobile Convergence: Which Role for Optical Networks", IEEE/OSA J. of Optical Commun. and Networks (JOCN), vol. 7, no. 11, pp. 1705-1083, Nov. 2015.

[3] C. Behrens, et. al., "Technologies for Convergence of Fixed and Mobile Access: An Operator's Perspective", in IEEE/OSA J. of Optical Commun. and Networks (JOCN), vol. 10, no. 1, pp. A37-A42, Jan. 2018.

[4] EU FP7 ICT IP COMBO "COnvergence of Fixed and Mobile BrOadband access/aggregation networks", http://www.ict-combo.eu/

[5] R. Muñoz, et. al., "CTTC 5G end-to-end experimental platform: Integrating heterogeneous wireless/optical networks, distributed cloud, and IoT devices", IEEE Vehicular Technology Mag., Vol. 11, No. 1, pp. 50-63, Mach 2016.

[6] ETSI, "Network Function Virtualization (NFV)", Oct. 2014.

[7] C- Lange, D. Kosiankowski, and A. Gladisch, "Use-Case based Cost and Energy Efficiency Analaysis of Virtualization Concepts in Operator Networks", in Proc. of ECOC, Spain, Sept. 2015.

[8] M. R. Sama, et. al., "Software-defined control of the virtualization mobile packet core", IEEE Commun. Mag., vol. 53, no. 2, pp. 107-115, 2015.

[9] X. Li, et. al., "5G-Crosshaul Network Slicing: Enabling Multi-Tenancy in Mobile Transport Networks", IEEE Commun. Mag., Vol. 55, Aug. 2017.

[10] J. Ordone-Lucena, et. al., "Network Slicing for 5G with SDN/NFV: Concepts, Architectures, and Challenges", in IEEE Commun. Mag., vol. 55, no. 5, May 2017.

[11] EU H2020 project 5G TRANSFORMER "5G Mobile Transport Platform for Verticals", http://5g-transformer.eu/

[12] E. Weiss, et. al., "Assessment of Fixed Mobile Converged Backhaul and Fronthaul Networks", in proc. of International Conf. on Transparent Optical Networks (ICTON 2016), Trento, Italy, July 2016.

[13] T. Pfeiffer, "Next Generation Mobile Fronthaul and Midhaul Architectures", in IEEE/OSA J. of Optical Commun. and Networks (JOCN), vol. 7, no. 11, pp. B38-B45, Nov. 2015.

[14] A. Mathew, et. al., "Multi-Layer High-Speed Network Design in Mobile Backhaul using Robust Optimization", in IEEE/OSA J. of Optical Commun. and Networks (JOCN), vol. 7, no. 4, pp. 3528-367, April 2015.

[15] J. M. Fabrega, et. al., "Experimental Validation of Mobile Front-/Back-Haul Traffic Delivering with OFDM Transmission and Direct Detection in Elastic Metro/Access Networks using Sliceable Transceivers", in Proc. of ECOC), Gotheborg, Sweden, Sept. 2017

[16] P. Olaszi, et. al., "Fixed-Mobile Convergence: Architecture and Functionality", in Proc. of IEEE High Performance Switching and Routing (HPSR 2015), (Tutorial), Budapest, Hungary, July 1-4,

[17] A. Rostamin, et. al., "Orchestration of RAN and Transport Networks for 5G: An SDN Approach", IEEE Commun. Mag., vol. 55, no. 4, pp. 64 – 70, April 2017.

[18] ETSI GS MEC 002, "Mobile Edge Computing (MEC); Technical Requirements", 2016

[19] D. King and A. Farrel, "A PCE-based architecture for Application-based Network Operations", IETF RFC 7491, March 2015.

[20] R. Martínez, et. al., "Experimental Validation of a SDN orchestrator for the Automatic Provisioning of Fixed and Mobile Services", in Proc. of European Conf. on Optical Commun. (ECOC), Spain, Sept. 2015.

[21] CTTC LTE-EPC Network Emulator (LENA), http://networks.cttc.es/mobile-networks/software-tools/lena/

[22] R. Vilalta, et. al., "Multidomain network hypervisor for abstraction and control of OpenFlow-enabled multi-tenant multi-technology transport networks" IEEE/OSA J. of Optical Commun. and Networks (JOCN), vol. 7, no. 11, pp. B55-B61, 2015.

[23] R. Martínez, et. al., "Integrated SDN/NFV Orchestration for the Dynamic Deployment of Mobile Virtual Backhaul Networks over a Multilayer (Packet/Optical) Aggregation Infrastructure", IEEE/OSA J. of Optical Commun. and Networks (JOCN), vol. 9, no. 2, pp. A135-A142, 2017.