Integrated SDN/NFV Orchestration for the Dynamic Deployment of Mobile Virtual Backhaul Networks over a Multi-layer (Packet/Optical) Aggregation Infrastructure

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Abstract: We propose and experimentally validate an SDN/NFV orchestrator to dynamically create virtual backhaul tenants over a multi-layer (packet/optical) aggregation network and deploy virtual network functions (vEPC and vSDN controller) to better adapt MNO's capacity increase.
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1. Introduction

The drastic growth of mobile traffic is pushing mobile network operators (MNOs) to invest in their backhaul network to cope with such demands. Typically MNOs deploy new dedicated network appliances for both control and data planes to deal with such requirements. These deployments are generally over-dimensioned considering the load foreseen for the next three to five years during peak hours [1]. By doing so, network resources may be wasted. This results in a not cost-efficient strategy in terms of both CapEx and OpEx. A more flexible, agile and cost-efficient solution achieving a better use of network resources relies on leveraging the features provided by two network concepts: Network Function Virtualization (NFV) and Software-Defined Networking (SDN) [2].

NFV deploys network functions, which were typically allocated in specialized / dedicated hardware, as software instances (virtual network functions - VNFs). VNFs run in commercial off-the-shelf (COTS) hardware within data centers (DCs) enabled by virtualization techniques. NFV is applicable to any data plane packet processing and control plane function. In this context, an appealing NFV use case for MNO is the virtualization of the Evolved Packet Core (vEPC) into the cloud [1][3]. The EPC cloudification provides important benefits like a better auto-scaling to accommodate traffic growth, homogeneity and openness, geo-distribution / migration of the EPC services/resources to different DCs, etc.

SDN deals with a logically centralized control enabling the programmability of network functions and protocols by decoupling data and control planes. SDN offers a logical forwarding plane abstraction, hiding vendor-specific hardware details and facilitating the inter-operability in multi-vendor scenarios. The abstraction enables network virtualization: slicing the physical infrastructure to create multiple co-existing and independent network tenants [2].

To deal with the increasing data traffic problem of MNOs, virtualization of network functions (NFV) and infrastructure (SDN) are appealing to attain a more scalable, cost-efficient and flexible MNO deployment, in particular, in the backhaul infrastructure. We assume that a number of MNOs owning their radio area network (RAN) are connected to a common physical multi-layer (packet and optical) aggregation infrastructure. This common and physical infrastructure is partitioned to compose individual virtual backhaul tenants on top of it. Furthermore, the MNO EPC functions are as well virtualized into the cloud connected to the aggregation network. This model enables MNOs to flexibly adjust their virtual backhaul and EPC necessities to the actual traffic loads.

We present and experimentally assess an integrated SDN/NFV orchestration architecture to dynamically compute and automatically deploy an MNO virtual backhaul along with a vEPC. The SDN/NFV orchestration coordinates the virtualization of heterogeneous transport technologies within the aggregation segment as well as compute cloud resources at the DCs (e.g., vEPC and/or vSDN controllers [2]). The proof-of-concept has been carried out in a setup connecting the CTTC SDN/NFV orchestrator for controlling both DC and packet domains and the ADVA Optical Network Hypervisor (ONH) [4] to configure the optical connectivity between packet domains.

2. Deployment of an SDN-controlled MNO virtual backhaul over a physical multi-layer aggregation network

Fig. 1.a shows the physical multi-layer (packet and optical switching) aggregation network to connect MNO's RAN and DC domains wherein vSDN controller and vEPC are instantiated. The aggregation network leverages the statistical multiplexing provided by MPLS packet switching and the huge transport capacity of optical switching applying multi-layer grooming techniques. An MNO creating/increasing its backhaul capacity is built upon the aggregation network as interconnected virtual packet domains. The MNO SDN controller's vision is an abstraction of a set of connected packet domains (via an optical connection) providing the connectivity between the RAN and vEPC. Each abstracted packet domain is represented by a virtual packet node whose interfaces are mapped to the

physical incoming/outgoing links of a packet flow. In the example, for MNO1 the virtual packet node of the domain linked to the RAN is formed by ingress link A and egress link E of the corresponding physical packet network.

The network topology and packet resource status is kept in the topology database of a dedicated SDN controller per MNO backhaul tenant. This is used to dynamically set up packet MPLS tunnels for backhauling upcoming mobile LTE signaling and data bearers (i.e., S1-MME and S1-U interfaces) between the RAN and vEPC [5]. The vSDN controller for the virtual backhaul is provided as a VNF in the DC [2]. Last but not least, the connectivity within the DC network is virtualized connecting the core packet domain and the deployed cloud VNFs.

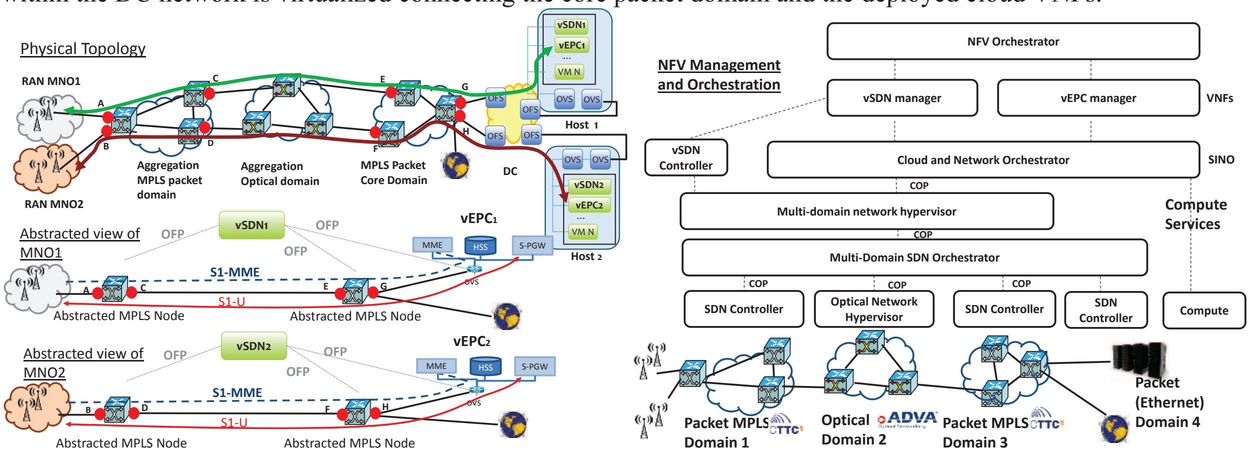

Fig. 1. a) Physical multi-layer aggregation network connecting RANs and DCs and abstracted view of the backhaul networks per MNO (left). b) SDN/NFV orchestration architecture providing MNO backhaul virtual networks (right).

3. SDN/NFV orchestration of MNO virtual backhaul and experimental assessment

The SDN/NFV orchestrator architecture to deploy a virtual backhaul along with DC VNFs is depicted in Fig. 1.b. The NFV orchestrator deploys VNFs on top of a common cloud and network platform (NFV infrastructure, NFVI). Such NFVI is formed by the physical aggregation network and the heterogeneous SDN controllers per domain. Whenever a new vSDN controller and vEPC are deployed, VNF Managers are created to handle VNF's lifecycle.

The Multi-domain SDN Orchestrator (MSO) is a unified transport network operating system handling the composition of end-to-end provisioning services across multiple domains of the aggregation network at an abstract level. This controller of controllers is based on the IETF ABNO implementation [5]. Another relevant element is the Multi-domain Network Hypervisor (MNH) [6]. It partitions and aggregates the physical resources (nodes, links, optical spectrum, etc.) in each domain into virtual resources and interconnects them to compose MNO virtual backhaul tenants. Additionally, MNH is responsible for the abstracted packet backhaul network configured by a vSDN controller. The MNH creates, modifies and deletes virtual backhaul in response to MNO requirements.

The Cloud and Network Orchestrator handles the coordination and management of cloud resources (virtual machines, VM) and network resources in the multi-layer aggregation infrastructure. Hence, it provides a common ecosystem for a cloud and network operating system towards deploying the MNO virtual backhaul and vEPC function. It communicates using the Control Orchestration Protocol (COP) [7] with the MNH. Finally, the NFV Orchestrator manages the physical and software resources to support the applications requesting the creation / enhancement of the MNO virtual backhaul as well as the corresponding VNFs (vSDN and vEPC) in the cloud.

Fig. 2.a shows the workflow between the involved functional blocks of the SDN/NFV orchestrator to manage the creation of an SDN-controlled virtual backhaul and the corresponding vEPC. Step 1 allows the NFV orchestrator to request the provisioning of the vSDN controller (for the virtual backhaul) and the vEPC. This is handled by the corresponding VNF managers sending requests to the Compute controller of VMs with the respective implementation of the VNFs (vSDN and vEPC). The response determines the IP / MAC addressing of each involved element (i.e., vSDN and vEPC including MME, SGW/PGW, etc.). Next, in step 2, the creation of the MNO virtual backhaul is conducted. This process entails building the virtual backhaul and allowing the connectivity of the created vSDN controller to configure such an infrastructure. To do that, the MNH receives the request and computes the domain sequence within the aggregation network in order to connect at the packet level the MNO RAN and the vEPC. This requires that at first the traversed packet domains are interconnected via an optical connection which is triggered by the Multi-Domain SDN orchestrator (MSO). When the optical connection is set up (by the ADVA Optical Network Hypervisor - ONH, using the COP [7]) at the packet level all the domains are interconnected. For those packet domains the MSO subsequently requests the packet flow provisioning specifying ingress/egress links of those domains to derive the abstracted (virtual) packet node forming the targeted virtual backhaul. It is worth

mentioning that this process is performed twice to support bidirectional packet communication within the backhaul. Finally, a L2 flow in the DC infrastructure (e.g., Ethernet) is created to connect the virtual (MPLS) node with the vEPC. Once the virtual backhaul connectivity is ready, this is notified to the NFV orchestrator, and at that time, the vSDN has a view of the virtual packet backhaul used to transport LTE bearers between the RAN and the vEPC.

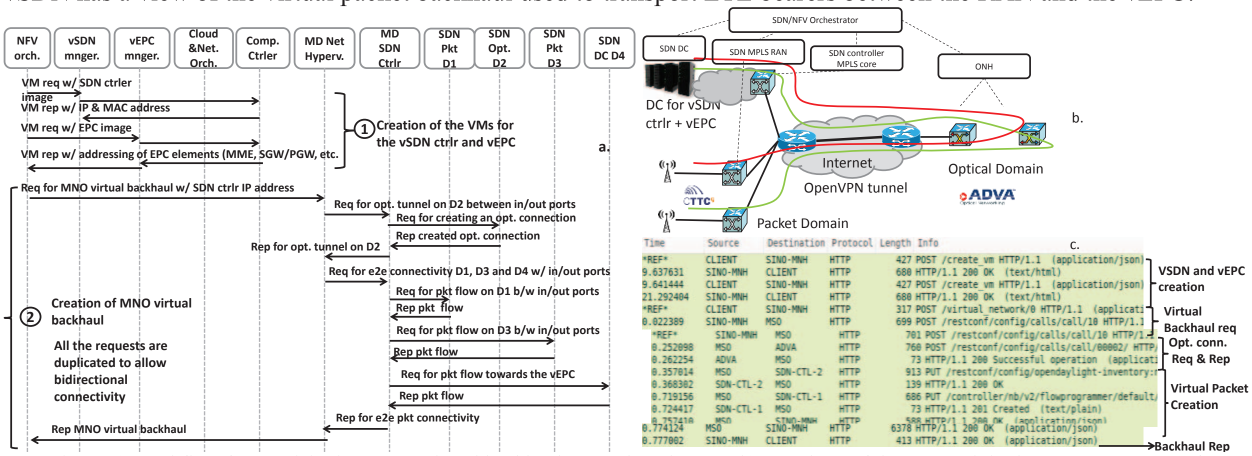

Fig. 2. a) Workflow for provisioning MNO virtual backhaul network and VNFs. b) Topology of the connectivity between CTTC SDN/NFV Orchestrator and the ADVA ONH. c) Capture of the experimental control messages for setting the VNFs and virtual backhaul network.

Fig. 2.b shows the interconnection between the CTTC SDN/NFV orchestrator and ADVA ONH. This is used to request an optical tunnel through the ADVA domain to connect packet domains between the MNO RAN and vEPC.

The experimental validation to create the VNFs and the virtual backhaul tenant using the implemented CTTC SDN/NFV orchestrator architecture interworking with the ADVA ONH (optical domain) is shown in the messages and workflow depicted in Fig. 2. First, a client MNO requests the SDN/NFV orchestrator to compose the VMs for both the vEPC and vSDN controller. For the sake of clarification the SDN/NFV Orchestrator (also referred to as SINO in the figure) and the MNH are deployed in the same building block. The used commands to instantiate VMs are implemented in a RESTful API. Once VMs are created, using another REST API the client triggers the virtual backhaul network request. This, as described above, is requested by the (SINO) MNH and served by the MSO. To do this, the IP addressing of the vEPC and vSDN controller of the allocated VMs is passed in the message. To provide the connectivity at the packet level through the multi-layer aggregation network, the MSO requests the establishment of an optical tunnel from the ADVA ONH. Once the packet domains are interconnected via the optical connection, the MSO communicates with the packet domain SDN controllers (SDN-CTL-1 and SND-CTL2) to create the flows enabling the connectivity at the packet layer between the MNO RAN and the deployed vEPC. Finally, the client MNO receives the confirmation that the virtual backhaul tenant is successfully set up.

5. Conclusions

To better adapt the increasing MNO capacity needs achieving a more efficient use of the backhaul resources an SDN/NFV orchestrator coordinates the deployment of virtual backhaul tenants over a multi-layer aggregation network. The SDN/NFV orchestrator allows instantiating in the DC the MNO vEPC functions/elements and a vSDN controller to configure the resulting virtual backhaul network used to transport LTE mobile bearers. The global architecture has been experimentally validated between the CTTC SDN/NFV orchestrator and the ADVA ONH.

6. Acknowledgments

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