Elastic optical technologies and SDN/NFV control for 5G mobile x-haul

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Abstract— This paper presents a 5G mobile x-haul architecture composed of central offices with OLT programmable S-BVTs, small-DC and Ethernet switching, and edge nodes located in the 5G cell-site cabinets with cloudlet, Ethernet aggregation and elastic ONT to meet the specific 5G mobile x-hauling requirements.

I. INTRODUCTION

5G will require high-capacity and low-latency transport networks in order to support the forecasted 1000x growth in mobile data traffic with sub-millisecond end-to-end latency. Additionally, the trend towards the centralized radio access networks (C-RAN) architecture, where the signal processing of the base-band unit (BBU) is decoupled from the remote radio-head (RRH) located in the base station (BS), and moved to the central office (CO), introduces very stringent requirements in terms of high-bandwidth and low-delay in the network segment between the BBUs and the RRHs (known as fronthaul). In order to reduce the bandwidth requirements of the mobile fronthaul, and keep most of the benefits of the C-RAN architecture, the industry is targeting a flexible functional RAN split, where some of the BBU functions are moved back to the RRH. This approach enables the virtualization of BBU functions in local clouds as well as the packetization (e.g. Ethernet) of the fronthaul interface to provide more efficient network utilization. Recent advances in flexible, elastic, and programmable optical device, system and transmission technologies and its integration with Ethernet will play a key role to enable the successful development of the 5G mobile x-haul (backhaul/ midhaul/ fronthaul) networks.

On the other hand, the wide adoption of network function virtualization (NFV) concepts, including BBU virtualization, requires cloud services for the deployment of virtualized network functions (VNFs). The virtualization of network functions that are typically deployed in specialized and dedicated hardware (e.g. mobile evolved packet core –EPC) is of crucial importance for 5G. Traditionally, cloud services have been implemented in large datacenters (DCs) in the core network. Core DCs offer high-computational capacity with moderate response time, meeting the requirements of centralized services with low-delay demands. However, there is a general trend to offer cloud services at the edge of the network leveraging on ultra/low-latency and high-bandwidth. Thus 5G requires to dynamically allocate computing and storage resources to flexibly deploy VNFs in multiple DCs, and to provide the required connectivity between DCs with Quality of Service (QoS). Software Defined Networking (SDN) and NFV reference architectures can provide efficient orchestration of network and cloud resources. This paper presents a converged SDN/NFV elastic optical access and transport network with edge & core computing for 5G mobile x-haul.

II. ELASTIC OPTICAL ACCESS AND TRANSPORT

Fig. 1 shows the scheme of the proposed network concept. There, a passive optical network (PON) scheme is employed to connect the COs to the edge nodes (ENs), where BSs are located. Each CO hosts the corresponding optical line terminals (OLTs) and aggregation stages for delivering fixed access services to the users across the corresponding access tree. Since a PON scheme is envisioned as external plant, the existing optical access infrastructure (e.g. NGPON1/2) can be leveraged. In this approach, the entire C-band is available for performing a wavelength overlay of channels for providing C-RAN services over the existing fixed access infrastructure (shared with fixed users) while following the elastic networking paradigm [1]. Additionally, NGPON2 also offers the option to establish virtual point-to-point links, for assigning different wavelength division multiplexing (WDM) channels to different ENs and/or services. As shown in Fig. 1, this can be performed directly over a common power-splitting tree or following the so-called wavelength-routed PON (with an intermediate WDM distribution stage). Moreover, selected mobile x-haul signals can be multiplexed/demultiplexed in wavelength at the CO and transparently routed to another node of the metro/core network for further processing [1].

At the transport level, COs and ENs are expanded with Carrier Ethernet switches for aggregation and switching of flows with quality of service (QoS). Thus, the statistical multiplexing nature of cost-effective Ethernet is employed to provide flexible allocation of capacity to the high number of endpoints and users in ultra-dense scenarios connected through C-RAN and fixed technologies.

Programmable S-BVTs are present at the CO/OLT side in order to concurrently serve different ENs. At the other end of the network, each EN has a programmable BVT at the optical network terminal (ONT). These (S-)BVTs can be remotely configured by the control plane, for an optimal management of the network resources [2]. The parameters to be configured at each (S-)BVT include wavelength, spectral occupancy and modulation format/power per flow. So, the (S-)BVTs deliver data flows with variable spectral occupancy and rate, according to the network and path conditions. Consequently, this solution is not only well-fitted for mobile fronthaul/backhaul, but also suitable for mobile midhaul, enabling the optimal management of different functional splits.

Among all the options for implementing the (S-)BVTs, those based on DD orthogonal frequency division multiplexing (DD-OFDM) are the most attractive for cost-effectively coping with the flexibility requirements of elastic optical networks [2]. In fact, OFDM provides advanced spectrum manipulation capabilities, including arbitrary sub-carrier suppression and bit/power loading. Thanks to these features, DD-OFDM transceivers can be ad hoc configured for achieving a certain reach and/or coping with a targeted data rate adopting low complex optoelectronic subsystems [2].

Figure 1. Converged SDN/NFV elastic optical access and transport network with edge & core computing for 5G mobile x-haul

III. SDN/NFV CONTROL AND ORCHESTRATION

The proposed SDN/NFV control and orchestration system provides global service orchestration of VNFs and network resources across heterogeneous multi-technology access and transport network domains and multiple NFV infrastructure point of presence (NFVI-PoP) at the edge and core of the network. An NFVI-PoP is a set of computing, storage and network resources that provides processing, storage and connectivity to VNFs through the virtualization layer (e.g. hypervisor). It is deployed in micro-DCs in the edge nodes, small-DCs in the COs, and core-DCs in the core network. The ETSI NFV management and orchestration (MANO) architectural framework [3] identifies three functional blocks; virtualized infrastructure manager / WAN infrastructure manager (VIM/WIM), NFV orchestrator (NFVO) and VNF manager (VNFM). The VIM is responsible for controlling and managing the NFVI-PoP's virtualized compute, storage and networking resources, whilst the WIM is used to establish connectivity between NFVI-PoP's. The VNFM is responsible for the lifecycle management of VNF instances, and the NFVO has two main responsibilities; the orchestration of NFV infrastructure resources across multiple VIMs (resource orchestration), and the lifecycle management of network services (network service orchestration). The network service orchestration is responsible to coordinate groups of VNF instances that jointly realize a more complex function (e.g. service function chaining), including joint instantiation and configuration of VNFs and the required connections between different VNFs.

We consider multiple NFV infrastructure (NFVI) domains composed of one or more NFVI-PoPs. NFVI domains can belong to the same or different administrative domains (i.e., multiple MANO orchestrator). Specifically, in the example of Fig.1, we consider an edge NFVI and a core NFVI interconnected by a Flexi-grid DWDM transport network controlled by a dedicated and independent Transport SDN controller. The edge NFVI is composed of several NFVI-PoPs (micro-DCs at the edge nodes and a small-DC in the CO), and a multi-technology (packet/optical) access network. The edge NFV MANO orchestrator is composed of an NFVO, multiple VNFMs, two VIMs (one for the micro-DCs and another for the

small-DC), and an SDN orchestrator. In the example of Fig.1, the access segment is composed of an optical access network (OLT and ONT systems) and an edge packet network with carrier Ethernet switches in the edge nodes and CO. Each of these technology domains has a dedicated SDN controller (e.g. OpenDaylight, ONOS, Ryu). On top of the SDN controllers, we deploy an SDN orchestrator [4] acting as a WIM. It allows the provisioning of connectivity and virtual tenant networks (VTN) across multi-technology domains through the use of the common Transport API defined in [5]. On the other hand, the core NFVI is composed of a core-DC. Typical implementation of NFV MANO's building blocks are OpenStack, open platform for NFV (OPNFV) and open source MANO (OSM). Finally, we deploy a global service orchestrator (GSO) on top of the NFV MANO orchestrators and the Transport SDN controller. It is responsible to provide end-to-end network services (e.g., service function chaining) across the edge and core NFVIs through the optical transport network.

IV. CONCLUSIONS

The combination of the recent advances in flexible and programmable optical device technologies, together with the emerging SDN/NFV control and orchestration paradigm is a key enabler for 5G end-to-end services.

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