Experimental Demonstration of the BlueSPACE's NFV MANO Framework for the Control of SDM/WDM-enabled Fronthaul and Packet-based Transport Networks by Extending the TAPI

R. Vilalta(1), R. Muñoz(1), G. Landi(2), L. Rodríguez(1), M. Capitani(2), R. Casellas(1), R. Martínez(1).

(1) Centre Tecnològic de Telecomunicacions de Catalunya (CTTC/CERCA), Castelldefels, Spain.
(2) Nextworks, Pisa, Italy.
{rvilata, rmunoz}@cttc.es, {g.landl, m.capitani}@nextworks.it

Abstract This paper presents the developed extensions to the NFV MANO framework for the control of SDM/WDM-enabled fronthaul and packet-based backhaul transport networks to deploy NFV network services. We develop a novel hierarchical Transport SDN solution that extends the Transport API.

Introduction
In the centralized radio access network (CRAN) architecture, the mobile fronthaul has very strict requirements in terms of high-bandwidth and low-delay because it is required to transport the digitally sampled radio waveform from the radio remote heads (RRHs) in the base stations to the central office (CO) where the pool of baseband units (BBUs) is located. The main drawback of this solution is that it does not scale in terms of bandwidth requirements for 5G. 3GPP is proposing to reduce the bandwidth and latency requirements for 5G by performing a function split of the baseband processing in eight options [1]. It brings the introduction of the next generation fronthaul interface (NGFI) that is packetized.

The BlueSPACE project [2] aims at reducing the bandwidth requirements using analog radio over fibre (aRoF) transceivers, where the radio waveforms are directly modulated onto light for connecting BBUs and RRHs (Fig.1). It can be used in combination with digital radio over fibre (dRoF) solutions for the 5G NGFI. Additionally, the BlueSPACE project also considers to include spatial division multiplexing (SDM) for further increasing the network capacity in the fronthaul segment. SDM is the key technology to overcome the capacity crunch driven by 5G mobile communications. It can be deployed with bundles of single mode fibers or exploiting the spatial dimension of the optical fiber, having parallel propagation in the same fiber using multicore fibers. The combination of SDM with flexi-grid DWDM enables to exploit the spectral and spatial dimensions in the fronthaul segment and to provide spectral channels (different wavelengths in the same core/fiber) together with spatial channels (same wavelength in different cores/fibers) to the different cell sites [3]. The BlueSPACE network architecture also deploys edge computing in the central office (CO) for Network Function Virtualization (NFV) (e.g. virtual EPC) and Mobile Edge Computing (MEC) applications (e.g. video analytics, data caching).

Fig. 1: BlueSPACE’s network architecture

The adoption of a reference control architecture such as the ETSI NFV Management and Orchestration (MANO) framework [5] can provide an efficient network service management and resource orchestration (i.e., optical and computing resources). However, it is required to extend the current NFV MANO framework. This paper presents the developed extensions for the control of SDM/WDM-enabled fronthaul and packet-based backhaul transport networks, in order to offer NFV network services. We develop a novel hierarchical Transport SDN solution for the fronthaul/backhaul networks that extends the Open Networking Foundation (ONF) transport API (TAPI). We have also extended YANG/NETCONF for the control of the CO and cell site nodes. We experimentally demonstrate NFV network services by instantiating VNFs in the edge computing and provisioning connectivity through the NFV orchestrator.

Extensions to the NFV MANO architecture
The target BlueSPACE’s NFV Infrastructure for experimental demonstration is shown in Fig.1. It is composed of multiple cell sites connected to a central office through an SDM/WDM-enabled fronthaul network with ARoF and DRoF transceivers. Additionally, the CO deploys a pool of BBUs, a small DC (edge computing) deploying VNFs, and a packet network for backhaul providing connectivity among the BBUs, the small DC, and the optical metro/core network.
The BlueSPACE’s NFV MANO architecture is shown in Fig.2. It is composed of an edge computing controller (VIM) responsible for the lifecycle management of virtual machines (VM), a Xhaul Transport SDN controller (WIM) used to provision transport connectivity between VMs and through the fronthaul/backhaul networks, and an NFV network service platform. The service platform is composed of VNF managers (VNFM) and an NFV orchestrator (NFVO). The VNFM is responsible for the lifecycle management of VNF instances. The NFVO is responsible for the orchestration of NFV infrastructure resources managed by the VIM and the Xhaul WIM (resource orchestration), and the lifecycle management of network services (network service orchestration).

First, it is required to develop a Transport SDN solution that integrates the control of optical spatial multiplexing (modes), optical spectral multiplexing (wavelengths), and the packet multiplexing in combination with ARoF and DRoF transceivers. Second, current NFV MANO framework considers the network as a commodity that provides packet pipes with QoS, either pre-provisioned or dynamically provisioned by the WIM (e.g., a Transport SDN controller) between the specified end-points. Currently, the interface with the Transport SDN defined by the ETSI NFV MANO framework is still lacking of maturity.

In this paper, we extend the ONF TAPI for the target SDM/WDM-enabled fronthaul network and use it as northbound interface for the Transport SDN controller as enabler for its interaction with the NFVO. TAPI is defined in [4]. It enables to abstract a set of common SDN control plane functions (e.g., path computation, topology and connection provisioning) and defines a common data model and protocol based on YANG/RESTconf. It allows to uniformly interact with heterogeneous SDN controllers, regardless of the specific SDN controller implementation.

Hierarchical Transport SDN control

In BlueSPACE, we rely on a hierarchical Transport SDN control approach with different levels of hierarchy (parent/child architecture) as shown in Fig.2. In particular, we propose two SDN controllers (child WIMs), one for the fronthaul segment and another for the backhaul segment, and an SDN controller on top (parent WIM) acting as the global transport network controller. The TAPI, including the extensions for the SDM/WDM fronthaul, is used as the northbound interface (NBI) of the parent SDN controller with the NFVO. Additionally, the TAPI is also used as the NBI of the child SDN controller and as SouthBound Interface (SBI) of a parent SDN controller. Thus, the considered architecture can be applied recursively.

The child WIM for the packet backhaul network segment is based on a regular SDN controller using OpenFlow or P4 protocols as SBI to configure the switches. On the fronthaul segment side, the proposed solution is to deploy SDN agents at the cell sites and another at the CO. The SDN agent’s purpose is to map high-level operations coming from the child SDN controller into low-level, hardware-dependent operations. We consider YANG data model and NETCONF protocol between the SDN agents and the child SDN controllers. The CO and the cell sites can be modelled as nodes with ports connected to A/DRoF transceivers (i.e., WDM ports) or to the optical distribution network (i.e., SDM ports) as shown in Fig.3.

The authors have presented in [6] the YANG data model for an SDM/WDM transceiver (sliceable-transceiver-sdm.yang). In this paper, we propose a YANG model for retrieving the topology of the nodes (CO and cell sites), and for configuring a connection between ports. The topology YANG model (node-topology.yang) encompasses a list of ports with their parameters (e.g. available/occupied frequency slots, available cores, transceiver type, supported modulation formats, bandwidth, central frequency, FEC and equalization, etc.). The connection YANG model (node-connectivity.yang) is composed of a connection ID, port_in ID, port_out ID, and the SDM/WDM transceiver yang model previously defined. The defined YANG models are on a public repository [7].
Extended TAPI SDM/WDM networks

Fig. 3 shows the modelled scenario using TAPI topology and connectivity service data models, based on Fig.1. A TAPI context is defined by a set of service interface points (SIP), which enable a TAPI client to request connectivity services between them. A TAPI provider may expose one or more abstract topology within a shared Context. Each topology is expressed in terms of nodes and links. Nodes aggregate node edge points (NEP). Links interconnect two nodes and terminate on NEP, which may be mapped to one or more SIP at edge of Network. A TAPI Client might request a connectivity service between two or more service interface points. The TAPI Provider creates one or more Connections in response to the requested connectivity service. The connection end points encapsulate information related to a Connection at the ingress/egress points of every Node that the Connection traverses in a Topology. TAPI has a flexible modularity and it allows extension of all its data models. In fact, extensions for OTSi, ODU, and Ethernet are included in official release. We have followed the same procedure in order to define a novel hybrid SDM/OTSi data model (tapi-sdm.yang), which allows the control and management of the proposed scenario. To this end, node edge point data model has been extended by introducing an sdm-pool container, which includes a list of available and occupied cores and available transceiver information.

Regarding connectivity service extensions, connection end points are augmented with information regarding the termination core id, as well as a list of selected frequency slots. Moreover, connectivity service requests have been augmented in order to include specific core and frequency slot requests, thus allowing hierarchical cascading of connectivity service requests. The extended YANG models for TAPI are published online on a public repository [7]. Fig.4 shows the extensions to node edge point that support SDM/OTSi capabilities.

Experimental demonstration

We propose an experimental demonstration where an extended NFVO deploys network services in the BlueSPACE’s NFV infrastructure, instantiating the VMs in the CO and automatically configuring the network connectivity in the fronthaul and backhaul domains. In the demo environment, the network data plane is emulated together with the RRHs and BBUs (modelled as particular network nodes), while an OpenStack instance controls compute nodes representing the CO.

The NFVO resource orchestration implements allocation algorithms that jointly computes VNF placement at the CO and network paths towards the RRH. At the southbound interface, the NFVO interacts with the parent WIM through a TAPI driver and acting as TAPI client. This approach allows the NFVO to retrieve the network topology of both fronthaul and backhaul domains, as built and exposed by the parent WIM. The topology, which can be provided with different levels of abstraction, feeds the resource allocation algorithms with transport related information.

The NFVO network service orchestration function is extended to establish the computed network paths as an integrated step of the network service instantiation procedure. The setup of the end-to-end connections is requested to the parent WIM invoking the connectivity service offered by the parent WIM through the TAPI driver. The setup of the paths is implemented at the parent SDN controller coordinating the provisioning in the fronthaul and backhaul domains interacting with the respective child controller, still using TAPI messages.

Conclusions

The integration of Transport SDN to the NFV MANO framework is key for the deployment of NFV network services for 5G. This paper has experimentally demonstrated a hierarchical transport SDN solution with an extended TAPI for seamless control of SDM/WDM/Packet networks.

Acknowledgements

Work supported by Spanish DESTELLO (TEC2015-69256-R) and EC H2020 BLUESPACE (762055) projects.

References

[1] Chih-Lin I, et all, RAN Revolution with NGFI (xhaul) for 5G, Journal of Lightwave Tech., v:36, n:2, Jan 2018.
[2] 5GPPP Bluespace project, https://5g-ppp.eu/bluespace/
[3] R. Muñoz et al., SDN control and monitoring of SDM/WDM and packet transport networks for 5G fronthaul/backhaul, IEEE Summer Topicals 2018.
[4] ONF technical recommendation, Functional Requirements for Transport API, ONF TR-527, Jun. 2016.
[5] ETSI GS NFV-MAN 001 (v.1.1.1) “Network Functions Virtualisation; Management and Orchestration, 2014.
[6] R. Muñoz, et al., SDN-enabled Sliceable Multi-dimensional (Spectral and Spatial) Transceiver Controlled with YANG/NETCONF, OFC 2018.
[7] https://github.com/CTTC-ONS/SDM