On-Demand Allocation of Control Plane Functions via SDN/NFV for Monitoring-enabled Flexi-grid Optical Networks with Programmable BVTs

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Abstract *A modular SDN architecture for flexi-grid networks, relying on the NFV framework, allows on-demand allocation and composition of virtualized control plane functions into instances, in a cost effective way. We demonstrate its use in the adaptive control of BVTs.*

Introduction

Several trends involve further progressing the adoption of Software Defined Networking (SDN) and related principles for the design of a generic network control and orchestration plane: i) 5G-services are increasingly conceived around the joint allocation and use of heterogeneous resources, combining networking functions (transmission, switching, forwarding) and computing ones (processing, storage); ii) there is growing interest in the concept of network slicing, understood as partitioning and composition of resources for the support of vertical sectors, and iii) the needed capability to instantiate, dynamically, and on-demand, control plane (CP) instances adapted to the specifics of the deployment, not limited to monolithic design, while enabling a cognitive approach.

In line with similar views[1], the clear functional CP demarcation and split, the definition of entities and standard/open interfaces and the modularity of the CP itself are a must to support efficient allocation and composition of CP functions. Consequently, beyond the dynamic allocation of control plane instances (e.g. on a per-slice basis[2]), a core set of functions may, in turn, use the same framework and procedures to allocate CP-specific functions at different time-scales. These functions may cover aspects such as path computation algorithms, or, generically, time consuming and scoped functions such as in-operation planning, defragmentation or re-optimization.

In this particular context, the efficient and flexible use of computing resources is one of the drivers for network function virtualization (NFV)[3]. The benefits are not only related to having virtualized functions over common hardware; the supporting containers (implemented in terms of e.g. virtual machines) can be instantiated on a per-needed basis and scaled dynamically. This applies especially in the cases where there is no clear known-pattern of resource usage.

The main concept behind this paper is to further refine the integration of SDN and NFV, where control plane functions are allocated and composed dynamically, in an operator private cloud infrastructure. While the architecture and procedures are widely applicable, we focus on the virtualization of CP functions for the adaptive optimization of Bandwidth Variable Transceivers (BVT) via dedicated algorithms.

Data and Control Plane architectures

We assume (Fig.1) a flexi-grid optical network with programmable BVTs under the control of an SDN control plane. BVTs are based on

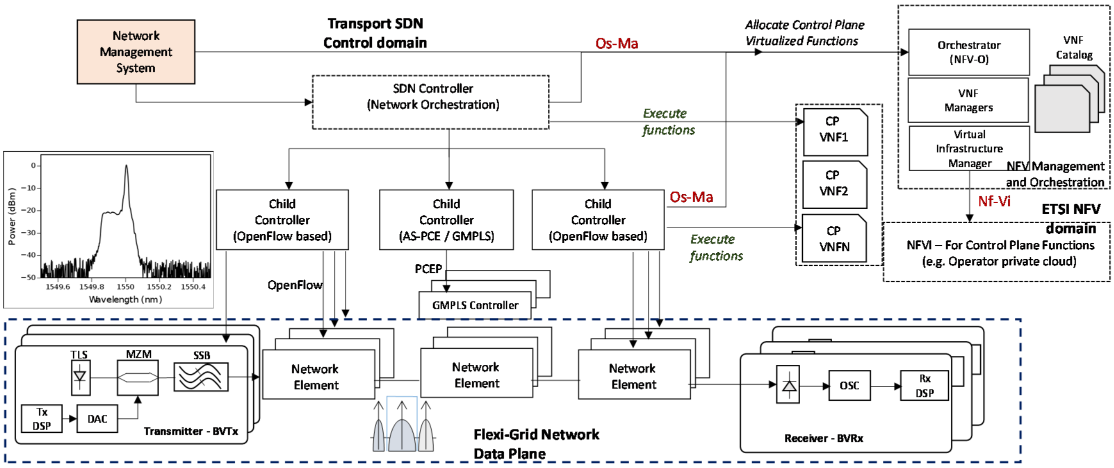


Fig. 1: Considered Flexi-Grid Control and Data plane architecture for the NFV-based allocation of Control Plane Functions

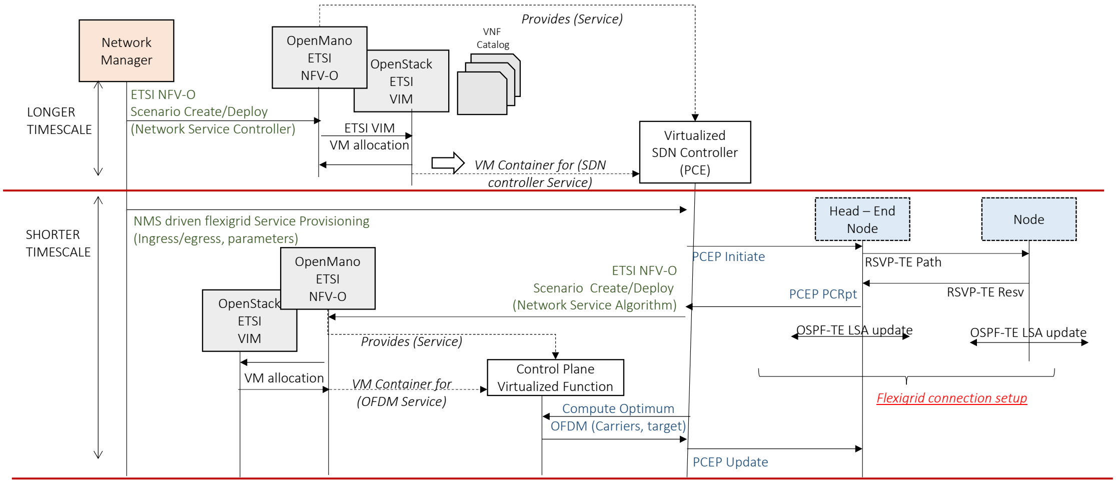


Fig. 2: Control Procedures involved in the virtualization of the SDN controller and of the OFDM throughput maximization algorithm as Virtualized Functions (VNFs) via an ETSI/NFV Infrastructure

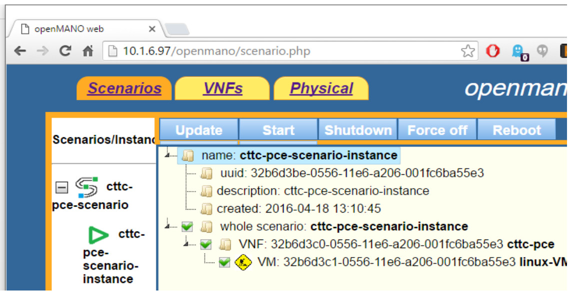
orthogonal frequency division multiplexing (OFDM) modulation and direct detection, featuring single sideband transmission. The bandwidth variable transmitter (BVTx) and receiver (BVRx) are rate/distance adaptive: each OFDM subcarrier can be individually adjusted to support arbitrary modulation format and power, in order to achieve the targeted bit rate and bandwidth occupancy, according to the requested demand, channel profile and path for an optimal spectral usage. Network Elements (ROADMs) perform frequency slot switching based on the ITU media layer only, defined by its central frequency (n) and slot width (m). A centralized SDN control plane is responsible for provisioning services[4] (although we do not exclude hierarchical systems or the ability to instantiate multiple redundant controllers for reliability and hot-pluggable purposes[5]). Besides the common functions such as topology management, resource reservation and service provisioning, specific modular functions (associated to the monitoring and configuring of the BVTs) are virtualized and allocated dynamically at different timescales and lifetimes.

Control and Management Procedures

As shown in Fig.2, the NMS is responsible for instantiating the SDN control instance to be deployed for the control of a flexi-grid network, which happens quasi-statically and at longer timescales. At a shorter timescale, the SDN controller itself is able to instantiate specific virtualized control plane functions using the same interface. The SDN controller thus acts as an NMS OSS/BSS consuming the ETSI/NFV Os-Ma interface. It is the SDN controller logic who decides when to instantiate such CP VNFs (implementing callable functions for specific tasks, with their constraints in terms of CPU and memory). In particular, the controller acts upon reception of quality of transmission parameters encoded within PCEP report messages (PCRpt, but opaque objects within OpenFlow messages could also be defined). We consider a CP function that takes advantage of the OFDM capabilities to adjust the modulation format of each subcarrier according to the channel SNR profile emphasizing on rate maximization and increased robustness against signal distortions. The results obtained from the virtualized CP function are applied back to the ingress node by means of a PCEP Update (PCUpd) message sent to the ingress node.

Experimental Evaluation in a Testbed

The architecture is implemented and deployed in a testbed to demonstrate its feasibility and applicability (see Fig.4) as follows: a private cloud is used as ETSI/NFV Infrastructure (NFVI) on top of which we can instantiate SDN controllers or callable functions. The OpenMano and OpenStack software[6] are used for the Management and Orchestration (MANO) components, notably the orchestrator (NFV-O) and its REST APIs for the instantiation of functions as described and as Virtual Infrastructure Manager (VIM) managing the allocation of Virtual Machines, respectively. It uses a (private) external network with a private range (10.1.6.X). From the point of view of



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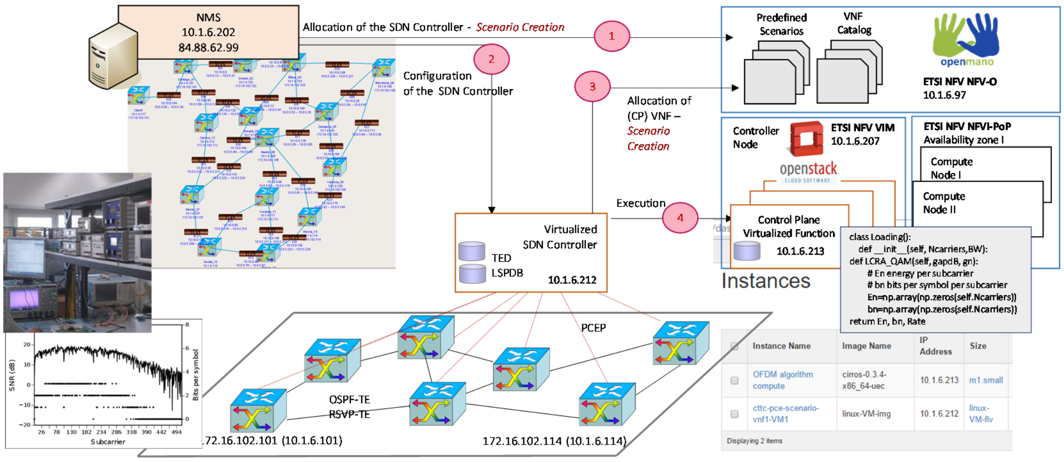
whole scenario: **cttc-pce-scenario-instance**
VNF: 32b6d3c0-0556-11e6-a206-001fc6ba55e3 **cttc-pce**
VM: 32b6d3c1-0556-11e6-a206-001fc6ba55e3 **linux-VM**

Fig. 3: OpenMano GUI after the instantiation of the scenario with an AS-PCE as SDN Controller



```
class Loading():
   def __init__(self, Ncarriers,BW):
def LCRA_QAM(self, gapdB, gn):
      # En energy per subcarrier
      # bn bits per symbol per subcarrier
      En=np.array(np.zeros(self.Ncarriers))
      bn=np.array(np.zeros(self.Ncarriers))
return En, bn, Rate
```

☐	Instance Name	Image Name	IP Address	Size
☐	OFDM algorithm compute	cirros-0.3.4-x86_64-uec	10.1.6.213	m1.small
☐	cttc-pce-scenario-vnf1-VM1	linux-VM-img	10.1.6.212	linux-VM-flv

Displaying 2 items

Fig. 4: Deployed testbed for the experimental evaluation.

ETSI/NFV MANO, we consider two different scenarios (NFV Network Services), both involving a single VNF and VM. The deployment latency for the SDN controller (Fig. 3) depends on the capabilities of hosting nodes and the VM image size (up to ~2 GB, operative in 60-120s). The SDN controller controls a 14-node flexi-grid network representing the Spanish topology, with links having 128 nominal central frequencies. Nodes have attached BVTs whose transmission parameters are configurable. The CP only performance is evaluated with requests following a Poisson arrival with neg. exp. holding times, with signalling delays O(10-100)ms. At this shorter time-scale (of connection lifetimes), the controller can instantiate a VNF for the execution of OFDM-tuning algorithms. With smaller image sizes of O(100) Mbytes or lower, the instantiation delay is lower (10-20s). According to hardware availability, the algorithm is demonstrated with three ROADM nodes over a single path. After provisioning, when characterizing the channel, all the OFDM subcarriers are set to 4QAM modulation at the transmitter, while the noise and power of each received symbol are estimated at the receiver. This information is used to find the optimum modulation format for each OFDM subcarrier. The bit/power loading is performed adopting the Levin-Campello rate adaptive algorithm, to maximize the throughput given an SNR gap and SNR profile. A flexi-grid connection is set up with frequency slot width m=2 (25 GHz), transmitting an OFDM signal with 20 GHz bandwidth. The obtained SNR profile (for 512 subcarriers) and the signal bandwidth (20 GHz) are given to the algorithm, together with the desired SNR gap (10 dB). The bit/power loading assignment targets the maximum bit rate. Results are shown in Fig.5, achieving 24.85 Gb/s at BER $1.1 \cdot 10^{-3}$ with hard-decision FEC.

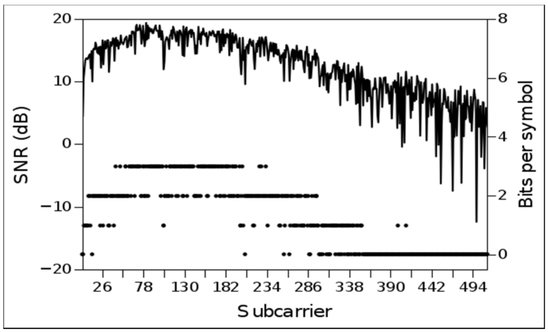


Fig. 5: Measured SNR profile (line) and resulting bits per symbol per subcarrier (dots)

Conclusions

We have further explored the integration of SDN and NFV, developing the concept of modular & virtualizable CP functions, with emphasis on the adaptive BVT parameter optimization. There is a cost in terms of latency, reasonable considering the gains in computing resource efficiency. It is straightforwardly applicable to functions with well-defined interfaces, relatively long lifetimes and stringent requirements of CPU and memory, for which the instantiation overhead is relatively small. This results in modular, hot-pluggable and upgradeable controllers, less over-dimensioned.

Acknowledgements

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