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# Performance verification of network function virtualization in software defined optical transport networks

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ABSTRACT

With the continuous opening of resource acquisition and application, there are a large variety of network hardware appliances deployed as the communication infrastructure. To lunch a new network application always implies to replace the obsolete devices and needs the related space and power to accommodate it, which will increase the energy and capital investment. Network function virtualization1 (NFV) aims to address these problems by consolidating many network equipment onto industry standard elements such as servers, switches and storage. Many types of IT resources have been deployed to run Virtual Network Functions (vNFs), such as virtual switches and routers. Then how to deploy NFV in optical transport networks is a of great importance problem. This paper focuses on this problem, and gives an implementation architecture of NFV-enabled optical transport networks based on Software Defined Optical Networking (SDON) with the procedure of vNFs call and return. Especially, an implementation solution of NFV-enabled optical transport node is designed, and a parallel processing method for NFV-enabled OTN nodes is proposed. To verify the performance of NFV-enabled SDON, the protocol interaction procedures of control function virtualization and node function virtualization are demonstrated on SDON testbed. Finally, the benefits and challenges of the parallel processing method for NFV-enabled OTN nodes are simulated and analyzed.



## 1. Introduction

With the emerging of various broadband applications, such as cloud computing, video on demand (VoD), and augmented reality (AR), the operators' networks are challenged by a large and increasing variety of hardware appliances. The Capital Expenditure (Capex) and Operating Expense (Opex) are becoming higher and higher compared with the achieved benefits. On the other hand, the utilization lifecycles of hardware appliances are limited, and much of the deployment cycle is required to be repeated with little or no revenue benefit. In order to solve the problem, Network function virtualization (NFV) is proposed as a disruptive technology for future networks, which aims to use IT virtualization techniques to virtualize the network and node functions. A virtualized network function (vNF) consists of a network function running as software on a single or several hosts, typically inside virtual machines (VMs), instead of having custom hardware appliances for the proposed network function [1]. Therefore, NFV can reduce Capex and Opex to a large extent.

Actually, the major barrier for the development of NFV is the bandwidth and peripheral number of these industry standard elements supporting large amount of vNFs. For instance, a server with only two GbE ports is impossible to virtualize a standard switch with 48 ports due to the limitation of port number. To address this issue, optical network devices, which provide sufficient bandwidth resources, could be considered as potential substrates to construct virtualized network functions [2]. Recently, some research works of NFV have been conducted in optical transport networks. An optical service chaining architecture using NFV is proposed for data centers, which can offload large flows to optical domain for steering across core vNFs at wavelength level [3]. The author also proposes a software defined networks (SDN)-based architecture to enable efficient traffic steering in support of NFV, which introduces an optical steering domain to steer classified packet flows as aggregated flows carried by wavelengths inside the data center connecting to core vNFs [4]. An optical packet and circuit integrated network is presented with NFV to provide both high-speed, inexpensive services and deterministic-delay, low data loss services [5]. NFV can also apply to data plane functions (e.g., packet processing or forwarding), as well as control plane functions (e.g., path computation) [6]. A novel optical transport node architecture

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based on NFV is proposed with the corresponding control plane framework [7].

As the evolution of intelligent optical networking, software defined optical networks (SDON) has been proposed, which attracts much attention from the academic and industry in optical network area. A lot of works have been done with SDON, including control architecture, protocol extension, transport network element, virtualization mapping, routing algorithm, and so on [8–12]. Advantages of SDON for highly virtualized data centers are discussed in [9], including lower power, improved scalability, and port density. SDON has also been introduced to the scenario of data center interconnection to provide high bandwidth resources for different tenants directly, considering the data center resources such as computing and storage resources, and network resources including bandwidth and spectrum resources together [11]. Different control architectures based on SDON have been designed to control heterogeneous multi-domain optical networks [10,12,13]. However, few works jointly study NFV and SDON, especially the NFV implementation in optical transport nodes.

This paper studies the relationship between NFV and SDON. NFV-enabled Software Defined Multi-Domain Optical Networks (SD-MDON) and NFV-enabled optical transport nodes are proposed and designed. Some emulation work has been done to verify the feasibility and efficiency. The paper is organized as follows. An implementation architecture of NFV-enabled optical transport networks based on SDN with the procedure of vNFs call and return is described in Section 2. NFV-enabled optical transport node is designed in Section 3, in which a parallel processing method for NFV-enabled OTN nodes is proposed. In Section 4, the protocol interaction procedures of control function virtualization and node function virtualization are demonstrated on SDON testbed to verify the performance of NFV-enabled SDON. Then, the benefits and challenges of the parallel processing method for NFV-enabled OTN nodes are simulated and analyzed in Section 5. Finally, the conclusion is given.

## 2. NFV-enabled software defined multi-domain optical networks

### 2.1. Network architecture

SD-MDON can provide high bandwidth resources for different tenants and consider multi-domain network resources at the same time. Based on our previous work [13,14], hierarchical control architecture is designed for SD-MDON as illustrated in Fig. 1. This control architecture can abstract the information of all the underlying resource as general API functions for the upper layer applications, such as port discovery, resources collection, path computation, connection creation and deletion, and so on. The architecture consists of three planes, i.e., data plane, control plane, and application plane, the functions of which are described as follows.

*Data plane* consists of all the transport equipment controlled by SDON controllers. In each domain, the transport nodes are equipped with specialized control boards to communicate with the domain controller via the domain-specified protocol, i.e., OpenFlow protocol. Actually, some functions of data plane can also be separated as vNFs, which will be discussed in next section.

*Control plane* is composed of two kinds of controllers. Each domain owns one local domain controller, and the local domain controllers are managed by a super controller, which is named as network orchestrator. Developed based on Open Daylight (ODL) controller, the orchestrator is responsible for communicating with the controllers of different domains via control virtual network interface (CVNI), which is implemented based on the extended OpenFlow protocol. The database module collects topology, ports and configuration information from each domain. Each domain controller can abstract local topology as one network element (NE) for the orchestrator. Based on an open source framework, i.e., open service gateway initiative (OSGI), we develop topology manager, path computation element (PCE), and connection control modules. The topology manager and connection control modules expose RESTful interfaces for applications. Note that the data processing in the function modules is independent with the communication protocol. Based on the implementation mechanism of different function modules, NFV is considered to be embedded into the control plane. Some function modules can be abstracted from the controller as vNF, such as path computation, resource allocation, grooming algorithm, security strategy, and user management. Both orchestrator and local domain controllers can call the necessary functions from different vNFs, and then the related vNF returns the necessary result.

*Application (APP) plane* contains various applications, such as bandwidth on demand (BoD) [15], network on demand (NoD) [16], and service scheduling expert (SSE) [17]. These service requests are initialed by APP plane, and served by the network orchestrator through RESTful interfaces. All the services can be accessed remotely with smart terminals, such as personal computer, laptop, smart phone, and ipad.

### 2.2. Procedure of vNF call and return

Fig. 2 depicts the main procedure of vNFs call and return in SD-MDON. First, the network orchestrator builds the connections with other controllers through TCP three-way handshake, then an OpenFlow protocol channel will be setup and the keep alive message will be sent between the orchestrator and each domain controller. The status information of network, link, bandwidth and port will be collected by the orchestrator and the domain controller. When an application request (such as virtual network construction) is invoked by the customer, the orchestrator first distributes the tasks to different controllers, which will call the vNFs in the local domain. Then the related vNF generates the results, and sends them to the controller, which sends Flow_Mod messages to the corresponding OpenFlow agent running in the control board of each optical transport node, and then returns path setup replies to the controller. When all the optical channels have been constructed successfully, reply is sent to the orchestrator.

## 3. NFV-enabled optical transport node

### 3.1. NFV-enabled optical transport node architecture

All the vNFs described in the above section are extracted from the control plane. However, an important objective of NFV is to simplify the data plane. Actually, except the function modules in the controller, the control function in optical transport node can also be offloaded from the hardware and implemented as a vNF. Then, it is important to extract the appropriate functions from the data plane of optical transport networks. As shown in Fig. 3, some electronic processing functions in Optical Data Unit (ODU) layer can be offloaded from optical layer and implemented based on X86 platform. NFV-enabled optical transport node architecture is designed as shown in Fig. 4.

Data processing fabric (DPF) can be installed between client interfaces and optical layer to analogically “process” the client data. This module is equipped with universal switching and process hardware. The vNFs in layer 2 can handle the traffic in ODU layer with actions such as Ethernet encoding and decoding, packet