Orchestration of Network Service Chains for Network Function Virtualization Using Optoelectronic Routers

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Abstract— This article presents an efficient network function virtualization infrastructure for the orchestration of network service chaining. Network Service Chaining is a service deployment concept that enables network operators to configure network services dynamically in software without making any changes to the hardware. With the infrastructure presented in this paper, applications can create and monitor their service chains. For this, we construct a virtual network with optoelectronic routers. Optoelectronic router helps in managing the service chains in virtual environments. Its optical domain can be used for deploying network functions and electronic for data storage and buffering. Due to this, optoelectronic routers can assist us in saving expensive optical/electronic/optical conversion.

Keyword— network virtualization; network service chaining; performance of data center; network orchestration; network function virtualization; SDN; O/E/O Conversion Cost

I. INTRODUCTION

Since last few years, the networking technology is going through a continuous change. Due to this, several new architectures and networking paradigms are evolving. This technological evolution in the networking arena pops up many new terminologies, such as Software Defined Networking (SDN), Network Function Virtualization (NFV), etc. SDN and NFV are complementary technologies and are playing a key role in resolving the problems of the future Internet, i.e., ossification and resource allocation [1]. They are also motivating several new cloud applications [2].

The concept of NFV was proposed within the European Telecommunication Standards Institute (ETSI) consortium [3] to provide innovation to the service delivery mechanism. NFV furnishes an environment where Network Functions (NFs) can be virtualized into Virtual Network Functions (VNFs). Currently, NFs are provided in terms of middle boxes, such as firewalls, Deep Packet Inspection (DPI), load balancer, etc. With virtualization and cloud technologies, NFV allows NFs, offered by specialized equipment, to run in software on generic hardware. Therefore, with NFV we can deploy VNFs when and where required.

On the other hand, Network Service Chaining (NSC) [4] is a service deployment concept that exploits the features of the NFV and SDN. An NSC is defined as a set of NFs, packet processing order (simple or complex), network resource requirements (node and links), and network forwarding graph. With NSCs, network operators can configure software dynamically without making any changes to the hardware. Traffic flows with various requirements need to flow through several NFs or VNFs. NSCs must be carefully crafted from statistically assembled components chosen at the design time. Once a network service is defined, operators can only make minor configuration changes.

A. *Optical Technologies to construct NSCs*

Optical technologies provides larger bandwidth and lower energy consumption in comparison with electronic technologies. Therefore, optical technologies can be used as complementary technologies for large flows inside data centers. They are also employed to perform service chaining for larger aggregated flows in parallel with conventional electrical fine-grained traffic steering schemes. When NFV is enabled, vNFs can be placed when and where needed.

In hybrid data centers, optical domain can serve as the backbone for the data center networks by providing larger bandwidth. Generally, when a flow arrives at a data center, it needs to be passed through several VNFs that satisfies the application's requirement. This allows for per application/per flow chaining where the application can orchestrate it according to their needs. First, the traffic coming from the data center is converted to optical traffic and then steered over the optical domain. At the destination router, flow is again converted back to the electronic traffic. This optical/electronic/optical (O/E/O) conversion consumes considerable amount of energy. When orchestrating NSCs over these hybrid data centers, VNFs should be placed in such a way that it requires less O/E/O conversions.

B. *Contributions*

The contribution of this paper consists of two things. First, we presented our NFV architecture that provides an environment for applications to orchestrate NSC using SDN in NFV, where they can monitor an NSC during its lifecycle. In this work, we consider the per-user/per-application service chaining, as well as optimization. In the core of the network, we use optical technologies. Each NSC is allocated to an application that is able to monitor and control the NSC throughout its lifetime. Second, in order to save the O/E/O conversions, we use the optoelectronic routers to construct the virtual network that will act as the core of the network. The optoelectronic router offer several advantages over the existing optical routers, its buffer can be used to store the information and make the deployment of VNF in the optical domain possible. Moreover, orchestration of VNF in the optical domain using optoelectronic router will also save the O/E/O cost.

II. RELATED WORKS

We divide our related work in two parts. In the first part, we discuss literature related to NSD, development of NF/VNF using SDN, and NFV. In the second part, we will talk about the work that proposes solution to reduce the O/E/O conversion.

A. Orchestration of NSC Functions

One of the early-stage SDN-based NSC work originates in OpenFlow. For example, OpenPipes [5] discussed the usage of modular network component system design where self-contained in NFs, e.g., image filters for video content distribution, can be included to create a video processing system. However, this work is just a feasibility study and do not contain any carrier network. Bari et al., [6] surveyed on the importance of virtualization to improve flexibility, scalability, and resource utilization for data center networks. Whereas, MobileFlow [7] introduces carrier-grade virtualization in EPC, but do not use it into NSF in a significant extent.

In order to take into account the requirements of services in building flexible networking, Paul et al. [8] present the foundations of making service-oriented adaptable networking architectures yielding to relax coupling between the NFs. They also consider some of the aspects of the dynamicity, such as services dynamicity or network relative dynamicity. Finding an adequate remedy to these issues through proposing a novel service-aware architecture represents the main focus of this research work. John et al. [9] discussed advantages of adopting NSC and also illustrated design considerations and system requirements with use cases for adopting NSCs. They also included research challenges occurs in the lifecycle of a service which researchers need to consider when crafting NSCs.

Han et al. [10] presented the key technological requirements of the NFV; introduced NFV architectural framework and standardized activities. Moreover, they described some use cases of NFV, such as virtualization of mobile base station, home network, etc. Munoz et al. [11] discussed an architecture for SDN/NFV orchestration of SDN controller for multi-tenant optical networks. This architecture introduces SDN controller as a VNF and offer in the cloud for dynamic use. Apart from these, some authors discussed the placement of service functions. For example, Sekar et al. [12] proposed to run software-centric middle-boxes on general-purpose hardware platforms with open application programing interfaces (APIs). Sherry et al. [13] proposed a method to deploy middle-boxes in the cloud.

B. Placement of NFs/VNFs to Improve the O/E/O Conversions

In data centers, optical technologies are used to support packet technologies in order to provide large bandwidth. First, packet traffic is converted into optical in order to propagate. At the destination, traffic is converted back to the electronic. These conversion results in overhead. Therefore, traffic should be steered in such a way that it requires less conversions. Some authors discussed the optimization when orchestrating NF/VNFs in NSC.

There are two significant approaches in this aspect. The first one is deploying the NFs/VNFs in the electronic domain and use packet domain for steering. In this regard, [15] tackles the problem of finding the optimal VNF placement for VNF chaining in packet/optical DCs, such that the overall O/E/O conversions can be minimized. This solution deploys the NFs on the pods and use the optical domain for only steering traffic. In order to reduce the conversions, all the NFs of an NSC, ideally, should be placed on one pod. Performance of this approach deteriorates when the number of service chains or NFs in a service chain grows. Another solution of orchestrating vNFs in hybrid data center is presented in [14] that deploying a service chain in both the packet and optical domain. Some of the vNFs/NFs are in optical domain and some in the packet domain as shown in Fig. 1. Though this approach improves the network performance, but the traffic flow needs to be traversed back and forth in the electronic and optical domain and this will result in the increased O/E/O conversions. Moreover, the choice of vNFs functions to be deployed in the optical domain without buffer requirement is quite limited since the optical buffer is still a question.

In order to use the optical domain for the placement of VNFs while not causing extra O/E/O conversions, we used optoelectronic routers. Since the optoelectronic routers have the electronic buffer that can be used to store the output of the VNF and its optical packet domain will be used for traffic steering.

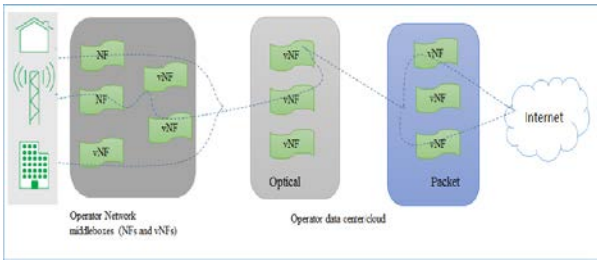


Fig.1. NSC in the hybrid (optical/packet) domain

III. ORCHESTRATION OF SDN ENABLED NSCS OVER NFV INFRASTRUCTURE

In this section, we will first explain the concept of NSC and then we will explain the construction of NDCs using optoelectronic routers over NFV infrastructure.

A. *NFS/VNFS over NSCs*

In this section, we will explain the concept of NSC and as well of NFs. In Fig. 2, three dynamic NSCs are given, where each NSC follows its own path. Nodes on the path are presented with *S* and each NSC orchestrates NFs/VNFs according to their demands. Each and every packet has to be processed by a series of NFs, such as security gateways (GWs), firewalls, DPI, content filters, etc. NSC can be implemented as a dynamic NSC where each flow processed by various NFs. Note that two NSCs can have common nodes or functions on its path. However, in this case, resource allocation and resource contention issue will rise, which at this moment is not our scope. The three NSCs are given as:

NSC 1: S1, S2, S3
NSC 2: S1, S4, S3, S7
NSC 3: S1, S4, S5, S8

Up to now, NSC deployment models are usually centered and installed at fixed locations in the network [16], [9]. Though [9] discusses several aspects of NSCs; however, which NF will be implemented on what layer is still not clear. Generally, several kinds of network elements, especially layer 3-7, can be incorporated into an NSC. In table 1, we discussed some of these NFs/VNFs in correspondence with network operations. A set of functions within an NSC will depend upon the application requirements. For example, video-optimization is likely to be used in the mobile operator networks, whereas, parental control is required by parents to keep an eye on the children's activities.

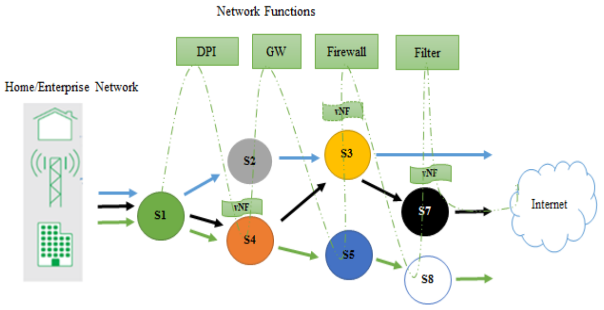


Fig. 2. NSCs: The three arrows: blue, black, and green shows the pathline of three service chains, The dashed lines shows the functions (physical and virtual) on the NSCs

TABLE I. NETWORK OPERATIONS AND THEIR CORRESPONDING VNFS

Operation	**Functions**
Packet Inspections	Ipfix, firewall, IPS, DDos, etc.
Traffic Optimization	TCP optimization, traffic shaping, DPI, IPTV, etc.
Protocol Proxies	Carrier-grade NAT, DNS cache, TCP proxy, HTTP proxy, session broader controller, etc.
Value Added Services	Ad insertion, head enrichment, WAN acceleration, URL filtering, parental control, advanced advertising, etc.
Network Optimization	Router, VPN, CDN (Content delivery network), gateway, etc.
QoS	Load-balancers, schedulers, etc.

B. *NFV Infrastructure Using Optoelectronic Routers*

In this section, we discussed the infrastructure for NSC over optoelectronic routers.

In Fig. 3, we presented the functional blocks of the proposed SDN/NFV based virtual architecture for deploying multiple NSCs. Applications of this NFV Infrastructures (NFVI) can dynamically create, modify, and delete NSCs in response to application demands, such as resource requirements or QoS requirements. This NFVI consists of an optical network that connect multiple DCs, providing services in terms of NFs. On top of this, we deploy a virtualization layer responsible for virtualizing these NFs into VNFs. It abstracts the physical resources and anchors the VNFs to the virtualized infrastructure. Mainly, it is based on two NFVI managers, SDN controller and cloud/NFV manager. SDN controller provision, control, and manage the optical network and provide virtual connectivity services to users between Virtual Machines (VMs) hosting VNFs. In other words, through SDN controller the applications can orchestrate their NSCs by accessing the resources of NFVI according to their demands. On the other hand, Cloud/NFV manager is responsible for managing VMs and storage resources. Moreover, it is also responsible for managing the VNFs during its lifetime, such as VNF creation, scaling, termination, and update events during the life cycle of VNF.

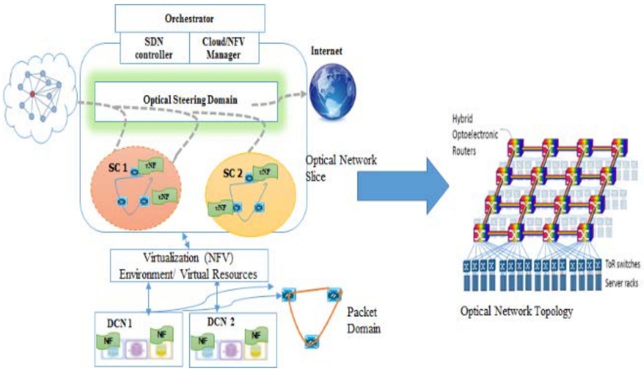


Fig. 3. Infrastructure for the orchestration of NSCs over optoelectronic routers

On top of this architecture, we proposed a network orchestrator for multiple-tenant SDN-enabled network. It is responsible for managing (provisioning, creation, modification, upgradation, and deletion) of multiple NSCs. It will logically divide the optical network into virtual slices and will allocate each slice to a single NSC. These slices can be constructed and maintained using our algorithm presented in our previous works [18], [19]. With this, applications can access the network resources according to their needs. For example, they can create, manage, and modify their own NSC/NSCs according to the way they want.

Structure of DCs in Fig. 3 is on Top-of-the-rack (TOR) switches. We construct core of the network with optoelectronic routers that use optical packet transmission. In addition, each packet has an electronic buffer attach to it.

This buffer is required in two conditions: 1. When the collision happens, 2. When the processing happens, e.g., inter-conversions of E/O/E packets, storing the VNFs data during their processes. In Fig 2, we explained the workflow for the creation of an NSC.

In the Fig. 4, we explained the workflow for the creation of an NSC on NFVI and they are stepwise given below:

1. Application requests the SDN manager for the creation of an NSC. This request consists of performance required parameters, such as bandwidth, required functionality, required latency, order of packet processing, etc.
2. SDN forwards this request to orchestrator. Orchestrator translates these requests and check the network resources (e.g. VNF/VNFs required, number of optical switches required, routing path, etc.) to fulfill the application request. Network orchestrator requests the cloud manager to provide the host, i.e. VM/VMs for these VNFs. Cloud manager can manage these VNFs on the already existing VMs or can provide new hosts for these functions.
3. After receiving the VNFs, orchestrator request the optical network hypervisor to create a slice.

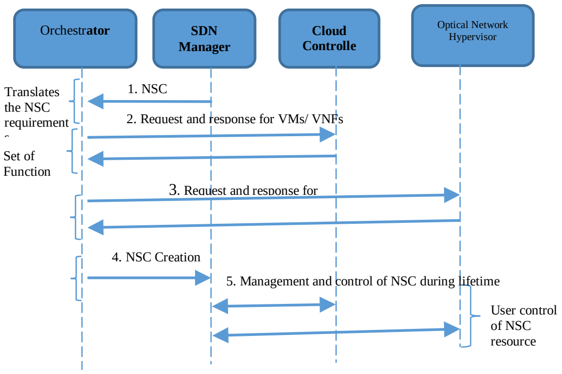


Fig. 4. Workflow of an NSC

1. Orchestrate receive all the required virtual resources and provide them to the user via SDN controller.
2. Application can receive their required flow and when require they can modify their parameters.

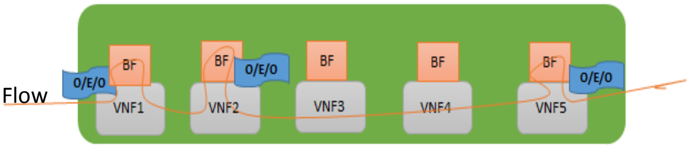
IV. Placement of VNF at the Optoelectronic Routers to save O/E/O Conversions

Optoelectronic routers offer several advantages over the existing hybrid data center network architectures. Hybrid optoelectronic buffer enable a low power, low-latency router for high-speed optical packets, capable of contention resolution, signal restoration, forward error correction, 3R(Reshaping, regeneration, retiming), QoS differentiation, packet duplication removal, multicast routing, switching between wavelength layers.

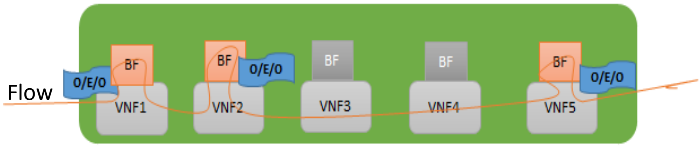
To prove the advantages of optoelectronic routers in order to save the O/E/O cost, in Fig. 5 (a), we consider an NSC with five vNFs that to be orchestrated over optoelectronic routers. Consider, some of these VNFs require buffer and others do not. Here, we assume that VNF 1, 2, and 5 requires buffer and VNF 3 and 4 do not. In case of VNFs that require the electronic buffer, the flow is converted from optical packets to electronic packets since the buffer is made of CMOS technology. VNFs whose buffers are not used, i.e., VNF 3 and 4 can be turned off to save the energy as shown in Fig. 5 (b).

Since the objective of this work is to save the O/E/O cost; therefore, in this work we propose to aggregate those VNFs whose buffer can be shared or combined in which output of one buffer can be used as the input for the second buffer. By this, we can save the O/E/O conversions of the flow as shown in Fig. 5(c). This scenario will be very helpful in orchestrating multiple NSCs when the network resources are limited. All these three NSCs are represented in Table 2 to show the network performance improvement when of using optoelectronic routers.

The functions should be interdependent in such a way that aggregating or combining them at one router make sense and improve network performance. Ideally network operators should place VNFs where they will be used most effectively and least expensively. Although the virtualization of certain NFs is straightforward, there are a number of NFs that have strict delay requirements. However, multiple VNFs that to be deployed on one single router need to be chosen carefully. One example of such VNFs can be implementation of firewall to provide security and combining it with parental control to inspect and filter the traffic.



a: Deployment of 5 VNFs over 5 optoelectronic routers



b: saving energy by turning off the unused buffers

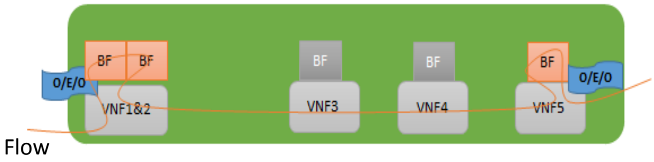


Fig. 5. Placement of VNFs in order to improve the performance: (the line shows the network flow coming from TOR switches. Each VNF represents an optoelectronic router and BF represents the electronic buffer attached to the router. BF that turned off is colored as grey).

TABLE II. PERFORMANCE IMPOVEMENT

FLOW	VNF 1	VNF 2	VNF 3	VNF 4	VNF 5	NETWORK GAIN
A	BF	BF	BF	BF	BF	NO GAIN
B	BF	BF	N-BF	N-BF	BF	ENERGY SAVING DUE TO TURNING OFF BUFFER OF VNF 3 AND VNF 4
C	VNF 1 & 2 WITH BF		N-BF	N-BF	BF	SAVING O/E/O CONVERSIONS

V. CONCLUSIONS AND FUTURE WORKS

In this article, we first presented an NFV infrastructure using SDN that assist applications create multiple NSCs over it. With this NFVI, applications can create, manage, and monitor their NSCs during its lifecycle. Each NSC is allocated with a virtual network slice. In order to construct this virtual network, we use optoelectronic routers since they provide electronic buffer that can help us storing the information of VNFs when adopted in the optical domain of these routers. Moreover, with a simple example, we explained that these optoelectronic routers can help in saving the O/E/O conversions.

The contents presented in this article are part of an ongoing research. We are in the process of obtaining results in order to show the evidences of the improved network performance using optoelectronic routers.

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