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Virtual Clusters for Dynamic Network Service Chaining

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Abstract— 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 Software Defined Networking and Network Function Virtualization, Network Service Chaining is gaining a serious attention in the research community. However, its concept is still not defined and advantages are not also clear. Therefore, in this paper, we discussed an architecture for the orchestration of multiple service chains on the underlying infrastructure. With this architecture, applications can dynamically, create, manage, modify, and delete services with ease.

Keyword— network virtualization; network service chaining; data center; infrastructure for cloud architecture; service provisioning; network orchestration

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 (FI), 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.

SDN is one of the pillars of the network infrastructure innovation, allowing the decoupling of the data and control planes. This decoupling is usually through open and standard interfaces that facilitates the network in programmability. SDN has also contributed to the network infrastructure virtualization, providing the grounds to isolate, abstract, and share the network resources. With SDN, adding a new service can be achieved by only adding a new application that interacts with the network controller.

Network Service Chaining (NSC) is a service deployment concept that exploits the features of the NFV and SDN. With NSC, 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. Typically, an NSC is determined depending on the traffic type, Service-level Agreements (SLAs), policies of the operators, and set of functions (virtual/physical) that need to be executed. 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.

The current NSC deployment models for advanced services are usually centered and installed at fixed locations in the network. They also lack in automatic configuration and inter-service connectivity is also usually poor. As SDN and NFV are complementary technologies; therefore with their help, NSC should increase flexibility and cost efficiency for the future carrier networks.

Efforts to improve the current NSC technology gained significant attention recently in research and standardization. The Internet Engineering and Task Forum (IETF) argues about the creation of dedicated working group on NSCs. In this, Quin et al. [4] defines an NSC as *the required functions and associated order that must be applied to packets and/or frames*. Conversely, Zhang et al. [5] motivates the need for *steering traffic at the granularity of subscriber* and *traffic types and through the right inline service path.* These approaches did not define NSC formally; therefore, John et al. [6] filled this gap and provide the design considerations along with the use cases that depicts the advantages of adopting NSC. They also discuss the research challenges occur during the service life cycle. Though these approaches propose and explain the concept of NSC, still there is a lot of undiscovered aspects of the NSCs that require the attention of the research community.

Therefore, in this paper, we discuss the orchestration of multiple NSCs on an underlying infrastructure. For this, we propose a virtual cluster architecture that, with the help of SDN, let applications create, manage, modify, and delete NSCs on the virtualized infrastructure. An NSC is defined as a set of network functions (need to be executed), packet processing order (simple or complex), network resource requirements (node and links), and network forwarding graph. In the core of the network, we use optical technologies. For each NSC, we create one slice of the network on this optical network. For the management purpose, each network slice along with the required VMs (hosting NFs or VNFs) are construct a group, which is called Virtual Cluster in this architecture. Managing each NSC separately and allocating dedicated network resources to them will give applications feelings of owning the infrastructure.

II. RELATED WORKS

One of the early-stage SDN-based NSC work originates in OpenFlow. For example, OpenPipes [7] 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. [8] surveyed on the importance of virtualization to improve flexibility, scalability, and resource utilization for data center networks. Whereas, MobileFlow [9] introduces carrier-grade virtualization in EPC, but do not use it into NSF in a significant extent.

Several studies investigates the SDN-enabled network architectures and their characteristics. In [10], the authors presented the GENI network and discussed the inherent limitations on top of it using OpenFlow and FlowVisor [11]. Heavy appearance of unplanned flows in the forwarding tables produce a scalability issue. Embedding a local module in the switches for the detection of unusual events is the key contribution of this work. In order to take into account the requirements of services in building flexible networking, Paul et al. [12] present the foundations of making service-oriented adaptable networking architectures yielding to relax coupling between the networking functions. 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.

Han et al. [13] 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. [14] 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. [48] proposed to run software-centric middle-boxes on general-purpose hardware platforms with open application programing interfaces (APIs). Sherry et al. [15] proposed a method to deploy middle-boxes in the cloud. Joseph et al. [16] proposed a policy-aware switching layer for DCs, but it requires installing rules for each new flow, which may not scale.

Though many researchers provided their solutions for NFV/SDN architecture, some discussed the construction and placement of service functions, i.e. VNFs, but definition of NSC and its advantages are still not clear. Therefore, 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. However, to the best of our knowledge, none of the work has presented an architecture or a framework for the orchestration of NSCs on the NFVI. Thus, in this paper, we provide an architecture that tend to fill this gap.

III. NETWORK SERVICE CHAINING (NSC)

A. Motivation for Adopting NSCs

With the expansion in the Internet volume and demands, network operators are struggling to meet the traffic demands using their traditional connectivity mechanism. Subscribers, on the other hand, are enjoying declining 'cost per bit' operator investments (CAPEX) and operational costs (OPEX) for the increasingly complex infrastructure. All this leads us to incorporating new technologies in the existing infrastructure and to designing new services carefully. Service designing and crafting has gained a lot of recent attention of the research community. For a given service, the abstracted view of the required NFs and the order in which they are to be applied for continuous delivery is NFC. In this context, continuous service delivery means the orchestration of dynamic NFs to meet the application requirements.

Another advantage of adopting NSCs is performance enhancement in inter-network communication. In intra-network communication (e.g. two users of the same network communicate with each other), data pass different service functions, such as balancers, gateways, schedulers, etc. On the other hand, in inter-network communication (when data pass different network domains), additional operator cost is applied. In the second case, functionality becomes complex and data can experience heavy delay due to the load of multiple networks. Therefore, implementation of dynamic NSCs will lead to intelligent traffic steering and will also provide traffic performance acceleration in inter-network domain.

B. NFs over NSCs

In this section, we will explain the concept of NSC and as well of NFs. In Fig. 1, three dynamic NSCs are given, where each NSC follows its own path. Nodes on the path are

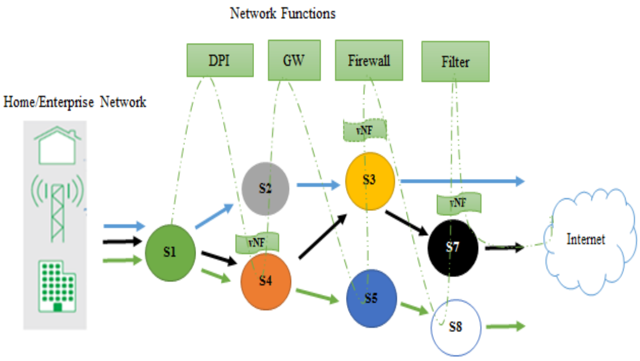

Fig.1. NSC Concept: The three arroms: blue, black, and green shows the pathline of three service chains, The dashed lines shows the functions (physical and virtual) on the NSCs.

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.

presented with *S* and each NSC orchestrate NFs/VNFs according to the their demands. Today, 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

In general, several kinds of network elements can be incorporated into an NSC. Especially, layer 3-7 functions that operate on top of IP protocol networks are the most likely candidates. Recently, several new functions are emerging. In table 1, we discussed some of the NFs, physical or virtual, that can incorporated in the NSCs. These functions can vary from one NSC to another, depending upon their application use and 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 activities.

IV. VIRTUAL CLUSTER ARCHITECTURE FOR NSCS

In this section, we discussed the proposed virtual cluster architecture.

In Fig. 2, we present the functional blocks of the proposed SDN/NFV based virtual cluster 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

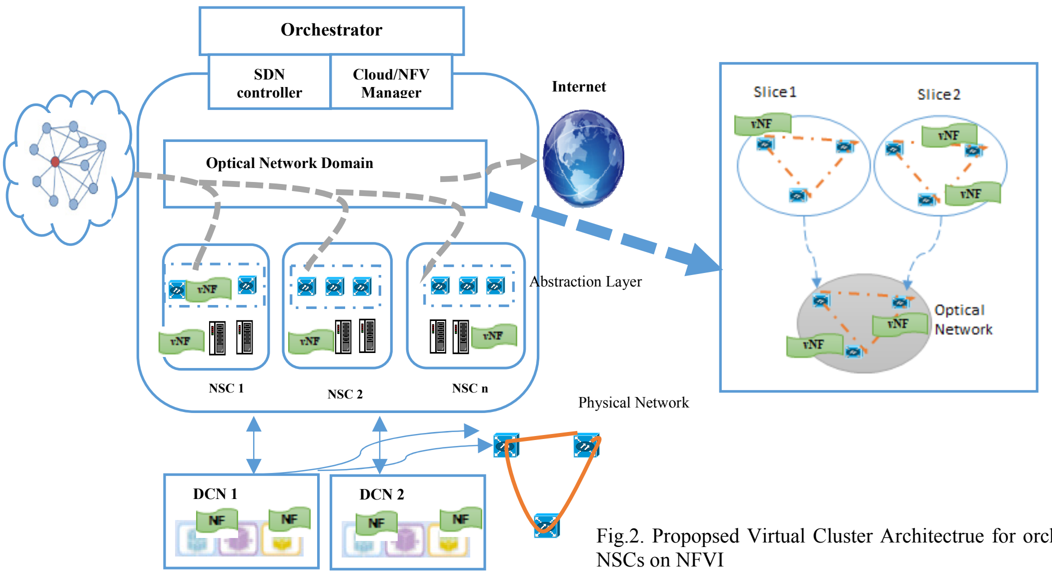

Fig.2. Propposed Virtual Cluster Architectrue for orchestration of multipe NSCs on NFVI

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 lifecycle of VNF.

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. 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. From the network perspective, each NSC, i.e. devices on its slice will be isolated with unique identifiers, named as Abstraction Layer (AL), as shown in the Fig. 2. In an optical network, ALs can be created in multiple ways. For example, in our previous work [18], and [19] we discussed an architecture, named, Abstraction Layer based Virtual Cluster (AL-VC) where we provided algorithm for the construction of ALs. We can adopt the same algorithm in this work to construct the AL or more intelligent algorithms can be crafted. Concept of an AL brings many advantages to the network (optical or packet), such as flexibility and scalability as proved in the earlier work. In this work, we use the concept of AL to construct NSCs.

A. Workflow of an NSC

In the Fig. 3, we explained the flow diagram 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.
4. After receiving the VNFs, orchestrator request the optical network hypervisor to create a slice.
5. Orchestrate receive all the required virtual resources and provide them to the user via SDN controller.
6. Application can receive their required flow and when require they can modify their parameters.

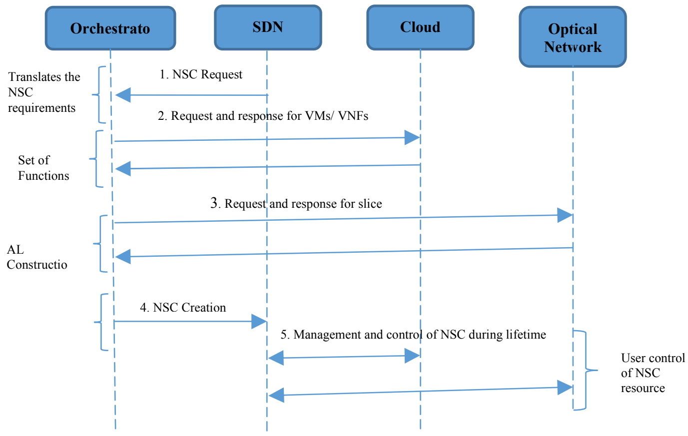

Fig. 3. Workflow for an NSC creation

V. CONCLUSIONS

NSCs is an advanced concept of service provisioning where applications can choose the network functions to be executed, and their order of execution. With SDN and NFV, NSC gained a lot of attention of the research community recently; however, the definition of NSC and orchestration of NSCs is still not clear. Thus, in this work, we discussed the concept of NSCs, provided some NFs to be used in NSCs. Mainly, we proposed a basic architecture that provides an environment for orchestration of multiple NSCs. This to our knowledge is the first architecture for the multiple NSC orchestration. In NFVI, we manage each NSC as an individual cluster that consists of set of VNFs, flow path, and slice of the optical network.

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