Network Function Virtualization in Optical Inter-Datacenter Elastic Optical Networks

Wei Lu, Menglu Zeng, Wenjian Fang, Zuqing Zhu

University of Science and Technology of China, Hefei, Anhui 230027, China, Email: zqzhu@ieee.org

Abstract: We first explain the motivations of studying network function virtualization (NFV) in inter-datacenter elastic optical networks (IDC-EONs). Then, we analyze the challenges for provisioning virtual network function forwarding graphs (vNF-FGs) in IDC-EONs, and give insights on how to customize vNF-FG orchestration and optimize IT and spectrum resource allocations jointly.

OCIS codes: (060.1155) All-optical networks; (060.4251) Networks, assignment and routing algorithms.

1. Introduction

Nowadays, network function virtualization (NFV) becomes one of the most attractive technologies in telecommunication industry since it can shaken up the traditional go-to-market strategies fundamentally [1]. Specifically, by leveraging standard IT virtualization technologies, NFV can realize virtual network functions (vNFs) on general-purpose servers, switches and storages to replace traditional middleboxes. Therefore, network services based on vNFs can be put on the market, maintained and upgraded more easily and timely. Meanwhile, with NFV, service providers (SPs) can deploy network services in a more flexible manner, which not only shortens new services' time-to-market but also creates a great potential for increasing the usage value of network resources.

As datacenter (DC) infrastructures are constantly strengthened, DCs become the premium NFV infrastructure points-of-presence for various types of vNFs [12]. For a vNF forwarding graph (vNF-FG), if necessary, its deployment may span multiple DCs to get the data traffic processed/forwarded by a sequence of vNFs instantiated in these DCs [3, 4]. Hence, inter-DC networks have to be flexible, programmable and cost-effectively to provide SPs with the right service delivery infrastructures. Since they enable efficient access to the tremendous bandwidth in optical fibers, elastic optical networks (EONs) have been considered as a promising physical infrastructure for inter-DC networks [5–7]. To this end, we can see that it would be beneficial for SPs to use an inter-DC EON (IDC-EON) to connect geographically distributed DCs. Fig. 1 shows the architecture of an IDC-EON to support diverse vNF-FG based network services.

Although IDC-EON brings obvious advantages for NFV, there are also new challenges: 1) A multitude of network services that have disparate requirements on vNF-FGs and traffic steering would coexist. For example, in additional to vNF service chains (vNF-SCs) [3, 4], vNF-FGs may also take tree topologies for supporting multicast-based network services [8], *e.g.*, DC backup and migration. Moreover, the dynamic dependencies between vNFs can make the topologies of vNF-FGs change with time [9]. And as to traffic steering, bandwidth-/data-intensive network services also have highly dynamic bandwidth requirements on the network connections between vNFs, and in some extreme cases, the data transfers can even be bursty [6, 7]. In such dynamic situations, it would be challenging for SPs to successfully provision customized vNF-FGs to satisfy the various quality-of-service (QoS) requirements of clients. 2) When deploying a vNF-FG, we need to determine both the vNF placement and the routing and spectrum allocation (RSA) on the lightpaths to connect its source, vNFs and destination(s). To do this effectively, the major difficulty is to optimize the IT resource allocation for the vNFs in DCs and the spectrum allocation in fibers in a joint manner, for realizing

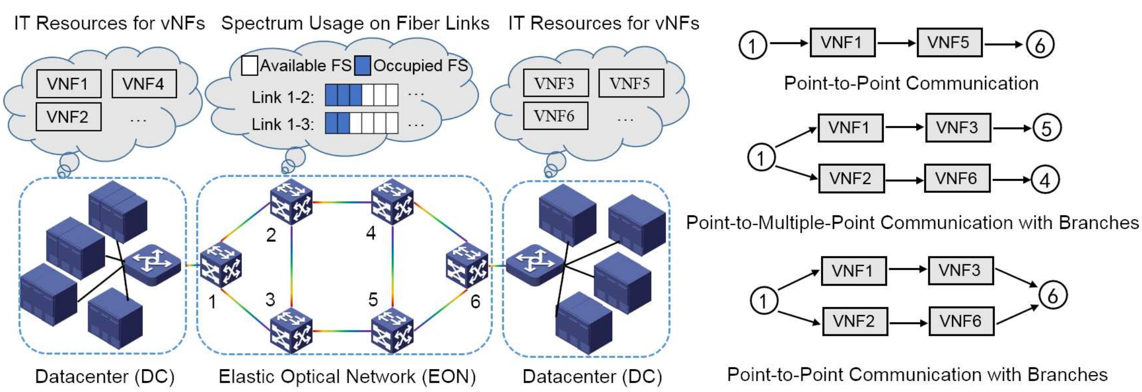

Fig. 1. IDC-EON architecture to support diverse vNF-FG based network services.

high throughput and making the SP more profitable [4, 8]. In the following, we will elaborate the aforementioned challenges and provide some insights on how to solve them effectively.

2. Orchestrating vNF-FGs in IDC-EONs

Multicast-based vNF-FGs: each request lets its data traffic be processed/forwarded by several vNF-SC branches in a tree-type topology and finally received by multiple destinations [8]. Note that, the different vNF sequences on the branches help to realize differentiated services to the destinations. The key to this problem is to build a proper tree in the IDC-EON to carry the vNF-FG as well as reuse the vNFs in DCs to the maximum extent.

Flexible vNF-FGs: each request has a flexible vNF arrangement that only rely on the dependencies between vNFs [9]. Specifically, if a vNF depends on another vNF, the data traffic has to be routed through the depended vNF before being processed by it. Hence, the actual topology of the vNF-FG is not fixed and can affect the effectiveness of the joint IT and spectrum resource allocation. The open question here is how to optimize the vNF-FG's topology to benefit the subsequent resource allocations.

Bandwidth-intensive vNF-FGs: each request demands bandwidth-guaranteed traffic being steering through the vNF-FG's source, vNFs and destination(s) in sequence throughout the duration of its service [4]. Hence, when performing RSA, enough bandwidth should be allocated to each related lightpath. Note that, spectrum fragmentation will be generated in the procedure [10], which should be addressed properly to avoid serious request blocking [11].

Data-intensive vNF-FGs: each request needs to transfer a certain amount of data through a sequence of vNFs before a deadline, but it might not apply a rigid bandwidth requirement [6]. This actually provides the SP with more flexibilities to manage its IT and spectrum resources. For instance, certain spectrum fragments can be reused for bulk-data transfers [12]. However, the major difficulty would be to optimize the task scheduling and bulk-data transfer of the vNF-FG to not only satisfy the deadline but also make the best use of network resources.

3. Joint IT and Spectrum Resource Optimization

Cost Model: a rational cost model would be of importance to optimize IT and spectrum resources jointly. The model should quantify the unit costs of IT and spectrum resources according to their rarities along the time axis. For instance, when IT resources are abundant while spectrum resources are insufficient, we should make the unit cost of spectrum resource be much higher than that of IT resource, and *vise versa*. By doing so, we can achieve the ultimate goal of maximizing the usage value of network resources.

vNF Placement and RSA: with the cost model, the optimization on vNF placement and RSA needs to minimize the total resource cost. Hence, when the unit cost of IT resource is higher, we need to reuse the vNFs in DCs as many as possible. Otherwise, we need to use the shortest paths to build vNF-FGs and place vNFs close with each other to save spectrum resources. Here, the major challenge is to design a universal strategy to address the joint optimization and consider multi-dimensional resource defragmentation in dynamic network environments [13, 14].

4. Conclusion

In this paper, we clarified the motivations of studying NFV in IDC-EONs, elaborated the challenges brought by the unique characteristics of vNF-FGs and IDC-EONs, and provided some insights on how to solve the challenges.

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