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Placement of Virtual Network Functions in Hybrid Data Center Networks

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Abstract—Hybrid data center networks (HDCNs), where each ToR switch is installed with a directional antenna, emerge as a candidate helping alleviate the over-subscription problem in traditional data centers. Meanwhile, as virtualization techniques develop rapidly, there is a trend that traditional network functions that are implemented in hardware will also be virtualized into virtual machines. However, how to place virtual network functions (VNFs) into data centers to meet the customer requirements in a hybrid data center network environment is a challenging problem. In this paper, we study the VNF placement in hybrid data center networks, and provide a joint VNF placement and antenna scheduling model. We further simplify it to a mixed integer programming (MIP) problem. Due to the hardness of a MIP problem, we develop a heuristic algorithm to solve it, and also give an on-line algorithm to meet the requirements real-time scenarios. To the best of our knowledge, this is the first work concerning VNF placement in the context of HDCNs. Our extensive simulations demonstrate the effectiveness of the proposed algorithms, which make them a promising solution for VNF placement in HDCN environment.

Index Terms—Virtual network function, placement, flow schedule, hybrid data center network.

1 Introduction

Cloud computing, known for its capability of providing innovative way to organize computing resources, has drawn a lot of attentions. It has changed the working behavior in both industry and academia. Data center, as the cornerstone, has a critical impact on the performance and further the economical ecosystem of cloud computing. Particularly, in a traditional data center network (DCN), such as FatTree [20], the interconnection links usually bear over-subscription problem. Although some novel structures have been studied recently [24] [21], due to different limitations and considerations, they are not adopted in empirical scenarios. To meet this challenge, hybrid data center network (HDCN) is proposed, in which each top-on-rack (ToR) switch is mounted with a directional antenna, so that physically adjacent ToR switches can directly communicate with each other without via any higher layer switches. In this way, the over-subscription problem in higher layer links can be alleviated. A typical HDCN is shown in Fig. 1, where directional antennas can automatically rotate to different directions to communicate with different ToR switches. Normally, each directional antenna can support either 8 directions or 6 directions. Examples of antenna scheduling for each spin mode are provided in Fig. 2. Experimental results in [5] illustrate that 60GHz antenna with 8-element Phocus array can provide a stable 1Gbps communication bandwidth between any two adjacent nodes with a distance up to 10 meters in the indoor environment. Thus, depending on the locations, ToR switches can communicate to each other either by a direct wireless connection or by multiple hops of wireless links via intermediate ToR switches. One clear advantage of adopting a wireless network is that by using directional antenna, wireless links can be established in a flexible and on-demand way according to the real-time cloud computing service demand, which facilitates offloading the traffic on the wired links. It has been shown in [5] that 60GHz directional antennas installed on ToR switches efficiently speed up traffic load running on a 1: 2 over-subscription network by 45% in 95% of the cases. As shown in [28], 60GHz communication techniques can provide up to more than 6Gbps bandwidth. In addition, instead of 60GHz techniques, free space optics (FSO) can even provide up to 10Gbps stable wireless links [29]. Thus, the benefits of introducing wireless links into traditional data center networks could be even more significant. Moreover, the communication connection can be established automatically without human interaction, which is a must in the case of connecting a wired link between two target nodes. Hence, wireless links help reduce the hardware cost and maintenance expenditure of data centers in a flexible way.

Meanwhile, as virtualization techniques undergo a profound development, there is a trend to virtualize traditional middle boxes, such as firewalls, proxies, load balancers, intrusion detection systems (IDSs) and intrusion prevention systems (IPSs), that used to be implemented in hardware, into virtual machines (VMs) implemented in software in data centers, due to the fact that hardware based middleboxes are usually extremely expensive and vendor specific. Even worse, hardware based middleboxes are not upward compatible for new features, which significantly hinders the pace of service innovation. On the other hand, network function virtualization (NFV) not only reduces the potential maintenance cost for the middle boxes, but also allows the network provider to get the most of benefits from the virtualization in terms of management of those middle boxes. To cater this trend, organizations, such as European

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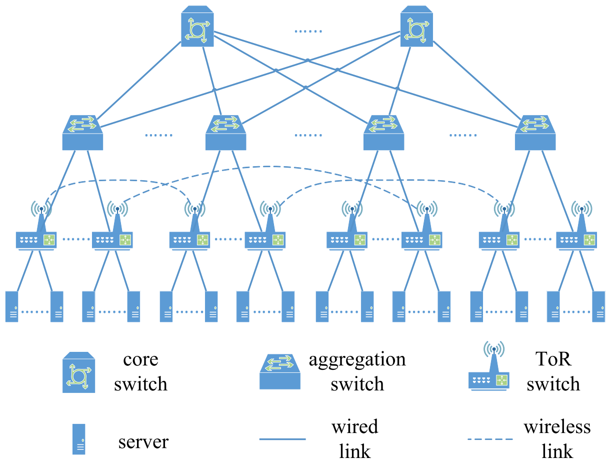

Fig. 1. Structure of a hybrid data center network composed of core switches, aggregation switches, ToR switches and servers. Each ToR switch is equipped with a directional antenna to form a wireless network among ToR switches.

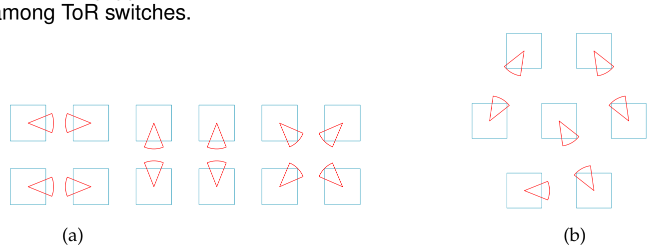

Fig. 2. Example of antenna schedule. (a) Octangle mode. (b) Hexagonal mode.

Telecommunications Standards Institute (ETSI), have issued documents to standarize the techniques and terminologies, and provide use cases as well [1][2][3].

However, despite the consistent effort of making VNF into reality, only a few works focus on efficient placement of VNFs. Besides, several issues essence in the presence of deploying VNFs, such as the cost of deploying a VM to support a VNF and the cost of forwarding traffic from and to a VNF according to the service request. In addition, different from normal traffic flows, traffic in a set of VNFs has to travel through these VNFs in an exact order specified by the service requester. This feature of VNFs is denoted as service function chain (SFC). For example, a service chain may contain a firewall first to prevent malicious access, then an IDS, and load balancer to dispatch the incoming traffic into the pool of servers. In [11], a near-optimal placement of VNFs is provided in the view of geographically distributed DCNs. However, the dependencies among VNFs is not considered. In other words, SFC is not considered, which makes the results in [11] less practical.

Several VNF placement models are proposed in [10][13][14], all of which assume that each VNF is implemented by one and only one virtual machine. However, limited by resources, a single VM provides limited capability of processing requested traffic. For example, a typical virtual IDS can process at most 600Mbps data. If a traffic request with more than 600Mbps bandwidth arrives, clearly, one virtual IDS is not enough. On the other hand, today's customer request can easily reach the order of Gbps. Therefore, this assumption is not suitable in today's scenarios and hinders the deployment of network function virtualization.

Similarly, most of efforts are put to technique details on implementing wireless links using 60GHz bandwidth in traditional DCNs in the indoor environment. However, little has been done on scheduling and routing for flows given the new HDCN. Thus how to arrange the requested VNFs into HDCN and jointly schedule the wireless links to find paths for each request becomes even more challenging. To address this problem, in this paper, we study the VNF placement model. We follow the HDCN structure in [5], which mounts a directional antenna on each ToR switch in a Clos-network based interconnection structure as shown in Fig. 1. Each ToR switch can only communicate with some adjacent ToR switch neighbors through 60GHz wireless links.

We propose a novel model to minimize NFV cost, by jointly placing VNFs into a hybrid DCN and scheduling the directional antennas in each ToR switch. The main contributions we make in this paper are as follows.

- We study the VNF placement problem in the newly emerging data center environment, hybrid data center networks, and propose a model for the problem which jointly considers the scheduling of each antenna and finding paths for each VNF request. We further simplify it into a mixed integer programming (MIP) problem.
- We provide a heuristic algorithm to efficiently find a solution to the joint VNF placement problem. We also extend it to the on-line scenario.
- We conduct comprehensive simulations to verify the efficiency of our algorithms.

To the best of our knowledge, this is the first work considering VNF placement problem in the context of hybrid data center networks.

The rest of this paper is organized as follows. Section 2 debriefs the related work in this area. Section 3 describes the VNF placement problem model in the context of hybrid data center networks and also provides a heuristic algorithm for it. Section 4 introduces an on-line algorithm for the VNF placement problem. Section 5 evaluates the efficiency and performance of the proposed algorithms through comprehensive simulations, and Section 6 concludes this paper.

2 Related Work

The VNF placement problem is studied in [10], by first determining the placement of the VNFs based on pods in a typical DCN. An orchestration layer of virtual middle boxes, called Stratos, is implemented in [12], which demonstrates the effectiveness of using virtual middleboxes via a prototype testbed. In [15] a soft real-time approach is provided for VNF placement by separating the problem into three independent placement sub-problems. A near-optimal VNF placement algorithm is provided in [11] which translates the original placement problem into generalized assignment problem (GAP), and adopts an approximation algorithm used for GAP to find solutions to both uncapacitated and capacitated NFV problems under a bicriteria bound. However, as mentioned earlier, the dependencies among VNFs, or SFC are not considered. Thus the proposed algorithms