Abstraction Layer Based Virtual Data Center Architecture for Network Function Chaining

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***Abstract*— Network virtualization is one of the most promising technology for the data centers. It was innovated to use the network resources efficiently by evaluating new protocols and services on the same hardware. This paper presents a virtual distributed data center network architecture in network function virtualization. A data center network is divided into multiple virtual clusters according to network design logic, where each cluster consists of a particular type of virtual machines and an abstraction layer. One of the main use case of this architecture is orchestration of network function chains, where each chain corresponds to one cluster. Lastly, we discuss how AL-VC helps in orchestrating multiple network function chains in NFV environment.**

Keyword-network virtualization; distributed data center; virtual data center network architecture; cloud; network function virtualization; network service chaining; network functions;

I. INTRODUCTION

Data center networks (DCNs) are experiencing a rapid growth in both scale and complexity as they can host large-scale applications and are acting as a backbone for clouds [1]. Companies like Amazon EC. [2], Microsoft Azure [3], Facebook [4], and Yahoo [5] routinely use data centers for storage, search, and computations. Such growth imposes a huge challenge to upgrade the current architectures of data centers. However, the current architecture is owned by a large number of Internet Service Providers and it is impossible to adopt new architectures without the agreement of all stakeholders.

Network Virtualization (NV) [6] [7] is one of the most promising technologies for the data centers (DCs). Introduced as a mean to evaluate new protocols and services [8]. It is already being actively used in research test-beds and applied in distributed cloud computing environments [9]. Now, it is seen as a tool to overcome the obstacles of the current internet to fundamental changes. As such, NV can be thought of as an inherent component of the future internet architecture [10]. For DCs, it works as a backbone technology and let concurrent applications execute on a single hardware. Today, NV approaches are even applied in the telecommunication market, e.g., Open-Flow [11].

With virtualization, we can create multiple logical Virtual Machines (VMs) on a single server to support multiple applications. However, virtualization of DCNs aims at creating multiple Virtual Networks (VNs) at the top of a physical network. VN, a primary entity in NV, is a combination of active and passive network elements (nodes and links) lies on top of a physical network. Virtual nodes are interconnected through virtual links, forming a virtual topology. With node and link virtualization, multiple VN topologies can be created and co-hosted on the same physical hardware. This virtualization introduces an abstraction that allows network operators to manage and modify networks in a highly flexible and dynamic way. On the other hand, without virtualization, we are limited to place a VM and also are limited in replacing or moving it.

The concept of Network Function Virtualization (NFV) was proposed within the European Telecommunication Standards Institute (ETSI) consortium [12] 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 Function Chaining (NFC) [13] is a service deployment concept that exploits the features of the NFV and Software Defined Networking (SDN).

In this paper, we propose an architecture named Abstraction Layer based Virtual Clusters (AL-VC). AL-VC groups VMs according to the network design logic. In this work, we group them according to their service types, e.g. VMs offering Map-reduce services can be grouped together and VMs offering web services can be grouped separately. Note that, the number of services in a data center is defined by the network operator. An abstraction layer consisting of virtual switches of the optical network is introduced to manage each group of VMs. A particular group of VMs and its corresponding AL forms a VC. This architecture offers several features to the underlying infrastructure, few of them were discussed in our previous works, such as low network update costs [14] , flexibility and scalability [15]. In this work, we first proposed a new method for the construction of abstraction layers. Moreover, we explained AL-VC in NFV environments. In NFV environments, NFCs are being orchestrated to meet the application demands. AL-VC provides the best virtual architecture for the implementation of NFCs over it, where ALs can be used to implement the VNFs.

The rest of the paper is organized as follows: in Section Ⅱ, we discus some important related works. In Section Ⅲ, we present the overview of the architecture, and an algorithm for AL construction. In Section Ⅳ, we explained the concept of NFCs and discussed it in AL-VC. Section Ⅴ concludes the article.

II. Related Works

In this section, we will discuss the most relevant work on NV and NFV.

In [16], the authors surveyed on the importance of virtualization to improve flexibility, scalability, and resource utilization for data center networks. Whereas, MobileFlow [17] introduces carrier-grade virtualization in EPC. Diverter [18] is a software based network virtualization approach that does not configure switches or routers. It logically partition IP networks for better accommodations of applications and services. VL2 [19] is a data center network architecture that aims at achieving flexibility in resource allocation.

SecondNet [20] focused on providing bandwidth guarantees among VMs in a multi-tenant virtualized DC. Another VN architecture, CloudNaas [21] provides support for deploying and managing enterprise applications in the clouds. It relies on OpenFlow forwarding [11]. In NetLord [22], a tenant wanting to run a Map-Reduce task might simply need a set of VMs that can communicate via TCP. On the other hand, a tenant running a three-tier Web application might need three different IP subnets, to provide isolation between tiers. Or a tenant might want to move VMs or entire applications from its own datacenter to the cloud, without needing to change the network addresses of the VMs.

PolyVine [23] and adaptive VN [24] are two more worth discussing distributed approaches. Polyvine embeds end to end VNs in decentralized manners. Instead of technical, it resolves the legal issues among infrastructure providers. In adaptive VNs [24], every server is supposed to have an agent. Each server agent communicates with another to make local decisions. This approach is expensive and needs additional hardware.

In NFV literature, Han et al. [25] 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. [26] 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. [27] proposed to run software-centric middle-boxes on general-purpose hardware platforms with open application programing interfaces (APIs). Sherry et al. [28] proposed a method to deploy middle-boxes in the cloud.

III. System Overview

VCs are more desirable than physical DCs because the resource allocation to VC can be rapidly adjusted as users' requirements change with time [20]. In DCNs, two servers providing similar service have high data correlation in comparison with servers providing different service [21]. This property is also reflected in their VMs. In other words, in order to execute one Virtual Network Request (VNR), two machines (servers/VMs) offering similar services are likely to interact with each other more. Logical representation of AL-VC is shown in Figure 1, where a DCN is virtualized into multiple VCs of different service types.

One of the motivation for this sort of architecture is that the DCs usually categorize their servers, such as file servers, data servers, backup servers, etc. Moreover, operators usually offer their services to users in packages. In this work, we group VMs according to similarity of their services. Having this kind of architecture that groups machines according to a design logic and manages each group separately offers many advantages. It offer scalability and flexibility to the devices and can save search and allocation time of queries.

Ideally, VN topology should be constructed in a way that it achieves minimum energy consumption and larger bandwidth without delay. The proposed architecture is capable to provide all these features. However, this is not the scope of this paper. Topology of AL-VC is presented in Figure 2, where all the servers in a server rack are connected to one Top-of- the-Rack (TOR) switch. Each server is hosting multiple VMs. In the core of the network, to construct virtual links, we use Optical Packet Switches (OPSs). Each TOR is connected to multiple OPSs. TOR switches produce electronic packets and they need to be converted into optical packets before sending over the optical domain of the network. Optical packets will be converted back to the electronic packets before forwarding to the TOR switches. This electronic/optical/electronic conversion is costly and should be reduced to increase the network

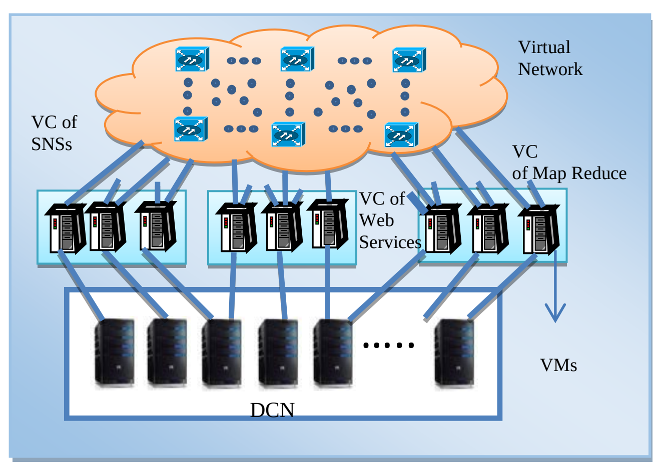

Figure 1. Overview of AL-VC

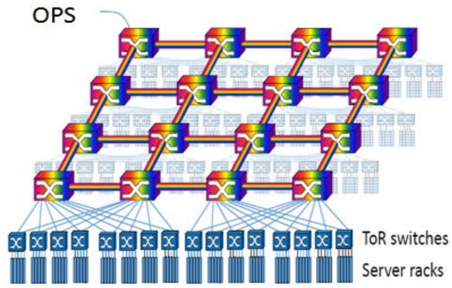

Figure 2. Topology of AL-VC

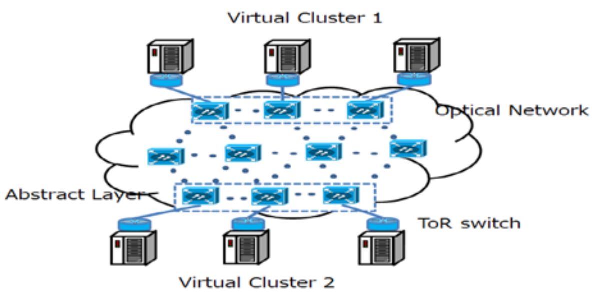

Figure 3. Virtual Clusters

performance. Note that, the proposed topology can be constructed using packet switches. However, in order to achieve higher bandwidth with small energy consumption, we use OPS [29].

A. *Abstraction Layer*

AL is the key concept of this paper that is constructed by logically assigning a subset of OPSs to a group of VMs. Group of VMs and an AL together is called a cluster. In this work, we assume that one OPS cannot be part or two AL at the same time. The logical representation of AL are presented in Figure 3.

An AL can be formed in several ways. In our previous works, we use random selection approach to construct AL. In this work, we use the vertex cover and max-weightage algorithms to construct AL. VMs of every cluster selects the minimum subset of OPSs that connects them as shown in Figure 4. Followings are the step that we adopted for AL construction.

1. Using the vertex cover algorithm, we draw a bipartite graph that connects all the VMs to ToRs.
2. After that select the minimum set of ToRs that cover all the VMs using max-weightage algorithm.
3. In the next phase, we select the OPSs against these selected ToRs as shown in the figure.
4. Among these OPSs we select the ones that have highest incoming links and final list will be declared as an AL of the group.
5. This procedure will be repeated for every group of VMs.

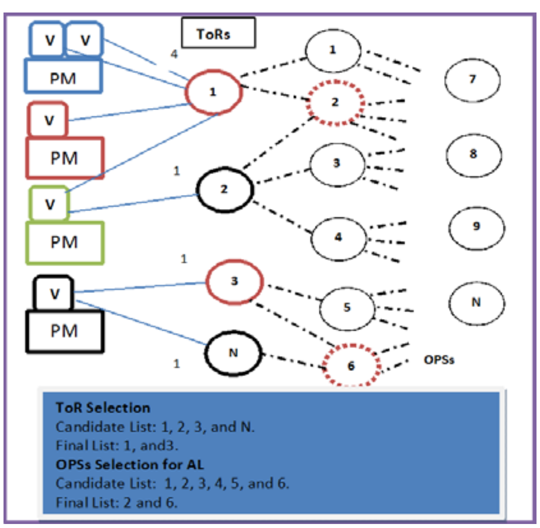

Figure 4. Construction of ALs

IV. AL-VC IN NFV ENVIRONMENTS

In this section, we will first explain the concept of NFCs and then we will discuss the AL-VC in NFV for the orchestration of NFCs. After that, we will use ALs to construct multiple NFCs.

A. *NFCs*

One of the use case for AL-VC is orchestration of NFCs in NFV. An NFC is a service deployment concept that exploits the features of NFV and SDN. An NFC is defined as a set of Network Functions (NFs), packet processing order (simple or complex), network resource requirements (node and links), and network forwarding graph. With NFCs, network operators can configure software dynamically without making any changes to the hardware. In this work, we consider the per-user/per-application service chaining. In the core of the network, we use optical technologies.

In Figure 5, three dynamic NFCs are given, where each NFC follows its own path. Nodes on the path are presented with S and each NFC orchestrates NFs/VNFs according to their demands. NSC can be implemented as a dynamic NSC where each flow processed by various NFs such as security gateways (GWs), firewalls, DPI, , etc.

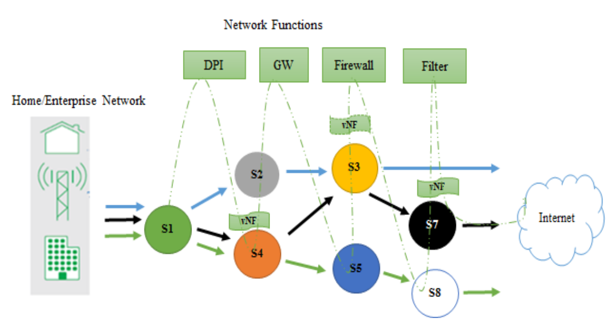

Figure 5. NFCs: The three arrows: blue, black, and green shows the pathline of three service chains, The dashed lines shows the functions (physical and virtual) on the NSCs

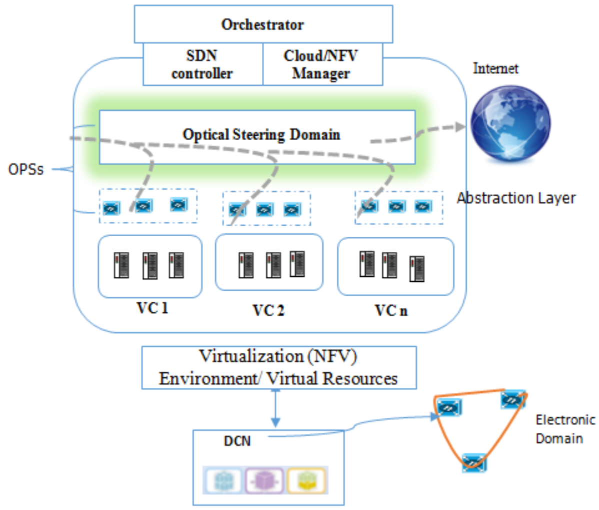

Figure 6. AL-VC in NFV

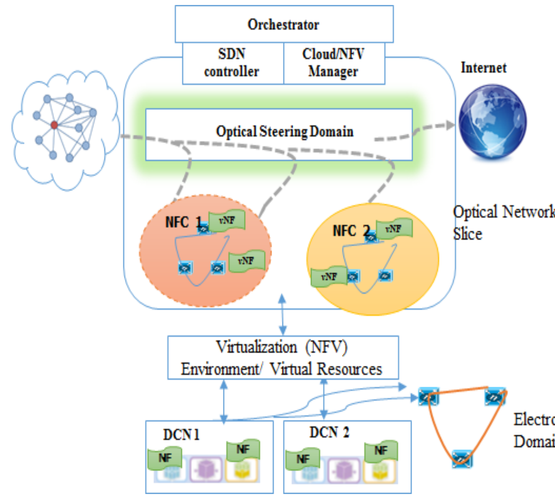

Figure 7. NF/VNFs in the AL-VC

B. *AL-VC in NFV for NFCs*

In Figure 6, we presented the functional blocks of the NFV based AL-VC architecture. The physical network can consist of one or multiple DCNs that are build using the conventional ToR switches. On top of this, we deploy a virtualization layer responsible for virtualizing network resources. 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 VMs hosting VNFs. 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.

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 NFCs. It will logically divide the optical network into virtual slices and will allocate each slice to a single NFC. In AL-VC, that division is in the shape of ALs.

C. *NF and VNFs Over AL-VC*

An NFC consists of set of NF or VNFs. In VNF environment, NFs when virtualized into VNFs can be deployed anywhere anytime. Figure 7, is a modification of Figure 6, here we present each AL as an optical slice of the optical network. Each optical slice will be allocated to a different application and they, according to their requirements, will request for the VNFs in the optical domain. Considering per the application NFV scenario, AL-VC can be modified in such a way where one VC represent one NFC. Each VC and its AL, i.e., optical slide will be working independently providing user with a solicited view of the network. This orchestration of the network will provide application with a control on their VCs.

D. *VNF Placement*

In the given environment, we have electronic and optical domain. Electronic domain is good for small flows, whereas, due to large bandwidth, optical domain is usually used for large flows. Here, we only consider the large flows. When a flow arrives at a DCN, it needs to pass through necessary VNFs that can be hosted by optical switches or ToRs. Most of the OPSs do not have a buffer or processing ability; however; in this work we use the optoelectronic routers. Optoelectronic routers have a limited buffer, storage and processing. Due to this, their resources are limited to host all kinds of VNFs. Note that some of the VNF requires huge amount of processing and not suitable for the optical domain. Such VNFs will be deployed in the electronic domain.

As we mentioned in the previous section that the traffic propagates between electronic and optical. When a flow arrives, it is steered through optical domain, but if a required VNF is on the electronic domain, the flow is converted to electronic traffic and after visiting the VNF, it is converted back to the optical. Each time, the flow is traversed from optical to electronic and back to optical, it consumes an expensive Optical/Electronic/Optical (O/E/O) conversion. In Figure 8, we consider three VNFs. In the left side of the Figure, two VNFs are deployed in the electronic domain and

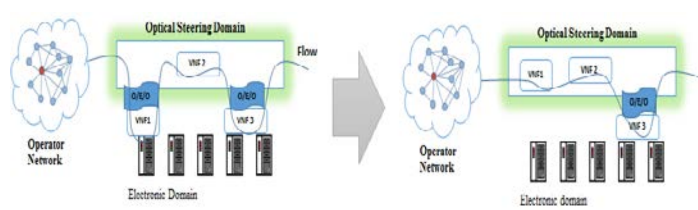

Figure 8. VNF Placement to save energy

one in the optical. Therefore, the flow need to traverse twice between the optical and electronic domain and consuming two O/E/O conversions. However, on the right side of the figure, we moved one more VNF in the optical domain to save another O/E/O conversions. Since the optoelectronic routers have limited capabilities, therefore, VNFs only with low resource demands need to be implement in this domain.

V. CONCLUSIONS

In this paper, we first presented a distributed virtual architecture named abstraction layer based virtual clusters where clusters are created according to network service types. Each cluster is controlled by an SDN enabled abstraction layer. In this work, we presented an algorithm for the construction of these abstraction layers. Then, we discussed the proposed architecture in NFV/SDN environment in which we manage the virtual clusters in the shape of NFCs. Each NFCs consists of several NF/VNFs and their place in the network is important for the energy consumption as every time a flow traverse between optical and electronic domain causing expensive O/E/O conversions.

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REFERENCES

[1] "Amazon Web Services: Overview of Security Processes," Amazon, pp. 1-75, Feb. 2015, Available from: https://d0.awsstatic.com/whitepapers/aws-security-whitepaper.pdf, 2015.12.03

[2] B. Calder, J. Wang, A. Ogus, N. Nilakantan, A. Skjolsvold, and S. McKelvie, "Windows Azure Storage: A Highly Available Cloud Storage Service with Strong Consistency," 23rd Symposium on Operating System Principles (SOSP 11) ACM, pp. 143-157, 2011, ISBN:978-1-4503-0977-6 doi: 10.1145/2043556.2043571

[3] N. Farrington and A. Andreyev, "Facebook's Data Center Network Architecture," Facebook, Inc, Available from: http://nathanfarrington.com/papers/facebook-oic13.pdf, 2015.12.03

[4] Y. Chen, S. Jain, V. K. Adhikari, Z.L. Zhang, and K. Xu. "A First Look at Inter-Data Center Traffic Characteristics via Yahoo! Datasets," in Proceedings of the INFOCOM 2011, pp. 1620-1628, Apr. 2011, ISBN: 978-1-4244-9919-9, doi: 10.1109/INFCOM.2011.5934955

[5] J. S. Turner and D. E. Taylor, "Diversifying the Internet," in Proceedings of the Global Telecommunication Conference (GLOBECOM 05) IEEE, Dec. 2005, ISBN: 0-7803-9414-3, doi: 10.1109/GLOCOM.2005.1577741

[6] N. M. M. K. Chowdhury, "Network virtualization: State of the art and Research Challenges," Comm. Mag., IEEE, vol. 47, no. 7, pp. 20–26, Jul. 2009, doi: 10.1109/MCOM.2009.5183468.

[7] T. Anderson, L. Peterson, S. Shenker, and J. Turner, "Overcoming the Internet Impasse through Virtualization," Comp. IEEE, vol. 38, no. 4, pp. 34–41, Apr. 2005, doi: http://doi.ieeecomputersociety.org/10.1109/MC.2005.136

[8] J. Carapina and J. Jiménez, "Network Virtualization: a view from the bottom," in Proceedings of the Workshop on Virtualized Infra Syst. and Arch (VISA 09) ACM, pp. 73–80, 2009, ISBN: 978-1-60558-595-6, doi:10.1145/1592648.1592660

[9] P. Endo, A. Palhares, N. Pereira, G. Goncalves, D. Sadok, and J. Kelner, "Resource Allocation for Distributed Cloud: Concepts and Research Challenges," Netw. IEEE, vol. 25, no. 4, pp. 42 –46, Jul. 2011, doi: 10.1109/MNET.2011.5958007

[10] N. Feamster, L. Gao, and J. Rexford, "How to lease the internet in your spare time," Comp. Comm. Rev. ACM SIGCOMM, vol. 37, pp. 61-64, 2007, doi:10.1145/1198255.1198265

[11] N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, and J. Rexford, "Openflow: Enabling Innovation in Campus Networks," Comp. Comm. Rev. ACM SIGCOMM, vol. 38, no. 2, pp. 69–74, Apr. 2008, doi>10.1145/1355734.1355746

[12] ETSI NFV ISG, "Network Functions Virtualization, An Introduction, Benefits, Enablers, Challenges & Call for Action," White Paper; http://portal.etsi.org/NFV/ NFV_White_Paper.pdf, Oct. 2012.

[13] A.K. Bashir, Y. Ohsita, and M. Murata, "Virtual Clusters for Dynamic Network Service Chaining", (ICIDB), Seoul, Korea, Nov, 2015.

[14] A.K. Bashir, Y. Ohsita, and M. Murata, "Abstraction Layer Based Virtual Clusters Providing Low Network Update Costs in Virtualized Data Centers", Adv. in Soft., vol. 8, pp.457-466, Dec. 2015

[15] A.K. Bashir, Y. Ohsita, and M. Murata, " Abstraction Layer based distributed architecture for virtualized data centers," Proc. Cloud Computing, pp. 46-51, France, 22-27 Mar. 2015.

[16] A.K. Bashir, Y. Ohsita, and M. Murata, "A Distributed Virtual Data Center Network Architecture for the Future Internet," Technical Reports of IEICE (IN2014-165), pp. 261-266, Mar. 2015.

[17] K. Pentikousis, Y. Wang, and W. Hu, "MobileFlow: Toward Software-Defined Mobile Networks," Communications Magazine, IEEE, vol. 51, no. 7, pp. 44-53, July 2013

[18] A. Edwards, F. A, and A. Lain, "Diverter: A New Approach to Networking Within Virtualized Infrastructures," in Proceedings of the 1st Workshop on Research on Enterprise Networking (WREN 09) ACM, pp. 103-110, Aug. 2009, ISBN: 978-1-60558-443-0, doi: 10.1145/1592681.1592698

[19] A. Greenberg, J. Hamilton, N. Jain, S. Kandula, C. Kim, and P. Lahiri, "VL2: A Scalable and Flexible Data Center Network," in Proceedings of the Data Communication Conference (SIGCOMM) ACM, pp. 51-62, Oct. 2009, ISBN: 978-1-60558-594-9 doi: 10.1145/1592568.1592576

[20] C. Guo, G. Lu, J. H. Wang, S. Yang, C. Kong, and Y.Zhang. "SecondNet: A Data Center Network Virtualization Architecture with Bandwidth Guarantees," in Proceedings of the 6th International Conference (Co-NEXT 10), ACM, 2010, ISBN:978-1-4503-0448-1 doi: 10.1145/1921168.1921188

[21] T. Benson, A.A.A. Shaikh, and S. Sahu, "CloudNaaS: A Cloud Networking Platform for Enterprise Applications," in Proceedings of the Symposium on Cloud Computing (SOCC 11) ACM, Oct. 2011, ISBN: 978-1-4503-0976-9, doi: 10.1145/2038916.2038924

[22] J. Mudigonda, P. Yalagandula, J. Mogul, B. Stiekes, and Y. Pouffary, "NetLord: A Scalable Multi-Tenant Network Architecture for Virtualized Datacenters," in Proceedings of the SIGCOMM, ACM, pp. 62-73, Aug. 2011, ISBN: 978-1-4503-0797-0, doi:10.1145/2018436.2018444

[23] M. Chowdhury, F. Samuel, and R. Boutaba, "PolyViNE: Policy-based Virtual Network Embedding across Multiple Domains," in Proceedings of the Workshop on Virtualized Infrastructure Systems and Architectures (VISA 10) ACM

SIGCOMM, pp. 49-56, Sep. 2010, ISBN: 978-1-4503-0199-2, doi: 10.1145/1851399.1851408

[24] I. Houidi, W. Louati, D. Zeghlache, P. Papadimitriou, and L. Mathy, "Adaptive Virtual Network Provisioning," in Proceedings of the 2nd Workshop on Virtualized Infrastructure Systems and Architectures (VISA 10) ACM SIGCOMM, pp. 41-48, Sep. 2010, ISBN: 978-1-4503-0199-2, doi: 10.1145/1851399.1851407

[25] B. Han, V. Gopalakrishnan, L. Ji and S. Lee, "Network Functions Virtualization: Challenges and Opportunities for Innovations," Communications, IEEE, vol. 53, pp. 90-97, Feb, 2015.

[26] R. Munoz1, R. Vilalta1, R.Casellas1, R.Martinez1, T. Szyrkowiec2, A. Autenrieth2, V. Lopez3, D. Lopez3, "SDN/NFV orchestration for dynamic deployment of virtual SDN controllers as VNF for multi-tenant optical networks". Optical Fiber Communication, Conference, Los Angeles, USA, March, 2015.

[27] V. Sekar et al., "The Middlebox Manifesto: Enabling Innovation in Middlebox Deployment," Proc. 10th ACM Wksp. Hot Topics in Networks, 2011.

[28] J. Sherry et al., "Making Middleboxes Someone Else's Problem: Network Processing as a Cloud Service," Proc. ACM SIGCOMM, 2012, pp. 13–24.

[29] Y. Ohsita and M. Murata, "Data Center Network Topologies using Optical Packet Switches," in Proceedings of the 32nd International Conference on Distributed Computing Systems Workshops (ICDCSW) IEEE, pp. 57-64, Jun. 2012, ISBN: 978-1-4673-1423-7, doi: 10.1109/ICDCSW.2012.53