Cloud Computing and Datacenter Networks: Part I

Yanan Wu, Kai Han, Infinite Lab
School of Information Science and Technology
University of Science and Technology of China, Hefei, China

***Abstract*—In this technical report, we briefly review our research efforts on cloud computing and datacenter networks, which were mainly done in the period of 2012-2017. Specifically, our studies covered three topics, 1) network virtualization with virtual network embedding (VNE), 2) network function virtualization (NFV) with virtual network function (vNF) deployment, and 3) agile management on intra-/inter-datacenter networks (intra-/inter-DCNs). For each topic, we studied the network architectures, the algorithms, and the system implementations.**

***Index Terms*—Cloud computing, Datacenter networks, Network virtualization, Network function virtualization (NFV).**

I. Introduction

NOWADAYS, the revolution on information and communication technology (ICT) makes cloud computing an attractive topic for both academia and industry [1–4]. The major innovation to enable cloud computing is resource virtualization, *i.e.*, tenants can lease both IT and bandwidth resources from infrastructure providers (InPs) dynamically and adaptively to realize their own services. Therefore, both the resource utilization in the InPs' networks and the time-to-market and cost-effectiveness of the tenants' services can be improved, and thus a "win-win" situation can be achieved. Meanwhile, being the fundamental network infrastructure to support cloud computing, the datacenter networks (DCNs) have been studied intensively to improve their scalability, sustainability, and cost-effectiveness. To this end, we studied three topics related to cloud computing and DCNs in our previous work, and the progresses on them are summarized here.

In this report, we first report our efforts on virtual network embedding (VNE) in Section II. Then, Section III discusses how to optimize virtual network function (vNF) deployment. The agile management on intra-/inter-DCN is reported in Section IV. Finally, Section V summarizes the report.

II. Virtual Network Embedding

Since its inception, the Internet has been growing rapidly in terms of network size, user population, traffic volume, and application variety, which makes supporting new networking mechanisms and services timely more and more difficult. To address this issue, network virtualization has been proposed to allow heterogeneous virtual networks (VNTs) to be built over the same substrate network (SNT). One of the major challenges to realize network virtualization is how to allocate resources in an SNT to VNTs efficiently, which is also known as the famous virtual network embedding (VNE) problem. Specifically, VNE includes both node mapping and link mapping, should be considered in different network scenarios, and the system implementations to realize VNE in practical networks should also be addressed.

In our research, we first considered how to solve the VNE problem for generic networks, and proposed several effective and time-efficient algorithms, *e.g.*, in [5, 6], and then use optical networks (*i.e.*, both fixed-grid and flexible-grid ones) as the SNTs to revisit the problem, such as in [7, 8]. Moreover, we also designed and implemented several network virtualization hypervisor systems to realize VNE in practical networks, *e.g.*, in [9, 10]. Our proposals were verified with both numerical and experimental results.

III. Network Function Virtualization

The whole idea of network function virtualization (NFV) is to replace the special-purpose hardware middle-boxes with general-purpose switches, servers and storages. Hence, by leveraging IT resources virtualization, we can realize virtual network functions (vNFs) on the general-purpose network equipment, to improve the cost-effectiveness and reduce the time-to-market of new network services. In order to orchestrate the IT and bandwidth resources in DCNs to deploy and provision vNFs, we have designed the algorithms for realizing vNF service chains in [11, 12], vNF trees in [13], and arbitrary vNF graphs in [14].

IV. Management of Datacenter Networks

The remaining of our research efforts in the area of cloud computing and DCNs were to achieve agile management of DCNs. We considered how to provision anycast and multicast services in inter-DCNs [15, 16], and studied how to jointly optimize the allocations of IT/bandwidth resources in inter-DCNs [17]. Note that, the routing of data-transfers and scheduling of computing tasks in inter-/intra-DCNs can greatly affect the performance of those networks, and thus we addressed them in [18, 19]. Finally, we considered the applications of cloud computing and DCNs in various areas [20].

V. Conclusion

For cloud computing and DCNs, our studies covered three topics, 1) network virtualization with VNE, 2) NFV with vNF deployment, and 3) agile management on intra-/inter-DCNs. We have published 28 conference papers and 23 journal papers for the topic. Students and researchers who interested in our work in this area are encouraged to check the full versions of the papers on http://www.zuqingzhu.info.

REFERENCES

[1] P. Lu *et al.*, "Highly-efficient data migration and backup for big data applications in elastic optical inter-datacenter networks," *IEEE Netw.*, vol. 29, pp. 36–42, Sept./Oct. 2015.

[2] Z. Zhu, W. Lu, L. Zhang, and N. Ansari, "Dynamic service provisioning in elastic optical networks with hybrid single-/multi-path routing," *J. Lightw. Technol.*, vol. 31, pp. 15–22, Jan. 2013.

[3] L. Gong *et al.*, "Efficient resource allocation for all-optical multicasting over spectrum-sliced elastic optical networks," *J. Opt. Commun. Netw.*, vol. 5, pp. 836–847, Aug. 2013.

[4] Y. Yin *et al.*, "Spectral and spatial 2D fragmentation-aware routing and spectrum assignment algorithms in elastic optical networks," *J. Opt. Commun. Netw.*, vol. 5, pp. A100–A106, Oct. 2013.

[5] L. Gong, Y. Wen, Z. Zhu, and T. Lee, "Toward profit-seeking virtual network embedding algorithm via global resource capacity," in *Proc. of INFOCOM 2014*, pp. 1–9, Apr. 2014.

[6] L. Gong, H. Jiang, Y. Wang, and Z. Zhu, "Novel location-constrained virtual network embedding (LC-VNE) algorithms towards integrated node and link mapping," *IEEE/ACM Trans. Netw.*, vol. 24, pp. 3648–3661, Dec. 2016.

[7] L. Gong and Z. Zhu, "Virtual optical network embedding (VONE) over elastic optical networks," *J. Lightw. Technol.*, vol. 32, pp. 450–460, Feb. 2014.

[8] H. Jiang, Y. Wang, L. Gong, and Z. Zhu, "Availability-aware survivable virtual network embedding (A-SVNE) in optical datacenter networks," *J. Opt. Commun. Netw.*, vol. 7, pp. 1160–1171, Dec. 2015.

[9] S. Li *et al.*, "SR-PVX: A source routing based network virtualization hypervisor to enable POF-FIS programmability in vSDNs," *IEEE Access*, vol. 5, pp. 7659–7666, 2017.

[10] Z. Zhu *et al.*, "Build to tenants' requirements: On-demand application-driven vSD-EON slicing," *J. Opt. Commun. Netw.*, vol. 10, pp. A206–A215, Feb. 2018.

[11] W. Fang *et al.*, "Joint spectrum and IT resource allocation for efficient vNF service chaining in inter-datacenter elastic optical networks," *IEEE Commun. Lett.*, vol. 20, pp. 1539–1542, Aug. 2016.

[12] J. Liu *et al.*, "On dynamic service function chain deployment and readjustment," *IEEE Trans. Netw. Serv. Manag.*, vol. 14, pp. 543–553, Sept. 2017.

[13] M. Zeng, W. Fang, and Z. Zhu, "Orchestrating tree-type VNF forwarding graphs in inter-DC elastic optical networks," *J. Lightw. Technol.*, vol. 34, pp. 3330–3341, Jul. 2016.

[14] Y. Wang, P. Lu, W. Lu, and Z. Zhu, "Cost-efficient virtual network function graph (vNFG) provisioning in multidomain elastic optical networks," *J. Lightw. Technol.*, vol. 35, pp. 2712–2723, Jul. 2017.

[15] L. Zhang and Z. Zhu, "Spectrum-efficient anycast in elastic optical inter-datacenter networks," *Opt. Switch. Netw.*, vol. 14, pp. 250–259, Aug. 2014.

[16] Z. Zhu *et al.*, "Impairment- and splitting-aware cloud-ready multicast provisioning in elastic optical networks," *IEEE/ACM Trans. Netw.*, vol. 25, pp. 1220–1234, Apr. 2017.

[17] W. Fang *et al.*, "Joint defragmentation of optical spectrum and IT resources in elastic optical datacenter interconnections," *J. Opt. Commun. Netw.*, vol. 7, pp. 314–324, Mar. 2015.

[18] J. Yao, P. Lu, L. Gong, and Z. Zhu, "On fast and coordinated data backup in geo-distributed optical inter-datacenter networks," *J. Lightw. Technol.*, vol. 33, pp. 3005–3015, Jul. 2015.

[19] P. Lu, Q. Sun, K. Wu, and Z. Zhu, "Distributed online hybrid cloud management for profit-driven multimedia cloud computing," *IEEE Trans. Multimedia*, vol. 17, pp. 1297–1308, Aug. 2015.

[20] L. Liang, W. Lu, M. Tornatore, and Z. Zhu, "Game-assisted distributed decision-making to build virtual TDM-PONs in C-RANs adaptively," *J. Opt. Commun. Netw.*, vol. 9, pp. 546–554, Jul. 2017.