Software-Defined Networking: Part I

Yanan Wu, Xiang Zhou, 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 software-defined networking (SDN), which were mainly done in the period of 2012-2017. Specifically, our studies covered three topics, 1) SDN with the protocol-oblivious forwarding (POF) technology to achieve a fully programmable data plane, 2) SDN in the optical layer to realize software-defined elastic optical networks, and 3) the combination of SDN with network virtualization to slice virtual software-defined networks (vSDNs). For each topic, we studied the network architectures, the algorithms, and the system implementations.**

***Index Terms*—Software-defined networking (SDN), Protocol-oblivious forwarding, Datacenter networks, Network virtualization, Network function virtualization (NFV).**

I. Introduction

RECENTLY, with the fast development of new network services and protocols, the existing distributed network control and management (NC&M) architecture of the Internet becomes more and more difficult to adapt to the increasing demands for network programmability, adaptability and application-awareness [1–5]. Therefore, software-defined networking (SDN) have been proposed to tackle these challenges, which decouples the control and data planes of a network and leverages the centralized NC&M to make the network more adaptive, programmable and application-aware. Despite the advantages, the current SDN technologies are dominated by OpenFlow, which is protocol-dependent and has to be updated for including more match fields and actions consistently when new network services and protocols are introduced. This motivated us to study SDN with protocol-oblivious forwarding (POF) to achieve a fully programmable data plane [6].

Meanwhile, the conventional fixed-grid wavelength-division multiplexing (WDM) networks are expected to be replaced by the flexible-grid elastic optical networks (EONs), which will make the spectrum management in the optical layer more adaptive and efficient. However, the flexible spectrum management introduced by EONs would also make the NC&M more complex, and thus how to leverage the programmability provided by SDN to manage EONs well becomes an interesting research topic. Therefore, we also considered the combination of SDN and EON to realize software-defined EONs (SD-EONs), proposed novel network architectures for SD-EONs, and conducted experimental demonstrations. Moreover, to fully explore the programmability provided by SDN, we also addressed how to slice virtual software-defined networks (vSDNs). We studied three topics related to SDN in our previous work, and the progresses are summarized here.

In this report, we first report our efforts on POF in Section II. Then, Section III discusses how to combine SDN and EON to realize SD-EONs. The network virtualization schemes to slice vSDNs are reported in Section IV. Finally, Section V summarizes the report.

II. Protocol-Oblivious Forwarding (POF)

Before moving onto POF, we have performed a few studies on OpenFlow-base SDN systems [7, 8]. However, we found that the protocol-dependent data plane really restricts the flexibility of SDN. In order to realize a protocol-independent and thus future-proof data plane, POF tries to decouple network protocols from the packet forwarding procedure in SDN switches and to make the data plane reconfigurable and programmable. Specifically, POF provides a protocol-oblivious forwarding instruction set (POF-FIS) that enables system designers to define protocol stack and packet processing procedure in a much more adaptive and flexible way than what they can get from OpenFlow. We first developed the basic controller and software-based SDN switch to realize a simple POF-enabled network system [9]. Then, we improved the switching capacity of our software-based POF switch to achieve a throughput of 10 Gbps per port in [10], and verified the effectiveness of POF-enabled networks by introducing source routing in them [11].

III. Software-Defined EONs (SD-EONs)

It is known that with a fine bandwidth allocation granularity at 12.5 GHz or even narrower, the NC&M in EONs becomes much more complex than its counterpart in fixed-grid WDM networks [2]. One example is the spectrum fragmentation in EONs, which refer to the existing of non-aligned, isolated, and small-sized unused bandwidth blocks in the optical spectrum, due to the frequent setting up and tearing down of dynamic connections [12, 13]. To properly address spectrum fragmentation, we have proposed and demonstrated a few SD-EON systems that can either perform fragmentation-aware routing and spectrum assignment (RSA) [14] or conduct defragmentation based on lightpath reconfigurations [15, 16]. Then, we consider various service provisioning schemes in SD-EONs, including multicast, protection and restoration, network function virtualization, and advance reservation [17, 18]. Finally, we consider to expand the applications of SD-EONs to multi-domain and/or multilayer networks [19, 20].

IV. Slicing of Virtual SDNs (vSDNs)

In addition to the programmability provided by POF and SD-EON, network virtualization can further improve the flexibility of network architecture to shorten the time-to-market and improve the resource utilization in the substrate networks. We proposed and demonstrated a few schemes to create vSDNs in POF-based or SD-EON-based network environments [21, 22].

V. Conclusion

For SDN, our studies covered three topics, 1) SDN with POF to achieve a fully programmable data plane, 2) SDN in the optical layer to realize SD-EONs, and 3) the combination of SDN with network virtualization to slice vSDNs. We have published 33 conference papers and 28 journal papers for the topics. 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.

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