Unified Control for IP over Optical Transport Networks Based on Software-Defined Architecture

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Abstract: We proposed a software-defined unified control architecture for IP over optical transport networks. A successful network experiment of end-to-end dynamic connection establishment is implemented across both IP and OTN layers with the scheme.
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1. Introduction

In today's commercial communication networks, the Internet Protocol/Multi-Protocol Label Switching (IP/MPLS) layer and the Optical Transport Network (OTN) layer are separately operated without dynamic interaction, which greatly extend the transmission latency in path provisioning and resource restoration, increase OPEX and CAPEX as well as lower the network efficiency. On the other hand, the enlarging communication demands lead optical networks towards multi-domain, highly complex and heterogeneous. In such traditional networks, control plane and data plane are coupled and ossified, which is incompatible with IP networks and refines the satisfaction of consumers and the flexible development of next generation networks. Meanwhile, distributed control architecture of traditional network makes it difficult to allocate network resources agilely and efficiently.

Software Defined Networking (SDN) is proved to be helpful in solving these difficulties by decoupling the control plane from the data plane and opening the northern Application Programming Interfaces (API) to flexible software control [5]. The administrator can use the API to deploy applications to realize the unified control of cross-layer cross-domain resource allocation and scheduling [1]. However, the mainstream protocol of SDN southern interface, OpenFlow, is designed mainly for packet-switched networks and is difficult to be extended to realize unified control of IP over optical transport networks.

Cross-layer unified control architecture needs to be proposed to solve the problems. However, when concerning billions of network equipment which are serving the communication need of people nowadays, the most economical way for smooth evolution to new architecture is to retain the basic IP over OTN infrastructure. Also, circuit switching varies a lot from packet switching and has many unique characteristics that packet-switch do not cover, so it is difficult to directly combine these two switching mode a under unified SDN southern interface like OpenFlow. Therefore, we need to find a new way to realize smooth evolution of IP over optical transport networks.

In order to achieve the smooth evolution of IP over OTN from tradition schema to software-defined schema, a new network architecture is proposed in this paper to integrate packet switching and circuit switching by setting an Optical Control Agent (OCA) between SDN control layer and OTN layer to virtualize the traditional optical transport devices. Both OCAs and OpenFlow switches are under direct control of general SDN controller. We conduct successful network experiment under the proposed architecture on an IP over OTN test-bed composed of commercial OpenFlow switches, emulated OTN switching nodes and OCAs.

2. Software-defined unified control architecture with OCA

Software-defined unified control architecture consists of four layers. Fig. 1 depicts the software-defined unified control architecture with OCA for IP over OTN.

In control layer, an SDN controller is introduced to control the whole network. The southern interface of the SDN controller is OpenFlow protocol. The SDN controller opens its northern APIs to user applications, which enables network administrator to establish/maintain/terminate end-to-end dynamic connections as well as other network functions.

In adaption layer, a new element, named Optical Control Agent (OCA) is introduced. OCA plays the role partly like the traditional GMPLS control plane, and each OCA represents one OTN domain. The OCA has some major functions, i.e. message filtering, and message format conversion between SDN controller and OTN switching nodes. From the view of the SDN controller, one domain of the OTN layer (including OTN switching nodes and fiber links) is virtualized by one OCA. All the intra-domain resources allocation, including light path setup and teardown are controlled only by the OCA of the corresponding OTN domain. Thus the SDN controller only deal with the network topology consisting of OpenFlow switches and OCAs.

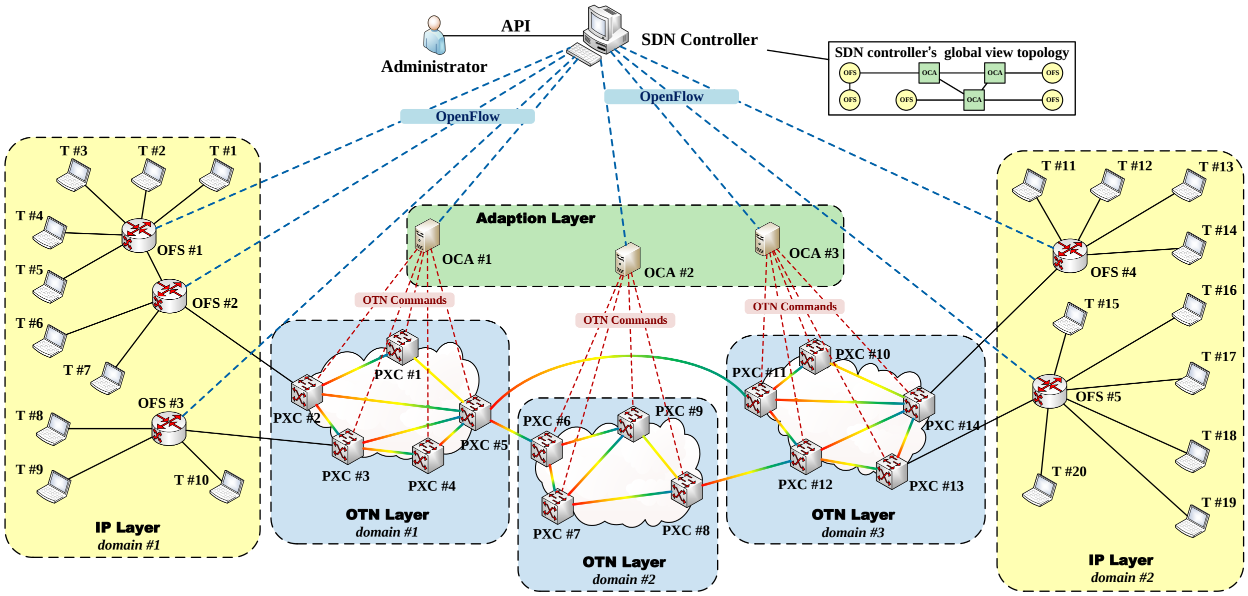

Fig. 1 Software-defined unified control architecture for IP over OTN

In IP layer, we use OpenFlow switches under OpenFlow protocol to communicate with SDN controller directly. Terminal PCs are also directly connected to OpenFlow switches.

In OTN layer, intelligent GMPLS-based OTN switching nodes are considered. Equipment from three different vendors compose three domains of optical transport networks.

3. Example of end-to-end dynamic connection establishment

Step I: End-to-end connection initialization

Each OCA initiates Intra-Domain Traffic Engineering Database (IDTED) from PXCs in relating OTN layer domain independently, meanwhile the SDN controller initiates Global Traffic Engineering Database (GTED) from OpenFlow switches and OCAs.

Step II: End-to-end path computation in SDN controller

When the source terminal requests a business from the destination terminal, a new flow is initialized. Once the first IP packet of the new flow arrives at the SDN controller via certain OpenFlow switch, the controller obtains the source and destination IP addresses of this flow and runs path computation algorithm based on its global view from the GTED of IP over OTN, and then gets the preliminary result of end-to-end path computation. Concerning the virtualization function of the OCA, the SDN controller considers a global view of the connection topology that only consists of the OpenFlow switches in IP layer and the OCAs in adaption layer.

Step III: Intra-domain optical path computation in OCA

According to the preliminary end-to-end path computation result, the SDN controller sends OpenFlow messages to the corresponding OCA to trigger intra-domain optical path computation. The OCA runs optical path computation algorithm based on its regional view from the IDTED of intra-domain OTN topology as well as the ingress and the egress of the flow in its relating domain.

Step IV: End-to-end connection setup

The SDN controller sends routing commands under OpenFlow protocol to OpenFlow switches in IP layer and OCAs in adaption layer. Then in IP layer, the relating flow is handled according to flow tables modified by these routing commands in OpenFlow protocol, like packet-out or flow-mod messages. Meanwhile in OTN layer the OCA sends standard OTN commands to cross-connect the corresponding ports of OTN switching nodes to setup or teardown the relating light path. Generally, the elapsed time of connection setup in OTN layer is much longer than that in IP layer due to different connection establishment procedures.

4. Network experiment and numerical results

As is shown in Fig. 2, we establish an IP over OTN test-bed based on our software-defined unified control architecture. This test-bed consists of two IP layers and one OTN layer. In both IP layers commercial Centec V330 OpenFlow switches and PC terminals are employed. In OTN layer, the OTN switching nodes are emulated by commercial Cisco switches. The whole software-defined unified control network is assumed to be controlled by an open source SDN controller, POX. Terminal #2 is set to be the source and terminal #14 is set to be the destination, both FTP service and video service are tested on this test-bed. The average end-to-end transfer time delay of three repeated measurements are listed in Tab. 1.

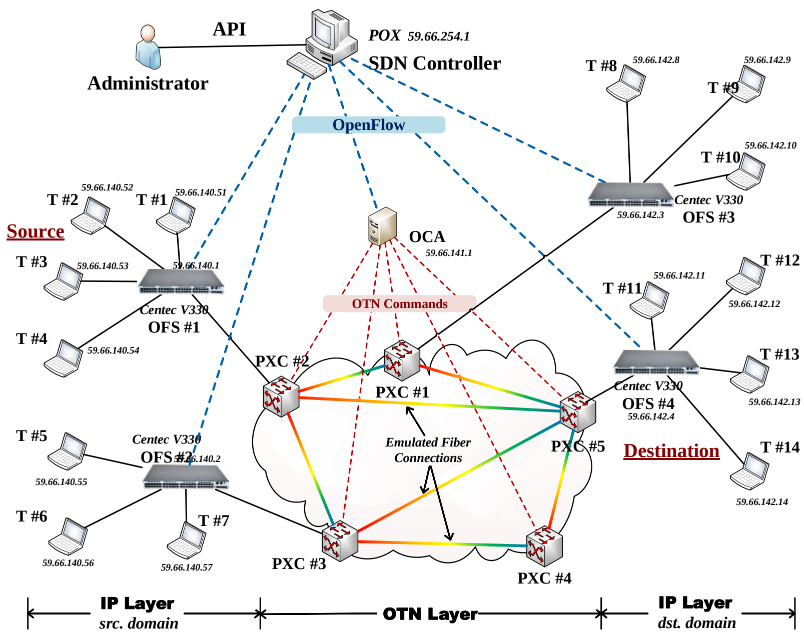

Fig. 2 Network experiment for end-to-end dynamic connection establishment on commercial test-bed

Tab. 1. Average transfer time delay of FTP and video file transfer

	IP layer src. domain	OTN layer	IP layer dst. domain
FTP transfer	0.137ms	443ms	0.122ms
Video transfer	0.146ms	382ms	0.098ms

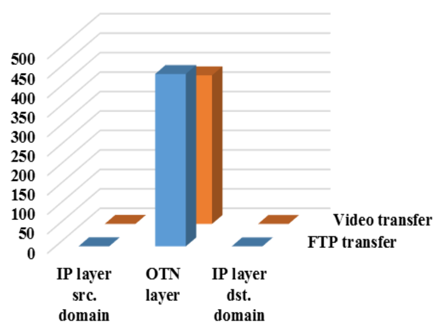

Fig. 3 Histogram of average testing time

5. Conclusions

In this paper, we review our recent research activities related to software-defined unified control architecture for IP over OTN. We put forward a new network architecture to achieve unified control in IP over OTN on the basis of software defined networking, and realize smooth evolution of IP over OTN by introducing OCA with its virtualization function.

We also report a successful network experiment of end-to-end dynamic connection establishment on our IP over OTN test-bed composed of commercial devices, and the transfer time delay in OTN layer is much longer than that in IP layer. Above all, these results demonstrate that our proposed architecture with the novel OCA is feasible to realize end-to-end dynamic connection establishment through software-defined unified control in IP over optical transport networks.

Acknowledgement

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