ACHIEVING HETEROGENEOUS PACKET-OPTICAL NETWORKS INTER-CONNECTION WITH A SOFTWARE-DEFINED UNIFIED CONTROL ARCHITECTURE

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ABSTRACT

We present a software-defined unified control architecture for heterogeneous packet-optical networks inter-connection. This architecture supports hybrid packet- and circuit-switched networks employing various switching technologies and can achieve fast and seamless connection establishment.

Keywords: *Heterogeneous network, software-defined network, packet-switched network, circuit-switched network, unified control*

1. INTRODUCTION

With the increment of communication demands and the innovations derived from data businesses, the scale and capacity of optical transport networks have been enlarged year by year, which leads optical networks towards multi-domain, highly complex and heterogeneous. Intelligently providing an inter-domain connection across multiple heterogeneous domains is a complex problem [1-2]. To solve this problem, we proposed a distributed architecture based on stateful PCE to realize end-to-end connection provisioning in heterogeneous multi-domain optical networks [3], and further reported the first successful field trial of end-to-end connection establishment across three domains using commercial devices from three equipment venders [4-5], with some of its key technologies proposed in [6-9]. However, inter-connection inside heterogeneous optical networks is not enough. A broader range of “heterogeneous networks inter-connection” is needed.

Future Internet will be characterized by global delivery of packet switched traffic. In order to provide dynamic and on demand end-to-end delivery of the packet switched traffic over an optical circuit switched network, it is vitally important to converge the IP packet networks and optical transport networks, and further realize, i.e. the packet-optical networks inter-connection. To achieve this, new problems will be raised.

IP packet and optical transport networks today are separated and do not interact, they are planned, designed and operated separately by different teams, which leads to significant inefficiencies [10]. Without interaction with the optical networks, packet-switching based Internet core cannot benefit from high-capacity and scalable circuit switching, and will suffer from exorbitant cost and high energy consumption. On the other hand, for optical transport networks, the lack of interaction means that it has no visibility into IP traffic and application requirements, making current optical networks stay static under the carriers’ manual control, taking days or even weeks to set up a new circuit.

The emerging software-defined networking (SDN) technology in IP networks provides a possibility for packet-circuit networks convergence. In our previous work, we put forward a new network architecture to achieve unified control of packet and optical networks on the basis of SDN, and reported a successful network experiment of end-to-end dynamic flow setup on our heterogeneous packet-optical network test-bed using commercial devices [11].

2. SOFTWARE-DEFINED UNIFIED CONTROL ARCHITECTURE FOR CONVERGED PACKET-OPTICAL NETWORKS

In order to extend SDN concepts to Layer 2 (L2) transport network architectures, many challenges will be faced since control plane implementations for L2 transport networks are more complex. They must take into account the constraints in physical and data link layers including power, impairments, signal reachability, switching granularity, bandwidth availability, connection setup speed, etc. [12].

An ideal architecture is to regard each L2 transport network as a "super virtual router", which can be controlled by the SDN controller through an OpenFlow (OF)-enabled virtual router agent using current OF protocol without significant extensions. This architecture preserves the GMPLS control plane for dynamic control of L2 transport networks. In this way, unified and seamless control in hybrid packet-optical networks can be realized. Fig. 1 illustrates such a unified software-defined control architecture supporting various types of converged packet-optical transport network architectures [13].

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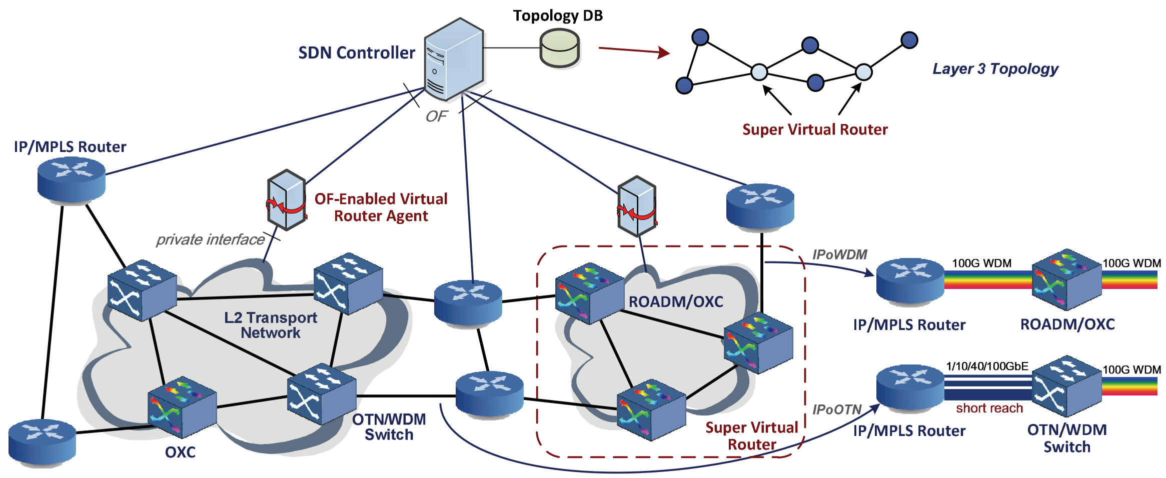

Fig. 1. Unified control architecture for packet-optical transport networks based on “super virtual router”

3. NETWORK EXPERIMENT AND NUMERICAL RESULTS

We establish a packet-optical network test-bed based on our proposed unified control architecture as shown in Fig. 2. This test-bed consists of two IP layers and one OTN layer. In the IP layers, commercial Centec V330 OpenFlow switches and PC terminals are employed. In the 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.

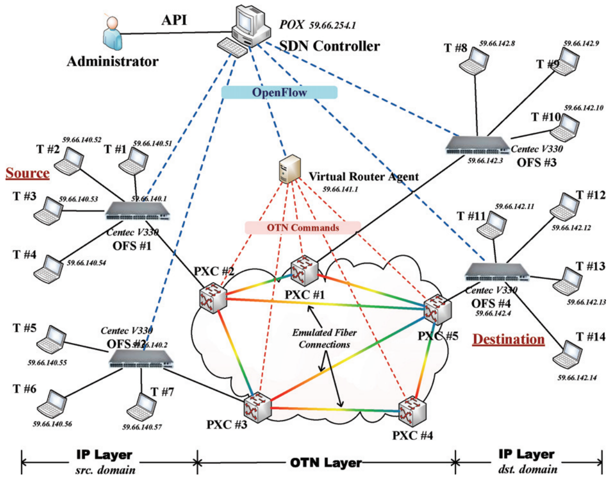

Fig. 2. Network experiment of end-to-end dynamic flow setup

Tab. 1. Average time delay of FTP and video 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

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. It can be seen that there is huge delay variance between the IP and OTN layers, where the latter occupies most of it. In order to eliminate the negative impacts of delay variance and to build low-latency networks, we introduce the concept of resource buffering to our proposed architecture.

4. RESOURCE BUFFERING TO REALIZE FAST END-TO-END CONNECTION ESTABLISHMENT

4.1 Concept of resource buffering

Resource buffering was initially proposed to absorb the impact of instantaneous high-intensity traffic arrival in wavelength-routed WDM networks [14]. In this paper, we introduce its concept to SDN to realize fast connection establishment and unified seamless control. To achieve this, a small portion of wavelength or ODUk resources, i.e. resource buffer, will be reserved in advance to establish dedicated fixed channels for each node pair in L2 transport networks (or super virtual routers). These channels constitute the logic “buffer layer”, and the other resources constitute the logic “payload layer”.

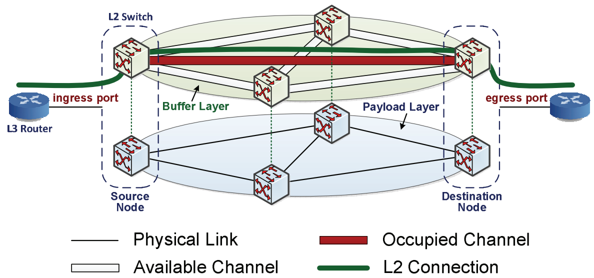

Fig. 3. Use dedicated fixed L2 channel to set up a temporary connection in the “buffer layer”

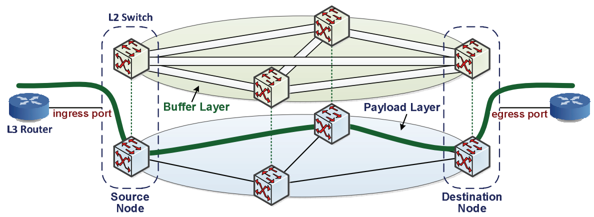

Fig. 4. Initiate connection setup process in the “payload layer” and switch the temporary connection to a new connection

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Upon the arrival of a connection request from the SDN controller, the virtual router agent will simply configure the ingress and egress switches to fast set up a temporary connection using a reserved channel in the buffer layer, as illustrated in Fig. 3. Meanwhile, the GMPLS control plane of the super virtual router initiates a connection setup process in the payload layer, and then switches the temporary connection to the new established connection (Fig. 4). The whole process is opaque to the SDN controller. If all the reserved channels between the ingress and egress nodes are occupied, connection will be established directly in the payload layer, which may lead to a high setup delay.

4.2 Results and analysis

Performance of resource buffering is evaluated via an optical transport network configured with the 14-node NSFNET topology. Assume that all the connection requests are ODU0 arriving in a Poisson process, and are uniformly distributed among all the node pairs. Resource buffer is set with the granularity of ODU0. In payload layer, connection setup time depends on path computing time, nodal processing and configuration delay, set to 1*ms*, 200*ms* and 5*ms* respectively, according to performance parameters obtained from commercial devices [4].

Fig. 5 shows the distribution of setup delay with and without resource buffer. It can be seen that end-to-end setup delay can be dramatically reduced when buffer is used. Furthermore, a large buffer will significantly reduce the proportion of slow-established connections.

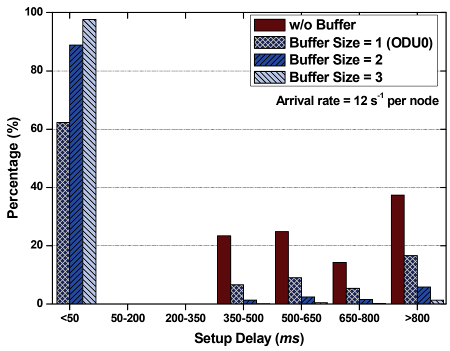

Fig. 5. Distribution of setup delay

5. CONCLUSIONS

A software-defined unified control architecture for heterogeneous packet-optical networks inter-connection is presented in this paper. This architecture supports hybrid packet- /circuit-switched networks employing various switching technologies, which is validated through a successful network experiment on our heterogeneous packet-optical network test-bed.

To achieve this, our proposed control architecture regards each L2 transport network as a "super virtual router" and thus be able to use current SDN protocols to realize unified control without significant extensions. In order to reduce connection setup delay in the optical transport networks, we introduce the concept of resource buffering to our proposed architecture. Results show that connection setup delay can be dramatically reduced when resource buffer is used.

6. ACKNOWLEDGMENTS

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