Multi-Dimensional Resources Integration in OpenFlow based Data Center Interconnection

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***Abstract*—Interconnected with IP and optical networks, data center networks have attracted an amount of attentions for end-to-end high-performance guarantee. It is more important that service, IP and optical network (which is referred to as multi-dimensional) resources can be controlled effectively for meeting this high-level application requirement. This paper proposes a multi-dimensional resources integration (MDRI) architecture in OpenFlow based data center interconnection. Multiple controllers cooperation can realize optimum utilization of these resources globally. The feasibility and efficiency of the proposed architecture are experimentally verified on our testbed.**

***Index Terms*—Data center, software defined networking, OpenFlow, IP network, optical network.**

I. Introduction

With the rapid evolving of high-performance network-based data center application, data center interconnection with IP and optical networks has attracted an amount of attentions. The mastery of comprehensive resources with a flexible control way becomes a key issue for meeting the integrated end-to-end dynamic connectivity and high-level requirement from these applications. The cross stratum optimization (CSO) [1, 2] is proposed to enable a joint optimization of service and optical network resources and realize the optical as a service (OaaS) [3]. Moreover, software defined networking enabled by OpenFlow protocol has been validated as a centralized control technique for IP and optical networks, since it can provide maximum flexibility for operators and abstract multiple resources as unified interface for unified control with a global view [4, 5]. A novel multi-dimensional resources integration (MDRI) architecture with service-aware flow estimation strategy (SA-FES) is designed in OpenFlow based data center interconnection to control service, IP and optical network (which is referred to as multi-dimensional) resources globally.

II. MDRI archiecture

MDRI architecture is illustrated in Fig. 1. The IP and optical networks are distributed into overlay stratums (i.e., IP and optical stratums) with interconnecting among data centers, which service stratum resources are deployed in (e.g., CPU and memory). Each stratum resources can be controlled locally by IP controller (IPOC), optical controller (OOC) and application controller (AOC) respectively through OpenFlow protocol (OFP). OpenFlow-enabled IP routers (OF-Router) and optical cross-connects (OF-OXC) are required respectively. The architecture especially emphasizes the cooperation among three controllers to realize MDRI with global optimization of multi-dimensional resources. Receiving the status of data center resources from AOC, IPOC is responsible for analyzing it with flow resources monitored in IP stratum for MDRI, while OOC sustains abstracted optical resources and lightpath provisioning with CSO of optical and service resources from AOC.

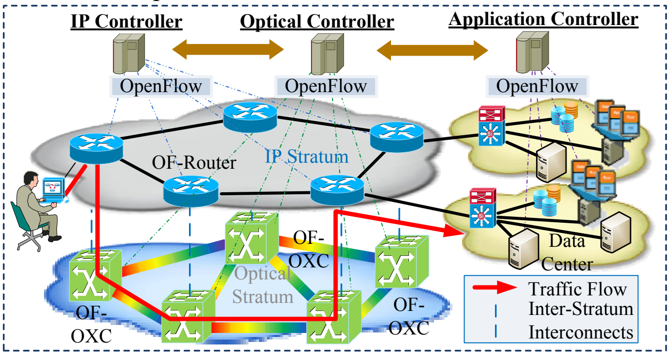

Fig.1 MDRI architecture

III. Controller implementation modules

The responsibilities and interactions of controllers are shown in Fig. 2, while AOC is verified in [2]. IPOC monitors flow statistics of OF-Routers and interworks service resources to perceive the data center through IP-application interface (IAI). After completing SA-FES, MDRI control decides to offload the flow into optical and provides MDRI request to OOC via IP-optical interface (IOI). In OOC, MDRI agent can receive this request and respond MDRI success reply with the lightpath and abstract optical resources. Path computation is completed in PCE considering CSO of optical and application constraint via optical-application interface (OAI).

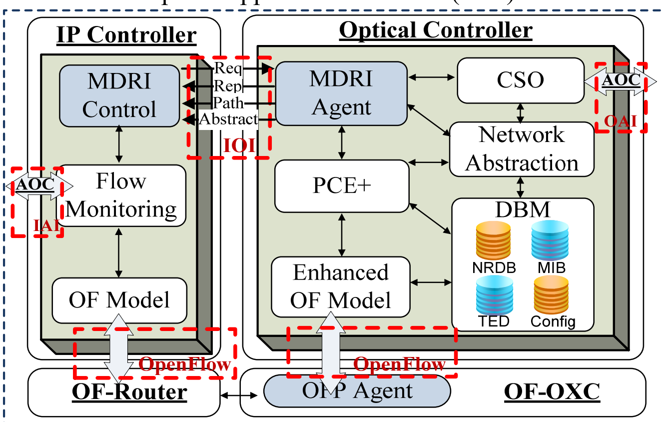

Fig.2 Controller implementation modules

IV. SERVICE-AWARE FLOW ESTIMATION STRATEGY

Based on functional architecture described above, we propose a ***service-aware flow estimation strategy*** (SA-FES) in the flow monitoring model of IPOC to estimate the flow status coordinated data center service resources from AOC.

To compile the flows from OF-routers, we utilize the statistics of the previous flows from IP stratum considering the application resources constraint to estimate the status of coming flow. For ith flow occurred at t time, the service-aware parameter, application utilization $U_i^{(t)}$ describes the situation of the flow occupation in data center server, while the flow consumption of IP stratum resources is denoted as the bandwidth usage $B_i^{(t)}$. From another perspective, the service usage $S^{(t)}$ of application resource at t time represents the overall efficiency of data center server. Therefore, the service-aware flow estimation $E[\tau_0, i_0]$ of the i_0 flows in the last τ_0 time in IP stratum is useful for emphasizing the average occupation degree of i_0 arrived flows recent, which is expressed as follow.

$$E\left[t,i \mid t=\tau_0, i=i_0\right] = \sum_{t=t_c-\tau_0}^{t_c} \sum_{i=i_c-i_0}^{i_c} U_i^{(t)} B_i^{(t)} f_i^{(t)} \Bigg/ \sum_{t=t_c-\tau_0}^{t_c} \sum_{i=i_c-i_0}^{i_c} f_i^{(t)} \left(1-S^{(t)}\right),$$

$$t \in [t_c-\tau_0, t_c], i \in [i_c-i_0, i_c]$$

Here, $f_i^{(t)}$ indicates the probability of occurrence of the ith flow at t time, moreover, t_c and i_c denote the current time and size of traffic flow respectively.

V. EXPERIMENTAL DEMONSTRATION

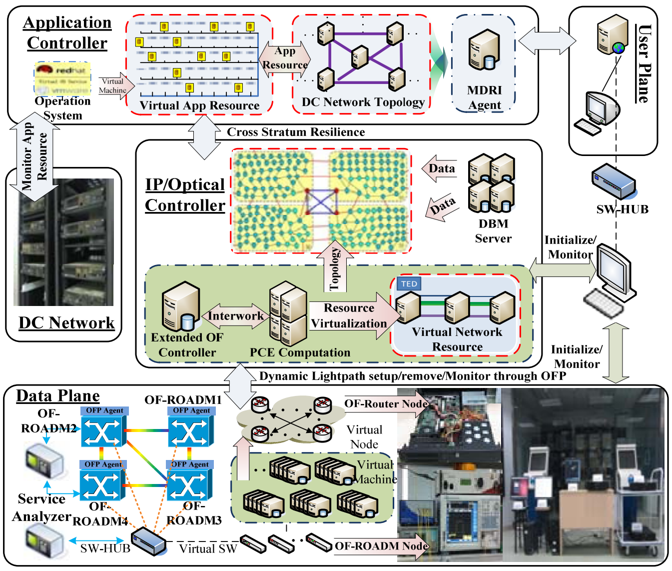

Fig.3 Experimental testbed

To evaluate the feasibility and efficiency of MDRI architecture, we set up an overlay IP over WDM multi-stratum network with data centers based on our testbed [3] as shown in Fig. 3. Four OF-enabled ROADM nodes supporting 40 wavelengths and multi-granularity client-side interfaces are utilized, while four NetFPGAs with Gbps interfaces are deployed as OF-routers in the upper layer. Data centers and the other nodes are realized on an array of virtual machines created by VMware software running at servers. Since each virtual machine has the operation system and its own computation resource, the virtual OS technology makes it easy to set up experiment topology which comprises 200 nodes and divided into 4 domains. MDRI based on SA-FES is implemented and experimentally compared with traditional optical bypass strategy (TOB) [2] on established testbed. The application interface, Wireshark captures of protocol implementation for MDRI and the experimentally results are shown in Fig. 4.

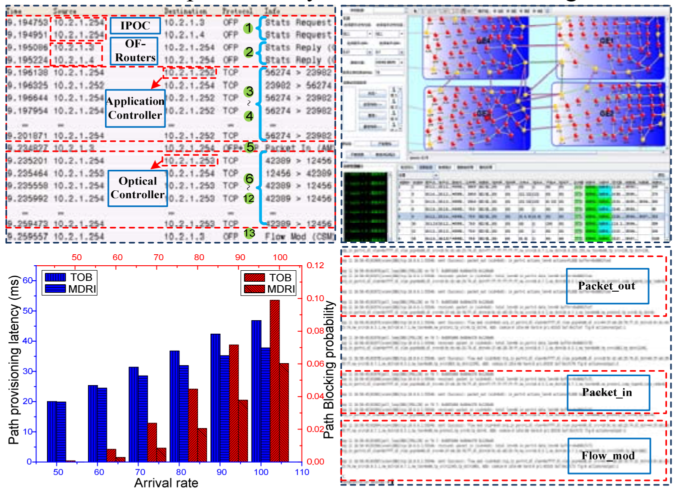

Fig. 4 Demonstration results

VI. CONCLUSIONS AND FUTURE WORK

We propose a novel multi-dimensional resources integration (MDRI) architecture with service-aware flow estimation strategy in OpenFlow based data center interconnection and experimentally demonstrate a MDRI testbed with 200 nodes to realize the joint optimization among service resource, IP and optical network resource. The various applications and resources virtualization and isolation using FlowVisor will be demonstrated on our testbed in the future.

ACKNOWLEDGMENT

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