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Experimental demonstration of time-aware software defined networking for OpenFlow-based intra-datacenter optical interconnection networks

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ABSTRACT

Nowadays, most service providers offer their services and support their applications through federated sets of data centers which need to be interconnected using high-capacity optical networks in intra-datacenter networks. Many datacenter applications in the environment require lower delay and higher availability with the end-to-end guaranteed quality of service. In this paper, we propose a novel time-aware software defined networking (TaSDN) architecture for OpenFlow-based intra-datacenter optical interconnection networks. Based on the proposed architecture, a time-aware service scheduling (TaSS) strategy is introduced to allocate the network and datacenter resources optimally, which considers the datacenter service scheduling with flexible service time and service bandwidth according to the various time sensitivity requirements. The TaSDN can arrange and accommodate the applications with required QoS considering the time factor, and enhance the data center responsiveness to quickly provide for intra-datacenter service demands. The overall feasibility of the proposed architecture is experimentally verified on our testbed with real OpenFlow-enabled tunable optical modules. The performance of TaSS strategy under heavy traffic load scenario is also evaluated based on TaSDN architecture in terms of blocking probability and resource occupation rate.

1. Introduction

With the rapid evolving of cloud computing and high-bitrate data-center-supported services, such as video on demand, remote storage and processing, and online games, datacenter applications have shown the high burstiness and high-bandwidth characteristics. Nowadays a large number of service providers and enterprises are hosting their storage contents and computing resources in data centers to achieve lower delay, higher availability and efficiency for their services at a lower cost [1]. The datacenter traffic patterns of inter- and intra-datacenter optical interconnection present different characteristics depending on the various scenarios. The datacenter traffic in inter-datacenter optical network has shown the high-bandwidth characteristic [2,3], since the traffic is converged into the core optical switch from thousands of datacenter servers. The fluctuation between the peak and valley traffic may be negligible over a relatively short period of time. Different from inter-datacenter network, the traffic in intra-datacenter optical network presents the characteristics of high burstiness. A mount of information interaction (e.g., virtual machine migration and service backup) among datacenter servers can be implemented in intra-datacenter optical interconnection scenario, while the huge traffic variation may lead to the waste of spectral and application resource [4]. Therefore, compared with inter-datacenter networks, optical interconnection in intra-datacenter networks is a more pressing need and promising scenario to accommodate these applications in a dynamic, flexible and efficient manner.

Additionally, various datacenter applications (e.g., service migration and backup) require higher availability and lower delay with corresponding level end-to-end guaranteed quality of service (QoS). So far, many studies have been focused on the datacenter interconnection architecture and equipment [5–7]. For example in work [5], a novel network on-and-off chip approach for highly efficient and transparent intra-datacenter communications is proposed to achieve the hitless adaptation between Ethernet and time shared optical network (TSON). The authors in reference [6] study arrayed waveguide grating router (AWGR)-based interconnect architecture with a distributed all-optical control plane, which can guarantee low latency and high-throughput at high traffic load when the packet transmission time is sufficiently low compared to the token requests propagation time. Ref. [7] proposes an efficient

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scheme to all-optically inter-networking the pods of a datacenter, which offloads heavy inter-pod traffic onto an optical multi-ring burst network. However, from the service's point of view, few of researches pay attention to the time feature of application to guarantee the services delivery with various QoS in intra-datacenter networks. On the other hand, aimed at guaranteed quality of service, some works have researched the resource accommodation using the time-aware algorithms in optical system [8–11]. In Ref. [8], Xia et al. consider time-differentiated resilience requirements for resilience in a novel service level agreement (SLA) framework, which can allow customers to specify critical windows (CWs) using pre-cross-connected protection. In Ref. [9], Muhammad et al. study a dynamic WDM network with nonideal components in the physical layer which use an impairment aware routing and wavelength (RWA) algorithm for connection provisioning. The authors also investigate how set-up delay tolerance combined with holding-time awareness can improve blocking probability performance caused by physical impairment. In Ref. [10], Morea et al. introduce a novel traffic-aware scheme to measure the energy savings in the optical networks. They also consider the maximum power required to transport the peak traffic and the average power required by the network to transport the traffic during a defined time-frame. In Ref. [11], Zhu et al. develop an availability-aware joint task scheduling (AAJTS) scheme, by both taking into account availability improvement and timing requirements. The AAJTS scheme iteratively enhances the application availability under deadline constraint to protect data communication tasks from network link failures. The above works research the connection provisioning, service resilience and the energy saving measure considering the time awareness in optical system in terms of holding-time and delay. However, they focus on the service requirement with the fixed spectral bandwidth and fixed service time in the current optical networks. The traditional time awareness schemes hardly perform the resources accommodation flexibly to enhance the resource utilization and quality of user's experience. Furthermore, how to realize the time awareness in the real environment with equipment, protocol and data center storage resource under intra-data center optical interconnection environment have not been mentioned in previous works.

Recently, as a centralized software control architecture, the software defined networking (SDN) enabled by OpenFlow protocol has gained popularity by supporting programmability of network functionalities and protocols [12–14]. OpenFlow-based control architectures can provide maximum flexibility for the operators and can help to build a unified control over various resources for joint optimization of services [15–17]. Therefore, nowadays operators are trying to apply SDN/OpenFlow technique to globally control network and application resources in intra-datacenter optical interconnection networks [18]. The SDN architecture with cross stratum optimization (CSO) between optical network and application stratum resources that allows to partially meet the QoS requirements focusing on inter-datacenter networks has been already discussed in our previous works [19–23]. In this paper, we propose a novel time-aware software defined networking (TaSDN) architecture in OpenFlow-based intra-datacenter optical interconnection for service migration. The traditional service scheduling strategies allocate the optimal application and network resources from datacenter server and corresponding lightpath at the arriving time. They may cause that the available network and datacenter resources are wasted, while the quality of use's service experience is hardly guaranteed in intra-datacenter optical interconnection. Different from the traditional schemes, a time-aware service scheduling (TaSS) strategy is introduced based on the proposed architecture, which considers the datacenter service scheduling with flexible service time and service bandwidth according to the various time sensitivity requirements. The TaSDN architecture with TaSS strategy can arrange and accommodate the applications with required QoS considering the time factor, and enhance the data center responsiveness to quickly provide for intra-datacenter service demands. The overall feasibility of the proposed architecture is experimentally verified on our testbed with real OpenFlow-enabled tunable optical modules. The performance of TaSS strategy under heavy traffic load scenario is also evaluated based on TaSDN architecture in terms of blocking probability and resource occupation rate.

The rest of this paper is organized as follows. In Section 2, we propose the novel TaSDN architecture and builds the functional model of the TaSDN. The time-aware service scheduling strategy under this architecture is introduced in Section 3. The interworking procedure for the TaSDN with TaSS strategy is described in Section 4. Finally, we describe the testbed and present the experimental results and analysis in Section 5, and conclude the paper in Section 6.

2. TaSDN architecture for OpenFlow-based intra-datacenter optical interconnection networks

In this section, we focus on the TaSDN architecture for OpenFlow-based intra-datacenter optical interconnection networks. First, the main structure and motivation of the novel architecture are briefly outlined. Then the functional building blocks of TaSDN and the coupling relationship between them as well as the main related protocol extensions are presented in detail.

2.1. Network architecture

The TaSDN architecture for OpenFlow-based intra-datacenter optical interconnection is illustrated in Fig. 1(a). Three levels of optical switches, including top-of-rack (ToR), aggregation and core optical switches, are used to interconnect datacenter servers in one domain, which application stratum resources (e.g., CPU and storage) are deployed in. Each stratum resource is software defined with OpenFlow and controlled by the application controller (AC) and the network controller (NC) respectively in a unified manner. To control intra-datacenter networks for service migration with extended OpenFlow protocol (OFP), OpenFlow-enabled optical switches with the OFP agent software are required, which are referred to as OF-OS. The motivations for the TaSDN architecture in intra-datacenter networks are twofold. Firstly, the TaSDN can emphasize the cooperation between the AC and NC to schedule datacenter services based on different time sensitivity requirements reasonably and optimize application and network stratum resources utilization with the TaSS strategy. Secondly, based on the burstiness of intra-datacenter application, the TaSDN can implement quickly burst service provisioning through centralized TaSDN control and essential procedure.

2.2. Functional model of TaSDN

The functional building blocks of TaSDN and the coupling relationship among different modules are shown in Fig. 1(b) and (c). The basic responsibilities and interactions among these functional modules are described as follows. The responsibility for the AC is concerned with monitoring and maintaining application stratum resources in datacenter servers for the TaSDN, while the NC sustains optical network stratum information abstracted from physical network and lightpath provisioning in intra-datacenter optical networks. The application controller controls the datacenter servers and allocates the application resource in servers through the VMware software, which can gather the CPU and storage resources, and configure and schedule the virtual machines via