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Resource management and control in converged optical data center networks: Survey and enabling technologies

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ABSTRACT

In addition to the optical interconnection among servers for the Intra Data Center (IDC), the optical interconnection of geographically distributed data centers also becomes increasingly important since data centers are geographically distributed so that one data center maybe far away from another. So the converged Optical and Data Center Network (ODCN) emerges as the times require. In the ODCN, each optically interconnected IDC locates at the edge of the optical backbone. In this article, we first make an extensive survey on the resource management and control in the ODCN, and we find that: (1) for this new network paradigm, the intelligent coexistence of heterogeneous technologies should be considered because the ODCN will be required to satisfy diverse and highly dynamic network services; (2) the integrated virtualization of backbone bandwidth and computing resources should be performed for the resource management in ODCNs, with the objective to improve the underlying infrastructure utilization; (3) after performing the integrated virtualization, a set of virtual networks are generated, and each of them has virtual lightpaths and virtual machines. But a static virtual network merely satisfies a certain range of Service Level Agreements (SLAs), and it merely adapts to a particular network status. When the SLA significantly varies or the Quality of Transmission (QoT) gets worse, it is necessary to trigger the dynamic planning for the virtual network reconfiguration; (4) to decrease the control overhead and the delay of making decisions for the dynamic planning, it is practical to embed a highly effective network control plane into intelligent ODCN. Consequently, we make a blueprint where we execute the intelligent coexistence, integrated virtualization and dynamic planning for the resource management in ODCNs. Some preliminary works and simulation results will guide the future work.

1. Introduction

In recent years, the developing cloud computing has gradually replaced the traditional office computing [1]. For service providers, cloud computing provides the opportunity of achieving enormous profits. For users, it makes service access convenient and quick. To support this application, the server virtualization has been applied to data centers, i.e., Cloud Data Centers (CDCs) such as Amazon EC2 [2], Microsoft Azure [3] and Infrastructure-as-a-Service (IaaS) [4]. In the CDC, by decoupling services from underlying servers, the utilization of computing resources is improved in a sharing manner, and the operational cost reduces.

Since the optical transmission has unique advantages (e.g., low energy, huge capacity and high reliability, etc.),

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some academic and industrial communities embedded the optical interconnection into the CDC [5,6]. But in fact, one data center maybe far away from another, the optical interconnection of geographically distributed data centers becomes also important. The converged Optical and Data Center Network (ODCN) thus emerges as a large-scale networking paradigm, where each optically interconnected CDC locates at the edge of the optical backbone.

Once CDCs are involved in the ODCN, the "pay-as-you-go" transaction model makes network services diverse and dynamic. But the existing Wavelength-Division-Multiplexing (WDM) optical transmission is simplistic, and it has a poor adaptation to satisfying high-level services. One promising solution is the intelligent coexistence of heterogeneous optical transmission technologies and elements, during the phase of network deployment. So, the ODCN should allow a diversity of new voices to bloom, such as elastic optical networking [7–16], OFDM (Orthogonal Frequency Division Multiplexing)-based CDC interconnection [17], and Cognitive Heterogeneous Reconfigurable Optical Networking (CHRON) [18–24], etc.

Additionally, similar to the CDC, it is very necessary to perform the integrated virtualization of backbone bandwidth and computing resources for the resource management in ODCNs. In fact, as one of forerunners focusing on the software-defined network, the global desktop virtualization vendor Nicira has the following statement in its white paper: the virtualization of the data center is only the tip of the iceberg [25]. In order to satisfy flexible and programmable requirements of the ODCN, the integrated virtualization has been imminent. The virtualization of wired networks has been reported, and Huawei enterprise put this topic into strategic goals. We can infer that with the unique advantages of optical interconnection, the integrated virtualization will become technically sound and industrially practical in the ODCN. Someone calls this integrated virtualization as link- and node-level mappings, i.e., virtual lightpath vs. physical links and virtual machine vs. physical server. Here, a virtual lightpath is a bridge between the user and the destination data center or a bridge of two different data centers, and a virtual machine is the software implementation of a machine (e.g., a computer) that executes programs like a physical machine. In addition, someone calls this collaborate mapping process as the virtual network embedding, because a group of virtual lightpaths and virtual machines comprise an entire virtual network.

But in fact, a static virtual network merely satisfies a certain range of Service Level Agreements (SLAs) or it merely adapts to a particular network status. When the SLA significantly varies or the Quality of Transmission (QoT) gets worse in the ODCN, to ensure the service quality and continuity, it is necessary to reconfigure virtual networks, i.e., performing the dynamic planning. Now, we have a new problem: what factors will trigger this dynamic planning? Apart from the degradation of SLA and QoT, there are the following triggering factors. Firstly, the energy consumption of cooling devices rises dramatically in the CDC, which makes the energy efficiency become an important factor of triggering the dynamic planning. Secondly, the failure of the fiber link will result in the huge data loss. Thus, we should improve the resilience of the optical backbone in the ODCN. Meanwhile, being faced with the hostile attack among virtual machines within the same server, we should not ignore the ODCN security because some private or confidential information maybe leaked. In a word, the ODCN resilience and security is also the triggering factor. Last but not least, with the frequent arrival and departure of requests, the ODCN will generate the fragments of backbone bandwidth and computing resources. This also motivates us to re-manage resources using the dynamic planning.

We can see that the above dynamic planning is a reactive process where we execute a series of emergency measures only after the triggering factor occurs. To decrease the control overhead and the delay of making decision for the dynamic planning, it is practical to embed a highly effective control plane into the intelligent ODCN. This control plane self-analyzes the SLA information and self-probes the underlying network status. According to the detected information, this control plane makes decision by itself (i.e., cognition) and sends the corresponding action to the underlying components via the extensional protocol such as OpenFlow [26]. More importantly, the self-learning is also utilized to perform the data mining of historical experiments, so that the proactive dynamic planning can be performed before the triggering factor occurs.

Undoubtedly, the intelligent coexistence, integrated virtualization, dynamic resource management, and proactive resource control become essential parts in the ODCN. The rest of this article is organized as follows. Section 2 makes an extensive survey on previous resource management and control in the ODCN, and Section 3 provides some enabling technologies for the future resource management and control in the ODCN, from the perspectives of data plane, control plane and enhanced database. Finally, we conclude our work in Section 4.

2. Survey and future challenges

In this section, we first make an extensive survey on the resource management and control in ODCNs before presenting the future challenges.

2.1. Survey on existing works

There have been existing solutions focusing on the convergence of optical and data centers, integrated virtualization, dynamic resource management (dynamic planning), as well as resource control. Though these works have their advantages, but they cannot well satisfy the requirements of the ODCN or they cannot be directly applied to the ODCN. Fortunately, some outstanding techniques are worth learning and they can be modified to make the improvements for ODCNs.

- Optical interconnection for intra data center
  In order to handle huge amounts of data, multiple servers are interconnected by high-bandwidth switches to form a CDC. Since the electronic device has the enormous cost of the power consumption, the optical interconnection of servers begins to receive extensive attentions. So, a set of architectures were proposed, for example, c-Through [27], Helios [28], DOS [29], Proteus [30] and petabit [31], etc. However, these architectures have the same problem,