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Fragmentation assessment based on-line routing and spectrum allocation for intra-data-center networks with centralized control

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ABSTRACT

As is well known, elastic optical network is quite attractive due to its great spectral efficiency and flexibility, which can allocate appropriate size spectrum based on efficient modulation modes such as Orthogonal Frequency Division Multiplexing (OFDM) modulation, etc. These characters are able to better meet the needs of the intra-data-center optical interconnection. To properly analyze and operate elastic optical networks with highly dynamic traffic of the intra-data-center, considering the continuity constraint and the contiguity constraint, efficient methods are required for the on-line routing and spectrum allocation (RSA) issue. In this paper, we propose two methods (AFD and CSL) for assessing the status (spectrum fragmentation) of the network, and present two algorithms (BSPR and HSR) which use the proposed assessment value to perform on-line RSA applied to intra-data-center networks which adopt the Software-Defined Network (SDN) control mode. Simulation results reveal that the proposed approaches allow solving the on-line RSA problem more efficiently with lower blocking probability of the networks.

1. Introduction

In the past few years, cloud adoption is not only an emerging technology, but also an established networking solution which is widely accepted and deployed by the telecom industry. According to statistics, the traffic volumes generated in total are large–over 10 GB per server per day in an intra-data-center network (intra-DCN) [1]. The Cisco global cloud index forecasts that global data center IP traffic will reach 644 exabytes per month in 2017 (nearly triple of the traffic in 2012) [2]. The quality of service (QoS) provisioning is the users' major concern, which depends on the communication efficiency between servers. All-optical switching technique can just cater to the intra-DCN's high efficient transport requirement. Compared with the rigid spectrum grid networks realized with the traditional WDM technology, spectrum-efficient and scalable optical transport network architecture called SLICE which is based on optical orthogonal frequency division multiplexing (O-OFDM) technology is better spectrum efficiency and flexibility [3,4].

In elastic optical networks, the available spectrum of a fiber link is divided into a set of spectral slots with substantially smaller spectral width (spectral slots widths are 6.25, 12.5 and 25 GHz) than a traditional wavelength (50 GHz ITU-T WDM grid). Instead of occupying a whole wavelength, connections are placed on series of contiguous subcarriers

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according to the bandwidth demand. Moreover, ultra high bit-rate super channels at 400 Gb/s sand 1 Tb/s will be allowed in future elastic optical networks.

Flexible and efficient features of elastic optical network (EON) are double-edged swords. EON face some important challenges, although they have a great advantage than traditional WDM networks. Due to the character of O-OFDM technology and the absence of spectrum converters, the allocated slots must be contiguous in the spectrum (contiguity constraint), and the same slots must be used in all links of the routing path (continuity constraint) [5]. These two constraints let EON a main challenge being the so-called spectrum fragmentation effect, which refers to the condition that, as the highly dynamic set up and remove traffic over a intra-DCN, the available spectral resources become highly fragmented, potentially leading to blocking situations.

At present, spectrum fragmentation has attracted a lot of attention in DCN. Some novel spectrum defragmentation algorithm has been proposed [6–8]. Generally, the defragmentation is accompanied by mass of light path or spectrum migrations, which is not a kind of suitable solution in highly dynamic intra-DCN. Therefore, how to reduce the extent of fragmentation at first as much as possible and choose a better way to set up a connection when the network has already been fragmental, which can be summarized as efficient on-line routing and spectrum allocation (RSA) problem is urgently needed to be solved in the intra-DCNs.

In [9], the authors proposed two RSA methods for super-channels accounting for sub-carriers dynamism, which are similar to the first-fit and best-fit used in the WDM networks. The authors of [10] introduce a service-oriented spectrum assignment framework and two algorithms to solve the RSA problem. In [10], spectrum is divided into some blocks for different set of services according to the chosen properties, and RSA are done in every block just as [9]. Both of them did the RSA one step by step without some criterion but just satisfy the bandwidth demand, while we may need to consider the routing and spectrum allocation together which way will make RSA more optimal. Therefore, we need an assessment value to evaluate the status (spectrum fragmentation) of the network, which can be used to choose different routing and spectrum allocation together. Also in very recently, the papers [11,12] focus on the static RSA problem, and Integer Linear Programming (ILP) formulations are presented to minimize the utilized spectrum.

The authors of [13] introduced a concept called 'Utilization Entropy (UE)' to assess the degree of spectrum fragmentation in flexible grid optical networks. The authors of [14] presented the 'Spectrum Compactness (SC)', which is calculated by analyzing the times of changing among the occupied and vacant spectrum blocks on a link. In [15], the authors proposed an assessment method based the fragmentation of a set of paths between every pair of nodes in the graph. However, some influence factors were less considered in design of the assessment methods in above work, such as the spectrum usage, the spectrum continuity constraint and the non-uniform sample of links. In this paper, we present two fragmentation assessment schemes of the whole network, which can be more effective and accurate to reflect the status of the network, and then use them on the on-line routing and spectrum allocation.

From the perspective of intra-DCN control, the authors of [16] describes the implemented control-plane which is consist of GMPLS (Generalized Multi-Protocol Label Switching), PCE (Path Computation Engine) and a resource allocation tool called Sub-wavelength Assignment Engine (SLAE) for the Time-Shared Optical Network (TSON). In [17], the authors demonstrate the star all-optical intra-DCN using extended OpenFlow-based software-defined networking. Recently, in [18], a network-driven transfer mode is proposed for cloud operations of data center with a Software-Defined Network (SDN) controller and an Application-Based Network Operations (ABNO) controller working together. A GMPLS-enabled FBON is discussed in [19], especially its distributed reservation approach. And for the first time, the authors investigate the backward reservation collision problem in an FBON, which would dominate the blocking performance in networks with light load or serving highly dynamic traffic. In highly dynamic intra-DCN, centralized control mode can effectively reduce the failure of the request which is because of the conflict of resource access with distributed control mode, and it will monitor resource of the whole network more efficiently which is more conductive to the inter-DCN connection. In [20] and [21], the authors respectively proposed routing algorithm and protection algorithm for multi-layer and multi-domain optical networks, which are playing guiding roles for the research of the connection control among the data centers. In fact, the survivability in optical network should also be considered [22], which is one of our future research points. We provide a feasible all-optical intra-DCN architecture based on SDN control (centralized control). The architecture of the intra-DCN is based on the previous EON based on O-OFDM. First, we need to extend the messages between the controller and the racks. Then, an OF agent is integrated on every rack, which can translate the messages which are from SDN controller into control orders for the O-OFDM ToR. The architecture and the SDN control model are illustrated in Fig. 1.

The rest of the paper is organized as follows. In Section 2, two fragmentation assessment schemes are proposed. In Section 3, two on-line RSA algorithms based on the fragmentation assessment in detail are presented. In Section 4, the performance of considered on-line RSA formulations are compared, and then the performance of our formulation over two realistic network topologies are introduced. Section 5 concludes the paper.

2. Proposed spectrum fragmentation assessment schemes

In the last section, we mentioned the continuity constraint and the contiguity constraint in elastic optical networks. If the spectrum is not continuous among connected links in a precomputed path, it cannot be used for the path. On the other hand, if the available slots are just enough for bandwidth demand but discrete, they also may not be provided for set up traffic. Therefore, the status of