Optical Fiber Technology 32 (2016) 13–22

Contents lists available at ScienceDirect

Optical Fiber Technology

www.elsevier.com/locate/yofte

Regular Articles

Dynamic time and spectrum fragmentation-aware service provisioning in elastic optical networks with multi-path routing

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ARTICLE INFO

Article history:
Received 17 May 2016
Revised 25 July 2016
Accepted 28 August 2016

Keywords:
Fragmentation-aware
Multi-path
Elastic optical networks
Advance reservation

ABSTRACT

In this paper, we propose a multi-path fragmentation-aware routing, modulation and spectrum assignment algorithm (RMSA) for advance reservation (AR) and immediate reservation (IR) requests in elastic optical networks. Immediate reservation requests should be provided with service immediately, while advance reservation requests have specific starting times and holding times. As lightpaths are set up and torn down, fragmentation may occur in both spectrum and time domains. To decrease the two-dimensional fragmentation and to solve the problem of resource scarcity, we propose splitting requests into different parts and transferring these parts along one or more paths utilizing sliceable bandwidth variable transponders. We first introduce a model to solve the problem and propose a two-dimensional fragmentation occurrence measurement in spectrum and time domains. Then we propose a multi-path fragmentation-aware RMSA algorithm (MPFA). Simulation results show that MPFA can achieve better performance than existing algorithms in terms of blocking probability and spectrum utilization.

1. Introduction

With the emergence of diverse new applications and services over optical networks, different levels of QoS must be offered to network customers. Real time applications, such as IPTV and e-Science applications, need to be provided with service immediately, and the service will be torn down upon completion. These types of requests are called immediate reservation (IR) requests. On the other hand, time-sensitive applications have specific starting times and holding times, such as data backup or data migration. Network operators can reserve resources for these applications in advance, and the resources will not be used until the starting time. These types of requests are called advance reservation (AR) requests [1].

As these applications have a variety of requirements, it becomes difficult to satisfy all of these applications in a flexible manner with traditional wavelength-division multiplexing (WDM) optical networks. Enabled by orthogonal frequency division modulation (OFDM) technology and sliceable bandwidth-variable transponder, elastic optical networks (EONs) can be a promising candidate for these diverse requirements [2]. In EONs, the optical spectrum is partitioned into finer granularity, such as 6.25 GHz or 12.5 GHz spectrum slots. In this way, requests with different rates can be adaptively converted into a variable number of frequency slots (FSs) considering the path distance and modulation formats [3]. Further flexibility is achieved in EONs by the assignment of multi-flow transponders (MF-OTP) [4] or sliceable bandwidth variable transponders (S-BVTs) [5–6]. S-BVTs support sliceability, i.e., the capability of generating multiple optical carriers that can be used to support different lightpaths to different destinations. Fig. 1 shows the architecture of a S-BVT connected with bandwidth-variable optical cross-connects (BV-OXC). The architecture of the S-BVT adopted here is formed by a flow classifier, OTN mappers, a set of sub-transponders, and an optical MUX. In the sender part, five sub-carriers are used. These sub-carriers can support three line rates, i.e., 40 Gbps, 100 Gbps, and 400 Gbps separately. It is worth noting that request A is served with three spectrum bands, A1, A2, and A3, which can transport 40 Gbps, 100 Gbps, and 100 Gbps, respectively. A1 is allocated on Path 1, but there are insufficient spectrum resources for A2 and A3. Thus A2 and A3 are allocated on Path 2. With S-BVTs, the request can be provided with service in a multi-path way.

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http://dx.doi.org/10.1016/j.yofte.2016.08.009
1068-5200/

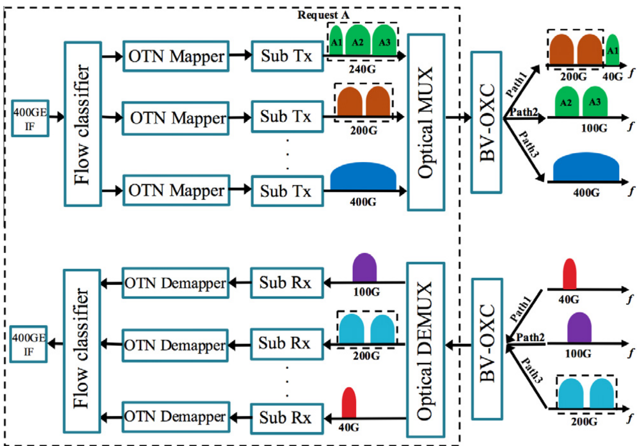

Fig. 1. Sliceable bandwidth variable transponder (S-BVT).

Due to the huge increase in applications, AR services are expected to be an important growing part of future networks. As these services are dynamic and lightpaths are set up and torn down, it is common for spectrum and time fragmentations to occur. As this two-dimensional fragmentation can waste many resources and decrease the network performance, it becomes extremely important for the network operator to decrease this two-dimensional fragmentation during service provisioning. Previous algorithms [7,8] can decrease fragmentation, but they focused on a single path, and if the requests cannot be provisioned on a single path, they will be blocked. One reason for blocked requests is that there are insufficient resources on a single path, therefore, a multi-path method may help to solve this problem and decrease the two-dimensional fragmentation.

In this paper, to decrease the two-dimensional fragmentation and solve the problem of resources scarcity, we propose splitting AR and IR requests into smaller parts, assigning the parts to different segments, and then transferring these parts along a single path or multiple paths. We also propose a fragmentation occurrence measurement to accurately evaluate if fragmentation will occur when we assign the requests to the available resources. In this way, the spectrum and time fragmentation can be decreased, and the resource utilization will increase. It is worth noting that the differential delay between the routing paths can be addressed with additional electronic buffering in the higher layer of the destination node [9].

The rest of the paper is organized as follows. In Section 2, we review the related works. In Section 3, we describe the problem formulation and fragmentation occurrence measurement in detail. We design a multi-path fragmentation-aware RMSA algorithm (MPFA) in Section 4. The performance evaluation is presented in Section 5. Finally, Section 6 summarizes the paper.

2. Related works

Researchers have previously studied various aspects of advanced reservation request provisioning over optical networks. Provisioning deadline-specific AR requests with flexible transmission rates in WDM mesh networks was proposed in [10]. Lu et al. investigated hybrid IR and AR service provisioning in elastic optical networks, with the objective to minimize IR/AR service conflicts [11]. A traffic grooming algorithm for the connection establishment of deadline-specific AR requests in elastic optical networks was studied in [12]. An OpenFlow-controlled revenue-driven advance reservation (AR) provisioning in software-defined elastic optical networks (SD-EONs) has been proposed in [13]. The experimental results showed that their proposed system performs well and can increase total revenue-gain effectively. In [14], Li et al. studied the provisioning schemes for dynamic advance reservation multicast requests in EONs and demonstrated these schemes on a Software-defined EON testbed that utilized OpenFlow in the control plane.

During the provisioning process for AR requests, as lightpaths are set up and torn down, fragmentations may occur in both the spectrum and time domains. To decrease this two-dimensional fragmentation, Wang et al. proposed a max volume selectivity algorithm to decrease the blocking probability for advance reservation requests in [7]. Lu et al. studied an adjustable routing and spectrum assignment (RSA) algorithm for bulk-data transfer to recycle spectrum fragments in EONs [8]. To further decrease the two-dimensional fragmentation, we propose a multi-path scheme.

Previously, multi-path solutions have been proposed to solve problems related to the scarcity of resources and survivability in EONs [15–21]. The split spectrum approach [15], a fundamental technology for multi-path was first proposed by Dahlfort et al. and simulation results showed that split spectrum can decrease the blocking probability by over 50% and can achieve 50% higher spectral efficiency compared to non-split elastic optical networking [16]. Chen et al. designed a multipath defragmentation method which aggregated spectrum fragmentation without interrupting existing services [17]. In [18], Zhu et al. proposed several online service provisioning algorithms that incorporate dynamic RMSA with a hybrid single-/multi-path routing (HSMR) scheme. Results showed that they could decrease the network bandwidth fragmentation ratio. Yang et al. proposed multi-flow virtual concatenation (MFVC) in elastic optical networks to improve spectrum utilization using noncontiguous spectrum fragments [19]. To solve the problem of multipath routing under heavy traffic load, Fan et al. designed a dynamic multipath routing algorithm with traffic grooming [20]. In [21], Dharmaweera et al. investigated the potential gains by jointly employing traffic grooming and multipath routing techniques with a realistic physical impairment model. In [22], a multi-path provisioning protection (MPP) scheme was proposed to guarantee survivability in flexible optical networks, and it was shown to provide protection with better efficiency than single-path provisioning protection (SPP). Yin et al. presented a survivable multi-path routing and resource assignment scheme to guarantee the survivability of virtual optical networks in [23].

In this paper, we study advance reservation requests provisioning in EONs with multi-path routing, in order to solve the problem of resources scarcity and to decrease the two-dimensional fragmentation.

3. Problem formulation

In this section, we first introduce a model to solve the problem, then we propose a fragmentation occurrence measurement considering both time and spectrum domains.

3.1. Problem description

The substrate elastic optical networks can be modeled as a graph $G_s = (L_s, N_s, R_{st}, D_s)$, where L_s represents the set of physical optical links, N_s is the set of physical optical nodes, and R_{st} is the state of the resources of the physical optical links and nodes at time t. In this paper, we assume that R_{st} includes the resources of physical fiber links, which is the status of the spectrum of the fiber links at time t, and the resources of physical nodes, which specifies the available number of sub-transponders at a node at time t. D_s is a set of physical distances between each pair of adjacent node in N_s. For example, $D_s(a, b)$ is the distance between node a and node