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Energy-efficient multicast traffic grooming strategy based on light-tree splitting for elastic optical networks

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ABSTRACT

In order to address the problem of optimizing the spectrum resources and power consumption in elastic optical networks (EONs), we investigate the potential gains by jointly employing the light-tree splitting and traffic grooming for multicast requests. An energy-efficient multicast traffic grooming strategy based on light-tree splitting (EED-MTGS-LS) is proposed in this paper. Firstly, we design a traffic pre-processing mechanism to decide the multicast requests' routing order, which considers the request's bandwidth requirement and physical hops synthetically. Then, by dividing a light-tree to some sub-light-trees and grooming the request to these sub-light-trees, the light-tree sharing ratios of multicast requests can be improved. What's more, a priority scheduling vector is constructed, which aims to improve the success rate of spectrum assignment for grooming requests. Finally, a grooming strategy is designed to optimize the total power consumption by reducing the use of transponders and IP routers during routing. Simulation results show that the proposed strategy can significantly improve the spectrum utilization and save the power consumption.

1. Introduction

The exponential growth of high-speed Internet traffic has brought a great challenge to optical networks. Meanwhile, the popularity of bandwidth-intensive applications such as video conferencing, interactive distance learning and IPTV is expected to be major drivers of Internet traffic growth. Multicast as a key technology to support these applications has attracted much attention [1].

To meet the ever-growing appetite for bandwidth, the optical network with spectrum-efficient and data-rate-flexible is needed for the future. Orthogonal frequency-division multiplexing (OFDM) is a multi-carrier transmission technology that transmits a high-speed data stream by splitting it into multiple parallel low-speed subcarriers [2]. Based on OFDM technology, elastic optical network (EON) architecture was proposed to meet the various kinds of spectrum granularity needs. By breaking the fixed-grid (50 GHz) spectrum allocation limit of conventional wavelength division multiplexing (WDM) networks [3], EONs have much finer spectrum slot (e.g., 12.5 GHz or 6.25 GHz) and can allocate just enough frequency slots (FSs) according to the rate of the request.

An EON mainly consists of bandwidth-variable transponder (BVT) and bandwidth-variable optical cross-connect (BV-OXC). A typical BVT (e.g., 40 Gb/s–400 Gb/s) can be used for all service types. However, the IP traffic demands are various. It is not cost-efficient to use a single type of BVT, especially for sub-wavelength services. In order to improve the utilization of high-capacity transponders, traffic grooming is applied [4]. Traffic grooming enabled by electrical switching fabric is called electrical grooming, which can improve spectrum efficiency and transponder usage. However, the condition of electrical grooming is strict, which requires the grooming requests should have the same source node and destination nodes. Otherwise, electrical grooming will lead to additional optical–electrical–optical (O/E/O) conversions at intermediate nodes [5]. Therefore, optical grooming was proposed, multiple sub-transponder channels can be groomed optically onto one transponder. The basic idea of optical grooming is to group several sub-wavelength optical channels into one BVT and switch them as a whole. Optical grooming just requires that the optical channels have the same source node and can be dropped or switched optically at any intermediate node without O/E/O conversions [6]. Both electrical grooming and optical grooming can save the guard bands by aggregating several channels.

In EONs, an important problem is the routing and spectrum assignment (RSA) problem. RSA is to find a path and allocate a

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set of contiguous subcarriers for a request while minimizing utilized spectrum [7,8]. However, a connection's requested bandwidth always much lower than the capacity of a transponder, and different lightpaths that go through one or more common fiber links must be separated by guard bands to avoid interference [9]. Hence, provisioning each connection by a separate lightpath leads to high spectrum wastage by guard bands and low utilization of high-capacity transponders. In [10], traffic grooming was first proposed to increase spectrum efficiency for elastic optical networks. However, the author didn't consider the spectrum continuity constraint and bandwidth variability of transponders. In [11], Zhang et al. proposed an integer linear programming (ILP) model and two heuristic algorithms to solve the RSA problem of optical grooming. The results showed that optical grooming achieved significant transponders savings and less spectrum usage compared to the non-grooming scenario. In [12], the author proposed a three-layered auxiliary graph model to address mixed-electrical-optical grooming under dynamic traffic scenario. Various traffic-grooming policies were achieved by adjusting the edge weight of auxiliary graph.

However, there are few studies research multicast traffic grooming in EONs. For multicast routing issue, a light-tree is usually established between the source node and destination nodes. Previous studies have investigated the multicast routing and wavelength assignment problem in WDM [13,14]. In [15], the multicast-capable RSA algorithms were designed to use the shortest path tree (SPT) and the minimal spanning tree (MST). However, the proposed SPT and MST algorithms did not consider adaptive modulation formats assignment. Hence, Krzysztof Walkowiak et al. proposed a heuristic algorithm based on distance-adaptive transmission to improve the spectrum utilization [16]. In [17], the integrated RSA for multicast with a layered approach (MC-RAS-LSPT) was proposed. According to the bandwidth requirement of a request, the MC-RAS-LSPT algorithm first found a proper layer that represents the network spectrum utilization, and then built a light-tree within the selected spectrum layer. MC-RAS-LSPT can realize integrated multicast RSA. However, the optimal modulation format could not be selected in this way. In [18], Yang et al. proposed a MC-RMSA Using Set-Cover (SC) algorithm that considered the physical impairments from both the transmission and light-splitting in EONs. Since a relatively large light-tree may use the lowest modulation format and consume too many FSs, the SC algorithm tried to sever a multicast request by dividing a light-tree into light-forest that consists of one or more light-trees. However, compared to the original light-tree, the SC algorithm would increase the number of transponders because different sub-light-trees may include the same source node or destination nodes.

In the last decade, the power consumption of data networks has become a critical issue and attracted much attention. In EONs, the power consumption of IP router ports, bandwidth variable transponders (BVTs) and erbium doped fiber amplifiers (EDFA) are considered as the main sources of power consumption [19]. In [20], the author investigated optical grooming scheme, which can save the number of transponders efficiently. In [21], an energy-efficient manycast routing and spectrum assignment (EEM-RSA) algorithm was proposed for EONs. The author proposed a power consumption model and designed a power consumption function (PCF) to describe the power consumption of corresponding links and nodes. The author of [22] proposed a novel distance-adaptive and fragmentation-aware optical traffic grooming algorithm, which achieves at least 14% spectrum savings and 13% transponder savings compared to the algorithms without traffic grooming. However, the solution did not consider the constraints of spectrum continuity and contiguity between the sub-optical paths, which degrades the performance of the algorithm. In [23], Lin et al. proposed an ILP formulation for light-tree and a sub-light-tree saturated grooming (SLTSG) algorithm for multicast traffic grooming in WDM. The resource utilization and power consumption were optimized jointly by grooming the sub-light-trees that have the same source node and destination nodes.

In this paper, we study how to optimize the spectrum resources and power consumption for all-optical multicast in EON. Specifically, we develop an energy-efficient distance-adaptive multicast traffic grooming strategy based on light-tree splitting (EED-MTGS-LS). The first phase of EED-MTGS-LS is to find the maximum grooming light-tree for a request. Then, the proposed EED-MTGS-LS algorithm tries to divide the existing light-tree into several sub-light-trees and uses the sub-light-trees to groom the new request. Therefore, resource utilization can be increased by sharing sub-light-trees. In the process of spectrum assignment (SA), the success rate of SA is improved for the grooming requests by constructing a priority scheduling vector. Moreover, a traffic preprocessing mechanism is designed to decide the multicast requests' routing order. Finally, in order to get the total power consumption of network, a power consumption model of light-tree is proposed according to the grooming strategy.

This paper is organized as follows. In Section 2, the problem descriptions of multicast traffic grooming strategy based on light-tree splitting in EONs are detailed. The EED-MTGS-LS algorithm is proposed in Section 3. The simulation results are presented with a discussion in Section 4. Finally, Section 5 summarizes the paper.

2. Problem description

The physical topology is described as $\boldsymbol{G(V, E, F)}$, where $\boldsymbol{V} = \{v_i \mid i = 1, 2, \ldots, n\}$ denotes the set of nodes and $\boldsymbol{E} = \{l_{ij} | i, j \in V\}$represents the set of fiber links. An ordered set $\boldsymbol{F} = \{f_1, f_2, f_3, \ldots, f_{|\boldsymbol{F}|}\}$denotes the number of FSs on each link. A multicast request is denoted as MR_i $\{s_i, \boldsymbol{D_i}, n_i\}$, where s_i is the source node for request i, $\boldsymbol{D_i}$ is the set of destination nodes for request i and n_i is the required number of contiguous FSs.

2.1. Light-tree grooming problem description

For a light-tree, the modulation format is decided by the quality-of-transmission (QoT), which depends on both the transmission distance of the longest branch. We obtain the number of contiguous slots n_i to be assigned on the multicast path as follows:

$$n_i = \left\lceil \frac{b_i}{(E \times M_i)} \right\rceil \tag{1}$$

where E is the size of a frequency slot, M_i is the highest modulation format that can be supported by MR_i. we derive M_i based on the longest transmission path in the light-tree. Therefore, a relatively large light-tree has to use the lowest modulation format and consumes too many FSs. Moreover, under spectrum continuity and contiguity constraints, a light-tree has to occupy the same range of FSs for all the fiber links that it traverses. So, it is wise to use several light-trees to serve one multicast request.

However, when a light-tree is split, it needs both extra guard bands and BVTs. Especially, under heavy network loads, spectrum resources are scarce and fragmented. To overcome this limitation, traffic grooming is used in conjunction with light-tree splitting.

The key issue of the light-tree grooming strategy is how to find the grooming light-tree r in the set of existing light-trees for a multicast request. In order to save more FSs and transponders, the grooming light-tree r should meet two conditions: the same source node as the new request and having the maximum subset of destinations of the new request. If the source node is different,