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Regular Articles

Traffic load-aware dynamic energy-efficient routing strategy with spectrum reservation and load balance in elastic optical networks

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ABSTRACT

For reducing the energy consumption in elastic optical networks (EONs) and mitigating the increasement of bandwidth blocking probability (BBP), a spectrum reservation and load balancing routing strategy (SRLBRS) is proposed. In SRLBRS, a spectrum state formula of node is designed to report the link spectrum usage of node-related links on the shortest path of traffic. Then, the node spectrum state can be determined by comparing the spectrum status of node-related links on the shortest path and average spectrum status in the EON. At the same time, the load state of candidate lightpath is decided by node spectrum state and available frequency slots of candidate lightpath. Available spectrum aware reservation grooming algorithm (ASARG) and load balancing routing algorithm (LBRA) are proposed and performed independently based on load state of candidate path. The ASARG focuses on energy saving by reserving lightpath dynamically according to available frequency slots of lightpath. While LBRA focuses on BBP by designing a lightpath cost formula, which is with respect to hops and spectrum continuity. Moreover, a balance index is designed to evaluate the balance between energy efficiency and blocking performance. Compared with the green grooming algorithms of distance-adaptive spectrum resource allocation (GGA + DASRA), simulation results show that the proposed SRLBRS can balance the energy consumption and blocking probability significantly. For instance in terms of balance index, our proposal achieved 57.9% better results averagely in a NSFNET topology.

1. Introduction

The rapid development of high-bandwidth services such as high definition television (HDTV), video conference, Internet of things and cloud computing, result in the increasing requirements for bandwidth resources in core optical networks [1]. The traditional wavelength division multiplexing (WDM) network is limited due to the fixed and coarse granularity wavelength grid, which causes the waste of bandwidth resources [2]. This issue requires scalable optical network infrastructure and efforts to increase the transport capacity, to improve its efficiency utilization, and to allow traffic with different granularities and flexible bit rates. Elastic optical networks (EONs) based on orthogonal frequency division multiplexing (OFDM) are proposed as a promising technique to mitigate the WDM's shortcomings [3,4]. EONs can achieve high spectrum efficiency by slicing the spectrum into finer granularity and partially overlapping the sub-carriers. Specifically, the bandwidth variable transponders (BVTs) adaptively choose the modulation level and the number of sub-carriers in EONs. So that, a lightpath which having an appropriate bandwidth can be established to transmit a traffic.

1.1. Basic concepts of EONs

The architecture of EONs is shown in Fig. 1. A group of traffic flows are given to the IP routers in IP layer firstly, and then BVT is responsible for ensuring a flexible granularity in the spectral domain, allowing the adjustment of the optical devices according to the required traffic. The bandwidth-variable optical cross-connect (BV-OXC) is responsible for establishing a lightpath with the exact bandwidth to accommodate the necessary spectrum resources by applying the splitter and bandwidth-variable wavelength selective switches (BV-WSSs) in a flexible way. In this architecture, different traffic requests are marked in different colors. The spectrum of the incoming optical tunnel is broadcasted to all outgoing ports and filtered by different BV-WSSs to form desirable spectrums at each outgoing port. A lightpath is established from BVT at the source node to BVT at the destination node. Moreover, the optical signal crosses the BV-OXC at intermediate nodes and optical amplifiers (OA) are provisioned in the fiber links to compensate for link losses at

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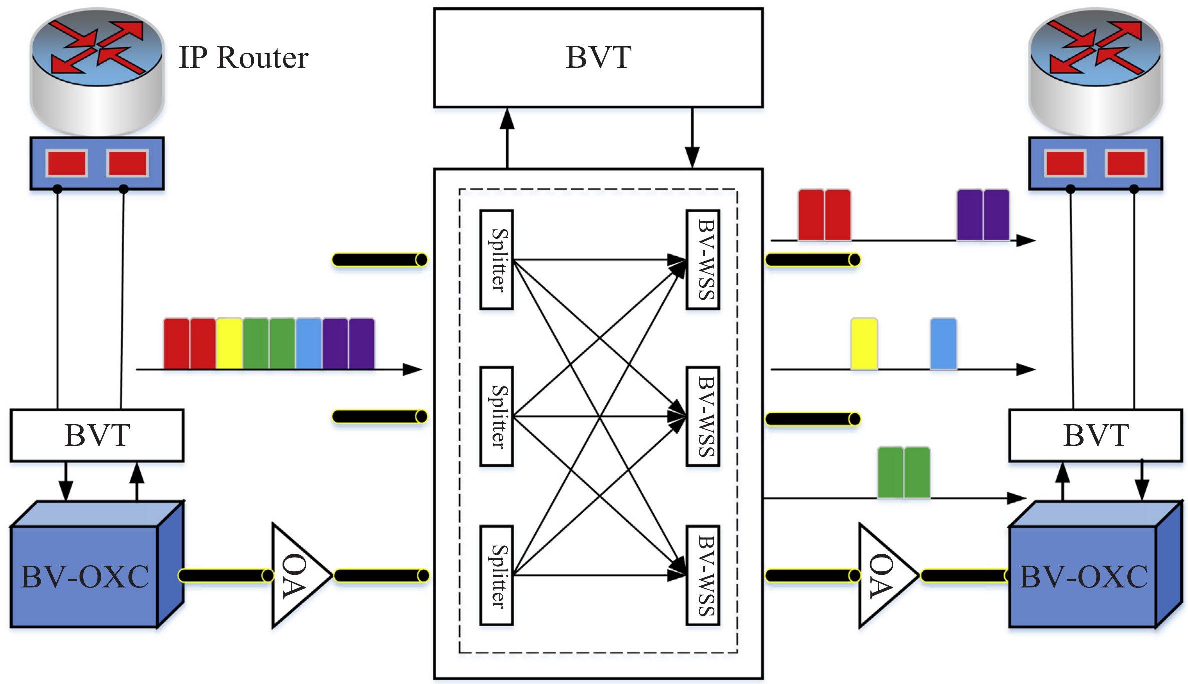

Fig. 1. Architecture of an elastic optical network.

120 km intervals [21].

One of the most important issues in EONs is routing and spectrum allocation (RSA) problem [5–7]. In EONs, the network spectrum is divided into a set of frequency slots (FSs). RSA algorithm tries to allocate FSs to each request efficiently, and then performance of networks can be improved. There are two important constraints in RSA related to the FS concept as the continuity and contiguity of spectrum resources [8–11]. Fig. 2 shows an example of RSA. In the example, three links with free frequency slots (in white) and used frequency slots (in red) are shown. When trying to establish a lightpath that requires three frequency slots in a route that passes through three links shown in Fig. 2(a). There must be the same three free slots simultaneously on all links. As shown in Fig. 2(a), there no availability of three free slots to meet the continuity constraint. In example of Fig. 2(b), a lightpath that needs two frequency slots can be established. BV-OXC and BVT are the key components needed for EONs. BVT with tunable central frequency can elastically accommodate diverse traffic connections by generating appropriate number of OFDM sub-carriers. Such flexibility allows the

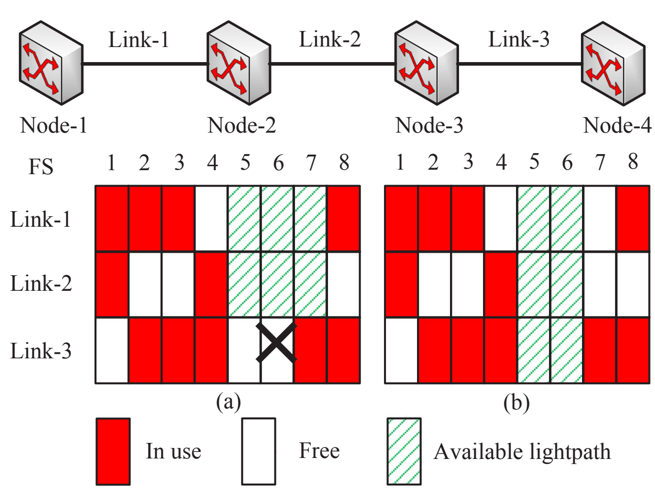

Fig. 2. Example illustrating the RSA problem.

operator who is optimizing network capacity to attain the most efficient use of the optical spectrum. BV-OXC, on the other hand, allows switching an optical signal based on the FSs rather than on a fixed wavelength. The node on the optical layer is configured with a BVT which is able to adjust the transmission ratio of each OFDM sub-carrier. So that an optical signal is generated by using just enough sub-carriers with an appropriate modulation level and an appropriately sized end-to-end optical path can be created [12].

1.2. Related work

Many studies related to RSA problem in EONs have been reported. A new distance-adaptive modulation multi-hop scheme (AMMS) based on a multi-hop constraint factor was proposed in [13], assuming that each node of the network was equipped with a BVT and BV-OXC. Compared with traditional RSA algorithms, AMMS algorithm could reduce bandwidth blocking probability (BBP) greatly by choosing the appropriate modulation level on multi-layer modulation auxiliary graph. However, the explosion growth of traffic in optical networks inevitably leads to the increase in energy consumption. Energy consumption is becoming one of the key design parameters for planning and operating communication networks [14].

To overcome the lack of energy efficiency, an Ant Colony Optimization Split Bypass heuristic (ACO-SB) that is proposed in [14] improves energy saving with minimal side-effect concerning the elongation of traversing paths. Authors in [15] proposed integer linear programming (ILP) model and heuristic algorithm. The algorithm reduces power consumption significantly by switching off some network elements. Whereas, optical networks carry a huge amount of information, so any interruption of the data flow would lead to massive data loss, and then cause network paralysis. Traffic grooming is an efficient method to improve spectrum efficiency and energy efficiency since fine-grained traffic can be aggregated into high-bandwidth lightpaths provisioned on optical networks. A novel optical traffic grooming approach with two sub-strategies least spectrum grooming (LSG) and Minimum Transmitter Grooming (MTG) was proposed firstly in elastic optical network [16], which supports grouping of multiple sub-wavelength services into a single BV-transmitter, and routing these services