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A spectrum allocation scheme based on first–last-exact fit policy for elastic optical networks

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ABSTRACT

In elastic optical networks, bandwidth fragmentation refers to the existence of non-aligned and non-contiguous available subcarrier slots in the set of all subcarrier slots. Since spectrum for a connection must be allocated on contiguous subcarrier slots and aligned along the routing path in the absence of wavelength converter, non-aligned and non-contiguous available subcarrier slots could cause blocking. This paper proposes a spectrum allocation scheme based on first–last-exact fit allocation policy for elastic optical networks in order to increase the number of aligned available slots and avoid small contiguous available slots. The proposed scheme separates the allocation of disjoint and non-disjoint connections. Connections with disjoint paths are allocated using the first-exact fit allocation policy, whereas connections with non-disjoint paths are allocated using the last-exact fit allocation policy. The separation of the disjoint and non-disjoint connections provides a higher number of aligned available slots. The exact fit policy provides a higher number of contiguous available slots. The contiguous aligned available slots reduce the bandwidth fragmentation, and hence the blocking probability is suppressed. Simulation results show that the proposed scheme outperforms the conventional scheme in terms of blocking probability.

1. Introduction

The rapid growth in world-wide communications has significantly modified the ways of life. This revolution has led to vast growth of communication bandwidth demand. Optical network based on wavelength division multiplexing (WDM) has been considered inefficient to overcome the exponential growth of bandwidth demand in telecommunication networks. Elastic optical networks with optical-orthogonal frequency division multiplexing (OFDM) have been researched for its efficient bandwidth utilization (Jinno et al., 2009). OFDM technology (Armstrong, 2009) uses overlapped subcarrier slots in the optical spectrum, which results in high bandwidth efficiency. The OFDM transponder (Zhang et al., 2013a) allocates an appropriate number of contiguous subcarrier slots, based on the required bandwidth demand of an optical connection request. In this way, flexible granularity can be achieved in the optical layer that enables elastic optical networks.

Elastic optical networks allocate spectrum on contiguous subcarrier slots. The size of contiguous subcarrier slots is elastic, which can be a few GHz or even narrower. These allocated spectrum slots should be placed near to each other to satisfy the spectrum contiguity constraint. Moreover, given a lack of wavelength conversion capabilities in the network, the allocated spectrum portion must align between the endpoints of the incoming connection requests due to the spectrum continuity constraint. Both spectrum contiguity and continuity constraints (Chatterjee et al., 2015) must be guaranteed by the routing and spectrum assignment in the elastic optical network. In elastic optical networks, dynamically setting up and tearing down connections generate bandwidth fragmentation problems (Christodoulopoulos et al., 2011; Khodashenas et al., 2014; Chatterjee and Oki, 2016). The bandwidth fragmentation problem occurs when available slots are isolated from each other as neither they are aligned along the routing path nor they are contiguous in the spectrum domain (Shi et al., 2013). Non-aligned available slots occur when one or more available slots of different links on the connection route are not the same, or aligned. Non-contiguous available slots occur when one or more available slots are not adjacent to each other. The non-aligned and non-contiguous available slots may be more difficult to be utilized for upcoming connection requests. When any available slot cannot fulfill the required bandwidth demand of a connection request, the connection request is rejected or blocked; this is called blocking. In this context, blocking probability is defined as a ratio of the number of blocked connection requests to the number of connection requests in the network.

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To overcome the bandwidth fragmentation problem in elastic optical networks, hitless defragmentation (Proietti et al., 2012; Aoki et al., 2012; Wang and Mukherjee, 2013; Zhang et al., 2013c) and hitfull/non-hitless defragmentation (Christodoulopoulos et al., 2011; Jinno et al., 2010; Wang et al., 2011; Sone et al., 2011; Zhang et al., 2014) approaches have been considered. Hitless defragmentation approaches have been presented as a defragmentation method that works continuously in elastic optical networks without service disruption. It advocates retuning the spectrum of the already established lightpaths after a connection is terminated to fill in the gap left behind. This process is executed without re-routing, and therefore it does not require any traffic interruption. On the contrary, the hitfull defragmentation scheme prevents spectrum fragmentation without retuning of the spectrum. Hitfull defragmentation scheme uses either proactive or reactive mechanism to handle the spectrum fragmentation issue. Proactive defragmentation approach is applied without waiting for a new request; it takes evasive actions to avoid the spectrum fragmentation. On the other hand, reactive defragmentation scheme is triggered at the arrival of a new connection request to avoid spectrum fragmentation.

The capital expenditure (CAPEX) and the operational expenditure (OPEX) using hitfull defragmentation approaches are less than that of using hitless defragmentation approaches. In a less CAPEX and OPEX network, hitfull defragmentation schemes are preferable compared to hitless defragmentation schemes. This paper only considers the hitfull defragmentation schemes; this paper does not consider hitless defragmentation approaches for handling bandwidth fragmentation issue. Note that, for the remaining of this paper, we refer to hitfull defragmentation method as the defragmentation scheme.

To suppress the bandwidth fragmentation, Kadohata et al. (2012) and Zhang et al. (2013b) developed bandwidth defragmentation schemes by considering the green field scenario, where connections are totally rerouted. Re-routing of connections causes the disruption and increases the system complexity. Therefore, a suitable spectrum allocation scheme is required in order to prevent the bandwidth fragmentation before its occurrence in the network. Taking this direction, Wang and Mukherjee (2012) presented a hitfull defragmentation scheme that prevents the bandwidth fragmentation without performing any rerouting of connections. Typically, when the connection requests with lower-bandwidth and higher-bandwidth are not separated during spectrum allocation, it may lead to a situation where the higher-bandwidth connection requests may be blocked. In order to overcome this drawback, they explored an admission control mechanism that captures the unique challenges posed by heterogeneous bandwidths. They adopted a preventive admission control based on spectrum partitioning to achieve higher provisioning efficiency. As a result, it prevents the blocking of connections due to the unfairness of bandwidth issues. However, this approach does not consider the effect of non-aligned and non-contiguous available slots, which may create bandwidth fragmentation.

To create more aligned available slots without rerouting, Fadini and Oki (2014) and Fadini et al. (2015) presented a partition scheme that suppresses the blocking by separating the disjoint and non-disjoint connections into different partitions. In this work, the entire spectrum is partitioned in an advance in order to handle spectrum resources efficiently. Partitioning the entire spectrum in an advance for dynamic traffic is not suitable as the connections that request a large number of slots may face difficulties to be accommodated over the small size partitions; these connection requests are dropped. As a result, the blocking performance may decrease significantly. On the other hand, the partition scheme has an another drawback in terms of blocking probability if the number of partitions is large; this is due to the lack of statistical multiplexing-gain (Lagrange and Jabbari, 1999).

Our objective in this paper is to suppress the blocking in the network without performing partitioning and rerouting of connections. The approach is to provide more contiguous aligned available slots by separating the disjoint and non-disjoint connections. This paper proposes a spectrum allocation scheme based on first–last-exact fit allocation policy for elastic optical networks. This scheme separates the disjoint and non-disjoint connections using the spectrum allocation policy. We introduce a first-exact fit allocation policy for disjoint connections and a last-exact fit allocation policy for non-disjoint connections.

The rest of the paper is organized as follows. The model and assumption are presented in Section 2. Section 3 provides the concept of the proposed scheme. In this section, we present the advantage and an overview of the proposed scheme. Section 4 describes how to create the disjoint connection group. Section 5 presents the spectrum allocation for connection requests. The performance of the proposed scheme is evaluated in Section 6. Finally, Section 7 concludes this paper.

2. Model and assumption

We model the optical network as a connected graph $G(N, L)$, where the set of nodes is denoted as N, and the set of bi-directional optical fiber links connecting two nodes in N is denoted as L. Each fiber link has an order set of slots $B = \{b_1, b_2, \ldots, b_{|B|}\}$. The following assumptions are considered in our model.

- Each fiber link can carry an equal number of subcarrier slots and the connections are established in the network under spectrum contiguity and continuity constraints. Note that the proposed scheme is applicable for the backbone optical networks that allow huge amount of data transmission. In backbone networks, the same link transmission capability for all the links is preferable in order to avoid the bottleneck of any link, as the well-known backbone networks, such as COST 239 network (Al Muktadir and Oki, 2015), NSF network (Chatterjee et al., 2012a), Germany 17 network (Al Muktadir and Oki, 2015), US IP backbone network (Al Muktadir and Oki, 2015), Japan Photonic network (JPN, 2016), Indian network (Chatterjee et al., 2012b), and European 28 network (Al Muktadir and Oki, 2015), are formed based on mesh-like topology. Therefore, each fiber link with an equal number of subcarrier slots is considered for backbone optical networks. In backbone networks, lightpaths are established under spectrum contiguity constraint as the network operators want to avoid using wavelength converters due to their additional deployment cost. If the lightpath establishment violates the spectrum contiguity constraint, the extra guard band is required, which reduces the efficiency of spectrum utilization.
- Two connections sharing at least one fiber link are allocated with different spectrums.

For the remainder of this paper, the notations used are summarized in Table 1.

3. Concept of proposed scheme

This section explains the concept of the proposed spectrum allocation scheme based on first–last-exact fit allocation policy. The proposed scheme is intended to increase the number of aligned available slots, which prevents the bandwidth fragmentation problem in the network. To achieve our goal, we separate