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A subcarrier-slot partition scheme with first-last fit spectrum allocation for elastic optical networks

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ABSTRACT

Bandwidth fragmentation refers to the existence of non-aligned and non-contiguous available subcarrier slots in elastic optical networks. Since spectrum for a connection must be allocated to contiguous slots and aligned along the routing path, non-contiguous and non-aligned available slots could cause call blocking. This paper proposes a subcarrier-slot partition scheme with first-last fit spectrum allocation for elastic optical networks in order to increase the number of contiguous aligned available slots, and hence the blocking probability in the network is suppressed. The partition approach creates more aligned available slots by separating the spectrum allocation of the non-disjoint connections. The first-last fit allocation policy creates more contiguous aligned available slots between two partitions. Simulation results show that the partition approach with first-last fit allocation policy provides lower blocking probability than that of the non-partition approach and the partition approach with other spectrum allocation policies. Furthermore, simulation results indicate that the blocking probability in the network using the proposed scheme improves as the number of partitions is reduced.

1. Introduction

The rapid growth in world-wide communications and proliferating use of Internet has significantly modified the ways of life. This revolution has led to vast growth of communication bandwidth. Recently, elastic optical networks [1–3] have been shown to be a promising candidate for future high-speed optical communication. An elastic optical network with optical-orthogonal frequency division multiplexing (OFDM) has the potential to allocate spectrum to lightpaths according to the bandwidth requirements of clients. OFDM technology [4] uses overlapped slots, which results in high bandwidth efficiency. The spectrum is divided into narrow slots and optical connections are allocated a different numbers of slots. As a result, network utilization efficiency is greatly improved compared to traditional dense wavelength division multiplexing (DWDM)-based optical networks.

Elastic optical networks with OFDM technology allocate spectrum for connections on contiguous slots. As the size of the contiguous slots is elastic, it can be a few GHz or even narrower. These allocated spectrum slots must 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 [3] must be guaranteed by the routing and spectrum assignment in the elastic optical network. In elastic optical networks, dynamically setting up and tearing down of connections create bandwidth fragmentation [5,6] problem. The bandwidth fragmentation problem occurs when the available slots are isolated from each other due to either they are non-aligned along the routing path or they are non-contiguous in the spectrum domain [7]. Non-aligned available slots occur when one or more available

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slots of different links on a connection route are not aligned. Non-contiguous available slots appear when one or more available slots of a link 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 the bandwidth demand of a connection request is not fulfilled, the connection request is rejected or blocked. The call blocking in the network is measured in terms of blocking probability, which is defined as a ratio of number of blocked connection requests to the number of connection requests in the network.

To overcome the bandwidth fragmentation problem, many routing and spectrum allocation approaches [1,5,8–11] have been presented. Taking this direction, Kadohata et al. [12] and Zhang et al. [13] developed bandwidth defragmentation schemes. However, they assume the green field scenario, where connections are totally rerouted, which increases the traffic delay and system complexity. Therefore, a suitable spectrum allocation scheme is required in order to prevent the bandwidth fragmentation before its occurrence in the network without rerouting of connections.

In this direction, Wang and Mukherjee [14] presented a 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 circumvent this drawback, they explore an admission control mechanism that captures the unique challenges posed by heterogeneous bandwidths. They adopt 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.

The objective of this paper is to prevent bandwidth fragmentation by reducing the number of non-aligned and non-contiguous available slots without rerouting of connections. To achieve the objective, we propose a subcarrier-slot partition scheme with first-last fit spectrum allocation for elastic optical networks. The partitioning approach separates the spectrum allocation of connections that use different routes and share a link. We define a connection group as a set of connections whose routes are exactly the same. We use the term of disjoint connections for connections that do not share any link. The term of non-disjoint connections refers to connections that share a link. When the spectrum for non-disjoint connections is allocated on adjacent slots, non-aligned available slots are created. By separating the spectrum allocation of non-disjoint connections, non-aligned available slots can be avoided. To separate it, the subcarrier slots of each fiber link are divided into partitions. The spectrum for disjoint connections is allocated in the same partition, while the spectrum for non-disjoint connections is allocated in different partitions. The first-last fit allocation policy applied in the partition approach in order to put the aligned available slots together between two partitions. This would lead to contiguous aligned available slots.

This paper is an extended version of our work presented in [15]. We extend our previous work with various additions, the extension parts are mainly described as follows. In this paper, we extensively discuss the ongoing researches on bandwidth fragmentation problem in elastic optical networks. To evaluate the advantage of the first-last fit spectrum allocation policy in the partition scheme, we compare with different spectrum allocation policies. Furthermore, we extend the performance evaluation of the proposed scheme. The performance of the proposed scheme is evaluated with different networks. We evaluate the performance of the proposed scheme in terms of the blocking probability under wider range of traffic loads. In addition, we analyze how the proposed scheme works under overloaded conditions, including 5, 10, and 50% blocking of connection requests in the network. We evaluate the effect of spectrum continuity and contiguity constraints on blocking probability. We investigate how the amount of admissible traffic volume for a specified blocking probability increases in the network when the (i) spectrum contiguity constraint, and (ii) both spectrum continuity and contiguity constraints are relaxed. To analyze the effect of the proposed scheme to the available slots in the network, we evaluate the aligned available slot ratio and the contiguous aligned available slot ratio, respectively. Finally, to evaluate the effect of the number of partitions, we analyze the blocking probability of the proposed scheme as the number of partitions is reduced.

The rest of the paper is organized as follows. Section 2 describes aligned available slots created by partitioning in elastic optical networks. Section 3 addresses the model, assumptions, and symbols, which are used throughout this paper. The proposed scheme is presented in Section 4. We elaborate the working principle of the proposed partition scheme with the help of examples. Section 5 evaluates the performance of the proposed scheme. Finally, Section 6 concludes this paper.

2. Aligned available slots created by partitioning

Partitioning the subcarrier slot of each fiber link can create more aligned available slots. This is because the partitioning enables the spectrum allocation to be organized by separating the spectrum allocation of connections that use different routes and share a link.

Fig. 1 shows that partitioning can create more aligned available slots in elastic optical networks. Figs. 1(a) and (b) show the physical and virtual topology of the sample network. When partitioning is not applied in Fig. 1(c), the available slots are isolated, thus create non-aligned available slots. When we apply partitioning in Fig. 1(d), the spectrum allocation is organized. Thus it creates more aligned available slots.

However, partitioning also negatively impacts the blocking probability due to the lack of statistical multiplexing gain [16]. In general, as the maximum number of acceptable connections, or channels, is increased, the blocking probability is decreased. For an example, we calculate the blocking probability using Erlang B loss formula [17] under a simple traffic model with a Poisson arrival process and an exponential distribution of the connection holding time. If the number of channels is 100 and the offered traffic is 100 Erlang, the