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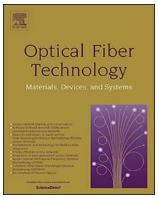

Regular Articles

Holding-time-aware spectrum allocation algorithm for elastic optical networks

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ABSTRACT

The spectrum fragmentation will impact the spectral utilization significantly in dynamic spectrum allocation (SA) over elastic optical networks (EONs). To reduce fragmentation, SA algorithm should sufficiently consider various factors so as to achieve optimization. In this paper we focus on the SA issue in dynamic scenario with holding time awareness in EONs. Firstly, a novel metric, considering the fragmentation impact from the perspectives of occupied frequency slots (FSs) and free FSs jointly, is designed to measure fragmentation in a path. Benefiting from the metric, a holding-time-aware algorithm is proposed, which considers different overall fragmentation states in the network to select the optimal approach to allocate spectrum. We examine the performance of the proposed algorithm through simulations, and the results indicate that the proposed algorithm obtains lower blocking probabilities and is able to make more use of network resource compared with traditional algorithms.

1. Introduction

The exponential growth of bandwidth requests coming from emerging services, such as data center interconnecting and high level video, requires new technologies to improve the network resource utilization [1]. To address the problem, optical transmission and networking technologies are approaching to the goals of the greater efficiency, flexibility, and scalability. The elastic optical network, which is a promising candidate for the next generation optical communication, allows the optical networks to accommodate more demands with fine granularity, where the bandwidth assigned to a light-path can span over a flexible slice of the optical spectrum. Such flexibility allows a finer match between required and provided bandwidths, which improves the spectral efficiency. As one of the key issues in EONs, the practical performance of spectrum allocation algorithm determines the spectrum utilization to a large extent, which has attracted more and more research interest in SA algorithms [2].

Though EONs take advantage of the finer granularity, it has to consider multiple constraints in usage of spectrum, such as spectrum continuity and spectrum contiguity, which makes it complex to allocate spectrum resource efficiently for traffic demands [3–5]. For a work route selected for one connection demand with specific bandwidth requirement in EONs, SA algorithm aims to properly find a set of enough contiguous FSs to accommodate the demand along the route. These allocated FSs must be placed near to each other to satisfy the spectrum contiguity constraint. In addition, the continuity of these FSs should be guaranteed as well. If a demand requires certain number of FSs, then the same number of contiguous FSs must be allocated for it (subject to the spectrum contiguity constraint), and the same (index and number) contiguous FSs must be allocated on each link along the work route (subject to the spectrum continuity constraint). Furthermore, in dynamic traffic scenario the allocation and release of spectral resources over time could lead to spectrum fragmentation. The spectrum fragmentation is the state in which available FSs become isolated from each other by being misaligned along the route. Therefore, it is difficult to utilize them to accommodate upcoming traffic demands so as to decrease spectrum resource utilization [6–8]. The constraints and the spectrum fragmentation bring great challenges to design an efficient algorithm to resolve SA issue dynamically in EONs.

For designing efficient SA algorithm, the appropriate metric measuring spectrum fragmentation and the comprehensive consideration of spectral ability impact by spectrum fragmentation are fundamental. In dynamic traffic scenario over EONs, spectrum fragmentation is difficult to define accurately and directly due to the lack of relevant comparison criteria and efficient metrics [9]. However, the quantity of the spectrum fragmentation in a link or path is mostly related to the spectral ability to

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meet upcoming traffic demands. The more spectrum fragmentation in a link or path should lead to the more reduction of the spectral ability. Previous works about SA algorithms mostly measured fragmentation relying on the capacity of remained free spectrum (CRFS) in the network. However, in dynamic scenario, release spectral ability of occupied spectrum (RAOS) is important as well. Few literatures have integrated the two factors to improve the performance of SA algorithms. Furthermore, the comprehensive consideration about the spectral ability impact by SA not only in the work route but also in other potential routes is necessary. This thinking is also rare in previous proposed algorithms.

There exist a lot of researches on SA algorithms and relevant metrics. First fit (FF) algorithm is preferred in practice because of its small computational overhead and low complexity. Various adaptations of the FF algorithm have been described in literatures [10,11]. However, the FF algorithm only tries to allocate spectrum in available contiguous free FSs form the starting index as lower as possible, which is suitable for the static scenario rather than the dynamic scenario. Based on FF algorithm, the first-last fit and first-last-exact fit algorithms achieve better performance in SA [7,12–14]. It results from the additional consideration in terms of efficient spectrum utilization through specially partitioning and efficiently allocating different patterns of connection demands in different partitions. However, the allocating policies only consider the spectrum dimension while ignore the time dimension in allocating spectrum, which hinders the algorithms to get better performance. In Refs. [15] and [9] two metrics were proposed to measure CRFS. Moreover, two SA algorithms based on the two metrics were proposed to improve the spectral utilization clearly. The metrics proposed in those works mainly rely on the probable numbers of satisfying different demand patterns in contiguous free FSs, in a link or a path, to measure CRFS of the link or the path. The physical significances are clear and definitions are exact. However, the metrics ignore the influence of the occupied holding time in FSs, which weakens the algorithms in the adaptation for dynamic scenario. Meanwhile, those algorithms process the impact of CRFS in single route without the consideration of other relevant routes. The work in Ref. [16] referred to the overall consideration of CRFS loss in all relevant routes. In this literature the author proposed an algorithm referring to as MSCL (*minimum slot-continuity capacity loss*), which also utilized the similar method discussed in Refs. [14] and [15] to measure the CRFS of a path. MSCL algorithm calculates the total CRFS loss of all relevant routes to select the optimal way to allocate spectrum. The algorithm gets acceptable performance shown by the simulation results. However, there is still margin to improve the performance of the algorithm by considering the influence of occupied holding time of each occupied frequency slot by traffic demands. The occupied holding time of occupied FSs can influence the release capacity of occupied FSs, which also determines the spectral capacity to accommodate incoming demands. Works in Refs. [17] and [18] noticed the importance of occupied holding time in FSs for accommodating incoming demands and proposed relevant metrics to benefit from the factor. The work in Ref. [17] proposed a SA algorithm referring to as Spectral-Time algorithm (without reconfiguration), which marched K-shortest path (KSP) algorithm to overcome routing and spectrum allocation (RSA) problem. The Spectral-Time algorithm takes both the free spectrum factor and the holding time factor into consideration to optimize spectrum allocation. However, the algorithm only considers the spectral ability loss within the work route instead of in all relevant paths together when allocating spectrum, which influences the performance of the algorithm. Moreover, the utilization of the holding time factor is confined within the range of contiguous occupied FSs rather than the entire link or path, which further influences the optimal performance in allocating spectrum. Work in Ref. [18] took advantage of the holding time factor to design a two-dimensional resource model, which helped to develop an algorithm to address RMSA (routing, modulation, and spectrum allocation) problem for immediate and advance reservation demands in EONs. The holding time factor plays an important role in the algorithm to reduce fragmentation. However the time reservation scenario discussed in this literature impacts the dynamic processing capacity of the algorithm. For the defragmentation approaches summarized in literatures [7,8], most of them mainly attempt to reconfigure the SA of existing connections with various specific schemes in order to consolidate available FSs into large contiguous FSs. The simulation results show that the defragmentation approaches get better performance than the non-defragmentation approaches. However, it is observed that most of the defragmentation approaches will, more or less, disrupt the existing connections and/or require the network devices to provide enough outstanding features for minimizing the disruption of connections, which impacts the applicability of these approaches [8].

In this paper, we propose a new metric for measuring the degree of fragmentation in a path. Based on the new metric, a holding-time-aware algorithm is developed, which indentifies the optimal allocating approach by accurately evaluating the overall fragmentation state in the network. Then, we evaluate the proposed algorithm's performance in terms of blocking probability and spectral resource occupation ratio through simulation experiments. Our proposed algorithm aims to reduce the spectrum fragmentation only through optimizing the allocating spectrum benefiting from the occupied holding time of FSs and overall consideration for spectrum ability loss. It enables our proposed approach to achieve broader applicability for EONs compared with the most of the defragmentation approaches.

The rest of the paper is organized as follows. In Section 2, we introduce the metric designed for measuring the spectral fragmentation. Then the holding-time-aware algorithm is proposed and introduced. In Section 3, we present simulation results for the proposed algorithm and other traditional algorithms, and we conclude the paper in Section 4.

2. Algorithm principle

It is necessary to design appropriate metric to measure the spectral ability meeting incoming traffic demands in a link or a path in order to reflect the level of spectrum fragmentation. In this section, we firstly design a new metric considering free spectrum and occupied spectrum jointly to quantify the spectrum fragmentation in a link or a path. Based on the metric, a holding-time-aware algorithm is designed to make more use of the spectrum. The algorithm takes account into the spectrum fragmentation not only in the work route but also in the all potential routes with different weights in order to get the more reasonable SA method. The comprehensive consideration helps to realize the reduction of fragmentation in SA issue.

2.1. A weighted holding time difference (WHTD) metric

For introducing the weighted holding time difference (WHTD) metric clearly, we initially introduce an affiliated metric. We design the affiliated metric to measure the capacity of remained free spectrum in a link, in which we call the metric as contiguous-slot remained capacity (CRC) in a link. Each block of contiguous free FSs in a link is referred to as a block, as illustrated in Fig. 1(a). The Eq. (1) can be used to calculate the value of the CRC of a link, where $C(link)$ represents the contiguous-slot remained capacity of *link* and $|block_i|$ represents the number of free FSs (the length of the block) in the *ith* block. In Eq. (1), the metric utilizes $(|block_i|-0.9)$ and $(1 + 0.1|block_i|)$ as the relative length and relative weight of a certain block, where subtracting 0.9 is for making sure the plus if single FS in block while encouraging more FSs in one block as possible and $(1 + 0.1|block_i|)$ is for further distinguishing the length of block. Since the total number of free FSs in a link is a constant at a certain time point, it means the less number of blocks in a link will get the less loss in length and the higher weights for more free FSs in blocks. Obviously, the more of the value of the metric means the less of the spectrum fragmentation in a link.