Dynamic Spectrum Allocation Based on Connection Alignment for Elastic Optical Networks

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***Abstract*—To deal with exponential traffic growth, Elastic Optical Networks (EONs) are necessary because they enable to provide large capacity transmissions. In EONs, multiple widths of spectra are assigned to optical paths. Therefore, fragmentation in frequency domain degrades network performance. We propose a spectrum allocation method to reduce blocking probability and node costs, especially in spatially and spectrally elastic all-optical networks. This paper demonstrates the connection alignment that classifies frequency slots into several prioritized areas.**

I. Introduction

To accommodate exponentially increasing network traffic, technologies exploiting spectrum resources have been researched [1]. Elastic optical networks (EONs) have a higher efficiency of frequency utilization than conventional rigid Wavelength Division Multiplexing (WDM) networks. In spite of such advanced network architecture, the transmission capacity of existing single mode fiber will eventually reach its physical limit. To deal with this limit, Space Division Multiplexing (SDM) technology has been intensively studied (*e.g.*, by using multi-fiber, multi-core fiber and few-mode fiber). It is necessary to consider EONs with SDM technologies, namely spatially and spectrally EONs. Reference [2] presents a node architecture of multi-fiber WDM networks with suppressed costs. As for EONs with multi-core fibers, Ref. [3] proposes a Routing and Spectrum Assignment (RSA) method reducing crosstalk without considering node costs. EONs need high cost switching nodes because they require bandwidth variable transponders and bandwidth variable wavelength selective switches. Therefore, there is a requirement for a suitable RSA solution in order to efficiently utilize spatially and spectrally EONs with lower costs of optical nodes. One of key problems is spectrum fragmentation in EONs. There are two popular approaches to solve the problem. The first one is rerouting and reallocation. In Refs. [4], [5], fragmentation is reduced by rerouting and reallocation when there are no available spectrum slots. On the other hand, the overhead on rerouting and reallocation becomes large. The second approach is a heuristic method of resource assignment which aims to mitigate fragmentation.

This paper proposes a spectrum management method for spatially and spectrally EONs. In this method, frequency slots are classified into several prioritized areas corresponding to typical width of frequency slots. Each prioritized area preferentially accommodates connections with the individual size of slots. This alignment of connections in the corresponding prioritized area reduces spectrum fragmentation dramatically without rerouting or reallocation. In addition, equipment costs are reduced because conventional rigid transponders can be used in our method. This paper demonstrates the performance evaluation of the proposed method mainly in terms of blocking probability.

II. Elastic Optical Networks

A. Fragmentation Problem

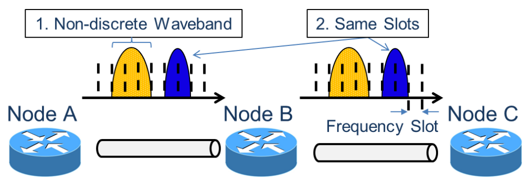

Fig. 1. Continuity Constraints in EON.

RSA problem is the one of essential issues for realizing elastic optical path networks. This RSA issue is almost similar to the Routing and Wavelength Assignment (RWA) problem in traditional WDM networks. In traditional WDM networks, it is important to assign the same wavelength channel to one path at all links on the transmission route. This is called wavelength continuity constraint. In elastic optical path networks, the network system assigns variable widths of spectra to a path based on the demand and optical reach. When we introduce spectrum slots with smaller granularity than the traditional ITU-T Grid, we can deal with RSA problem using a similar framework of RWA problem with new continuity constraints shown in Fig. 1. In traditional WDM networks, a path has to be assigned the same wavelength channel at each link of the transmitting route. In elastic optical path networks, a path needs to satisfy not only this continuity constraint but also the contiguity spectrum assignment constraint. This second constraint means that assigned spectrum slots for one path have contiguousness in spectrum domain. It is important to consider these two constraints for RSA method.

B. Related Works

Most spectrum assignment algorithms try to reduce fragmentation by solving optimization problems using Integer Linear Programming. Reference [6] proposes a spectrum management method for mix-line-rate optical networks. This method partitions resources for dedicated usage by different bandwidth lightpaths. The partitions are calculated as an optimization problem. This approach is better when traffic demands are known in the form of a traffic matrix that does not change dynamically. In addition, the calculation time increases, and the problem can be solved only when the network size is small.

III. Spectrum Allocation Method based on Connection Alignment

A. Overview of Connection Alignment

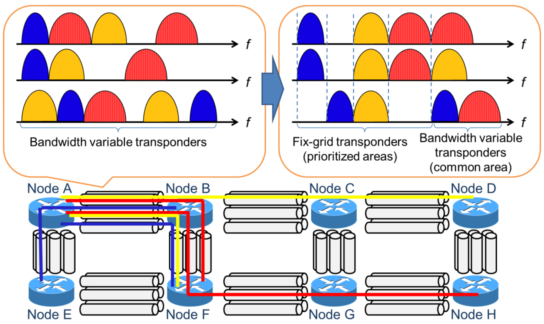

Fig. 2. Cost effective spatially and spectrally EON.

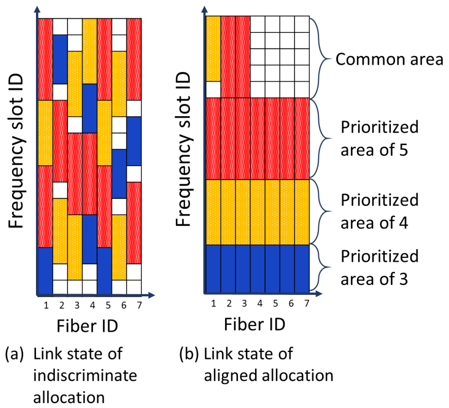

Fig. 3. Effect of aligned allocation.

This paper proposes a spectrum allocation method reducing spectrum fragmentation in spatially and spectrally EONs without rerouting or reallocation. Our key concept is to classify frequency slots into several prioritized areas and to align various optical paths in network level (Fig. 2). Figure 3(a) shows the indiscriminate spectrum allocation of conventional first-fit assignment policy. In contrast, our proposed method orderly concentrates connections requiring f slots into the prioritized area of f, as shown in Fig. 3(b). Based on this connection alignment, fragmentation does not occur in the prioritized area because there are always identical bandwidth connections. In the case that there are no available frequency slots in the corresponding prioritized area, the common area is statically configured in advance. This common area prevents our proposed method from degrading network resource utilization when the traffic demand is spatially or temporally congested to some extent. Figure 3 shows the difference between two link states originated from different spectrum management methods in a specific case. In addition, some of flexible transponders can be replaced with fix-grid transponders without degrading network performance.

B. Configuration of Prioritized Areas

In the proposed method, prioritized areas are designed based on statistical characteristics of bottleneck link. This is because other links other than the bottleneck link have more available spectrum resources compared with the bottleneck link. In our method, if a specific link is spatially or temporarily congested, the overflowed connection requests are accommodated into a common area. The size of each prioritized area should be a multiple of the number of required frequency slot. The prioritized area is divided into blocks, each of which is the same size as the required frequency slots. In other words, the prioritized area can accommodate maximally B_f connections when the number of blocks represents B_f with f required frequency slots.

The number of connections per size of frequency slots in the bottleneck link is measured/estimated and the ratio of required slots, r_f, per size of frequency slots is calculated in advance. Then, prioritized areas are configured according to the calculated ratio r_f. When the number of frequency slots in a fiber is W and the parameter of common area ratio is c, the size of common area is $W \times c$ slots. The size of prioritized area is calculated as follows.

$$B_f = \lceil \frac{W \times (1-c) \times r_f}{f} \rceil. \quad (1)$$

The size of the prioritized area is the product of the required frequency slots. Therefore, the sum of all prioritized areas and the common area may not equal W. In this case, the remaining slots are included into the common area. Such a classification reduces the number of bandwidth variable transponders.

C. Spectrum allocation Method based on Prioritized Area

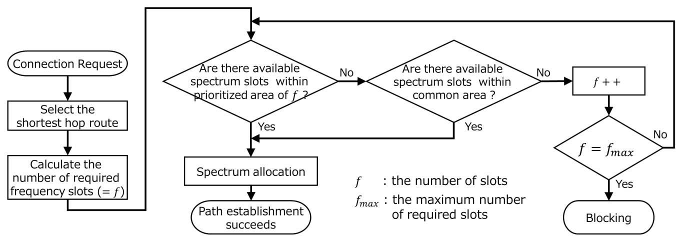

Fig. 4. Flowchart of the proposed method.

Figure 4 shows the flowchart for the proposed spectrum allocation method. First, when a path provisioning is requested, the shortest route is selected by using Dijkstra's Algorithm. Second, the number of required slots is determined according to the number of hops. Third, spectrum assignment is processed, and next, an available fiber is selected at each link based on the first-fit policy. The assignment of required frequency slots within the corresponding prioritized area follows ascending order, whereas descending order is applied for the assignments of the slots in the common area. This is especially true for connections requiring even slots, or for involuntary assignments within non-prioritized area because of a lack of slots in the corresponding area. This occurs because spectrum fragmentation is reduced by using spectrum resources from both sides.

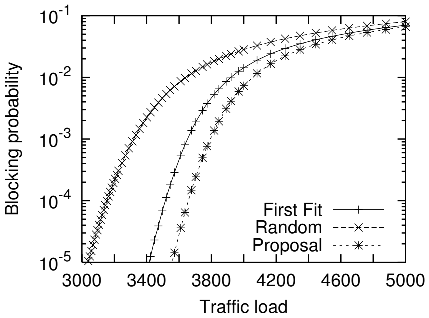

Fig. 5. Effect of traffic load.

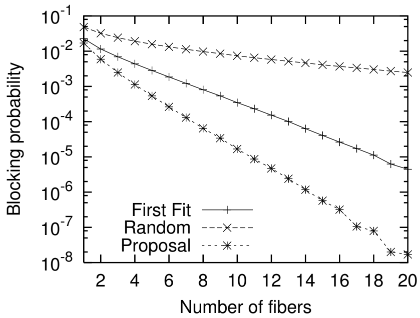

Fig. 6. Effect of the number of fibers.

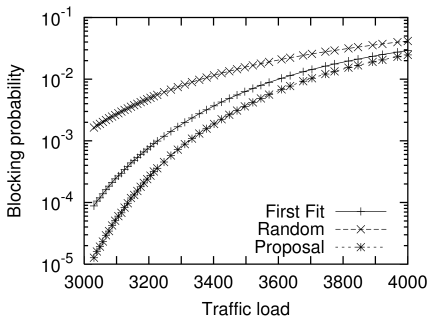

Fig. 7. Effect of traffic load when traffic matrix dynamically changes.

IV. Performance Evaluation

We evaluate the performance of the proposed method through computer simulations. The JPN-12 topology [8], which has 12 nodes and 16 links, is adopted as our test topology. Each link has eight bidirectional fibers. The number of frequency slots per fiber is 320. We assume that the service rate of connection requests follows an exponential distribution with a constant parameter μ. We also assume that the inter-arrival rate of connection requests of the source-destination pair (s, d) follows an exponential distribution with parameter $\lambda_{s,d}$. First, the values of inter-arrival rate of all source-destination pair are set to an equal value λ. Then, traffic load is defined by Traffic load $= \frac{\sum_{all(s,d)} \lambda_{s,d}}{\mu}$. Three different modulation formats are applied to the generated connections according to the number of hops, and the number of required frequency slots depends on the selected modulation format. Specifically, the number of required slots is determined by scaling the parameter set-up in Ref. [7] for the JPN-12 topology. The proposed method is compared with two major spectrum allocation methods: the first-fit policy (represented as "FF") and a random policy (represented as "Rnd"). We set the parameter of the common area ratio, c, to 0.2.

Figure 5 shows the results of the blocking probability when traffic load changes. From this figure, the proposed method can achieve better blocking probability than the other methods in all ranges of traffic load. Figure 6 shows the relationship between blocking probability and the number of fibers per link. When the number of fibers increases, the network capacity also increases, and hence, the blocking probability decreases. In order to confirm the effectiveness of the proposed method, we changed the traffic load depending on the number of fibers. The reference value for traffic load is 5000 when the number of fibers is 11. In this graph, the improvements on blocking probabilities in the proposed method are enhanced by the effect of statistical multiplexing. In other words, the proposed method is suitable for a multi-fiber (or other SDM) environment. Finally, we evaluate the tolerance to more dynamic traffic circumstance. Figure 7 shows the results of blocking probability when traffic matrix changes dynamically. Each value $\lambda_(s, d)$ randomly selected from values that are half to double rates of the average of all $\lambda_(s, d)$. This graph shows that the proposed method can achieve effective performance compared with the other methods. However, the improvement of the proposed method reduces compared with static traffic matrix case. This is because when the inter-arrival rate of each source destination pair is different from each other, the statistical characteristics of bottleneck link also change dynamically. Therefore, the calculated size of the prioritized area becomes a non-appropriate value. However, the proposed method has a common area to deal with traffic changes. In addition, the proposed EON needs a smaller number of flexible transponders because of the spectrum alignment.

V. Conclusion

This paper proposed a spectrum management method reducing spectrum fragmentation in spatially and spectrally elastic optical networks. In the proposed method, frequency slots are classified into several prioritized areas where the corresponding required slots of the connections are aligned. Simulation results showed that the proposed method achieved better blocking probability by reducing fragmentation. In future works, we will consider spectrum allocation based on dynamic configuration of prioritized areas. It would enhance the tolerance of traffic fluctuation.

Acknowledgment

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