# Spectrum Slicer Placement Optimization by Betweenness Centrality in Elastic Optical Network

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***Abstract*—This paper proposes a more effective placement way of slicers to increase bandwidth efficiency in elastic optical network (EON). EON enhances the potential of the network by dividing available bandwidth into a small region called "slot" and assigns bandwidth to communication requests dynamically. Spectrum slicing also improves the availability of bandwidth. However, these technologies cause bandwidth waste due to the lost opportunities of spectrum slicing with the incomplete placement of slicers. We provide more optimal placement of spectrum slicers to advance bandwidth efficiency. Betweenness centrality (BC) shows the importance of nodes in sight of network routing. It allows us to predict which node will be crowded and plan better slicer installation assignments in advance. We simulate how effective the proposed method is to reduce communication conflicts with the index allocation blocking ratio. As a result of simulations, the proposed method reduces communication conflicts by up to 91.01% compared to a previous BC method.**

***Index Terms*—Elastic optical network, spectrum slicing, optimization**

## I. Introduction

In recent years, the diversification of Internet services has continued to increase the transmission capacity required of backbone networks. It is difficult to make drastic improvements in existing network architectures. Therefore, the elastic optical network (EON) was proposed.

EON is a network architecture that aims to improve bandwidth utilization efficiency by dynamically allocating the optimal bandwidth to communication requests. The minimum number of slots that can be allocated to the requested bandwidth is dynamically provided. This system prevents the reduction in bandwidth utilization efficiency caused by the fixed bandwidth allocation seen in wavelength division multiplexing (WDM).

In EON, bandwidth allocation must be continuous at both the frequency and link levels. In response, Akaki *et al.* proposed a method to relax this constraint by using the spectrum slicing technique [1].

Although this method was useful in reducing the number of slicers installed and decreasing the initial construction cost of the network, there was a problem that slicer placement did not sufficiently take detailed traffic behavior into account. In this paper, the slicer placement decision problem in EON is solved by predicting traffic flow using betweenness centrality.

The rest of this paper is organized as follows. Section II describes EON with spectrum slicing and its associated problems in detail. Section III explains the slicer placement decision problem to minimize the probability that a communication request will not be bandwidth efficient. Section IV presents simulation results and analysis, and finally Section V summarizes the main points.

## II. Basics of EON and Spectrum Slicing

EON improves bandwidth utilization efficiency by varying the bandwidth allocated to communication requests. The bandwidth is divided into narrow bandwidth units called slots. When a request for bandwidth allocation is received, the consecutive slots are concatenated on the frequency axis to provide the minimum bandwidth that matches the required amount. This process reduces unnecessary bandwidth usage.

When allocating requests, it is necessary to observe all three constraints described below. First, slots already in use by other requests on the route must not be used. Second, the slots allocated to a request must be contiguous on the frequency axis. This constraint is henceforth referred to as the "frequency constraint". Finally, the slots provided to the request must be contiguous on the link axis. This constraint is henceforth referred to as the "link constraint". In EON, requests must be allocated according to the three constraints.

Fragmentation occurs due to the request allocation according to the constraints [2]. Fragmentation is a phenomenon in which slots that have already been used by other requests are scattered along the path. In this situation, the area that satisfies the allocation constraint is reduced because they are not contiguous on the frequency axis or link axis even if the total number of free slots on the path itself is sufficient. The phenomenon makes it difficult to secure the frequency range to be allocated to optical signals. When fragmentation occurs frequently, it becomes difficult to allocate frequencies to requests, leading to a decrease in bandwidth utilization efficiency.

Spectrum slicing technology is a technique that can reversibly split and synthesize an optical signal as multiple optical signals [3]. The splitting process is called slicing, and the synthesis process is called stitching. In slicing, a spectral splitter called a slicer is used to split an optical signal by duplicating the original signal to different frequencies and then filtering both signals to cut off overlapping parts. Stitching combines the optical signals divided by slicing and restores the original signal.

The use of the spectrum slicing technique in EON allows the frequency constraint among the allocation constraints to be relaxed. This cooperation allows optical signals to be allocated more flexibly over bandwidth and improves bandwidth utilization efficiency. However, the spectrum slicing technique only achieves reversible splitting of optical signals. Therefore, a control algorithm is needed to determine which slots to allocate optical signals to and which requests to split.

For the fragmentation problem in EON, defragmentation methods [4] - [7] that optically shift the used bandwidth during communication, were proposed. As a different approach, allocation methods [2], [8] that improve the slot allocation algorithm itself, were also proposed. On the other hand, these methods require a significantly longer time or are not compatible with slot allocation control when using the spectrum slicing technique. Akaki et al. proposed the largest L-shape fit method [1], which uses the L-shaped region with the largest number of available slots from among all slots from the source node to the destination node within a bandwidth allocation range that does not become excessive. By using the L-shape, it is possible to handle the sections that can be transmitted as a single optical signal without using a slicer and the sections that can be transmitted using a portion of the bandwidth of the original signal if a slicer is used. Figure 1 shows an example of allocation based on the largest L-shape fit method for a request to communicate from node A to E using four slots.

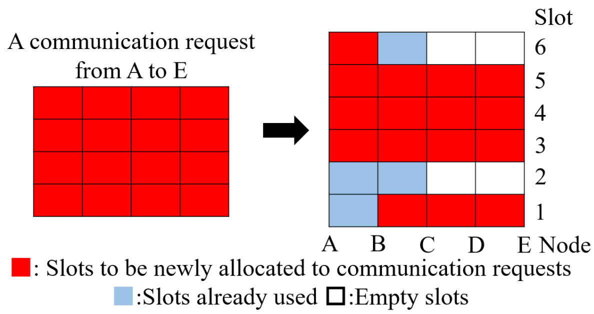


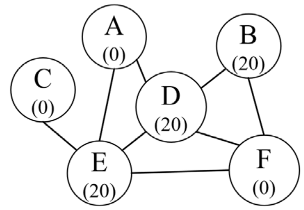

Fig. 1: Largest L-shape fit method

When using the spectrum slicing technique in EON, it is necessary to pre-position slicers at each node on the network for request partitioning. The betweenness centrality (BC) method [9] determines whether or not to set a slicer according to the BC value of node $i$, $B(i)$, obtained by Eq. (1).

$$B(i) = \sum_{p \neq i \neq q} \frac{\delta_{pq}(i)}{\delta_{pq}}, \tag{1}$$

where $\delta_{pq}$ is the number of shortest paths connecting node $p$ and node $q$, and $\delta_{pq}(i)$ is the number of shortest paths connecting node $p$ and node $q$ that pass through node $i$. Figure 2 shows a placement in the method. It is assumed that 60 slicers are given. The top three nodes with the highest BC value are nodes B, D, and E. Each of them is equipped with 20 slicers.

However, these previous methods did not sufficiently take detailed traffic behavior into account for slicer placement. It is possible to optimize the opportunities for splitting optical signals and improve the transmission efficiency of the entire network.




| Node index | BC value |
|---|---|
| A | 0.1 |
| B | 0.2 |
| C | 0.0 |
| D | 0.3 |
| E | 0.3 |
| F | 0.1 |

Fig. 2: Number of slicer placements in BC method

## III. Proposed Method

In this method, the BC value of each node in the network is directly used as the allocation ratio of slicers. Since the BC value is the number of shortest paths through node $i$ relative to the total number of shortest paths, this value is the best indicator to analyze which and how many nodes the shortest paths go through and to predict routing trends. First, the maximum total number of slicers installed in the network is determined, followed by the mediating centrality of each node. Then, the ratio of the numerical value of the relevant node to the sum of the BC value of all nodes is calculated, and the ratio is treated as the allocation ratio of slicers.

Figure 3 shows an example of the application of this method in Figure 2 network.

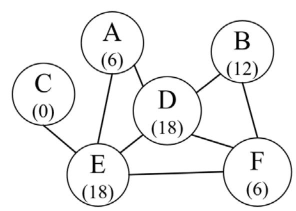



Fig. 3: Number of slicer placements in the proposed method

In Fig. 3, the BC value of node B is 0.2, its ratio to the total mediating centrality is $\frac{0.2}{1.0} = 0.2$ and the number of installed slicers is $60 \times 0.2 = 12$. The same calculation is performed for the other nodes to determine the number of slicers.

## IV. Performance Evaluation

The performance was evaluated by computer simulation. The maximum total number of installed slicers was set to $10 \times nodes$ and two topologies were used: JPN12 and JPN48. 400 slots per link were used. The number of requested slots was randomly created from 1 to 16, and a total of 10 million requests were generated. The source and destination nodes were both randomly selected. The network traffic intensity $e$ [Erlang] was given by $e = \lambda \times b$, and requests were generated to keep the traffic intensity at this level throughout the simulation. It should be noted that $\lambda$ is the arrival rate following the Poisson distribution and $b$ is the communication time following the exponential distribution. The expected value of $b$ is equal to the average communication time $\mu$. In this case, $\mu = 10$. The simulation was performed in five cases, raising the traffic intensity value from 100 Erlang to 300 Erlang by 50. The routing of requests was based on the shortest path, and the largest L-shape fit method was used for the slot allocation. The evaluation index was the request blocking probability (RBP) obtained by Eq. 2.

$$\text{RBP} = \frac{\text{Total number of blocked requests}}{\text{Total number of communication requests}} \quad (2)$$

This simulation was also performed for the previous BC method for comparison.

We also investigated the trend of bandwidth utilization efficiency when the minimum number of $m$ slicers installed in a node was specified and a certain amount of slicer utilization opportunities were reserved for each node. When $m$ is set to five, the number of slicers at each node is as shown in Fig. 4.

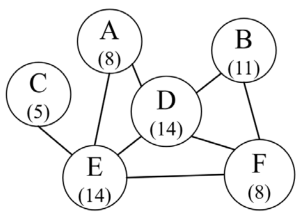



Fig. 4: Number of slicers in each node when $m = 5$

In the simulation, $m$ is set to 0, 3, 5, and 7.

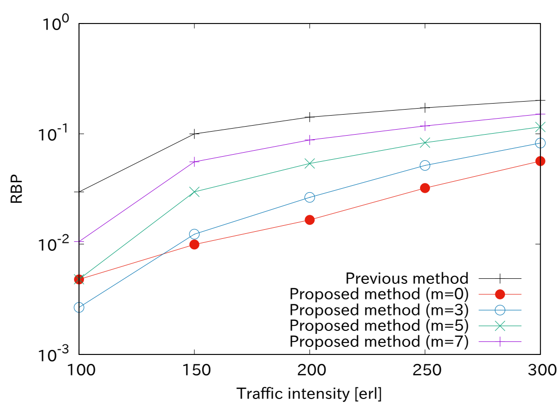



Fig. 5: RBP in JPN48

Figure 5 shows RBP in JPN48. RBP reduction was 91.0% compared to the previous method when the traffic intensity was 100 erlang when $m$ was 3, and 25.0% when the traffic intensity was 300 erlang when $m$ was 0. Similar simulations were performed for JPN12, a simplified topology of JPN48, with 83.7 % at 100 erlang and 4.1 % at 300 erlang in Figure 6. Thus, the proposed method is found to be more effective when the number of nodes in the network is large.

In addition, a comparison of RBP for each minimum number of slicers $m$ shows that, overall, the case where the minimum number of slicers was set to 0 tends to produce better results. Therefore, when determining slicer placement based on mediator centrality, it is more likely to produce better results if only the prediction of traffic flow based on mediator centrality is considered, rather than setting a minimum guarantee and providing all nodes with opportunities to use the slicers.

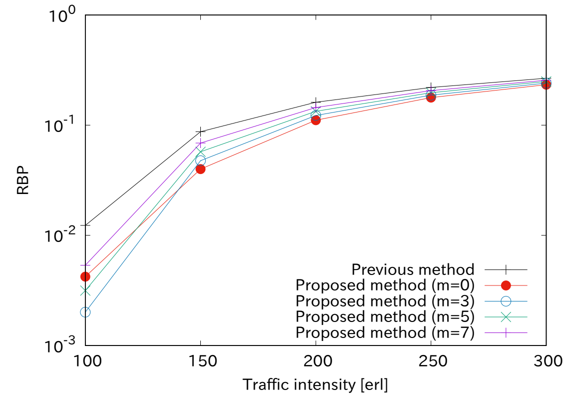



Fig. 6: RBP in JPN12

## V. Conclusion

In this paper, we proposed a slicer allocation method to reduce the request blocking probability when introducing spectrum slicing technology to EON. The proposed method calculates the value of mediation centrality per node as a percentage of the total sum and uses this value to determine the allocation of slicers. Performance evaluation confirmed that the proposed method reduces the request blocking probability by up to 91.0%.

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