Scale-Based Slicer Placement in Elastic Optical Networks

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***Abstract*—This paper proposes a scale-based slicer placement scheme to reduce bandwidth blocking rate (BBR) in elastic optical networks (EONs). In EONs, a slicing-stitching technology is adopted to overcome a spectrum slot allocation rule that the spectrum slots of the same request must be consecutive on the same link. This technology is done by slicers to split a spectrum band into multiple sub-spectrum components. In EONs with limited slicers, determining equally the number of slicers on every node may not result in a low BBR since the traffic volume on each node is not the same. We investigate and determine the number of slicers needed for each node as a scale-based policy. The simulation results show that our scheme achieves a BBR reduction of 91%, compared to the conventional scheme.**

***Index Terms*—elastic optical network, spectrum allocation**

I. Introduction

By dynamically assigning spectrum in response to each incoming request, an elastic optical network (EON) is a network architecture that effectively uses the channel space. EON offers a spectrum slot that is more precisely segmented than a spectral grid of the most recent dense wavelength-division multiplexing (DWDM) technology [1]. In order to support large amounts of data rate traffic and boost network capacity, EON reduces unnecessary channel space compared to DWDM.

In EONs, spectrum allocation is based on two rules. First, if spectrum conversion is not taken into account, spectrum slots for a request on each connection from a source to a destination must be the same. Second, the spectrum slots of each request must be adjacent to the same link. The occupied spectrum slots on the channel are scattered due to these restrictions. A fragmentation problem occurs since a request cannot be filled into the channel. This problem reduces the effectiveness of spectrum utilization. To increase the effectiveness of spectrum utilization, it is essential to provide a solution to overcome this problem.

A slicing-stitching technology is adopted for spectrum slot allocation to overcome the second rule of the spectrum allocation process. It consists of slicing and stitching processes. The slicing process divides the requested spectrum band into several sub-spectrum components at a node if the available consecutive spectrum slots from a source to its destination are insufficient. It is accomplished by replicating the original spectrum band and assigning it to the required spectrum slots. Undesirable spectrum slots on the original and replicated spectrum bands are chopped using an optical filter [2]. A device to accomplish these processes is called a slicer. The remaining chopped spectrum bands are called sub-spectrum components. The sub-spectrum components are transmitted to the destination. Phase-preserving wavelength conversion is used at the destination to reconstruct the original spectrum band from the sub-spectrum components. Inter-symbol interference arises as a result of the non-ideality of the optical filter during the slicing process. A digital linear equalizer can be used to compensate for this problem. This technology was confirmed in the experiment with three-channel slices of a 28-Gbaud quadrature-phase-shift-keying (QPSK) channel using an optical frequency comb [3]. When a slicer is utilized, the question arises of where to divide the spectral band to achieve the lowest bandwidth blocking rate (BBR).

There are several schemes to realize slicers. Slicers are deployed on every node in the network, however, the slicing process is performed only at the source node [4]. The source node confirms the available spectrum slots across each link on a given lightpath to the destination and determines the number of slicers for the request, if necessary. The request is blocked if the number of slicers at the source node is insufficient, or if there are no available spectrum slots from the source to the destination. The computation under this policy is not complicated since it simply considers the availability from only the source node. To decrease BBR, a policy that considers the slicing process at intermediate nodes is introduced [5]. The problem is more complex since there is a variety of possible slicing patterns for all intermediate nodes. The computation of the optimization formulation requires a long time to finish and may not be completed in a reasonable amount of time. To solve this issue, a heuristic approach is employed. A large L-shape fit scheme was introduced to assign the requested slots for the policy that considers the slicing process at intermediate nodes [6]. The scheme searches for the largest slot area with L-shape for the request. If the request remains unassigned slots, the scheme repeats the searching process for the unassigned slots until all requested slots are assigned. The slicing process is utilized at the corner node of the L-shape.

The number of slicers in the network is limited due to the implementation cost. Employing slicers for all nodes is costly. The above policies consider the limited number of slicers in the network. In addition, the same number of slicers is utilized for selected nodes. The number of slicers may not enough at nodes with high traffic. In contrast, the number of slicers at nodes with low traffic is redundant. Employing more slicers at the nodes with high traffic and fewer slicers at the nodes with low traffic is more efficient than employing the same number of slicers at selected nodes. In this paper, we investigate the required number of slicers for each node and assign a different number of slicers for each node.

II. Employing same number of slicers

The set of slicing nodes is determined by betweenness centrality (BC) [6]. The same number of slicers is employed for each slicing node. The shortcoming of this scheme is that the nodes with high traffic require more slicers, while the nodes with low traffic waste slicers.

Figure 1 shows an example of using the same number of slicers. The network is considered to have 30 slicers. We may utilize the slicers in four cases. Case 1 represents ten nodes with three slicers, as shown in Fig. 1(a). Case 2 represents six nodes with five slicers, as shown in Fig. 1(b). Case 3 represents five nodes with six slicers, as shown in Fig. 1(c). Case 4 represents two nodes with 15 slicers, as shown in Fig. 1(d). Cases 2 and 3 achieved lower BBR than Cases 1 and 4. However, the difference in traffic across nodes is huge. Moving slicers from nodes with low traffic to nodes with high traffic may result in a lower BBR.

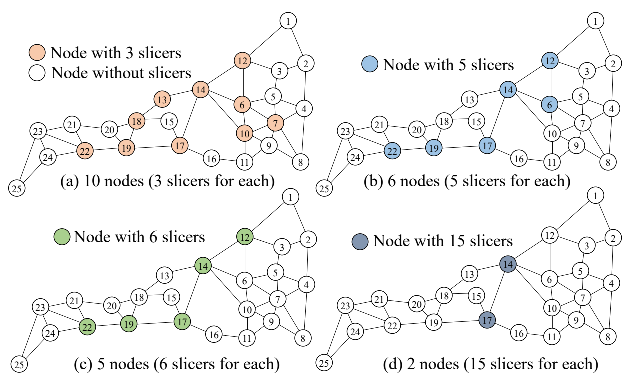

Fig. 1. Example of employing same number of slicers at nodes selected by BC.

III. Employing different number of slicers

This scheme aims to decrease BBR by using an appropriate number of slicers for each slicing node. The number of slicers on each slicing node differs. A large number of slicers are used for nodes with high traffic, while a small number of slicers are used for nodes with low traffic.

We first determine the maximum number of required slicers for each node. An unlimited number of slicers is assumed. The traffic is injected into the network. The number of utilized slicers for each node is counted. After all traffic is completely transferred, we find the maximum number of slicers for each node where multiple requests simultaneously use the slicers.

In a network with N nodes, let m_i be the maximum number of slicers at node i. Let S be the total number of slicers in the network. The number of required slicers for node i, s_i, is scaled as below.

$$s_i = \left\lceil \frac{m_i}{\sum_{n=1}^{N} m_n} S \right\rfloor \tag{1}$$

Here, $\lceil x \rfloor \equiv \lfloor x + \frac{1}{2} \rfloor$ denotes the integer closest to the real number x.

IV. Performance evaluation

The performance of a scheme that employs a different number of slicers is evaluated in terms of BBR, compared to that of a scheme that employs the same number of slicers. The BBR is the ratio of the rejected bandwidth to the total requested bandwidth. The JPN48 topology [7], which is a Japanese nationwide network, is used for the simulation. The network consists of 48 nodes with 82 bidirectional links, as shown in Fig. 2. It is assumed that a spectrum converter is not allowed. 400 spectrum slots per fiber are considered.

The request is randomly generated based on Poisson distribution with an arrival rate of λ. The number of utilized spectrum slots is uniformly distributed between 1 and 16 slots. The holding time of the light path follows an exponential distribution $H = 1/\mu$ with an average time of $\mu = 10$. The routing from a source to a destination for each request is based on the shortest path. The traffic load (ρ) is given in Erlang where $\rho = \lambda/H$. Ten million requests are generated for the simulation.

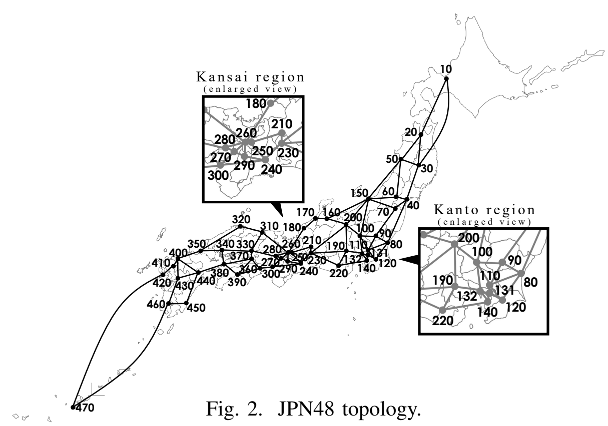

Fig. 2. JPN48 topology.

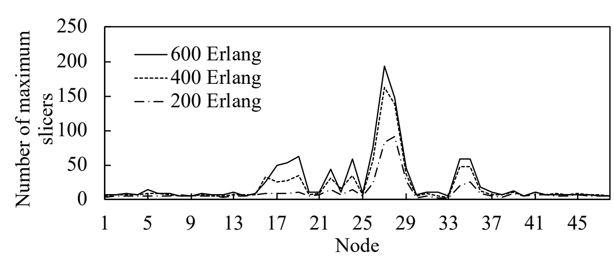

Fig. 3. Maximum slicers for each node.

We first determine the maximum number of slicers for each node where multiple requests are simultaneously used. Figure 3 shows the maximum number of slicers for all nodes. Nodes between 26 to 29 need a large number of slicers. This is because most traffic passes through those nodes. Nodes 16-19, 22, 24, and 34-36 require less number of slicers than half of the nodes between 26 and 29. The other nodes require a small number of slicers.

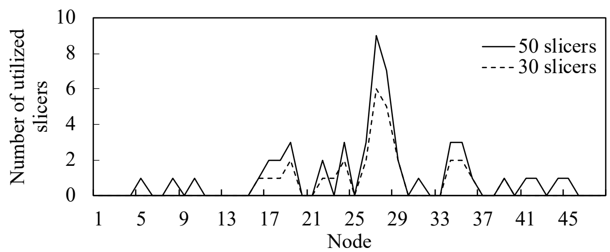

Fig. 4. Number of utilized slicers for each node (the total number of slicers in the network are 30 and 50).

Next, we estimate the required number of slicers for each node when the number of slicers in the network is limited. 30 and 50 slicers in the network are used in the simulation. The required number of slicers for each node, which is calculated by Eq. (1), is shown in Fig. 4.

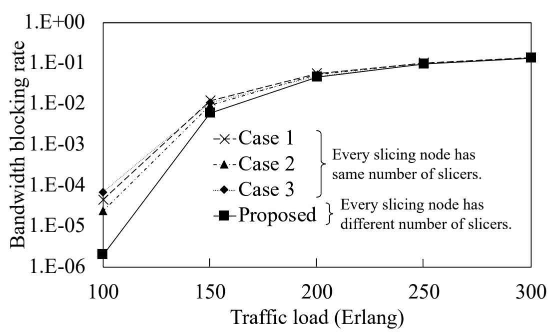

Fig. 5. Bandwidth blocking rate between employing same slicers and different slicers (50 slicers).

Figure 5 shows a comparison between the BBR of the proposed scheme and the conventional scheme when the total number of slicers in the network is 50. Slicers distribution is categorized into three cases. In case 1, 25 nodes are equipped with two slicers. In case 2, ten nodes are equipped with five slicers. In case 3, two nodes are equipped with 25 slicers. The result shows that employing different numbers of slicers in different nodes achieves lower BBR than employing same number of slicers in every slicing node. The BBR of the proposed scheme and the conventional scheme does not have much effect in a high traffic load. The effect of the proposed scheme is apparently seen in low traffic. The BBR of the proposed scheme has 91% and 37% reduction, compared to case 2 of the conventional scheme when the traffic load is 100 and 150 Erlang, respectively.

Figure 6 shows the BBR when the total number of slicers in the network is 30. The conventional scheme is categorized in three cases. Case 1 represents 15 nodes equipped with two slicers. Case 2 represents six nodes equipped with five slicers. Case 3 represents three nodes equipped with ten slicers. The BBRs for all cases of the conventional scheme are almost the same. The BBR of the proposed scheme is lower than that of the conventional scheme. The BBR of the proposed scheme has 78% and 28% reduction, compared to case 2 of the conventional scheme when the traffic load is 100 and 150 Erlang, respectively.

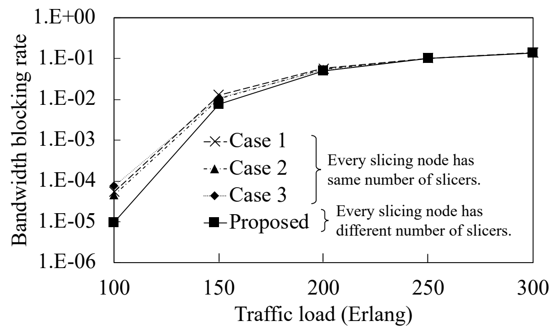

Fig. 6. Bandwidth blocking rate between employing same slicers and difference slicers (30 slicers).

V. Conclusion

A scale-based policy for slicer placement in EONs that use slice-and-stitch technology was proposed. Depending on the amount of traffic passing through, different nodes employ a variable number of slicers. When an infinite number of slicers was considered, the maximum number of slicers required for each node was initially examined. When the total number of slicers in the network was restricted, the required number of slicers for each node was then estimated from the scale of the maximum number of slicers. The results indicated that the BBR was reduced by 91% compared to the conventional scheme in the JPN48 network.

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