Dynamic Resource Allocation for All-Optical Multicast based on Sub-tree Scheme in Elastic Optical Networks

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Abstract: All-optical multicasting with a single light-tree suffers inefficient distance-adaptive spectrum allocation from its large tree-spanning size. We propose a routing modulation format and spectrum allocation (RMSA) algorithm based on sub-tree scheme to improve spectrum utilization.
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1. Introduction

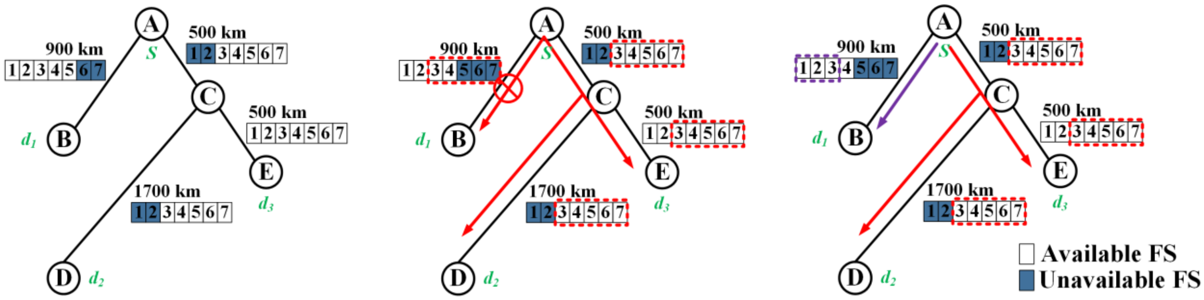
In elastic optical networks (EONs), all-optical multicasting can adopt distance-adaptive spectrum allocation to efficiently support large-bandwidth traffic [1]. A single light-tree is usually constructed to serve a multicast request due to its cost and spectrum efficiency [2]. In such a scheme, the distances from a source node to all the associated destination nodes of a light-tree are random and diverse, so the modulation format is determined by the distance from the source to the farthest destination node [3]. But for the other closer destination nodes, which could use higher level modulation formats, spectrum wastage would be caused especially when the required capacity is high. Moreover, under dynamic traffic load, the issue of spectrum fragmentation makes network operators more difficult to allocate the same frequency slots (FSs) for a large-size light-tree. The sub-tree scheme, which uses several transparent sub-trees to jointly serve one multicast request, has been introduced and formulated for network design in EONs [2]. Compared with the single light-tree scheme, the sub-tree scheme improves the flexibility of spectrum allocation.

In this paper, we propose a dynamic RMSA algorithm to improve spectrum utilization based on the sub-tree scheme. The algorithm groups the destination nodes, which may share a large portion of their paths, to a common sub-tree. By separating the destination nodes sharing few hops between each other to reduce the size of each spanning tree, the algorithm can flexibly perform distance-adaptive spectrum allocation. Then each sub-tree is established by taking into account the constraints of spectrum continuity and contiguity in EON. Although the sub-tree scheme may need more transmitters for one multicast request, simulation results show that the proposed algorithm can effectively reduce blocking probability.

2. RMSA for all-optical multicast using sub-tree scheme

We consider an all-optical EON without spectrum converter. Every node is capable of all-optical multicasting and equipped with an enough number of transmitters. For distance-adaptive spectrum allocation, four modulation formats (i.e., BPSK, QPSK, 8QAM, and 16QAM) are considered with 8000, 4000, 2000, and 1000-km maximum optical reaches, respectively. By enabling polarization mode multiplexing, each FS occupies 12.5-GHz bandwidth and carries 25, 50, 75, and 100-Gb/s capacity for BPSK, QPSK, 8QAM, and 16QAM, respectively. One extra FS is allocated as guard-band.

As an example, Fig. 1 illustrates the advantage of the sub-tree scheme over the single light-tree scheme. Fig. 1(a) shows a network topology with spectrum usage. A multicast request arrives and needs 200-Gb/s capacity from source node *A* to three destination nodes *B*, *D*, and *E*. For the single light-tree scheme, as the distance of path *A*-*C*-*D* is 2200 km, the highest feasible modulation format of the light-tree is QPSK, which requires 5 FSs for 200-Gb/s capacity. But link *A*-*B* does not have sufficient spectrum resources, the request will be blocked as in Fig. 1(b). In contrast, for the sub-tree scheme, if the paths to the destination nodes share few hops, they can be accommodated through different sub-trees to enhance allocation flexibility and spectrum efficiency. As illustrated in Fig. 1(c), we can setup the transmissions to d_1, d_2, and d_3 through two sub-trees, i.e., sub-tree 1 containing d_1 and sub-tree 2 containing d_2 and d_3. According to their transmission distances, sub-tree 1 can use 16QAM requiring 3 FSs and sub-tree 2 can use QPSK requiring 5 FSs. Therefore, compared with the single light-tree scheme, the sub-tree scheme can successfully accommodate the multicast request and reduce the total spectrum usage by 2 FSs. Of course, the cost for spectrum saving is that the sub-tree scheme requires an extra transmitter.



(a) Network (b) Single light-tree scheme (c) Sub-tree scheme

Fig. 1. Examples of the single light-tree and sub-tree schemes

3. Heuristic algorithms

We propose a K-shortest-path-based sub-tree (KP-ST) algorithm to group destination nodes to several sub-trees based on their sharing ratio. K shortest paths between every node pair are pre-computed and stored. We define the sharing ratio r of two destination nodes i and j as $r=(h_{ij}/H_i)+(h_{ij}/H_j)$, where H_i is the number of hops of path p_{si}, h_{ij} is the number of shared hops between p_{si} and p_{sj}, and p_{si} and p_{sj} are the pre-computed shortest paths from source node s to destination nodes i and j, respectively. Because the finally selected routing path to destination node is not known in advance for both alternative and adaptive routing approaches, we use the shortest path to measure the sharing ratios between destination node pairs, which is also compatible with the adaptive routing approach such as spectrum window plane scheme [4]. A larger r means that, in term of hops, the two destination nodes could be closer to save spectrum resources if a light-tree is used rather than two individual lightpaths.

When a multicast request arrives, KP-ST algorithm firstly tries to accommodate the request through a single light-tree using K-shortest-path-based tree (KP-T) algorithm in order to reduce transmitter usage. KP-T algorithm is shown in details as Algorithm 1. If the single light-tree attempt fails, we compare the value of r for every destination pair and assign the pairs satisfying $r \geq \alpha$ to the same sub-tree, where $0 < \alpha < 2$ is a threshold. If one of the pair has already been assigned to a sub-tree, the other will also be assigned to the same sub-tree. Then the destination nodes, which cannot match any pair, are assigned to individual sub-trees. Every destination node will be assigned to only one sub-tree. KP-ST algorithm corresponds to Algorithm 2 below. The constraints of spectrum continuity and contiguity should always be satisfied when assign spectrum for each sub-tree. The first-fit strategy has been employed for the spectrum assignment. The details of the two algorithms are shown next.

Algorithm 1: KP-T

Step 1: Set modulation format to 16QAM, and then compute the corresponding number of FSs required.
Step 2: Check the distance feasibility for all pre-computed paths under current modulation format.
Step 3: Search for the FSs that can reach all destinations using any feasible pre-computed path in first-fit manner.
Step 4: If feasible solution is found, return the corresponding spectrum usage.
Step 5: If lower level format is unexplored, set format one level lower and go to **Step 2**. Else block the request.

Algorithm 2: KP-ST

Step 1: Run KP-T algorithm. If solution is found, reserve the FSs and go to **Step 5**.
Step 2: Assign destination nodes to sub-trees according to their sharing ratio r and pre-defined threshold α.
Step 3: Choose an unhandled sub-tree and invoke Algorithm 1 to find a solution. If no feasible solution can be found, block the multicast request and release all reserved spectrum resources.
Step 4: Check spectrum non-overlapping among current solution and reserved spectrum resources. If not satisfied, go back to **Step 3** to find other solutions. Else, reserve the FSs used in current solution.
Step 5: If all destination nodes are accommodated, allocate all reserved FSs and update network spectrum usage. Else, go to **Step 3**.

4. Performance evaluation

We evaluate the performance of proposed KP-ST algorithm with different threshold values (α=1.0, 1.4, and 1.8). The simulation is performed for 14-node, 21-link NSFNET network, in which the average link distance is 1081 km, and each fiber link is assumed to carry 320 FSs. Multicast requests arrive one by one in a Poisson process and their holding times follow a negative exponential distribution. For each multicast request, the required capacity is uniformly distributed within a range from 10 to 200 Gb/s. Source node and destination nodes are randomly selected, and the average size of destination node set is 5. For every traffic load, 10^5 multicast requests are simulated and

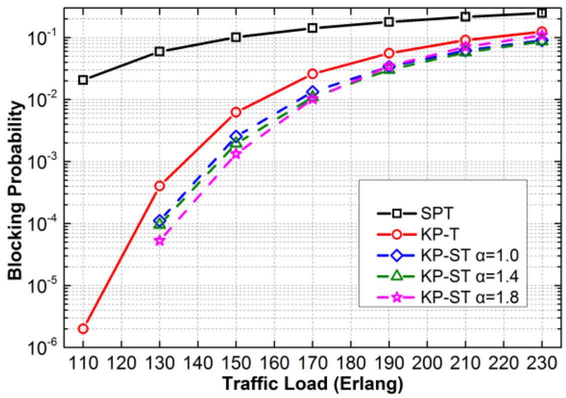


Fig. 2. Request blocking probability

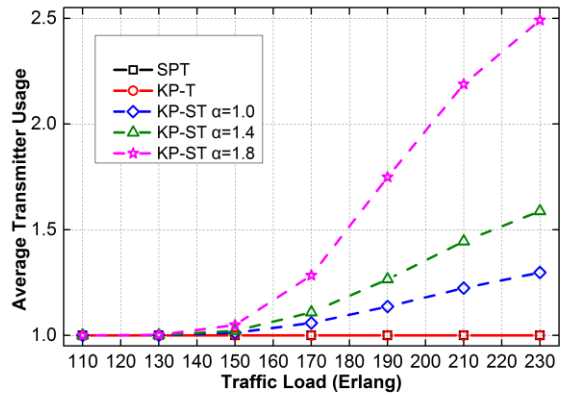


Fig. 3. Average transmitter usage

repeat 10 times to calculate the request blocking probability (BP) and average transmitter usage, which is defined as the total number of consumed transmitters over the total number of provisioned requests. Also, for performance comparison, two single light-tree RMSA algorithms are used as benchmarks, which are KP-T algorithm and shortest-path tree (SPT) algorithm based on [5]. The number of pre-computed shortest paths between every node pair K is 5 for both KP-T and KP-ST algorithms.

Fig. 2 shows BP with an increasing traffic load. KP-ST algorithm achieves a lower BP than both of the single light-tree algorithms regardless of the value of α. Under light traffic loads, the BP of KP-ST algorithm reduces when α is increased. Because it is harder to find the destination node pairs with larger sharing ratios, more sub-trees are created with small sizes for large α case. When traffic load is low and spectrum resources are relatively sufficient, small-size sub-trees can be flexibly established and lead to a lower BP. However, when traffic load is high, BP will firstly decrease and then sharply increase with the increase of α. Compared with KP-T algorithm under 230-*Erlang* traffic load, KP-ST algorithm reduces 27.2%, 29.9%, and 12.8% in BP for α equal to 1.0, 1.4, and 1.8, respectively. For a very large α such as 1.8, each sub-tree contains few destination nodes or even only one destination node, which performs similarly to the unicast lightpath approach. In this situation, transmission barely benefits from spectrum saving by sharing fiber links in light-trees. Therefore, the value of threshold should be configured to be relatively high to balance spectrum sharing among destination nodes and the size of sub-trees under heavy traffic loads.

As each sub-tree consumes an individual transmitter, the number of established sub-trees equals to that of required transmitters, which is in turn proportional to system cost. We evaluate the number of average transmitter usage to study the system costs for different algorithms. The numbers of average transmitter usage for the single light-tree benchmarks are always equal to 1. In Fig. 3, the number of average transmitter usages for KP-ST algorithms increase with the increase of traffic load. KP-ST algorithm with a larger α consumes more transmitters and results in a higher system cost. For α equal to 1.8, average transmitter usage rapidly rises due to the lightpath-like sub-tree assignment. Here our assumption is that an individual transmitter is required for each sub-tree. However, with the technology of sliceable bandwidth-variable transponders (S-BVT), a single S-BVT may support multiple sub-trees simultaneously, which will be our subsequent research.

5. Conclusion

To improve the flexibility of spectrum allocation and utilization in all-optical multicasting, we proposed a sub-tree scheme based KP-ST algorithm, which groups destination nodes according to their sharing ratios. Simulation results showed that KP-ST algorithm achieves lower BP than the single light-tree benchmarks. With a relatively high α such as 1.0, KP-ST algorithm can reduce the blocking probability over 27% with a slight increase of transmitter usage.

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