Performance Analysis of Multicast Traffic over Spectrum Elastic Optical Networks

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Abstract: We analyze the multicast performance over spectrum elastic optical networks. Results demonstrate the flexible spectrum allocation provides lower blocking probability for multicast compared to that in ITU-T grid-based WDM networks.
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1. Introduction

The rapidly increasing capacity demand for backbone networks has attracted both academy and industry to the optimization of network resource. Although the ITU-T grid-based wavelength–division multiplexing (WDM) networks offer obvious advantages, the coarse granularity leads to spectrum inefficiency when the traffic is not sufficient to fill one entire wavelength. The recently proposed spectrum-slice elastic optical path networks (SLICE) can improve spectrum utilization by introducing fine spectrum granularity [1]. In the SLICE technology, the necessary spectral resource is allocated in an integer multiples of 12.5 GHz, called frequency slot, thus making SLICE more efficient than ITU-T WDM optical networks based on 50-GHz grid. To develop SLICE, two key technologies are i) bit rate-variable transponders based on optical orthogonal frequency division multiplexing (OFDM) [2] and ii) bandwidth-variable wavelength cross-connects (WXC) based on, for example, bandwidth-variable wavelength selective switch (BV-WSS).

Multicasting over WDM optical networks has enabled many popular point-to-multipoint applications, such as video conferencing, interactive distance learning. However, the low-rate multicasting traffic demands cannot make full use of the whole wavelength capacity. Therefore in order to increase the network spectrum efficiency, it is essential to exploit multicasting over spectrum elastic optical networks. The broadcast-and-select mechanism at the WXC node by employing bandwidth-variable WSS is suitable for multicasting traffic, as shown in Fig. 1. Multicast routing and spectrum allocation (MC-RSA) is important to achieve high spectrum utilization in elastic optical networks. In MC-RSA problem, a light-tree is introduced to support multicast [3]. If no wavelength conversion is allowed, the light-tree transmits data on the same particular spectrum along the branches, which is the well-known spectral continuity constraint. Additionally, the channel setup for connections must also follow spectral conflict constraint, which means no spectrum overlapping for different channels on the same link. Although RSA problem for unicast over elastic optical networks has been studied recently [4,5], there is few investigation on MC-RSA problem over elastic optical networks.

In this paper, we investigate multicasting over spectrum elastic optical networks by developing two heuristic algorithms. The multicast performance over elastic optical networks is compared to that over ITU-T grid-based WDM optical networks.

2. Network model and MC-RSA algorithms

In elastic optical networks, we consider a fine spectrum grid based on 12.5-GHz frequency slot. The necessary spectrum allocation for each request will be in multiples of frequency slots. In comparison, the ITU-T grid-based optical networks have fixed wavelength spacing (i.e. 50-GHz grid), which equals to four continuous frequency slots. We assume the total available spectrum is 4000 GHz for both cases (320 frequency slots for elastic optical networks and 80 wavelengths for ITU-T grid-based optical networks). When a multicast request arrives, an integer multiple of continuous frequency slots, adaptive to the data rate, is allocated for the flexible-slot case (i.e. elastic optical networks). For the fixed-slot case (i.e. ITU-T grid-based optical networks), fixed optical spectrum is assigned no matter how much bandwidth is required.

We assume the source node and destination nodes are randomly selected for every multicast request. A source node is first selected, and then the destination nodes are selected from all remaining nodes independently with an equal probability, called multicast group-size (MGS) factor. For example, a 20% MGS means each node except the source node has 20% probability to be the destination node independently, which indicates the ratio of the expected number of destination nodes to the total nodes except the source node is 20%.

We assume every node is equipped with WXC and no wavelength conversion is allowed. To achieve high network spectrum resource utilization, it is essential to develop an efficient MC-RSA algorithm for elastic

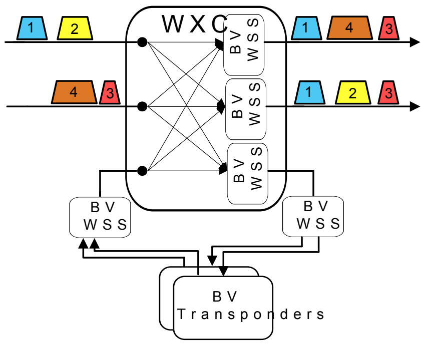

Fig. 1. Broadcast-and-select mechanism of WXC.
Channel 1 to 4 denote traffic with different spectrum bandwidth

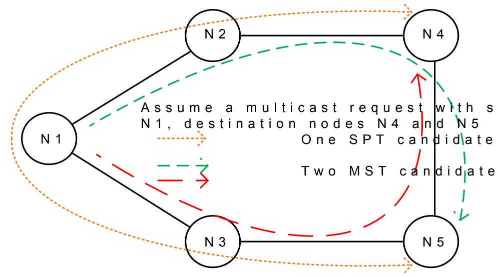

Fig. 2. An illustrative example for SPT and MST

optical networks. For ITU-T grid-based WDM optical network, there are many investigations on multicast routing and wavelength assignment (MC-RWA) [6]. All the algorithms for route session are the variants of the shortest path tree (SPT) and the Steiner minimal tree (SMT). SPT is constructed to minimize the delay between the source node to every destination node, while SMT is constructed to minimize the total cost (e.g. the average spectrum utilization). SPT is constructed by connecting every source-destination node pair with the shortest path. The well-known SMT is NP-complete [7]. Hence, a well-known method to approximate SMT is to use minimal spanning tree (MST) [8]. One routing example for SPT and MST is shown in Fig. 2. In the simulation, we use both SPT and MST for routing in the elastic optical networks to evaluate the multicast performance. To ensure fairness, the ITU-T grid-based WDM optical networks adopt the same routing algorithms. We also employ the first-fit (FF) algorithm for wavelength and spectrum allocation. Two heuristic algorithms are developed for MC-RSA problem in spectrum elastic optical networks (shown in Table. 1), namely SPT-FF and MST-FF.

In elastic optical networks, the spectral gap caused by non-uniform frequency slot allocation may degrade the spectrum utilization. We would like to investigate the effect of the frequency slot fragmentation on spectrum utilization. We notice that more unused spectrum and smaller frequency slot fragmentation will reduce blocking probability. We use the normalized unused spectrum to evaluate the frequency slot fragmentation at certain blocking probability. Larger normalized unused spectrum indicates worse frequency slot fragmentation.

Table 1: SPT-FF and MST-FF algorithms for MC-RSA problem in elastic optical networks

Step 1: Initialize the network topology and the overall free spectrum matrix. Calculate the shortest-path matrix for each node pair with the minimal number of hops. **Step 2:** Pick up one of the multicast requests in order of arrival. **Step 3:** Construct SPT/MST route candidates for the multicast request using the shortest-path matrix. Among the SPT/MST route candidates, search for the first-fit (FF) necessary continuous frequency slots in ascending order of frequency slot index. If found, assign the FF continuous frequency slots along the respective SPT/MST route, and update the free spectrum matrix. If not, block the request. **Step 4:** Check all the current connections whose holding time expire, release the occupied frequency slots along the respective SPT/MST rout, and update the free spectrum matrix. **Step 5:** Repeat Step 2 to Step 4 for all multicast requests.

3. Numerical results

In the simulation, we assume the data rate for each multicast is uniformly distributed between 10 Gb/s and 40 Gb/s. The ITU-T grid-based optical networks have the capacity equal to 40 Gb/s per wavelength with a fixed 50-GHz grid. To be fair, four continuous frequency slots (12.5 GHz per slot) in elastic optical networks offer the same capacity of 40 Gb/s, so as to have the same bit/s/Hz. The elastic optical networks, however, provide more flexible spectrum allocation, since two or three continuous frequency slots can offer 20 Gb/s and 30 Gb/s respectively.

The dynamic multicast request follows the Poisson distribution and the holding time for each connection is of negative exponential distribution. The source node and destination nodes for each multicast are selected randomly as mentioned above, and we adopt 20%, 30% and 40% MGS. We use the NSF network (14 nodes, 21 bi-directional links) topology to evaluate the multicast performance over elastic optical networks.

Figures 3 and 4 illustrate the blocking performance vs. traffic load by employing SPT-FF algorithm and MST-FF algorithm, respectively. The results show that elastic optical networks offer lower blocking probability for multicast than ITU-T grid-based optical networks under different MGS due to flexible slot allocation. Smaller MGS has more improvement in blocking probability at the same traffic load. As expected, the MST-FF algorithm outperforms the SPT-FF algorithm on blocking probability because of more efficient light-tree employed. Figures 5 and 6 compare the normalized unused spectrum of elastic optical networks and ITU-T grid-based optical networks at blocking probability of 10%. The results show the normalized unused spectrum for elastic optical networks is about 8% higher, thus indicating worse spectrum fragmentation status due to the spectral gap caused by non-uniform frequency slot allocation. It is also shown that for a fixed blocking probability, the normalized unused spectrum is nearly independent of MGS.

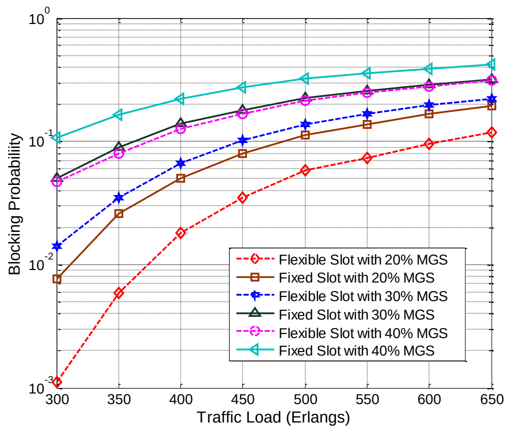

Fig. 3. Blocking probability vs. traffic load employing SPT-FF

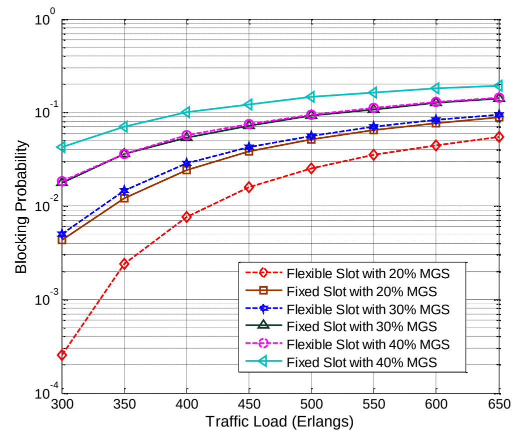

Fig. 4. Blocking probability vs. traffic load employing MST-FF

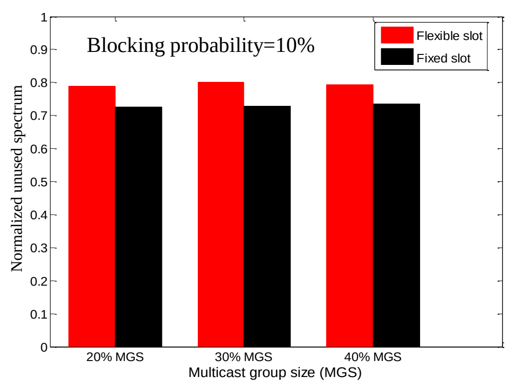

Fig. 5. Normalized unused spectrum comparison employing SPT-FF

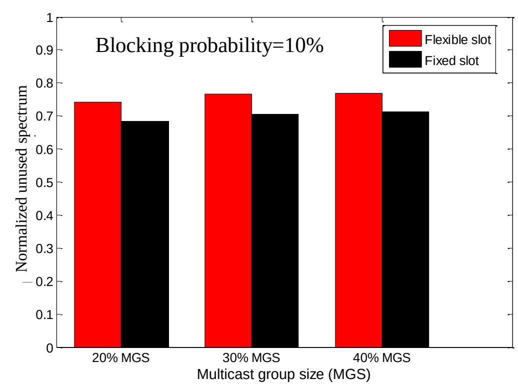

Fig. 6. Normalized unused spectrum comparison employing MST-FF

4. Conclusion

We investigate the multicast performance over spectrum elastic optical networks by developing two heuristic algorithms. Simulation results show the flexible spectrum allocation in elastic optical networks provides lower blocking probability for multicast compared to the ITU-T grid-based optical networks. However, elastic optical networks suffer more spectrum fragmentation due to the spectral gap caused by non-uniform frequency slot allocation. The project is supported in part by RGC GRF 410910.

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