Routing and Spectrum Allocation in Flexi-Grid Optical Networks

(Invited Paper)

Jiamin Ning, Gangxiang Shen*

School of Electr. & Inform. Engineering, Soochow University, China; *email: shengx@suda.edu.cn

ABSTRACT

We compare three lightpath routing and spectrum allocation algorithms for the flexi-grid optical transport networks. The three algorithms include fixed shortest path routing algorithm, grid-plane-based first-fit algorithm, and grid-plane-based exhaustive search algorithm. We evaluate the performance of these algorithms through simulations. It is found that the grid-plane-based algorithms can achieve much better blocking performance than that of the shortest routing algorithm and there is tradeoff between lightpath blocking performance and computation time for the three algorithms.

Keywords: Flexi-grid optical networks, lightpath routing, grid plane, lightpath blocking probability, OFDM

1. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) distributes data among a number of low-rate subcarriers to provide better spectrum utilization. Based on the optical OFDM transmission technique [1-2], a type of spectrum-sliced elastic optical path networks (SLICE) was proposed [3-4] and has received extensive interests due to its flexibility in bandwidth allocation and better fiber spectrum utilization.

Similar to the traditional optical transport networks, efficiently utilizing spectrum resources in a flexi-grid optical transport network is an important research issue. In this paper, we investigate three different routing and spectrum allocation (RSA) algorithms and make a performance comparison among these algorithms.

In the traditional wavelength division multiplexing (WDM) networks, many studies were performed for the problem of lightpath routing and wavelength assignment (RWA) and various RWA algorithms were proposed [5-6]. Compared to the RWA problem, the current RSA problem shows the following key similarities and differences.

First, in the RWA problem, the frequency spacing is typically coarse (e.g., 50 GHz), while in the RSA problem, the frequency spacing is much smaller (e.g., 6.5 GHz). Actually, under the gridless case, there is no concept of frequency spacing. Second, in the RWA problem, each optical channel corresponds to a single wavelength (or frequency grid). In contrast, in the RSA problem, each optical channel may be allocated with multiple optical frequency grids. Third, in the RWA problem, there is a concept referred to as wavelength continuity, which requires a lightpath that traverses different links to use the same wavelength on all the links. Likewise, in the RSA problem, there is a concept called spectrum continuity, which requires a lightpath traversing different links to occupy the same spectrum on all the links.

Due to the above similarities, we may extend the existing RWA algorithms to solve the RSA problem through some modifications. In this paper, we consider three RSA algorithms, including (i) fixed shortest path routing algorithm, (ii) grid-plane-based first-fit allocation algorithm, and (iii) grid-plane-based exhaustive search algorithm. The latter two algorithms are extended from the traditional waveplane-based algorithms for the RWA problem. We compare the performance of the three algorithms in terms of lightpath blocking and computation time through simulations.

2. ROUTING AND SPECTRUM ALLOCATION ALGORITHMS

Fig. 1 shows a network model of this study. The slices by each link represent the spectrum slots available on the link. Each link is assumed to be bi-directional and have the same maximum number $W$ of spectrum slots, which is the capacity up-limit of each link. Each node is assumed to support elastic or flexi-grid optical spectrum switching.

To facilitate the description of the algorithms, we also define an important concept called spectrum slot window as shown in Fig. 2, which is a set of continuous (neighboring) spectrum slots in the fiber spectrum. A spectrum slot window is considered free or eligible if all the spectrum slots contained in the window are free; otherwise, as long as any one of the contained spectrum slots is occupied, the window is considered occupied. Based on the network model and the related concept, we next introduce three RSA algorithms.

2.1. Fixed Shortest Path Routing Algorithm

---
A simple solution to the RSA problem is to find a shortest route and then allocate a suitable commonly available spectrum slot window along the found route. When allocating spectrum slots, we need to satisfy the constraint of spectrum continuity along the route. For this, we scan all the traversed fiber links to find a common free spectrum slot window along the path and employ the first-fit strategy to assign the first eligible spectrum slot window for the lightpath. The algorithm is advantageous of simplicity. However, it may suffer from network congestion due to the employment of the fixed shortest route between each pair of nodes.

2.2. Grid-Plane-Based First-Fit Algorithm

The fixed shortest path routing algorithm belongs to the category of independent routing and wavelength assignment as it separates the routing and spectrum allocation steps. The algorithm may not achieve the best blocking performance.

In this section, we introduce a new RSA algorithm, which jointly considers the routing and spectrum allocation steps. The algorithm is extended from the waveplane-based RWA ones in [7]. The key difference or novelty here is that multiple neighboring grid-planes are considered to find a free spectrum slot window that is commonly available on links when routing a lightpath. The detailed steps of the algorithm are shown by the flowchart in Fig. 3.

The above spectrum allocation algorithm is called \textit{first fit} algorithm because the algorithm stops scanning grid-planes whenever a first eligible starting grid-plane index \( k \) is found. The benefit of the first-fit strategy is that we can avoid using brand-new grid-planes, thereby preserving more unused complete grid-planes for future lightpath requests.

2.3. Grid-Plane-Based Exhaustive Algorithm

The first-fit algorithm in Section 2.2 may suffer from the situation of lower network spectrum resource utilization if there exists a route shorter than a first-fit route when a higher-index grid-plane is further considered. To remedy such a situation, we also consider an algorithm that exhaustively searches all the grid-plane sets. Specifically, rather than stopping the search process whenever the first set of eligible grid-planes is found, we scan and compare all the eligible grid-plane sets (windows) to find the first spectrum slot window that consumes the least network spectrum resource (i.e., the shortest route). This algorithm can be easily extended from the first-fit algorithm and was also studied in [8].

Compared to the first-fit algorithm, the exhaustive search algorithm is expected to achieve better blocking.
performance due to its effort on searching for the shortest routes among all the eligible grid-plane sets. This is however at the cost of a longer computation time.

3. SIMULATION RESULTS

Under the assumption of dynamic lightpath traffic demand, we evaluated the performance of the three RSA algorithms in terms of lightpath blocking and computation time through simulations. We considered three test networks, including the 14-node 21-link NSFNET network [9], a 16-node ring network, and the 11-node 26-link COST239 network [9]. We assumed on each link there are a total of 200 spectrum slots. Also, we assumed the lightpath request arrival follows a Poisson distribution with an arrival rate \( \lambda \) and the mean holding time of each established lightpath follows a negative exponential distribution with a mean \( 1/\mu \) (here we normalize \( 1/\mu \) to 1.0 such that the lightpath traffic load is \( \lambda \) Erlang). The required number of spectrum slots of each lightpath request is random and evenly distributed among 1 to 10 slots. We simulated network-wide total traffic load in Erlang.

Each simulation point was obtained through simulating a total of \( 10^6 \) lightpath arrival requests. We evaluated lightpath blocking probability, which is defined as the ratio of the total number of blocked lightpath requests to the total number of arrived lightpath requests. We also considered spectrum blocking percentage, which is defined as the ratio of the total number of blocked lightpath requests weighted by their corresponding spectrum slots to the total number of arrived lightpath requests weighted by their corresponding spectrum slots.

In the results, we use abbreviations "sp", "fl", and "exh" to represent the fixed shortest path, grid-plane-based first-fit, and grid-plane-based exhaustive algorithms, respectively.

Fig. 5, Fig. 6, and Fig. 7 show the performance of the three algorithms for the NSFNET network. Specifically, Fig. 5 shows the lightpath blocking probability versus traffic load (network-wide), Fig. 6 shows the spectrum blocking percentage versus traffic load, and Fig. 7 provides the computation time for obtaining each simulation point in Fig. 5. Based on the results, we can see that that the performance of the RSA algorithms is traded off between lightpath blocking and computation time. Specifically, the shortest path algorithm shows the highest lightpath blocking, but is advantageous of the lowest computation time. In contrast, the exhaustive search algorithm achieves the best blocking performance, which is however at the cost of the longest computation time. As an intermediate case, the first-fit algorithm achieves lightpath blocking performance close to that of the exhaustive algorithm, but much better than that of the shortest algorithm. Meanwhile, the computation time of the first-fit algorithm is very close to that of the shortest path algorithm, but much shorter than that of the exhaustive algorithm.

In addition, we evaluated the impact of network connectivity on the performance of the three RSA algorithms. We ran the same sets of simulations for the other two test networks, i.e., the ring and COST239 networks.

For the COST239 network, which has the highest average nodal degree among the three networks, we can see that the exhaustive algorithm can well take
advantage of the multi-route selection capability to improve lightpath blocking performance as shown in Figs. 11 and 12. Specifically, the blocking performance difference between the exhaustive algorithm and the first-fit algorithm becomes larger, which is of course at the cost of a longer computation time as shown in Fig. 13.

We evaluated and compared three routing and spectrum allocation (RSA) algorithms. Based on the simulation results, we found that the lightpath blocking performance is traded off with computation time. For a dense network, in order for better lightpath blocking performance, the first-fit and exhaustive algorithms should be applied, while for a sparse network, we should employ the shortest path routing algorithm to take advantage of shorter computation time since the grid-plane-based algorithms cannot bring much benefit in blocking performance improvement over the shortest path routing algorithm.

4. CONCLUSION

Through comparing the results of the three test networks, we have the following key observations for the three RSA algorithms. For a sparse network, the exhaustive algorithm does not show much benefit in blocking performance improvement over the other two algorithms, while the computation time of the exhaustive algorithm is much longer than those of the other two algorithms. In contrast, in a dense network, the exhaustive algorithm shows a stronger blocking performance improvement over the other two algorithms, which is at the cost of a longer computation time. Thus, it is suggested that for a sparse network we should employ the simple shortest path routing algorithm, while for a dense network, the more advanced first-fit or exhaustive algorithms should be applied for better lightpath blocking performance.

5. ACKNOWLEDGMENTS

This work was jointly supported by the National 863 Plans Project of China (2012AA011302), National Natural Science Foundation of China (NSFC) (61172057), and the Open Project (2011GZKF031110) from the State Key Laboratory of Advanced Optical Communication Systems and Networks, Shanghai JiaoTong University, China.

6. REFERENCES