Frequency Dispersion Index based Spectrum Defragmentation for Multicast Services in Fixed/Flex-Grid Optical Networks

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***Abstract*—In this paper, frequency dispersion index based spectrum defragmentation method for multicast services in fixed/flex-grid optical networks is proposed. Simulation results show that compared with baseline algorithm, the proposed algorithm can achieve lower blocking probability.**

Keywords—optical networks; multicast; defragmentation

I. Introduction

The rapid development of large-capacity services dominated by high-bit-rate video, cloud computing services and distributed services constantly challenge optical networks in terms of network capacity, energy consumption and economic benefits. With the popularity of multimedia communication applications, multicast technology plays a very important role in the network. The multicast technology is widely used in network video conferencing, remote classroom, network remote video monitoring and other aspects, which can improve office efficiency, enhance timeliness, and better adapt to the development of social technology and people's requirements for efficient real-time data transmission. In the process of optical network development, there will be a fixed/flex-grid optical network in which fixed-grid and flex-grid coexist [1-3]. Spectrum defragmentation is to re-establish the existing optical paths by means of network interruption, or to move the allocated spectrum, so as to achieve the purpose of maximizing fragmentation concentration and integration [4-6]. When services arrive, appropriate spectrum resources are allocated to establish transmission connections according to the requirements of spectrum consistency and continuity. After a period of time, the spectrum resources no longer remain in the original state of neat division, the small spectrum fragments in network can not be effectively used by service, and the disordered state of spectrum resources makes it impossible to find enough free spectrum segments when new services arrive, which leads to service blocking. Therefore, the research on spectrum defragmentation of multicast services in fixed/flex-grid optical networks has important practical significance.

There has been a lot of research on techniques for spectrum defragmentation in optical networks. Periodic defragmentation of elastic optical network (EON) under dynamic conditions was analyzed, and the influence of different defragmentation parameters on EON performance was evaluated[7]. A spectrum reconstruction algorithm based on resource allocation was proposed. Classify the services, divide areas according to service types of spectrum resources, and allocate services in the corresponding spectrum division [8]. An EON node structure supporting spectrum defragmentation and a new control scheme based on software defined network (SDN) are proposed to solve the problem of spectrum defragmentation[9].

In this paper, a frequency dispersion index based spectrum defragmentation (FDI-SD) method for multicast services is proposed for fixed/flex-grid optical networks. In this method, the measurement index of frequency dispersion in fixed/flex-grid optical network is proposed. On this basis, the services to be reconstructed are selected according to the service measurement index. In the process of spectrum reconstruction, multiple alternative paths are compared to select a more suitable path to carry the service, which improves the utilization of spectrum resources and reduces the congestion of services.

II. Frequency Dispersion Index based Spectrum Defragmentation for Multicast Services

The directed graph G(V,E,S) is used to represent the physical topology of a fixed/flexible optical network, where V represents optical nodes, E denotes directed fiber links, and S represents a collection of available frequency slots (FSs). The network contains two kinds of optical node sets, namely fixed-grid node set V_{fixed} and flex-grid node set V_{flex}. The multicast service (MS) is defined as MS(s,D,v), where s is the source node, D represents the set of destination nodes, and v denotes the speed required by the MS.

In this paper, We propose a frequency dispersion index based spectrum defragmentation algorithm for multicast services in fixed/flex-grid optical networks. Considering the frequency dispersion index (*FI*) and service measurement index (*SI*) of the network, spectrum defragmentation of some MSs is carried out. When MS(s,D,v) arrives, the shortest path tree (SPT) algorithm is used to generate optical trees and the first-fit (FF) algorithm is used to allocate spectrum resources. If reach the spectrum defragmentation time, calculate *FI* value, as shown in (1), where N is the number of links of the network, M indicates the number of spectrum fragments of each link, B_{ave_i} represents the average number of FSs occupied by services on link i, $LF_{frag_{ij}}$ is the number of FSs occupied by the spectrum fragment j on link i, $LF_{\max_i}$ denotes the maximum position of spectrum occupied on link i, and LF_{used_i} is the number of FSs occupied on link i. The formula (1) takes into account the degree of spectrum fragmentation and the proportion of spectrum fragments. The larger the FI value is, the more serious the spectrum fragmentation of the current network is. If the FI value exceeds a threshold FI_{block}, spectrum defragmentation needs to be performed for some currently running MSs to reduce the proportion of spectrum fragments. Firstly, the MSs set running in the network is read, and the SI of each MS is calculated to determine whether the MS needs to be reconstructed. In Formula (2), α, β, γ represents three variable constants that sum to 1, $SF_{\max}$ indicates the maximum number of FSs occupied by the service, SF_{avenum} indicates the number of FSs required by the service on each link, $LF_{\max}$ denotes the maximum number of FSs occupied by all links, SF_{num} represents the maximum number of FSs required by services, LF_{mnum} indicates the maximum number of FSs required by the services running set, Δt indicates the remaining running time of the service, $\Delta t_{\max}$ indicates the maximum remaining running time of services on the network. The larger the SI value, the greater the network improvement effect after service reconstruction, and the more necessary the spectrum reconstruction operation.

$$FI = \frac{\sum_{i=1}^{N} \frac{\sum_{j=1}^{M} \frac{B_{ave_i}}{LF_{frag_{ij}}}}{M} \cdot \frac{LF_{\max_i} - LF_{used_i}}{LF_{\max_i}}}{N} \tag{1}$$

$$SI = \alpha \cdot \frac{SF_{\max} - SF_{avenum}}{LF_{\max}} + \beta \cdot \frac{SF_{num}}{LF_{mnum}} + \gamma \cdot \frac{\Delta t}{\Delta t_{\max}} \tag{2}$$

TABLE I. PROCEDURES OF FDI-SD ALGORITHM

FDI-SD-Algorithm
Input: G(V,E,S), MS(s,D,b).
Output: Allocated FSs $\mathcal{F}$ for MSs.
1 MS arrive; Calculate a SPT T_0; Allocate FSs for multicast service;
2 **if** service id % n = 0 **then**
3 Calculate FI value;
4 **If** $FI > FI_{block}$ **then**
5 Calculate SI value for MSs in operation;
6 Sort in descending order based on the SI value;
7 Select the top λ of the MSs for spectrum reconstruction;
8 **for** the selected MSs **do**
9 Calculate k SPT T_k; Sort in ascending order based on the length of the path;
10 Record LF_{max} values according to the T_k;
11 Compare the LF_{max} values calculated and choose the best path for the MS;
12 Reallocate FSs for MS according to the new path;
13 **end for**
14 **end if**
15 **else**
16 Carry the next MS;
17 **end if**
18 **return** $\mathcal{F}$;

Table 1 shows the detailed procedures of the FDI-SD algorithm. Line 1 indicates the optical tree is calculated and spectrum resources are allocated when the service arrives. Line 2 indicates if the service id is a multiple of n, the FI value of the network is calculated, as shown in line 3. Line 4 represents that if the calculated FI is larger than the threshold FI_{block} at this time, spectrum defragmentation will be carried out. Lines 5-7 represent the process of selecting reconstruction services. Calculate the SI of MSs running on the current network and select the first λ MSs in descending order for spectrum defragmentation. Lines 8-13 represent the process of selecting the refactoring path. The SPT algorithm is used to calculate k shortest paths of services and allocate spectrum resources in turn. Record the $LF_{\max}$ value of each path and compare the $LF_{\max}$ value of k paths. Select the most appropriate path to reconnect to the service and update the network status.

III. ILLUSTRATIVE EXAMPLE

Fig. 1 shows an illustrative example of the FDI-SD algorithm. The physical topology and network spectrum usage graphs are shown in Fig. 1.

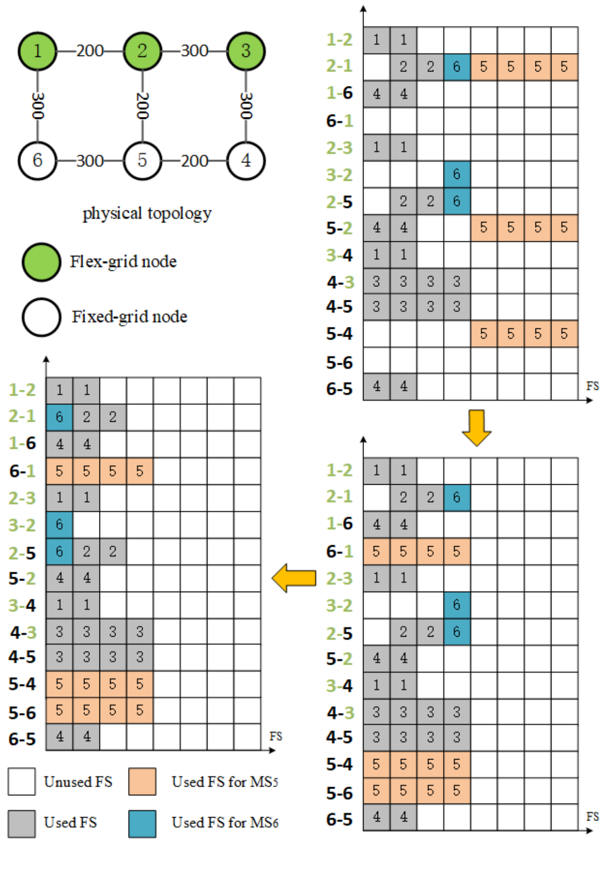

Fig. 1. physical topology and network spectrum usage graphs

After the service has been running for a period of time, the spectrum usage graph in the network is shown in the upper figure of Fig. 1. According to (1), it can be calculated that the FI value of the current network is about 0.1. Assuming that FI_{block} is less than 0.1, then spectrum defragmentation is required at this time. Assuming that the influence of the remaining services time is not taken into account at this time, α is set to 0.6, β is set to 0.4, and the SI value is calculated according to (2) as $SI_1 = 0.2$, $SI_2 \approx 0.208$, $SI_3 \approx 0.267$, $SI_4 = 0.2$, $SI_5 = 0.7$, $SI_6 = 0.325$ respectively. If spectrum reconstruction is required for two services, then it is MS_5(5, {1, 4}, 50) and MS_6(3, {1, 5}, 30). Setting alternative path number to 2. For MS_5, firstly calculate the two shortest paths from the source node to each destination node respectively, which are 5-2-1, 5-6-1 and 5-4, 5-2-3-4. Then, the two paths with the shortest length after combination are obtained, the alternative path 1 is 5-2-1, 5-4, and the alternative path 2 is 5-6-1, 5-4. It can be seen that the alternative paths include the original path, because with the arrival and departure of MSs, the location of the FSs allocated at different times will also change, and the spectrum allocation of the original path may get different allocation results. Next, the spectrum resources of the original path are pre-released, and the two alternative paths are pre-allocated spectrum resources respectively. Alternative path 1 has $SF_{\max}$ of 8 after spectrum resources are pre-allocated, and alternative path 2 has $SF_{\max}$ of 4 after spectrum resources are pre-allocated. After comparison, the alternative path 2 is selected to carry the MS, and the reconstructed spectrum usage graph is shown in Fig. 1 below. After the same procedure of spectrum defragmentation for MS_6, the FI value of the network is 0, and the degree of spectrum fragmentation in the network is improved compared with the figure above.

IV. Simulation Results And Analysis

In this paper, different FI_{block} is used to simulate the proposed FDI-SD algorithm. The benchmark algorithm is based on the distance-adaptive modulation mode and is represented by SPT-FF. The baseline algorithm uses SPT algorithm to calculate the service path and FF algorithm to allocate resources. The simulation uses the NSFNet network topology with 14 nodes and 21 bidirectional links. The simulated traffic load ranges from 200 Erlang to 300 Erlang, with spacing of 20 Erlang. Considering the number of different flex-grid nodes in the network, we carried out simulation in three cases where the number of flex-grid nodes are 5, 8 and 11 respectively.

Fig. 2 shows the blocking ratio of each algorithm when the number of flex-grid nodes in the fixed/flex-grid optical network is 5. It can be found that compared with blocking ratio shown by benchmark algorithm SPT-FF, the FDI-SD algorithm has lower blocking ratio under different traffic load, because the FDI-SD algorithm will conduct spectrum defragmentation on a part of the network MSs that has a great influence on spectrum fragments at appropriate time. Spectrum fragmentation is reduced after spectrum defragmentation, and spectrum allocation becomes more compact. The probability that MSs can successfully allocate resources becomes higher, and the blocking probability is reduced. In addition, as shown in Fig. 2, with the increase of traffic load, blocking probabilities of all algorithms will increase, because the more services co-exist in the network, the more FSs will be occupied, and the higher probability of new MS blocking.

Fig. 3 shows the blocking ratio of some algorithms under 5 flex-grid nodes. With the increase in the number of flex-grid nodes, blocking probability under all algorithms decreases. The reason is that the spectrum granularity of flex-grid links is smaller than that of fixed-grid links, spectrum utilization is improved, and more services can be carried in the case of the same spectrum. Therefore, under the condition of the same traffic load, the more flex-grid nodes, the lower blocking probability. Compared with Fig. 2, the value of FI_{block} in Fig. 3 is set higher, because with the increase of the number of flex-grid nodes, the network is more inclusive to spectrum fragmentation, and the fragmentation degree of spectrum will be higher when traffic blocking occurs, and the corresponding FI value will be higher. When the number of flex-grid nodes is 5, blocking probability differentiation is not high when FI_{block} is less than 0.6. However, when the number of flex-grid nodes is 8, the discrimination of blocking probability is not high when FI_{block} is less than 0.75. The higher the value of FI_{block}, the closer the blocking probability will be to baseline algorithm.

Fig. 4 shows the blocking ratio of the algorithms under 8 flex-grid nodes. Compared with Fig. 2, the optimization degree of the FDI-SD algorithm for blocking ratio in Fig. 4 is more obvious. Due to the increase in the number of flex-grid nodes, the flexibility of spectrum reconstruction is higher, more appropriate spectrum locations can be selected to carry services, higher efficiency of fragmentation, and better optimization effect of blocking ratio.

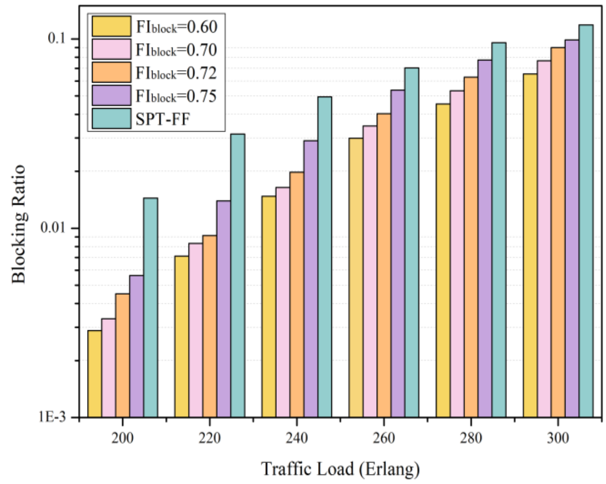

Fig. 2. Blocking ratio under 5 flex-grid nodes

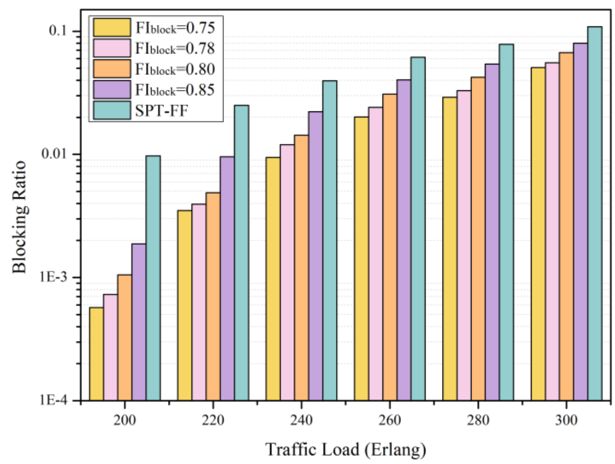

Fig. 3. Blocking ratio under 8 flex-grid nodes

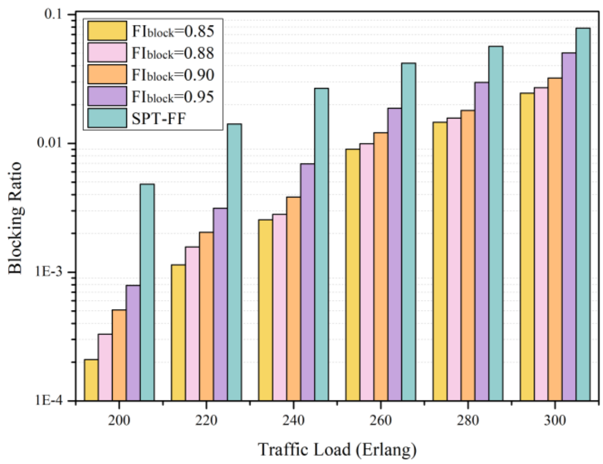

Fig. 4. Blocking ratio under 11 flex-grid nodes

V. CONCLUSION

This paper proposes a frequency dispersion index based spectrum defragmentation algorithm (FDI-SD) for multicast services in fixed/flex-grid optical networks. The simulation results show that the FDI-SD algorithm can reduce the blocking probability compared with the traditional algorithm, and the performance of the FDI-SD algorithm is also different under different parameter settings.

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REFERENCES

[1] X. Yu, et al., “Migration from fixed grid to flexible grid in optical networks,” in IEEE Communications Magazine, 53(2), 34-43, 2015.

[2] Y. Tang et al., “Distributed sub-tree based multicasting aggregation scheme in elastic optical data center networks,” 2018 Asia Communications and Photonics Conference (ACP), Hangzhou, China, 2018, pp. 1-3, doi: 10.1109/ACP.2018.8596253.

[3] X. Tian, B. Li, R. Gu and Z. Zhu, "Reconfiguring multicast sessions in elastic optical networks adaptively with graph-aware deep reinforcement learning," in Journal of Optical Communications and Networking, vol. 13, no. 11, pp. 253-265, November 2021, doi: 10.1364/JOCN.431225.

[4] B. C. Chatterjee, S. Ba, and E. Oki, “Fragmentation problems and management approaches in elastic optical networks: a survey,” IEEE Communications Surveys and Tutorials, vol. 20, no. 1, pp. 183-210, First Quarter 2018.

[5] T. Sawa, F. He, T. Sato, B. C. Chatterjee, and E. Oki, “Defragmentation using reroutable backup paths in toggled 1+1 path protected elastic optical networks,” in Proc. APCC, Ningbo, China, 12-14 Nov. 2018.

[6] N. Kitsuwan, K. Akaki, P. Pavarangkoon and A. Nag, "Spectrum allocation scheme considering spectrum slicing in elastic optical networks," in Journal of Optical Communications and Networking, vol. 13, no. 7, pp. 169-181, July 2021, doi: 10.1364/JOCN.422915.

[7] J. Comellas, L. Vicario and G. Junyent, “Periodic defragmentation in elastic optical networks,” 2018 20th International Conference on Transparent Optical Networks (ICTON), Bucharest, Romania, 2018, pp. 1-4, doi: 10.1109/ICTON.2018.8473581.

[8] L. Wu, P. Guo, and L. Du, “Spectrum reconstruction algorithm based on resource partition allocation in elastic optical networks,” Journal of Physics: Conference Series. 1971(2021). 012096. 10.1088/1742-6596/1971/1/012096.

[9] P. Zhu et al., “Software-defined elastic optical network node supporting spectrum defragmentation,” in Journal of Optical Communications and Networking, vol. 9, no. 1, pp. A63-A70, Jan. 2017, doi: 10.1364/JOCN.9.000A63.