Spectrum Reconstruction Algorithm based on Resource Partition Allocation in Elastic Optical Networks

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Abstract. In order to solve the problem of spectrum fragment in elastic optical networks, a spectrum reconstruction algorithm based on resource partition allocation is proposed in this paper. Services are classified according to the different frequency of the services that occupy different number of frequency slots in the networks. Region division of spectrum resources is made according to the type of services and services are allocated in the corresponding spectrum partitions. When defragmenting in the networks, we reconstruct the spectrum for different regions with comprehensively considering the factors in time domain and frequency domain, integrating current resources and preventing the generation of spectrum fragment in the future. Simulation results show that the algorithm can reduce the degree of network fragmentation and reduce traffic blocking.

1. Introduction

With more flexible resource allocation methods, support for super-wavelength transmission and a variety of different modulation formats, elastic optical networks can better meet the needs of future optical networks[1]. However, it must comply with more stringent resource allocation constraints, spectrum consistency constraints and continuity constraints[2]. With the operation of networks, a large number of spectrum fragment will be generated, which cannot be used by subsequent services, so the performance of networks is seriously affected[3-4]. Therefore, scientific and effective spectrum defragmenting mechanism is needed to reintegrate spectrum resources. From the perspective of reducing cost, integrating resources and preventing fragment, this paper proposes a method of spectrum resource partition allocation and arrangement to reduce the scope of service processing and calculation, and improve the efficiency of the algorithm while reducing the computational overhead and network operation burden. In addition, the adjacent services with the same remaining time and larger bandwidth are selected to integrate the current resources and prevent spectrum fragmentation.

2. Spectrum reconstruction algorithm based on resource partition allocation

According to the specification of the optical network equipment in actual networks, the coding mode and the frequency slot size specified by ITU-T, the maximum bandwidth of a single request in elastic optical networks is usually no more than 10 frequency slots, so the services occupying different number of slots are divided into high-frequency services, intermediate-frequency services and low-frequency services at a ratio of 3:3:4 according to the frequency of occurrence from high to low. According to the classification of services, 320 frequency slots are divided into high-frequency region, intermediate-frequency region and low-frequency region, as shown in Figure 1. When resources in corresponding partition of requests are sufficient, high-frequency services are allocated by exact-fit(EF)[5] at high-frequency region, intermediate-frequency services are allocated by last-fit(LF)[6]...
at intermediate-frequency region and low-frequency services are allocated by first-fit (FF) \cite{4} at low-frequency region. If resources in target region are insufficient, high frequency services are allocated by FF at non-high frequency regions, and intermediate frequency services are allocated by LF at high frequency region firstly, if it is not successful, they are allocated by FF at low frequency region. Low frequency services are allocated by LF at non-low frequency regions.

![Figure 1. Schematic diagram of spectrum resources partition.](image)

On the basis of the above resource allocation, three problems are solved in the design of spectrum reconstruction algorithm. The first problem is the object of the reconstruction algorithm: the spectrum reconstruction algorithm based on resource partition allocation is carried out for different spectrum partitions, and the object of the reconstruction algorithm is all services carried in the reconstructed spectrum partition of all links in the network. The second problem is the order of service reconfiguration: the service with short remaining time in the network can release spectrum resources quickly, so integrating the services with short remaining time as a priority can obtain continuous available resources in a short time. The third problem is the reconfiguration service migration: before the spectrum migration of the reconfiguration service, all the available candidate spectrums conforming by EF principle are selected in the reconfiguration partition and added into the set of candidate spectrum. The final reallocated spectrum is selected from the candidate spectrum by the cost function, and its calculation is shown in equations (1) and (2).

\[
\text{cost}^i(sp_j) = \frac{\Delta \tau_j + \Delta \tau_{jm} + \Delta \tau_j}{|B_j|} \tag{1}
\]

\[
\text{cost}(sp_j) = \sum_{e \in p} \text{cost}^i(sp_j) \tag{2}
\]

Combined with Figure 2 and Figure 3, the calculation of equation (1) and equation (2) is illustrated. \(\text{cost}^i(sp_j)\) represents the cost of candidate spectrum \(sp_j\) in the link \(e_i\). As shown in Figure 2, there are two candidate spectrum \(sp_1\) and \(sp_2\) for service 8. \(|B_j|\) represents the bandwidth of the spectrum block \(B_j\) composed of candidate spectrum and spectrum of left and right adjacent services, which is represented by the number of frequency slots contained in the spectrum block. As shown in Figure 3, the candidate spectrums of service 8 and the spectrum of left and right adjacent services constitute spectrum blocks \(B_1\) and \(B_2\). \(\Delta \tau_j, \Delta \tau_{jm}, \Delta \tau_j\) represent the difference between remaining time of the left, middle and right services that in the spectrum block and the maximum of the three values, respectively. In equation (2), \(\text{cost}(sp_j)\) represents the cost of the candidate spectrum \(sp_j\) in the work path, and \(p\) is the set of links contained in the path. According to equation (1), the value of the cost function is proportional to the time difference of the adjacent services and inversely proportional to the bandwidth of the spectrum blocks composed of the reconstructed services and the adjacent services. When selecting the candidate spectrum, the candidate spectrum with the lowest cost function value is selected. The smaller the cost function value is, the smaller the time difference between the reconfigured services and the left and right adjacent services is,
and the larger the width of the spectrum block composed of the three is. So reconfigured services and the left and right adjacent services will be end in a smaller time interval. As a result, more continuous spectrum resources will be obtained.

Figure 2. Services distribution on the path in frequency domain.

If the candidate spectrum cannot be obtained by EF in the above process, and according to the method of resource partition allocation, the distribution status of services in each spectrum partition is shown in Figure 4, the service distribution in the dark spectrum region is denser while the service distribution in the light-colored region is sparse. In order to integrate spectrum resources, when performing spectrum reconstruction, the reconstructed services need to be shifted to the direction of more intensive service distribution in spectrum partition. Therefore, the following standby strategies are designed for reconfiguration: If the current spectrum partition for the reconfiguration operation is in the high-frequency region or the low-frequency region, the FF mode is used to reallocate the reconfigured services. If it is currently in the intermediate-frequency region, the LF mode is used to reallocate the reconfigured services.

Figure 3. Remaining time distribution of services in link2.

Figure 4. Density of service distribution in different regions.

The flow chart of the spectrum reconstruction algorithm based on resource partition allocation is shown in Figure 5.
Figure 5. Flow chart of spectrum reconstruction algorithm based on resource partition allocation.

3. Simulation realization and result analysis

The service blocking rate is expressed by BP, as shown in equation (3), where $N_{\text{blocked}}$ is the number of blocked services and $N_{\text{sum}}$ is the total number of requests access to the network. The fragmentation index is used to evaluate the degree of spectrum fragmentation in the network, which is calculated as shown in equation (4). $NFI$ is the network fragmentation index, $N_{vf}^i$ and $N_{vp}^i$ represent the number of idle frequency slots and their connection points, respectively. $N_{fs}$ is the total number of frequency slots in a link, and $t$ is the total number of links in the networks.

$$BP = \frac{N_{\text{blocked}}}{N_{\text{sum}}}$$

$$NFI = \frac{1}{t} \sum_{i=1}^{t} \left[ \left( 1 - \frac{N_{vp}^i}{N_{vf}^i} \right) \cdot \frac{N_{vp}^i}{N_{fs}} \right]$$

The topologies use NSFNET network and USNET network in the simulation. Each optical fiber link is set to 4THz and the size of each frequency slot is 12.5GHz, then one link contains 320 frequency slots. The source nodes and the destination nodes of the requests are randomly generated from the nodes of the adopted networks. The arrival rate of the requests in the networks obeys the Poisson distribution with the mean value of $\lambda$, and the services duration obeys the negative exponential distribution with the mean value of $1/\mu$. In the simulation, BPSK[7] is adopted for modulation and KSP[8] is adopted for routing, which K is set to 3. The spectrum allocation algorithm is the algorithm based on the partition allocation method proposed in this paper. It is assumed that
services with 2, 3 and 5 frequency slots are the high-frequency services, services with 4, 6 and 7 frequency slots are the intermediate-frequency services and services with 1, 8, 9 and 10 frequency slots are the low-frequency services. The rate range of generating requests in the network is between 10Gbit/s and 125Gbit/s, and the ratio of arrival rate of three kinds of services is set to 3: 2: 1. The rate range of the three services is shown in Table 1. The fragmentation index of the current network partition is calculated when every 100 services leaving the partition, and the threshold of triggering partition reconstruction is set to fragmentation index greater than or equal to 0.05.

| Type of services        | Range of rate                     |
|-------------------------|-----------------------------------|
| High-frequency services | 12.5Gbit/s \(< C \leq 37.5\) Gbit/s and 60Gbit/s \(< C \leq 72.5\) Gbit/s |
| Intermediate-frequency services | 37.5Gbit/s \(< C \leq 60\) Gbit/s and 72.5Gbit/s \(< C \leq 87.5\) Gbit/s |
| Low-frequency services  | 10Gbit/s \(\leq C \leq 12.5\) Gbit/s and 87.5Gbit/s \(< C \leq 125\) Gbit/s |

Figure 6 and Figure 7 show the number of times of performing spectrum reconstruction for defragmenting in each partition and the fragmentation index before and after each defragmenting respectively in NSFNET network and USNET network under the same load during a simulation. It can be seen from the figures that the two kinds of networks perform the most reconstruction times in the high-frequency region, because the high-frequency region carries more frequent services, resulting in a serious degree of fragmentation. During the whole simulation process in NSFNET network, the average fragmentation index after each reconfiguration is respectively 14.96%, 17.10% and 14.58% lower than that before reconfiguration in high-frequency region, intermediate-frequency region and low-frequency region. And in USNET network, the average fragmentation index after each reconfiguration is respectively 15.43%, 15.59% and 15.57% lower than that before reconfiguration in high-frequency region, intermediate-frequency region and low-frequency region.

Figure 8 and Figure 9 show the variation of service blocking rate with load intensity using spectrum reconstruction algorithm with defragmenting and without defragmenting respectively in NSFNET network and USNET network. It can be seen that with the increase of network load intensity, the improvement effect of the reconfigured network is more and more obvious compared with the non-reconfigured network. When the load reaches 600erlangs, the blocking rate of the reconfigured

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![Figure 6](image6.png)

**Figure 6.** Comparison of fragmentation index before and after reconstruction in NSFNET network.

![Figure 7](image7.png)

**Figure 7.** Comparison of fragmentation index before and after reconstruction in USNET network.
NSFNET network is 12.25% lower than that of the non-reconfigured network, and the blocking rate of the reconfigured USNET network is 10.71% lower than that of the non-reconfigured network.

Figure 8. Comparison of blocking rate with or without reconstruction in NSFNET network.

Figure 9 Comparison of blocking rate with or without reconstruction in USNET network.

4. Conclusion

In order to solve the problem of spectrum fragment in elastic optical networks, firstly, this paper partitions the spectrum resources and designs a partition-based resource allocation algorithm. Secondly, on the basis of resource partition allocation, a spectrum reconstruction algorithm is designed, which performs reconfiguration in different spectrum partitions separately to reduce the cost and network burden. When the spectrum partition is reconstructed, the time domain and frequency domain factors are comprehensively considered to effectively integrate the current resources and prevent the generation of new spectrum fragments at the end of service. Finally, the simulation results show that the spectrum fragmentation index is reduced and the service blocking rate is obviously reduced after the implementation of the algorithm.

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