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Regular Articles

A spectrum defragmentation strategy for service differentiation consideration in elastic optical networks

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A R T I C L E I N F O

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A B S T R A C T

The spectrum fragmentation problem remains to be an open issue in elastic optical networks. In addition, the quality of service cannot be ignored during the transmission process. In this paper, we propose a novel spectrum defragmentation strategy considering the service differentiation, named SDSD, to improve the network performance in terms of the spectrum resources utilization, blocking probability (BP), and the set-up time for the serving connections. The presented results show that the proposed scheme can allocate the spectrum resources efficiently while decreasing the BP and connection set-up time. Moreover, the low grade services will be migrated preferentially during the phase of spectrum defragmentation, decreasing the number of migration.

1. Introduction

Elastic optical network (EON) technologies arise as promising solutions for the future high speed and capacity optical transmission, since they can provide superior flexibility in spectrum assignment strategy toward seamless support for diverse services, such as internet of things and cloud computing etc. [1–3]. It enables that one service can be allocated a number of subcarriers corresponding with its bandwidth demand [4]. Meanwhile, data and control plane innovations are driving the evolution of EON enabling more granular reservation for spectrum portion. EON allow an efficient utilization of spectrum resources using 12.5 GHz (even 6.25 GHz) frequency slot (FS) multiples instead of a fixed spacing. However, the spectrum fragmentation (SF) is also introduced [5]. SF is often assumed to be a serious problem specifically in a dynamic traffic context. Dynamic operation might cause optical spectrum to be divided into more fragments, which makes it difficult to find available contiguous spectrum resource for the incoming services, leading thus to an increased blocking probability (BP).

To address the above issue, the central frequency of already established connections can be shifted to create wider contiguous spectrum resources segments, which can be assigned to the incoming services. This can also be called spectrum defragmentation which aims at re-optimizing the spectrum resources utilization. In dynamic scenarios, spectrum converters are rarely used in optical networks for their high cost. Thus, the BP of the services will be increased and the grade of services will also be degraded.

Against this background, we present a spectrum defragmentation strategy taking into account of the service differentiation (SDSD). The proposed algorithm can make good performances in terms of the spectrum utilization, BP, and the connection set-up time. In addition, the number of migration can also be decreased. The reminder of the paper is structured as follows. We first describe the current researches on the spectrum defragmentation in more detail in Section 2. The presented scheme is shown in Section 3 and the simulation results are given in Section 4. Then the conclusions are drawn in Section 5.

2. Related works

To improve the utilization efficiency of the spectrum resources in EON, the spectrum defragmentation strategies are aroused much attention mainly from the view of techniques, the spectrum defragmentation under the novel network architectures, and the services' point. Some studies are also from the point of hardware design to decrease the spectrum fragmentation blocks.

2.1. Spectrum defragmentation techniques

To address the spectrum defragmentation issue, two main techniques, namely push-pull and make-before-break, are widely studied.

A number of defragmentation solutions were implemented at the physical layer, not free from limitations. Given this, the effective push-pull technique based on optical channel re-tuning was proposed. Then

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its performance was evaluated in [6,7]. Note that this push-pull technique does not need additional transponders and also does not lead to traffic disruption. Nevertheless, authors in [8] presented a technique, named source-independent push-pull (SIPP), which is suitable for super channels.

For the make-before-break technique, if any connection was identified for reconfiguration, an additional connection was first established between the same source and destination nodes. It is typically exploited to perform defragmentation at the physical layer and additional transponders are needed at both the source and destination node [6], which makes the cost higher. This limitation can be overcome by the spectrum sweeping based on tuning techniques [9]. This method does not need any additional transponders and can achieve optical layer hitless defragmentation by using automatic frequency control abilities of coherent receivers. However, this method may still lead to partial spectrum defragmentation for the difficulty to move spectral slots over other connections' spectra. Thus, the hop tuning technique has been presented to support full spectrum defragmentation with a quite short retuning latency.

2.2. Spectrum defragmentation under novel network architectures

In addition, some spectrum defragmentation solutions have been proposed under novel network architectures. More attention has been paid for spectrum defragmentation issue in software-defined EON (SD-EON). Authors in [10,11] investigated the online spectrum defragmentation to improve spectrum utilization efficiency. However, authors in [12] first presented an EON node structure supporting spectrum defragmentation. Bulk traffic can be separated and fit into multiple fragments to mitigate fragmentation induced blocking.

Note that the semi-flexible grid networks match the hardware complexity in the present fixed grid systems while matching the spectrum efficiency of elastic networks. In case of this, authors in [13] proposed a disruption minimized dynamic spectrum defragmentation from the service perspective.

2.3. Traffic attributes considered scheme

To enhance the network performance, the efficiency of the spectrum defragmentation must be improved. One important way is to minimize the disruption of the in-service connections during the spectrum defragmentation.

A utilization technique of spectrum defragmentation by using wavelength inverse-mux, called as elastic inverse-mux (EIMUX), was proposed [14]. This technique can utilize spectrum fragmentation without reconfiguration of in-service optical paths, realizing the efficient use of spectrum resources.

To minimize traffic disruptions, authors in [15] designed a best-effort traffic migration scheme for rerouting and tried to apply the make-before-break scenario. In addition, authors in [16,17] proposed a novel spectrum defragmentation algorithm by using independent sets based on auxiliary graph model to efficiently consolidate the spectrum allocation. The simulation results showed that the proposed algorithms made better performance on BP while minimizing the number of disrupted connections. Moreover, dynamic and adaptive bandwidth defragmentation with time-varying traffic was studied in [18,19].

The services migration delay and the BP for the whole network also need to be reduced. C. You et al. [18] and M. Zhang et al. [20,21] investigated parallel defragmentation and estimated its performance on the latency and disruption. Authors in [22] introduced the accommodation capability of spectrum block. Then the bandwidth BP of the proposed fragmentation-aware algorithm was validated with different traffic granularity distributions. However, R. Zhu et al. [23] presented a multi-path fragmentation-aware routing, modulation and spectrum scheme for advance reservation (AR) and immediate reservation (IR) requests to improve the BP performance.

But beyond all that, authors in [24–27] handled with the spectrum defragmentation from the perspective of hardware design, including the flexible photonic node architecture, the Reconfigurable Optical Add-Drop Multiplexer (ROADM) architecture, also the flexible transmitter and receiver.

3. The proposed spectrum defragmentation strategy

Undoubtedly, the above researches have been very useful for solving the spectrum fragmentation problem to some extent. Nevertheless, very few studies focus on the service differentiation provision during the process of the spectrum defragmentation. In this section, we grade the services first based on the bit error rate (BER) requirement, and then present a spectrum defragmentation strategy considering the service differentiation, named SDSD, which has been described specifically in the following.

3.1. QoS definition and service differentiation

QoS has been defined as the collective effect of service performances, which can determine the degree of satisfaction of a user of the service. The service quality criteria include speed, accuracy, availability, reliability, and security and so on. The QoS definition can be viewed from four perspectives and their relationship has given in Fig. 1.

We focus on the customer's QoS requirements, which may be expressed in non-technical language. A user does not care about how a service is implemented. But the same service offered by different providers may be compared on the user-oriented performance parameters, including delay, delay variation, information loss.

In this study, we just select the typical BER requirement which is widely used to represent the QoS metric. Based on the different QoS requirements for various services, the spectrum defragmentation strategy considering the service attributes must be paid much more attention. The service class categories and typical applications are given in Table 1.

3.2. SDSD scheme

To address the spectrum fragmentation issue, simultaneously support the QoS requirements for various services, we design a scheme considering the service differentiation. Our proposed algorithm based on the Section 3.1 is shown in Fig. 2. Then, the key steps are described in more detail.

When a service arrives at the network, the routing and spectrum assignment (RSA) process will be first taken. In our scheme, the available routes set for each service is calculated by the *k* shortest paths (K-SP) algorithm. For the spectrum assignment, we exploit the first-fit (FF) algorithm. All the frequency slots will be labeled as S_i (i = 0,1,2, …,max-1). For each service, the available spectrum resources searching will be always from S_0 until first finding the continuous and contiguous spectrum resources for *R*. It should be pointed out that the service grade is determined first as the service reaches the network.

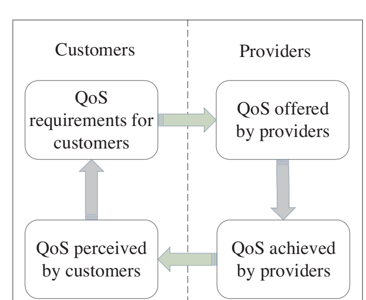

Fig. 1. Four viewpoints of QoS.