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Time-aware service-classified spectrum defragmentation algorithm for flex-grid optical networks

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ABSTRACT

By employing sophisticated routing and spectrum assignment (RSA) algorithms together with a finer spectrum granularity (namely frequency slot) in resource allocation procedures, flex-grid optical networks can accommodate diverse kinds of services with high spectrum-allocation flexibility and resource-utilization efficiency. However, the continuity and the contiguity constraints in spectrum allocation procedures may always induce some isolated, small-sized, and unoccupied spectral blocks (known as spectrum fragments) in flex-grid optical networks. Although these spectrum fragments are left unoccupied, they can hardly be utilized by the subsequent service requests directly because of their spectral characteristics and the constraints in spectrum allocation. In this way, the existence of spectrum fragments may exhaust the available spectrum resources for a coming service request and thus worsens the networking performance. Therefore, many reactive defragmentation algorithms have been proposed to handle the fragmented spectrum resources via re-optimizing the routing paths and the spectrum resources for the existing services. But the routing-path and the spectrum-resource re-optimization in reactive defragmentation algorithms may possibly disrupt the traffic of the existing services and require extra components. By comparison, some proactive defragmentation algorithms (e.g. fragmentation-aware algorithms) were proposed to suppress spectrum fragments from their generation instead of handling the fragmented spectrum resources. Although these proactive defragmentation algorithms induced no traffic disruption and required no extra components, they always left the generated spectrum fragments unhandled, which greatly affected their efficiency in spectrum defragmentation. In this paper, by comprehensively considering the characteristics of both the reactive and the proactive defragmentation algorithms, we proposed a time-aware service-classified (TASC) spectrum defragmentation algorithm, which simultaneously employed proactive and reactive mechanisms in suppressing spectrum fragments with the awareness of services' types and their duration times. By dividing the spectrum resources into several flexible groups according to services' types and limiting both the spectrum allocation and the spectrum re-tuning for a certain service inside one specific spectrum group according to its type, the proposed TASC defragmentation algorithm cannot only suppress spectrum fragments from generation inside each spectrum group, but also handle the fragments generated between two adjacent groups. In this way, the proposed TASC algorithm gains higher efficiency in suppressing spectrum fragments than both the reactive and the proactive defragmentation algorithms. Additionally, as the generation of spectrum fragments is retrained between spectrum groups and the defragmentation procedure is limited inside each spectrum group, the induced traffic disruption for the existing services can be possibly reduced. Besides, the proposed TASC defragmentation algorithm always re-tunes the spectrum resources of the service with the maximum duration time first in spectrum defragmentation procedure, which can further reduce spectrum fragments because of the fact that the services with longer duration times always have higher possibility in inducing spectrum fragments than the services with shorter duration times. The simulation results show that the proposed TASC defragmentation algorithm can significantly reduce the number of the generated spectrum fragments while improving the service blocking performance.

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1. Introduction

Nowadays, due to the co-existence of diverse services with heterogeneous bandwidth requirements in data transmissions, high spectrum-allocation flexibility and resource-utilization efficiency are intensively desirable in an optical network. However, the current wavelength-division-multiplexing (WDM) optical networks, which allocate uniform spectral bandwidth to diverse services regardless of their different bandwidth requirements, can provide neither high spectrum-allocation flexibility nor high resource-utilization efficiency in accommodating various kinds of services. In order to improve the flexibility in spectrum allocation and the efficiency in spectrum utilization, flex-grid optical networks have been proposed recently [1]. By employing a finer spectrum allocation granularity, frequency slot (FS), flex-grid optical networks can adaptively allocate spectrum to diverse services according to their respective bandwidth requirements. In this way, flex-grid optical networks accommodate diverse services in a spectrum-efficient manner, which increases not only the flexibility in spectrum allocation but also the efficiency in resource utilization [2].

A sophisticated routing and spectrum assignment (RSA) algorithm, which seeks the routing paths for services and assigns the optimized spectral resources to them, is one of the key enabling technologies to realize spectrum-efficient service accommodation in flex-grid optical networks [3]. Therefore, many RSA algorithms, such as the typical shortest-path-routing first-fit RSA algorithm [4], the distance-adaptive RSA algorithms [5,6], and the multi-path-routing traffic-split RSA algorithms [7,8], have been proposed for flex-grid optical networks. All these RSA algorithms are focus on seeking the optimized routing paths and assigning a minimum number of contiguous FSs for services, but they ignore some isolated, small-sized, and unoccupied spectrum bands, which are remained after spectrum allocation in flex-grid optical networks [9]. Due to the spectrum continuity and contiguity constraints in spectrum allocation, these remained isolated and small-sized spectrum bands can hardly be allocated to subsequent services even though they are unoccupied. And they are thus known as spectrum fragments. These generated spectrum fragments may deplete the available spectrum resources for subsequent services and thus worsen the networking performance (e.g. service blocking probability) of a flex-grid optical network [10]. Therefore, many spectrum defragmentation algorithms, employing either reactive or proactive mechanisms, have been proposed to reduce spectrum fragments generated in a flex-grid optical network [11–31]. By employing reactive mechanisms, such as path-rerouting and spectrum-retuning techniques, many reactive defragmentation algorithms have been proposed to reduce the amount of the spectrum fragments generated in flex-grid optical networks [11–24]. In [11], the author employed make-before-break rerouting technology to reduce the number of the generated spectrum fragments via rerouting the paths for the existing services and re-optimizing the arrangement of the used FSs for them. In [12–16], spectrum-retuning technique was used by reactive defragmentation algorithms to reduce the number of the spectrum fragments generated in time-varying traffic via re-assigning spectrum resources for the existing services. Both path-rerouting and spectrum-retuning techniques were adopted by reactive defragmentation algorithms in [17,18], but these defragmentation algorithms may always disrupt the traffic of the existing services and require extra components. Besides path-rerouting and spectrum-retuning techniques, independent-sets maximizing technique [19,20], and push-pull technique [21] were introduced into reactive defragmentation algorithms to mitigate traffic disruption existing in either path-rerouting or spectrum-retuning procedure but at the cost of system complexity or extra components. In [22,23], Software-Defined Networking (SDN) technique was introduced into spectrum defragmentation to realize highly-efficient online defragmentation, which can provide a control-plane solution for flex-grid optical networks. In [24], Greedy and genetic algorithms employing periodic defragmentation mechanisms were proposed for filterless flex-grid optical networks. By inheriting the passive nature of a filterless optical network, these defragmentation algorithms can provide a cost-effective, agile, and multicast-enabled solution for flex-grid optical networks. But the existence of unfiltered signals induced by the drop-and-continue node architecture may greatly exhaust the available spectrum resources for subsequent services, since the FSs occupied by the unfiltered signals cannot be reused by other services. In this way, the networking performance of these defragmentation algorithms will be greatly affected, especially when the traffic load is high. All the above-mentioned reactive defragmentation algorithms are successful in reducing spectrum fragments generated in a flex-grid optical network, but the induced cost in handling the fragmented spectrum, such as traffic disruption or system complexity, always affects their feasibility in reality. Besides, these reactive defragmentation algorithms usually introduce no mechanisms to suppress spectrum fragments from their generation, which may also degrade their efficiency in reducing spectrum fragments. Besides reactive defragmentation algorithms, some proactive defragmentation algorithms, such as fragmentation-aware RSA algorithms, fixed grouping RSA algorithm and flexible grouping RSA algorithms [25–31], were proposed to restrain the generation of spectrum fragments instead of handling the generated spectrum fragments. In fragmentation-aware RSA algorithms, a variable “cut” is defined to evaluate the extent how a candidate provisioning scheme can split a spectral band into pieces [25–27]. With such variable “cut”, fragmentation-aware RSA algorithms can decrease the generated isolated spectrum blocks in a spectral band, which helps reduce the generation probability of spectrum fragments. But fragmentation-aware RSA algorithms cannot suppress spectrum fragments from generation thoroughly and have no mechanism to handle the generated spectrum fragments. In the fixed grouping RSA algorithm, the whole spectrum resources are pre-sorted into several fixed groups and the resources in one group are allocated to one specific kind of services [28]. Since the released or the remained spectrum resources in one group can always be re-utilized by the services of the same kind, the fixed grouping RSA algorithm can suppress spectrum fragments from generation thoroughly, but the fixed spectrum group limits the flexibility in spectrum allocation and thus degrades the networking performance. In flexible grouping RSA algorithms, the whole spectrum resources are pre-sorted into several flexible groups and the resources in one group are allocated to one specific kind of services [29–31]. Since the released or the remained spectrum resources inside one group can always be re-utilized by the services of the same kind, these flexible grouping RSA algorithms induce no spectrum fragments inside spectrum groups, but spectrum fragments may still be generated in the spectrum interval between two adjacent spectrum groups. However, these flexible grouping algorithms have no mechanisms to handle the spectrum fragments generated in the intervals between spectrum groups. And the unhandled spectrum fragments left between spectrum groups may finally deteriorate the service blocking performance of these flexible grouping RSA algorithms.

In this paper, by comprehensively considering the characteristics of both the reactive and the proactive defragmentation algorithms, we propose a time-aware service-classified spectrum defragmentation algorithm to suppress spectrum fragments in flex-grid optical networks, which simultaneously adopts proactive and reactive mechanisms in suppressing spectrum fragments with the awareness of services' types and their duration times. By dividing the spectrum resources into several flexible groups according to the classified services' types and limiting both the spectrum assignment and the spectrum re-tuning for a certain service inside one specific spectrum group according to its type, the proposed TASC defragmentation algorithm cannot only successfully prevent spectrum fragments from generation inside one spectrum group but also reduce the spectrum fragments generated between two adjacent groups. In this way, the proposed TASC defragmentation algorithm obtains the advantage in reducing spectrum fragments over both the reactive and the proactive defragmentation algorithms. Besides, as the generation of spectrum fragments is retrained between spectrum