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A novel fragmentation-aware spectrum allocation algorithm in flexible bandwidth optical networks

Xin Chen, Songwei Ma, Bingli Guo *, Yan Wang, Juhao Li, Zhangyuan Chen, Yongqi He

State Key Lab. of Advanced Optical Communication Systems and Networks, Peking University, Beijing 100871, China

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ABSTRACT

Flexible bandwidth optical networking (FBON) based on optical orthogonal frequency-division multiplexing (O-OFDM) technology has been proposed to accommodate traffic over 100 Gb/s in the future due to its flexibility in spectrum allocation. In FBON, due to the limit of spectrum continuity constraints (SCC), routing and spectrum allocation (RSA) suffers a lot from spectrum fragments. Therefore, a lot of schemes have been proposed to deal with spectrum fragmentation, including spectrum conversion, spectrum sweeping retuning, multi-path routing, and fragmentation-aware RSA algorithm. These schemes are carefully designed to lower blocking probability. However, they usually need extra/high-quality infrastructures, require complex processing, or cause traffic interruption. To reduce spectrum fragmentation, we investigate spectrum allocation approach through utilizing the relationship between spectrum blocks' accommodation capability and traffic bandwidth distribution. Based on this, a fragmentation-aware spectrum allocation (FSA) algorithm is presented. Generally, this algorithm probabilistically optimizes the spectrum resource allocation process. The simulation results show that it is able to achieve a lower bandwidth blocking probability.

1. Introduction

Efforts have been devoted to optical communication systems to meet increasing capacity requirements in traditional wavelength division multiplexing (WDM) [1] network in the past years, e.g. advanced modulation formats and digital equalization, which enable per-channel bandwidths of 40 Gb/s and 100 Gb/s with improved transmission distance. However, their coarse granularity and rigid grid lead to underutilization of spectrum resources: when assigning a whole wavelength channel for a traffic demand (even after grooming) smaller than the capacity of one wavelength, the WDM network has lower spectrum utilization efficiency (SUE), which is defined as the traffic data rate divided by the occupied spectrum bandwidth.

In order to fix this problem and improve the SUE of optical network, optical orthogonal frequency division multiplexing (O-OFDM) [2–4] has been introduced into optical transport network because of its large capacity, finer granularity, and flexible spectrum allocation. Based on O-OFDM technology, the flexible bandwidth optical network (FBON) [5,6] has been proposed as a bandwidth-variable and high SUE network infrastructure, which could provide sub- and super-wavelength services. More specifically, in flexible optical network, the spectrum is divided into a great number of sub-carriers with finer granularity than ITU-T grid in WDM network, e.g. 12.5 GHz instead of 50 GHz or 100 GHz, thus enabling a more

* Corresponding author.
E-mail addresses: cnew@pku.edu.cn (X. Chen), bingliguo@pku.edu.cn (B. Guo).

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elastic bandwidth allocation to match the allocated bandwidth with the traffic requirement better.

With regard to routing and spectrum allocation (RSA) [7–10] in FBON, we have to consider the spectrum continuity constraints (SCC) in transmission direction and in frequency axis. The SCC in transmission direction is similar to the wavelength continuity constraint in routing and wavelength assignment (RWA) in WDM network, i.e. the same spectrum segment should be allocated along the routing path. The SCC in frequency axis means a consecutive fraction of spectrum (or a group of contiguous spectrum slots) must be allocated when setting up an optical path. Also, the modulation format selection for traffic with different transmission distances [7] should be taken into consideration.

With its bandwidth allocation flexibility for un-uniform traffic, RSA suffers a lot from spectrum fragments (SFs) [8] which would deteriorate SUE and increase traffic blocking probability. Some early researchers have defined some parameters to quantify the level of spectrum fragmentation from different aspects (e.g. bandwidth fragmentation ratio [16], the spectrum utilization entropy [18], and spectrum compactness [19]), while some other works have proposed schemes to deal with spectrum fragmentation, including spectrum conversion [11,12], rerouting [13], spectrum sweeping retuning [14,15], multi-path routing method [16,17], and fragmentation-aware RSA [20–22]. These schemes could alleviate the adverse impact of spectrum fragmentation, reduce blocking probability, but bear their own flaws. The efficiency of spectrum conversion and its limited conversion range both impede its application [11,12]. Traffic rerouting would cause traffic interruption and high computation complexity [13]. Spectrum sweeping retuning raises high quality requirements to the transponders (e.g. continuously adjustable laser) and controller [14,15]. Multi-path routing scheme needs extra processing and transponders [16,17].

Fragmentation-aware RSA [20–22] does not need any extra infrastructure or high quality infrastructure. However, former fragmentation-aware RSA always needs a centralized resource allocation scheme (or flooding broadcast) and pure dynamic routing with high computation complexity. These schemes analyze the sub-carrier occupation or available spectrum block (a combination of several continuous available frequency slots) distribution. A parameter (e.g. link fragmentation ratio) is usually introduced to describe spectrum occupation. They try different resource allocation methods to optimize the parameter's value and then improve RSA algorithm.

In this paper, we focus on the fragmentation-aware spectrum allocation scheme. Routing schemes with different flexibilities always lead to different performances of RSA schemes (e.g. with similar spectrum allocation algorithm, a k-path routing scheme usually performs better than a fixed routing scheme). When a fragmentation-aware RSA performs better than a normal RSA with different routing flexibilities, we cannot clearly attribute the improvement to a more flexible routing or a better fragmentation-aware allocation scheme. In order to rule out the effects of routing flexibility, most of our discussion in this paper is based on a fixed routing scheme. We only adapt the spectrum allocation algorithm to reduce the blocking probability caused by spectrum fragments. This fundamental enables a distributed resource allocation scheme and significantly reduces the computation complexity. Also we have tested the algorithm with some more flexible routing schemes (load balance routing scheme and pattern-layered routing scheme with centralized scheduling) to prove its applicability.

In former fragmentation-aware RSA schemes, there are some parameters defined to quantify the level of spectrum fragmentation (e.g. link fragmentation ratio [21]) or evaluate the spectrum accommodation (e.g. possible accommodation states [20]). A weighted RSA scheme is then used to allocate resources based on these parameters. However, these schemes neglect the impact of traffic granularity distribution. We proposed our algorithm based on the following consideration:

First, the impact of spectrum fragmentation on SUE is closely related to traffic granularity distribution and this is why different spectrum slot widths perform diversely in blocking probability, e.g. [23] shows that the optimal slot width can be calculated as the greatest common divisor of the required optical connections' bandwidths.

Second, intuitively, for a group of available spectrum blocks with different sizes, the selection of spectrum blocks to place one specific request would influence the capability of these spectrum blocks to accommodate future incoming traffic. For example, Fig. 1 shows a spectrum segment with two available spectrum blocks (their sizes are 5 and 7 spectrum slots, separated by an occupied sub-carrier, the dark blue one). The gray spectrum slots stand for the guard-bands. The traffic in this network requires 1 or 4 spectrum slots, i.e. the occupied bandwidth will be 2 or 5 spectrum slots considering the guard-band. Therefore, there are two options for an incoming request requiring 1 slot: place it in the 5-size block and leave the available spectrum blocks to be 3 and 7, or put it in the 7-size block and leave the available spectrum blocks to be 5 and 5 (assuming that placing the request in the front/end of the spectrum block instead of in the middle). Apparently, {5, 5} has greater potential to serve more different traffic combinations compared with {3, 7}, because the former has better traffic accommodation capability, i.e. two 5-unit requests could fit in {5, 5} but not in {3, 7}. So, we prefer to put this 1-slot request in the 7-size spectrum block. As shown in Fig. 1, the

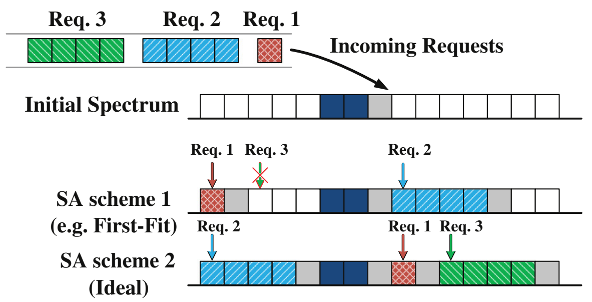

Fig. 1. Blocking in different SA schemes. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)