A Novel Spectrum Assignment Algorithm to Restrain the Generation of Fragments in Elastic Optical networks

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Abstract: We propose a slot-weighted variable-group-based spectrum assignment algorithm to restrain the generation of spectrum fragments in elastic optical networks. Simulation results show more than 76% fragment reduction compared to the defragmentation algorithm.
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1. Introduction

Elastic optical networks (EONs) have attracted much attention, owing to their advantage in spectrum provisioning [1]. By introducing a finer spectrum allocation granularity, frequency slot (FS), EONs are capable of assigning varying number of contiguous FSs to different services adaptively, according to their bandwidth requirements. This remarkably improves the flexibility of spectrum allocation and the efficiency of resource utilization. However, due to the high cost & complexity of spectrum conversion in reality, the FSs assigned to the same service are required to be contiguous and kept unchanged over the whole transmission path before the service expires. These are known as spectrum contiguity and continuity constraints, which may possibly induce spectrum fragments in network evolutions, connection tear-down operations, or some network maintenance procedures. These induced fragments not only reduce the available spectrum resources but also degrade the network performances. Therefore, fragmentation has become a critical issue in EONs. Recently, a number of defragmentation algorithms have been proposed to solve the fragmentation problem in EONs [2-5]. In [2-3], an alternative spectrum was re-allocated or re-tuned for the existing service so as to re-optimize the spectrum resource distribution. In [4], lightpath-rerouting algorithms were proposed to reduce the spectrum fragments by changing the lightpaths for some existing service connections. However, these retuning or rerouting schemes would lead to service disruption and thus cause enormous data loss in high-speed transmissions. Push-pull algorithm [5] was proposed to eliminate any possible disrupted traffic, but its effectiveness was limited by the current laser technique.

In this paper, we propose a novel slot-weighted variable-group-based (SW-VGB) spectrum assignment (SA) algorithm for EONs. By employing a variable grouping mechanism, the spectrum resources are sorted into several variable groups, according to the kinds of services. The generation of the spectrum fragments is restricted in the spectrum intervals between the groups. In addition, a new index, slot-weight (SW), is introduced to record the usage of a FS in the variable-group-based (VGB) spectrum assignment. By assigning the FS with the highest SW, the remaining vacant spectrum has a lower SW, which is more likely allocated to a new service with success. As a result, the proposed SW-VGB SA can dramatically restrain the fragment generation and also reduce the blocking probability. Besides, no traffic disruption is required, which enhances its practicality.

2. Proposed SW-VGB SA

In SW-VGB SA, we first define a new index, SW, based on the following formula:

$$SW_i = \sum_{j=1}^{j=|E|} U_{ij} \qquad (1)$$

where SW_i represents the slot-weight of FS #i, $|E|$ represents the total number of edges in the network, U_{ij} is a Boolean variable that equals 1 if FS #i on the edge #j is used by a service, and 0 otherwise. In the proposed SW-VGB SA algorithm, $r(s, d, b_r)$ represents a service request, where s and d denote the source and the destination nodes, respectively, and b_r denotes the requested bandwidth, represented in FS. Each kind of services is allocated with a designated spectrum group, specified by its start FS and its last FS. The vacant FSs available between two adjacent designated spectrum groups can be used by either kind of services that the two spectrum groups belong to. Hence, the whole spectrum resource is sorted into several variable groups, according to the kinds of services. Since the spectrum resource inside each designated spectrum group can always be re-used by the services of the same kind, the generation of spectrum fragments is restricted between the spectrum groups.

Algorithm SW-VGB SA

Pre-compute K shortest paths for each s-d node pairs
Divide the spectrum into several variable groups by specifying the allocation start FSs for each kind of service requests
while network is running **do**
  When a request $r(s, d, b_r,)$ arrives, make an empty routing and spectrum assignment solution set L, and load the pre-computed paths set P for node pair s-d
  Then determine the allocation start FS f_r for r, and construct the slot set F from f_r to the nearest FS occupied by the other kind of services
  for each path p in P **do**
    for each b_r FSs from f in the slot set F along p **do**
      Check the availability of the b_r FSs
      if all the b_r FSs from f are available **then**
        Calculate the SW of the b_r slots and add p, f and SW to L as an possible solution l
      end if
    end for
  end for
  Check the solution set L
  If L is non-empty **then**
    Found the solution l with maximum SW in L
    Select the path and assignment the spectrum to r according to l
    Update the network
  else
    Block the request r
  end if
end while

The complexity of the proposed SW-VGB SA is mainly determined by the adopted routing and spectrum assignment strategies. By adopting the Dijkstra algorithm, the time complexity for finding the first K shortest paths for each s-d node pairs is $O(K\times|E|\times|V|^2)$, where $|V|$ is the number of nodes in the network. Since the construction of the solution set L for a service request is the main procedure in the spectrum assignment, the time complexity of assigning spectrum to a service request is $O(K\times|F|\times|E|^2)$, where $|F|$ is the number of FSs on a fibre link in the network, and it is polynomial.

3. Numerical results

In this section, numerical simulations were performed to evaluate the network performance under the proposed algorithm. Two typical network architectures, NSFNET and USNET, were adopted in our simulations. In the simulations, none of the network nodes had optical spectrum-conversion capability, given its high cost and complexity in reality, and each link in the network consisted of two unidirectional fibres with a total spectrum of 4000 GHz on each fibre. A spectrum of 12.5-GHz was employed as a FS. We also assumed that there were three typical kinds of service connection requests accommodated by the network: 100-Gb/s, 400-Gb/s and 1 Tb/s, with their required bandwidths (including guard-band) of 50-GHz, 80-GHz, 150-GHz, respectively [6]. Therefore, the three kinds of service connection requests required 4 FSs, 7 FSs and 12 FSs, respectively, and the whole spectrum were accordingly divided into three variable groups. Group #1 assigned the spectrum from the lowest FS to 100-Gb/s services, while group #2 and group #3 assigned the spectrum from the middle and the highest FSs to 400-Gb/s and 1 Tb/s services, respectively. In the simulations, the proportion of the three kinds of service requests was set as 1:1:1, and all the service requests were generated dynamically using the Poisson traffic model, in which Poisson and negative exponential distributions were employed to simulate the arrival and holding times of a service request, respectively. For each request, its source and destination, as well as its type, were also randomly determined using uniform distribution.

We have compared the network performance among the cases of (I) conventional ungrouped SA, (II) variable-group-based SA without SW selection strategy (denoted as VGB SA), (III) variable-group-based SA with SW selection strategy (denoted as SW-VGB SA), and (IV) defragmentation SA [2]. Fig. 1(a) shows that the proposed SW-VGB SA has lower blocking probability than the ungrouped SA and the VGB SA, but not for the case of the defragmentation SA. Nevertheless, the performance difference between SW-VGB SA and defragmentation SA decreases to less than 6% when the traffic load was larger than 300 Erlang. Furthermore, we have also investigated the number of generated spectrum fragments, which were defined as isolated free spectrum chunks that could not be used by any kind of services in the simulations. As shown in Fig. 1(b), both VGB SA and SW-VGB SA could dramatically reduce the number of spectrum fragments by more than 84% and 76%, respectively, compared to the

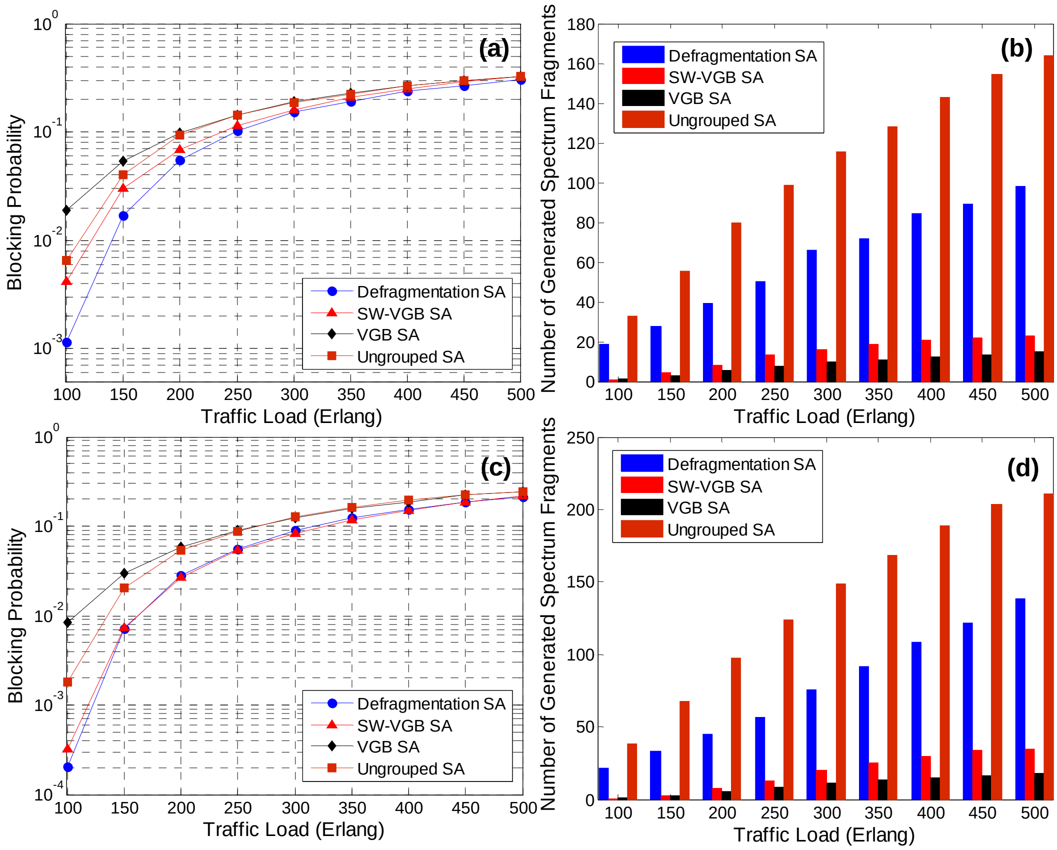

Fig. 1: Networking performances. (a) Blocking probability vs. traffic load in NSFNET; (b) Generated spectrum fragments vs. traffic load in NSFNET. (c) Blocking probability vs. traffic load in USNET; (b) Generated spectrum fragments vs. traffic load in USNET

defragmentation SA, hence confirmed the effectiveness of the proposed VGB mechanism in restraining the generation of spectrum fragments. Noticeably, SW-VGB SA even exhibited better defragmentation performance than VGB SA. Fig. 1(c) and (d) show the network performances for the case of larger network, USNET, and the results also showed that SW-VGB SA exhibited satisfactory low blocking probability and could successfully restrain the generation of spectrum fragments.

4. Summary

We have investigated the fragmentation issue in elastic optical networks, and proposed a novel SW-VGB SA to restrain the generation of spectrum fragments with no traffic disruption. The simulation results have shown that the proposed algorithm could effectively reduce fragments by more than 76% compared with the conventional defragmentation algorithm and exhibit low blocking probability. This work was partly supported by the Fundamental Research Funds for the Central Universities, Southwest University for Nationalities (Project No. 13NZYBS04), and Sichuan Provincial Science and technology project (Project No. 2014GZ0015).

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