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Shared path protection through reconstructing sharable bandwidth based on spectrum segmentation for elastic optical networks

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ABSTRACT

In order to address the problems of spectrum fragmentation and low sharing degree of spectrum resources in survivable elastic optical networks, an improved algorithm, called shared path protection by reconstructing sharable bandwidth based on spectrum segmentation (SPP-RSB-SS), is proposed in the paper. In the SPP-RSB-SS algorithm, for reducing the number of spectrum fragmentations and improving the success rate of spectrum allocation, the whole spectrum resource is partitioned into several spectrum segments. And each spectrum segment is allocated to the requests with the same bandwidth requirement in priority. Meanwhile, the protection path with higher spectrum sharing degree is selected through optimizing the link cost function and reconstructing sharable bandwidth. Hence, the protection path can maximize the sharable spectrum usage among multiple protection paths. The simulation results indicate that the SPP-RSB-SS algorithm can increase the sharing degree of protection spectrum effectively. Furthermore, the SPP-RSB-SS algorithm can enhance the spectrum utilization, and reduce the bandwidth blocking probability significantly.

1. Introduction

Recently, elastic optical networks (EONs), based on optical orthogonal frequency division multiplexing (O-OFDM) technology, have attracted widespread attentions because of its high spectrum efficiency and flexible grid bandwidth assignment [1,2]. The available spectrum resources on each fiber link are divided into some narrow segments called frequency slots (FSs). Therefore, EONs can allocate spectrum resources with fine granularity, such as 6.25 GHz or 12.5 GHz, and provision FSs according to the rate of the request [3]. So it can enhance the spectrum utilization compared with traditional fixed frequency grid wavelength division multiplexing (WDM) networks [4,5].

Meanwhile, the network survivability has been an important problem for EONs [6]. With human environmental deterioration and unpredictable natural disasters, the EONs would be damaged easily. Hence, a single link failure can cause the loss of a large number of data [7]. In order to guarantee reliable transmission of the requests, the problem of maintaining network survivability is necessary in EONs.

What is more, routing and spectrum assignment (RSA) problem is subjected to spectrum contiguity and spectrum continuity in EONs for both the protection path and the working path. It means that when the request is transmitted, a spectrum-block of adjacent FSs is allocated to set up a lightpath, and all links along the end-to-end lightpath must use the same FSs range [8,9]. These constraints not only bring the challenge of RSA, but also lead to the problem of spectrum fragmentation, which decreases the spectrum utilization and network performance [10]. Therefore, the study of the survivable RSA problem is also necessary in EONs.

For addressing the survivable RSA problem in EONs, some RSA strategies and survivability mechanisms are proposed in many literatures. The RSA problem was verified to be a NP-hard problem in [11]. Thus, under the constraints of spectrum contiguity and spectrum continuity, an integer linear programming (ILP) model was formulated and its performance was evaluated by minimizing network spectrum resources usage in [12]. However, ILP model for RSA algorithm is only available for the small scale networks due to its complexity. Hence, heuristic algorithms and genetic algorithms were proposed in [13,10] to solve the RSA problem in large scale networks for the static and dynamic requests.

The aforesaid algorithms are dedicated to minimize the network spectrum usage, but they neglect the problem of spectrum fragmentation. Thus, related works focus on the spectrum fragmentation problem and many algorithms are proposed. In [14], a split spectrum-enable RSA (SS-RSA) mechanism was presented. Although SS-RSA algorithm decreases the bandwidth blocking probability by splitting a request into many smaller sub-requests, the number of guard bands and transponders are increased

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accordingly. Thus, in [15], a novel spectrum compactness scheme (SCS) was proposed in EONs. Although the number of spectrum fragmentations can be reduced by selecting a compactness threshold, its complexity is really high.

The problem of network survivability is also extensively discussed in some papers. Some protection and restoration methods have been proposed and the former have shorter recovery time. The protection methods include path protection and link protection, where path protection has the advantages of simple operation and fast recovery time. Hence, most research concentrate on path protection.

A dedicated path protection (DPP) was proposed to configure a protection path in [16], but DPP consumes large amounts of protection spectrum resources and deteriorates the performance of EONs. In [17], the shared path protection (SPP) algorithm was proposed to enhance the spectrum utilization and reduce free spectrum usage. SPP algorithm improves the spectrum utilization compared with DPP algorithm by sharing the protection spectrum among multiple protection paths. Moreover, in [18], a dynamic load balancing shared path protection (DLBSPP) scheme was proposed to improve the spectrum sharing degree. Moreover, the spectrum utilization could be enhanced by avoiding bottleneck links.

The above survivability solutions all have lower sharing degree of sharable bandwidth and cannot improve the performances significantly. In order to enhance the sharing degree of sharable bandwidth, SPP-SWP-FF algorithm based on spectrum windows was proposed to decrease the link cost value of the protection path in [19]. Although the SPP-SWP-FF algorithm optimizes the link cost value of the protection path to some extent, it does not increase the proportion of large spectrum blocks in the link cost function.

From the above analysis, we can conclude that the shared path protection problem also have many unsolved problems. In this paper, the problem is studied by dividing into the working path RSA sub-problem and the protection path RSA sub-problem.

For the working lightpath RSA sub-problem, the corresponding spectrum segment according to the request rate has the priority to be assigned to avoid spectrum fragmentation efficiently. If the corresponding spectrum segment has not enough bandwidth resources, the request which would probably lead to spectrum fragmentation should be concentrated on shared spectrum segment to minimize the number of spectrum fragmentations.

For the protection lightpath RSA problem, when we find the protection lightpath, we can improve bandwidth sharing degree and reduce link cost value by reconstructing sharable bandwidth. When we assign bandwidth to the protection lightpath, the continuous spectrum block on the protection lightpath should be assigned in priority. If it is less than the bandwidth requirement of the request, the rest protected bandwidth can be assigned by the working lightpath spectrum assignment strategy.

The rest of paper is organized as follows. The next section presents the constraint of the shared path protection problem and takes an example illustrating the problem. Sections 3 introduces the proposed improved heuristic algorithm for both the working path RSA sub-problem and the protection path RSA sub-problem. The simulation results are analyzed in Section 4. Finally, in Section 5, we conclude the paper.

2. Problem description

It has been verified that the survivable RSA problem is a NP-hard problem. What is more, the ILP model has been proposed and simulated in [20]. Due to its inherent complexity, the ILP approach faces scalability issues for medium and large-sized networks. A more efficient heuristic algorithm will be developed in Section 3. In this part, the shared path protection problem is described in advance for better analysis of the proposed algorithm.

The EONs can be modeled as a graph $\boldsymbol{G}(\boldsymbol{V}, \boldsymbol{E}, \boldsymbol{S})$, where $\boldsymbol{V} = \{v_i \mid i = 1, 2, \ldots, |\boldsymbol{V}|\}$ is the node set. $\boldsymbol{E} = \{e_{ij} \mid i, j \in \boldsymbol{V}\}$ and $\boldsymbol{S} = \{s_i \mid i = 1, 2, \ldots, |\boldsymbol{S}|\}$ is the set of links and frequency slots set, respectively. The request can be denoted as $r_i(s_i, d_i, TR_i)$ where s_i and d_i ($s_i, d_i \in \boldsymbol{V}$) is the source node and destination node, respectively. TR_i is the bandwidth requirement in terms of the number of contiguous FSs.

It assumes that there are no spectrum converters in EONs. Hence, the spectrum assignment for both the working paths and protection paths is subjected to spectrum continuity and spectrum contiguity. These constraints are given in the following and an example is given to illustrate the shared path protection.

2.1. Constraints

$$WP_e^{r_i} + PP_e^{r_i} \leqslant 1, \quad \forall r_i \in R, \quad \forall e \in E \tag{1}$$

$$\sum (PP_e^{r_i} + PP_e^{r_j}) \geqslant 1, \quad \forall r_i, r_j \in R, \quad i \neq j, \quad \forall e \in E \tag{2}$$

where $WP_e^{r_i}$ and $PP_e^{r_i}$ is a boolean variable that equals 1 and 0 otherwise if link e belongs to the working path and protection path of request r_i respectively.

Eq. (1) guarantees that the working path and protection path are link-disjoint for request r_i. And constraint (2) guarantees the shared bandwidth conditions of request r_i and r_j.

$$WP_{e,s}^{r_i} = WP_{e',s}^{r_i}, \quad \forall e, e' \in WP_{r_i}, \quad \forall r_i \in R, \quad \forall s \in S \tag{3}$$

$$WP_{e,s}^{r_i} = WP_{e,s+1}^{r_i}, \forall e \in E, \quad \forall r_i \in R, \quad \forall s \in WS_{r_i} \tag{4}$$

$$PP_{e,s}^{r_i} = PP_{e',s}^{r_i}, \quad \forall e, e' \in PP_{r_i}, \quad \forall r_i \in R, \forall s \in S \tag{5}$$

$$PP_{e,s}^{r_i} = PP_{e,s+1}^{r_i}, \quad \forall e \in E, \quad \forall r_i \in R, \quad \forall s \in PS_{r_i} \tag{6}$$

where WPr_i and PPr_i is the working links and protection links of request r_i respectively. WSr_i and PSr_i is the working FSs set and protection FSs set of request r_i respectively. $WP_{e,s}^{r_i}$ is a boolean variable that equals 1 if slot s on link e from $\boldsymbol{WP}r_i$ is occupied, and 0 otherwise. $PP_{e,s}^{r_i}$ is a boolean variable that equals 1 if slot s on link e from $\boldsymbol{PP}r_i$ is occupied, and 0 otherwise.

Constraints (3) and (4) indicate the spectrum continuity constraint and the spectrum contiguity for the working paths. Constraints (5) and (6) represent the spectrum continuity constraint and the spectrum contiguity for the protection paths.

2.2. Example

An important features of shared path protection is to share the protection capacity on the same links among multiple requests. If multiple working paths are link-disjoint, their corresponding protection paths can share the spectrum resources on the same links, as shown in Fig. 1. It assumes that there are request r_1(A, I, 3) with the working path (A-B-C-F-I), protection path (A-E-I) and request r_2(D, I, 3) with the working path (D-G-H-I), protection path (D-E-I).

An illustrative example for shared path protection is shown in Fig. 1. In Fig. 1(a), as the working path (A-B-C-F-I) of request r_1, path (D-G-H-I) of request r_2 are link-disjoint. The protection path (A-E-I) of request r_1, path (D-E-I) of request r_2 have a common link (E-I). So, two protection paths may share spectrum resources. The request r_1 occupy protection spectrum range from FS5 to FS7. If link (D-E) has free spectrum range from FS5 to FS7, then request r_2 allocates spectrum range from FS5 to FS7, sharing spectrum with request r_1 in Fig. 1(b).