A Novel Migration-Aware Protection Scheme in Co-Existing Fixed and Flexible Grid Optical Networks

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Abstract: This paper addresses the traffic survivability issue in the migration scenario from fixed grid to flexible grid in optical networks, proposes a novel Migration-Aware Protection (MAP) scheme, and evaluates its performance under different traffic models.

OCIS codes: (060.1155) All-optical networks; (060.4257) Network survivability; (060.4510) Optical communications

1. Introduction

With the exponential growth of Internet traffic, flexible grid technology in optical transmission has received extensive attention due to its high capacity and flexibility in spectrum allocation [1]. Considering both CAPEX and OPEX, the gradual migration from fixed grid to flexible grid has been researched among scholars and operators [2-5]. In our previous study, the problem of when and how should the optical network be upgraded to flexible grid has been investigated [3-5]. However, none of existing study had considered the survivability issue during network migration in optical networks.

When migration begins (either by upgrading the entire ROADMs or by upgrading the WSSs in ROADMs), connections existing in the network become fragile and may be interrupted, causing a large amount of traffic losses. This situation becomes much serious especially for mission-critical services. Various traditional protection techniques can be extended in the migration scenario to resist connection interruption. For example, as a straightforward scheme by choosing a node disjoint pair of primary and backup paths, Dedicated Path Protection (DDP) can realize fast restoration by switching to the reserved backup path to avoid connection interruption. Nevertheless, traditional DPP schemes are unaware of migration, which means that they can hardly handle the situation where the network survivability suffers damage from the network migration.

In this paper, we focus on the traffic survivability issue of reducing the interruption when the optical network migrates from fixed grid to flexible grid. We propose a novel Migration-Aware Protection (MAP) scheme by introducing the concept of Potential-Upgrade Nodes Group (PUNG), and evaluate its performance under different traffic models. Compared with traditional Non-Migration-Aware Protection (N-MAP) scheme, the proposed MAP scheme can achieve better performance on the connection interruption ratio.

2. Network Model

As illustrated in Fig. 1, there are three lightpaths in a co-existing fixed grid and flexible grid network. *A-F-I-L* is the working path from Town *A* to Data Center *L*. Two other paths, i.e., *A-C-E-H-L* and *A-B-D-G-K-L*, are selected as backup paths to protect the working path. When two nodes are selected to be upgraded to flexible grid (i.e., *E* and *I*), the backup path *A-C-E-H-L* becomes fragile while the other one, *A-B-D-G-L-L*, won't be affected. Compared to the traditional protection scheme that cannot differentiate two candidate backup paths, we need to find backup paths which are aware of network migration.

In the network migration scenario, different fixed grid node has different probability to be upgraded to flexible grid. In order to assess their upgrading potential, we use a normalized p_i to describe their upgrading probability, and, introduce the concept of Potential-Upgrade Nodes Group (PUNG). PUNG is a set of selected fixed grid nodes which have larger possibility to be upgraded. Considering different network migration strategies, there are two PUNG construction schemes. General PUNG construction scheme is that the nodes in PUNG are identical to the actual upgraded nodes, while worst PUNG construction scheme is that the nodes in PUNG are not urged to be upgraded to flexible grid.

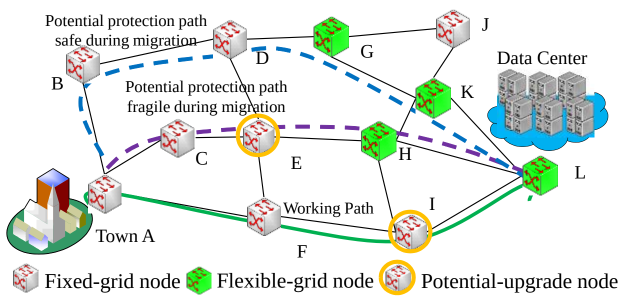

Fig 1: The influence of node upgrade on the hybrid network during migration from fixed grid to flexible grid

In general, the upgrading probability of a node can be evaluated by two aspects. One is self-influence of nodes, such as the degree of nodes, the traffic load on the nodes, and so on. Here, those factors are called intrinsic upgrading probability, and we use α_i to express its value. The other one is interaction-effect by considering the link established between two adjacent nodes, i.e., node *i* and node *j*. We define $pair(i,j)$ to represent the interaction-effect between two adjacent nodes, which is called inter-influence of nodes. Hence, we use α_i and $pair(i,j)$ as a part of nodes upgrading potential by formula (1), where d_i presents the degree of node *i* and β is used as an influenced factor of the interaction effect between adjacent nodes.

$$p_i = \alpha_{\mathrm{i}} + \beta \times \sum pair(i,j) / d_i \tag{1}$$

Except the above concepts, there are some other notations which needs to be paid attention to. $\boldsymbol{G}(\boldsymbol{N},\boldsymbol{E},\boldsymbol{f})$ represents the network model in optical networks, where $\boldsymbol{N}$ **and** $\boldsymbol{E}$ represent the set of nodes and links respectively. $\boldsymbol{f}$ stands for the spectrum slots, and $(\boldsymbol{i},\boldsymbol{j})$ presents any link in set *E*, which means a link from node *i* to node *j*, $\boldsymbol{i},\boldsymbol{j} \in \boldsymbol{N}$. $\boldsymbol{R}(\boldsymbol{S},\boldsymbol{D},\boldsymbol{B})$ represents a service request where $\boldsymbol{S}$ is the source node, and *D* is the destination node. $\boldsymbol{B}$ is the bandwidth requirement of the request $\boldsymbol{R}(\boldsymbol{S},\boldsymbol{D},\boldsymbol{B})$, including the guard bands.

3. Migration-Aware Protection (MAP) Scheme

Tab 1: Description of MAP Scheme

	Migration-Aware Protection (MAP) Scheme
1.	Get the value of $\mathrm{pair(i,j)}$ and calculate $\mathrm{p_i}$ for each node $\mathrm{i \in N}$ by formula (1), and put the potential nodes into set PUNG;
2.	Run KSP algorithm to find K-shortest paths, and put them in a primary path vector $\mathrm{V(x_n)}$ for $\mathrm{x_n \in \{x_1, x_2, \dots, x_k\}}$ and a backup path vector $\mathrm{V(y_n)}$ for $\mathrm{y_n \in \{y_1, y_2, \dots, y_k\}}$;
3.	**For** each primary path $\mathrm{x \in V(x_n)}$ **do**
4.	**For** each backup path $\mathrm{y \in V(y_n)}$ **do**
5.	**If** x and y are PUNG disjoint **then**
6.	Search for B available spectrum along the selected paths, **If** successful **then**
7.	Allocate the spectrum resources for the service request $\mathrm{R(S,D,B)}$;
8.	**End if**
9.	**End if**
10.	**End for**
11.	**End for**

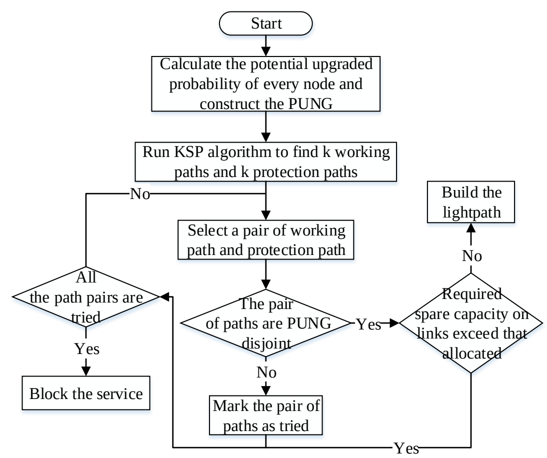

Fig. 2: Flowchart of MAP scheme

In order to protect the existing services in the migration scenario, we propose a novel Migration-Aware Protection (MAP) scheme in this paper. In MAP, a pair of primary path and backup path, which are PUNG disjoint are calculated for each request. The proposed MAP scheme is designed as shown in Tab. 1, and the flowchart is shown in Fig. 2. Fig. 3 illustrates an example. There is a 9-node topology in Fig 3(a), and node 4, node 8 and node 9 are selected to form a general PUNG. As shown in Fig. 3(b) and Fig. 3(c), the differences of backup path between the N-MAP and MAP have been presented. Fig. 3(b) shows that the backup lightpath will be established through node 4 without any awareness of migration, and it will become weak if the potential-upgrading nodes get upgraded. What's worse, the service will be interrupted when node 9 and node 4 are upgraded at the same time. Fig 3(c) shows the nodes in PUNG are different to general nodes under MAP scheme, and the route of primary and backup path are PUNG disjoint. Obviously, the proposed MAP scheme is aware of network migration, compared to the non-migration-aware one.

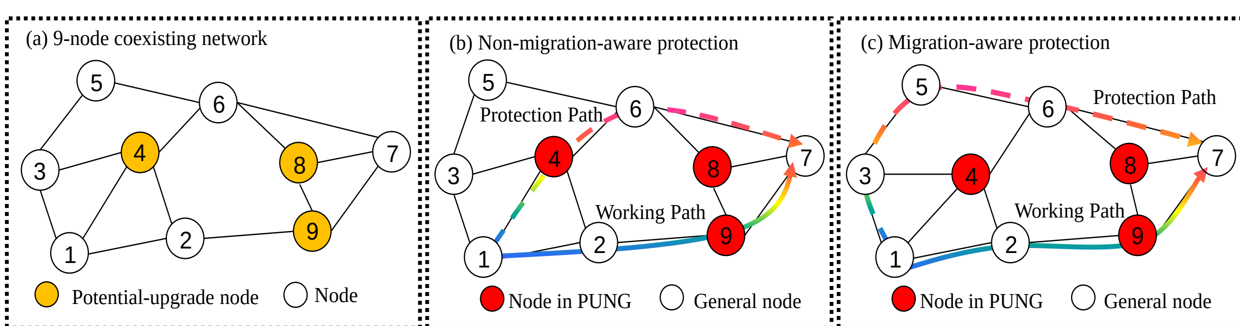

Fig. 3: An example: (a) 9-node topology; (b) N-MAP scheme; (c) MAP scheme.

4. Numerical Results

The proposed MAP scheme is evaluated on NSF Network. Connection requests following Poisson arrivals are generated, and their bandwidth demands are chosen among {40, 100, 200, 400} Gbps. For each channel type, the need for spectrum and number of lambda/slots are summarized in [4]. In addition, two traffic models, i.e., uniform traffic model and non-uniform traffic model, are considered and compared. The performance in terms of Bandwidth Blocking Ratio (BBR, i.e., the rejected bandwidth over the total bandwidth) and Connection Interrupted Ratio (CIR, i.e., the statistical average of the interrupted connection over the total connection working in the network at a certain point) are evaluated. The results are shown in Figs. 4(a)-(f). Fig. 4(a) illustrates the BBR varies with traffic load under general PUNG construction scheme. From Fig. 4 (a) we can see that the BBR increases as the traffic load increases. Under both uniform and non-uniform traffic model, MAP scheme and N-MAP scheme get similar performance in terms of BBR. Fig. 4 (b) and Fig. 4 (c) present the BBR varies with traffic load under worst PUNG construction and under general PUNG construction when 2 nodes have been upgraded, respectively. From Figs. 4 (b) and (c) we can see the similar curve, which makes us speculate that N-MAP and MAP have a similar performance in terms of BBR. Figs. 4(d-f) show CIR varies with traffic load with different PUNG construction schemes. Fig. 4(d) is with general PUNG construction, Fig. 4(e) is with worst PUNG construction, while Fig. 4(f) is with general PUNG construction when 2 nodes have been upgraded. From Fig. 4(d) we can see that MAP scheme get lower CIR compared with N-MAP scheme, and Figs. 4(e-f) present the similar tendency. The differences between Fig. 3(d) and Fig. 3(e) tell us that PUNG construction scheme has a very important impact on the CIR performance. The reason is that there is a tradeoff between the affected range and the performance improvement during network migration. From these numerical results we can conclude that, MAP can provide safer connections than N-MAP, especially under uniform traffic model.

5. Conclusion

We address the survivable problem when the optical network migrating from fixed to flexible grid. A novel Migration-Aware Protection (MAP) scheme is proposed, and its performance is evaluated. It is found that MAP scheme can achieve considerable benefits of CIRs with similar BBRs to N-MAP scheme.

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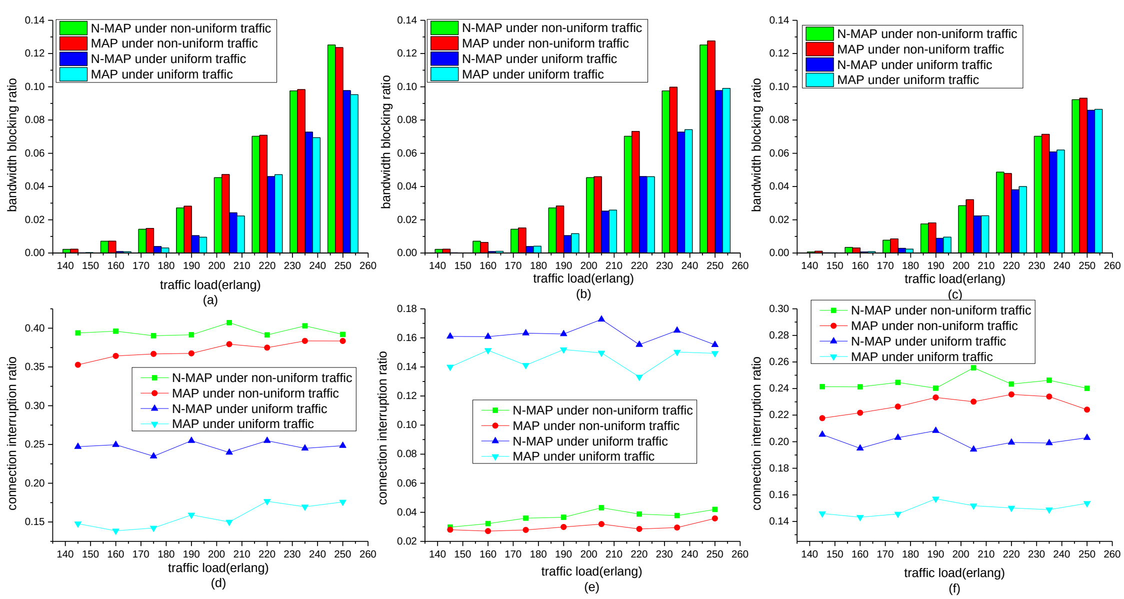

Fig.4: Numerical Results: (a)BBR with general PUNG; (b)BBR with worst PUNG; (c)BBR with general PUNG when 2 nodes upgraded; (d)CIR with general PUNG; (e)CIR with worst PUNG; (f) CIR with general PUNG when 2 nodes upgraded