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# Survivable waveband grooming in multi-domain optical networks

Jingjing Wu [a], Cunqian Yu [a], Lei Guo [a,b,*]

[a] College of Information Science and Engineering, Northeastern University, Shenyang 110819, China
[b] State Key Laboratory of Information Photonics and Optical Communications, Beijing University of Posts and Telecommunications, Beijing 100876, China

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ABSTRACT

Since the size of traffic demands ranges from sub-wavelength-level to wavelength-level, traffic demands need to be aggregated and carried over the network in a cost effective manner to make sure that the resources can be utilized effectively. Therefore, the technique called waveband grooming is proposed to save the cost and to reduce the number of switching ports in Optical-Cross Connects (OXCs). However, the existing waveband grooming algorithms are mostly limited to single-domain optical networks and also do not consider the survivability. The current optical backbones keeps enlarging, and the backbones are actually divided into multiple independent domains to provide the needed scalability and the confidentiality. It is necessary to study the survivable waveband grooming in multi-domain optical networks. In this paper, we propose two new heuristic algorithms called Intra-domain Sub-path Survivable Grooming (ISSG) algorithm and Inter-domain End-to-end Survivable Grooming (IESG) algorithm, respectively. In ISSG, we allocate an end-to-end inter-domain working path for each demand and then calculate a link-disjoint backup sub-path for each intra-domain working sub-path. In IESG, we allocate two link-disjoint end-to-end inter-domain paths for each demand, one is working path and the other one is backup path. Simulation results show that ISSG and IESG have similar trend with different parameters. In addition, IESG has lower blocking probability while ISSG has lower average port-cost.



## 1. Introduction

In Wavelength-Division-Multiplexing (WDM) optical networks, traffic grooming addresses the gap between the high bandwidth capacity of wavelength channels and the low bandwidth requirement of connections. On the other hand, fiber failures may affect a large volume of traffic since each wavelength channel in fiber link carries a lot of data. Therefore, survivability is critical for optical networks [1,2]. Survivable traffic grooming that addresses both grooming provisioning and survivability [3] seeks to provide survivable capability for connections and minimize the consumption of spare capacities in the network. By combining the survivable traffic grooming with the waveband switching technique [4–6], which groups several wavelength-level lightpaths into one waveband to be switched by one port and thus utilizes the network resources effectively, previous work remains a relatively unexplored issue and gains much attention recently.

At the same time, with the development of intelligent optical networks, today's optical networks are primarily hybrids and can be divided into several independent domains. Each domain is a local Automatic System (AS) [7] and usually has a different structure and provides a different service type than the other domains. Moreover, different domains are typically managed by different operators [8], and they may use different technologies from each other. In order to satisfy the scalability requirements, only the aggregated routing information can be exchanged among different domains. Therefore, the emergence of multi-domain networks poses a serious challenge to existing network mechanisms. The lack of complete global knowledge of the network information makes it much more complex to apply the tradition routing method of single domain optical networks to multi-domain optical networks. Thus, survivable waveband grooming in multi-domain optical networks has become a challenging research.

Recently, a lot of work has addressed the survivable traffic grooming issue. For example, the authors in [9] showed how grooming decisions can be directly integrated into an overall *p*-cycle network design for more efficiency. The authors in [10,11] considered the dynamic traffic grooming with a single working path. In [10], the authors proposed three approaches for grooming a connection with shared protection. The research in [11] was an extension of that in [10] and was applied to multipath routing. It is obvious that traffic grooming and survivability have been studied extensively. On the other hand, waveband switching network also has been investigated from different perspectives. The authors in [12] investigated the protection in waveband switching optical networks with considering shared backup wavelengths.

* Corresponding author at: P.O. Box 365, College of Information Science and Engineering, Northeastern University, Shenyang 110819, China. Tel.: +86 24 83684219; fax: +86 24 83684219.
*E-mail address:* haveball@gmail.com (L. Guo).

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The authors in [13] proposed heuristic algorithm which is suitable for the same source-destination waveband grouping. The authors in [14] proposed a new heuristic algorithm based on survivable integrated auxiliary graph to tolerate the single-link failure in waveband switching optical networks. Although the above papers studied the survivable traffic grooming and the protection in waveband switching networks respectively, they did not consider multi-domains. The heuristic algorithms proposed above are all suitable for single-domain topology.

Multi-domain routing is a challenging field [15–17]. The authors in [18] studied the problem of inter-domain dynamic routing under a multi-layer multi-domain network model. The model allowed the end-to-end connections to be set up not only across multiple routing domains but also through two transport layers: the optical layer and the digital layer. The authors in [19] studied the Routing and Wavelength Assignment (RWA) problem in multi-segment optical networks, and then presented a resource abstraction technique called blocking island and defined a multi-segment blocking island graph network model. Finally, based on this model the authors in [19] proposed a simple and flexible 2-phase RWA algorithm. Also, previous work proposed some hierarchical model for multi-domain traffic grooming. In [20], with the objective of minimizing the total number of electronic ports, a framework for hierarchical traffic grooming in mesh network has been developed. The logic topology within a cluster was formed as a virtual star. As a multi-granular multi-domain grooming problem, the authors in [21] presented a hierarchical algorithm for grooming lightpaths into wavebands and routing wavebands over a network of multi-granular switching nodes. In the presented model, the network was partitioned into clusters and one node in each cluster was designated as the hub. All the above-mentioned studies are all limited in determining the logical topology of lightpath or waveband grooming within each cluster or domain only. However, the inter-domain grooming problem is not introduced in detail. As in the scenario in [22], the problem of inter-domain routing based on the virtual topology of the multi-domain networks was considered, but how to perform the survivable waveband grooming was not described in this paper. Therefore, the survivable waveband grooming in multi-domain networks is an interesting and challenging problem.

In this paper, in order to well address the survivable waveband grooming in multi-domain optical networks, we propose two novel algorithms, Intra-domain Sub-path Survivable Grooming (ISSG) algorithm and Inter-domain End-to-end Survivable Grooming (IESG) algorithm based on our proposed Layered Auxiliary Graph (LAG) for each domain. In ISSG, we allocate an end-to-end inter-domain working path for each demand, and then we calculate a link-disjoint backup sub-path for each intra-domain working sub-path. In IESG, we allocate two link-disjoint end-to-end inter-domain paths for each demand, one is working path and the other one is backup path.

In particular, for each single domain, we build an LAG according to its physical topology. Each LAG is composed of one Virtual Topology Layer (VTL), multiple waveband Plane Layers (BPLs) corresponding to the number of wavebands in the fiber, and some virtual links connecting the VTL to each BPL. When we need to calculate the intra-domain path for each demand, we first compute a single-hop or multi-hop route pair on VTL. If the route pair is not found on the VTL, we compute the new route pair on the BPLs. Conversely, if the new route pair is not found on the BPLs, we compute the hybrid multi-hop route pair on the IAG. Simulation results show that IESG has lower blocking probability while ISSG has lower average port-cost.

To the best of our knowledge, the work in this paper is the first study addressing the survivable grooming for waveband granularity meanwhile considering the inter-domain routing in multi-domain optical network. The rest paper is organized as follows: Section 2 is the problem statement; Section 3 describes the two heuristic algorithms; Section 4 presents the simulation and analysis; Section 5 concludes this paper.

## 2. Problem statement

### 2.1. Multi-domain topology aggregation

A multi-domain network is composed of several single-domain networks that are connected by inter-domain links going from boundary nodes of one domain to boundary nodes of another (see Fig. 1(a)). We adopt the full-mesh topology aggregation scheme [23]; namely, the multi-domain network is transformed to an aggregated graph containing only the boundary nodes and the virtual intra-domain links connecting all pairs of boundary nodes. Each virtual intra-domain link can be computed beforehand, and it denotes the physical route between two boundary nodes in one single-domain.

After abstracting, the whole network is divided into a two-layer topology, i.e., a high-layer aggregative topology and a low-layer physical topology, as shown in Fig. 1(b). Each internal node can only view the full local information in its own domain, and each boundary node can view both the full local information in its own domain and the global aggregated information of the multi-domains.

### 2.2. Network model

A given multi-domain optical network is represented by $G(InterL,D)$, where $InterL$is the set of inter-domain links, each of which connects two boundary nodes in different domains, and $D = \{D_r(BN_r,IN_r,InterL)|r = 1, 2, \ldots\}$ is the set of physical topologies

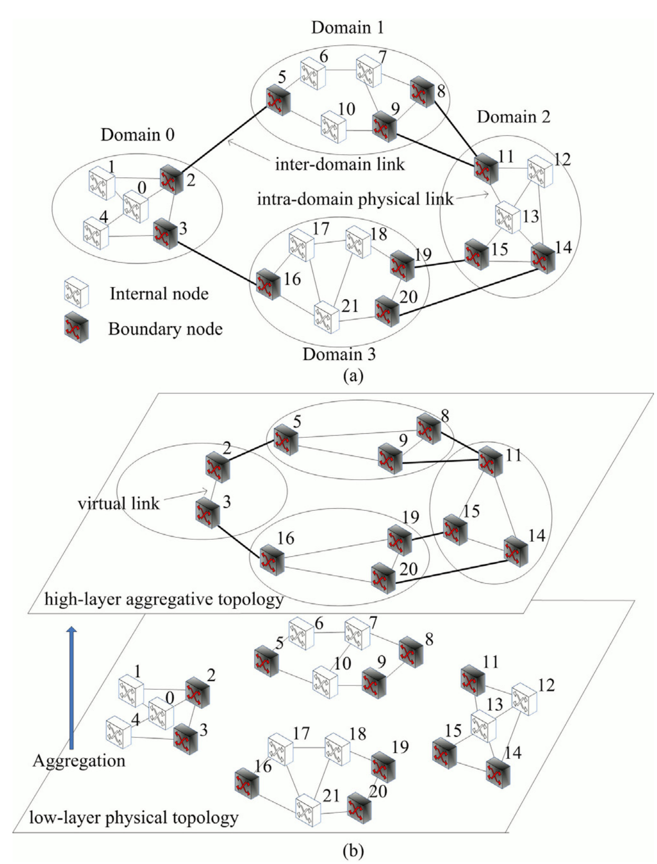


**Fig. 1.** A multi-domain optical network. (a) Physical topology. (b) Topology aggregation of the multi-domain network.