Traffic Grooming in Spectrum-Elastic Optical Path Networks

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Abstract: We propose a novel approach of traffic grooming in Spectrum-Elastic Optical Path Networks. Higher spectrum efficiency is achieved by our approach comparing with non-traffic-grooming scenario.

OCIS Codes: (060.4250) Networks; (060.4256) Networks, network optimization

1. Introduction

As the traffic load of the optical networks grows rapidly annually, how to properly utilize the bandwidth of optical networks becomes one major interest by both academy and industry in recent years. Wavelength-Division-Multiplexing (WDM) network is an existing network infrastructure to increase the spectrum efficiency. The signals in multiple wavelength channels are multiplexed into one fiber with a method of "*Grid*" to increase the spectrum utilization (Fig.1). The center frequencies of neighboring channels have fixed intervals between each other. However, when different line rates of wavelength channels are multiplexed to one fiber, the gap between the neighboring wavebands could be large when the line rate of a channel is low (e. g. 10Gbps channel in Figure 1). Consequently, large amount of bandwidth may be wasted.

Considering the shortage of traditional WDM method, finding a more elastic method of spectrum allocation to make the spectrum "*Gridless*" is a possible method to increase the spectrum efficiency. The authors in [1] proposed a promising "*Gridless*" network architecture based on O-OFDM transport system, which is called Spectrum-Sliced Elastic Optical Path Network (SLICE). In this new type of network, the bandwidth of a waveband on the spectrum is elastic to fit the amount of the traffic demand from upper layer (Figure 2), instead of using multiple wavelength channels on the spectrum. Although there is still a Filter Guard Band between two wavebands, a large bandwidth could be saved without the "*Grids*". To support the concept of this new network architecture, bandwidth-variable optical filter has already been proposed [2]. Bandwidth-variable wavelength-selective switch (WSS) has also been proposed to support the bandwidth-variable optical switching [3]. Recently, the authors in [4] compare its higher spectrum efficiency with the conventional Mixed-Line-Rate WDM Networks.

In traditional optical WDM networks, traffic grooming is considered as a key functionality, in which, multiple low-speed traffic requests are groomed onto a high-capacity lightpath (wavelength) [5]. Traffic grooming plays an important role to optimize the resource utilization in WDM networks. In Spectrum-Elastic Optical Path Networks, traffic grooming has not been mentioned in existing literatures. In this paper, we focus on adding the functionality of traffic grooming into the Spectrum-Elastic Optical Path Networks. We consider not only the bandwidths of the wavebands are elastic to be allocated to the spectrum at optical layer, but also multiple lower-speed traffic requests from upper layer are able to be groomed onto these elastic wavebands. Considering the overhead of Filter Guard Band exists between wavebands on the spectrum, we prove that the traffic-grooming approach can minimize this overhead and achieve higher spectrum efficiency comparing with non-traffic-grooming scenario.

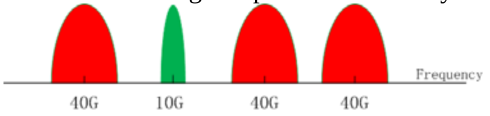

Fig. 1. Spectrum of WDM networks.

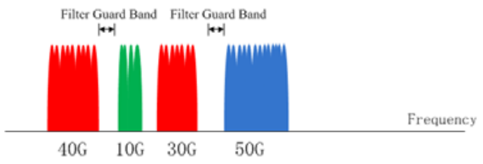

Fig. 2. Spectrum of Spectrum-Elastic Optical Path Networks.

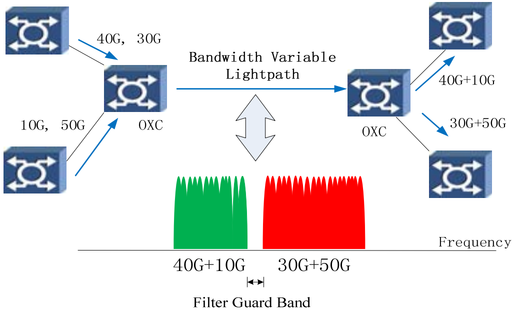

Fig. 3. Traffic grooming in Spectrum-Elastic Optical Path Networks.

2. Traffic-Grooming Approach

Inspired by the functionality of traffic grooming in WDM networks, we propose a traffic grooming scheme in Spectrum-Elastic Optical Path Networks, which is shown in Figure 3. The multiple wavelength channels in one fiber, which are defined in traditional WDM networks, no longer exist. Instead, bandwidth-variable wavebands share the entire spectrum in one fiber in a “*Gridless*” manner. Therefore, the lightpaths in traffic-grooming of Spectrum-Elastic Optical Path Networks are also bandwidth-variable. In our scheme, multiple low-speed traffic requests in virtual connection at electrical layer are groomed into bandwidth-variable lightpaths, and then the lightpaths are mapped to the routing in physical topology at optical layer. The traffic requests carried by the same bandwidth-variable lightpaths are groomed into a same waveband on the spectrum. The O-OFDM method is used to multiplex the signals. When the traffic requests arrive at their destination node, the waveband which carries the traffic requests is demultiplexed and dropped to the upper electrical layer. Similarly, the new traffic requests which need to be groomed into the bandwidth-variable lightpaths are added to the corresponding waveband, without establishing new lightpaths. In this way, minimal number of wavebands on the spectrum can be achieved. Therefore, the total overhead of Filter Guard Band can be minimized and higher spectrum efficiency can be obtained.

3. MILP Formulations of Traffic-Grooming and Non-Traffic-Grooming Approach

We use Mixed Integer Linear Programming (MILP) approach to minimize the average spectrum utilization by our traffic grooming approach in Spectrum-Elastic Optical Path Networks. We also formulate the problem of minimizing average spectrum utilization by non-traffic-grooming approach in the same network scenario in order to make them comparable. The given conditions of the two approaches are the same.

Given:

N: Set of nodes in the network
E: Set of edges in the network
C: Capacity of each Fiber
D_{mn}: Fiber length of link *m n*
FGB: Filter Guard Band between wavebands
F_{mn}: Number of fibers on link *m n*
Λ_{sd}: Traffic demand from node *s* to node *d*
M: A large number M

<u>a) Traffic-Grooming approach:</u>

Variables:

V_{ij}: Bandwidth of the bandwidth-variable lightpath from node *i* to node *j*.
λ_{ij}^{sd}: Traffic flow from source node *s* to destination node *d*, employing the lightpath from node *i* to node *j*.
P_{mn}^{ij}: Traffic flow using lightpath from nodes *i* to *j*, being routed through fiber link *m n.*
A_{mn}^{ij}*:* Binary, equals to 1 if $P_{mn}^{ij} > 0$; equals to 0 if $P_{mn}^{ij} = 0$.

Objective:

$$\text{Minimize:} \quad \sum_{mn}\left[\sum_{ij}\left(P_{mn}^{ij} + FGB \times A_{mn}^{ij}\right) \times D_{mn}\right] \Big/ \left(C \times \sum_{mn} D_{mn}\right) \qquad \text{(a1)}$$

Constraints:

$$\sum_j \lambda_{ij}^{sd} - \sum_j \lambda_{ji}^{sd} = \begin{cases} \Lambda_{sd} & i = s \\ -\Lambda_{sd} & i = d \\ 0 & i \neq s, d \end{cases} \quad \forall \text{i, j} \in \text{N} \quad \text{(a2)}$$

$$\sum_{sd} \lambda_{ij}^{sd} = V_{ij} \qquad \forall \text{i, j} \in \text{N} \qquad \text{(a3)}$$

$$\sum_n P_{mn}^{ij} - \sum_n P_{nm}^{ij} = \begin{cases} V_{ij} & m = i \\ -V_{ij} & m = j \\ 0 & m \neq i, j \end{cases} \quad \forall \text{i, j} \in \text{N}, \forall \text{ (m, n)} \in E \quad \text{(a4)}$$

$$\sum_{ij}\left(P_{mn}^{ij} + FGB \times A_{mn}^{ij}\right) \leq C \times F_{mn} \quad \forall \text{i, j} \in \text{N}, \forall \text{ (m, n)} \in E \quad \text{(a5)}$$

$$A_{mn}^{ij} \geq P_{mn}^{ij}/M \qquad \forall \text{i, j} \in \text{N}, \forall \text{ (m, n)} \in E \qquad \text{(a6)}$$

<u>b) Non-Traffic-Grooming approach:</u>

Variables:

λ_{mn}^{sd}: Traffic flow from source node *s* to destination node *d*, being routed through fiber link *m n*
B_{mn}^{sd}: Binary, equals to 1 if $\lambda_{mn}^{sd} > 0$; equals to 0 if $\lambda_{mn}^{sd} = 0$

Objective:

$$\text{Minimize:} \quad \sum_{mn}\left[\sum_{sd}\left(\lambda_{mn}^{sd} + FGB \times B_{mn}^{sd}\right) \times D_{mn}\right] \Big/ \left(C \times \sum_{mn} D_{mn}\right) \qquad \text{(b1)}$$

Constraints:

$$\sum_n \lambda_{mn}^{sd} - \sum_n \lambda_{nm}^{sd} = \begin{cases} \Lambda_{sd} & m = s \\ -\Lambda_{sd} & m = d \\ 0 & m \neq s, d \end{cases} \quad \forall \text{ (m,n)} \in E \quad \text{(b2)}$$

$$\sum_{sd}\left(\lambda_{mn}^{sd} + FGB \times \lambda_{mn}^{sd}\right) \leq C \times F_{mn} \quad \forall \text{ (m, n)} \in E \quad \text{(b3)}$$

$$B_{mn}^{sd} \geq \lambda_{mn}^{sd}/M \quad \forall \text{ (m, n)} \in E \qquad \text{(b4)}$$

We consider fiber lengths in the network topology to be the weight of the fiber link in our model. Therefore, the average spectrum utilization rate in our objective is a weighted average value in terms of the fiber length. In MILP formulations, the Traffic-Grooming approach has the process of establishing bandwidth-variable lightpaths and virtual topology, while the Non-Traffic-Grooming approach does not. Part a) is the Traffic-Grooming approach. Eqn. (a1) denotes the objective function, i.e., minimizing the average spectrum utilization by traffic grooming. Eqn. (a2) is the flow conservation constraints of flows on virtual topology (grooming layer). Eqn. (a3) denotes that low-speed traffic flows are groomed into bandwidth-variable lightpaths. Eqn. (a4) is the flow conservation constraints of routing at optical layer. Eqn. (a5) denotes that the utilized bandwidth (including Filter Guard Band) should not exceed the spectrum capacity of the fiber. Eqn. (a6) is used to count the amount of FGB overheads. Part b) is the Non-Traffic-Grooming approach. Eqn. (b1) is the objective function, i.e., minimizing the average spectrum utilization without traffic grooming. Eqn. (b2) is the flow conservation constraints of routing at optical layer. Eqn. (b3) denotes the capacity constraints of the fiber. Eqn. (b4) is used to count the amount of FGB overheads.

4. Illustrative Numerical Examples

We use NSFnet (14 nodes, 21 links) and USnet (24 nodes, 43 links) topologies (with link length values) [6] to evaluate the performance of Traffic-Grooming and Non-Traffic-Grooming approaches in the Spectrum-Elastic Optical Path Networks. We assume that there is one pair of bidirectional fiber on each link, and the available spectrum width of each fiber is set to be 1000GHz. The Filter Guard Band between wavebands is set to be 10GHz [2]. The data rate-to-bandwidth ratio is set to be 4bit/s/Hz. The traffic demand is uniform for each source-destination pair, and increases from 20Gbps to 100Gbps. The average spectrum utilizations by both Traffic-Grooming and Non-Traffic-Grooming approach for NSFNET and USNET are shown in Fig. 4 and Fig. 5, respectively.

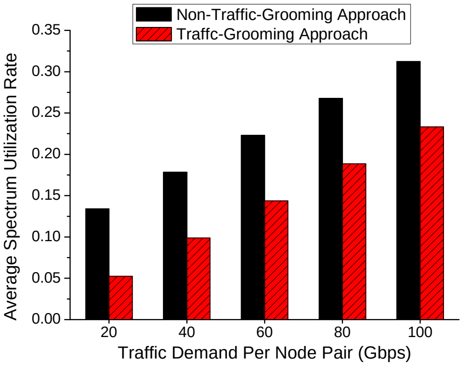

Fig. 4. Average Spectrum Utilization in NSFnet (FGB: 10GHz).

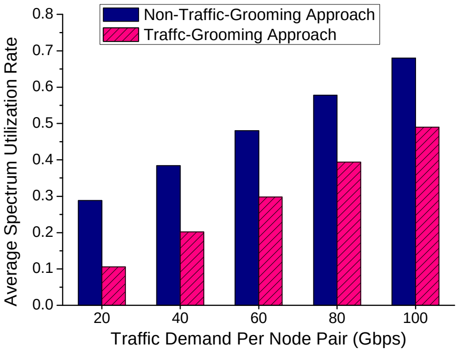

Fig. 5. Average Spectrum Utilization in USnet (FGB: 10GHz).

Fig. 4 shows that our Traffic-Grooming approach can save about 8% of the total spectrum in NSFnet, comparing to the Non-Traffic-Grooming approach. The saving ratio is almost stable under different amounts of traffic demand. Therefore the spectrum saving appears more obvious when traffic load is low. Fig. 5 shows that our Traffic-Grooming approach can save about 18% of the total spectrum in USnet, which is 180GHz in absolute amount. The reason why the saving ratio in USnet is higher is probably that the USnet has higher connectivity so that it has more opportunities to groom traffic. Besides, since the spectrum saved by traffic grooming comes from the reduction of the overhead of Filter Guard Band, the spectrum saving by traffic grooming is higher if we use optical filters of higher Filter Guard Band (Table 1).

Table 1: Spectrum savings using filters of different Filter Guard Bands in NSFnet.

Filter Guard Band	10GHz	20GHz	30GHz
Spectrum Saving	8%	17%	24%

5. Conclusion and Acknowledgement

We have proposed a novel traffic grooming scheme based on Spectrum-Elastic Optical Path Networks. We have built a numerical example to illustrate the performance of our Traffic-Grooming approach. Comparing to the Non-Traffic-Grooming approach, our approach save more bandwidth on the spectrum. This work is supported in part by 863 Project under No. 2008AA01A328 and 2008AA01A329, 973 Project under No. 2010CB328203 and 2010CB328205, National Science Foundation Project under No.60972020.

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