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A new multi-granularity traffic grooming routing algorithm in IP over WDM networks

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ABSTRACT

In IP over WDM networks, since there is a large bandwidth gap between a wavelength capacity and the actual bandwidth required by each user, it is necessary to multiplex low-rate traffic streams (LRSs) into lightpaths by traffic grooming. However, with the number of wavelengths increases, a large number of all optical (OOO) transmitting ports are consumed. Meanwhile, the multi-hop grooming with incorporating full-wavelength conversion capacity in each node requires too many optical–electrical–optical (OEO) ports inevitably. To solve theses problems, waveband switching and intra-band wavelength conversion are proposed. By integrating traffic grooming and waveband switching, this paper devises a new multi-granularity traffic grooming mechanism with the function of intra-band wavelength conversion. Based on the proposed mechanism and integrated grooming policy (IGP), a new heuristic routing algorithm called multi-granularity traffic grooming based on integrated auxiliary graph (MGIAG) is also proposed since the traffic grooming problem is NP-hard. Simulation results show that, compared to traditional integrated grooming algorithm (IGA), MGIAG can save more ports and obtain lower blocking probability. Compared to traditional single-hop traffic grooming algorithm (SHA), lower blocking probability and more savings in transmitting ports can be achieved by multi-hop grooming in MGIAG and IGA although they consume more OEO ports.

1. Introduction

In the general case, recent researches on multi-granularity traffic grooming typically come into two flavors. First, traditional traffic grooming used in wavelength-routed networks (WRNs), the process of multiplexing several low-rate traffic streams (LRSs) from the access layer into high-capacity lightpaths established on wavelength-plane layer, can enhance the resource utilization and decrease the cost and power consumption of electric equipments [1–4]. Second, waveband switching based on the notation of merging several wavelength-routes into waveband tunnel established on waveband-plane layer, is able to save more all optical (OOO) transmitting ports compared to wavelength-routed algorithms, such as traditional traffic grooming used in WRNs. However, as a new switching unit called WavEband Label Switched Path (WE-LSP) is defined in generalized multi-protocol label switching (GMPLS) [5], a more complex multi-granularity network structure of different vertical layers has resulted, that is IP over WDM network whose integrated configuration comprises of access layer, wavelength-plane layer, and waveband-plane layer. Accordingly, the sub-wavelength, wavelength and waveband granularities should be taken into account synchronously in the new joint routing problem available for IP over WDM network. A promising and practical solution is to combine the advantages of traditional traffic grooming and waveband switching based on the multi-granular photonic cross-connect switches (MG-PXCs). MG-PXC is fundamentally different from an ordinary multi-granular optical cross-connect (MG-OXC) because it is equipped with an additional bank of OEO grooming switch matrix. The ordinary MG-OXC is merely applied to support waveband switching, but MG-PXC can support both waveband switching and traditional traffic grooming. On the other hand, the more rational wavelength-grooming schemes (WG-schemes) or waveband merging strategies (WM-strategies) one uses, the better performances can be obtained in WRNs or waveband switching (WBS) networks. Therefore, it is necessary to develop an effective integrated grooming policy to employ WG-schemes and WM-strategies together. Therefore, the new mechanism called multi-granularity traffic grooming is proposed in this paper. The new mechanism can integrate the advantages of traditional traffic grooming and waveband switching effectively to further save ports and to obtain low blocking probability in IP over WDM networks under the dynamic connection request environment.

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1.1. Related work

With the number of wavelengths in a fiber increases, ordinary OXCs that only switch wavelength-granularity demands require a large number of transmitting ports, which results in increasing cost and control complexity. MG-OXC is the foremost solution due to its small scale modularity, crosstalk and complexity reduction. The authors in Refs. [6,7] proposed the use of MG-OXC without any other additional function matrixes. But recently, the concept of using sub-wavelength, wavelength, waveband and even fiber switches in a hierarchical manner has received growing attention, and then the authors in Refs. [8,9] provided MG-PXC that contains a three-layer MG-OXC with the function of converting wavelength or waveband and a OEO traffic grooming unit used to support multiplexing LRSs. Since the joint routing algorithm and the integrated grooming policy based on MG-PXC was not considered in Ref. [9], the proposed MG-PXC was lack of the necessary policy control plane and improvements for decreasing the overall cost of the IP over WDM network system.

On the other hand, an integrated auxiliary graph was presented in Ref. [10] to compute the route and assign the wavelength for lightpath synchronously with constrained transceivers in a dynamic environment. Based on that integrated auxiliary graph, the authors proposed an algorithm called IGA to obtain lower blocking probability followed by multi-hop grooming since it can perform full-wavelength conversion on each node. But the problem here is that, the full-wavelength conversion may consume a large number of OEO ports inevitably. In addition, IGA and other traditional traffic grooming algorithms choose route for lightpath in wavelength-routed manner. If the lightpath has no available bandwidth for LRSs, we will compute another wavelength-route for establishing new lightpath with two same end nodes, and that new wavelength-route also consumes transmitting ports at intermediate nodes, which is not desirable. Waveband switching can save additional consumption of transmitting ports because it can bind several wavelength-routes into a waveband tunnel as a single entity. The WBS algorithms and several WM-strategies were introduced in Refs. [11–17], among which, the authors in Ref. [16] described a new dynamic WBS algorithm called RA-IAG followed by sub-path merging strategy, compared to the other WBS algorithms followed by end-to-end merging strategy, it can save more OOO transmitting ports. But RA-IAG did not have the function of traffic grooming and also performed full-wavelength conversion in each node. The additional consumption of OEO ports has not still been solved. A practical way to solve this problem is to pay attention on sparse placement of a limited number of wavelength converters or limited-range wavelength converters. The authors in Ref. [17] proposed a waveband switching algorithm with considering the intra-band wavelength conversion technology, where a wavelength can only be converted to any other wavelengths within the same waveband. Intra-band wavelength conversion technology has an ability of reducing the times of converting wavelengths so that it can save the consumed OEO ports. However, the authors in Ref. [17] only considered the wavelength-granularity demands and ignored the sub-wavelength-granularity demands, i.e., LRSs. Moreover, although the idea of integrating the advantages of traditional traffic grooming and waveband switching was first presented in Ref. [9], how to perform the multi-granularity traffic grooming was not described in this paper. Therefore, the multi-granularity traffic grooming is an interesting and challenging problem we face in IP over WDM networks.

1.2. Our contribution

As mentioned above, some wavelength-convertible traffic grooming algorithms can attain low blocking probability by incorporating wavelength conversion capability at all of the nodes. However, as the number of active wavelengths in a fiber increases, the solution of multiplexing several LRSs into the high-capacity lightpaths, whose consumed wavelengths are different from each other, followed by full-wavelength conversion technology may cost a large number of expensive OEO ports and also may require many transceivers if most of lightpaths are set up anew since each new lightpath will consume transceivers on its two end nodes. The idea of implementing with the limited wavelength conversion technology to save OEO ports by decreasing the times of wavelength conversion is readily necessary. Therefore, the intra-band wavelength conversion is conceivably of interest to us. In addition, the waveband switching wherein several wavelengths can be grouped into a waveband and be switched as a single entity can save more all optical transmitting ports than other technologies using wavelength routing switches at intermediate nodes. Therefore, in our opinion, the intra-band wavelength conversion and waveband switching are both practical and should be considered when solving the multi-granularity traffic grooming problem.

In this paper, we devise an identified structure of MG-PXC and the new integrated grooming policy (IGP) that contains three WG-schemes and two WM-strategies, introduce three important technologies including multi-hop grooming, intra-band wavelength conversion and waveband switching, and present the mathematical model for calculating the number of consumed ports. Since the traffic grooming problem is the NP-hard [18], we propose a new heuristic joint routing algorithm MGIAG for routing traffic with different granularities starting from sub-wavelength granularity (i.e., LRSs) to individual wavelength granularity and then to waveband granularity. Finally, to support our algorithm MGIAG, we employ a novel graph model called IAG. The algorithm MGIAG is developed based on the auxiliary graph IAG and applies the least-cost-path routing algorithm in that auxiliary graph for each traffic demand and updates that auxiliary graph accordingly. Our proposed MGIAG can integrate the advantages of traditional traffic grooming using multi-hop grooming scheme and waveband switching using sub-path waveband merging strategy effectively to save OOO ports and obtain low blocking probability. On the other hand, MGIAG can reduce a large number of OEO ports by using the intra-band wavelength conversion.

This paper is organized as follows. In Section 2, we firstly introduce the identified structure of MG-PXC, the multi-hop grooming, the intra-band wavelength conversion and the waveband switching technologies in our proposed mechanism, and then we present the integrated grooming policy and demonstrate how to calculate consumed ports by using our proposed mathematical model. In Section 3, we construct an integrated auxiliary graph according to the network state. Based on that auxiliary graph, we proposed the joint routing algorithm MGIAG in Section 4, and give an illustrative example to explain the routing and wavelength/waveband assignment in MGIAG in Section 5. In Section 6, we make the simulation and performance analysis. Section 7 concludes this paper.

2. Problem statement

2.1. Network model

The physical network topology can be denoted as *PNT* (*N*, *L*, *B*, *W*, *T*, *G*), where *N* is the set of physical nodes, *L* is the set of fiber links, *B* is the set of active wavebands per fiber link, *W* is the set of active wavelengths per fiber link (i.e., fiber capacity), *T* is the set of tunable transceivers per physical node and *G* is waveband granularity, in this work, we ensure $\left|W\right| = \left|B\right| \times G$. The set of wavelengths in a waveband is specified beforehand. Each waveband B_y ($1 \le y \le \left|B\right|$) consists of *G* contiguous