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Grooming of non-uniform traffic on unidirectional and bidirectional rings

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Abstract

Traffic grooming in WDM networks is obtained by intelligently allocating the traffic onto a given set of wavelengths. This paper presents heuristics for grooming of non-uniform general traffic demands onto a given set of wavelengths available on a unidirectional or bidirectional ring. The objective is to minimize the number of higher layer equipment, like SONET Add/Drop Multiplexers (ADMs), or MPLS routers. We map the unidirectional ring onto a linear topology and develop a generalized two-step approach to solve the grooming problem on the mapped topology. In the first step, we allocate the traffic while minimizing the possible number of *strings* (each string being a collection of non-overlapping traffic streams) in a manner that yields the optimal number of strings in the linear topology case. We also prove the optimality of this step in the number of the strings (wavelengths). In the second step we employ a grouping technique to efficiently combine *g* strings onto a wavelength while minimizing the total number of the ADMs. We also address the problem of grooming the non-uniform traffic on a bidirectional ring by mapping it onto unidirectional rings, and applying the two-step approach. Moreover, in the case of bidirectional rings we propose an approach to route the traffic that reduces the total number of the required wavelengths and ADMs. The time complexity of our technique is at least an order of *n* less than other proposed approaches, where *n* is the total number of nodes in the network. The efficacy of the proposed technique has been demonstrated through a large number of experiments.

Keywords: WDM networks; Traffic grooming; ADMs; Linear topology; Unidirectional ring; Bidirectional ring; Non-uniform traffic; Asymmetric traffic; NP-completeness

1. Introduction

During the last decade, Wavelength Division Multiplexing (WDM) networks have emerged as an attractive architecture for backbone networks. WDM networks provide high aggregate bandwidth, on the order of several Terabits per second. Also, WDM networks eliminate the electro-optic processing delays using wavelength routing [1]. However, the cost-effectiveness of WDM networks depends on the amount of the optical passthrough provided by the network to the given traffic. The amount of the optical passthrough in turn depends on the traffic pattern and on the way the traffic between different source and destination pairs is groomed (multiplexed) on the available set of wavelengths. Traffic grooming is thus defined as an intelligent allocation of the traffic demands, between different network nodes, onto an available set of wavelengths in such a way that reduces the overall cost of the network.

WDM routing networks support lightpaths, which is a pure optical communication path between two nodes. In order to optimize the cost of the network, one needs to take into account the higher layer that will use these lightpaths and its connectivity patterns. The Synchronous Optical Networks (SONET) is currently being used as a higher layer in WDM networks, and because of its wide deployment and efficient protection schemes will remain the most likely option for some time.

In Fig. 1, a typical WDM network is shown with three nodes. Each node is equipped with an Optical Add/Drop Multiplexer (OADM), which can selectively add or drop wavelengths at each node, thus providing an optical passthrough to the rest of the wavelengths. Each of the wavelengths dropped at a node is then processed by the higher layers Add/Drop Multiplexers (ADMs), e.g. a

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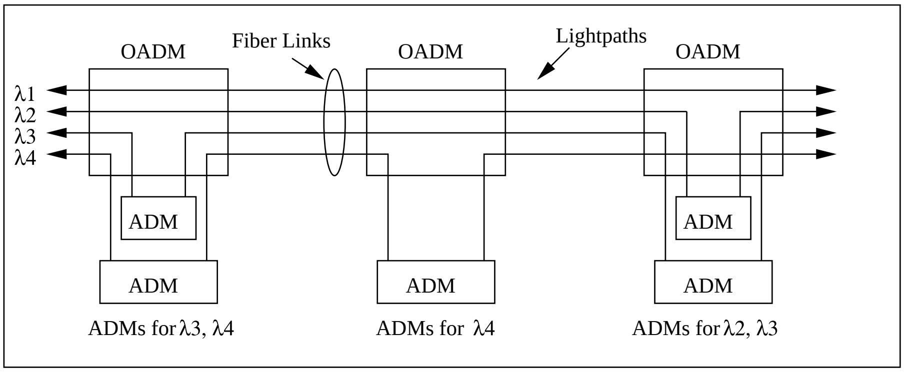

Fig. 1. An example of an optical network with OADMs and ADMs.

SONET ADM, after conversion into the electronic form. Thus, the equipment needed at each node corresponds to the number of wavelengths dropped at each node. To reduce this number, and consequently the cost of equipment, one needs to reduce the number of wavelengths dropped at a node. We can achieve this goal by grooming the traffic in such a way that all the traffic to and from a node is carried on the minimum number of wavelengths.

As an example, consider a five-node linear topology network, shown in Fig. 2. Let each node be equipped with an OADM. Each OADM is in turn connected to a number of SONET ADMs (not shown in the figure). Having an OADM on each node will help only drop those wavelengths that carry the traffic to, or from that specific node. A wavelength can bypass a node if it carries no traffic that is transmitted or received by that node. This will result in the saving of a SONET ADM. Hence, our objective is to minimize the total number of the SONET ADMs used in the network to support all of the traffic by intelligently assigning traffic to the wavelengths. Let g denote the total number of basic units of traffic supported by each wavelength. For example, if a wavelength supports an OC-12 connection, and the basic unit of traffic is an OC-3, then $g=4$. For illustrative purpose, we assume that $g=2$ in Fig. 2. Traffic demands or connections are shown by the line segments between the source and destination nodes. Also, black circles are used on the edges of the segments to represent a SONET ADM that is used at the corresponding node, and for a specific wavelength. To minimize the total number of ADMs required, out of many possibilities, we could have the following two allocations of traffic to wavelengths.

(a) λ_1: $1\leftrightarrow 2$, $3\leftrightarrow 4$; λ_2: $1\leftrightarrow 5$; λ_3: $2\leftrightarrow 4$; λ_4: $2\leftrightarrow 5$;
(b) λ_1: $1\leftrightarrow 2$, $2\leftrightarrow 4$; λ_2: $1\leftrightarrow 5$; λ_3: $3\leftrightarrow 4$; λ_4: $2\leftrightarrow 5$;

Assignments (a) and (b) are shown in Fig. 2(a) and (b), respectively. For the first assignment the total number of required ADMs is 10, while for the second assignment the total number of ADMs is 9. Note that in the second assignment the traffic between nodes 1 and 2, and between 2 and 4 are sharing the same ADM. This example shows that by assigning the traffic to appropriate wavelengths, one can reduce the number of required ADMs. Also, given very high cost of SONET ADMs, approximately $40,000 for a single port version, even saving few ADMs translates into savings of hundred thousands of dollars.

2. Related work

Traffic grooming in WDM networks is comparatively a new field, and has recently started to receive attention. Few survey papers have been published in this area [3–5].

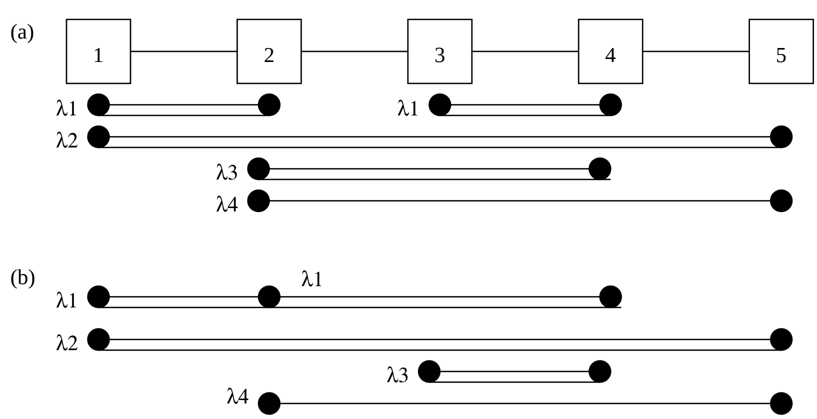

Fig. 2. Two different traffic assignments on a linear topology, for the same traffic demands.