Design and Dimensioning of a WDM Mesh Network to Groom Dynamically Varying Traffic

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Abstract. In this paper, we address the traffic grooming problem in WDM mesh networks when the offered traffic is characterized by a set of traffic matrices—a variant of dynamically changing traffic. We justify the need to address this problem in mesh networks and also argue for the validity of our approach to solve this problem. Our primary objective is to design the network in terms of the number of wavelengths and transceivers required to support any offered traffic matrix. We provide a simple and generic framework to minimize the number of transceivers needed in the network. Simulation results have been presented in contrast with a possible approach, to enable comparison with our solution strategy. An ILP formulation of our approach is also presented.

Keywords: WDM optical mesh networks, traffic grooming, dynamic traffic, network design, dimensioning, virtual topology, network cost, set of traffic matrices

1 Introduction

Wavelength division multiplexing (WDM) has emerged as a promising technology for effective utilization of the huge bandwidth of an optic fiber. In WDM transmission, traffic in the network is transmitted on different wavelengths and each wavelength corresponds to a data communication channel. The capacity of each wavelength channel is of the order of a few Gbps while the electronic rates are only of the order of a few tens of Mbps. Aggregating such low speed connections onto a high-speed wavelength is referred to as traffic grooming. This problem can be studied under two objectives: Minimize the overall network cost (including the transceivers required as well as the number of wavelengths) or Maximize the throughput under constrained network resources.

Initially the work in traffic grooming had been explored only in WDM SONET ring networks. The electronic cost (cost of equipment to convert the optical signals into electronic signals) dominates the network cost. Hence the primary focus has been on minimizing the number of add/drop multiplexers (ADMs) or switching ports. Primarily this was done without increasing the required number of wavelengths. The hardness of these problems has led to the development of heuristics [1,2], and design and analysis of various ring networks [3]. A survey related to various network models and traffic scenarios can be found in Dutta and Rouskas [4]. In what follows, a transceiver is used as a generic term to denote either the line terminating equipment or an ADM.

With the evolution of optical networks from ring to mesh topologies, traffic grooming in mesh networks has emerged as a prominent research area. It is observed that almost all efforts in traffic grooming in mesh networks have tried to either maximize the throughput or minimize the network cost, for static or dynamic traffic. In Zhu et al. [5], a generic graph model has been provided to address dynamic traffic grooming in mesh networks and the survivability aspect has been addressed in Thiagrajan and Somani [6]. In Konda and Chow [7], the static traffic grooming problem of minimizing the number of

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transceivers has been considered for a general topology. The assumption that it is possible to map the resulting virtual topology onto the physical topology has been made. This limitation is handled in Zhemin and Hamdi [8]. An ILP formulation has been provided to minimize the overall network cost (cost of both transceivers and wavelengths) to support a traffic requirement but no algorithmic approach has been suggested in that direction. The heuristic based on the Blocking Island paradigm and the heuristics suggested in Zhu and Mukerjee [9] try to maximize throughput with a fixed number of wavelengths and transceivers. Usually the traffic requirement is characterized by a single traffic matrix (static traffic). A better description of the traffic may be a set of traffic matrices. In this paper, we consider this traffic variant and design a network with minimum number of transceivers needed to support any traffic matrix in the given set. We are the first to consider this kind of traffic in WDM mesh networks and term it dynamic traffic as the resulting network can handle any traffic which dynamically changes within the given set. However, significant efforts have been made to address this problem in ring networks [10].

The organization of the rest of the paper is as follows. In Section 2, we identify the need for addressing the above problem and formally state our problem in Section 3. We discuss the possible solution strategies in the context of existing traffic grooming approaches in this section and also describe a possible ILP formulation for the same. The formulation takes as input a set of traffic matrices enumerating the possible traffic scenarios, and provides a design solution which minimizes the number of transceivers and wavelengths. Section 4 projects a heuristic to tackle the problem. Results have been presented in Section 5 and the possible improvements of our heuristic are analyzed. Finally we conclude in Section 6 and provide some directions for future work.

2 Motivation behind the Problem

It should be observed that traffic pattern of the optical network changes with time. Dynamic traffic grooming algorithms for reconfiguration in SONET ring networks have been presented in Zhang and Ramamurthy [11]. We can either try to route as much new traffic as possible without adding SADMs or add the minimum number of SADMs to satisfy all the new traffic. A more practical proposition would be to determine the total number of network components (transceivers) and the virtual topology needed to support any possible traffic in the network. This is precisely what our approach strives to achieve. The advantage of this approach is zero reconfiguration at any stage of the operation of the network though some lightpaths might not be utilized for a particular traffic scenario. The importance of this claim will become clear when we discuss the possible solution strategies to address the problem at hand.

A pertinent question at this point would be—How can we determine the set of possible traffic matrices? These matrices could reflect either the traffic requirements at various instants of a day or over a period of time. These can also be obtained from the statistical data of similar traffic scenarios. Also, a general traffic matrix (similar to the single static traffic matrix) could be obtained and the net individual demands be varied in and around the current value. This approach is acceptable considering the fluctuations that could be possible in traffic. Further, the value of the offered traffic could vary either in time or in space or in both, and a similar assumption has been made in Gencata and Mukerjee [12]. Space variation in traffic here refers to varying traffic intensity in different portions of the network.

3 Our Work

3.1 Problem

Assume the possible traffic requirements are provided in the form of a set of traffic matrices \( T^1, T^2, \ldots, T^n \). The assumptions made in our study are listed below:

1. Every connection request has the same bandwidth requirement. The number of connection requests between the node pairs \((i, j)\) in \(k\)-th matrix is given by \( T^k(i, j) \). For instance, \( T^2(3, 7) = 4 \) is read as four independent connection requests between nodes three and seven in the second traffic matrix.
2. Transceivers are tunable to any wavelength on the fiber.
3. Duplex communication channels have been considered.

The problem is to design a physical topology with the minimum number of transceivers and wavelengths