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A global approach for designing reliable WDM networks and grooming the traffic

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Abstract

In this paper, we address the global problem of designing reliable wavelength division multiplexing (WDM) networks including the traffic grooming. This global problem consists in finding the number of optical fibers between each pair of optical nodes, finding the configuration of each node with respect to transponders, finding the virtual topology (i.e., the set of lightpaths), routing the lightpaths, grooming the traffic (i.e, grouping the connections and routing them over the lightpaths) and, finally, assigning wavelengths to the lightpaths. Instead of partitioning the problem into subproblems and solving them successively, we propose a mathematical programming model that addresses it as a whole. Numerical results are presented and analyzed.

Keywords: Wavelength division multiplexing (WDM) networks; Network design; Traffic grooming; Virtual and physical topologies; Mathematical programming model

1. Introduction

Wavelength division multiplexing (WDM) is now a mature and reliable optical network technology. It is widely deployed to exploit the huge optical fiber bandwidth. WDM is convenient for synchronous optical network (SONET) and multi-protocol label switching (MPLS) based networks. It is able to establish lightpaths to carry the traffic between the nodes. A lightpath is an optical communication path between two nodes uniquely identified by a wavelength and a physical path. The lightpaths in a WDM network form a virtual topology (i.e., a logical network) over the underlying physical network. For instance, see [1–3] for technical information concerning optical networks, and [4] concerning the architecture of the MPLS/WDM and SONET/WDM nodes.

Nowadays, dense WDM (DWDM) allows 64 wavelengths per optical fiber and a wavelength may operate at up to 10 Gbps (OC-192). Forty Gbps (OC-768) cards are actually in development for near future use. Therefore, the available bandwidth (over a terabit) is outsized compared to the requests. Typically, a connection between two network edge-nodes is up to OC-12 and rarely more than the gigabit per second [3]. As a result, only a fraction of each wavelength is used. This under exploitation leads to a loss of provider incomes and to a premature saturation of the network. Consequently, the problem is less a bandwidth one than the management of this bandwidth. (Note that OC stands for optical carrier and denotes a fundamental unit in the SONET technology. OC-n represents an optical signal, and n denotes the number of increments of 51.84 Mbps. For the technical aspects related to SONET networks, see [5].)

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Traffic grooming can be an appropriate solution to this bandwidth management. It is a well-known traffic engineering technique which packs low-speed traffic streams into high-capacity optical channels. The traffic streams are composed of connections and each connection is a traffic flow of a certain rate (e.g., OC-3 and OC-12) between two nodes. Thus, the traffic grooming permits grouping several connections, possibly of different origin-destination node pairs, into the same lightpath. This aggregation is allowed by space-division multiplexing (SDM), frequency-division multiplexing (FDM) and time-division multiplexing (TDM). An aggregation involving these levels or granularities is called full grooming. A node performing an aggregation at all the levels is a transparent node and a node performing only some of them is called translucent. An opaque node is a node without any grooming facilities [4]. Virtual concatenation [6] is a grooming technique at the TDM level, used within SONET, which allows carrying, for instance, up to 16 OC-3 over an OC-48. Therefore, traffic grooming helps to optimize the network resources by increasing the utilization of the lightpaths and thus minimizing the required number of lightpaths.

In order to illustrate the traffic grooming mechanism, an example is provided in Fig. 1. Tables 1 and 2 present, respectively, the number of transponders for each node and the characteristics of the connections for the example. Fig. 1(a) illustrates the physical topology and Fig. 1(b) illustrates the starting virtual topology where the connection C1 uses the

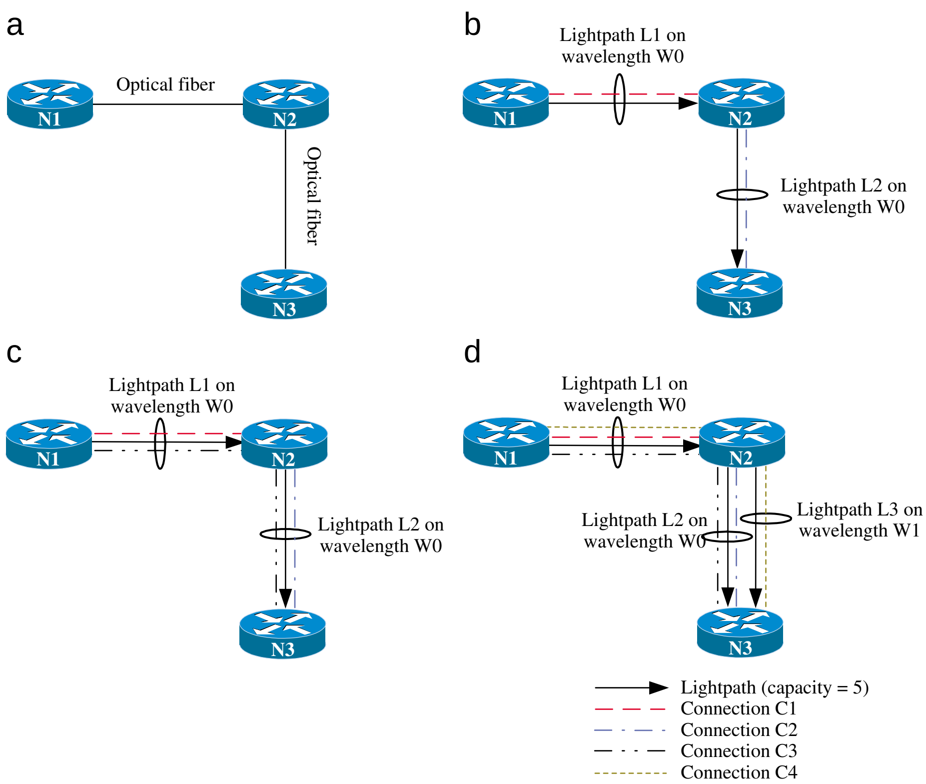

Fig. 1. Illustration of the traffic grooming mechanism.

Table 1
Number of reception and transmission transponders for each node

Node	Number of reception transponders	Number of transmission transponders
N1	1	1
N2	3	3
N3	2	2