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Algorithms for the global design of WDM networks including the traffic grooming

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Abstract

In this paper, we propose a model and algorithms for the global design problem of wavelength division multiplexing (WDM) networks including the traffic grooming. This problem consists in finding the number of fibres between each pair of nodes (i.e. the physical topology), finding the number of transponders at each node, choosing the set of lightpaths (i.e. the virtual topology), routing these lightpaths over the physical topology and, finally, grooming and routing the traffic over the lightpaths. Since this problem is NP-hard, we propose two heuristic algorithms and a tabu search metaheuristic algorithm to find solutions for real-size instances within a reasonable amount of computational time.

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

1. Introduction

The wavelength division multiplexing technology is widely deployed over different optical networks such as synchronous optical network (SONET) to fully exploit the important optical fibre bandwidth by using multiple wavelengths over a single fibre. This leads to a huge fibre bandwidth, over a terabit per second, available in each fibre. Since, nowadays, a connection between two nodes has rarely more than a gigabit per second, this bandwidth is outsized compared to the requests. This under-exploitation may lead to a premature saturation of the network.

Traffic grooming can be an appropriate solution to 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 of several connections, possibly of different origin-destination node pairs into the same lightpath. This aggregation is allowed by space, frequency and time-division multiplexing. An aggregation involving these levels or granularities is called full grooming. A node performing switching within only its optical devices is a transparent node and a node performing switching only at the electronic level is called opaque. A hybrid node is a translucent node, it is a able to perform switching at the optical

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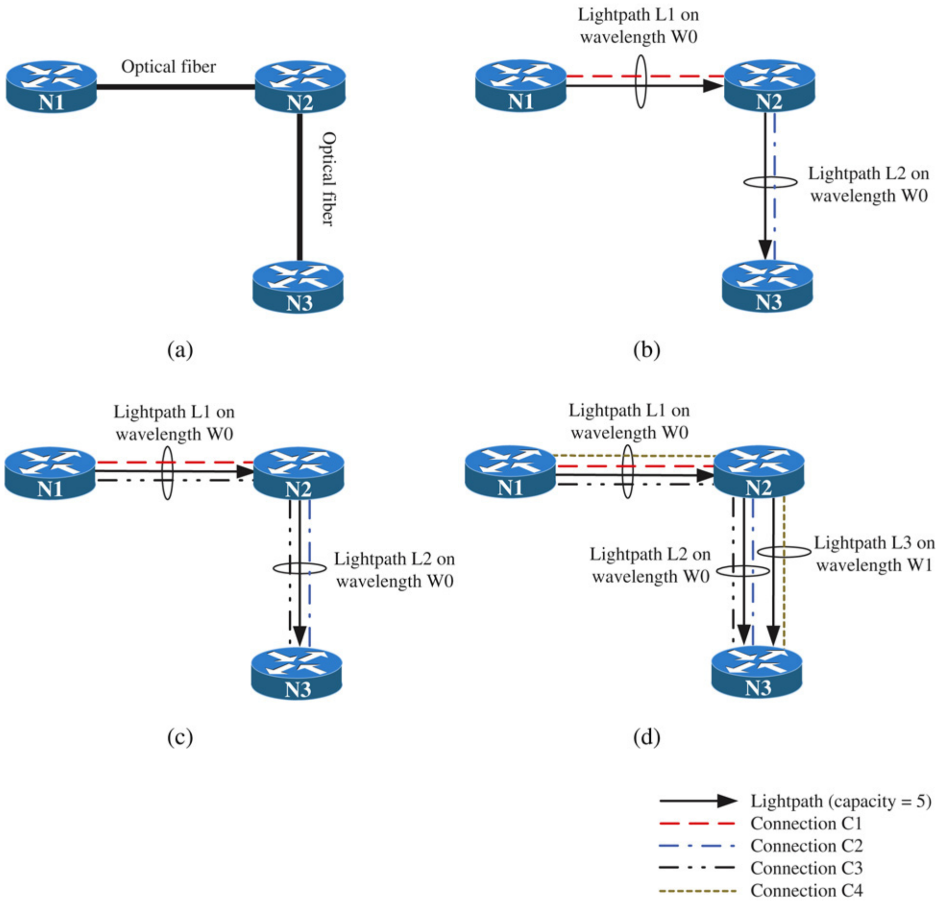

Fig. 1. Illustration of the traffic grooming mechanism.

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

or electronic levels. For more details concerning the optical networks, see Goralski [4] and Laude [8].

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 lightpath L1 on the wavelength W0 between the nodes N1 and N2 and the connection C2 uses the lightpath L1 on the wavelength W0 between the nodes N2 and N3. In the case of a network with no grooming facilities, if a connection between the nodes N1 and N3 is requested, this connection is rejected because the lightpath L1 is already in use and all transmission transponders are used at node N1 (see Table 1). This is not the case if the network performs traffic grooming as illustrated in Fig. 1(c) where the connection C3 is groomed with the connection C1 on the lightpath L1 and with the connection C2 on the lightpath L2. Moreover, consider that an additional connection of two capacity units is requested between the nodes N1 and N3. If the node N2 does not perform traffic grooming at the wavelength level, the connection C4 cannot be routed because lightpath L2 does not have enough spare capacity and the wavelength W0 is already used. Otherwise, if the node N2 has full grooming facilities, an additional lightpath L3 may be established between the nodes N2 and N3 on the wavelength W1. Thereby, the connection C4 can be groomed with connections C1, C2 and C3 on the lightpath L1, then