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An improved multiobjective approach inspired by the flashing behaviour of fireflies for Traffic Grooming in optical WDM networks

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A B S T R A C T

Nowadays, the traffic demands in optical networks are low-speed traffic requests (low bandwidth requirement of a few Mbps) that employ the huge capacity of a fiber channel (Gbps), causing a waste of bandwidth as a result. Fortunately, by using electronic grooming nodes, we can multiplex (groom) several low-speed demands onto one channel in order to optimize the available resources in an optical network. The problem of grooming low-speed traffic requests is known in the literature as the Traffic Grooming problem and is considered an NP-hard optimization problem. In this work, we use both multiobjective optimization and evolutionary computation with the aim of facing this optical networking problem. The selected evolutionary algorithm is based in the behaviour of fireflies, the Firefly Algorithm (FA). In order to optimize more than one conflicting objective function of the Traffic Grooming problem simultaneously, we have modified the standard FA to the multiobjective domain (MO-FA). After carrying out different experiments with diverse real-world optical networks, comparing the results of the MO-FA with other multiobjective approaches and different standard heuristics for this problem, we can conclude saying that the new version of the MO-FA is an effective approach for dealing with this telecommunication problem.

1. Introduction

Recent years have witnessed a great expansion of optical fibers in data networks. The expansion of these data networks is principally motivated by the exponential increase in users that make use of the Internet, causing an urgent necessity of replacing the low-speed copper links by high-speed optical fiber links.

The bandwidth of a single fiber link is around Tbps; however, the maximum speed for an end user is constrained by the processing speed of their devices, commonly a few Gbps. Wavelength Division Multiplexing (WDM) is a technology developed for making the most of each optical fiber link by adding concurrency in transmission data. In this way, a fiber link is divided into several channels and each channel on a different wavelength (λ). Therefore, a fiber link with bandwidth in the Tbps range may be divided into a number of wavelength channels [1], each of which can have a transmission speed in the Gbps range (e.g. OC-48, OC-192, and OC-768).

Basically, any optical link based on WDM technology consists of transmitters, multiplexers, optical pre-amplifiers, post-amplifiers, demultiplexers, and receivers [2]. The term of *lightpath* is commonly used to designate the optical connection carried end-to-end from a source node to a destination node over a specific wavelength on each intermediate link, see Fig. 1.

The bandwidth requirement of the vast majority of current traffic demands is much lower than the full channel capacity, a few Mbps compared with the high bandwidth of each channel (Gbps) [3]. In order to solve this drawback, each WDM node is equipped with access stations to groom or multiplex several low-speed traffic connections on a high-speed wavelength channel.

The Traffic Grooming problem in WDM networks may be classified by traffic pattern and by the number of hops in the virtual topology. On the one hand, regarding the traffic pattern, if the set of traffic requests is known in advance we can say that the problem is static; otherwise, if the connections are not known in advance but they arrive and departure along the time [4], we say that the problem is dynamic. On the other hand, regarding the number of hops in the virtual topology, we refer to single-hop Traffic Grooming problem when the low-speed connections are restricted to using no more than a single lightpath to be established. On the contrary, if the low-speed requests may use several concatenated lightpaths, we say that is a multi-hop Traffic Grooming problem.

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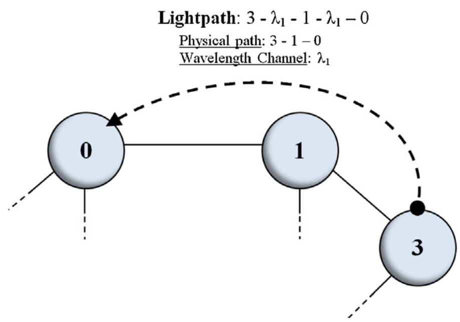

Fig. 1. The *lightpath* concept.

The Traffic Grooming problem consists of three subproblems: *lighpath routing*, *wavelength assignment*, and *traffic routing*. In the *lightpath routing*, we establish diverse lightpaths over the physical topology with the aim of obtaining a virtual topology, in which the edges between nodes represent an established lightpath. In the *wavelength assignment* subproblem, we assign an available wavelength to each edge of the virtual topology. Finally, in the third subproblem (*traffic routing*), we establish each low-speed connection request over the virtual topology.

By solving these three subproblems we try to maximize the number of low-speed traffic requests established successfully, to minimize the number of transceivers used at each WDM node, and to minimize the propagation delay of each established lightpath. The main advantage of solving each subproblem separately is that it makes the Traffic Grooming problem easier to handle; however, it is probably that it does not lead to the optimal solution to the whole problem [5].

Since the Traffic Grooming problem contains two NP-hard subproblems [6]: *lightpath routing* and *wavelength assignment* subproblems, we can say that this optical networking problem is itself an NP-hard problem. In addition, Chen et al. [7] proved that the *traffic routing* subproblem (the third subproblem) is also NP-hard, even in very small optical networks, in which the other two subproblems (*lightpath routing* and *wavelength assignment*) may be solved in polynomial time. All in all, we can say the Traffic Grooming problem is an NP-hard optimization problem; so, the design of effective metaheuristics that can groom low-speed traffic requests in a reasonable amount of time is extremely important for the industry.

In this work, we propose the use of multiobjective optimization and evolutionary computation for tackling this optical networking problem, optimizing the total throughput established, the number of transceivers used, and the average propagation delay at the same time. We have selected an evolutionary algorithm inspired by the flashing behaviour of fireflies, the Firefly Algorithm (FA) [8]. Since we are dealing with a multiobjective optimization problem, we have modified the standard FA in order to optimize two or more conflicting objective functions simultaneously, we refer to it as Multiobjective Firefly Algorithm (MO-FA).

With the aim of testing the goodness of the MO-FA, we have conducted diverse experiments and comparisons with other relevant methods published in the literature. In the experiments, we have used a simple benchmark topology of six nodes and three real-world optical networks. These optical networks are the European Optical Network, the National Science Foundation network, and the Nippon Telegraph and Telephone network. In addition, we have used diverse scenarios for each optical network, each scenario with different number of transceivers per node and wavelengths per fiber link in order to test the accuracy of our proposal in very different situations. The MO-FA have been compared with diverse Multiobjective Evolutionary Algorithms (MOEAs) published in the literature and with other heuristics and metaheuristics developed by other authors.

The remainder of this paper is organized as follows. A review of the evolution of the Traffic Grooming problem, and how it has been solved by other researchers is included in Section 2. Section 3 describes the problem formulation in a formal way, as well as giving an illustrative example of the problem. Some essential multiobjective concepts and the representation of the chromosome appear in Section 4. A detailed description of the MO-FA is presented in Section 5. Section 6 is devoted to analyze the experiments performed and also to compare with other approaches published in the literature. Finally, Section 7 summarizes the conclusions of the paper and presents possible lines of future work.

2. Related work

In this section, we briefly describe how the Traffic Grooming problem has been tackled in the literature and also its evolution.

In [9], the Traffic Grooming problem was handled as a generic traffic maximization problem. An intuitive interpretation of the equivalence between both problems and a greedy algorithm for transceiver minimization were provided. In addition, some computational results were presented comparing the greedy approach with optimal solutions for several small networks.

Li et al. [10] tackled this telecommunication problem with the aim of finding optimal wavelength assignment and grooming, that is to say, minimizing the total number of wavelengths required in the network.

The traffic-grooming problem in WDM-based optical mesh topology network was considered in [11]. The main goal in this work was to improve the total network throughput, so, the authors studied the WDM node architecture for mesh networks with traffic-grooming capabilities. By using integer linear programing, they provided both a mathematical formulation of the problem and two fast heuristics for solving it: *Maximizing Single-hop Traffic* (MST) and *Maximizing Resource Utilization* (MRU). The MST and MRU have been considered by many authors in their research in order to prove the goodness of each new heuristics proposed. On the one hand, a modified version of the MRU heuristics was proposed by Lee et al. [12]. The only difference between the standard MRU and this approach is that it uses a table for shortest Edge Disjoint Paths (EDPs) with clever selection of demands, but the virtual topology construction is carried out according to the maximum resources utilization (MRU). On the other hand, Yoon et al. [13] modified the MST heuristics by using an heuristics algorithm that considers the shortest path on the original graph, using as many shortest paths as possible for the low-speed traffic demands. However, this heuristics constructs the virtual topology according to maximum single-hop traffic (MST).

Zhu et al. [14] developed an auxiliary graph model for Traffic Grooming in WDM mesh networks. By using the auxiliary graph model, they presented an integrated grooming algorithm (IGABAG) that solves the traffic-grooming subproblems for one traffic demand, and a grooming procedure (INGPROC) for facing static and dynamic traffic patterns. They also presented several grooming policies: *Minimizing the Number of Traffic Hops* (MinTH), *Minimizing the Number of Lightpaths* (MinLP), and *Minimizing the Number of Wavelength-Links* (MinWL); and diverse traffic selection methods: *Least Cost First* (LCF), *Maximum Utilization First* (MUF), and *Maximum Amount First* (MAF).

In [15] the Traffic Grooming problem was considered as a combination of the following subproblems: *traffic routing* and *wavelength assignment*; solving them separately with the objective of minimizing the total number of transceivers.

A multiobjective definition of the Traffic Grooming problem was proposed by Prathombutr et al. [16]. In this version of the problem, the authors suggested to optimize both performance and cost