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Performance assessment of multiobjective approaches in optical Traffic Grooming

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ABSTRACT

In wavelength division multiplexing optical networks, the vast majority of traffic demands present a bandwidth request in the range of Mbps which is much lower than the available bandwidth of an optical channel (Gbps). These low-speed traffic requests can be groomed or multiplexed onto one single channel with the aim of optimizing the resources and costs of the network topology. In the literature, this problem of grooming low-speed requests is known as the Traffic Grooming problem, and is considered as an optimization problem. In this work, we present a comparative study of nine multiobjective evolutionary algorithms for solving this NP-hard problem. Two of them are standard metaheuristics in the multiobjective domain: the Fast Non-Dominated Sorting Genetic Algorithm and the Strength Pareto Evolutionary Algorithm. The rest of them are multiobjective versions of well-known evolutionary algorithms: Differential Evolution, Variable Neighbourhood Search, Gravitational Search Algorithm, Artificial Bee Colony, Firefly Algorithm, Ant Colony Optimization, and Particle Swarm Optimization. In the comparative study, the approaches are compared when tackling four optical networks with a different number of nodes: 6, 11, 14, and 55 nodes. Furthermore, for each topology, we use different amounts of traffic: small, medium, and large. The results of this comparative study indicate that the multiobjective versions based on swarm intelligence obtain very good performance in almost all optical networks. Finally, we present a comparison between the best multiobjective approach and other methods published in the literature.

1. Introduction

In the last decades, the number of traffic requests has grown exponentially; however, due to the lack of bandwidth in our current data networks, the use of the enormous bandwidth of optical fibers is common.

In these kinds of networks, the bandwidth is in the Tbps scale; unfortunately, the vast majority of traffic demands require connections at rates that are lower than the optical link capacity. In order to overcome this waste of bandwidth, we can apply the Wavelength Division Multiplexing technology (WDM). This technology is applied in many telecommunication companies and consists in dividing the bandwidth of each physical link of the network into over a number of wavelengths (λ) (Zhu and Mukherjee, 2003). Each wavelength or channel presents a transmission speed in the Gbps range (e.g. OC-48, OC-96, OC-192, and OC-768), so WDM is rapidly becoming the dominant transport infrastructure in communication networks (Liao et al., 2008).

A traffic request established end-to-end from one node to another in an optical network over a wavelength of light is commonly known as lightpath (Chen et al., 2008). In Fig. 1, we present a lightpath for connecting N_B and N_A over the first wavelength (λ_1).

The use of the WDM technology improves the throughput of the optical networks; however there exists a waste of bandwidth at each lightpath. This is due to the fact that the requirements of data connections are a few Mbps, and the capacity of a lightpath is in Gbps range. With the aim of overcoming this drawback, each node of the optical network can employ electronic grooming nodes for grooming several low-speed connections onto a high-speed lightpath (Modiano and Lin, 2001).

In the literature, this problem of grooming low-speed requests is known as the Traffic Grooming problem. It consists of three subproblem: *lightpath routing*, *wavelength assignment*, and *traffic routing*. In the first place, the *lightpath routing* subproblem aims to obtain a virtual topology where each edge corresponds with a unidirectional lightpath between a pair of nodes. In the second place, in the

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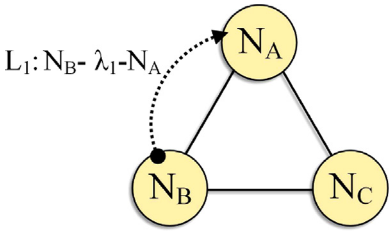

Fig. 1. Illustrative explanation of the *lighpath* concept.

wavelength assignment subproblem, we try to assign to each lightpath an available wavelength. In the third subproblem (*traffic routing*), we try to route the largest number of low-speed traffic requests over the virtual topology as possible.

Thus, given an optical network, a fixed number of available wavelengths per optical link, a fixed number of transmitters and receivers per node, a capacity of each wavelength, and a set of low-speed traffic requests, the objective is to optimize the total throughput of the network, the number of lightpaths established, and the propagation delay of these lightpaths.

The strategy of solving these subproblems separately makes the Traffic Grooming problem easier to handle; however, the optimal solution in one of the subproblems might not lead to the optimal solution on the whole problem (Corcoran et al., 2009). Therefore, the use of multiobjective optimization and evolutionary computation is a great option for solving this telecommunication problem because it allows us to optimize the total throughput, the number of lightpaths established, and the average propagation delay at the same time (Rubio-Largo et al., 2012a).

The main contribution of this work is a comparative study among nine Multiobjective Evolutionary Algorithms (MOEAs) for solving the Traffic Grooming problem. Seven out of the nine MOEAs that we have selected for making comparisons are multiobjective versions of well-known evolutionary algorithms: the Differential Evolution with Pareto Tournaments (DEPT), the Multiobjective Variable Neighbourhood Search (MO-VNS), the Multiobjective Gravitational Search Algorithm (MO-GSA), the Multiobjective Artificial Bee Colony (MO-ABC), the Multiobjective Firefly Algorithm (MO-FA), the Pareto Ant Colony Optimization (P-ACO), and Multiobjective Particle Swarm Optimization (OMOPSO). The last two MOEAs have been taken as references due to the fact that they are standard algorithms in the Multiobjective domain: Fast Non-Dominated Sorting Genetic Algorithm (NSGA-II) and the Strength Pareto Evolutionary Algorithm 2 (SPEA2).

In the comparative study, we assess the performance of the MOEAs when tackling four optical networks: 6-node network (6 nodes), the European Optical Network topology (11 nodes), the National Science Foundation (14 nodes), and the Nippon Telegraph and Telephone (55 nodes). Furthermore, for each optical topology, we have used three traffic matrices with different amounts of traffic: small, medium, and large. Finally, to obtain a global view of the performance of each MOEA when solving a specific topology and a specific traffic matrix, a wide range of number of transceivers per node and wavelengths per link have been tested. To sum up, more than 500 scenarios have been tested to assess the performance of nine MOEAs in the Traffic Grooming problem.

Finally, we have also compared the best MOEA with several heuristics and metaheuristics published in the literature by other authors.

The remainder of this paper is organized as follows. In Section 2 we present the background of the Traffic Grooming problem. Section 3 is devoted to explaining the Traffic Grooming problem. A short description of each MOEA used in the comparative study is presented in Section 4. In Section 5, we study the behaviour of the MOEAs when solving optical networks with different numbers of nodes, as well as comparing the best metaheuristics with other approaches published in the literature. Finally, we summarize the conclusions of the manuscript and enumerate possible lines of future work in Section 6.

2. State of the art

The background of the Traffic grooming problem, as well as a review of how other authors have dealt with this telecommunication problem in the literature, is presented in this section.

Some authors have tackled this problem by reducing the number of transmitters at each node, or by minimizing the number of available wavelengths per optical link. In Li et al. (2002), the authors focus on minimizing the number of wavelengths required by proposing a heuristics which solves the wavelength assignment subproblem, as well as the traffic routing subproblem. According to Konda and Chow (2001), the traffic grooming is equivalent to a certain traffic maximization problem where the goal is to minimize the number of transceivers – they propose a greedy algorithm. Hu and Leida (2004) tackle the traffic grooming by dividing it into two subproblems and solving them separately. Firstly, they groom and route traffic demands onto lightpaths with the aim of minimizing the number of transceivers per node. Then, they consider the wavelength assignment subproblem in which the main objective is to minimize the number of wavelengths required per link.

In Zhu and Mukherjee (2002), the authors focus on solving the traffic grooming problem in optical mesh topology networks with the goal of establishing as much low-speed traffic demands as possible. In addition, they present an outline of a WDM optical node, a formal formulation of this telecommunication problem based on integer linear programming, and two heuristics which have been considered approaches of reference by many authors in the literature (Lee et al., 2005; Yoon et al., 2005). These heuristics are known as *Maximizing Single-hop Traffic* (MST) and *Maximizing Resource Utilization* (MRU).

Zhu et al. (2003) present a methodology based on an auxiliary graph model for grooming demands in WDM mesh networks. Taking this model as a reference, they propose an algorithm (IGABAG) for establishing one single demand. By using the IGABAG algorithm, they propose a procedure (INGPROC) which is able to solve both the static and the dynamic traffic grooming. Furthermore, they test the performance of the INGPROC procedure with several grooming policies; such as Minimizing the Number of Traffic Hops (MinTH), Minimizing the Number of Lightpaths (MinLP), and Minimizing the Number of Wavelength-Links (MinWL); as well as diverse traffic selection schemes: *Least Cost First* (LCF), *Maximum Utilization First* (MUF), and *Maximum Amount First* (MAF).