Traffic Grooming on Designing Elastic Optical Networks

Suzana Miladić-Tešić[1], Goran Marković[2] and Valentina Radojičić[3]

Abstract – **In the design of next generation optical networks, the concept of elasticity has been proposed. This means optical paths provisioning using just enough spectrum to best fit the user demands and diverse type of services. Between adjacent optical paths guard bands are needed and consequently a large portion of spectrum is wasted. To further improve the resource usage, traffic grooming technique could be applied. Grooming technique allows the establishment of optical tunnels carrying a several connections in a contiguous block of spectrum without inserting guard bands in between, therefore minimizing the spectrum usage or the number of transmitters. Solving the grooming problem together with the routing and spectrum allocation, as a key issue in elastic optical networks (EON), is a highly challenging task particularly in the case of large problem instances. In this paper we consider grooming capability at the optical layer. Using metaheuristic approach, we solved the traffic grooming problem with static traffic demands, therefore suitable on designing EON. The proposed algorithm aims to minimize the total spectrum usage while serving all traffic demands. Significant spectrum savings are obtained compared to the non-grooming case.**

Keywords – **elastic optical network, optical grooming, metaheuristic approach**

I. INTRODUCTION

Today's huge volume traffic demands cannot be efficiently satisfied with traditionally deployed wavelength division multiplexing (WDM) technology due to its coarse bandwidth granularity and rigid spectrum allocation. Based on O-OFDM (Optical Orthogonal Frequency Division Multiplexing) technology, spectrum-efficient, data-rate flexible and energy-efficient optical network architecture was analyzed in [1] to meet different traffic granularity needs. In such a network, flexible data rates are supported through bandwidth variable transponders (BVT) at the network edge and the bandwidth variable optical cross-connects (BV-OXC) in the network core. The term flexibility or elasticity refers to the ability of a network to dynamically adjust its resources such as the optical bandwidth and the modulation format, according to the requirements of each connection.

ITU (International Telecommunication Union) updated its G.694.1 recommendation [2] to include the flexible grid option based on a frequency slot (FS) concept. The frequency slot presents the minimum frequency range of an optical signal could take. The available optical spectrum is then divided into smaller granularity FSs and the optical connections (flexible lightpaths) are allocated a proper number of slots (bandwidth on demand). Unlike the current WDM frequency channels of 100 or 50 GHz width, a FS in EON could be of finer granularity, such as 25 GHz, 12.5 GHz or even 6.25 GHz.

Network performances could be further improved if some spectrum management techniques such as traffic grooming are been applied and combined with elasticity property. Traffic grooming enables grouping of traffic demands with the same source into one transmitter and switching them together over the network forming in such a way an optical tunnel with the capacity equal to the capacity of a transmitter. In this paper, we assumed a grooming approach to aggregate traffic directly at the optical layer and such eliminating the O/E/O (Optical/Electrical/Optical) conversions. Solving the traffic grooming (TG) problem together with the routing and spectrum allocation (RSA), namely TG-RSA is a highly challenging task particularly in the case of large networks. We applied the bee colony optimization (BCO) metaheuristic approach to solve the static optical TG-RSA problem.

The paper is organized as follows. Section II describes the optical grooming problem in EON. Section III is dedicated to the proposed BCO metaheuristic applied to the researched TG-RSA problem. Simulations and results to demonstrate the benefits of optical grooming versus non-grooming case are given and discussed in Section IV. Concluding remarks are given in Section V.

II. OPTICAL GROOMING PROBLEM IN EON

A. Basic concept

Optical layer grooming has been considered by the research community in case of static traffic scenario [3-5] as well as for dynamic scenario [6, 7]. The problem was mostly solved using ILP (Integer Linear Programming) formulations for small size networks and using heuristic approaches for large networks.

The benefits of grooming technique are related to spectrum and transmitters' savings. Transmitters' savings arise from the fact that grouping several same source demands leads to a better utilization of capacity and therefore their less number. For switching demands, guard bands are needed to avoid interference. If a separate optical tunnel is needed to provision each of these demands, spectrum wastage by guard bands may occurred. Because of the orthogonality, demands starting from the same source within the same tunnel are not separated by guard bands and they are only needed between different optical tunnels. Therefore, more spectrum slots could be saved by eliminating the guard bands.

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The grooming benefits are illustrated in Fig. 1. Connections with the same source (node **a** for example) are grouped since they share some links from source to destination and guard bands are not needed in this case. When a connection needs to be separated from the optical tunnel at any intermediate node (such as node **b** or **c** in Fig. 1), it is dropped or switched optically using BV-OXC and continue its way to the destination.

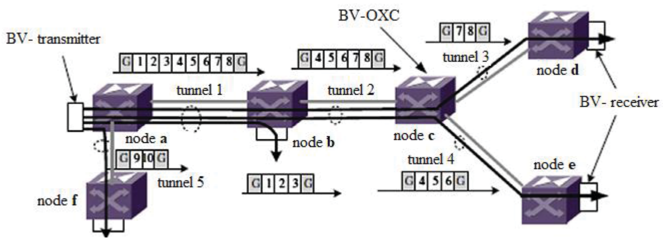

Fig. 1. Optical layer grooming in EONs [3]

B. Problem statement

Optical grooming, besides the main RSA constraints, includes the constraints related to the transmitter resources. Hence, the main constraints configuring in optical grooming problem are the following: 1) RSA spectrum contiguity constraint - to establish a flexible lightpath with the capacity of *f* frequency slots, the constraint assumes that *f* consecutive frequency slots must be allocated to establish a flexible lightpath, 2) RSA spectrum continuity constraint- the same FSs must be allocated on each physical link on a chosen route and 3) The number of groomed connections is limited by the capacity of BVT.

We solved the static traffic grooming problem in EON which typically appears during the network planning or designing phase. The problem could be defined in the following way: for a given traffic demand matrix (specified by the number of requested FSs between network node pairs), available FSs on network links and the capacity of transmitters, minimize the total spectrum usage with the assumption that all connection requests have to be satisfied in the network by aggregating multiple optical connections with the same source into one transmitter. By grooming the connections that share the longest common route from the same source node, the number of guard bands is minimized. As a result, the spectrum gain is maximized. Spectrum gain, *H*, defined in [3] has been incorporated in our model:

$$H = 2G \times X - (Y - Z) \times W^{'} \tag{1}$$

where G presents the guard band ($1G$ on each side of the tunnel), X refers to the common route length (number of common links), Y refers to the length of the path that is considered for grooming (path that has the same source node), Z is the length of the first path placed in a tunnel with a capacity of ($W + 2G$) and W' is the number of FSs for the connection request Y. These terms are going to be explained in more detail in section III.

For the routing subproblem, fixed-alternate routing (FAR) method is used, which assumes that *k*- shortest paths are calculated in advance for each node pair. For the frequency allocation subproblem, the first fit (FF) policy [8] is applied which assumes that FSs are indexed and a list of indexes of available and used slots is maintained. The policy always attempts to choose the lowest indexed slot from the list of available slots and allocates it to the lightpath to serve the connection request [8]. The objective function *F* is assumed as follows:

$$F = \min \sum_{l} FS_l, \forall l \in L \tag{2}$$

and presents the total spectrum usage (the number of occupied frequency slots on all network links L) while FS_l presents the number of occupied slots on link l.

III. BCO METAHEURISTIC APPLIED TO THE OPTICAL GROOMING PROBLEM

C. BCO metaheuristic

Metaheuristics as a global search method examine solutions produced by a heuristic algorithm and move to better ones in a sophisticated manner [9]. BCO metaheuristic is at first proposed by Lučić and Teodorović [10] to solve complex transportation engineering problems. An overview of BCO with its applications could be found in [11, 12]. It is a population-based stochastic random-search technique that is inspired by the foraging habits of natural bees looking for nectar sources.

During the search process, bees generate and evaluate their individual partial solutions by steps. Each step consists of two phases: the forward and backward pass. Every bee starts with the forward pass to discover its partial solution and after that makes the backward pass (flies back to the hive) to evaluate and compare the quality of its solution. Bees exchange the information about the quality of their solutions in the hive. The quality of the bee's solution corresponds to the considered objective function value. During each step, every bee decides with a probability whether to discard the created partial solution and become an uncommitted follower or to continue to expand its current solution with or without recruiting other bees. The bees have a certain level of loyalty to their partial solutions, depending on its solution quality. Bees that are loyal to their solutions form the set of recruiter bees advertising their solutions, while other bees from the colony become uncommitted followers. The sets of recruiter bees and uncommitted followers are changed from one backward pass to another. Each uncommitted bee accepts previously created partial solution of the recruiter bee, but in the next forward pass every bee is free to continue the solution exploration independently of other bees. The best-found solution among *B* created solutions in the iteration is saved. The algorithm iterates through the pre-specified number of iterations and the best solution obtained during all iterations is chosen as the final solution [10-12]. Therefore, the BCO optimization consists of the following phases: initialization, partial solutions generation, solutions comparison and recruitment phase.

The initialization phase requires the input data such as: the number of iterations I, number of demands (requests) r to be tested in each algorithm step, number of bees B in population, physical network topology given by the set of nodes N and set of physical links L, set of k- shortest paths for each node pair, guard band value, capacity of transmitters U and the traffic demand matrix.

During each forward pass (or algorithm's step) s =1, 2, ..., S, every bee investigates a given number of demands chosen from the set of all demands in a random manner. By choosing a specific demand, bees attempt to establish a lightpath between one real source-destination node pair in the optical network and find the same source node demands. In each new step the bee chooses the demands that have not been previously tested. The exploration procedure is performed until all traffic demands are tested during an iteration.

D. Grooming procedure

We explored the application of BCO metaheuristic while solving the offline optical grooming problem in EON and denoted our algorithm as BCO-TG-RSA.

The grooming procedure is incorporated in the generation of partial solutions and contains the following steps during an iteration:

Step 1 - For each shortest path of the randomly chosen demand, the network is searched for the first possible placement with the capacity ($W + 2G$), where W is the number of FSs requested for a given demand. The maximum index of the occupied FSs is determined for every route/path and the one with lowest starting spectrum slot index is chosen to establish the lightpath. We called this route as the *referent one* and it has been denoted as Z in the Eq. 1. This connection is the first one in a potential optical grooming tunnel.

Step 2- For every chosen demand in the previous step, connections having the same source and their k-shortest path routes are searched. The routes having common links (at least one link) with the referent one, starting from the source node are investigated for grooming (denoted as Y in the Eq. 1) following the spectrum gain given by the Eq. 1 and availability of frequency slots on all links of the route. Connections where spectral gain $H > 0$ are groomed and added into the tunnel with the capacity W'.

Step 3- If the spectrum gain is $H = 0$, only the first chosen demands with their *referent routes* are placed in the network, without grooming with some of the other requests.

IV. SIMULATIONS AND RESULTS

E. Simulation settings

To evaluate the performances of the proposed BCO-TG-RSA grooming algorithm, simulation experiments are carried out on two network topologies: scenario 1 and 2 (shown in Fig. 2) with bidirectional fibers.

The input data are: traffic demand for each (s, d) pair in terms of FSs number was randomly generated between 1 and $M \in [4, 8, 12, 16]$ with the uniform distribution, where M is the maximum required capacity in number of FSs between each node pair, guard band value $G = 1$, capacity of a transmitter $U = 16$ FS, the number of k- shortest paths $k = 3$ (using Yenn's algorithm), the number of requests tested in each step of the algorithm $r = 2$ and the maximum number of iterations $I = 10$. 10 different traffic scenarios are generated randomly and simulated. The objective is to minimize the total spectrum usage while serving all the requests. We used the population of $B = 3$ bees for scenario 1 (due to small network size) and $B = 5$ bees for scenario 2. All simulation tests have been performed by running the programming code that is implemented in Python, using PC with the processor on 2.71 GHz and installed RAM of 8 GB.

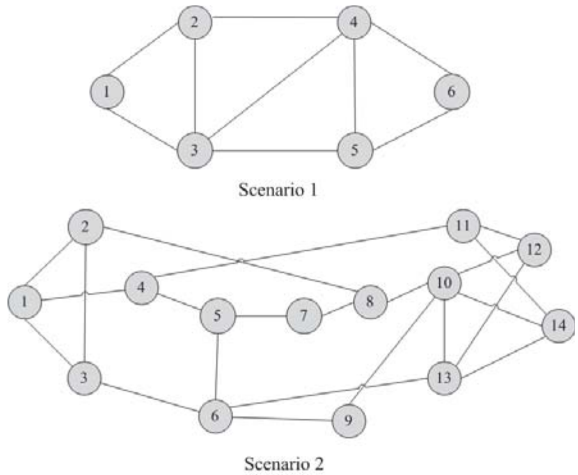

Fig. 2. Network topologies used for simulations

F. Results

After performing extensive simulations, it could be stated that grooming technique leads to a significant spectrum savings in case of large networks examples with complex traffic scenarios. Considering scenario 1, spectrum savings are within 5 %- 6 % versus non-grooming case. Note, that this is a small network example with simple traffic scenario and therefore grooming benefits cannot be fully expressed. Due to space limit, we presented in more detail the results for scenario 2 where grooming benefits are significantly higher.

Fig. 3 (a) shows the total spectrum usage (occupied frequency slots on all network links) of the grooming and non-grooming case for scenario 2. Different values of M are chosen in order to study the relationship between grooming efficiency and service granularity. It could be seen that optical grooming with the objective of minimizing the total spectrum usage achieves significant 5 %- 20 % of spectrum savings compared to the non-grooming case. Therefore, it is highly recommended to be applied in the design of EON.

We also analyzed the relation between spectrum savings and traffic granularity. The results of maximal and average spectrum savings relative to non-grooming case are shown in Fig. 3 (b). The highest spectrum savings are obtained when M = 4- average 19.72 %. The lowest spectrum savings are obtained when M was set to be 16- average 4.8 %. This leads to a conclusion that spectrum savings decrease as the traffic granularity grows. The obtained results show that spectrum savings are mostly achieved for small traffic demands. The reason is that grooming opportunities are higher in this region and unused transmitter capacities are easier to be exploited. Also, it should be noted that grooming benefits increase as the transmitter's capacity increase as well as the guard band size.

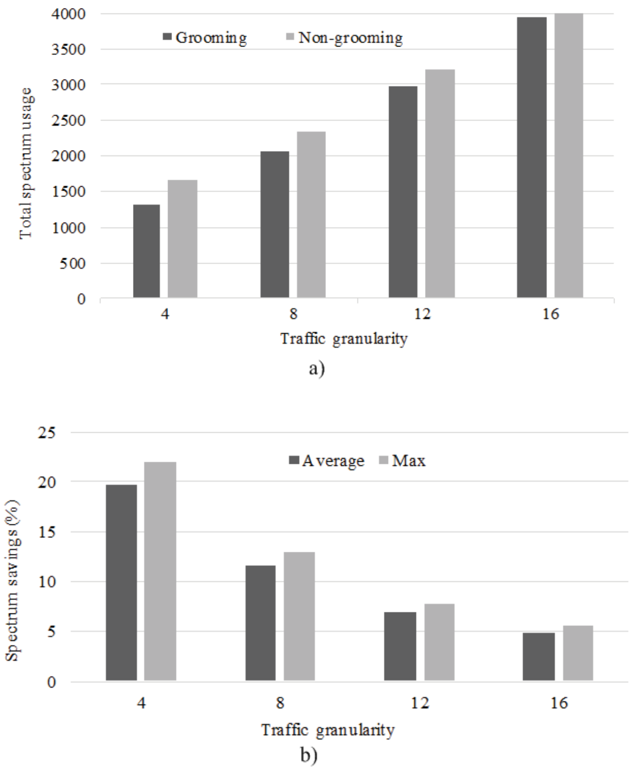

Fig. 3. a) Total spectrum usage and b) spectrum savings for different values of M

The simulations showed that, the greater number of bees does not necessarily lead to the improvement of the solution quality and that solution quality does not change significantly. Our experiences show that the population of B = 5 bees is enough to obtain high-quality solution within acceptable computational time with tens of seconds. Also, we performed simulations for higher number of iterations (I = 20, 30, 50) but due to the solution improvement and its repeating in iterations, we assumed I = 10. Therefore, the algorithm is able to find the same solution quality within the smaller number of iterations.

V. Conclusion

In light of the above, we believe that optical grooming has great potential for spectrum savings for future elastic optical networks and hence its designing. Our results show that optical grooming achieves significant spectrum savings compared to the non-grooming scenario, especially for small traffic demands granularity and for complex networks and traffic scenarios. Therefore, the algorithm such as the one we proposed is highly recommended for solving the complex grooming RSA problem in such networks. To the best of our knowledge, it is the first application of BCO method to the TG-RSA problem.

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