NOC
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Multilayer Networks (2/2): GMPLS

Contents

Resources optimization in GMPLS-based optical multilayer networks

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Dynamic label switched paths (LSP) set-ups and teardowns in control plane based optical networks derive into non-optimal resource utilization. That situation gets worse in multilayer networks since the network complexity grows exponentially. In this paper, we present several meta-heuristic algorithms to improve resources utilization. The performance of the algorithms is compared with the exact solution obtained with an Integer Linear Programming (ILP) model. Finally, the performance of the best candidate heuristic is experimentally demonstrated.

1. Introduction

In the last years data traffic is sharply increasing and thus networks need to be managed more efficiently than ever. Dense Wavelength Division Multiplexing (DWDM)-based optical networks provide huge transmission capacity. However, clients usually request for lower bandwidth. An aggregation layer between client and optical layers, improving resource utilization, is thus needed. Both optical and aggregation layers can be controlled by a unified Generalized Multiprotocol Label Switching (GMPLS) control plane, thus creating a multilayer GMPLS-based Automatically Switched Optical Network (ASON). In such architecture, the optical layer consists on optical nodes connected by DWDM links. Here, optical LSPs (λ-LSPs) are set-up and teardown. The aggregation layer consists on grooming-capable nodes connected by optical arcs (supported by λ-LSPs) and client LSPs. Therefore every optical arc is dynamically created and needs two Opto-Electronic (O/E) ports. O/E ports are expensive resources and thus capital expenditures (CAPEX) can be reduced optimizing the necessary number of O/E ports.

In static traffic scenarios the initial network-planning phase can determine the number of O/E ports in every node. Nevertheless, in dynamic traffic scenarios, client connection requests are routed using the set of currently available optical arcs; when new optical arcs are needed, new λ-LSPs are set-up at the optical layer. When optical arcs do not transport any client LSP they are removed and the underlying λ-LSPs are torn-down, thus releasing the used O/E ports. This dynamic process leads to a non-optimal use of resources.

Optimization problems can be solved defining an ILP model. In such a case, the obtained solution is exact. However, the time needed to solve trend to be very long, and thus, that method may be not applicable to real-time problems. In contrast, heuristic methods provide, in general, sub-optimal solutions but in more affordable times. In this paper, our objective is to find good solutions for these problems within few seconds.

In our previous work [1], we presented an ILP model and a Greedy Randomized Adaptive Search Procedure (GRASP)-based heuristic. In this work we present several alternative GRASP-based heuristics, which differ on the randomized greedy criterion. We compare the candidate heuristics with the exact solution obtained with the ILP model. Finally, the best heuristic is implemented at the centralized management system (NMS) in the ASON/GMPLS grooming-capable CARISMA test-bed network [2], where its performance is experimentally demonstrated.

Several prior works have proposed solutions to optimize resources utilization. In [3]-[5] the authors propose different methods for adapting the network when the offered traffic changes. They consider the re-configuration of network topology by setting up and tearing down λ-LSPs. Our main optimization goal is to reduce the maximum number of O/E ports needed. As a consequence, only λ-LSPs releasing and client LSPs re-routing is considered.

Hereafter a simpler and clearer notation is used: the term *optical arcs* (or, simply, *arcs*) is used instead of λ-LSPs and the term *paths* instead of client LSPs.

The remainder of the paper is organized as follows: section 2 presents the ILP model. Using that model, small network instances can be solved. However, when the complexity of the problems increases, execution times are not valid to that method be applied to real systems. Section 3 presents several heuristic algorithms, which provide sub-optimal solutions but within a limited execution time. Finally, in section 4 we draw the main conclusions of this work.

2. Optical resources optimization problem

Optical resources optimization (ORO) problem has been defined and formulated in [1]. For approaching important information to the reader, we present here the ILP formulation of this problem. The following notations are used for sets and parameters:

E: Set of paths (indexed by i)

$R(i)$: Set of possible routes for path i (indexed by j)

S: Set of optical arcs (indexed by k)

C_k : Cost of optical arc k

M_k : Capacity of optical arc k

N_{ij} : Equal to 1 if path i was using route j before optimization

L_{ij}: Cost of route j for path i

Q^k_{ij} : Equal to 1 if route j of path i uses optical arc k

W_i : Bandwidth of path i

Additionally, the following notations are used for variables:

ζ_k: Equal to 1 if optical arc k is used after optimization (not removed)

δ_k: Optical arc k used bandwidth

η_{ij}: Equal to 1 if path *i* uses route *j* after optimization

ρ_i: Equal to 1 if path *i* has been moved after optimization

The ORO formulation releases as much optical resources as it can by releasing optical arcs, so that the affected paths are re-routed using the minimum cost route, obtaining a most compacted network. The formulation is based on an arc-path model, where the set of distinct routes for every path need to be pre-computed. The ILP formulation is as follows:

ORO:
$$\min -\sum_{k\in S}(C_k \times (1-\zeta_k)) + \frac{\sum_{i\in E}\sum_{j\in R(i)}(L_{ij}\times\eta_{ij})}{\sum_{i\in E}\sum_{j\in R(i)}(L_{ij}\times N_{ij})} + \frac{\sum_{k\in S}\delta_k}{\sum_{k\in S}M_k} \tag{1}$$

subject to

$$\sum_{j\in R(i)}\eta_{ij} = 1, \quad \forall i\in E \tag{2}$$

$$\sum_{i\in E}\sum_{j\in R(i)}(W_i \times Q_{ij}^k \times \eta_{ij}) \le \delta_k, \quad \forall k\in S \tag{3}$$

$$\zeta_k \le \delta_k \le (M_k \times \zeta_k), \quad \forall k\in S \tag{4}$$

$$\rho_i + \frac{\sum_{k\in S}\left(\zeta_k \times \sum_{j\in R(i)}(N_{ij}\times Q_{ij}^k)\right)}{\sum_{k\in S}\sum_{j\in R(i)}(N_{ij}\times Q_{ij}^k)} \ge 1, \quad \forall i\in E \tag{5}$$

$$\sum_{k\in S}\left((1-\zeta_k)\times \sum_{j\in R(i)}(N_{ij}\times Q_{ij}^k)\right) - \rho_i \ge 0, \quad \forall i\in E \tag{6}$$

$$\sum_{j\in R(i)}((1-N_{ij})\times\eta_{ij}) = \rho_i, \quad \forall i\in E \tag{7}$$

$$\zeta_k, \eta_{ij}, \rho_i \in \{0,1\}, \ \delta_k \text{ int} \tag{8}$$

Constraint (2) ensures that every path is assigned to one and only one route. Constraints (3) and (4) guarantee a feasible path re-routing in terms of capacity of optical arcs kept in the solution. Constraint (5) makes sure that every path using an optical arc to be removed is re-routed. Conversely, constraint (6) ensures that paths supported on optical arcs kept in the solution are not re-routed. Constraint (7) provides the paths to be re-routed. Finally, constraint (8) defines variables as binary or integer. We assume that every optical arc supports at least one path. The objective function structure (1) and the cost values of arcs and paths ensure that the optimal solution releases as much O/E ports as possible.

We have tested the proposed model generating several instances with different traffic intensity over a network similar to the European Optical Networks described in [6]. For these tests we assume that every bidirectional optical link is equipped with 3 wavelengths. These instances have been solved on a 3GHz CPU computer with 1 GB RAM memory, using CPLEX v.11.0 [7] as solver. The obtained results are shown in Figure 1, where the instances have been grouped in intervals of network load. For each interval, the amount of released O/E ports (in percentage) and the execution time is drawn.

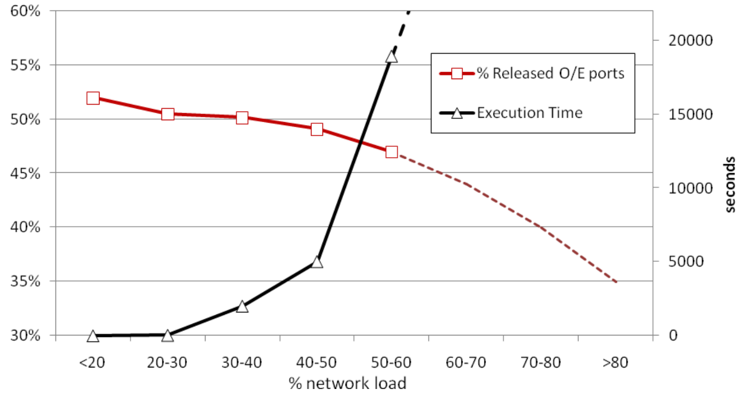

Figure 1 Released O/E ports and execution time against network load

As shown, the ORO formulation allows reducing the use of O/E ports in about 50%. Nonetheless, each execution takes several hours for moderate traffic intensity scenarios. For network loads higher than 60%, the size of the problems is too large and CPLEX runs out memory without giving, in many cases, any solution.

Figure 2 shows the relation between network load and problem sizes (in terms of number of binary variables). It is clear that network load and the number of variables of the ORO formulation present a closed correlation. Highly loaded instances could not be solved because of the large amount of variables. Moreover, the logarithm of the execution time increases linearly, which means that execution time increases exponentially when the problem size increases. Therefore, even solving the ORO formulation in more powerful computational environments, executions times would not be within an acceptable and practical range.

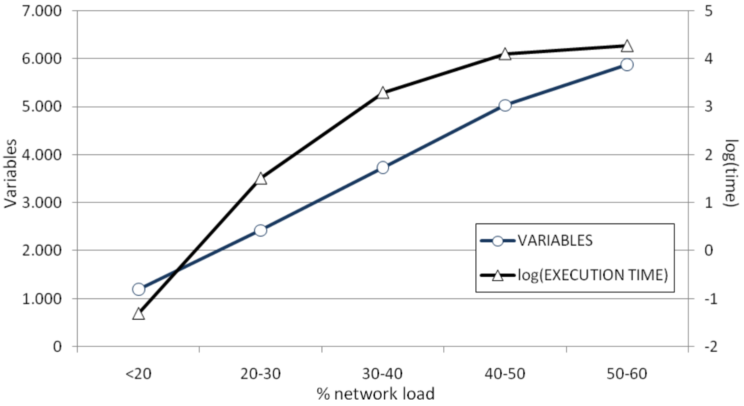

Figure 2: Problem size and execution time against network load

Therefore, we can conclude that although the presented ILP formulation gives a significant reduction of used O/E ports, solving times are unacceptable for real scenarios. For this reason, in the next section we propose alternative heuristic methods which provide near-optimal solutions but within limited times.

3. GRASP-based meta-heuristics

In this section, we propose several algorithms based on the GRASP meta-heuristic [8]. GRASP is an iterative procedure that generates several feasible solutions and, when the stop condition of main algorithm is reached, returns the best of them. It consists of two different phases: a constructive phase for creating a feasible solution, and a post-processing phase to improve built solutions. In the constructive phase, GRASP meta-heuristic use what is called the restricted candidate list (RCL), a list where candidate elements to be included in a feasible solution are sorted by a defined criterion.

```
Algorithm 1: ORO GRASP Constructive Phase
Input: Candidate list, network graph
Output: List of optical arcs to remove, paths to move with its new route and the cost of the solution
begin
  while candidate list size ≠ 0 do
      RCLo = {optical arc ∈ candidate list | $Bw \leq Bw_{min} + \alpha_{arc}(Bw_{max} + Bw_{min})$}
      Get a random optical arc from the RCLo and remove it from the candidate list
      if re-route (arc, network graph) then
          Add the optical arc to the solution
          Add every moved path to the solution
          if there is any path in its original route then
              remove that path from the solution
          endif
      endif
      Compute solution cost
  endwhile
end

Algorithm 2: re-route algorithm
Input: Arc to re-route, network graph
Output: Successful or failed re-route
begin
  Create an empty path list
  Remove the arc from the graph
  for every path using the optical arc do
      Get a copy of the current route of the path and tear it down
      Set available candidate routes for path
      if no route found then
          Restore the original route of the path and set it up
          Add the optical arc to the graph
          for every path in the list do
              Tear down the path
              Establish the path in its original route
          endfor
          return (failed to re-route)
      endif
      RCLr = {route ∈ candidate routes | $cost \leq cost_{min} + \alpha_{path}(cost_{max} + cost_{min})$}
      Get a random route from the RCLr and remove it from the candidate list
      Establish the path for the selected route and Add the path to the list
  endfor
  Mark every path in the list as moved
  return (success)
end
```

Table 1: GRASP constructive phase algorithm

Let us define a solution of the ORO problem as a set of arcs to remove and a set of paths to re-route. We define two different RCLs: firstly, the *RCLo* contains the list of arcs sorted in ascending order as a function of its used bandwidth. Its size is determined by the α_{arc} parameter; secondly, for every path, the *RCLr* contains the list of feasible routes that do not contain a given arc. The *RCLr* is sorted in ascending order by optical resources cost. The random degree of route selection is determined by α_{path}. Table 1 shows the constructive phase adapted for solving the ORO problem.

The post-processing method consists on single arc exchanges between used and removed sets. We defined as stop criterion a maximum number of iterations without improving the best solution founded at that moment.

Four different versions can be obtained by setting different values in the α parameters. The basic one has no randomness (both parameters fixed at 0) and we called it as the *GREEDY* version. In the *ARC GRASP* heuristic only α_{arc} has non-zero values. In the *PATH GRASP* heuristic the random selection is given by the α_{path} parameter. Finally, the *ARC-PATH GRASP* version combines both parameters. Figure 3 and Figure 4 show a performance comparison of the previously presented GRASP heuristics. For each heuristic, we have determined the best values for the tunable parameters (α_{arc}, α_{path} and stop iterations), by performing several executions of the heuristics. The figures show the best results reached for each heuristic version.

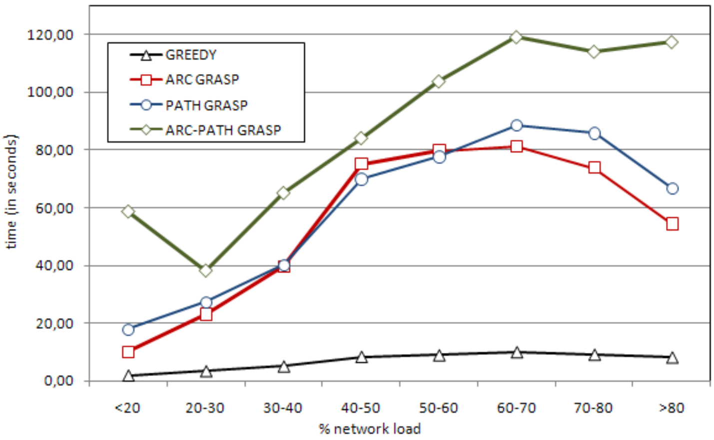

Figure 3: Execution time against network load

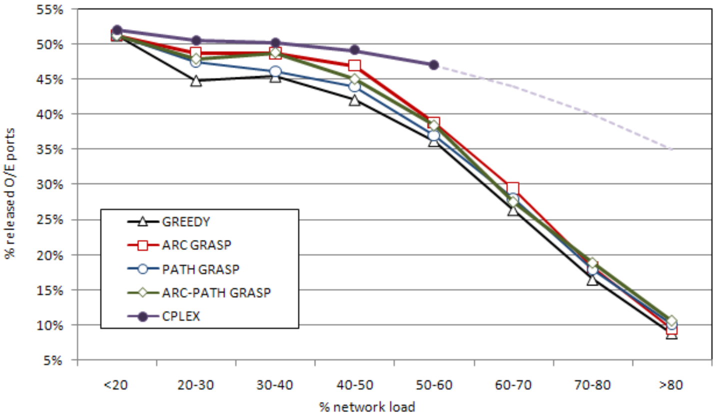

Figure 4: Released O/E ports against network load

Execution times for the heuristics increase linearly with the problem size, and it is higher in randomized versions. The number of released O/E ports is higher in randomized versions that in the basic *GREEDY* one. In case of medium-loaded networks, the *ARC GRASP* gives the better values for the objective function. In highly-loaded networks, all the heuristics give similar results. The distance between the heuristics and the exact solution increases with the problem size and it could be very significant in highly-loaded networks. Nevertheless, after an ORO application in a dynamic traffic scenario, the optimal solution lasts until any change on the network (setup or teardown of paths) is done. For this reason, reaching the optimal solution is not strictly needed.

The analysis of results over simulated instances allows us choosing *ARC GRASP* as the most suitable optimization method for solving ORO problem. The quality of the solutions is near the exact references in comparable instances. Running time is acceptable in every case and it can be adjusted by setting different values on the stop criterion. Tuning this parameter, we obtain a simply way to balance the quality of the solutions and the execution times. Moreover, this algorithm does not need distinct routes pre-computation, since every affected path is always re-routed through the available shortest path. This condition is a key factor for choosing this heuristic instead of any of the rest of randomized versions.

The *ARC GRASP* meta-heuristic has been implemented in the CARISMA Network Management System (NMS), and several sets of tests have been carried out over the test-bed. The CARISMA test-bed network has been configured as a 9-node mesh topology, with 11 DWDM links and 8 wavelengths per link. The performance of the *ARC GRASP* meta-heuristic has been tested with different traffic loads.

Figure 5 shows the obtained experimental results in comparison with the obtained over simulated topologies depicted in Figure 4.

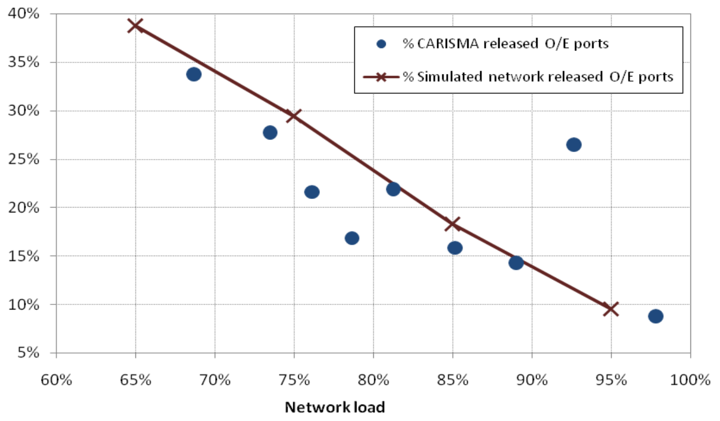

Figure 5: Released O/E ports in the CARISMA test-bed network

The number of released O/E ports is similar in both simulated and experimental cases. This fact validates the simulated scenarios as good instances for testing optimization methods. Moreover, execution times in the CARISMA NMS have been within one second in all cases (between 200 and 700 ms).

4. Conclusions

In this paper, the optical resources optimization problem has been introduced as an adaptive mechanism for O/E ports use reduction in multilayer ASON/GMPLS networks. An integer linear programming formulation has been presented for describing the problem.

In the proposed examples, the exact solution reduces the needed O/E ports up to 50%. Executions using CPLEX toke several hours for real traffic instances. These long execution times make the exact solution to be not suitable to be implemented in real networks.

As an alternative, four heuristic algorithms have been developed and compared. The proposed greedy randomized heuristics give values for total reduction of optical cost near exact values. In contrast, execution times for the different heuristics are in the order of few seconds, which is much shorter than the exact method.

The *ARC GRASP* meta-heuristic has been chosen to be implemented in a real network management system, because of its good combination of solution quality and execution times. Moreover, this heuristic does not need route pre-computation.

The application of the *ARC GRASP* meta-heuristic in real traffic scenarios over the CARISMA test-bed network gave significant O/E ports reduction, obtaining execution times under one second. With these results, the proposed heuristic has been proved to be a good method to optimize resources in optical networks.

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