Addressing the GRWA Problem in WDM Networks with a Tabu Search Algorithm

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Abstract: We developed a Tabu Search algorithm that can be used to solve simultaneously the grooming, routing and wavelength assignment problems in WDM networks. This algorithm, called GRWABOU, is adequate for network cost minimization in a general context.

OCIS codes: (060.0060) Fiber optics and optical communications; (060.4250) Networks

1. Introduction

The traffic Grooming, Routing and Wavelength Assignment (GRWA) problem in Wavelength Division Multiplexed (WDM) networks has been the topic of many studies over the past years. Under simplifying assumptions, some authors have been able to provide exact solutions although most practical cases have been addressed with heuristic algorithms. As an example, some considered only the ring network topology [1-3]. Others took into account simplistic traffic demand models like the unitary all-to-all traffic [2]. Moreover, the GRWA problem has often been divided in sub-problems that were solved sequentially [3]. Although this approach is appropriate to simplify the computational effort, it does not allow the exploration of the complete solution domain and may systematically discard optimal solutions. Finally, various objective functions have been used (e.g. blocking probability [4], total number of wavelength [5], etc.).

We present a new heuristic algorithm to address the GRWA problem in WDM networks in a more general way. This algorithm, called the GRWABOU algorithm, has been developed from Tabu Search techniques [6] and considers the GRWA problem as a whole. It can be applied to WDM networks with arbitrary topologies, whether ring or general mesh architecture. It can operate on any type of traffic demand with any type of granularity on the client side (e.g. a mixture of OC-12, 1GE, FC, etc.). On the transport side, it supports multiple bit rates simultaneously. For example, it can be applied to an hybrid OC-48/OC-192 metropolitan WDM network. Finally, since it has been realized that the electronic grooming equipment represents the dominant cost in a WDM network [7], its objective function seeks the minimization of overall network cost through the minimization of the number of electronic cards needed in the MultiService Provisioning Platforms (MSPP) that are used in network nodes.

First, we describe the GRWABOU algorithm. Second, we present the results of some computational experiments. Finally, we discuss the results and conclude.

2. Description of the GRWABOU algorithm

Many heuristic frameworks are available for solving combinatorial problems (genetic algorithms, scatter search, path relinking methods, simulated annealing, grasp algorithms, etc.). The GRWABOU algorithm has been developed from Tabu Search techniques.

A Tabu Search is an iterative procedure that evolves from one point to another one in the solution domain through elementary moves. At a given point in the search, the choice of the elementary move to select depends on the past history of the search and on the local value of an objective function. A particularity of the Tabu Search is its capability to evolve in the non-feasible solution domain to quickly travel between points of a nonconvex, nonlinear or disjoint feasible solution domain. This is extremely useful for speed of convergence and for evolution in a solution domain with multiple local minimums, which is often the case when the solution domain dimension is large.

Let f^{obj} be the objective function to be minimized. In our case f^{obj} is an expression of the overall cost of the network based on the number of MSPP electronic cards. However, the GRWABOU algorithm is versatile enough to consider other parameters to be minimized depending on the type of network design task to be accomplished (e.g. number of hops, number of wavelengths, etc.). We define an evaluation function f^{eval} as follows:

$$f^{eval} = f^{obj} + p^{capacity} \sum_{e \in W : W(e) > W} \left(W(e) - W\right) + p^{hops} \sum_{k \in K : Hops(k) > Max\_Hops} \left(Hops(k) - Max\_Hops\right) \quad (1)$$

where $p^{capacity}$ and p^{hops} are penalty weights for number of wavelengths (limited to W) and number of hops (limited to *Max_Hops*) violations respectively, $W(e)$ denotes the number of wavelengths used in link e of the network and $Hops(k)$ denotes the number of hops for connection k.

For a given solution s in the solution domain of the GRWA problem that corresponds to a complete grooming, routing and wavelength assignment combination for the set of connections that represent the traffic demand to be satisfied over the considered network, a neighborhood $N(s)$ is defined by applying a particular move to the solution based on the history of the search. In the GRWABOU algorithm, five different moves have been defined: move a connection, remove a port, decrease infeasibility, groom or degroom connections. Selecting the proper move for a given solution is key to the good performance of the algorithm. The two first moves are the ones that are the most used in GRWABOU. Move a connection consists, for a particular network node, in moving a connection from one MSPP port to another. Remove a port is a much more radical move since it requires all the connections from a particular MSPP port to be rerouted to a different port in order to eliminate the considered port.

At each iteration, the best move, defined as the one going from s to the best solution in $N(s)$ is selected. If no solution in $N(s)$ improves the current value of the evaluation function, the least deteriorating solution is chosen. In order to avoid going back to a previous solution, we use a Tabu list in which the deteriorating move is inserted for a given number of iterations.

To allow controlled evolution in the non-feasible solution domain, penalty weights are increased if the current iteration corresponds to a non-feasible solution s, i.e. a solution that violates some constraints. Conversely, as soon as the solution becomes feasible, penalty weights are decreased, possibly at a rate different from the increase rate. Among the five moves that have been defined, one of them (decrease infeasibility) is used to bring back the algorithm in the feasible solution domain in priority if it has evolved in the non-feasible solution domain for too long. This controlled evolution in the non-feasible solution domain is an advantageous feature of Tabu Search techniques. Instead of slowly traveling in the feasible solution domain, the GRWABOU algorithm can quickly reach a better solution by taking a short cut through the non-feasible solution domain. This is good in situations where the feasible solution domain is nonconvex and absolutely required when it is not connected.

3. Computational experiments

In order to show the usefulness of the GRWABOU algorithm, we conducted computational experiments on three different mesh networks named NSF, EON and Brazil [8]. The goal of the computational experiments was to investigate the effect of an increase of the number of available transport wavelengths on the network cost. Figure 1 on next page shows the results. Number of iterations were 1000, 1000 and 1800 for the NSF, EON and Brazil networks respectively.

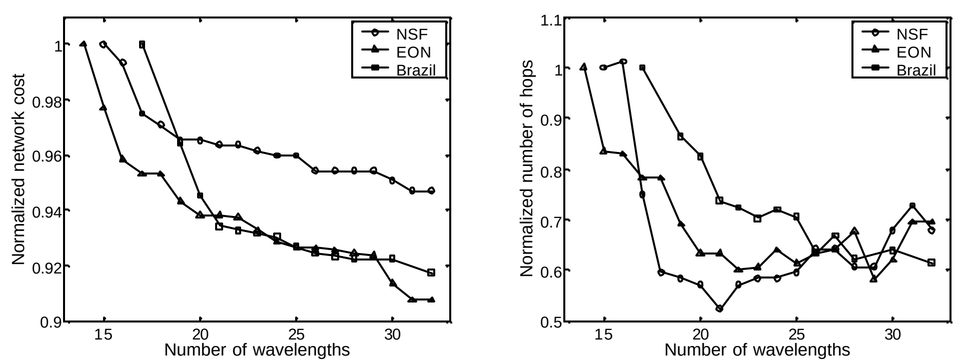

Fig. 1. On the left, normalized network cost as a function of the number of wavelengths. On the right, normalized number of hops as a function of the number of wavelengths.

Normalized network cost, as one would normally expect, decreases as the number of available transport wavelengths increases. In the case of the EON and Brazil networks, network cost decreases by 9,3% and 8,3% respectively as number of available transport wavelengths increases from 14 to 32 and 17 to 32. The network cost decrease is more modest in the case of the NSF network as its cost decreases by 5,3% when the number of available transport wavelengths grow from 15 to 32.

The graph on the right of figure 1 depicts the normalized number of hops that corresponds to the three investigated networks as a function of the number of available transport wavelengths. The normalized number of hops does not decrease monotonically as the number of available transport wavelengths increases. This is because the number of hops is considered when evaluating constraint violations but not as a quantity to be minimized. As the Tabu-based GRWABOU algorithm is flexible, it would be possible to include the number of hops in the objective function as a quantity to be minimized. This, however, would result in a computational experiment with a totally different scope.

Interestingly, for the NSF and EON networks, the total number of hops decreases significantly to a minimum around 21 and 22 wavelengths. Adding additional available wavelengths contributes to the reduction of network costs but results in a slight increase of the total number of hops. This behavior is not seen for the Brazil network. It is needed to investigate what is the signification of the presence or absence of such a minimum in the total number of hops. It may be a clue to whether the optimization process is close to an optimal solution but this is definitely for further study.

In a deeper analysis, we investigated wavelength capacity usage and MSPP port usage. When increasing the number of available transport wavelengths, wavelength capacity usage decreases as more wavelengths become available for the same traffic demand. MSPP port usage increases as network cost (i.e. number of MSPP electronic cards) is minimized. In the case where traffic demand can possibly grow, increasing the number of available transport wavelengths possesses the double advantage to minimize network costs while offering a better margin to accommodate future traffic growth.

4. Conclusion

We presented the GRWABOU algorithm. This algorithm is a Tabu Search algorithm that can be used to minimize networks costs without restrictions on network topology or traffic granularity. It considers simultaneously the grooming, routing and wavelength assignment problems. It minimizes an objective function directly related to the network cost through the number of MSPP electronic cards. It uses an evaluation function that, in addition to depending on the objective function, provides means to handle constraint violations in order to travel in the non-feasible domain in a controlled way. Five moves were defined and these are applied to the local solution based on the past history of the search. In the case where no move provides an improvement, the least deteriorating move is selected and placed in a Tabu list to avoid using the same move for a given number of iterations. We showed the usefulness of the GRWABOU algorithm for network design tasks by studying the cost minimization opportunity as a function of available transport wavelengths on three different WDM mesh networks. Many aspects of network design (number of hops, wavelength capacity usage, MSPP port usage) have been investigated with the GRWABOU algorithm.

5. References

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