Availability optimization of static path-protected WDM networks

Massimo Tornatore, Guido Maier, Achille Pattavina, Marco Villa, Aldo Righetti, Roberto Clemente, Mario Martinelli

ABSTRACT

We developed a heuristic procedure to optimize WDM networks with reliability as objective function. Optimization experiments have been carried out on a case study network, exploring the trade-off between network cost and reliability.

Introduction

Quality of service is a main issue of concern in present WDM networks. Contracts between operators and their customers are almost always made on the basis of service-level agreements which are very strict on optical circuits reliability, an important quality-of-service (QoS) aspect.

Reliability is measured by the connection availability, i.e. the fraction of mean failure-repair cycle in which the connection is active and working properly. The ability to guarantee high availability is fundamental for the operator in order to attract customers: it comes however at extra network costs. The availability of an optical circuit depends on the availability of the network elements (WDM links and nodes) it crosses. The operator can choose to spend more to equip his network with high-quality hardware. However, improving the quality of these elements above the levels of present commercial systems is hard and usually beyond the control of the operator. A more feasible strategy is the adoption of a protection mechanism for the connections. This requires extra transmission capacity to support the backup circuits. The availability of each connection strictly depends on the Routing, Fiber and Wavelength Assignment (RFWA) of lightpaths that have been setup to support it. Thus, careful network planning is in any case fundamental to fully exploit the benefits of good-quality hardware and protection strategy.

The introduction of availability as objective function in WDM network optimization is a rather new research target [1,2], important for the future. In our work, to our knowledge one of the first on this topic, we develope a network planning tool able to optimally plan a WDM network when availability is a key parameter. The availability parameters of the network elements are given as an input, as well as the static traffic matrix (the set of all the requested optical point-to-point connections) and the physical topology. The number of wavelengths per fiber W is preassigned, while the number of fibers per each link is a variable of the problem. All the connections are protected by Dedicated Path Protection (DPP), i.e. two link-disjoint lightpaths (working + protection, or a w/p pair) are setup per connection. A heuristic algorithm performs RFWA of all the w/p pairs, simoultaneously dimensioning the necessary transmission capacity of the links (in terms of number of fibers) according to a specific objective function (e.g. connection availability or network cost).

A heuristic has been preferred to an exact approach due to its lower computational complexity, which allows to plan also large networks in a reasonable time. The tool is based on a deterministic heuristic procedure described in details in Ref. [3]. Here we would like to present only the procedure added specifically to support availability optimization, which finds the RFWA for the w/p pair of a connection that has the maximum possible availability under link-disjoint constraint, given source and destination nodes and graph of the idle wavelength channels.

An availability model of a connection adopting DPP is a parallel of two series, representing the working and the protection lightpath, respectively (Fig. 1). Each series models the sequence of WDM channels assigned to the lightpath from the source to the destination node. Each element of the series accounts for the total availability of the sequence of devices crossed by the lightpath form one node to the next: a booster Optical Amplifier (OA), a pre-OA, a O/E/O transponder (a lightpath crosses one transponder in every node with the possibility of wavelength conversion - VWP network) and line OAs (equally spaced along the link), their number depending on the link length. In this first study switching nodes has been assumed ideal, i.e. always available.

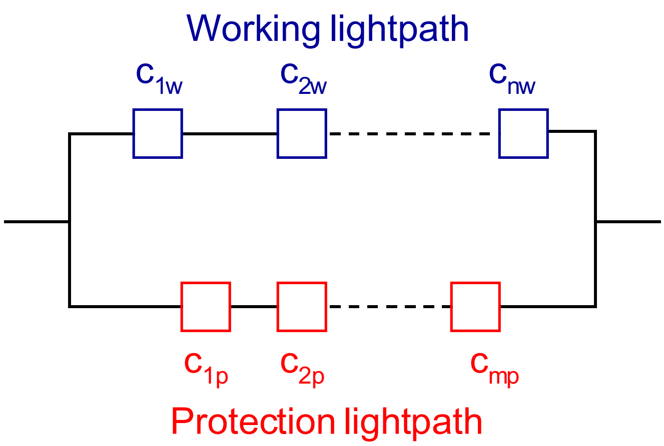

Fig. 1. DPP connection availability model

According to well known equations [4], the availability A of a connection is given by: $A = 1 - U_W \cdot U_P$, where $U_W \cong \sum_{i=1}^{n} U_{i,W}$, $U_P \cong \sum_{j=1}^{m} U_{j,P}$ and $U_{i,W}$ $(U_{i,P})$ is the unavailability of the i-th element of the working (protection) lightpath. The RFWA for the link-disjoint w/p pair that minimizes the non-linear function $U_W \cdot U_P$ could be found by non-liner programming, with a high computational complexity. We propose instead a heuristic method based on a graph in which all the arcs representing idle wavelength channels are labeled with a weight equal to their unavailability. Two known algorithms can be applied: the "One-step" (or Bandhari's), finds the link-disjoint pair of paths having the minimum total weight $(U_W + U_P)$; the "Two-step", finds out the least-unavailability path (working) and the second link-disjoint least-unavailability path (protection). None of the two algorithms actually minimizes $U_W \cdot U_P$, but the sub-optimal solutions they find are expected to be very close to the absolute optimum. Our method applies both the algorithms for each connection and keeps the one solution found which gives the lowest unavailability. It can be proved that when the two solutions are identical, they also coincide with the actual optimum: we verified that this happened for all the connections of the case-study we solved. We conjecture that the heuristic approach gives results sensibly far from the optimum only in extremely connected networks.

Case-study discussion

Let us discuss now the application of our tool to the planning of a case-study network. The physical topology (Fig. 2) and the matrix of the connection requests (~250 requests in whole) have been provided by Telecom Italia Lab and are based on a realistic model of a hypothetical Italian long distance network. It comprises terrestrial and submarine WDM links, which differ in OA spacing (100 km and 60 km, respectively) and Mean Time Between Failure (MTBF) value. Per each lightpath (working and spare) we have also taken into account unavailability of one WDM mux/demux pair and of one electronic receiver. The value of MTBF for all the components have been chosen by estimating real typical values of commercial systems. The Mean Time to Repair (MTTR) for the terrestrial and submarine links is 2 hours and 14 days, respectively.

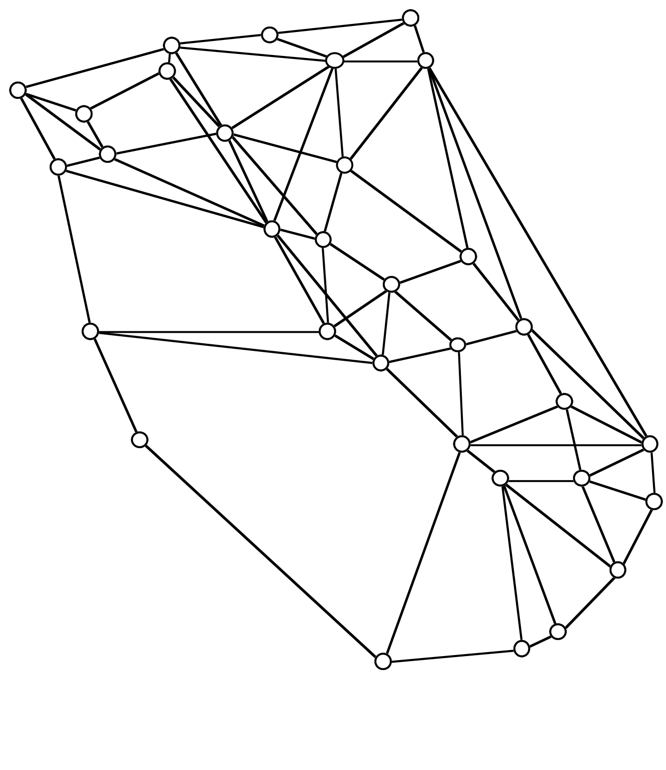

Fig. 2. Case-study physical topology

We developed this study not only as an application experiment of our new approach, but also with the purpose of exploring the trade-off between network availability and cost, obtaining some interesting results we are going to show. We chose a simple but relevant network cost parameter, which is the total number of fibers M that must be installed in the network to support all the demanded (DPP) connections in a given RFWA solution. We repeated planning for three values of W (2, 4 and 8).

The planning tool is used a first time (phase **U**) setting up a w/p pair for each connection so to obtain the minimum possible unavailability. RFWA is solved by the heuristic procedure described above, while the cost of the network is not taken into account at all.
Then the solution found is reprocessed to minimize the cost (by the optimization procedure described in Ref. [3]). This is done under the constraints that the unavailability of each connection is kept equal (case **mU**) or is allowed to rise at most a factor 10 (case **rU**) compared to the value obtained by phase **U**.
By comparison, the network has been also optimized by minimizing the cost, regardless of the availability (case **mM**).

Fig. 3 shows the cumulative distribution of the connection unavailability for the cases **mU**, **rU** and **mM** with $W = 8$. This distribution does not change sensibly with W, so the curve is well representative also for $W = 2$ and $W = 4$. The availability optimization is effective in improving the most unreliable connections, while it leaves the values of the mean and average availability almost unchanged. In fact, while the minimum unavailability is always $5.2 \cdot 10^{-9}$, the maximum unavailability is decreased from $3.85 \cdot 10^{-7}$ in the case **mM** to $2.24 \cdot 10^{-7}$ in the case **mU**. **rU** leads to maximum unavailability very close to **mU** ($2.45 \cdot 10^{-7}$), showing that the relaxed-constraint optimization can be an effective approach to reduce the cost without losing in QoS.

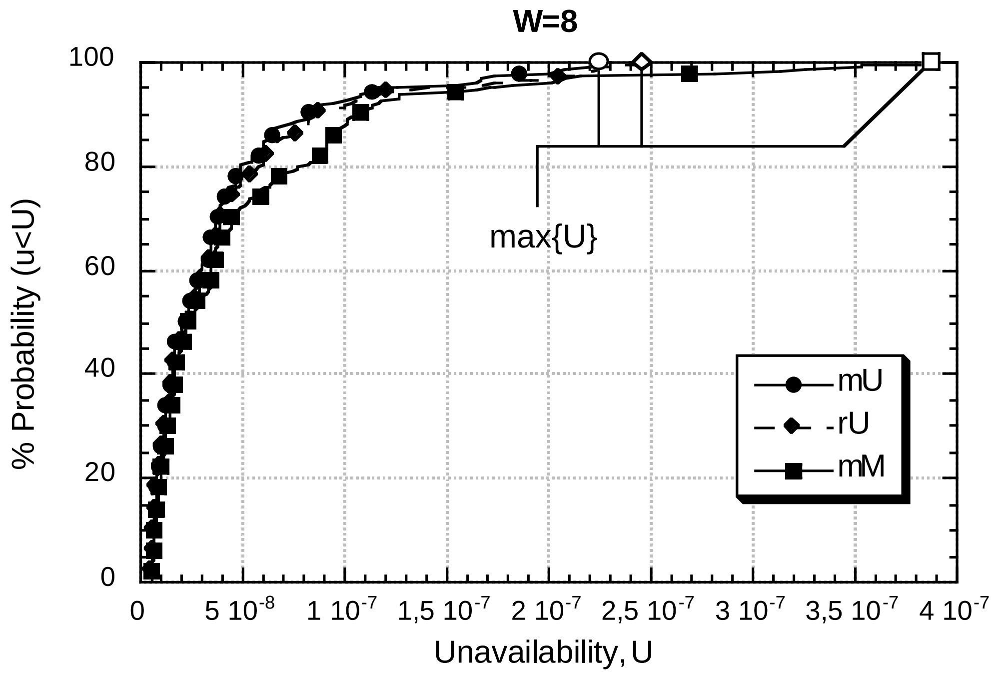

Fig. 3. Unavailablility cumulative distribution functions.

We should note that all the three cases of optimization led to unavailability levels which are well below the figure typically required to an operator by his customers (around 10^{-6}: the five-nines availability). This shows how the DPP technique is effective per-se in improving the QoS.

The resulting cost values are reported in Fig. 4 in term of total number of fibers.

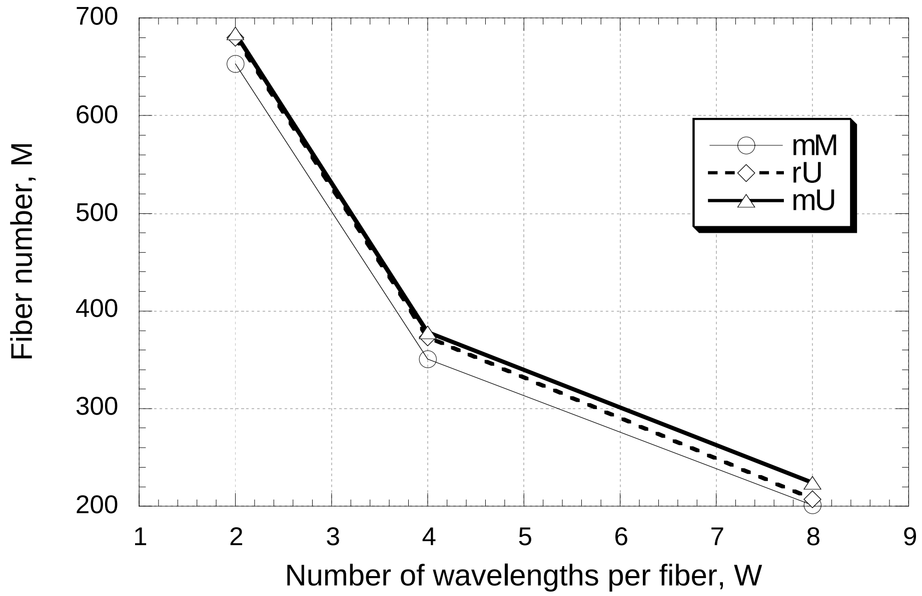

Fig. 4. Network cost comparison

To better appreciate the differences between the optimization cases Fig. 5 shows the extra cost due to availability improvement. This cost is measured by the difference in the number of fibers between the unavailability-constrained optimizations (**mU** and **rU**) and **mM** (in absolute and percent terms on the two vertical axes). By comparison, the extra-cost at the end of phase **U** is also plotted. The cost of the maximum availability can be quite high, even when a cost minimization reprocessing is performed (e.g. 9 fibers = 9 eight-wavelengths transmission systems, comprising all the line devices). The optimization approach with relaxed constraint **rU** can sensibly reduce the extra cost (e.g. to only 2 fibers) while preserving a good QoS level.

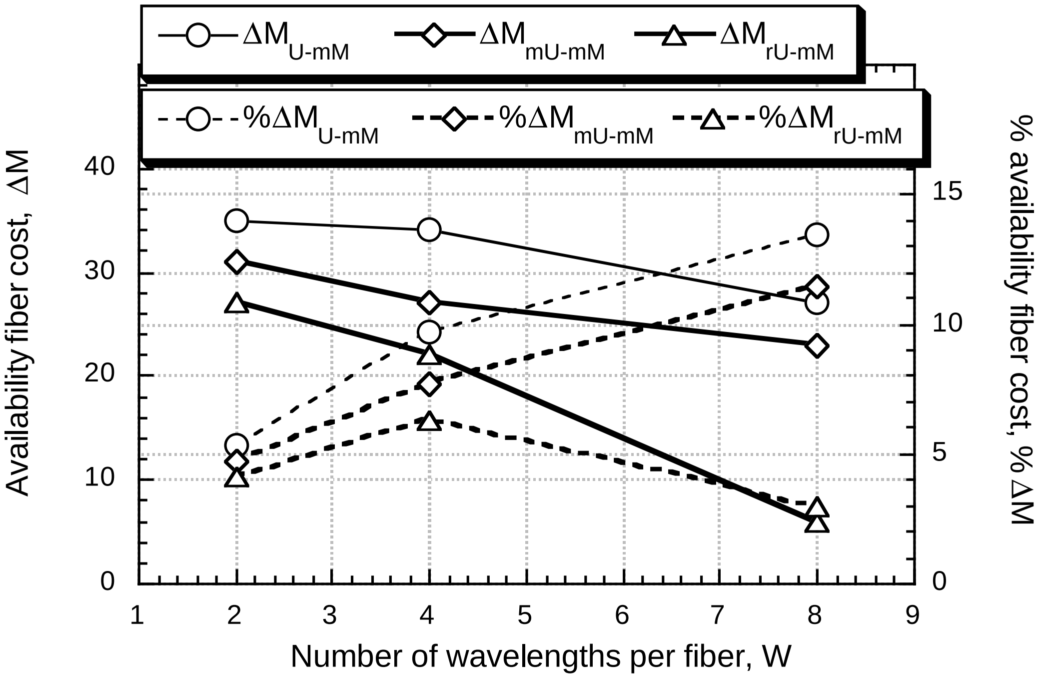

Fig. 5. Availability extra-cost under different optimization conditions.

Conclusions

We have presented a novel approach to WDM network planning which introduces availability as optimization objective function. The tool that exploits such a procedure is useful to investigate the trade-off between cost and availability, allowing to fine-tune the availability target. A first planning solution have been found with a realistic case-study network which minimizes the cost while guaranteeing the minimum possible unavailability for all the connections; a second less expensive solution has been given by relaxing this constraint.

Reference

[1]. W.D. Grover and M. Clouquer, Availability Analisys of Span-restorable Mesh Networks , IEEE Journal on selected Areas in Communications, Vol. 20, No. 4, pp. 810-821, May 2002.
[2]. K.C. Hung Chu, M. Mezhoudi and Y.Hu, Comprehensive End-to-End Reliability Assesment of Optical Transport Networks , in Proceedings of the Optical Fiber Communications (OFC) 2002, March 2002.
[3]. A. Dacomo, S. De Patre, G. Maier, A. Pattavina and M. Martinelli, Design of static resilient WDM mesh-networks with multiple heuristic criteria , Proceedings of INFOCOM 2002, pp.1793-1802, June 2002
[4]. E.E.Lewis, *Introduction to Reliability Engineering*, John Wiley & Sons, 1987