Path-based Recovery in Flexgrid Optical Networks

A. Castro, M. Ruiz, L. Velasco, G. Junyent, and J. Comellas
Advanced Broadband Communications Center (CCABA)
Universitat Politècnica de Catalunya (UPC), Barcelona, Spain
**e-mail: acastro@ac.upc.edu*

ABSTRACT

With the advent of flexgrid optical networks, the rigid wavelength-division multiplexing (WDM) technology will be enhanced by providing better spectrum efficiency and flexibility. In those future flexible optical networks, optical connections (lightpaths) can allocate a flexible number of spectrum slices, also known as frequency slots, so to match better with its requested bitrate. In this paper, we propose to take advantage of this flexible spectrum allocation in recovery mechanisms to be triggered when a failure occurs to provide recovery of part of the requested bitrate, i.e. the allocated spectrum by backup lightpaths could be lower than that of the working lightpaths provided that client service level agreements are fulfilled. This reduction in the recovered bitrate (bitrate squeezing) allows optimizing the use of network capacity. We propose path-based recovery alternatives, based on protection and restoration, specially designed for flexgrid networks. The performance of the proposed recovery mechanisms is exhaustively evaluated on a national reference network.

Keywords: Flexgrid Optical Networks, Bitrate squeezed recovery, Network Optimization.

1. INTRODUCTION

Future flexgrid optical networks featuring flexible and elastic spectrum allocation [1], [2] are attracting high interest from network operators and the research community in general as a result of its higher spectrum efficiency and flexibility with respect to wavelength switched optical networks (WSON) [3], based on the wavelength division multiplexing (WDM) technology. In flexgrid optical networks, the available optical spectrum is divided into frequency slots of fixed spectrum width, e.g. 25GHz or 12.5GHz. Optical connections (*lightpaths*) can use a variable number of these slots, which is a function of the requested bitrate, the modulation format used, and the slot width.

Owing to the huge bitrate associated to each established path, *recovery* schemes need to be used to guarantee that the associated client connectivity demand continue being served even in case of failures [4]. As in WSON, recovery can be provided by either *protection*, where the failed working path is substituted by a pre-assigned backup one, or *restoration*, which is based on rerouting the working path. Backup lightpaths use resources, i.e. each of the frequency slots in a fiber link, that are *dedicated* to protect a single working path, or they can be *shared* to provide protection to multiple working lightpaths. As a consequence, the former scheme is called dedicated path protection (DPP) and the latter shared path protection (SPP).

Although protection schemes reserve resources to guarantee that all protected lightpaths are recovered in case of any single failure, SPP provides better resource utilization than DPP due to spare resources are shared among several working lightpaths. On the other hand, restoration is the most efficient scheme since resources are only allocated after a failure impacts a working path and, for this very reason, no guarantees of recovery are given in dynamic scenarios. In addition, recovery times are usually much shorter in SPP since spare resources are reserved beforehand and they are activated in case of failure. Both, protection and restoration schemes have been widely studied in the literature applied to WSON [4]-[8].

In this paper, we define the BitRAte SquEezed Recovery Optimization (BRASERO) problem to maximize the recovered bitrate which is served in case of failure of any single fiber link. To solve the BRASERO problem we make use of the recently proposed Biased Random-Key Genetic Algorithm (BRKGA) meta-heuristic [9]. Our proposed heuristic algorithm provides near-optimal solutions to the MP-BRASERO problem in practical computation times. Exhaustive numerical results performed over a nation-wide network topology and for different traffic scenarios allow comparing the performance of SPP and restoration.

2. BRASERO PROBLEM STATEMENT

The problem can be formally stated as follows:

Given:

- a network topology represented by a graph G(N, E), where N is the set of optical nodes and E is the set of fiber links connecting two optical nodes,

---

The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement n° 247674 STRONGEST project. Moreover, it was supported by the Spanish science ministry through the TEC2011-27310 ELASTIC project.

- a set S of available frequency slots of a given spectral width in each fiber link in E. Each slot of Δ_S width,
- a set D of demands to be transported, each requesting a fixed bitrate,
- a squeezing factor $q\in(0,1]$ representing the minimum percentage of bitrate to be guaranteed in case of failure for all $d\in D$.

Output: the routing and spectrum assignment for each $d\in D$, including those scenarios where a failure in a fiber link $e\in E$ impacts the working route of d.

Objective: maximize the total recovered bitrate served in case of failure of any single fiber link $e\in E$ provided that all demands are served in the non-failure scenario.

As previously discussed, the problem can be faced using different either protection (in this paper we concentrate into SPP) or restoration. The BRASERO problem has been modeled as a Mixed Integer Linear Problem (MILP) using the formulation proposed in [10]. However, due to its complexity, heuristics algorithms need to be developed to obtain near-optimal solutions. To this end, in the next section we propose heuristics for both SPP and restoration.

3. HEURISTIC ALGORITHMS

In this section, we provide a detailed description of the heuristic algorithm that we have developed so as to efficiently solve the BRASERO problem. It is based on the recently proposed BRKGA metaheuristic [9] which has proved to effectively solve optimization problems, in particular, network related problems such as routing in single layer and multilayer optical networks [11].

Briefly, BRKGA is a class of genetic algorithm where a population of p individuals evolves over a number of generations to produce high quality solutions in short running times. Each individual represents a solution of the problem to be solved. Individuals are encoded into *chromosomes*, i.e. arrays of n real values, each of them called a *gene*. Populations are partitioned into two sets: those individuals with the best fitness values belong to the so called *elite set*, and the rest to the *non-elite set*. Finally, a deterministic algorithm, named decoder, transforms any input chromosome into a feasible solution and computes its fitness value. As described in [9], the only problem-dependent parts to specify a BRKGA heuristic are the decoder and the chromosome internal structure.

Since the order in which the demands are routed influences the goodness of the solution, we need one gene for each demand to specify the order in which the demands are routed. Therefore, each individual is represented by an array of $|D|$ genes.

The algorithm in Table 1 specifies the decoder pseudo-code. Essentially, the decoder is divided into three phases. First, demand's order is initialized using the assigned gene of the input chromosome and them demands are sorted (lines 1-4).

Second, demands are routed and a working path, including route and spectrum allocation, is found (lines 5-14). If the recovery mechanism is SPP (lines 5-9), the CAFES algorithm proposed in [5], adapted to the flexgrid technology, is used to find the backup path. Specifically, modifications consist in considering frequency slots as the shared resources, spectrum allocation must guarantee both continuity and contiguity, and routes length must to be consistent with reach limitations used for the requested bitrate. For the spectrum allocation, we use channels as defined in [10] and assume that the QPSK modulation format is used; its spectral efficiency is B_{mod}=2 bits/s/Hz. Then, the number of frequency slots in the set of channels for working lightpaths of each demand d, can be computed as $nw = \text{ceil}(b^d/(B_{mod}*\Delta_S))$. As a result, the new CAFES algorithm returns the route and channel for both the working and the backup lightpaths. When restoration is used, the shortest path algorithm properly modified is used in case of restoration to compute routes and channels (lines 10-14).

Third, when allowed, restoration paths are found for each demand impacted in each failure scenario (lines 15-28). Finally, an improvement phase tries to increase the restored bitrate in each failure scenario (lines 27-28) and the protected bitrate (lines 29-31).

The decoder algorithm ensures the minimum protected bitrate allocating a number of frequency slots np so that $np*B_{mod}*\Delta_S \geq q*b^d$. Once, the minimum bitrate is ensured, the improvement phase tries to increase the number of slots allocated for restoration (lines 27-28) and protection (lines 29-31). To this end, the reallocate recovery paths algorithm is used to reallocate the used resources. The algorithm first tries to increase the assigned spectrum of each demand in steps of one slot from np until reaching, at most, $[b^d/(m*\Delta_S)]$-1. Next, the last slot of each demand (which capacity might not be completely used) is established in the last round. The fitness value, defined as the total amount of bitrate recovered, is eventually returned.

The performance of the proposed heuristic was compared against the optimal solution obtained solving the developed MILP models over small topologies. In all the tests performed, the optimal solution was found within running times of some seconds, in contrast to several hours needed to find the optimal solution with the models.

Table 1 Decoder Algorithm for SPP

```
Procedure Decoder
IN: N, E, D, recoveryType, Chromosome ch;
OUT: fitnessValue
i ← 0
for each d ∈ D do
    d.order ← ch[i++]
sort (D, D.order, ascending)
if recoveryType = "SPP" then
    for each d ∈ D do
        {{d.kw, d.cw},{d.kp, d.cp}}←CAFES(d, d.b, $B_{mod}*\Delta_S$)
        if not exist d.kw or d.kp then
            return NOT FEASIBLE
else /* recoveryType ="Restoration" */
    for each d ∈ D do
        {{d.kw, d.cw}← shortestPath(d, d.b)
        if not exist d.kw then
            return NOT FEASIBLE
if recoveryType ="Restoration" then
    for each failure scenario f ∈ F do
        for each shortest route k ∈ K do
            compute $a^{k}_{f}$ = availability of route k under failure f
        for each d ∈ D do
            if $d.a^{kw}_{f}$ = 0 then
                D[f] ← D[f] ∪ {d}
        sort(D[f], D.order, ascending)
        for each d ∈ D[f] do
            {d.kr,d.cr}←shortestPath(d, $B_{mod}*\Delta_S$)
            if not exist d.kr then
                return NOT FEASIBLE
        reAllocateRestPaths(N, E, D[f], "diffSlots")
        reAllocateRestPaths(N, E, D[f], "diffBW")
else /* recoveryType = "SPP" */
    reAllocateBackupPaths(N, E, D, "diffSlots")
    reAllocateBackupPaths(N, E, D, "diffBW")
return fitnessValue
```

4. ILLUSTRATIVE NUMERICAL RESULTS

In this Section, we present the network scenario that we consider in order to carry out our experiments and then, we solve the BRASERO problem considering a set of realistic traffic instances.

In order to conduct all the experiments, we consider the 21-node Spanish Telefónica topology shown in Fig. 1. Regarding the optical spectrum, 800 GHz and tree slot widths: 25, 12.5 and 6.25GHz were considered. Table 2 reports the number of slots that each demand requires under the different slot widths evaluated.

As for the traffic, we make use of two traffic profiles (TP) (see Table 3) where demand bitrates are 10, 40, 100 or 400 Gb/s. For the sake of a comprehensive study, one can observe that the TPs selected range from a scenario with a high number of 10 and 40 Gb/s demands and 52 Gb/s on average (TP-1) to a scenario with fewer demands but with a higher bit-rate (80 Gbps on average in TP-2). These TPs are a realistic representation of the expected evolution of bandwidth necessities for the years to come. In our experiments, however, the average amount of Tb/s offered to the network is equal for all TPs.

Table 2 Number of slots Required for each bitrate

Slot width (Δ_S) (GHz)	**10 Gb/s**	**40 Gb/s**	**100 Gb/s**	**400 Gb/s**
25	1	1	2	8
12.5	1	2	4	16
6.25	1	4	8	32

Table 3 Traffic Profiles Analyzed

Traffic Profile	**Avg. bitrate (Gb/s)**	**Demands (%)**			
		10 Gb/s	**40 Gb/s**	**100 Gb/s**	**400 Gb/s**
TP-1	52.0	40	40	16	4
TP-2	80.0	0	66.7	26.7	6.7

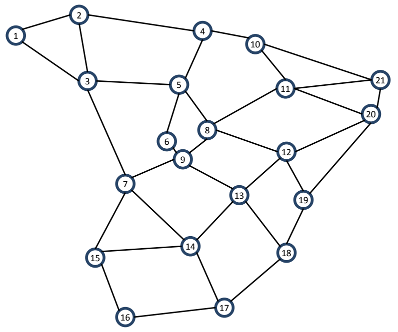

Fig. 1 The 21-node Spanish Telefónica topology used in this paper.

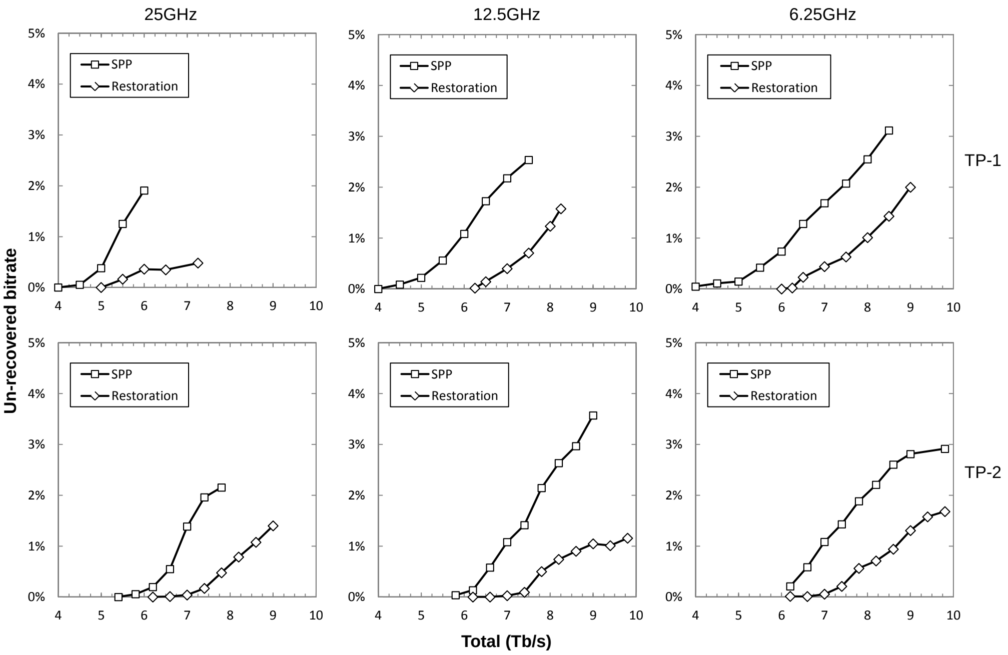

Fig. 2. Percentage of bit-rate that is un-recovered after a failure. The two proposed TPs are analyzed under the different slot widths.

Fig. 2 shows the obtained results, where the average percentage of bitrate that is un-recovered after each failure is plotted against the total load (Tb/s). Each point represents the average fitness value from solving three independent instances. The demand matrix of each instance consists in uniformly distributed origin-destination pairs where the requested bitrate follows the above-defined TPs. Six graphs are represented, one per each of the proposed TPs and the different slot widths. In each of the graphs, the results for SPP and for restoration are shown. The value of q was selected so as to guarantee that, at least, one slot ($B_{mod}*\Delta_S$ in Gb/s) is assigned for the recovery of each demand.

As clearly shown, much more traffic can be recovered using the restoration scheme, in fact a gain in the order of 250% at the 1% of un-recovered bitrate is observed. However, since restoration times are generally longer than that of the SPP, the latter is preferred.

In view of the above, multi-path-based recovery schemes mixing SPP and restoration can be devised so to improve the trade-off between un-recovered bitrate and recovery time.

REFERENCES

[1] M. Jinno, H. Takara, B. Kozicki, Y. Tsukishima, Y. Sone and S. Matsuoka, “Spectrum-efficient and scalable elastic optical path network: architecture, benefits, and enabling technologies,” IEEE Commun Mag., vol. 47, pp. 66-73, 2009.

[2] M. Jinno, B. Kozicki, H. Takara, A. Watanabe, Y. Sone, T. Tanaka and A. Hirano, “Distance-adaptive spectrum resource allocation in spectrum-sliced elastic optical path network,” IEEE Commun. Mag., vol. 48, pp. 138-145, 2010.

[3] X. Wang, Q. Zhang, I. Kim, P. Palacharla, and M. Sekiya, “Blocking Performance in Dynamic Flexible Grid Optical Networks - What is the Ideal Spectrum Granularity?,” in Proc. European Conference on Optical Communication (ECOC), 2011.

[4] W. Grover, “Mesh-based Survivable Transport Networks: Options and Strategies for Optical, MPLS, SONET and ATM Networking,” Prentice Hall, 2003.

[5] C. Ou, J. Zhang, H. Zang, L. Sahasrabuddhe, and B. Mukherjee, “New and Improved Approaches for Shared-Path Protection in WDM Mesh Networks,” IEEE/OSA J. Lightwave Technol., vol. 22, pp. 1223-1232, 2004.

[6] L. Velasco, S. Spadaro, J. Comellas, and G. Junyent, “Shared-path protection with extra-traffic in ASON/GMPLS ring networks,” OSA J. of Opt. Netw., vol. 8, pp. 130-145, 2009.

[7] L. Velasco, M. Ruiz, J. Perelló, S. Spadaro, and J. Comellas, “Service and Resource Differentiation in Shared-Path Protection Environments to Maximize Network Operator's Revenues,” IEEE/OSA J. of Opt. Commun. and Netw., vol. 3, pp. 117-126, 2011.

[8] L. Velasco, F. Agraz, R. Martínez, R. Casellas, S. Spadaro, R. Muñoz, and G. Junyent, “GMPLS-based Multi-domain Restoration: Analysis, Strategies, Policies and Experimental Assessment,” IEEE/OSA J. of Opt. Commun. and Netw., vol. 2, pp. 427-441, 2010.

[9] J. Gonçalves and M. Resende, “Biased random-key genetic algorithms for combinatorial optimization,” J. Heuristics, vol. 17, pp. 487-525, 2011.

[10] L. Velasco, M. Klinkowski, M. Ruiz, and J. Comellas, “Modeling the Routing and Spectrum Allocation Problem for Flexgrid Optical Networks,” Springer Photonic Network Communications, DOI: 10.1007/s11107-012-0378-7, 2012.

[11] M. Ruiz, O. Pedrola, L. Velasco, D. Careglio, J. Fernndez-Palacios, and G. Junyent, “Survivable IP/MPLS-Over-WSON multilayer network optimization,” IEEE/OSA J. of Opt. Commun. and Netw., vol. 3, pp. 629-640, 2011.