Spectrum sharing for elastic transmission parameter adaptation

N. Sambo(1), K. Christodoulopoulos(2), P. Castoldi(1), E. Varvarigos(2)

(1) Scuola Superiore Sant'Anna, Pisa, Italy, nicola.sambo@sssup.it
(2) *Computer Technology Institute and Press, and National Technical University of Athens, Greece*

Abstract *We propose spectrum sharing between different service classes: part of spectrum used by low-priority traffic can be reconfigured and used by high-priority traffic, enabling adaptation to more robust transmission. Even 70% of high-priority traffic is recovered from soft-failures without rerouting.*

Introduction

A key feature of elastic optical networks (EONs) is the possibility to optimize transmission parameters[1-3] (e.g., modulation format, forward error correction –FEC) depending on the path and, eventually, adapt such parameters in case of traffic or physical layer condition changes. In this sense, EONs provide mechanisms to recovery from soft-failures, e.g. increase of bit error rate due to network devices malfunction or equipment ageing.

The adaptation of modulation format or FEC is not straightforward because of bandwidth constraints. Indeed, by keeping the same baudrate, if the modulation format is changed to a more robust one (e.g., from PM-16QAM to PM-QPSK), the bit rate is reduced and a new sub-carrier or a new lightpath should be setup to keep the initial bit rate. This happens also by incrementing the redundancy, e.g. to keep the initial bit rate, the baudrate should increase. Thus, generally, the adaptation to a more robust transmission requires the availability of extra bandwidth to maintain a given bit rate[4]. At the service level, different classes can be requested[4]. In particular, in case of a soft failure or hard failure (e.g., link cut implying loss of connection), the same bit rate should be kept for *gold* traffic, while not necessary for a *bronze* traffic[4,5]. Such classification drives the main idea of this work.

In this paper we propose the sharing of spectrum between gold and bronze adjacent lightpaths: in normal conditions the shared spectrum is used by bronze traffic and both gold and bronze transmit at the full bit rate; in case a more robust transmission is required for a gold because of a soft failure, the shared spectrum is reconfigured to be used by the gold one to satisfy its full bit rate, while the adjacent bronze is downgrade to a lower bit rate. We also propose a routing and spectrum assignment (RSA) algorithm to maximize the spectrum sharing. Simulation results show that spectrum sharing is effective to recover the full bit rate of high-priority traffic without rerouting (up to 70% with the proposed RSA).

Spectrum sharing among different service classes

An elastic optical network equipped with flexible transponders is assumed. Transmission can be adapted by changing the modulation format or FEC. Two service classes are considered: i) *gold*: in case of recovery, the initial bit rate must be assured; ii) *bronze*: the assurance of the bit rate is not mandatory. Two adjacent 100 Gb/s lightpaths, gold and bronze respectively, are assumed in Fig. 1. In normal working conditions (Fig. 1a), the full bit rate is satisfied for both classes, e.g. considering PM-16QAM and a given FEC (7% for example). Then, in case of soft failure affecting the gold lightpath, the adaptation to PM-QPSK is required. Such adaptation requires to double the initial bandwidth to guarantee the bit rate of 100 Gb/s. Thus, traversed filters along nodes A, B, and C

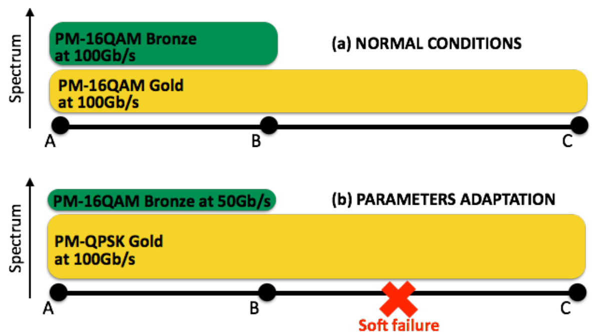

Fig. 1 Example of spectrum sharing before (a) and after (b) a soft failure.

are reconfigured to switch the doubled bandwidth of the gold lightpath and to halve the bandwidth of the bronze one. The transponder related to the bronze lightpath has to be reconfigured to transmit 50 Gb/s. Finally, the initial bit rate is guaranteed for the gold traffic, while the bronze is downgraded to 50 Gb/s. In a subsequent maintenance phase, the soft failure could be fixed or a regenerator could be added and both lightpaths would return to their previous operation.

Sharing-Spectrum-based RSA (SS-RSA)

A centralized control plane (e.g., software defined networking - SDN) is assumed[6]. The

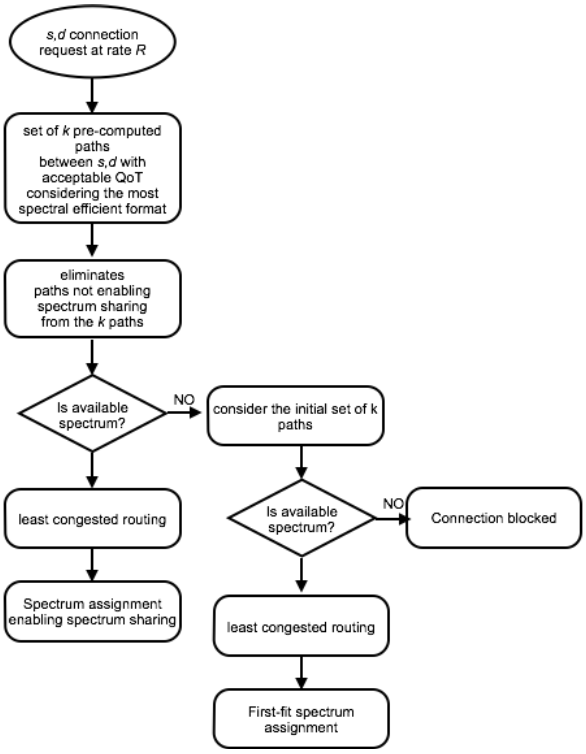

Fig. 2 Flow chart of SS-RSA.

centralized controller consults databases including traffic engineering information and the state of lightpaths (e.g., traversed links and ports)[6] for RSA. Fig. 2 shows the flow chart of the proposed SS-RSA. Upon request for a lightpath at rate R from source s to destination d, the centralized controller computes a set of k-paths between s and d satisfying quality of transmission (QoT) with the most efficient modulation format (e.g., accounting for noise and non-linear effects[7]). Then, spectrum sharing is evaluated for each path: i.e., if the new request is gold (or bronze), the controller checks if available spectrum satisfying the continuity constraint in all the links is available close to a bronze (or gold) lightpath (as in Fig. 1). Then, a new set of paths obtained by removing all the paths not enabling spectrum sharing among different classes is considered. On this set, the least congested path is selected. Then, spectrum assignment is performed on the first available frequency slot enabling spectrum sharing. If no frequency slot satisfies wavelength continuity constraint, spectrum sharing is not considered and least congested routing is performed on the initial set of k paths with first fit spectrum assignment.

Simulation results

To examine the benefits of spectrum sharing and estimate the efficiency of the proposed algorithm we developed a custom event-driven C++ simulator. We considered a Spanish network topology with 30 nodes and 55 bi-directional links. Transceivers are able to tune between PM-16QAM, PM-QPSK, and PM-BPSK formats. We assumed 100 Gb/s connection requests, which arrive dynamically according to a Poisson process with average inter-arrival time of $1/\lambda$ time units and uniformly distributed among node pairs and classes. The holding time of the connections followed a negative exponential distribution with mean $1/\mu$=500 time units. The set of k paths is composed of all the paths within one hop from the shortest hop path. Spectrum sharing is evaluated by randomly generating single link soft failures and averaging the collected data. In case the impacted gold service is PM-16QAM, the adaptation is done to PM-QPSK, while if it is PM-QPSK then it is adapted to PM-BPSK. In all examined case, the adaptation requires one 12.5-GHz frequency slot more (assuming that the original frequency slot was over dimensioned with respect to the actual signal bandwidth to limit filtering effects). QoT is estimated through the signal-to-noise ratio model in[8]. Spectrum sharing is evaluated in terms of recovered gold lightpaths without the need of rerouting upon soft failure. Such evaluation is performed considering two RSA algorithms: the proposed SS-RSA and the (sharing unaware) RSA in[8] based on least congested routing and first fit spectrum assignment.

Fig. 3 shows the percentage of gold traffic, recovered through modulation format adaptation, vs. the provisioned traffic load. Such load is considered instead of the offered load λ/μ for fairness. Indeed, the two adopted RSA strategies may affect provisioning blocking probability P_b, thus the number of lightpaths interested by a failure and, consequently, the recovery. Provisioned load is defined as the product between the offered network load and the establishing probability (1-P_b): $\lambda/\mu \times (1-P_b)$. The figure shows that even with a simple RSA up to 40% of gold traffic can be recovered by adapting transmission parameters, thus avoiding new path and frequency slot computation and rerouting. The proposed SS-RSA achieves up to 70% of gold traffic recovered through adaptation, at the expense of bronze traffic (e.g., an average of around 30 bronze connections has to be downgraded, almost independently on the traffic load). Such percentage decreases with provisioned load because once the network is more loaded it becomes more difficult to find lightpaths that facilitate spectrum sharing and simple least congested routing and first-fit spectrum assignment are applied (see right-side

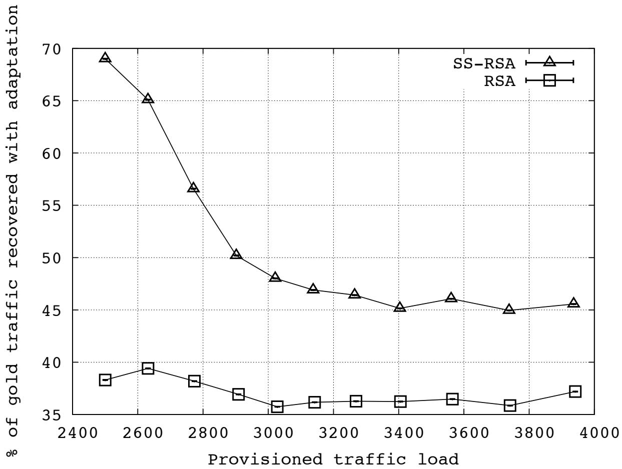

Fig. 3 Percentage of adapted gold traffic vs. provisioned network load.

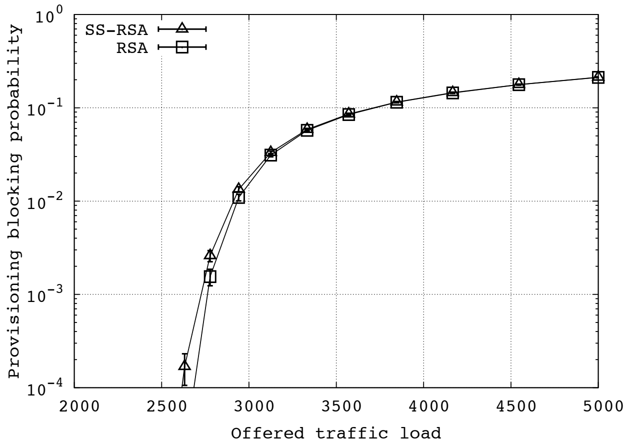

Fig. 4 Provisioning blocking probability vs. offered network load.

branch of Fig. 2). For simple RSA, the percentage of recovered gold through adaptation is almost not affected by the provisioned load because, during provisioning, spectrum sharing does not drive the decisions, as in SS-RSA.

To further characterize SS-RSA and RSA, we also report Fig. 4 that shows the provisioning blocking probability vs. the offered network load λ/μ. SS-RSA does not negatively impact provisioning blocking probability since the two RSAs experience almost the same performance during provisioning. The slightly high provisioning blocking of SS-RSA is due to a more fragmented spectrum experienced with SS-RSA, since it prefers to enable spectrum sharing, thus it does not apply first fit spectrum allocation which tends to optimize spectrum utilization to achieve low blocking. Thus, the SS-RSA can be a very effective solution since it facilitates transmission parameter adaptation of high-priority traffic without causing excessive spectrum fragmentation, thus without negatively impact provisioning blocking probability.

Conclusions

We proposed the sharing of spectrum between high- (*gold*) and low-priority (*bronze*) traffic: in normal conditions the shared spectrum is used by bronze traffic; in case a more robust transmission is required for gold traffic, e.g. because of a soft failure, the shared spectrum is reconfigured to be used by the gold one to satisfy its full bit rate. A routing and spectrum assignment (RSA) algorithm has been also proposed to maximize the spectrum sharing. Simulation results show that spectrum sharing is effective to recover high-priority traffic without the need of rerouting: up to 70% of gold traffic can be recovered with transmission parameter adaptation considering the proposed RSA, at the expense of low-priority traffic.

Acknowledgements

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