QoT Aware Adaptive Elastic Optical Networks

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Abstract: Operating Elastic Optical Networks with low margins increases their efficiency but suffers from soft-failures, rendering the QoT of lightpaths unacceptable. We present a toolkit that leverages the flexibility dimensions to survive against QoT problems.

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1. Introduction

During the lifetime of an optical transport network, equipment ageing (e.g. amplifiers, fibers), maintenance operations (e.g. fixing fiber cuts) and interference from new lightpaths, degrade the quality of transmission (QoT) of the established lightpaths. The current practice is to provision lightpaths with high margins that take into account such possible future degradations, ensuring that the QoT will be acceptable until the End of Life (EOL) of the network [1]. Such margins result in the deployment of regenerators or more robust transponders that are not strictly necessary at the initial set-up time. Lowering the margins can clearly result in significant cost savings [2,3,4], but requires new mechanisms to monitor the QoT and take appropriate actions to resolve the issues that may arise because of that [5].

In an optical network operating with low margins, accumulated deteriorations or minor equipment malfunctioning may lower the QoT of the lightpaths beyond the acceptable level, what we will refer to as *soft-failure*. To resolve a soft-failure, the network operator may consider placing a regenerator or rerouting the problematic lightpath. Both operations are considered expensive in that they result in traffic disruption and/or require additional equipment to be installed at non-programmed periods. Assuming an elastic optical network (EON) [6] with tunable transmitters and flex-grid switches, we can leverage the available flexibility dimensions to recover from QoT degradations. In [7], an elastic network testbed with a real-time adaptive control plane was demonstrated that adjusted modulation format and spectrum positioning to maintain acceptable QoT.

In this paper we present a novel toolkit that performs dynamic reconfiguration of the network and aims to render the network survivable from QoT degradations. In particular, the toolkit considers the combination of three re-configuration techniques to restore the QoT of a problematic lightpath: (i) increasing its Forward Error Correction (FEC) overhead, (ii) creating spectrum guard-band to decrease the interference, and (iii) changing its modulation format to a more robust one. To maintain the original transmission rate, the first and third techniques are combined with appropriate baud-rate adaptations. Thus, all these techniques result in a set of network adaptation actions that involve spectrum re-configuration of one or more lightpaths. Since the optimization dimensions in an EON are vast, we need to search the possible solutions space in an intelligent way. To do so we rely on a specific ordering of the related actions in terms of control plane overhead. We also need a fast and accurate way to estimate the QoT and check whether the problem will be solved before we apply a possible solution. To this end we use the QoT estimation framework presented in [8]. The proposed toolkit provides survivability to a certain degree of soft failures, by pro-actively deciding on the re-configuration actions and place regenerators to restore the QoT problems, in a similar manner that we decide the re-routing actions in pro-active hard failures restoration [9]. Our results quantify the savings in regenerators that the proposed re-configuration toolkit can achieve as opposed to a) planning with high margins and b) pro-active placing regenerators (without optimizing the transmission options).

2. Network scenario

We assume an elastic [6] optical network (EON) with tunable transceivers that transmit using Nyquist WDM and can adapt a number of transmission parameters: modulation format, baudrate, FEC, and spectrum used. We assume coherent receivers that can be extended almost for free to function as OPMs [5]. OPMs are used to identify QoT problems and for QoT estimation purposes [8]. Each lightpath uses the same wavelength end-to-end, while for long connections regenerators are placed, and each segment between regenerators is considered a separate lightpath that may use a different wavelength.

We assume that the network is operated close to its actual condition, in the sense that the lightpaths are provisioned with reduced (i.e. just enough, and not worst case) margins [1]. As the network evolves, equipment ageing, maintenance operations, increased interference due to new lightpaths and equipment malfunction can make the QoT of some established lightpath degrade below a given threshold. Advanced OAM handler functionalities [10] are required to track the QoT of the lightpaths and identify such failures. In a "soft-failure" event, we want to avoid rerouting or adding new regenerators. So our goal is to find the set of re-configuration actions that solve the QoT problem at hand but also have a low control plane overhead. To increase the QoT of the lightpath, we harvest the flexibility degrees of transceivers and flexgrid switches. The toolkit we developed includes three techniques.

- FEC adaptation: we assume FEC tunable transmitter and lightpaths provisioning with reduced margins. In such an environment there are cases where the most robust FEC available was not used when the lightpath was initially provisioned: the selected lower FEC yields acceptable QoT, while the most robust FEC requires an additional slot (e.g. for 25 net baudrate, using 12% or 28% FEC results in 3 or 4 slots for 28 or 32Gbaud, respectively).
- Creating spectrum guard-band: Reducing interference increases the QoT and can provide a solution especially at medium to heavy load, when interference is high. The developed technique reduces interference by using spectrum as guard-band, that is, leaving spectrum space between lightpaths to reduce interference.
- Modulation format adaptation: Adapting transmission to a more robust modulation format can improve substantially the QoT of the lightpath.

Assuming that we want to keep the same effective line rate, in the first and third technique we need to increase the baud-rate accordingly. So, all the above described techniques require some amount of extra spectrum for the problematic lightpath: the first and the third technique due to the increase of the baud-rate to avoid bandwidth losses, while the second one relies exactly on the creation of spectrum guardband and spectrum reconfiguration. The push-pull technique presented in [11] can be used to perform the required spectrum reconfiguration actions in a hitless (without traffic interruption) manner.

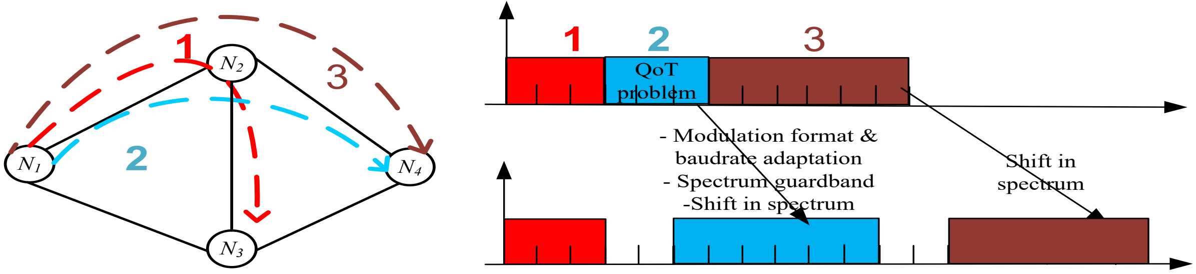

Fig 1. Paths 2 and 3 are shifted in order to create guardbands and assign more slots to increase baud rate and decrease mod format of path 2

Since all the aforementioned techniques can provide a solution to the QoT problem, we decided to investigate them in the order presented above, considering cheaper, from the control plane of view, the adaptation of the FEC (which can be done hitlessly and at the cost of just an extra slot), and most expensive the adaptation of the modulation format (which will probably result in some loss of data). The spectrum guardband solution is considered of middle complexity, the reason being that the guardband can be created hitlessly, but requires much more spectrum than FEC adaptation (several slots of guardband are needed to reduce interference), affects more lightpaths and involves more control operations. Note that, in addition to failure resolution, our secondary goal is to avoid a high number of control operations. Taking this into account, we have developed an algorithm to free spectrum assuming the use of the push-pull technique, following [12]. The first step of the algorithm is to look for all the available adjacent empty slots at all links contained in the problematic lightpath. In case the links have the required spectrum slots, no pushing is required. Otherwise, the algorithm tries to recursively push the adjacent lightpaths. In doing so, it tries all the possible combinations of slots both higher and lower to the occupied spectrum, and chooses the one resulting in the lowest number of recursively pushed lightpaths. Having described the order in which the solutions are searched, we need to estimate in a fast and accurate way the QoT of the lightpath experiencing the soft failure, and of all the others that participate or are affected by each considered solution using the method presented in [8].

3. Performance results

To evaluate the efficiency of the proposed toolkit we performed a number of simulation experiments. We assumed the SPARKLE topology, SSMF fiber with attenuation coefficient 0.25 dB/km, dispersion parameter 16.7 ps/nm/km, and nonlinear coefficient 1.3 1/W/km. The span length was set at 100 km and EDFA noise figure to 6 dB. We examined two traffic loads: 20 and 49.2 Tbps. We assumed 100 and 200 Gbps connections that are served using the following options: modulation format: PM-16QAM, and PM-QPSK, baudrate: 28, 32, 56, 64 Gbaud, and FEC: 12% and 28%, with pre-FEC BER limits of -2.2dB and -1.88dB, respectively.

We first calculated the BER savings that each reconfiguration action can yield. The FEC adaptation modifies the blocking threshold by 0.32 dB, however a slight baud rate increase is required in order to preserve the original transmission rate. This translates to a fixed maximum penalty of 0.1 dB (the QoT estimation of [8] is not necessary for this simple case), so the resulting BER saving of the FEC adaptation is 0.22 dB. The creation of spectrum guard band yields at most 0.2 dB when the two direct neighbours (one at each side) are pushed and 0.3 dB when the four neighbors are pushed (which results in large control plane overhead, due to the pushing of many lightpaths, and is not used in the subsequent simulations). However, in most cases the benefit is much less, and combined with the fact that our QoT estimation in [8] requires 0.2 dB margin for the estimation error, makes the spectrum guard band technique inappropriate to be used by itself. Therefore we combine it with the modulation format adaptation, so that their BER savings can be added. In particular, the modulation format adaptation from QPSK to BPSK along with the baud rate adaptation (from 28 to 56, or from 32 to 64Gbaud) yields maximum benefit of 1.6 dB, while the adaptation of 16QAM to 8PAM yields 2.2 dB. When combined with spectrum guard band generation, the BER benefits are 1.8 and 2.4 dB, while the QoT estimation margin penalty subsequently reduces these values by 0.2 dB in BER.

In the simulations we assume a single link at a time suffers an SNR degradation of 1, 2 or 3 dB. For each single link failure we examine whether the proposed toolkit can absorb the created QoT problems by re-configuring the lightpaths that fall below the QoT threshold, and if not we place regenerators. Then we return to the initial state of the lightpaths and examine the next single link failure. Regenerators placed can be re-used when examining a different link failure (following the concept of backup multiplexing restoration [9]). We compare: (i) The proposed re-configuration toolkit, (ii) Planning with high margins: here, we decide on transmission configuration and place regenerators so as to absorb the QoT problems; the margins are used to absorb the QoT problems. This is equivalent to soft-failure protection, as one single-link failure is examined at a time and we decide the transmission configuration of the lightpaths and place regenerators to protect against that. The decisions are kept when we examine the next link failure, (iii) Pro-active restoration with regenerators. In this case we examine each single-link failure and in case of QoT problem we place regenerators, without examining reconfiguration options.

The total required number of regenerators is the ultimate comparison metric. In cases (i) and (iii), which both rely on backup multiplexing, we calculate the required regenerators per node, and then sum the maximum numbers for each node. In those cases we strive to reuse regenerators for different single-link failures. In case (ii) we sum the regenerators for each node. We also consider the total spectrum utilization.

Figure 2 presents the required number of regenerators for traffic loads of 20 and 49.2Tbps. Under both loads, our toolkit (i) requires approximately at least 22% less and at most 40% regens than case (ii) and 68% less regens than case (iii). The spectrum utilization is 2% lower in the proposed solution-case (i) when compared to case (ii), since we examine restoration for each single link failure instead of planning for all link failures. The proposed solution exhibits 4% higher spectrum compared to case (iii), since the latter prefers low spectrum configurations and employs more regenerators. We notice that using our toolkit results in significant equipment savings, as we harvest the available re-configuration options and place regenerators when needed as opposed to case (iii) that relies only on regenerators.

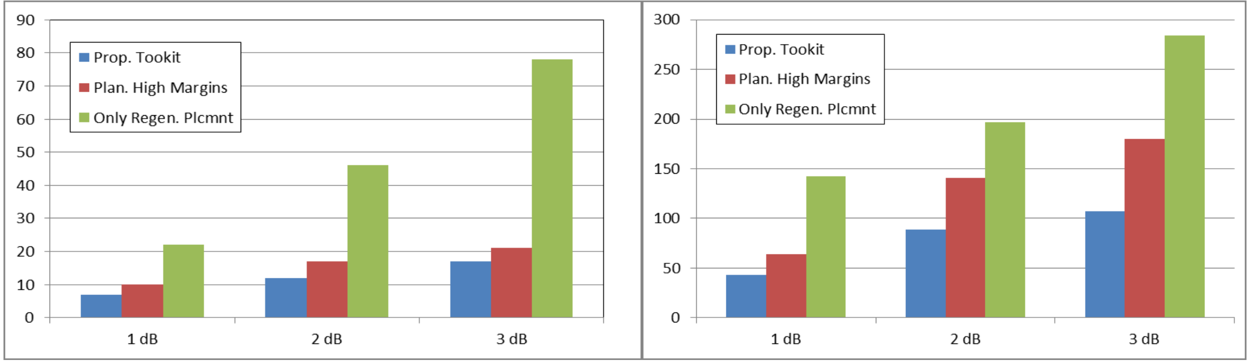

Fig 2. Total Number of Regenerators in the network for single link soft failure of 1, 2 and 3 dB for a) 20Tbps and b) 49.2Tbps loads.

4. Conclusions

Provisioning lightpaths with reduced margins is susceptible to QoT degradations, e.g. due to equipment malfunctioning, ageing, increased interference, or maintenance degradations. We proposed a toolkit that leverages the flexibility dimensions of elastic optical networks to provide survivability against soft failures: lightpaths are re-configured to restore their QoT. We observed that we can save at least 22% and at most 40% in regenerators when compared to planning with high margins.

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5. References

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