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Experimental Demonstration of Adaptive Combinational QoT Failure Restoration in Flexible Bandwidth Networks

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Abstract: We propose and demonstrate an adaptive quality of transmission restoration scheme combining methods of lightpath rerouting and modulation format switching to combat real-time impairments in flexible bandwidth networks. Testbed demonstration achieved error-free performance.

OCIS codes: 060.4261 Networks, protection and restoration; 060.2330 Fiber optics communications

1. Introduction

Flexible bandwidth elastic optical networking [1, 2] offers spectrally efficient and adaptive methods to allocate spectral resources to varying traffic demands with differing Quality of Transmission (QoT) requirements. Specifically, it enables simultaneous transmission of multiple connections of different data rates on variable bandwidth channels (flexpaths) with variable modulation formats [1, 2]. Each flexpath can utilize high spectral efficiency if the QoT for the required end-to-end transmission is satisfactory even with the increased sensitivity to physical layer impairments (PLIs). Failure to meet the required QoT would trigger protection or restoration. Traditional WDM networks perform restoration via the typical method of lightpath rerouting (LR) when the QoT of a particular connection degrades below an acceptable threshold. Due to the ITU-T grid spacing, this process can be spectrally inefficient. Further, rerouting many simultaneously-affected connections on an impaired span can result in a surge of high blocking probability and of load leap on the restoration links. Flexible bandwidth networking can achieve real-time impairment-aware networking by performance monitoring and modulation format switching (MFS) [2, 3]. In this paper, we propose and experimentally demonstrate an adaptive combinational QoT restoration scheme (ACQoTRe), which jointly uses both LR and MFS methods to combat impairments and coordinate the restoration of simultaneously-impaired connections within the common risk group on the same physical link. Simulation results show significant decrease in blocking probability (by more than 2x) and reduces the load leap in the bypass path down to 25% compared to rerouting only. The flexible bandwidth network testbed with an adaptive control plane successfully demonstrates the ACQoTRe algorithm.

2. Networking Scenario and Hybrid Objective Algorithm

The objective of the ACQoTRe is to **a)** re-establish QoT-degraded flexpaths (*e.g.* FP A and FP B in Fig. 2) by jointly exploiting MFS and rerouting while **b)** using the least amount of spectral consumption, *i.e.*, bypass load leap in this case. Here we perform the "hybrid-objective heuristic" which can adaptively use the better objective to guide the selection of restoration paths when the network is in different condition. The hybrid penalty to be minimized consists of two parts: **a)** the *spectral consumption* (*SC*) penalty, which is the additional *SC* of this solution compared with the least-*SC* one for the same demand and **b)** the *interference* penalty, which represents how this solution would interfere other demands and is used to avoid creating paths which would render many other restoration paths infeasible. A simple but effective way for defining the interference function is shown as below:

$$\textit{Interference of Solution } \boldsymbol{i} = \frac{\textit{bandwidth of Sol.}\boldsymbol{i}}{\textit{(1-NU)}\cdot\textit{fiber capacity}}\cdot\left(\begin{array}{l}\textit{number of other demands'}\\ \textit{solutions touched by Sol.}\boldsymbol{i}\end{array}\right)$$

$$\textit{hybrid penalty} = \textit{SC penalty} + \mu\cdot\textit{Interference}, \quad (\mu \textit{ is a constant})$$

The auto-tuning feedback for adaptive control is made possible by the denominator, which increases the weight of interference penalty in the gross penalty as network utilization (*NU*) grows high. Preliminary evaluation of ACQoTRe in comparison with the conventional rerouting based restoration scheme using the COST266 Pan-European network topology indicates that ACQoTRe (with $\boldsymbol{\mu}$=4) significantly reduces *BP* (by more than 2x) compared with rerouting. Also, it greatly reduces the bypass load leap of restoration (as low as 25% of that of rerouting), since the spectrum of the impaired span is efficiently utilized rather than abandoned, which in return helps reduce the *BP*.

Fig.1 (a) and (c) show the four-node topology of the flexible bandwidth network used for the experimental demonstration. The upper part of Fig. 1(b) and (d) show the original bandwidth utilization on link b, c, d, and e. The OSNR on link b suffers from OSNR degradation over time. Each node includes a performance monitoring module

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to notify the network control plane when impairments occur. After the OSNR on link b degrades, node 4 informs the control plane of the problem, and the control plane runs hybrid objective algorithm and decides on how to jointly perform MFS and LR while minimizing SC and interference penalty. In **Case 1** of Fig.**1**, Flexpath **B** is rerouted and its spectrum released on the impaired span is used for MFS of flexpath **A**. Similarly, in **Case 2**, Flexpath **A** is rerouted and flexpath **B**, which would otherwise be blocked, lowers its modulation format over A’s legacy spectrum to retain an acceptable level of QoT.

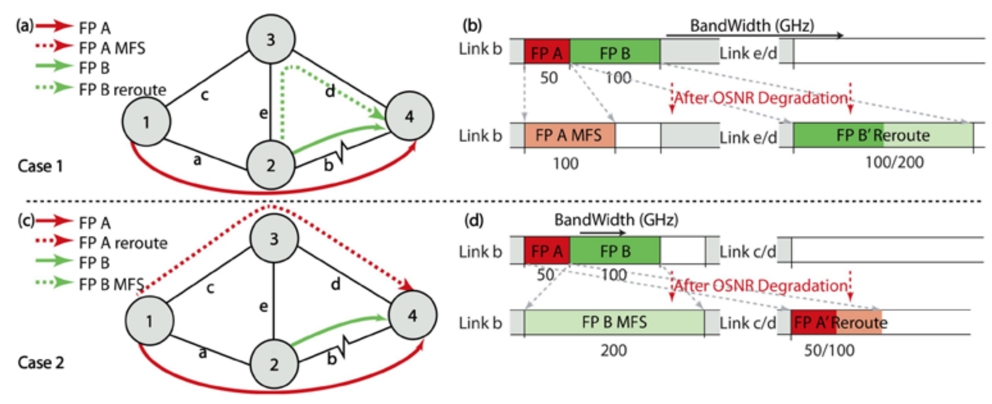

Fig. 1. (a) ACQoTRe case 1. Solid red and green lines: FP A and FP B before OSNR impairment. Dashed green line: Rerouted FP B. (b) Spectrum utilization on Link b before OSNR impairment (upper) and Link b,e,d after OSNR impairment (lower). (c) ACQoTRe case 2. Solid red and green lines: FP A and FP B before OSNR impairment. Dashed red line: Rerouted FP A. (d) Spectrum utilization on Link b before OSNR impairment (upper) and Link b, c, d after OSNR impairment (lower).

3. Flexible Bandwidth Network Testbed Demonstration with Real-Time Impairment Aware Control Plane

Fig. 2(a) and (b) show the experiment arrangement for the four-node network testbed explained in Fig. 1. Two separate lasers with 5GHz spacing generate 2 decorrelated 4.74 GBaud/s subcarriers with In-phase and Quadrature-phase (IQ) modulators. The IQ modulators are driven by electrical arbitrary waveform generator, which can be controlled by control plane to switch from 4.74GBaud BPSK and QPSK waveform. Two subcarriers are coupled with 260MHz guard band in a Nyquist WDM fashion and enter a 40 line spectrum replicator with 10GHz spacing that produces replica of 10 GHz spectrum 40 times to form a 400GHz broadband multicarrier spectrum shown in Fig. 2 (c). The spectrum replicator is effectively optical frequency combs (OFC) with 10 GHz spacing generated by strong modulation of a cw laser[4]. The spectrum is then split and used as Tx1 and Tx2 in Fig.2 (b). Hence, the ingress nodes can use Wavelength Selective Switch (WSS) to truncate any segment of the 400GHz spectrum from the two transmitters to serve as the data for the flexpath. Link a and b are each 25 km, whereas link c, d, and e are 50 km to emulate the typical case where rerouted lightpaths are longer than the primary paths. At receiver in node 4, digital coherent receiver detects the full field (both amplitude and phase) information of the signal be tuning the reference laser at the wavelength of the desired subcarrier.

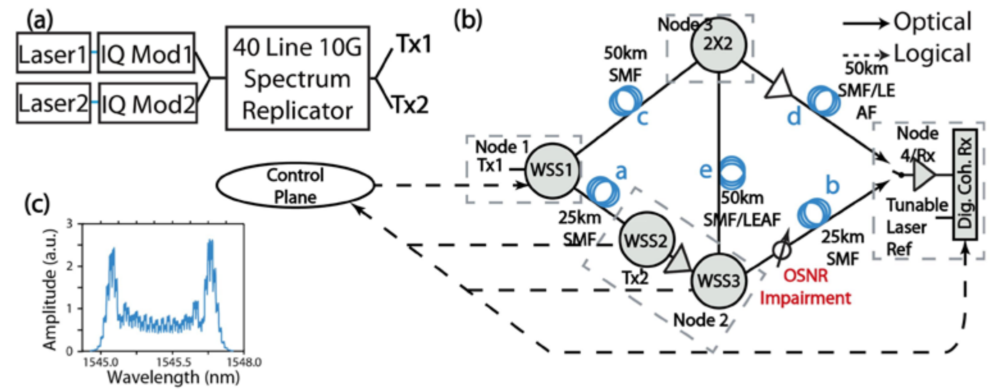

Fig. 2. (a) Transmitter (b) network testbed (c) 400 GHzspectrum at the output of spectrum replicator

Fig. 3 shows the BER results of all the related FPs (A, A reroute, B, B reroute) in the above networking scenario. A 200GHz super channel with 40 5GHz subcarriers is transmitted through the path being characterized. 3 subcarriers across the total spectrum are sampled. Fig. 3 (b) and (d) show a significant BER floor for QPSK format at around 10^{-3}. This information is stored and maintained in the control plane to keep track of the QoT of each modulation format on each path. In this case, rerouted path of FP A and B cannot support QPSK transmission, and BPSK is utilized upon rerouting.

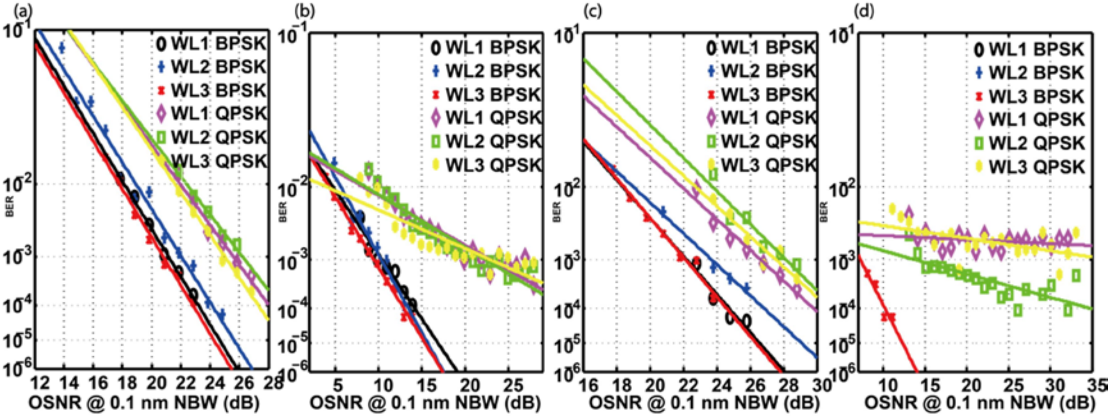

Fig. 3. BER curves for (a) FP A (b) FP A reroute (c) FP B (d) FP B reroute with BPSK and QPSK format. WL1: 1546.0863 nm, WL2: 1546.7200 nm, WL3: 1547.2769 nm .

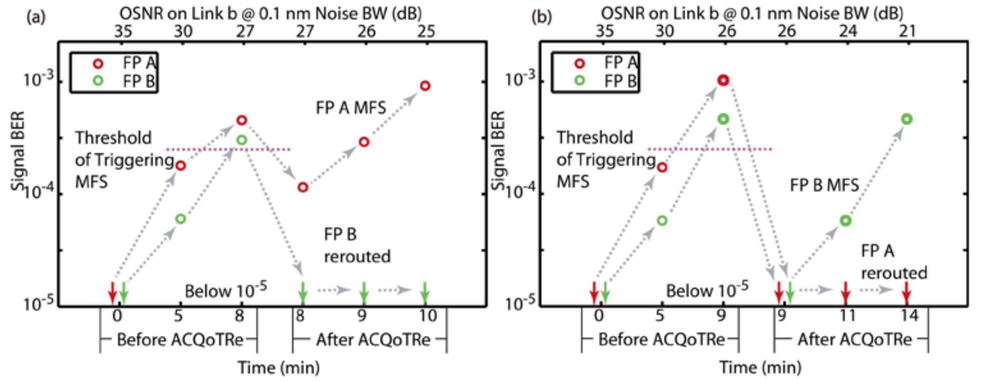

Fig. 4. Real time BER measurement for ACQoTRe equipped 4 node network for (a) case 1 and (b)

Fig. 4 shows real time BER variation on the ACQoTRe network testbed. OSNR on link b is reduced by 1dB every minute. Both BERs on FP A and B starts off with error free transmission (below 10^{-6} due to limited number of symbols measured). When OSNR downgrades, BERs of both paths gradually go up. When BERs of both flexpaths exceed a pre-set BER threshold of 2×10^{-4}, node 4 informs control plane of the OSNR downgrade. The network control plane reaches decisions on rerouting and MFS based on existing network condition, and communicates with eAWG to switch the modulation format and the transmitters, and reconfigure WSS1-3 on ingress nodes for rerouting and bandwidth expansion. After MFS and rerouting, both BERs drop, and QoT of both flexpaths are increased. When the OSNR degradation continues on link b after ACQoTRe, the flexpath undergoing MFS shows an increasing BER over time, while the rerouted path shows a constantly error-free transmission.

4. Conclusion

We demonstrate, for the first time to our knowledge, spectrally efficient QoT restoration method combining LR and MFS methods to combat impairments and to coordinate the restoration of simultaneously-impaired connections within the common risk group. The experimental testbed showed successful restoration by triggering both MFS and LR as OSNR degraded with time.

5. Reference

[1] B. o. Kozicki, H. Takara, Y. Tsukishima, T. Yoshimatsu, K. Yonenaga, and M. Jinno, "Experimental demonstration of spectrum-sliced elastic optical path network (SLICE)," *Opt. Express,* vol. 18, pp. 22105-22118, 2010.

[2] D. J. Geisler, R. Proietti, Y. Yin, R. P. Scott, X. Cai, N. K. Fontaine, L. Paraschis, O. Gerstel, and S. J. B. Yoo, "Experimental demonstration of flexible bandwidth networking with real-time impairment awareness," *Opt. Express,* vol. 19, pp. B736-B745, 2011.

[3] D. J. Geisler, R. Proietti, Y. Yawei, R. P. Scott, C. Xinran, N. K. Fontaine, L. Paraschis, O. Gerstel, and S. J. B. Yoo, "The first testbed demonstration of a flexible bandwidth network with a real-time adaptive control plane," in *Optical Communication (ECOC), 2011 37th European Conference and Exhibition on*, 2011, pp. 1-3.

[4] T. Sakamoto, T. Kawanishi, and M. Izutsu, "Asymptotic formalism for ultraflat optical frequency comb generation using a Mach-Zehnder modulator," *Opt. Lett.,* vol. 32, pp. 1515-1517, 2007.

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