Real-time monitoring of the impact of cascaded wavelength-selective switches in digital coherent receivers

Real-Time Monitoring of the Impact of Cascaded Wavelength-Selective Switches in Digital Coherent Receivers

Dario Pilori[1,4], Antonello Nespola[2], Fabrizio Forghieri[3], Stefano Piciaccia[3] and Gabriella Bosco[1]

[1]DET, Politecnico di Torino, C.so Duca degli Abruzzi 24, 10129 Torino, Italy, gabriella.bosco@polito.it
[2] LINKS Foundation, Via Pier Carlo Boggio 61, 10138 Torino, Italy, antonino.nespola@linksfoundation.com
[3]Cisco Photonics Italy S.r.l., via Santa Maria Molgora 48/C, 20871 Vimercate, Italy, fforghie@cisco.com
[4]INRiM, Strada delle Cacce 91, 10135 Torino, Italy, d.pilori@inrim.it

Abstract: A simple real-time monitoring algorithm for the impact of cascaded WSSs in elastic optical networks, which exploits the information available in a digital coherent receiver, is proposed and demonstrated through both numerical simulations and experiments.

1. Introduction

In flexible grid networks, signals pass through multiple reconfigurable optical add-drop multiplexers (ROADMs), which employ wavelength-selective switches (WSSs) and provide reconfigurable optical routing with dynamic bandwidth allocation [1]. In order to fully exploit all the available capacity for each specific link in a meshed optical network, the optical transceivers need to adapt the modulation format to the link conditions. It was shown in [2,3] that bandwidth-variable transceivers (BVTs) with flexible symbol rate and modulation format enable the optimization of the capacity by balancing the optical filtering tolerance and the required signal-to-noise ratio (SNR). In order to achieve this, the cascaded WSS filtering penalty needs to be constantly monitored. In this work, we explore the feasibility and accuracy of a real-time monitoring technique of the filtering penalty due to cascaded WSSs, using only the information which is available in the digital receiver. The data provided by the monitoring algorithm can be exploited by the BVTs to select the optimum symbol rate, enabling a full exploitation of the available bandwidth.

2. Theory and simulations

In [4,5] it was shown that the taps of the receiver adaptive equalizer can be used to monitor several propagation effects, such as chromatic dispersion, polarization-mode dispersion and polarization-dependent losses. In addition to this, the transfer function $H_{eq}(f)$ of the equalizer can be used to monitor the impact of the bandwidth limitations, since it is inversely proportional to the transfer function $H_{WSS}(f)$ of the cascaded WSSs. In order to achieve this, we propose to use a synthetic parameter that can be easily extracted from the equalizer transfer function: the peak-to-center ratio (PTC). The PTC is defined as the ratio between the peak of the transfer function of the equalizer, which is located at the edge of the signal bandwidth, and its center (DC frequency). The height of the peaks at the sides of the equalizer transfer function increases when the bandwidth limitations become stronger and thus the PTC parameter can be used to monitor the impact of the WSSs filtering effects on the transmitted signal.

In the numerical simulations, a 32 Gbaud 16-QAM signal was generated and shaped with a root-raised cosine (RRC) filter with 20% roll-off. The signal then went through N_{stg} stages, each of which emulated a WSS. Each stage was composed of a 4^{th}-order Super-Gaussian band-pass filter, followed by ASE noise loading. At the receiver, a 50-tap LMS adaptive equalizer recovered the original signal. The performance was assessed in terms of signal-to-noise ratio (SNR), directly measured on the equalized constellation. The combined filter bandwidth of the cascaded WSSs was varied between 25 and 37 GHz in steps of 1 GHz. The simulations were run over 1000 Monte-Carlo realizations of the filters, randomly varying the center frequency and the 3-dB bandwidth of each filter around their nominal values.

Fig. 1a shows a set of the numerical results, in terms of SNR (measured on the equalized constellation) as a function of the PTC, over all 1000 different filter realizations for each bandwidth, for a total of 15,000 points. For those results, the number of stages was set to 4, and the total power of ASE noise (hence, the OSNR) was kept fixed. Hence, any SNR penalty was due only to filtering. In can be seen that the relationship between PTC and SNR is well approximated by a parabola. The solid line in Fig. 1a has been obtained by a quadratic fit on the first 2,000 simulation points. The estimation error shown in the lowest part of Fig. 1a has been evaluated considering the remaining 13,000 points, evaluating the difference between the real SNR and the one inferred using the quadratic fit. We noticed that the SNR vs. PTC curve shows a very weak dependence on the modulation format, the system OSNR and the shape of the filters (results not shown here due to space constraints). It is instead dependent on the number of stages, as shown in Fig. 1b in terms of SNR penalty vs. PTC. However, it can be observed that, for a number of stages higher than 4, all the curves

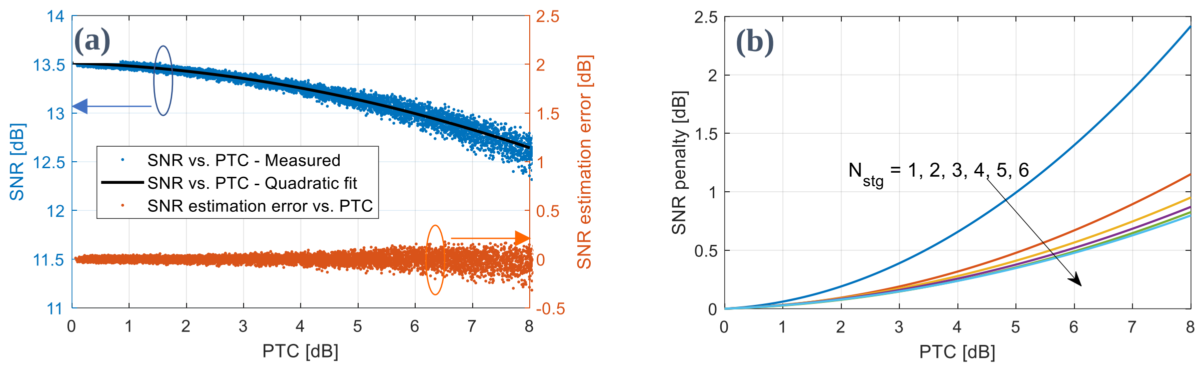

Fig. 1 (a): Results of the Monte-Carlo simulations as SNR as a function of the PTC. Number of stages: N_{stg} = 4. (b): Parabolic fit of the SNR penalty as a function of the PTC with different number of stages (each emulating a WSS).

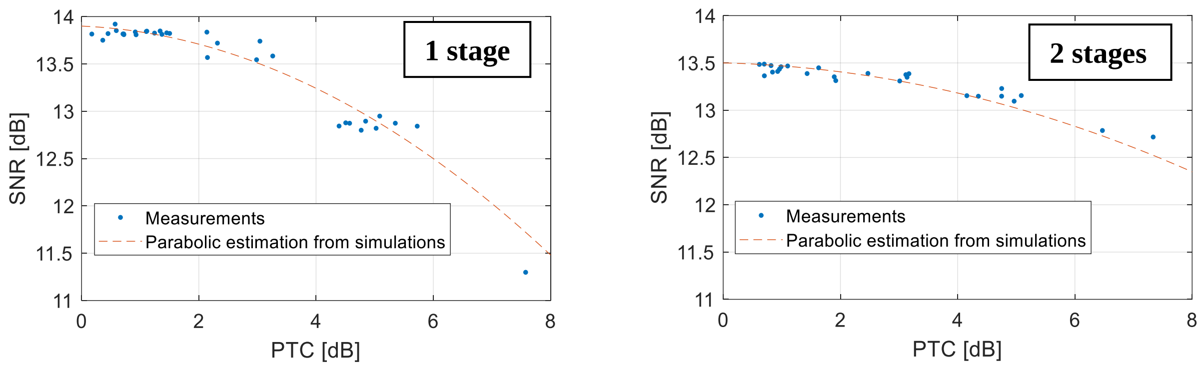

Fig. 2 Experimental results as SNR as a function of the PTC (blue dots). Results are compared with the parabolic estimation obtained from the Monte-Carlo simulations (dashed red line).

start to converge. This means that, in a realistic situation with several WSSs, the SNR-PTC relationship does not strongly depend on the actual number of WSSs, which could be difficult to be estimated, and a single curve can be used to estimate the impact of filtering and to optimize the symbol rate of the transmitted signal.

3. Experimental results

In the experiment, an RRC-shaped 16-QAM digital signal was converted into a 32 Gbaud analog optical signal by means of a 92 Gsample/s digital-to-analog converter (DAC), an external cavity laser (ECL) with <100 kHz linewidth and a dual-polarization IQ modulator. Two waveshapers (Finisar 1000E) were used to mimic the filtering narrowing effect due to different WSSs distributed in the elastic optical network. At the receiver, the filtered channel was mixed with a local oscillator (ECL with <100 kHz linewidth), coherently detected and sampled by a 200 Gsa/s real-time oscilloscope. The same DSP used in simulation was applied to the detected samples. The experimental results are shown in Fig. 2. Each dot corresponds to a different nominal value of the filter bandwidth (varied from 20 to 50 GHz, in steps of 1 GHz). The experimental measurements are compared with the analytical curves (red dashed lines) estimated from the Monte-Carlo simulations described in Section 2 (see Fig. 1b). Despite of some random fluctuations of the actual value of the filters bandwidth used in the experimental measurements, caused by the limited resolution of the waveshapers, the semi-analytical parabolic estimations well fit the experimental results, demonstrating that the PTC is a reliable metric for the estimation of the penalties due to optical filtering.

This work was supported by Cisco Systems through an SRA and by PhotoNext Center of Politecnico di Torino.

4. References

[1] O. Gerstel, et al., “Elastic Optical Networking: A New Dawn for the Optical Layer?” IEEE Comm. Mag., **50**(2), s12-s20 (2012)

[2] X. Zhou et al., “On the capacity improvement achieved by bandwidth-variable transceivers in meshed optical networks with cascaded ROADMs,” Opet. Exp., 25(5), 4773- 4782 (2017).

[3] Z. Dong, “Optical Performance Monitoring: A Review of Current and Future Technologies,” J. Lightw. Tehnol.,**34**(2), 525-543 (2016)

[4] F.N. Hauske et al., “Optical Performance Monitoring in Digital Coherent Receivers,” J. Lightw. Technol., **27**(16), 3623-3631 (2009)

[5] G. Bosco et al., “Joint DGD, PDL and Chromatic Dispersion Estimation in Ultra-Long-Haul WDM Transmission Experiments with Coherent Receivers”, ECOC 2010, Torino (Italy), paper Th. 10.A.2.