Tunable ROADM with Crosstalk Reduction for Overlapped 20-25 Gbaud QPSK WDM Channels using Wave Mixing

M. Ziyadi[(1)], A. Mohajerin-Ariaei[(1)], Y. Cao[(1)], A. Almaiman[(1)], C. Bao[(1)], F. Alishahi[(1)], A. Fallahpour[(1)], P. Liao[(1)], Asher J. Willner[(1)], B. Shamee[(1)], S. R. Wilkinson[(2)], L. Paraschis[(3)], M. Tur[(4)], C. Langrock[(5)], M. M. Fejer[(5)], J. D. Touch[(6)], and A. E. Willner[(1)]

1) Ming Hsieh Department of Electrical Engineering, University of Southern California, 3740 McClintock Ave, Los Angeles, CA 90089, USA
2) Raytheon Company, Los Angeles, CA, USA
3) Cisco Systems, 170 W. Tasman Drive, San Jose, CA 95134, USA
4) School of Electrical Engineering, Tel Aviv University, Ramat Aviv 69978, Israel
5) Edward L. Ginzton Laboratory, 348 Via Pueblo Mall, Stanford University, Stanford, CA 94305, USA
6) Information Sciences Institute, University of Southern California, 4676 Admiralty Way, Marina del Rey, CA, 90292, USA
ziyadi@usc.edu

Abstract: We experimentally demonstrate a tunable simultaneous ROADM with crosstalk reduction using optical nonlinear elements in spectrally overlapped 20-25 Gbaud QPSK WDM channels. OSNR gain of 5 dB shows the effectiveness of the approach.

OCIS codes: (060.2360) Fiber optics links and subsystems; (190.4223) Nonlinear Wave Mixing.

1. Introduction

Many optical communication networks view the available wavelength spectrum as a valuable and scarce resource [1]. In a wavelength-division-multiplexed (WDM) system, the guard-band between wavelength channels represents "wasted" spectrum, and reducing the guard-band can increase the network spectral efficiency [2]. One approach is to decrease the guard-band to the point at which the various WDM channels significantly overlap in their spectra [3-5]. There have been reports of reducing the crosstalk that is induced when recovering overlapped channels by detecting all the channels and implementing electronic digital signal processing (DSP) [3-5]. The problem of overlapped channels becomes even more difficult when considering a WDM reconfigurable optical add/drop multiplexer (ROADM). In general, a ROADM uses optical filter to drop the channel without any crosstalk mitigation, and the approach of using DSP and recovering all data channels is typically not possible.

In this paper, we demonstrate tunable ROADM with crosstalk reduction for overlapped 20-25 Gbaud QPSK WDM channels. In our proposed scheme, we use optical nonlinear elements to generate the copy of the shared spectrum and add it to the overlapped channels with 180 degree phase difference to mitigate the crosstalk. We experimentally implement the simultaneous ROADM with crosstalk mitigation to drop any combination of channels in overlapped 20-25 Gbaud QPSK WDM channels. OSNR gain of more than 5 dB is measured for different channel spacing and different baud rates. The improved signal constellation and Q factor confirm the effectiveness of the proposed method.

2. Concept

Existing deployed ROADMs are optical filters based on wavelength-selective-switch that do not mitigate the crosstalk between channels in the overlapped and spectrum shared system (Fig. 1(a)). Moreover, dropping the channels and adding new ones will increase the crosstalk. Exploring new add/drop techniques can potentially help mitigate this crosstalk. Our proposed scheme for the channel selection of overlapped channels is based on $\chi^{(2)}$ nonlinear processes in a set of PPLN waveguides (see Fig. 1(b)). In this figure, first, the channels 1, 2, …,7 along with a CW pump laser are sent into a PPLN waveguide to generate the conjugate copies via nonlinear processes of SHG and DFG. A programmable filter is used to select the desired channels and adjust their amplitudes and phases. Fig. 1(b) shows the scheme to drop channels 2, 5 and simultaneously mitigate the crosstalk on these channels as implemented on port 2 of the programmable filter. Also, we want to mitigate the crosstalk on other channels from channels 2, 5, as

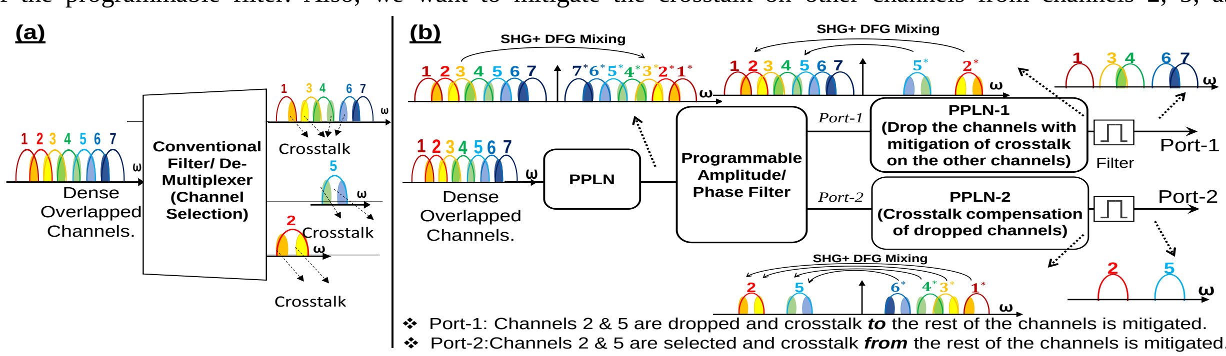

Fig. 1: (a) Existing deployed channel selection using filter/de-multiplexer which **does not mitigate the crosstalk.** (b) Conceptual diagram of the proposed ROADM, *i.e.*, channel selection, of overlapped channels **simultaneous with crosstalk mitigation**

implemented on port 1. In port 1, we select all the channels and the conjugates of the dropped channels and send all of them and the original pump into another PPLN to map the conjugate of the dropped channels onto the original channels with a 180-degree phase shift to mitigate the crosstalk. In other words, we could mitigate the crosstalk by subtracting the shared spectrum. In another port and PPLN, we drop the desired channels 2 and 5, and mitigate the crosstalk on these channels. The approach is data format transparent, and can be tuned to drop any desired channels.

3. Experimental Setup

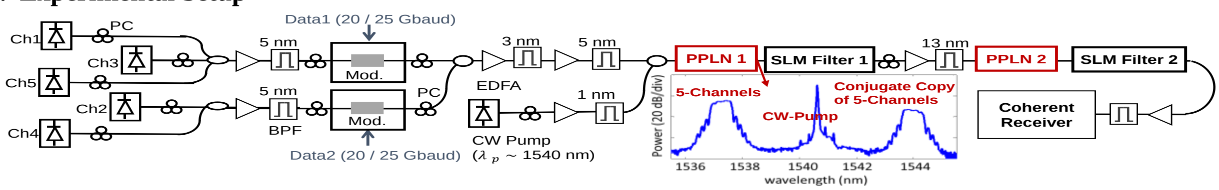

Fig. 2. Experimental setup. BPF: Band Pass Filter, PC: Polarization Controller, EDFA: Erbium-Doped Fiber Amplifier

Fig. 2 shows the experimental setup of 5 overlapped channels with shared spectrum. First, we modulate three channels of 1, 3, and 5 in one modulator and other two channels of 2 and 4 in another one with (20/25 Gbaud) 2^{31}-1 PRBS QPSK data. These channels with the uniform channel spacing (Δf<baud-rate) are sent into a PPLN waveguide, along with a CW pump at the 1540 nm, to generate conjugate copies of the channels (shown in the spectrum). Then, all the signals are sent into a SLM filter for channel selection and amplitude/phase adjustment. Based on the dropped channels, we select desired signals and copies inside SLM-1 and send them to the second PPLN. In this experiment, we use one PPLN for the second stage to implement both experiments of port-1 and port-2 in Fig. 1(b). The QPM of the PPLN-2 is tuned to be the same as PPLN-1 at 1540 nm. Finally, the crosstalk mitigated channels are filtered using another SLM to clean the spectrum and the output channels are sent to the coherent receiver to be analyzed.

4. Results and Discussion

Fig. 3 shows the spectrum of the PPLN-2 and SLM-2 outputs for both port 1 and port 2 in the concept figure for 20 Gbaud signals with channel spacing of Δf =17.5 GHz and we want to drop channels 2 and 4. The experimental results show constellation quality improvement for all the channels due to the crosstalk mitigation. Q-factor measurement shows more than 4 dB OSNR improvement at FEC threshold for the all the channels.

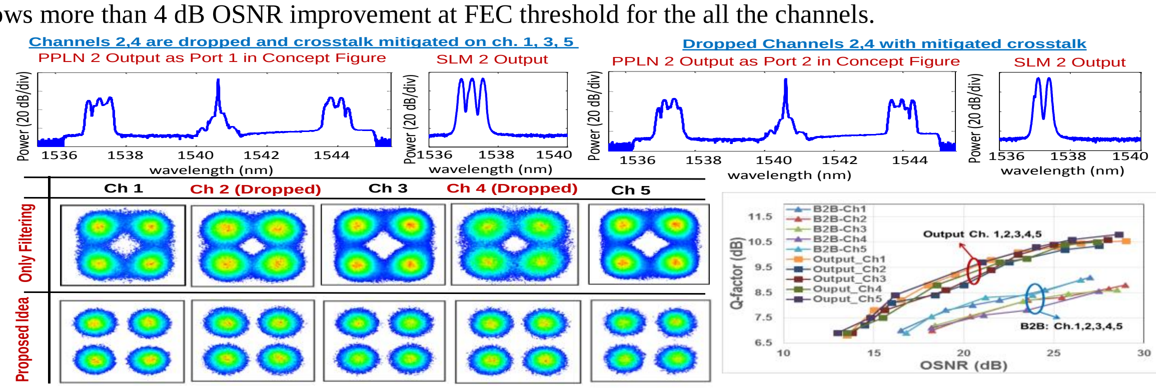

Fig. 3. Experimental results on **5 overlapped channels carrying 20 Gbaud QPSK signals with 17.5 GHz spacing.** Channels 2 and 4 are dropped simultaneous with crosstalk mitigation. Optical spectrums and constellation of the channels and Q-factor measurements are shown.

We also implement the scheme for 25 Gbaud system with channel spacing of 22.5 GHz and the results are shown in Fig. 4. In this figure, only channel 3 is dropped and other channels are on the line. ~4.4 dB and ~3.5 dB OSNR improvement for channel 3 and channels 2, 4 are measured, respectively.

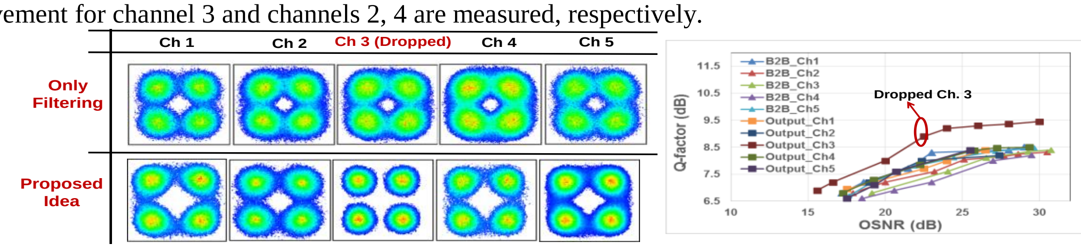

Fig. 4. Experimental results on **5 overlapped channels carrying 25 Gbaud QPSK signals with 22.5 GHz spacing.** Channel-3 is dropped simultaneous with crosstalk mitigation. Crosstalk effects on channels 2 and 4 are also mitigated. Constellations and Q-factor are shown.

Acknowledgements: The authors would like to thank the support of CIAN, Huawei, NIST, and NSF.

5. References

[1] T. Ohara, et al., JLT, vol. 24, no. 6, pp. 2311–2317, (2006)
[2] X. Liu, et al Opt. Exp., vol. 19, pp. B958–B964, (2011)
[3] F. Hamaoka et al., Proc. ECOC, Mo.3.5.4, Cannes (2014).
[4] J. Pan et al., JLT, 30, no. 24, 3993-3999 (2012).
[5] N. Kaneda et al., Proc. ECOC, Th.2.C.1, London (2013).