Optical Mitigation of Inter-Channel Crosstalk for Multiple Spectrally Overlapped 40-Gbit/s QPSK WDM Channels using Nonlinear Wave Mixing

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Abstract: Using an all-optical method and without multi-channel detection, the inter-channel interferences of overlapped WDM data channels are mitigated simultaneously. We experimentally demonstrate performance improvement for 20-Gbaud QPSK overlapped channels under different channel spacing. The scheme results in near 4dB OSNR gain for QPSK data channels at a BER of 10^{-3}.

OCIS codes: (060.2360) Fiber optics links and subsystems; (070.4340) Nonlinear optical signal processing

1. Introduction

It is considered fairly important to maximize the efficient utilization of the available spectrum [1,2]. One approach to increasing the spectral efficiency in terms of bits/sec/Hz is to spectrally overlap the data channels, which produces increased inter-channel crosstalk [3,4].

This crosstalk can be mitigated by electronic means. In a multi-channel wavelength-division-multiplexed (WDM) system, each wavelength channel is individually recovered, and the information about a data channel's spectrally close adjacent channels is used by a digital signal processing (DSP) algorithm to reduce the crosstalk [5-8].

Alternatively, inter-channel crosstalk can be mitigated using optical techniques. Previously, optical multicasting, complex tailoring, and multiplexing was used to reduce crosstalk for each individual channel for data recovery [9,10] It might be desirable to change this approach such that multiple, spectrally overlapped WDM channels can be recovered simultaneously with reduced crosstalk in concurrent optical nonlinear processes.

In this paper, we demonstrate optical mitigation of inter-channel crosstalk for multiple spectrally overlapped 40-Gbit/s quadrature-phase-shift-keyed (QPSK) WDM channels using nonlinear wave mixing without multi-channel detection and channel spacing estimation. The optical ICI mitigation is performed by mixing the signals with the conjugate copies of neighboring channels and their delay variants. In this method, the conjugate signal copies are separated in two sets of even and odd channels, and the amplitude, phase, and delays of signals in each set are adjusted. The signals are mixed with the corresponding neighbors in either even or odd sets to mitigate the ICIs. The system performance is experimentally evaluated for 20Gbaud QPSK overlapped data channels under different channel spacing conditions. The improved signal constellations and bit error rates demonstrate the effectiveness of this approach. Near 4dB OSNR gain is achieved for QPSK data channels at a BER of 10^{-3}.

2. Concept

Figure 1 shows the conceptual block diagram of the proposed scheme for optical ICI mitigation of seven overlapped data channels. The incoming overlapped channels along with a CW pump laser are injected into a periodically poled lithium niobate (PPLN) waveguide. Inside the PPLN, the conjugate copies of the signals are generated through the cascaded nonlinear processes of second harmonic generation (SHG) and difference frequency generation (DFG). Next, the signals are sent through an optical programmable filter based on liquid crystal on silicon (LCoS) technology and are separated at the ports 1 and 2 of the LCoS filter, respectively (Fig. 1(a)). The signals at each port is then directed to separate optical ICI compensation modules. The output of each module is filtered out to render the ICI mitigated desired channels. Figure 1 (b) shows the conceptual block diagram of the embedded optical ICI compensation module of Fig. 1(a) for ICI mitigation of even channels as an example. This module is composed of two PPLNs and a programmable LCoS amplitude and phase filter. To mitigate the ICI of even (odd) channels, the odd (even) channels from the conjugate copies are filtered and the amplitude and phase of each conjugate copy is adjusted in the first LCoS filter. The signals and the selected conjugate copies are sent through the second PPLN waveguide where each target channel is mixed with neighboring cross talk channels. By mixing the target channels with amplitude/phase-adjusted cross talk channels, a moderate level of ICI mitigation can be obtained. The signals and their conjugates are then sent to another LCoS filter where new complex coefficients and delays are properly applied to the conjugate copies of the crosstalk signals. The target signals and their corresponding cross talk signals are mixed coherently in another PPLN waveguide where the ICI of the target channels are further mitigated through the cascaded nonlinear processes of SHG-DFG. As an example, suppose signal S_2 is a target signal, this signal is mixed with its neighboring channels and their delay variants to reduce the crosstalk of the channel, i.e., the signal is coherently added to $c_1.S_1$, $c_3.S_3$, $c_1'.S_1(t-\tau_1)$ and $c_3'.S_3(t-\tau_3)$ where c_1, c_3 ,c_1', and c_3' are the appropriate complex coefficients adjusted in LCoS filter. Note that since the pump laser is preserved through the nonlinear processes, the desired signal and the adjacent interfering signals are added with the same channel spacing as of the overlapped channels. Therefore, accurate channel spacing estimation is unnecessary in this method.

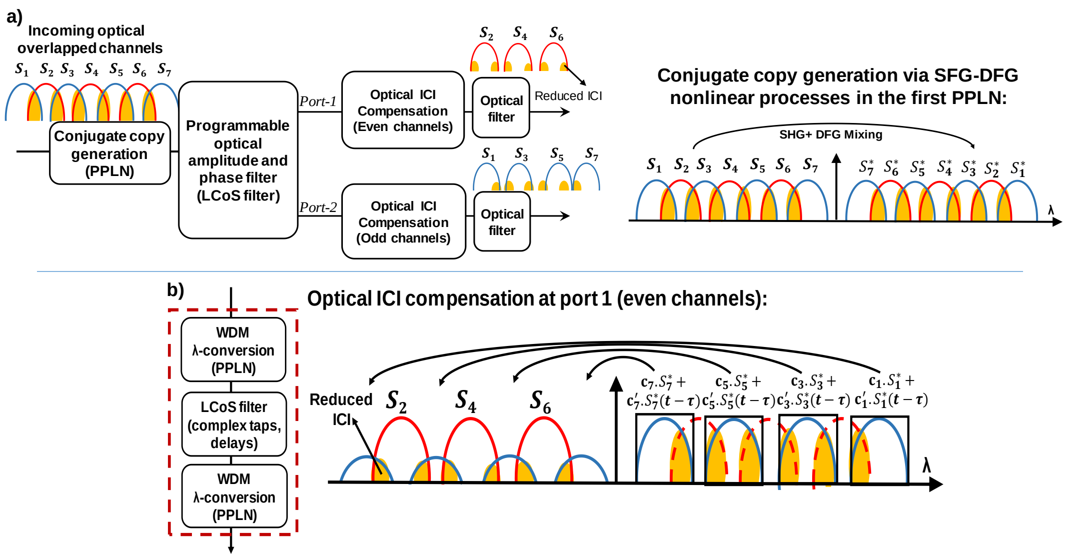

Fig. 1. (a) Conceptual diagram of the proposed optical inter-channel interference (ICI) mitigation method. The signal conjugate copies are generated in the first PPLN waveguide. In an optical programmable filter, the conjugate copies of data channels are separated in two sets of even and odd channels and are adjusted with desired complex taps. The original signals with the even and odd sets of conjugate copies are directed to optical ICI compensation modules. (b) Conceptual diagram of the optical ICI compensation module for even channels. This module is composed of two PPLNs and a LCoS filter for amplitude, phase and delay adjustments. The target signals are mixed with neighboring channels and their delayed variants to mitigate the ICI.

3. Experimental Setup

Figure 2 shows the experimental setup of the optical ICI mitigation method for seven overlapped channels with channel spacing Δf. Odd and even channels are modulated with independent QPSK data in separate Mach Zehnder modulators. All channels along with a CW pump laser at 1540 nm are amplified and then sent into a PPLN waveguide to generate the conjugate copies.

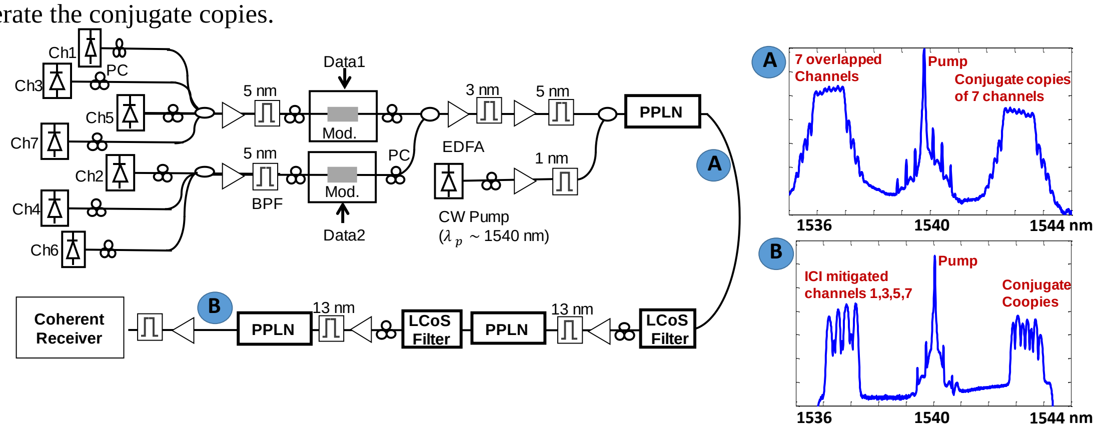

Fig. 2. (a) Experimental setup. PC: polarization Controller, PPLN: periodically poled lithium niobate, LCoS: liquid crystal on silicon, (b) optical spectra of conjugate copies of 20 Gbaud overlapped QPSK signals(A) and ICI mitigated channels 1,3,5 and 7 (odd channels) after the last nonlinear stage (B).

The quasi-phase matching (QPM) wavelength of PPLN is temperature-tuned to the CW pump wavelength. The signals, including the pump, are sent into a spatial light modulator (SLM) filter based on LCoS technology for channel selection and amplitude/phase adjustment. In the LCoS, the conjugate copies of the neighboring channels of each target channel are selected. The selected and adjusted signals along with the pump are sent to a second PPLN with the same QPM as the first PPLN. Through the second PPLN, each target channel is mixed with properly amplitude and phase adjusted cross talk signals. The signals are sent to another LCoS filter where complex coefficients and delays are applied on the signals. The signals and the pump are injected into another PPLN waveguide where the target channels and the crosstalk channels with complex coefficients and delays are mixed to mitigate the ICI of the target channels. The channels with reduced ICI are filtered and sent to coherent receiver to detect the constellation diagrams and measure the BER of the signals. In this method, there is no need to estimate the amount of channel spacing Δf since the lasers are preserved from previous stages and the signals are mixed coherently with the exact channel spacing.

3. Results and Discussion

The performance of the system is assessed for overlapped channels of seven overlapped 20 Gbaud QPSK signals in different channel spacing of 17.5, 20, and 25 GHz. Figure 3 shows the constellation diagrams of channels 1, 3, and 6 with and without the ICI mitigation method. The ICI mitigation for the smaller channel spacing of 17.5 GHz is more significant than the channel spacing of 20 GHz. The ICI mitigation is insignificant when the channel spacing is larger than the baud rate of the signals, i.e., 25 GHz.

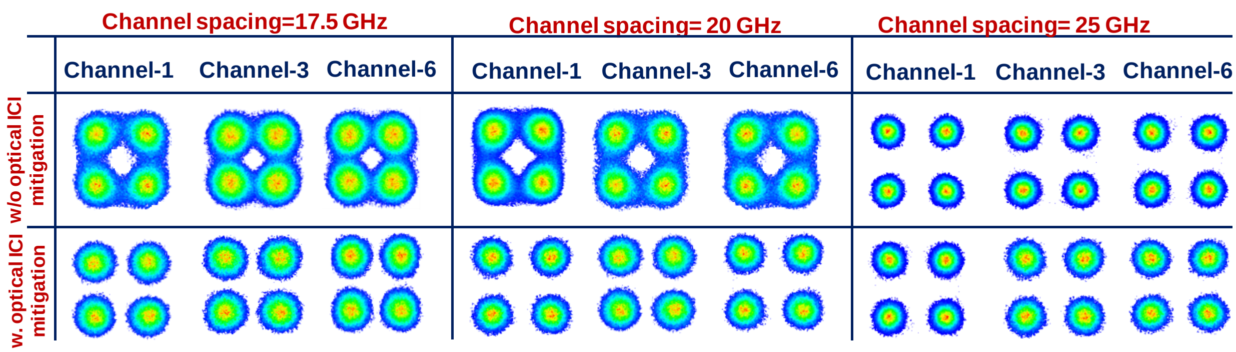

Fig. 3. Experimentally measured signal constellation diagrams of channels 1, 3, and 6 with(w.) and without(w/o) optical ICI mitigation method for 20 Gbaud overlapped QPSK signals and at channel spacings, Δf of 17.5 GHz, 20 GHz and 25 GHz.

Figures 4(a,b) shows the BER results for 20-Gbaud QPSK signals for channel spacings of 17.5 GHz and 20 GHz respectively. As it can be seen, the ICI mitigation results in lower BER at same OSNR values for both channel spacings of 17.5 GHz and 20 GHz. This scheme provides near 4dB OSNR gain for QPSK data channels at a BER of 10^{-3}.

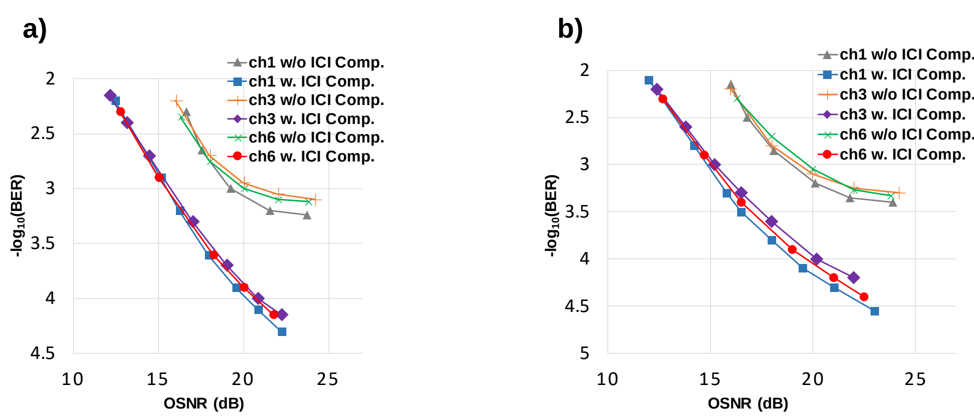

Fig. 4. BER measurements with(w.) and without(w/o) optical ICI compensation method for QPSK overlapped channels (1,3 and 6) and for different channel spacing conditions. (a) Δf =17.5 GHz (b) Δf = 20 GHz.

Acknowledgements

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

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