Demonstration of Tunable Mitigation of Interchannel Interference of Spectrally Overlapped 16-QAM/QPSK Data Channels using Wave Mixing of Delayed Copies

A. Mohajerin-Ariaei(1), M. Ziyadi(1), Y. Cao(1), A. Almaiman(1), F. Alishahi(1), A. Fallahpour(1), C. Bao(1), P. Liao(1), B. Shamee(1), J. Touch(2), M. Tur(3), C. Langrock(4), M. M. Fejer(4), 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) Information Sciences Institute, University of Southern California, 4676 Admiralty Way, Marina del Rey, CA, 90292, USA
3) School of Electrical Engineering, Tel Aviv University, Ramat Aviv 69978, Israel
4) Edward L. Ginzton Laboratory, 348 Via Pueblo Mall, Stanford University, Stanford, CA 94305, USA
mohajera@usc.edu

Abstract: A tunable all-optical inter-channel interference mitigation method is proposed for an overlapped channel system that avoids the need for multi-channel detection. We experimentally demonstrate the system performance improvement for 16QAM and QPSK overlapped channels for both 20/25 Gbaud data and under different channel spacing conditions.

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

1. Introduction

It is valuable to maximally utilize any available spectral bandwidth in an optical communication system [1,2]. One approach for increased spectral efficiency is to partially overlap the wavelength-division-multiplexed (WDM) channels in the spectral domain. This produces inter-channel interference (ICI), which should be mitigated in order to recover the transmitted data [3,4].

The ICI can be mitigated by: (i) recovering all the overlapped WDM channels, and (ii) using one receiver for each individual WDM channel. After detection, digital signal processing (DSP) algorithms in the electronic domain are used to mitigate the ICI [5-8].

Recently, there have been reports of using optical methods to mitigate the ICI without the above requirements of the electronic approach; such a function may be desirable when adding and dropping channels at intermediate ROADM locations [9]. In that approach, optical nonlinearities are used to generate the complex conjugate of the signal and mix with the signal itself to achieve ICI mitigation for quadrature-phase-shift-keyed (QPSK) data channels [9,10].

In this paper, we demonstrate the tunable mitigation of ICI of spectrally overlapped 16QAM/QPSK data channels by wave mixing of delayed copies. In this method, the ICI of the data channels are reduced without multi-channel detection and channel spacing estimation. Experiments using 16QAM and QPSK overlapped data channels with both 20Gbaud and 25Gbaud under different channel spacing conditions evaluate the performance of the method. Improved signal constellations and bit error rate results demonstrate the effectiveness of this approach.

2. Concept

Figure 1 shows the conceptual block diagram of the optical ICI compensation method. The input signals are two overlapped data channels with channel spacing Δf. Here, channel S_1 is a 16QAM signal and channel S_2 is a QPSK signal. The two overlapped signals along with three dummy pump laser and another laser as a CW pump are injected into a periodically poled lithium niobate (PPLN) waveguide to generate three copies of the overlapped channels via cascaded nonlinear processes of sum-frequency-generation (SHG) and difference-frequency-generation (DFG). All signals are sent into an optical programmable filter based on liquid crystal on silicon (LCoS) for filtering the desired signals and adjusting the amplitudes and phases. In more details, for ICI compensation of data channel S_1, the three generated copies of the overlapped channel in PPLN-1 are filtered in the LCoS to generate S_1, $c_1.S_2$, and $c_2.S_2(t-T)$, where c_1 and c_2 are the appropriate complex coefficients and T is the one symbol delay interval adjusted by the LCoS. The adjusted signals along with preserved the dummy pump lasers from PPLN-1 and a new pump laser P_2 are sent into a second PPLN waveguide. The signals $c_1.S_2$, and $c_2.S_2(t-T)$ are added coherently to approximate the crosstalk of channel S_1 which is caused by channel S_2. Finally, the estimated crosstalk signal is added to S_1 with 180-degree phase difference in PPLN-2 to mitigate the interference via the cascaded nonlinear processes of SFG-DFG. Note that since the dummy pump lasers are preserved from PPLN-1, the selected signals S_1, $c_1.S_2$, and $c_2.S_2(t-T)$ will be added with the exact channel spacing Δf and accurate estimation of Δf is unnecessary. A similar operation can be done in parallel for ICI mitigation of the other channel, S_2.

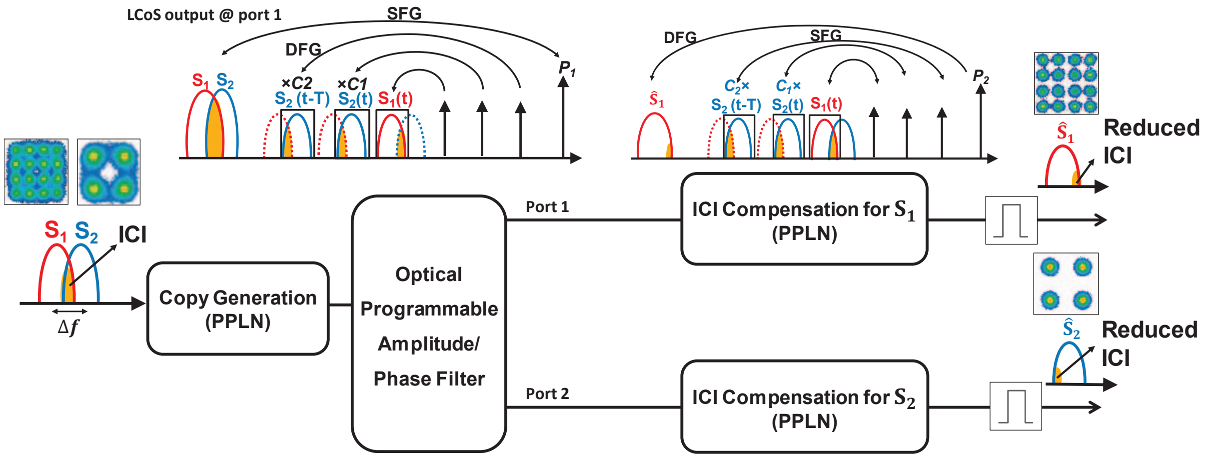

Fig. 1. Conceptual diagram of the proposed optical inter-channel interference (ICI) compensation method. The signal copies are generated in the first PPLN waveguide. In an optical programmable filter, the desired channels are selected and adjusted with desired complex taps and delays. In the following PPLN, the adjusted signals are added coherently to the desired data channel to mitigate the ICI.

3. Experimental Setup

Figure 2 shows the experimental setup of the optical ICI compensation method for the overlapped 16 QAM and QPSK signals. The wavelengths of the lasers are tuned to induce the desired channel spacing Δf. Lasers of channel-1 and channel-2 are modulated in separate modulators with independent 16QAM and QPSK data streams. A polarization controller (PC) and a pre-amplifier are placed after each modulator to maximize the amount of induced crosstalk with near same power level. The signals along with three dummy pump lasers at ~1551, ~1552, and ~1553 nm are injected with another CW pump laser at ~1562 nm to a PPLN waveguide to generate three signal copies in cascaded SFG-DFG processes. All signals are sent into a LCoS programmable optical filter to select and adjust the amplitudes and phases of the signals. The adjusted signals along with the preserved dummy pump lasers and another CW pump laser at ~1560 nm are injected into a second PPLN waveguide. In PPLN-2, the coherent summation of the desired signal with the crosstalk channel and its delayed copy, mitigates the ICI on the desired channel. The channel with reduced ICI is filtered and sent to a coherent receiver to detect the constellation diagrams and measure BER of the signals.

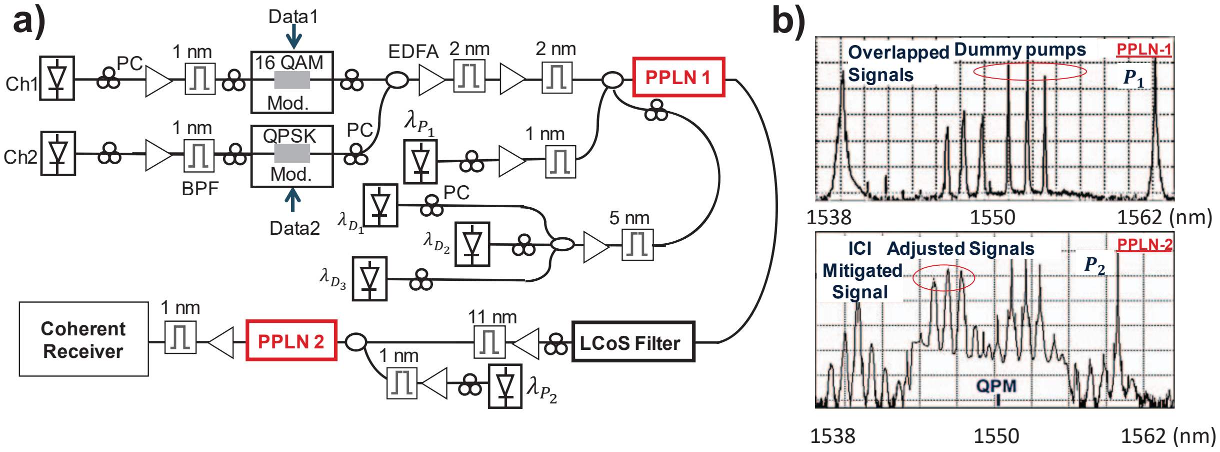

Fig. 2. Experimental setup. PC: polarization Controller, PPLN: periodically poled lithium niobate, LCoS: liquid crystal on silicon, (b) optical spectra after PPLN-1 and PPLN-2 waveguides.

4. Results and Discussion

The performance of the system is assessed for two overlapped channels: a 16QAM signal and a QPSK signal for different channel spacing conditions of 17.5, 20, and 25 GHz and for both 20 Gbaud and 25 Gbaud signals. Figure 3 shows the constellation diagrams of the two channels with and without optical ICI compensation method for 20 Gbaud signal. As it can be seen, the cross talk reduction for lower channel spacing conditions 17.5 GHz and 20 GHz are more significant. However, the amount of reduction is insignificant when the channel spacing is larger than the baud rate of the signals, i.e., 25 GHz.

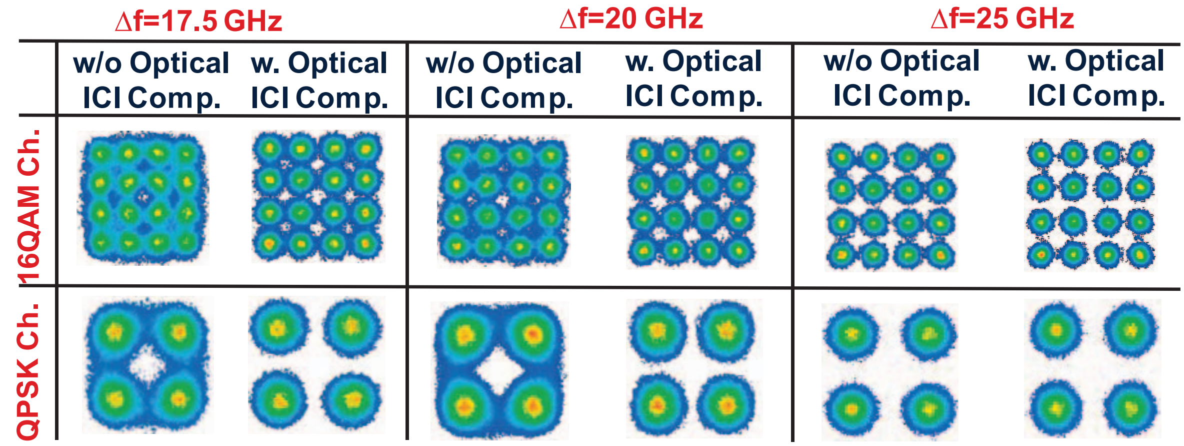

Fig. 3. Experimentally measured signal constellation diagrams with(w.) and without(w/o) optical ICI compensation method for the overlapped channels of a 20-Gbaud 16QAM signal and a 20 Gbaud QPSK signal at different channel spacing Δf.

Figure 4(a,b) shows the BER results of QPSK and 16QAM signals for 20 Gbaud signals and for different channel spacing conditions of 17.5 GHz and 20 GHz. The proposed scheme is baud rate tunable. Figure 4(c,d) shows the BER results of QPSK and 16QAM signals for 25 Gbaud signals and for different channel spacing conditions of 22.5 GHz and 25 GHz. This scheme results in over ~4 dB OSNR gain for 16QAM data channel at a BER of 10^{-3}.

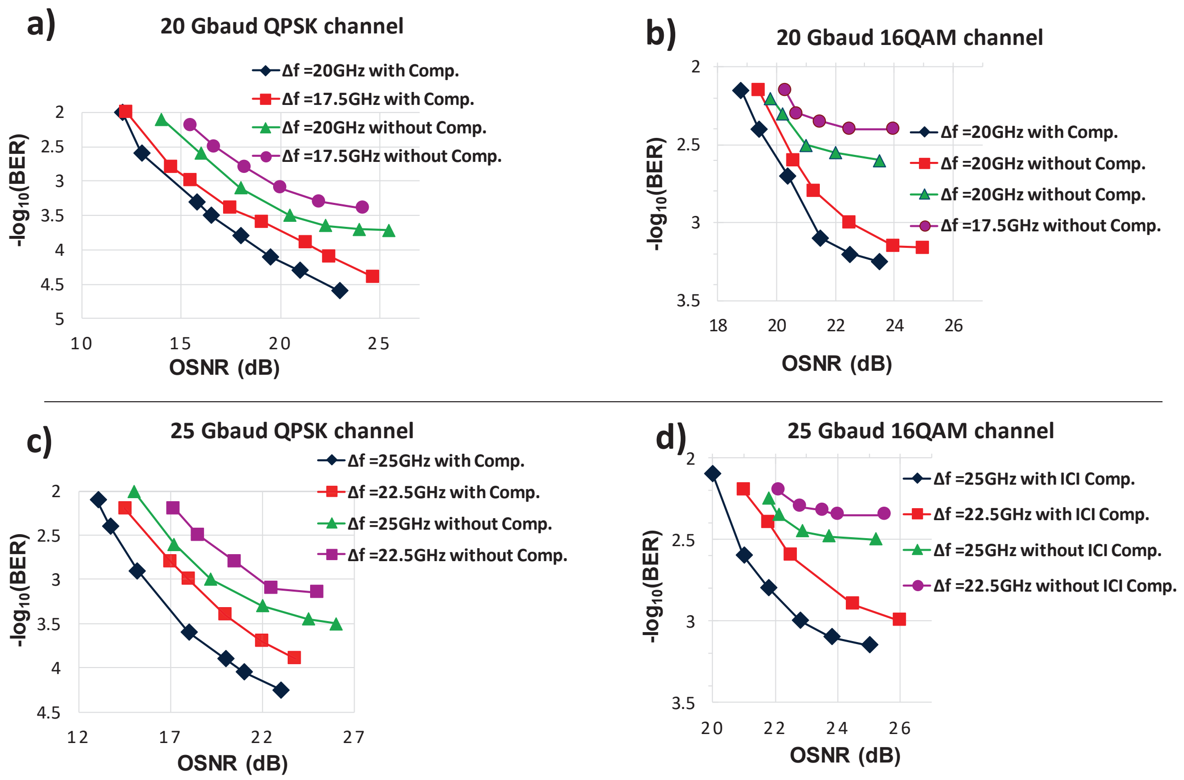

Fig. 4. BER measurements with and without optical ICI compensation method for QPSK/16QAM overlapped channels and for different channel spacing conditions. (a) 20 Gbaud QSPK channel (b) 20 Gbaud 16QAM channel (c) 25 Gbaud QPSK channel (d) 25 Gbaud 16QAM channel.

Acknowledgements

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

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