All-Optical Sub-Channel Data Erasing and Updating for a 16-QAM Signal using a Single PPLN Waveguide

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Abstract: We demonstrate all-optical sub-channel data erasing/updating based on cascaded sum- and difference-frequency generation in a single PPLN waveguide. OSNR penalty of 2-dB for RZ and 4-dB for NRZ at a BER of 2e-3 are achieved.

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1. Introduction

High-order advanced modulation formats have attracted much interest due to their capability of achieving higher spectral efficiency through data modulation on amplitude, phase and polarization [1]. One promising candidate of interest is 16-quadrature amplitude modulation (QAM) that carries 4-bits information in each symbol and can be considered as two independent quadrature phase-shift-keying (QPSK) channels at the same baud rate. On the other hand, data grooming with flexible granularity is highly desired in the network switch nodes to meet the demands of variable traffic [2]. Therefore, a network element that can perform QAM signal sub-channel data erasing and updating could be valuable in the near future.

Optical nonlinearities can achieve ultrafast operation as well as parallel processing. Processing of a signal with higher-order modulation format and its sub-channel, (e.g., multiplexing and extraction) have been reported in the literature, including multiplexing of three OOK data streams into a 8-PSK signal [3] and two QPSK channels into a star 16-QAM signal using cross-phase modulation [4]. Multiplexing of four OOK signals into a rectangular 16-QAM was simulated by using a nonlinear optical loop mirror [5]. Extraction of a DPSK channel from a QPSK signal was also demonstrated by using four-wave mixing [6]. However, there has been little research on sub-channel manipulation of a rectangular QAM signal. A laudable goal would be to develop a network element that can perform sub-channel information erasing and updating of a QAM signal for data grooming applications, such that the QAM signal can be tailored and shared among many different channels as the traffic demands vary in a dynamic, heterogeneous network.

In this paper, we experimentally demonstrate sub-channel data erasing/updating for a rectangular 16-QAM signal based on the cascaded sum- and difference-frequency generation (SFG/DFG) in a periodically poled lithium niobate (PPLN) waveguide. One QPSK sub-channel of a 16-QAM at 10-Gbaud/s is erased and then updated in a single stage. An optical signal-to-noise ratio (OSNR) penalty of ~ 2 dB for return-to-zero (RZ) operation and 4 dB for NRZ operation are obtained at a BER of 2e-3 (enhanced forward error correction (EFEC) threshold [7]).

2. Concept and Principle

Fig. 1. Conceptual diagram of 16-QAM sub-channel information updating. QPM: quasi-phase matching. S1: 16-QAM, S2: New QPSK, S3: old QPSK.

Fig. 2. Experimental setup. LD: laser diode. PC: polarization controller. OC: optical coupler. BPF: band-pass filter. ODL: optical delay line. PPLN: periodically poled lithium niobate. PM: power meter.
Fig. 1 shows the concept of sub-channel information updating. A data channel with 16-QAM modulation format can be considered as a combination of two independent QPSK sub-channels. Assuming that one of the two QPSK sub-channels (i.e., QPSK 1) needs to be erased and replaced with a new sub-channel (QPSK 3), with the other sub-channel (QPSK 2) untouched, this information erasing and updating operation can be achieved by using SFG/DFG in a single PPLN waveguide. As illustrated in Fig. 1, three signals (S1, S2 and S3, corresponding to 16-QAM, QPSK 3 and QPSK 1, respectively) are fed into the PPLN waveguide. Consequently, an idler will be generated, following the linear phase relationship expressed as \( \Phi_{\text{idler}} = \Phi_{S1} - \Phi_{S3} \). The principle of the phase erasing and updating can be explained in two steps. In the first step, S2 is a continuous wave (CW) instead of a QPSK signal and thereby the phase relationship becomes \( \Phi_{\text{idler}} = \Phi_{S1} - \Phi_{S3} \). If S3 is a QPSK signal which carries the same information as the sub-channel QPSK 1, this sub-channel will be erased with the other sub-channel (QPSK2) remaining as an offset QPSK. For the second step, if S2 carries a new QPSK signal (QPSK 3), its phase will be added into the offset QPSK (QPSK 2) and thereby a new 16-QAM signal with one sub-channel updated can be obtained.

3. Experimental Demonstration and Results

The experimental setup of 16-QAM information erasing and updating is illustrated in Fig. 2. The 16-QAM is generated through a serial modulation method, in which two IQ modulators driven by four independent 10-Gbit/s binary data channels are used to modulate a continuous-wave (CW) laser (LD1). The first IQ modulator generates a typical QPSK channel (QPSK 1), and the second IQ modulator generates an offset QPSK channel (QPSK 2). In this proof-of-concept experiment, the second IQ modulator is replaced with a delay-line interferometer (DLI) with 6-dB attenuation in one arm [8]. Two other CW lasers (LD2 and LD3) are also coupled into the first IQ modulator and then properly delayed to emulate the known QPSK 1 channel and the unknown QPSK 3 channel, respectively. After amplification, all three channels are coupled into a PPLN waveguide. The spectrum at the output of the PPLN waveguide is shown in Fig. 3. It can be seen that an idler with a conversion efficiency of around -12 dB is obtained. The idler is then selected and detected through a coherent receiver (Agilent 4391A). Fig. 3 (a)-(c) display the measured constellation of the old and new QPSK signals, as well as the 16-QAM signal to be updated. First, we verify the information-erasing process by using a CW instead of a new QPSK signal for S2. After SFG/DFG, an offset QPSK signal is obtained as the idler, as shown in Fig. 3(d). One can clearly see that one of the sub-channels (the old QPSK, i.e., QPSK 1) of the 16-QAM signals has been successfully erased. We further change S2 into a QPSK signal (the new QPSK, i.e., QPSK 3). A new NRZ 16-QAM signal with one QPSK sub-channel being updated is obtained, as shown in Fig. 3(e). We also demonstrate simultaneous information updating and format conversion into a RZ 16-QAM signal by pulse curving S3 through a Mach-Zehnder modulator, as shown in Fig. 3(f).

Fig. 4 shows the measured BER curves of the back-to-back and updated 16-QAM signals in both RZ and NRZ formats at 10 Gbaud/s. The observed power penalty at a BER of 2e-3 is ~ 2 dB for RZ 16-QAM and ~ 4 dB for NRZ 16-QAM. Shown in Fig. 5 is the BER performance as a function of the relative time offset among three input signals with an OSNR of 20 dB. The time offset tolerance to achieve BER of < 2e-3 is ~ 20 ps for two QPSK signals and ~15 ps for NRZ 16-QAM signal.

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4. References