Optical Channel De-aggregator of 30-Gbaud QPSK and 20-Gbaud 8-PSK Data Using Mapping onto Constellation Axes

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Abstract *We experimentally de-aggregate the 8-PSK signal (EVM 8.7%) onto two 4-PAM signals (EVM 8.8%). QPSK signals are demultiplexed into two BPSK signals with EVMs ~11.4 %. De-aggregation performance as a function of the OSNR of the incoming signals is evaluated. The effect of phase noise is also studied.*

Introduction

Aggregation of lower-capacity channels into a single higher-capacity channel and de-aggregation of one higher-capacity channel into many lower-capacity channels are common functions in generic communication systems[1]. This is true because often single users do not need the full bandwidth available in a high-capacity portion of a network[1]. For a high-capacity optical network, there might be a desire to achieve aggregation and de-aggregation in the optical domain to potentially: (i) avoid inefficient optical-to-electrical conversions, (ii) enable the possibility of higher speed, and (iii) achieve linear transformations over a wide dynamic range.

Given the present importance of phase-based data modulation formats, e.g., quadrature-phase-shift-keying (QPSK) or multi-level phase-shift-keying (M-PSK), it would be valuable to demonstrate these two functions for phase-encoded data channels. In general, optical aggregation has been demonstrated for higher-order phase-based modulation formats[2,3].

There have been reports of optical de-aggregation of QPSK signals. However, in general, these approaches have required the use of a feedback loop to stabilize the phase within the de-aggregator[4,5,6]. A laudable goal would be to demonstrate a technique for the optical de-aggregation of QPSK and higher-order PSK into multiple data channels of lower capacity.

In this paper, we demonstrate optical channel de-aggregator of 30-Gbaud QPSK and 20-Gbaud 8-PSK data using mapping onto constellation axes. In order to map the signal onto the axes, we add the signal with its conjugate coherently. To keep the coherency without a feedback loop, we implement the de-aggregation on the differentiated version of the signal. In other words, first in a nonlinear element, we generate a copy and two conjugate copies and then in a programmable phase/amplitude filter, one symbol time delay is induced on the signal and its copy. Finally, in another nonlinear element the differentiated signal could be added coherently with its conjugate which could provide the mapping concept. A 30-Gbaud QPSK signal with error vector magnitude (EVM) of 9.9% is de-aggregated onto in-phase (I) and quadrature-phase (Q) BPSK signals with EVMs of ~11.4 %. A 20 Gbaud 8-PSK data with EVM of 8.7% is also mapped onto I- and Q-parts (4-pulse amplitude modulation (PAM)) with EVMs of ~8.8%. We could also implement the de-aggregation of 20-Gbaud QPSK signal to show the tunablity over the bit-rate. Bit error rate (BER) measurements are also shown. To study the de-aggregator performance, we change the input optical signal to noise ratio (OSNR) and measure the output OSNR and EVM. Also, we induce phase-noise on the input signal and at the output, the phase-noise could be squeezed on the mapping axes.

The conceptual block diagram of optical channel de-aggregator is shown in Fig. 1. In order to de-aggregate the QPSK/8-PSK signals, we use mapping concept onto constellation axes. In other words, if we could add the signal, $e^{j\varphi}$, with its conjugate, *i.e.,* $e^{j\varphi} + e^{-j\varphi}$, it would provide us the I-component of the signal. Also, to achieve the Q-component of the signal, we would need to map the constellation onto Q-axes, *i.e.,* $Q = e^{j\varphi} - e^{-j\varphi}$ (as shown in Fig. 1(a), (b)). Figure 1(c) shows the block diagram of mapping implementation. At first, the input signal (QPSK/ 8-PSK) with two continuous wave (CW) pumps, *i.e.,* pump-1 and pump-2, are sent through a highly nonlinear fiber (HNLF) to generate a copy and two conjugate copies of the signal in a four wave mixing

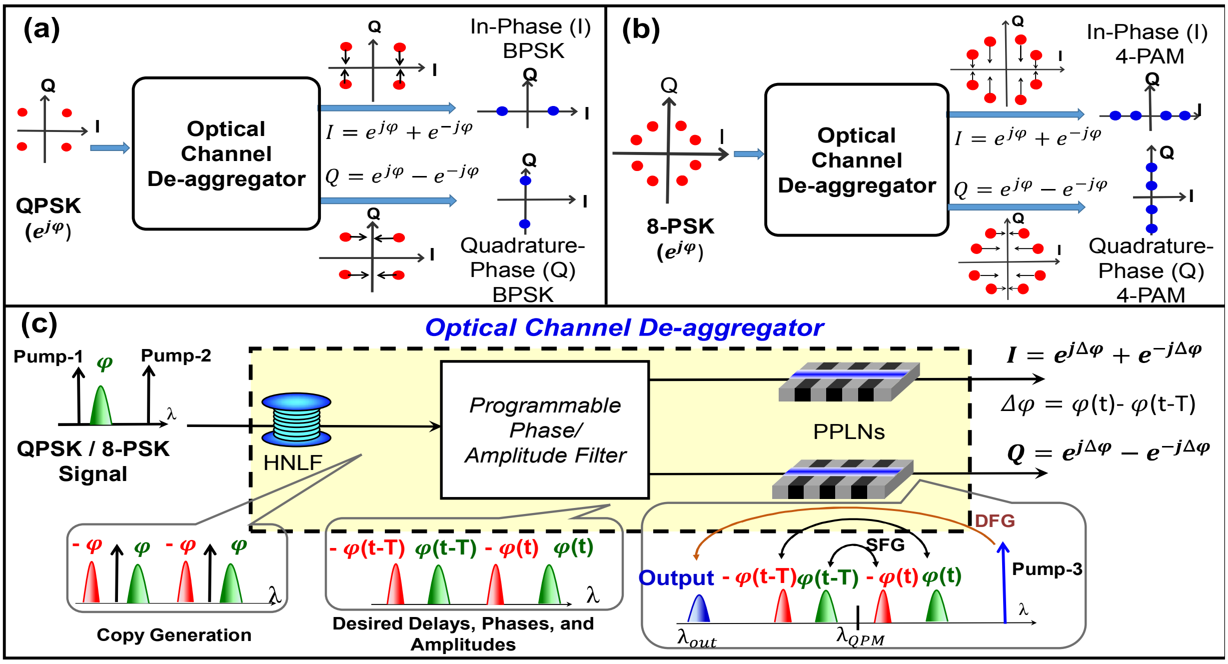
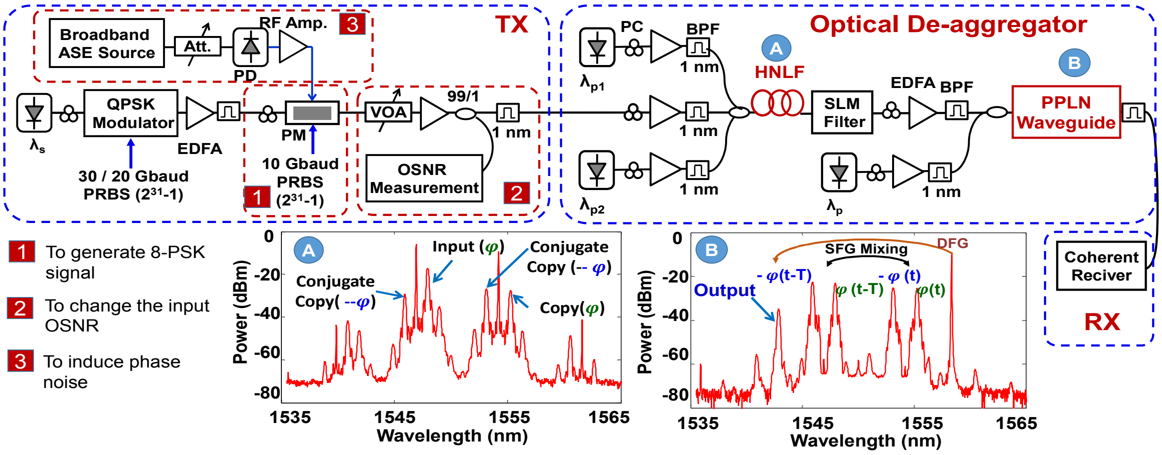


Fig. 2: Conceptual block diagram of the optical channel de-aggregator, **(a)** Concept of optical mapping the QPSK signal onto in-phase (I) and quadrature-phase (Q) axes to extract two BPSK signals, **(b)** Concept of optical demultiplexing of 8-PSK signal into two 4-PAM signals using a mapping concept, **(c)** Block diagram of the optical channel de-aggregator

process. Then, using a programmable phase/amplitude filter based on Liquid Crystal on Silicon (LCoS) technology, the signals are filtered and desired delays and coefficients are induced. We put a one symbol time (T) delay on the signal and its conjugate copy (shown in Fig. 1(c)). In other words, using delay, we could provide coherency between the differentiated signal and its conjugate which enables the de-aggregation without a feedback loop. In the final stage, in a periodically poled lithium niobate (PPLN) waveguide with quasi-phase matching (QPM) wavelength of λ_{QPM}, each delayed signal mixes with another conjugate copy at $\lambda = 2\times\lambda_{QPM} - \lambda_s$ through the sum-frequency-generation (SFG) process to create a signal at $1/2\times\lambda_{QPM}$. Another pump laser at λ_{Pump-3} is also injected into the PPLN waveguide for the difference-frequency generation (DFG) process to multiplex these signals onto λ_{out} as the output of the de-aggregator, which is processed by the coherent receiver. In fact, using this method, the differentiated version of the signal could be added to its conjugate, *i.e.,* $e^{j[\varphi(t)-\varphi(t-T)]}+\alpha e^{-j[\varphi(t)-\varphi(t-T)]}$. In which inside the LCoS filter, we could change the coefficient α to map the signal onto different axes. For I-component, we tune $\alpha=1\measuredangle 0$ and for the Q-part we have $\alpha=1\measuredangle 180=-1$ (shown in Fig. 1(c)).

The experimental setup for the tunable optical channel de-aggregator is shown in Fig. 2. At the transmitter side (TX), the signal at 1548 nm is modulated in a nested Mach-Zehnder modulator with 30 (20) Gbaud QPSK data (PRBS 2^{31}-1). In order to generate an 8-PSK signal, we use a phase modulator driven in $V_\pi/8$ with a 10 Gb/s data (PRBS 2^{31}-1) after QPSK data transmitter. Another part of the TX box is composed of a variable optical attenuator followed by a pre-amplifier to change OSNR of the input signal. Also, as it is shown later, we use a phase modulator driven by a random noise generated by a photodiode to induce phase noise on the input



PM: Phase Modulator, **PC**: Polarization Controller, **EDFA**: Erbium Doped Fiber Amplifier, **VOA**: Variable Optical Attenuator,

Fig. 2: Experimental setup for optical channel de-aggregator

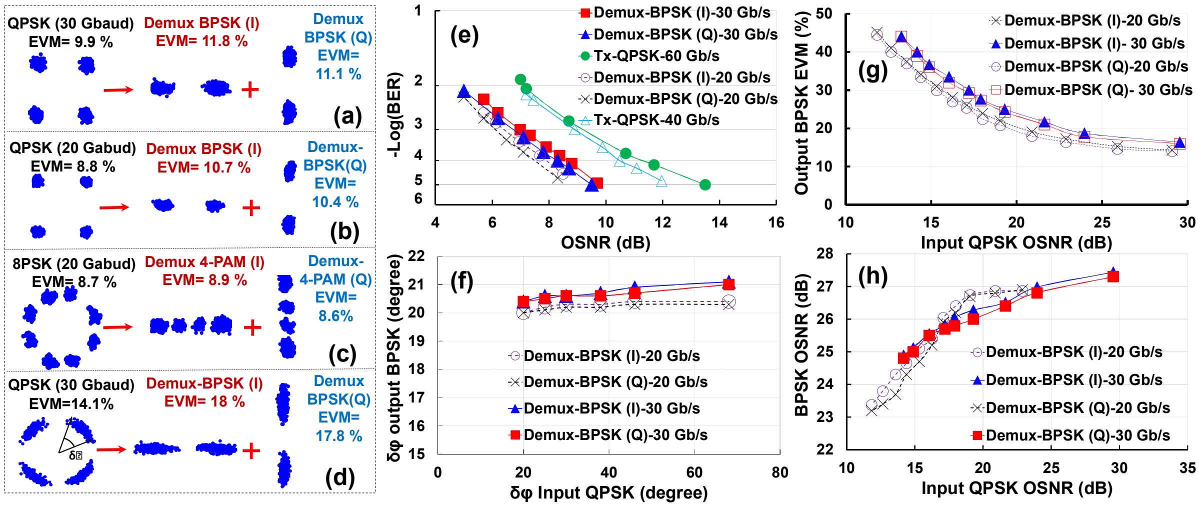


Fig. 3: Experimental results for the optical channel de-aggregator, **(a)** Constellations of the 30 Gbaud-QPSK and de-aggregtedd I- and Q- BPSK signals with corresponding EVMs, **(b)** Constellations for the 20 Gbaud-QPSK and de-multiplexed BPSK (I & Q) signals, **(c)** Constellations for the 20 Gbaud-8-PSK and de-multiplexed 4-PAM (I & Q) signals, **(d)** Constellations for the input 30 Gbaud-QPSK with some phase noise on it and de-multiplexed BPSK signals, **(e)** BER measurements of the QPSK and output BPSK signals at 30 and 20 Gbaud. **(f)** Measured total phase of the output BPSK signals vs total phase of the QPSK signal with phase noise, **(g)** EVM of the demultiplexed BPSK signals vs the OSNR of the input at 30 and 20 Gbaud, **(h)** OSNR of the de-aggregated BPSK signals for the input QPSK signal with different OSNR values.

signal. In fact, inside TX box, wecould potentially emulate the signal in the transmission line. To de-aggregate the optical channel, transmitted signal with other two pumps of λ_{p1}=1547 nm and λ_{p2}=1554 nm, after being amplified, are sent to an HNLF (450m) to generate the copies (the spectrum is shown as (A) in Fig. 2). Followed by a spatial light modulator based on LCoS technology, the signal and its copies are filtered and the desired delays are induced on them. The corresponding signals with another CW pump at λ_{p3}=1558 nm are then sent to a 4-cm-long PPLN waveguide to create the de-aggregator output with the spectrum shown in the figure as (B). The QPM wavelength of the PPLN waveguide is temperature tuned to the wavelength of ~1550.5 nm. The output signal is then filtered and sent to the coherent receiver to be analyzed. Figure 3 shows the optical channel de-aggregator results. Figures 3(a), (b) and (c) show the constellations of the input QPSK and 8-PSK signals and the corresponding de-multiplexed signals. A 30-Gbaud QPSK signal with EVM of 9.9% could be de-aggregated into I- and Q- BPSK signals with EVMs of ~11.5%. Similar results are achieved for 20-Gbaud QPSK de-aggregation. We could also de-aggregate a 20-Gbaud 8-PSK (8.7% EVM) signal into I- 4-PAM (8.9% EVM) and Q- 4-PAM signal (8.8% EVM). Bit error rate (BER) measurements are shown in Fig. 3. (e). which shows the good performance of the de-aggregator. In order to study the de-aggregator in a network, we change the noise values of the signal. Fig. 3(d) shows the constellation of the QPSK signal with phase noise and corresponding de-multiplexed I- and Q- BPSK signals. As it is shown, the phase noise of the signal is also mapped and squeezed on the mapping axes. For different values of phase-noise, the output BPSK total phase values are measured and shown in Fig. 3(f). Based on this figure, the output phase of the de-aggregated BPSK signals is almost fixed. Another parameter is the effect of OSNR degradation. Figure 3(g) shows the EVM of the de-multiplexed BPSK signals for the input QPSK signal with different OSNR values. As shown in this figure, for the input signal with lower OSNR, the EVM of the output BPSK signal is increased. Also, the OSNR of the de-multiplexed BPSK signals are measured and shown in Fig. 3(h) in which the output OSNR does not vary too much for the variations of the input OSNR. But it is still gets worse when the input signal has lower OSNR.

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