Tunable Optical De-aggregation of a 40-Gbit/s 16-QAM Signal into Two 20-Gbit/s 4-PAM Signals using a Coherent Frequency Comb and Nonlinear Processing

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Abstract: We experimentally de-aggregate the 16-QAM signal (EVM 6.9%) onto two 4-PAM signals (EVM 8.5%). Tunability of the approach over modulation format and bit rate is also shown by de-aggregating QPSK signals at two different baud rates.

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1. Introduction

Higher-order modulation formats, such as QAM, have received much attention due to their higher spectral efficiency [1]. Typically, 16-QAM data modulation is a multiplexed version of multiple lower-order modulation data streams at the transmitter and is de-aggregated at the receiver back into the lower-order formats. Such aggregation and de-aggregation is commonly performed in the electrical domain. However, (de)aggregation requires highly linear techniques, something that electronic approaches find challenging. Moreover, electronic methods do require optical-to-electrical (O-E) (or E-O) conversion, which is inefficient if the lower-order data signals either begin or end still in the optical domain. An optical approach to (de-)aggregation might provide advantages of linearity and no O/E conversion, and tunability in an optical method may be beneficial for heterogeneous and reconfigurable systems.

Previous reports have shown the ability to perform optical aggregation of lower-order formats into a 16-QAM signal [2, 3]. This was accomplished by coherently mixing two lower-rate signals in a nonlinear element and delaying one relative to the other. Although there have been reports of optical de-aggregation of QPSK signals [4-8], there have been few reports of optical de-aggregation of 16-QAM signals.

In this paper, we demonstrate tunable optical de-aggregation of a 40-Gbit/s 16-QAM signal into two 20-Gbit/s 4-PAM signals using a coherent frequency comb and nonlinear processing. We use a coherent pump in a nonlinear device to generate the conjugate of the signal and at the second nonlinear element, using a coherent frequency comb, we combine the signal with its conjugate to map the data points onto the constellation axes. We experimentally de-aggregate the 16-QAM signal (EVM 6.9%) onto two 4-PAM signals (EVM 8.5%). Tunability of the approach over modulation format and bit rate is also shown by de-aggregating 20/40 Gbit/s QPSK signals into two BPSK signals.

2. Concept

The conceptual block diagram of the optical channel de-aggregator is shown in Fig. 1. To de-aggregate the signal, we map the data onto the constellation axes. When we add the signal, A, and its conjugate, A^*, we obtain the in-phase (I)-component of the signal, *i.e.*, $I=A+A^*$ (Fig. 1(a)). Furthermore, to obtain the quadrature (Q)-component of the signal, we map the constellation onto the Q-axis, *i.e.*, $Q=A-A^*$ (Fig. 1(b)). Fig. 1(c) shows the block diagram of the mapping implementation. The input signal and a CW pump which is in coherence with the data signal, are sent through a HNLF

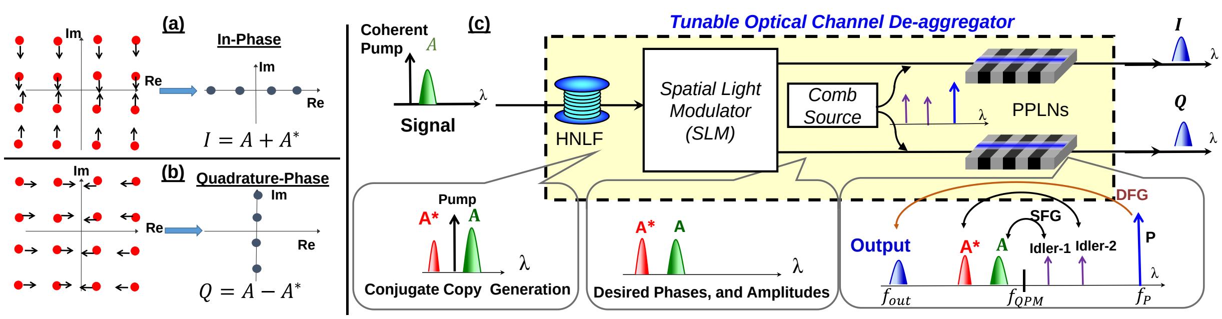

Fig. 1: **Fig. 1:** Conceptual block diagram of the optical channel de-aggregator, **(a), (b)** Concept of optical mapping of the 16-QAM signal onto in-phase (I) and quadrature-phase (Q) axes, **(c)** Block diagram of the tunable optical channel de-aggregator.

to generate a conjugate copy of the signal in a nonlinear (FWM) process. Then, using a spatial light modulator (SLM) based filter, the signals are filtered and desired coefficients are induced. Finally, we send two coherent pumps, *i.e.*, *idler-1,2* from an optical comb source along with the signals into a PPLN waveguide with a QPM frequency of f_{QPM}, to combine the signal and its conjugate through the sum-frequency-generation (SFG) process to create a signal at $1/2 \times f_{QPM}$. Another pump laser at f_P is also injected into the PPLN waveguide for the difference-FG (DFG) process to multiplex these signals onto the output at f_{out}, which is processed by the coherent receiver. Using this method, the signal has thus been added to its conjugate, *i.e.*, $A + \alpha A^*$. Inside the SLM filter, we can change the coefficient α to map the signal onto different axes, if desired. The system has the tunability over the modulation format and baud rate.

3. Experimental Setup

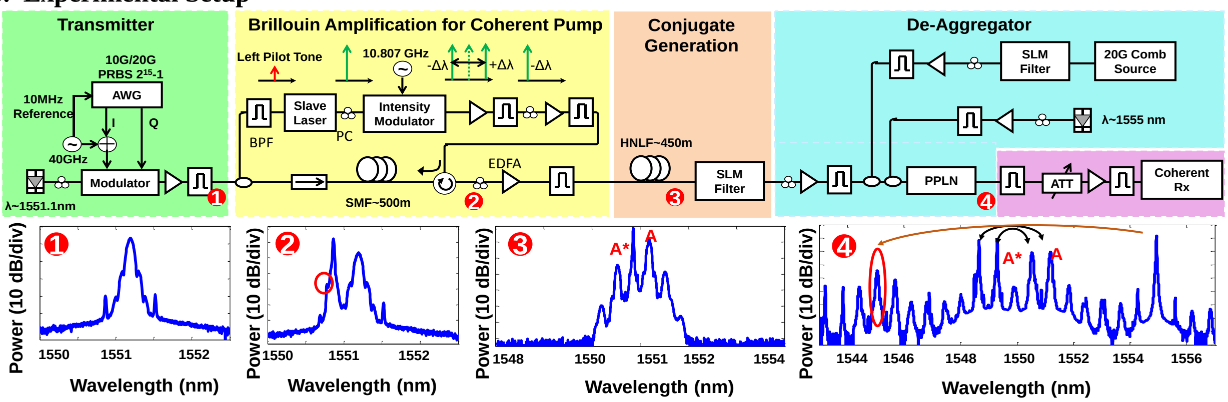

Fig. 2. Experimental setup. BPF: Band Pass Filter, PC: Polarization Controller, EDFA: Erbium-Doped Fiber Amplifier

Fig. 2 shows the experimental setup. 2^{15}-1 PRBS data at 10/20 Gbaud is generated by an AWG. The I- component is then combined with a sinusoidal tone, which is generated by a 40GHz frequency oscillator. The signal wavelength is at 1551.1nm (spectrum-1). After the transmitter, the signal goes to the Brillouin amplifier (BA) to amplify the tone as the coherent pump. The signal is separated into two paths. The upper one is for the pump generation of BA by injection locking the tone and modulating by 10.807 GHz (Brillouin frequency for the SMF) signal in a MZM. The left tone is used as BA pump. BA is realized by the bidirectional propagation between the pump and the original signal in a 500m SMF (spectrum-2). By narrow-band BA, only the left tone is amplified. Due to the effect of Rayleigh back-scattering, there is a low peak in the spectrum. The amplified signal and coherent pump are sent to a 500m HNLF to generate conjugate of the signal (spectrum-3) and the output is sent to SLM to select the signal and it's conjugate. At the de-aggregator part, we use two coherent pumps generated by a frequency comb source. The pair of comb lines come from a 20GHz repetition rate mode-locked laser passed through a SLM filter for both filtering and phase adjustment. The comb lines are then coupled with the signals and another pump at 1555.2 nm in a PPLN waveguide (spectrum-4). It can be seen that the signal and its conjugate are transferred and combined at the output which operates the mapping functionality on the data points. The output signal is then filtered and sent to the coherent receiver to be analyzed.

4. Experimental Results

Fig. 3 shows the experimental results. 40Gbit/s 16-QAM signal is de-aggregated into two 20Gbit/s 4-PAM signals with EVMs of around 8.6%. In order to show the tunability of the approach over the modulation format, we send QPSK signal at 20Gbaud and de-aggregated it into two BPSK signals. Moreover, we de-aggregated the QPSK signal at different baud rate of 10Gbuad to show the baud rate tunability of the setup. Fig. 3(c) shows the system performance.

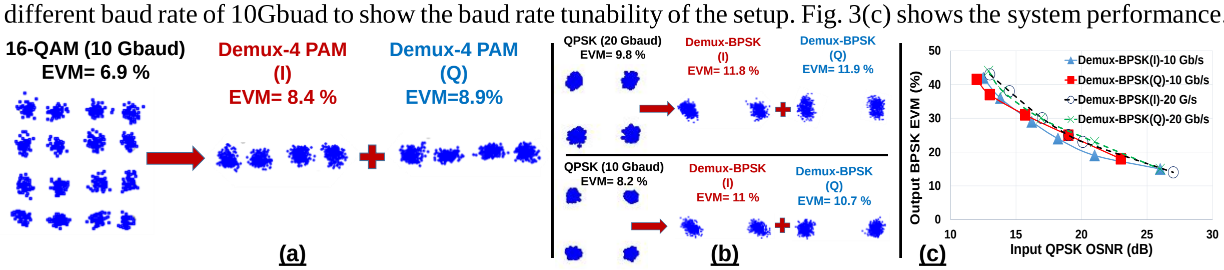

Fig. 3. Results on: (a) 40Gbit/s 16-QAM de-aggregation, (b) 20Gbaud-,(c) 10Gbaud-QPSK signal de-aggregation. (c) system performance.

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5. References

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