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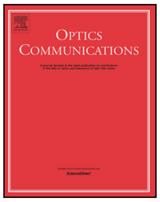

Mitigate the impact of transmitter finite extinction ratio using K-means clustering algorithm for 16QAM signal

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ABSTRACT

A method of recognizing 16QAM signal based on k-means clustering algorithm is proposed to mitigate the impact of transmitter finite extinction ratio. There are pilot symbols with 0.39% overhead assigned to be regarded as initial centroids of k-means clustering algorithm. Simulation result in 10 GBaud 16QAM system shows that the proposed method obtains higher precision of identification compared with traditional decision method for finite ER and IQ mismatch. Specially, the proposed method improves the required OSNR by 5.5 dB, 4.5 dB, 4 dB and 3 dB at FEC limit with ER= 12 dB, 16 dB, 20 dB and 24 dB, respectively, and the acceptable bias error and IQ mismatch range is widened by 767% and 360% with ER =16 dB, respectively.

1. Introduction

Recently, coherent optical communication has been widely taken into application because of improving spectral efficiency and power efficiency, and further mitigating the communication impairments by off-line processing [1]. To get a higher transmission data rate, research based on the technique of new modulation formats was intensified during latest decade, especially multi-level quadrature amplitude modulation (QAM) formats [2]. However, error performance of the multi-level QAM modulated is unstable owing to the non-ideal hardware setup, such as nonlinear phase noise, frequency offset, amplified spontaneous emission noise, in-phase/ quadrature (IQ) mismatch and finite extinction ratio (ER) of transmitter. Therefore, recently quite a few ongoing researches focus on digital signal processes (DSP) based algorithms for signal detection and optical transceiver impairment compensation. In our study, we principally pay attention to the influence of finite ER and IQ mismatch in multi-level coherent optical system. The Mach–Zehnder (MZ) modulator owning a finite ER will be always along with residual chirp [3] and IQ mismatch of transmitter will introduce inter-carrier interference in direct down conversion operation at coherent receiver [4], which has negative effect on the system performance observably. Therefore, various types of modulation and equalization techniques, such as all-optical modulation based on quad-parallel MZ modulator [5], parameter adjustment [6,7], material of modulator optimization [8] and moment estimation algorithms [9], were investigated to mitigate the impact of finite ER and IQ mismatch for multi-level coherent optical communication.

In this paper, we investigate the effect of finite ER and IQ mismatch on 16QAM modulated coherent optical communication, and further provide a method of recognizing 16QAM based on *k*-means clustering algorithm for impairment compensation. Clustering algorithms are taken as a class of efficient implements for data analysis, which devote to classify data instances into groups such that instances are more similar to each other which are in the same group, while instances in different groups become more different [10]. For high-order coherent optical system, traditional clustering algorithms are used for basically modulation recognition considered that the group-labels of all instances are unknown beforehand [11,12]. Our simulation demonstrates a pilot-symbols-aided clustering algorithm to weaken the effects of finite ER and IQ mismatch of modulator in 16QAM system. The bit error rate (BER) performance of proposed method shows a higher precision of identification compared with traditional demodulation method for finite ER and IQ mismatch. Specially, the superiority of proposed method is even more significant with low optical signal noise ratio (OSNR) or large combined linewidth. Numerical simulation results of 10 GBaud 16QAM system show that, by using *k*-means cluster method, the required OSNR is improved by 5.5 dB, 4.5 dB, 4 dB and 3 dB at forward error correction (FEC) limit with ER = 12 dB, 16 dB, 20 dB and 24 dB, and the acceptable bias error and IQ mismatch range is widened by 767% and 360% with ER = 16 dB.

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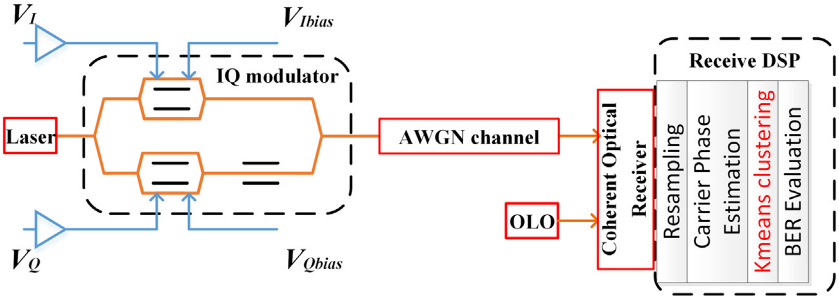

Fig. 1. Schematic of the generation and detection of 16QAM. OLO: optical local oscillator.

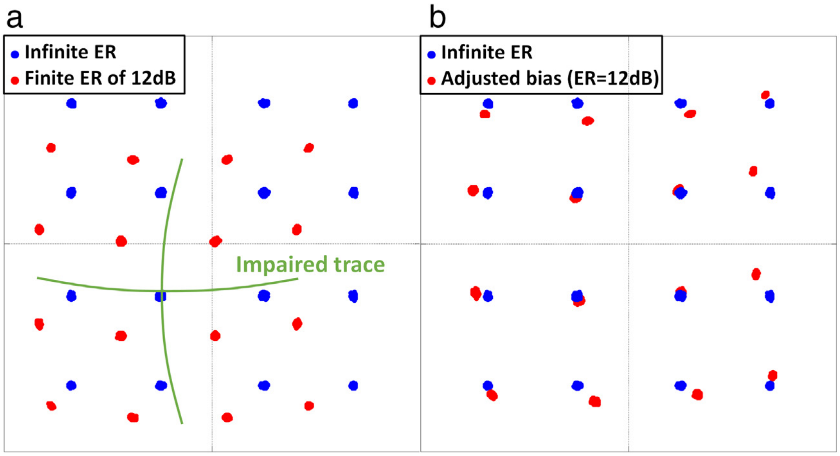

Fig. 2. Constellations of 16QAM signals for infinite ER and finite ER (a) without special bias control; (b) with special bias control. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Principle and simulation setup

Fig. 1 shows the simulation setup for generation and coherent detection of 16QAM signal. On the transmitter side, taking 10GBaud 16QAM as an example, the optical carrier is generated from a continuous wave laser with a linewidth of 100 kHz and is modulated by a IQ modulator. The data sequence with bit length of 262144 is mapped by 16QAM-encoded and converted from digital to analog, which is used to drive the modulator. After going through the additive white Gaussian noise (AWGN) channel, the generated 16QAM signal is coherent detected and further processed by a digital coherent receiver.

As we all known, an optical IQ modulator (such as dual parallel MZ modulator) consisting of two sub-MZ modulators and a main-MZ modulators is shown in Fig. 1 [13]. The output optical field of the IQ modulator with finite ER and IQ mismatch should be expressed by

$$\begin{aligned} E_{out} = & \left[-\sin\left(\frac{V_I + V_{Ibias}}{2V_\pi}\pi\right) + i\frac{1}{\sqrt{R_e}}\cos\left(\frac{V_I + V_{Ibias}}{2V_\pi}\pi\right)\right] E_{in} \\ & + ie^{i\theta}\left[-\sin\left(\frac{V_Q + V_{Qbias}}{2V_\pi}\pi\right)\right. \\ & \left. + i\frac{1}{\sqrt{R_e}}\cos\left(\frac{V_Q+V_{Qbias}}{2V_\pi}\pi\right)\right] E_{in} \end{aligned} \tag{1}$$

where E_{in} is the input optical field, R_e denotes ER, V_π is the half-wave switching voltage, V_I is the radio frequency voltage of in-phase branch, V_{Ibias} is the bias voltage of in-phase branch, V_Q is the radio frequency voltage of quadrature branch, V_{Qbias} is the bias voltage of quadrature branch and $e^{i\theta}$ is IQ mismatch factor.

Fig. 2 shows the constellations of 16QAM optical signals with ideal infinite ER and non-ideal finite ER of 12 dB. As shown in Fig. 2(a), the radio frequency signal is set with peak voltage from $-V_\pi$ to V_π, and the bias is set to null mode without special bias control. Ideal IQ modulator yields ideal constellation without any error, which is depicted by blue points. The output of each MZ modulator contains only real number component or imaginary number component when $ER \rightarrow \infty$, however, the output optical field with finite ER can be introduced an error. The green curves show the impaired trace of the output optical field on the in-phase branch and quadrature branch with finite ER modulator and without special bias control [6]. The constellation with finite ER is described by red points, and its error corresponds to the vector sum of these impaired trace. Comparing ideal signal with non-ideal signal, the constellation error can be regarded as a nonlinear distortion and an offset between green lines and horizontal/ vertical axis. It is assumed that the radio frequency signals and output are zero, so the bias voltages ($V_{Ib-null}/V_{Qb-ull}$) can be achieved with following equation.

$$\begin{aligned} V_{Ib-null} &= -\frac{2V_\pi}{\pi}\sin^{-1}\left(\sqrt{1/1+R_e}\right) \\ V_{Qb-null} &= \frac{2V_\pi}{\pi}\sin^{-1}\left(\sqrt{1/1+R_e}\right). \end{aligned} \tag{2}$$

For finite ER of 12 dB, the bias voltages, $V_{Qb-null} = -V_{Ib-null} \approx 0.16V_\pi$, are adjusted to correct the offset error as shown in Fig. 2(b). The nonlinear constellation error still be retained, which meaning high-order modulation formats are vulnerable to the finite ER.

Fig. 3 shows the BER results versus V_{Ibias}/V_π of 10 GBaud 16QAM signals for different ER without k-means clustering algorithm. The OSNR is set to be 20 dB. The optimal bias control points are achieved, which are −0.04, −0.07, −0.11 and −0.17 for ER = 24 dB, ER = 20 dB, ER = 16 dB and ER = 12 dB, respectively. Insets indicate that the demodulated constellation of 16QAM strongly impaired by finite ER. Meanwhile, the constellation of 16QAM with infinite ER are also plotted for comparison at the top left. It should be noticed that the entire constellation with finite ER is tilted (phase offset introduced), and the outer points have been compressed. Therefore, the information cannot be recognized by common decision algorithm (red dotted), and it degrades performance of carrier phase estimation by increasing the BER.

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