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Adaptively Loaded IM/DD Offset-QAM OFDM Based on Set-Partitioned QAM Formats

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Abstract: We propose an adaptive-loading algorithm for SP-QAM formats, and experimentally show that SP-offset-QAM outperforms conventional offset-QAM and conventional SP-QAM, in adaptive-loaded IM/DD OFDM systems, and achieves >40 Gbit/s at 50 km without any guard interval.
OCIS codes: (060.0060) Fiber optics and optical communication; (060.4080) Modulation

1. Introduction

Set-partitioned (SP) quadrature amplitude modulation (QAM) formats have attracted much attention recently in coherent systems [1, 2] due to their superior power efficiency. However, few works have been done on employing SP-QAM formats in low-cost intensity-modulated direct-detection (IM/DD) systems [3], which are more favorable in cost-sensitive local and access networks. In particular, conventional adaptive bit and power loading technique [4], which enhances IM/DD multi-carrier systems towards capacity limit, cannot be directly applied to the SP-QAM formats. It should be customized based on their symbol error rates (SERs). On the other hand, offset-QAM OFDM has been proposed in coherent detection and has shown its unique advantages over conventional OFDM and Nyquist FDM [5].

In this paper, we propose an adaptive loading algorithm for SP-QAM formats for any IM/DD multi-carrier systems, and experimentally demonstrate >40 Gbit/s transmission over 50-km single-mode fiber (SMF). The proposed adaptive-loaded SP-offset-QAM OFDM is shown to outperform the conventional offset-QAM OFDM and can also avoid the guard interval (GI) required in conventional SP-QAM OFDM. Consequently higher net data rate could be achieved.

2. Principles

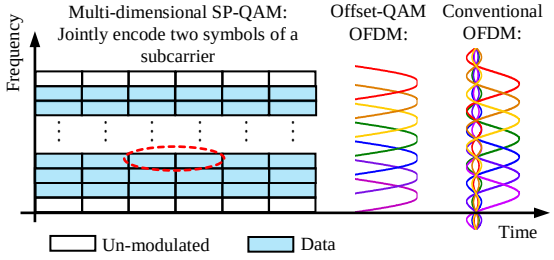


Fig. 1. Principles of SP-offset-QAM OFDM

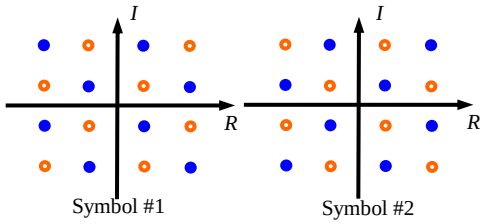


Fig. 2. Constellation of SP-128QAM.

Fig. 1 illustrates the principles of SP-offset-QAM OFDM. Offset-QAM OFDM can greatly relax the required signal spectrum for subcarrier orthogonality [5] and avoid the sinc function employed in conventional OFDM. In this paper, the square-root-raised-cosine function with a roll-off factor of 0.5 is employed for the spectral profile of the offset-QAM OFDM. Every two symbols of the same subcarrier are jointly encoded to generate the SP-QAM formats. Fig. 2 depicts the constellation of SP-128QAM, as an example. The two consecutive symbols of a subcarrier construct a 4-dimensional constellation. When the point in Symbol #1 is a solid (or empty) point, only the solid (or empty) points in Symbol #2 can be selected. The number of possible constellation points per two symbols is 16×8=128. The Euclidean distance is increased by $2^{1/2}$ while the spectral efficiency (SE) is reduced from 4 to 3.5 per symbol. Other SP-QAM formats (SP-2QAM, SP-8QAM, SP-32QAM, and SP-512QAM, with the SEs of 0.5, 1.5, 2.5, and 4.5, respectively) can also be designed, accordingly. These SP-QAM formats may not be optimal in terms of power efficiency in the 4-dimensional space, but their data mappings are simple.

The key differences of SERs between these SP-QAM formats and the conventional QAM ones are the increased Euclidean distance by $2^{1/2}$, the loss of the SE by 0.5 bit, and the average number of points giving the minimal Euclidean distance (denoted as K). The upper bound of SERs for these SP-QAM formats can be derived as:

$$SER < K \times Q(\sqrt{\frac{3\times 2}{2^{m+1/2}-1} SNR}) \tag{1}$$

where K is bounded by 12 and m is the SE per symbol. SNR is defined as E_s/N_0, where E_s and N_0 are the average power per symbol and the noise spectral power density, respectively. In OFDM, if the SNR for the i^{th} subcarrier, SNR_i, is obtained, we can derive the allocated number of bits for that subcarrier by re-writing Eq. (1) as:

$$m_i = \log_2(1+\frac{3\times 2\times SNR_i}{(Q^{-1}(SER_{pre-set}/K))^2 \cdot \gamma}) - 0.5 \tag{2}$$

$$\hat{m}_i = round(m_i + 1/2) - 1/2 \tag{3}$$

where $SER_{pre\text{-}set}$ is the pre-set SER. γ is a parameter which can be determined by iteration, similar to the Chow's algorithm [4]. A training sequence is used to estimate SNR_i:

$$SNR_i = \frac{\left|E(r_i^* \cdot s_i)\right|^2}{E(|r_i|^2)E(|s_i|^2) - \left|E(r_i^* \cdot s_i)\right|^2} \tag{4}$$

where r_i and s_i are the received and transmitted signals in the i^{th} subcarrier, respectively.

3. Experimental setup and results

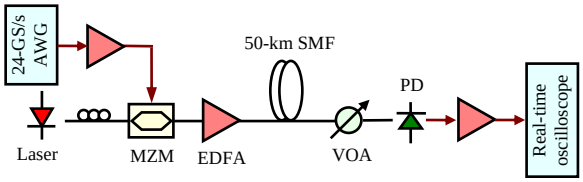


Fig. 3. Experimental setup.

Fig. 3 shows the experimental setup. The OFDM signal consisted of 63 subcarriers and the point size of the fast Fourier transform (FFT) was 128. The first and the last subcarriers were zero-padded. For adaptive loading, 8QAM OFDM signal was firstly used to estimate the SNR (Eq. (4)) and the number of bits was calculated based on Eq. (3). The signal was then uploaded into a 24-GS/s arbitrary waveform generator (AWG). A laser with ~5-MHz linewidth was used to generate the CW light. A Mach-Zehnder modulator (MZM) was used for modulation and the input electrical peak-to-peak voltage was ~$V_\pi/2$. The optical signal was amplified by an Erbium doped fibre amplifier (EDFA) before being transmitted over 50-km SMF. At the receiver, the optical signal was detected by a photodiode (PD). A variable optical attenuator (VOA) was used to vary the received power. The detected signal was sampled by a 50-GS/s oscilloscope. About 1 M bits were measured and bit error rate (BER) was obtained by error counting.

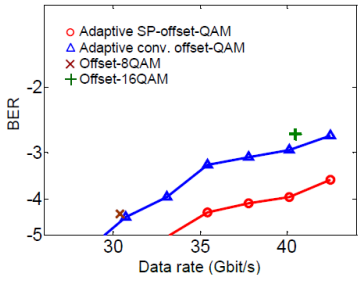


Fig. 4. BER versus data rate of offset-QAM OFDM at 0 km.

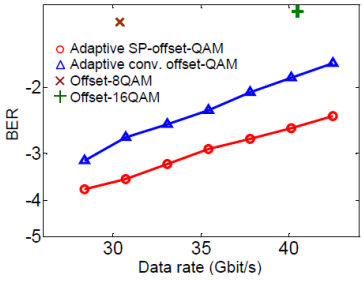


Fig. 5. BER of offset-QAM OFDM at 50 km. Guard interval is not used and the signal power into the fiber is 10 dBm.

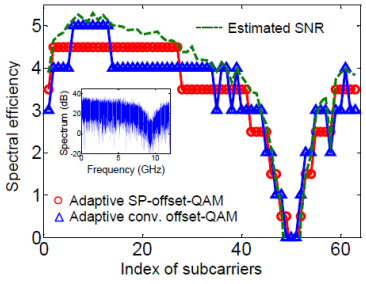


Fig. 6. SE versus the index of subcarriers at 40.2 Gbit/s and 50 km. The dashed line is the estimated SNR (= SNR (dB) /3). The inset is the spectrum of the received signal.

Fig. 4 shows the BER versus the signal data rate of offset-QAM OFDM at -3-dBm received power. The performance of offset-8QAM and offset-16QAM for all data subcarriers are also shown, for comparison. In these two cases, 54 out of 64 subcarriers were modulated and the data rates were 30 Gbit/s and 40 Gbit/s for 8QAM and 16QAM, respectively. It is shown that conventional adaptive loading algorithm got slight performance improvement

at 0 km, compared to the systems with a single format for all subcarriers. In contrast, the adaptive-loaded SP-offset-QAM formats greatly improved the performance due to the enhanced Euclidean distance.

Fig. 5 shows the BER of offset-QAM OFDM at 50 km. Fig. 6 depicts the allocated SE over subcarriers and the estimated SNR profile. In both figures, the[JZ1] received power was -3 dBm. It is seen that dispersion has resulted in a spectral null and there was significant performance degradation when a single format was employed for all subcarriers. Conventional adaptive loading algorithm allocated formats according to the SNR with low-level formats around the spectral null. Consequently, the performance was improved, but the supported data rate was limited to ~35 Gbit/s at the BER of 3.8×10^{-3}. By using the proposed adaptive-loaded SP-offset-QAM format, the performance was further improved and >40 Gbit/s has been achieved at 50 km.

The proposed algorithm can also be applied to other multi-carrier systems. Fig. 7 shows the BER of both conventional OFDM and SP-offset-QAM OFDM. The signal launch power was 10 dBm and the received power was -3 dBm. It is seen that the proposed algorithm has also achieved much improved performance in conventional OFDM. In addition, SP-offset-QAM OFDM outperformed conventional SP-QAM OFDM in the absence of GI. This is because offset-QAM OFDM is more tolerant to inter-symbol interference (ISI) and inter-carrier interference (ICI) by avoiding the long spectral tails of the sinc function. Fig. 7 also depicts the constellations of conventional SP-QAM OFDM and SP-offset-QAM OFDM under the same experimental parameters. It is shown that the latter gives a clearer constellation.

We have further investigated the impact of GI. Fig. 8 shows the performance versus the length of GI, while Fig. 9 depicts the estimated SNR over subcarriers at 50 km. It is seen that the SNR of the SP-QAM based conventional OFDM was degraded when the length of GI was zero. Conventional OFDM uses the sinc function with infinite spectral tails. When the orthogonality is broken, this system is more vulnerable to the ISI/ICI induced by dispersion and low-pass responses of devices than offset-QAM OFDM. Increasing the length of GI can mitigate the impairments but at the expense of reduced net data rate. A GI of 8 samples was required to achieve similar performance as SP-offset-QAM OFDM, resulting in ~ 6.25% loss in the net data rate for the FFT size of 128.

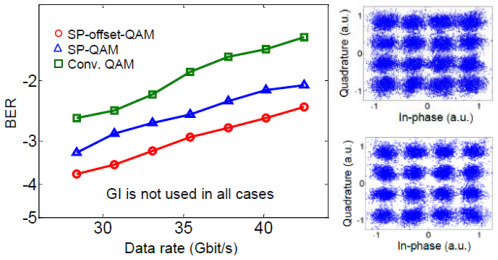


Fig. 7. BER of conventional OFDM using QAM and SP-QAM, and SP-offset-QAM OFDM at 50 km. Right column shows the constellations of subcarriers at 30-Gb/s overall rate allocated with SP-128QAM for SP-QAM OFDM (top) and SP-offset-QAM OFDM (bottom) without GI.

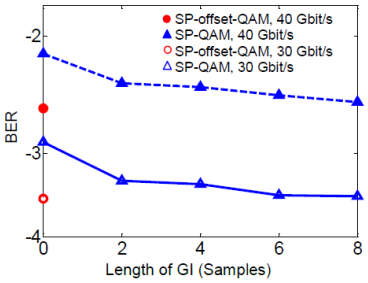


Fig. 8. BER versus the length of GI for SP-QAM OFDM and SP-offset-QAM OFDM at 50 km.

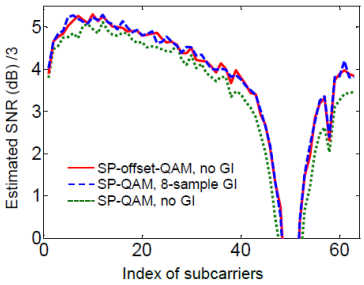


Fig. 9. SNR versus the index of subcarriers for SP-QAM OFDM and SP-offset-QAM OFDM.

4. Summary

We have proposed an adaptive loading algorithm for SP-QAM formats that can be applied to any multi-carrier systems. Their performances have shown to outperform conventional adaptively loaded OFDM or offset-QAM OFDM in IM/DD systems. The SP-offset-QAM OFDM has been shown to achieve >40 Gbit/s over 50-km SMF without any GI and thus it is promising to realize higher data rate for IM/DD systems. The work was supported by Science Foundation Ireland (SFI) grant 15/CDA/3652 (please check if a HK grant should be acknowledged here).

5. References

[1] M. Karlsson et al., "Which is the most power-efficient modulation format in optical links," *Opt. Express* (Optical Society of America, 2009) vol. 17, pp. 10814.

[2] S. Alreesh et al, "Transmission performance of 4D 128SP-QAM with forward error correction coding," *IEEE Photonics Technology Letters* (IEEE, 2015), vol. 27, pp. 744.

[3] R. R. Muller et al., "Multi-dimension coded PAM4 signaling for 100 Gb/s short reach transceivers," in *Optical Fiber Communication Conference (OFC)* (Optical Society of America, 2016), paper W1I.2.

[4] P. S. Chow et al., "A practical discrete multi-tone transceiver loading algorithm for data transmission over spectrally shaped channels," *IEEE Transactions on Communications* (IEEE, 1995), vol. 43, pp. 773.

[5] J. Zhao, "DFT-based offset-QAM OFDM for optical communications," *Opt. Express* (Optical Society of America, 2014), vol. 22, pp. 1114.