Effective Symbol-Amplitude Scaling Scheme in DD-OFDM Transmitter with 4.3-dB Receiver-Sensitivity Improvement

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Abstract: A simple and effective scheme of symbol-amplitude scaling is proposed and experimentally demonstrated to significantly improve OFDM transmitter performance. Up to 4.3-dB sensitivity improvement is achieved for OFDM QPSK signal in a LR-PON scenario.

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1. Introduction

Driven by the rapidly increasing demands for broadband services, passive optical network (PON) has emerged as a promising candidate to economically provide high bandwidth to end-users. To achieve high capacity, low cost, and flexible bandwidth allocation, the use of orthogonal frequency division multiplexing (OFDM) with direct detection (DD) (DD-OFDM) has attracted great attention [1]. However, when implemented in a PON scenario, especially in a long-reach (LR) PON system, the intrinsic high-peak nature of the OFDM signal prevents high receiver sensitivity of the system, resulting in a constrained power budget [1]. Diverse schemes have been investigated and most of them focus on effective reduction of signal peaks, i.e., reduction of peak-average power ratio (PAPR) [2-4]. By equalization of constellation symbols with a prefixed matrix to obtain reduced PAPR, a sensitivity improvement of 2.5 dB was observed in [2]. Recently, we also exploited unused frequency guard band to achieve 2.8-dB sensitivity improvement [4]. However, these schemes exhibit high complexities.

Here, we propose and experimentally demonstrate a simple yet effective scheme of symbol-amplitude scaling to significantly improve the transmitter performance and therefore the receiver sensitivity in a LR OFDM-PON. In our proposed scheme, by multiplying a self-adaptive scaling factor, low-amplitude OFDM symbols can be upscaled. Benefiting from the increased swing range of the transmitted sequence, more electrical power can be transferred onto lightwave and the electrical SNR at the receiver side can be increased [4]. System demonstration with QPSK modulated OFDM signals over 80-km fiber transmission is performed. Compared to conventional scheme, up to 4.3-dB sensitivity improvement is achieved at a prefixed forward error correction (FEC) threshold (BER = 10^{-3}). Experimental results verify our scheme as a promising method to multiply end-users by a factor of ~2.7. Furthermore, the proposed scheme exhibits attractive advantages of very low implemented complexity with no additional operation required at receiver side, and good compatibility with PAPR reduction methods.

2. Operation principle

Electro-optic modulation of OFDM signal is considered quasi-linear, which is usually assured by aligning the dynamic range of a digital-to-analog convertor (DAC) with the linear region of a Mach-Zehnder modulator (MZM) [5]. An OFDM sequence usually consists of hundreds of symbols, which are defined as the output of a single inverse fast Fourier transform (IFFT) operation [6]. Since OFDM symbols carry different information, the amplitude distribution varies from one symbol to another. As illustrated in Fig. 1(a), where a segment of an OFDM sequence is depicted, the DAC range is fitted by symbol 3, whereas other symbols exhibit relatively low swing amplitude. Consequently, the linear region of a MZM would only be partially exploited for the majority of the symbols, leading to a low modulation index. An improved modulation index means that more electrical signal energy can be delivered, and the receiver sensitivity can thus be improved [7]. The proposed symbol-amplitude scaling scheme is illustrated in Fig. 1(b), where each OFDM symbol is weighted by a real scaling factor. The factor is determined as the ratio of

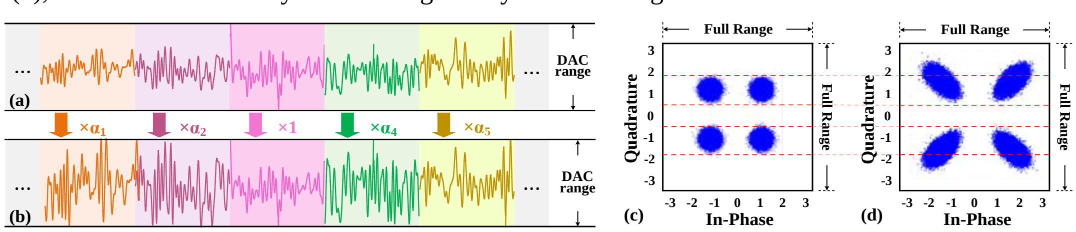

Fig. 1. Waveforms of (a) conventional OFDM symbols and (b) scaled OFDM symbols. Measured accumulated constellation diagrams of (c) conventional sequence and (d) scaled sequence for a received optical power of –26 dBm after 80-km fiber transmission.

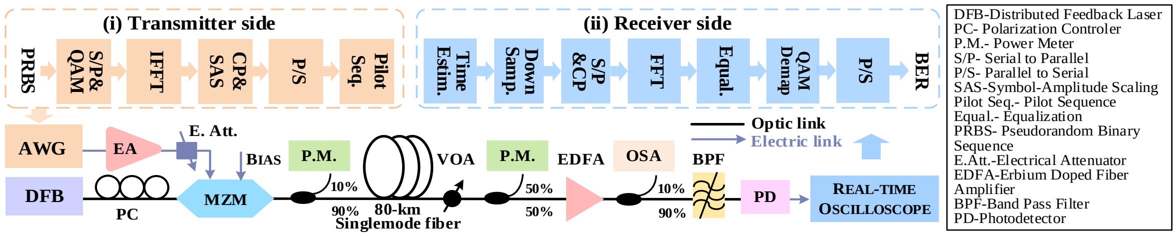

Fig. 2. Block diagram of the experimental setup for an OFDM-PON system with the proposed symbol-amplitude scaling scheme.

symbol's maximal peak to that of the whole sequence. By this means, the great majority of the symbols can be upscaled and the power of the transmitted signal can be highly increased. An upscaled symbol results in an increased Euler distance and therefore an ellipse-like accumulated constellation diagram, as presented in Fig. 1(d). The unscaled diagram is depicted in Fig. 1(c). The data in Fig. 1(c) and 1(d) are taken from experimental measurement.

3. Experimental demonstration

We performed a proof-of-concept experiment to assess the sensitivity improvement brought by the proposed scheme, as presented in Fig. 2. The OFDM sequences are generated offline by Matlab and output by an arbitrary waveform generator (AWG) (Tektronix 7122C) with a 5-GSa/s sampling rate. Such a low sampling rate is chosen for a better frequency response and an alleviation of power fading [8]. Three subcarrier numbers, N = 64, 128, and 256 are used. The symbol number is 1000 and QPSK mapping is adopted with Hermitian symmetry. Symbol-amplitude scaling is then applied. Channel estimation and time synchronization is provided by a pilot sequence of 20 symbols. To ensure a quasi-linear conversion, an electrical amplifier (EA) together with electrical attenuators are employed to align the range of DAC to the linear region of the MZM. The light is launched into an 80-km fiber with 5-dBm launch power. Due to the lack of avalanche photodetectors (APDs), the signal is detected through a pre-amplified receiver comprising of an EDFA, a 0.8-nm BPF, and a 10-GHz PD. The offline processing steps are shown in the insets of Fig. 2.

Figure 3(a) and (b) show the measured BER curves of the proposed scaled sequences and the conventional sequences for back-to-back (B2B) and 80-km fiber transmission, respectively. The power penalty is ~1.9 dB. Significant transmission performance improvements are observed. The received power at the FEC threshold for a conventional 64-subcarrier sequence is –29 dBm over 80-km fiber transmission, which is 4.3-dB higher compared to the scaled one. Moreover, improvements of 3.6 dB and 3.4 dB are obtained for sequences with 128 and 256 subcarriers, respectively. Sensitivity improvements are due to the fact that the upscaled symbols own a larger Euler distance between adjacent constellation symbols, leading to an increased SNR at the PD. In addition, mitigated quantification noise at both transmitter and receiver sides can also improve the transmission performance. As a result, the ellipse-like constellation diagram at a given received optical power shows a higher error vector magnitude (EVM) level and a much lower BER value compared to the conventional one, as shown in the insets of Fig. 3(b).

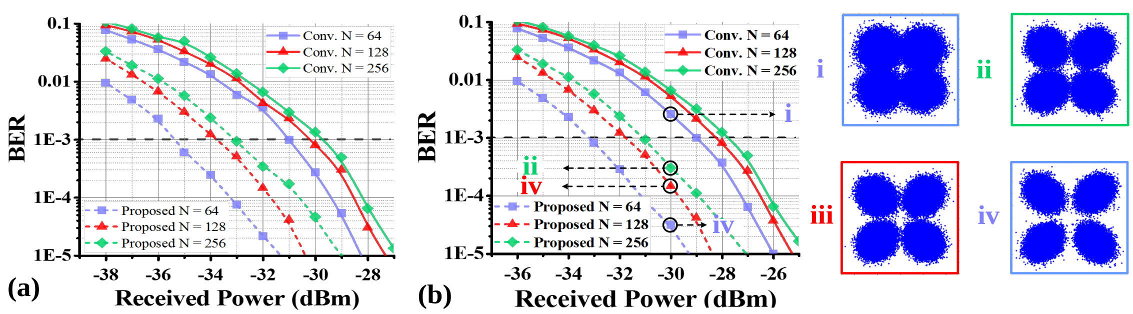

Fig. 3. Measured BER curves versus received optical power for the scaled and unscaled sequences (a) for B2B condition, (b) after 80-km fiber transmission. Insets (i)-(iv) present constellation diagrams of received scaled and conventional sequences at the receiver power of –30 dBm.

4. Conclusion

By utilizing amplitude margins of OFDM symbols, a receiver-sensitivity improvement scheme implemented in the transmitter is proposed and experimentally demonstrated for an OFDM-PON system. The feasibility was verified by a system demonstration where a sensitivity improvement of 4.3 dB was recorded for QPSK modulated 64-subcarrier OFDM signal over 80-km fiber transmission.

5. References

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