Sensitivity Improvement in IM-DD OFDM-PON by Amplitude Scaling and Subcarrier Enabled PAPR Reduction

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Abstract: An effective sensitivity-improving scheme combining symbol-amplitude scaling and peak-amplitude reduction is proposed for IM-DD OFDM-PONs. Sensitivity improvements of 3.8 dB and 4 dB are observed in two ONUs with 40-km and 80-km transmission distances, respectively.

OCIS codes: (060.4510) Optical communications; (060.4080) Modulation

1. Introduction

Fueled by the exponential growth for new broadband services, spectral-efficient optical orthogonal frequency division multiplexing (OFDM) has been emerged as an attractive technology and can be used in the next-generation passive optical network 2 (NG-PON2). In such access networks, OFDM enjoys the merits of robust dispersion tolerance and flexible bandwidth allocation. However, when implemented in intensity-modulated direct-detection PON (IM-DD PON) scenarios, the high peak-to-average power ratio (PAPR) of an OFDM signal can result in a degraded receiver sensitivity and therefore a constrained power budget.

An improved receiver sensitivity can be achieved by simply increasing optical modulation index. This is often realized by an effective PAPR reduction, such as partial transmit sequences (PTS) [1], null-tone shifting (NTS) [2], and tone reservation using guard band [3]. With a reduced PAPR, more electrical power can be delivered by lightwave and a desired electrical SNR can be obtained with less optical power. In [2], a 2.6-dB improvement on receiver sensitivity was obtained with ~2-dB PAPR reduction. Alternatively, to improve the optical modulation index, we proposed a simple scheme of symbol-amplitude scaling [4] which weights each OFDM symbol with its adaptive scaling factors. Sensitivity improvement by 3.4 dB was achieved for 256-subcarrier signals. But those improvements may not be sufficient for practical applications.

Based on our previously proposed two methods [3,4], here we develop an effective scheme to further optimize an IM-DD OFDM transmitter in both frequency and time domains, achieving a better receiver sensitivity improvement. In this scheme, the deeply-attenuated high-frequency subcarriers are utilized to reduce the signal's peaks, combining with the symbol-amplitude scaling scheme to adaptively upscale symbols' swing range. By this means, the optical modulation index can be greatly increased, leading to improved receiver sensitivity. A proof-of-concept experiment using 8.64-Gbps 16-point quadrature amplitude modulation (16-QAM) OFDM signals is performed in an IM-DD OFDM-PON. In comparison with conventional schemes, 3.8-dB and 4-dB sensitivity improvements are obtained by using our proposed one at a bit-to-error ratio (BER) threshold of 2×10^{-3} for optical network units (ONUs) with transmission distances of 40 km and 80 km, respectively.

2. Operation principle

Owing to anti-alias filters, the roll-off frequency response of a digital-to-analog converter (DAC) can be one major impairment in an IM-DD OFDM system. Fig. 1(a) shows the measured electrical spectrum of a received 4-GHz-bandwidth OFDM signal output by a DAC with a 3.2-GHz analog-bandwidth. The high-frequency subcarriers are ~10 dB lower than the low-frequency ones. These subcarriers with low signal-to-noise ratios (SNRs) can lead to a poor BER performance when carrying information. In our scheme, we categorize the subcarriers as signal tones in low frequencies and PAPR reduction tones (PRTs) in high frequencies. Clipping components of an OFDM signal can be projected onto PRTs to cancel the signal peaks, while no distortion would affect the signal tones. We use an iterative PAPR-reduction algorithm [3] and present complementary cumulative distribution functions (CCDFs) in Fig. 1(b). Compared with the original signal, PAPR reductions of 1.7 dB, 2.2 dB, and 2.7 dB are achieved for 5, 10,

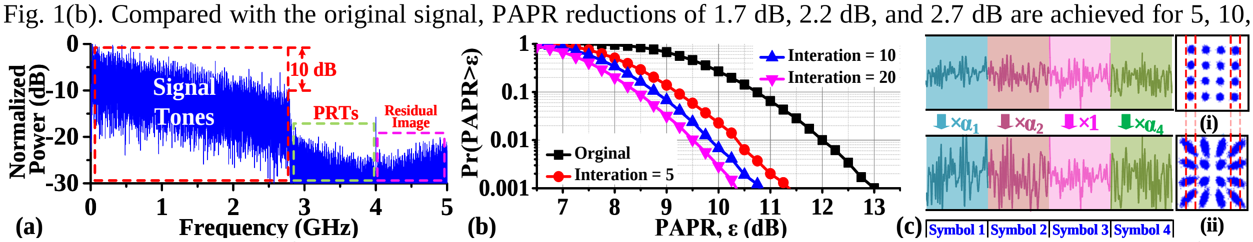

Fig. 1. (a) Electrical spectrum of a 4-GHz-bandwith OFDM signal, in which signal tones and PRTs are indicated. (b) CCDF curves for the conventional signals and the peak-reduced signals for 5, 10, and 20 iterations, respectively. (c) Waveform segment of the conventional and upscaled signals. Inset (i) and (ii) depict the accumulated constellation diagrams for the two signals, respectively.

and 20 iterations, respectively. A PAPR-reduced signal means that more electrical energy can be carried in the same DAC range, leading to an improved optical modulation index.

On the other hand, with different temporal waveforms for the OFDM symbols, the dynamic range of the DAC can hardly be fully exploited for the signal, resulting in an insufficient optical modulation index. A scaling factor adaptive to each symbol has recently been proven effective for receiver-sensitivity improvement [4]. Fig. 1(c) shows the principle of the symbol-amplitude scaling used in our scheme. The DAC dynamic range can be fully utilized by multiplying OFDM symbols with their respective scaling factors. The peak-reduced signal can thus be processed in the same way to maximize the transmitted electrical energy and to fully exploit the linear region of the Mach-Zehnder modulator (MZM). An enhanced electrical SNR and an improved receiver sensitivity can be obtained.

3.Experimental demonstration

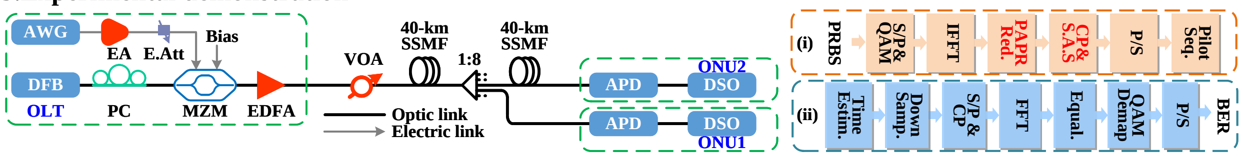

Fig.2. Experimental setup for a proof-of-concept IM-DD OFDM system by using our proposed scheme. Insets (i) and (ii) show the DSP processing for the transmitter and receiver, respectively. (DFB: distributed feedback laser, PC: polarization controller, E.Att: electrical attenuator, S/P: serial to parallel, P/S: parallel to serial, PAPR Red.: PAPR reduction, S.A.S.: symbol-amplitude scaling, Pilot Seq.: pilot sequence insertion, Equal.: equalization)

Fig. 2 shows a proof-of-concept experiment to assess the sensitivity improvement brought by our scheme in an IM-DD OFDM-PON. In the optical line terminal (OLT), a continuous-wave light at 1547.52 nm is fed into a MZM biased at quadrature point of its transmission curve. The OFDM signal is generated offline by Matlab and output by an arbitrary waveform generator (AWG) (Tektronix 7122C) with an 8-GSa/s sampling rate and a 3.2-GHz analog bandwidth. The OFDM signals with 1000 symbols are built from 16-QAM symbol mapping. To realize IM-DD modulation, Hermitian symmetry is imposed to all 256 subcarriers of the signal. The first 90 subcarriers serve as signal tones for the OFDM signal. The 91^{st}–128^{th} subcarriers are vacant for conventional signals while they are used as PRTs in our proposed scheme for an effective PAPR reduction. After inverse fast Fourier transform (IFFT), a 16-point cycle prefix (CP) is added. Symbol-amplitude scaling is then applied to the peak-reduced signal to increase the symbol's swing range. An electrical amplifier (EA) is employed to carefully align the signal's amplitude with the linear region of the MZM. The modulated light is fed into a 40-km SSMF with a 5-dBm launch power. The downlink signal is then split by a 1:8 splitter. Two ONUs are tested in our experiment with one split signal being routed to ONU_1 through a 40-km distribution fiber, while another towards ONU_2 via a short-distance (~3 m) distribution fiber. In the receiver side, the light is detected through an avalanche photodetector (APD), followed by a digital storage oscilloscope (DSO) (LeCroy 36Zi-A) operating at 40 GSa/s sampling rate to sample the electrical signals. The demodulation is performed offline, whose steps are shown in the inset of Fig. 2. For the sake of simplification, we use the prior-know scaling factors to descale OFDM symbols for each ONU.

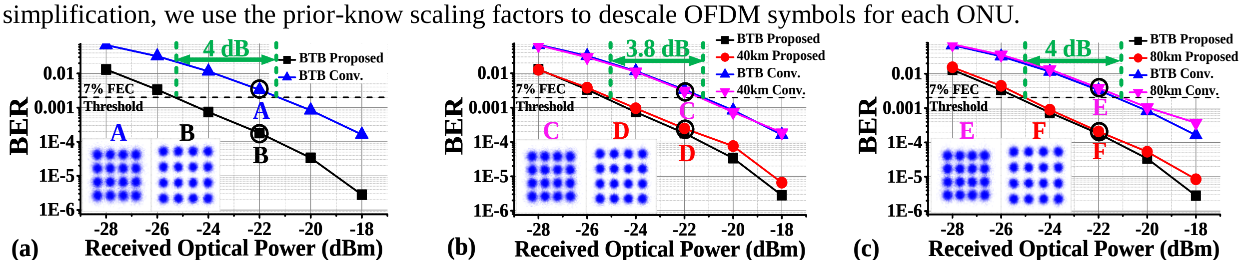

Fig. 3 (a) Measured BER curves for BTB condition. (b) and (c) Measured BER curves for 40-km ONU_1 and 80-km ONU_2, respectively. BTB curves are added as referential curves. Insets show the corresponding constellation diagrams.

Fig. 3 depicts the BER curves for back-to-back (BTB), 40-km ONU_1 and 80-km ONU_2 cases, respectively. In the BTB condition, our scheme improves the receiver sensitivity by 4 dB. After transmissions, 3.8-dB and 4-dB sensitivity improvements are achieved respectively in the two ONUs. The 4-dB improvement can be translated to a distance extension of ~22.2 km or an increase of end-user numbers by a factor of ~2.51 in a PON scenario.

4.Conclusion

We have proposed and experimentally demonstrated sensitivity improvement in an IM-DD OFDM system by high-frequency subcarrier enabled PAPR reduction and symbol scaling to increase the signal modulation index. Significant sensitivity improvements of 3.8 dB and 4 dB are respectively achieved in two ONUs with transmission distances of 40 km and 80 km.

5.References

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