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PAPR Reduction in DCO-OFDM and PAM-DMT Based VLC Systems

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Abstract: In this paper, a pilot-assisted scheme is used to reduce the peak-to-average power ratio of multicarrier signalling based visible light communication systems and the system throughput is maximised with bit and power loading.

1. Introduction

In wireless communication, there is increasing interest in using the huge, unlicensed visible light communication (VLC) spectrum for connectivity. VLC systems use off-the-shelf front end devices i.e. light emitting diodes (LEDs) and photodiodes (PDs). The data transmission mechanism in VLC is based on intensity modulation with direct detection (IM/DD) which restricts the transmitted signal to be real and non-negative. Multicarrier modulation techniques are attractive candidates for VLC systems due to their intersymbol interference (ISI) mitigation, multiple path propagation resilience and simplified equalisation process [1]. However, multicarrier signalling techniques are affected by high peak-to-average power ratio (PAPR). Two multicarrier modulation techniques are considered in this study; these are direct-current optical orthogonal frequency division multiplexing (DCO-OFDM) and pulse-amplitude-modulated discrete multitone (PAM-DMT). In DCO-OFDM, the bipolar signal is converted to unipolar by adding direct current (DC) bias, whereas in PAM-DMT, zero level clipping process is performed to obtain the real time domain signal.

Due to the limited dynamic range of VLC light sources and high PAPR of the multicarrier modulation techniques, the pilot-assisted (PA) scheme is applied to reduce the high PAPR. PAPR reduction allows for higher input signal swing levels while minimising the non-linear distortion that results from operating beyond the dynamic range of the optical source; LED in this case.

In this paper, the high PAPR of the transmitted signal of DCO-OFDM and PAM-DMT is reduced by the low computational complexity PA scheme whose details can be found in [1]. The performance of the resulting PA-DCO-OFDM and PA-PAM-DMT with adaptive bit and power loading is investigated experimentally in terms of bit error rate (BER) and achievable data rate. The performance of PA-DCO-OFDM and PA-PAM-DMT is compared to that of conventional DCO-OFDM and PAM-DMT.

2. Experimental Setup

The experiment starts by generating DCO-OFDM/PAM-DMT time domain signal that have their PAPR reduced by PA scheme. The pilot sequence with the lowest PAPR value is embedded to their corresponding block of frames. The signal is generated in MATLAB and sent to arbitrary waveform generator (AWG) (81180A). The output of the AWG is DC-biased with bias-tee (ZFBT-4R2GW+) at optimum bias current value of I_{DC} = 20 mA, and an optimum signal depth, V_{pp} = 450 mV is used. The optimum values are selected to give the highest signal-to-noise ratio (SNR) per subcarrier and hence achieve the highest data rate. The bias-tee output is fed to a blue LED (VLMB1500-GS08) which has a -3 dB bandwidth of 11.7 MHz. The output of the LED is collimated and focused on the active area of a PD (PDA10A-EC-Si) using aspheric condenser lenses. The link distance is 1 meter. The PD output is connected to an oscilloscope (MSO-X-3104T) then captured and processed off-line.

First, the SNR in each subcarrier is evaluated. Then, bit and power loading is applied to maximise the achievable data rate. In bit and power loading, the modulation level per subcarrier M_k is determined by the available SNR_k per subcarrier k and the target forward error control (FEC) level of 3.8×10^{-3}. The BER of quadrature amplitude modulation (QAM) modulated DCO-OFDM can be approximated as [2]:

$$\mathrm{BER}_{(M_k,\mathrm{SNR}_k)} \approx \frac{4(1-\frac{1}{\sqrt{M_k}})}{\log_2(\mathrm{M_k})} \times \sum_{l=1}^{\min(2,\sqrt{\mathrm{M_k}})} Q\left((2l-1)\sqrt{\frac{3\times \mathrm{SNR}_k}{(M_k-1)}}\right) \tag{1}$$

For pulse amplitude modulation (PAM) format, the BER is approximated as [3]:

$$\mathrm{BER}_{(M_k,\mathrm{SNR}_k)} \approx \frac{2}{\log_2(M_k)} \times (1 - \frac{1}{M_k}) \times \sum_{l=1}^{\min(2,\sqrt{\mathrm{M_k}})} Q\left((2l-1)\sqrt{\frac{6 \times \mathrm{SNR}_k}{(M_k^2-1)}}\right) \tag{2}$$

The number of data subcarriers used is N_{subs} = 127, IFFT size, N_{IFFT} = 1024, and cyclic prefix size, N_{CP} = 5. Oversampling factor of $L = 4$ and pilot iterations number, $R = 10$ are used in this experimental work.

PA-DCO-OFDM and PA-PAM-DMT with bit and power loading systems are transmitted over the VLC channel at different sampling rates, F_s = [40, 80, 200, 400, 800, 1000] MSa/s. The sytem data rate, R_b, is calculated as [2]:

$$R_b = \frac{\sum_{k=1}^{\frac{N_{\text{IFFT}}}{2}} \log_2 M_k}{(N_{\text{IFFT}} + N_{\text{CP}})/2B} \quad \text{(bit/second)} \tag{3}$$

where B is the single-sided modulation bandwidth of the system.

3. Experimental Results and Discussions

Fig. 1 compares the experimental BER of DCO-OFDM and PAM-DMT with the corresponding PA schemes at varying transmission rates. For both cases, the PA scheme results in improved system BER. This is due to the PAPR

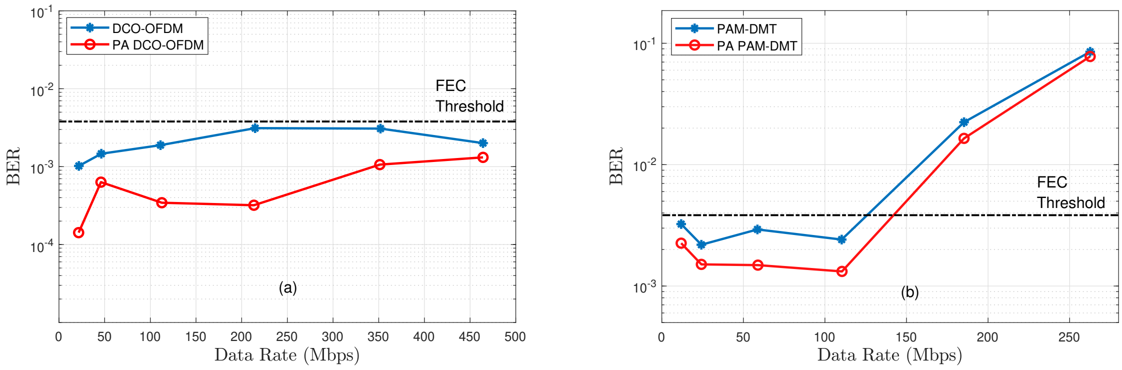

Fig. 1. Experimental BER versus data rate of (a) DCO-OFDM and (b) PAM-DMT with PA PAPR reduction.

reduction which minimises the clipping noise and distortion level in the system. Consequently, the system SNR is improved and hence enhanced BER performance. At higher transmission rates, far beyond what the available link bandwidth can support, severe distortion in the system causes error in the PA pilot sequence estimation. This is shown to result in the BER of PA systems approaching that of the conventional systems with no PAPR reduction. The results demonstrate that the PA PAPR reduction approach can be used to improve the system performance while retaining the high transmission rate capability of the multicarrier modulation techniques.

4. Conclusion

Pilot-assisted scheme is used to reduce the PAPR of multicarrier modulated VLC systems, improve the error performance without data rate degradation. The achieved BER and SNR enhancement by the PA scheme can be traded for longer range and/or higher data rate transmission compared to the conventional multicarrier systems with no PAPR reduction. In addition, the PA scheme has the potential to reduce the transmitted average optical power resulting in increased the reliability and life time of the LED.

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