Indoor OFDM Visible Light Communications Employing Adaptive Digital Pre-Frequency Domain Equalization

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Abstract: We experimentally demonstrate an indoor OFDM-VLC system employing an adaptive digital pre-frequency domain equalization (pre-FDE) technique. By adaptively optimizing the modulation bandwidth of the OFDM signal, the proposed pre-FDE technique can maximize the system capacity.

OCIS codes: (060.2605) Free-space optical communication; (230.3670) Light-emitting diodes; (060.4230) Multiplexing.

1. Introduction

White light-emitting diodes (LEDs) enabled visible light communication (VLC) is a promising candidate for future indoor high-speed wireless access, owing to its inherent advantages such as license-free spectrum, high security and immunity to electromagnetic interference [1,2]. As a spectral-efficient modulation scheme, orthogonal frequency-division multiplexing (OFDM) has been intensively applied in VLC systems so as to overcome the limited modulation bandwidth of LEDs [3]. In order to further improve the capacity of OFDM-VLC systems, two main techniques have been proposed: one is bit and power loading [4] and the other is pre-frequency domain equalization (pre-FDE) [5,6]. As reported in [7], OFDM-VLC systems can achieve similar data rate employing either the bit and power loading technique or the pre-FDE technique. However, practical implementations of the bit and power loading technique are relatively difficult since different orders of quadrature amplitude modulation (QAM) constellations might be applied to different subcarriers. In contrast, the pre-FDE technique is simpler and more suitable for practical applications since all the subcarriers use the same order of QAM constellation. Moreover, pre-FDE can be effectively implemented by either hardware circuits [5] or software digital signal processing (DSP) [6]. Compared with hardware circuits based pre-FDE which usually has a fixed modulation bandwidth, the modulation bandwidth of software based digital pre-FDE can be dynamically adjusted in practical OFDM-VLC systems.

In this work, for the first time, we experimentally demonstrate an indoor OFDM-VLC system employing a novel adaptive digital pre-FDE technique. By using the proposed adaptive digital pre-FDE technique, the modulation bandwidth of the OFDM signal can be adaptively optimized according to the estimated signal-to-noise ratio (SNR) information and thus the achievable data rate of the indoor OFDM-VLC system is maximized.

2. Principle and experimental setup

The principle of the proposed adaptive digital pre-FDE technique for indoor OFDM-VLC systems is illustrated in Fig. 1. Pre-FDE is adaptively performed in the OFDM transmitter (Tx) according to the estimated SNR information. SNR estimation is executed in the OFDM receiver (Rx) and the obtained SNR information is then fed back to the OFDM Tx. Using the feedback SNR information, an optimal modulation bandwidth can be achieved for the OFDM signal. Fig. 1 shows the experimental setup. The digital OFDM signal is generated in the OFDM Tx via serial-to-parallel (S/P) conversion, QAM mapping, pilot insertion, pre-FDE, IFFT, CP insertion and parallel-to-serial (P/S) conversion. In the OFDM Rx, the received digital OFDM signal is demodulated via S/P conversion, CP removal, FFT, post-FDE, QAM demapping and P/S conversion.

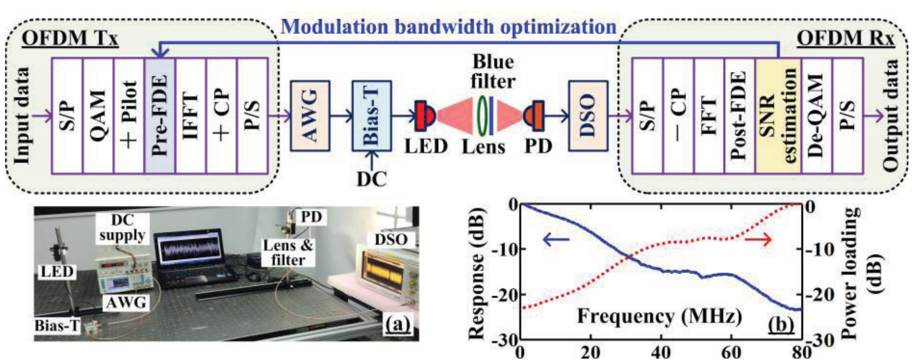

Fig. 1. Experimental setup. Insets: (a) photo of the overall system and (b) frequency response and power loading coefficients of pre-FDE.

The digital OFDM signal is generated offline by MATLAB with an IFFT size of 256 and a CP length of 8, which is loaded to an arbitrary waveform generator (AWG, Tabor WW2074) with a sampling rate of 200 MSa/s. The modulation bandwidth of the generated OFDM signal can be dynamically adjusted by allocating different number of subcarriers for data transmission. The analog OFDM signal is superimposed onto a DC bias without electrical pre-amplification through a bias-T (Mini-Circuits, ZFBT-6GW+), which is then used to drive a commercially available white LED (Luxeon Star). After passing through an optical lens and a blue filter, the resultant light is received by a photodetector (PD, Thorlabs PDA10A-EC). The detected signal is recorded by a digital storage oscilloscope (DSO, Agilent infiniium 54832B) with a sampling rate of 4 GSa/s. The photo of the overall system is shown in Fig. 1(a). The measured normalized electrical-optical-electrical (EOE) frequency response and the corresponding power loading coefficients of the pre-FDE are shown in Fig. 1(b). As we can see, the 3-dB bandwidth of the system was about 13 MHz after blue filtering and the power fading for 80 MHz bandwidth is more than 20 dB.

3. Results and discussions

Using the measured power loading coefficients, adaptive pre-FDE was performed digitally for various modulation bandwidths. Fig. 2(a) depicts the measured electrical spectra of OFDM signals after performing pre-FDE over 1.0 m indoor transmission. It can be found that, for a fixed transmitted electrical power, the SNR of the received pre-equalized OFDM signal gradually decreases with the increase of the modulation bandwidth. For each modulation bandwidth, as shown in Fig. 2(b), the achievable maximum QAM constellation order is examined. As can be seen, the maximum QAM constellation order is decreased as the modulation bandwidth increases. Moreover, the maximum QAM constellation order is further decreased when the transmission distance is increased.

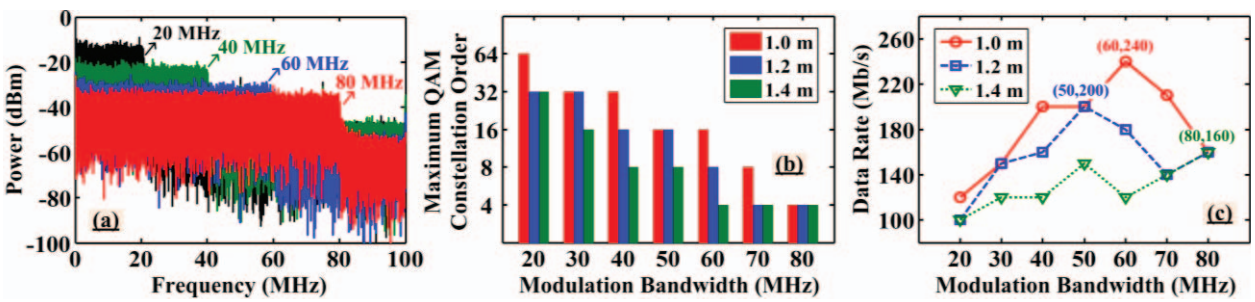

Fig. 2. (a) Electrical spectra after performing pre-FDE, (b) maximum QAM constellation order versus modulation bandwidth and (c) achievable data rate versus modulation bandwidth.

The achievable data rate of an OFDM-VLC system is given by $R = B\log_2 M$ where B is the modulation bandwidth of the OFDM signal and M is the achievable maximum QAM constellation order. Fig. 2(c) shows the achievable data rate versus modulation bandwidth. When the distance is 1.0 m, the maximum data rate is 240 Mb/s with an optimal modulation bandwidth of 60 MHz. However, when the distances are increased to 1.2 and 1.4 m, maximum data rates of 200 and 160 Mb/s are achieved with 50 and 80 MHz modulation bandwidths, respectively. Therefore, the achievable data rate of an indoor OFDM-VLC system can be maximized by employing adaptive digital pre-FDE.

4. Conclusions

We have experimentally demonstrated an indoor OFDM-VLC system employing adaptive digital pre-FDE. By adaptively optimizing the modulation bandwidth of the OFDM signal, the achievable data rate of the system can be maximized in practical indoor environments. In the demonstration, a maximum data rate of 240 Mb/s is achieved over 1.0 m indoor transmission with an optimal modulation bandwidth of 60 MHz. To the best of our knowledge, it is the first time that an adaptive digital pre-FDE technique has been implemented in indoor OFDM-VLC systems.

5. References

[1] H. Haas, “Visible light communication,” in Proc. OFC, paper Tu2G.5 (2015).
[2] M. Rahaim, et al., “Toward practical integration of dual-use VLC with 5G networks,” IEEE Wireless Commun. **22**, 97–103 (2015).
[3] H. Elgala, et al., “OFDM visible light wireless communication based on white LEDs,” in Proc. VTC, pp. 2185–2189 (2007).
[4] J. Vucic, et al, “513 Mbit/s visible light communications link based on DMT-modulation of a white LED,” J. Lightw. Technol. **28**, 3512-3518 (2010).
[5] X. Huang, et al., “750Mbit/s visible light communications employing 64QAM-OFDM based on amplitude equalization circuit,” in Proc. OFC, paper Tu2G.1 (2015).
[6] Y. Liu, et al., “Equalization and pre-distorted schemes for increasing data rate in in-door visible light communciation system,” in Proc. OFC, paper JWA83 (2011).
[7] J. Li, et al, “Hybrid time-frequency domain equalization for LED nonlinearity mitigation in OFDM-based VLC systems,” Opt. Express **23**, 611-619 (2015).