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Optical Wireless Communication System with PAPR Reduction

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***Abstract*:** Optical wireless communication has been recently proposed as a viable alternative to RF wireless communication. The optical wireless systems involve intensity modulation of the optical signal using various digital modulation schemes such as On-Off Keying (OOK), Pulse Code Modulation (PCM) and so on. Multicarrier modulation scheme known as Orthogonal Frequency Division Multiplexing (OFDM) is the growing trend in LED optical wireless systems due to its inherent robustness against Inter Symbol Interference (ISI) as the symbol period of each subcarrier can be made longer than the delay spread of the multipath distortion. Orthogonal frequency division multiplexing (OFDM) is a method of parallel transmission of data on multiple subcarriers. However, OFDM inherently causes Peak-to-Average Power Ratio (PAPR) problem when the parallel data streams are summed up to create the OFDM signal which results in nonlinear signal distortion. The main aim of this work is to reduce the PAPR of the OFDM signal which can be used for intensity modulated-direct detection (IM-optical wireless communication system. A method of nonlinear exponential companding transform is used to reduce the peak-to-average-power ratio in OFDM signal. The comparison of OFDM signal with and without PAPR reduction is done to analyze the performance. The optical wireless communication channel is implemented for the further analysis of the system.

Keywords- *Optical Wireless Communication (OWC); Light Emitting Diode (LED); Peak to Average Power Ratio (PAPR); Orthogonal Frequency Division Multiplexing (OFDM); nonlinear companding, Visible Light Communication (VLC).*

I. Introduction

Growing demand for higher internet speeds and low power consumption motivates the researchers to upgrade the existing communication infrastructure. Optical wireless communication has explored as a promising advancement in wireless communication technology. High quality data transmission, unregulated and unlicensed electromagnetic spectrum, immunity to electromagnetic interference and highly secured communications are the major factors for the new momentum of optical wireless systems. Thus optical wireless technology is considered as a low cost

supplement or even an alternative to the RF technology. Optical radiations with wavelengths ranging from Infrared (IR) to Ultraviolet (UV) including visible light spectrum are used to convey information in optical wireless communication. The deployment of energy efficient solid state lighting devices in general lighting has led to the realization of Light Emitting Diodes (LED) as the major visible light source of Optical Wireless Communication. Since this emerging technology provides both communication and lighting simultaneously it is called as Visible Light Communication (VLC).

LED"s present a number of advantages over conventional light sources that makes them the ideal component for VLC systems, with the most important being the fact that any LED is a semiconductor, and therefore has an inherent fast switching ability. The added advantage of LED also includes long lifetime and high power efficiency. As the LED is deployed for the primary function of lighting, the value-added communication function can be implemented at very little extra cost [1]. But, interference from the illumination sources such as fluorescent light sources or AC-power LED can degrade the performance of the optical wireless link and forms the major challenge in the implementation of LED optical wireless system. Also, with many LEDs used, there would be multipath propagation that leads to inter-symbol interference (ISI). ISI is a severe obstacle in VLC, as it can degrade the data rate of the system as well as bit error rate (BER) performance [2].

In an optical communication the phase/frequency, polarization, or the intensity of the optical signal can be modulated. In intensity modulation, the optical output power of the source is varied according to the modulating signal and hence it is easy to implement. The optical signal thus produced can be easily detected by the direct detection of the photodiode [3]. The advanced multicarrier modulation such as Orthogonal Frequency Division Multiplexing (OFDM) provides an excellent choice for the intensity modulation of the optical signal and to reduce the multipath effects. The time domain OFDM signal is used to modulate (IM-DD) the optical source. However, the inherent disadvantage of OFDM is the peak-to-average power ratio (PAPR) problem when the parallel data streams are summed up to create the OFDM signal which causes nonlinear signal distortions. Due to the high peak power, LED chips may be overheated. Therefore, the high PAPR of the OFDM signal should be reduced before it is fed into transmitter LEDs.This paper proposes an optical wireless communication system with a reduction in the high PAPR of OFDM signal which is used for intensity modulation. The exponential companding technique is used to improve the performance of PAPR reduction in this optical wireless communication system.The paper is organized as follows. Section II describes the OFDM technique in VLC. Section III explains about PAPR and exponential companding function. Section IV describes the proposed optical wireless communication system with exponential companding technique to reduce the PAPR. The results of the simulation are discussed in Section V and the conclusion is drawn in Section VI.

II. Ofdm In Vlc

The block diagram of OFDM technique in VLC is shown in Figure 1. At the transmitter, the serial stream of pseudorandom binary sequence (PRBS) data is demultiplexed into parallel streams, such that each is transmitted on a separate sub-carrier. The parallel bit streams are then mapped to 4-QAM (Quadrature Amplitude Modulation) constellation points. The Inverse Fast Fourier Transform (IFFT) operation modulates the sub-carriers and generates the time domain OFDM signal. A Cyclic Prefix (CP) is needed in wireless OFDM systems due to multipath propagation which acts as a guard interval and avoids ISI. To realize the CP, the last G samples of the OFDM symbol are repeated at the beginning. The minimum length for G is the channel impulse response duration. After CP insertion the OFDM symbols are upsampled and transmitted to the channel.

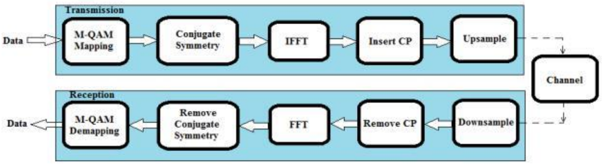

Figure 1. Block diagram of OFDM VLC system

The system can be analysed through an additive white gaussian noise channel. At the receiver, the received optical wireless signal is first converted to digital signals by analog to digital converter and then downsampled. After the downsampling operation the Cyclic Prefix is removed. These data symbols are then demodulated and converted to frequency domain N-1 samples by a Fast Fourier Transform (FFT). A 4-QAM demappingproduces the output parallel data streams and it is multiplexed to form the serial data output bits.

III. Papr And Exponential Companding Function

The original OFDM signal tends to have a high PAPR value since the subcarriers with the same phase may be added together and that creates signal peaks with high power. Since LEDs have a limited operating voltage range and nonlinear V-I characteristics, the high PAPR causes signal distortion and damages to LEDs at the signal transmission. The purpose of the companding function is to reduce the PAPR in such a way that it will limit those high peaks in the signal and reduce the peak power, as well as increasing the low signal values and the average signal power. Therefore, the ratio of peak and average powers will be reduced. This companding operation for reducing PAPR can readily be performed for VLC-OFDM signal as it is a real-valued signal. The exponential companding technique that is applied for OFDM systems in [2] is considered. For N subcarriers the time domain OFDM signal is represented as,

$$-1$$

$$1 \qquad 2$$

$$X_k = X_n \qquad (1)$$

$$=0$$

The PAPR of the discrete OFDM signal is the ratio of the maximum signal power to the average signal power [2], that is,

$$\mathrm{PAPR} = \frac{\max\{|X_k|^2\}}{E\{|X_k|^2\}},\ k \in [0,\ -1] \qquad (2)$$

Let the companded signal be *yn*. In VLC, the OFDM signal is a real-valued signal and the companding function is applied to the positive and negative amplitudes of the signal. Let the companding function be $f\,|x_k|$. Therefore,

$$= f\,|x_k| \qquad (3)$$

Let $|yn|^2$ be the squared magnitude of companded output and also assume it to be uniformly distributed over the interval [0, *a*], where *a* is an arbitrary value. Thus the exponential companding function can be derived as,

$$(x) = a\left[1 - \exp - \frac{x^2}{\sigma^2}\right] \qquad (4)$$

In order the average power level to remain unchanged during the companding operation, the value of „*a'* needs to be appropriately determined. That is,

$$E\{|xk|^2\} = E\{\,^2(|xk|)\} \qquad (5)$$

Hence,

$$a = \frac{E\{|Xk|^2\}}{E\{1-\exp - \frac{|Xk|^2}{\sigma^2}\}} \qquad (6)$$

At the receiver the inverse of the companding function is performed and is given by,

$$^{-1}(x) = -\sigma^2 \ln 1 - \frac{x^2}{a}] \qquad (7)$$

IV. Optical Wireless Communication System

WITH PAPR REDUCTION

The proposed optical wireless communication system with PAPR reduction is implemented using MATLAB R2014a, a digital to analog converter (DAC), LED driver, LED, photodiode (PD), amplifier and analog to digital converter (ADC). In the proposed system, the time domain OFDM signal after the CP insertion is fed to the exponential companding transform to reduce the peak to average power ratio of the OFDM signal as shown in Figure 2. The PAPR reduced signal is then up-sampled for transmission through the channel.

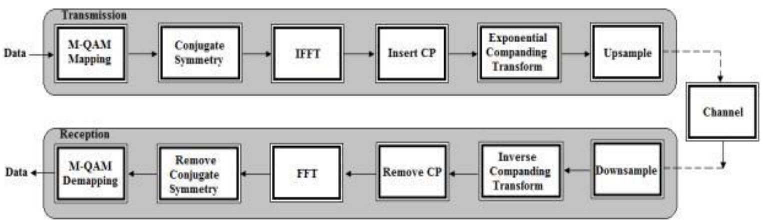

Figure 2. Block diagram of optical wireless system with exponentialcompanding transform

At the receiver the down-sampled samples undergoes an inverse exponential companding transform to recover the original OFDM signal.

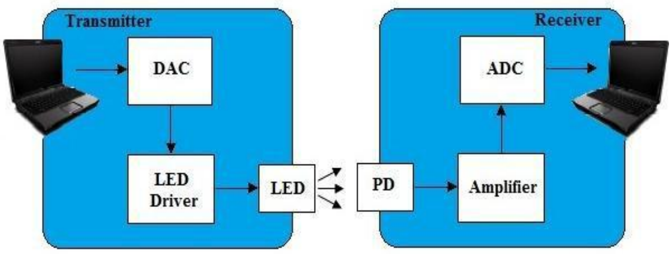

Figure 3. Block diagram of the optical wireless communication channel

The block diagram of the optical wireless communication channel is shown in the Figure 3. The OFDM signal after exponential companding transform in MATLAB is fed to the DAC from the laptop or desktop PC at the transmitter. The analog output from the DAC drives the LED for the intensity modulation of the optical signal. An LED driver is used to drive the LED. The photo diode at the receiver detects the intensity of the LED and converts the optical signal to electrical signal. An amplifier amplifies the detected signal and it is converted to the digital signal by the ADC. For further processing in the MATLAB these digital signals are fed to another laptop or desktop PC at the receiver side. The commercially available white LED with a power of 1W is used as the transmitter and the silicon photodiode SFH229 is used as the detector. A USB to serial converter interfaces the PC with the hardware.

V. Results

The simulation results shows that the PAPR of the OFDM signal has been reduced to a considerable amount by the nonlinear exponential companding transform. The PAPR reduced OFDM signal is shown in the Figure 4. It can be seen that the signal peaks of the OFDM signal without exponential companding transform ranges from -5V to +5V. But after the exponential companding transform the signal peaks are reduced to a range of -2V to +2V. Hence the signal distortion and LED damages can be avoided at the signal transmission.
The measured PAPR of the OFDM signal without exponential companding is 7.3947dB whereas for the OFDM signal with exponential companding transform the PAPR is 1.7262dB.

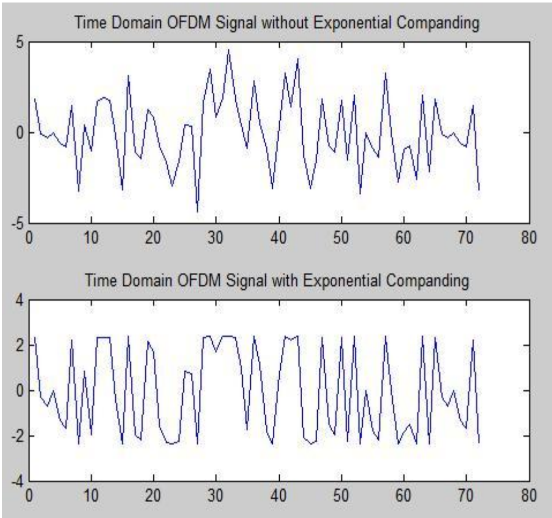

Figure 4. OFDM Signal

The random generated bits at the transmitter are recovered back at the receiver after the transmission through the optical channel. The transmitted and the received bits are shown in the figure 5. Errors in some of the bits are caused by the background light noises.

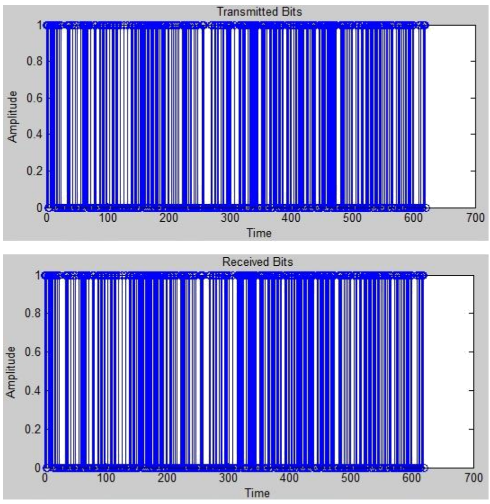

Figure 5. Transmitted and received bits through the optical wireless channel

VI. Conclusion

The PAPR in OFDM can significantly affect the performance of an optical wireless communication system based on OFDM for intensity modulation. Here, it is proposed that by the use of exponential companding transform we can significantly reduce the PAPR problem in OFDM optical wireless communication system. The experiments resulted in the conclusion that the background light from other illumination sources and the sunlight is the main cause of noise in the optical wireless channel.

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