PAPR Reduction in O-OFDM using Non-Linear Companding Scheme

Subrateshvar Kumar Dwivedi, Prabhat Patel

Abstract: Visible light communication is hot and novel area of research in indoor wireless applications. In VLC, information is transmitted using LEDs; therefore uni-polar signals are used. OFDM technology is used in wireless communication very efficiently for data transfer, however, in VLC OFDM cannot be directly applied, due to uni-polar nature. The VLC counterpart of OFDM is known as O-OFDM where only positive part of time domain signal is transmitted. However, O-OFDM also suffers from PAPR. This paper discusses PAPR reduction technique based on non-linear companding scheme, along with clipping schemes.

Index Terms: VLC, OFDM, and PAPR.

I. INTRODUCTION

Using visible light for data transmission entails many advantages and eliminates most drawbacks of transmission via electromagnetic waves outside the visible spectrum. For instance, few known visible light-induced health problems exist today, exposure within moderation is assumed to be safe on the human body. Moreover, since no interference with electromagnetic radiation occurs, visible light can be used in hospitals and other institutions without hesitation. Furthermore, visible light is free. No company owns property rights for visible light and thus no royalty fees have to be paid nor does expensive patent-license have to be purchased in order to use visible light for communication purposes. Visible light can serve as an entirely free infrastructure to base a complex communication network on. VLC is mostly used indoors and transmitted light consequently does not leave the room when the doors are closed and the curtains drawn, because light cannot penetrate solid objects such as walls or furniture. Therefore, it is hard to eavesdrop on a visible light based conversation, which makes VLC a safe technology if the sender intends to transmit confidential data. In VLC systems, intensity modulation (IM) is employed at the transmitter. The forward signal drives the LED which in turn converts the magnitude of the input electric signal into optical intensity. The human eye cannot perceive fast changing variations of the light intensity, and only responds to the average light intensity. Direct detection (DD) is employed at the receiver. A photodiode (PD) transforms the received optical power into the amplitude of an electrical signal.

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OFDM is an efficient technique for transmission and reception of digital signals. OFDM is also known for its disadvantage of high peak-to average power ratio (PAPR) and thus is very sensitive to nonlinearity of LEDs.

II. PEAK-TO-AVERAGE POWER RATIO

The transmit signals in an orthogonal frequency-division multiplexing (OFDM) system can have high peak values in the time domain since many subcarrier components are added via an inverse fast Fourier transformation (IFFT) operation. As a result, OFDM systems are known to have a high peak-to-average power ratio (PAPR) when compared to single-carrier systems. In fact, the high PAPR is one of the most detrimental aspects in an OFDM system as it decreases the signal-to-quantization noise ratio (SQNR) of the analog-digital convertor (ADC) and digital-analog convertor (DAC) while degrading the efficiency of the power amplifier in the transmitter. As a side note, the PAPR problem is more of a concern in the uplink since the efficiency of the power amplifier is critical due to the limited battery power in a mobile terminal.

Let's start by showing why PAPR problems are an important problem to take care of in an OFDM system. The PAPR of a signal is expressed by the following formula:

$$PAPR_{dB} = 10\log\left(\frac{\max[x(t)x^*(t)]}{E[x(t)x^*(t)]}\right) \qquad (1)$$

Where ()* corresponds to the conjugate operator. Since an OFDM symbol can be express as a sum of complex tones equally spaced in frequency, let's start by calculating the PAPR of a single complex tone. Consider a complex tone signal:

$$x(t) = e^{j2\pi ft}$$

with a period T. The peak value of the signal is:

$$\max[x(t)x^*(t)] = \max[e^{j2\pi ft}.e^{-j2\pi ft}] = 1 \qquad (2)$$

The mean square value of the signal is:

$$E[x(t)x^*(t)] = E[e^{j2\pi ft}.e^{-j2\pi ft}] = 1 \qquad (3)$$

This gives us a PAPR of 0 dB. Consider that an OFDM time signal is made of K complex tones (usually called subcarriers). Our signal can be represented by the following formula:

$$x(t) = \sum_{0}^{K-1} a_k e^{\frac{j2\pi kt}{T}} \qquad (4)$$

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For simplicity, let's assume $a_k = 1$ for any k. In this scenario, the peak value of the signal is:

$$\max[x(t)x^*(t)] = \max\left[\sum_{0}^{K-1} a_k e^{\frac{j2\pi kt}{T}} \sum_{0}^{K-1} a_k^* e^{\frac{-j2\pi kt}{T}}\right] = K^2 \quad (5)$$

The mean square value of the signal is:

$$E[x(t)x^*(t)] = E\left[\sum_{0}^{K-1} a_k e^{\frac{j2\pi kt}{T}} \sum_{0}^{K-1} a_k^* e^{\frac{-j2\pi kt}{T}}\right] = K \quad (6)$$

Given this, the PAPR of an OFDM symbol with K subcarriers, with each subcarrier having the same modulation, is simply K.

III. PAPR MITIGATING TECHNIQUES

This section deals with PAPR mitigating techniques:

A. Clipping and Filtering

The simplest and most widely used technique of PAPR reduction is to basically clip the parts of the signals that are outside the allowed region.

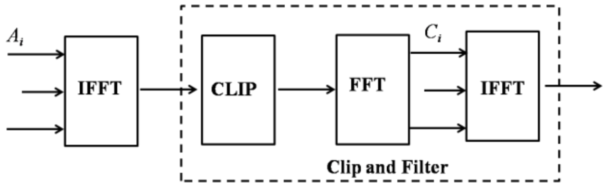

Fig. 1: Block Diagram of Clipping and Filtering

Generally, clipping is performed at the transmitter. However, the receiver needs to estimate the clipping that has occurred and to compensate the received OFDM symbol accordingly. Typically, at most one clipping occurs per OFDM symbol, and thus the receiver has to estimate two parameters: location and size of the clip. However, it is difficult to get these information. Therefore, clipping method introduces both in band distortion and out of band radiation into OFDM signals, which degrades the system performance including BER and spectral efficiency. Filtering can reduce out of band radiation after clipping although it cannot reduce in-band distortion. However, clipping may cause some peak re-growth so that the signal after clipping and filtering will exceed the clipping level at some points. To reduce peak re-growth, a repeated clipping-and filtering operation can be used to obtain a desirable PAPR at a cost of computational complexity increase.

B. μ-Law Mapping

Companding techniques are used to decrease dynamic range of the signal in order to prevent it from distortions caused by channel with limited range [64]. The companding technique compresses the signal, making its distribution quasi-uniform, such that signal's maximum amplitude does not exceed system's limitations. Thereby, no distortions will occur at the bottlenecks. At the receiver site the original signal is obtained by reverse operation of expanding. The commanding scheme is claimed to have better performance than clipping method, due to absence of clipping noise In the μ-law commanding, compressor squeezes the signal at the transmitter site according to the following formula:

$$s_n' = \frac{\max(s_n)\ln\left(1+\frac{\mu|s_n|}{\max(s_n)}\right)}{\ln(1+\mu)}\operatorname{sgn}(s_n) \quad (7)$$

where μ is the μ-law compression parameter.

And at the receiver site μ-law expander restores original signal by:

$$s_n = \frac{\max(s_n)}{\mu}\left(e^{|s_n'|\frac{\ln(1+\mu)}{\max(s_n)}} - 1\right)\operatorname{sgn}(s_n') \quad (8)$$

Figure 2, demonstrates the μ-OFDM system building blocks. We can differentiate O-OFDM and RF-OFDM in the way that O-OFDM requires the transformation of the complex input signal $X(k)$ into the positive and real output signal $x_t(n)$. As per the probability density function (PDF), basically range mapping of $x(n)$ that is close to zero into the centre of the LEDs dynamic range can ensure vast of the samples are transmitted without making any sort of distortion. In addition, we conclude that the companding procedure is an effective technique to compress more samples into the LEDs dynamic range, due to the fact that it has been ended up to be a feasible strategy to compress the dynamic range of OFDM signals. In as of late exhibited work, μ-law companding for instance is utilized to demonstrate the achievability of the plan. After the application of quadrature amplitude modulation (QAM), the symbols are just doled out to even index subcarriers in the IFFT operation, which implies odd indexed subcarriers are set to zero.

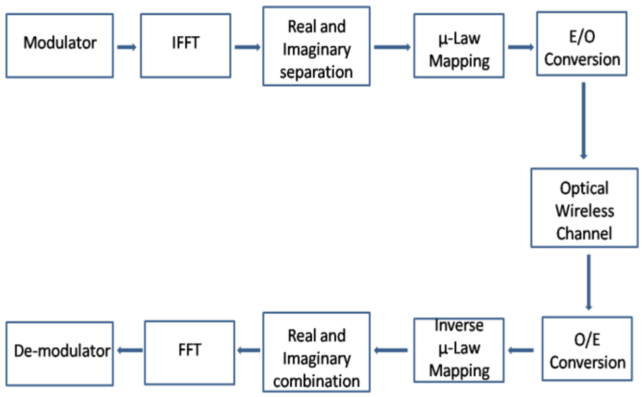

Fig. 2 μ-Law Based Optical OFDM System

Not in the way like ACO-OFDM, no Hermitian symmetry is required. A half portion of the output signals of the IFFT operation are rehashed due to the symbol assignment, which is illustrated as:

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$$x\left(n+\frac{N}{2}\right)=\frac{1}{N}\sum_{k=0}^{N-1}X(k)\exp\left\{\frac{j2\pi\left(n+\frac{N}{2}\right)k}{N}\right\} \quad (9)$$

$$x\left(n+\frac{N}{2}\right)=x(n),\ n=0,1,..............\frac{N}{2}-1$$

In the above equation, $x(n)$ represents the n-th time domain sample, $X(k)$ is the k-th frequency domain sample while the parameter N denotes the number of subcarriers.

The excess of information provides the likelihood of isolating the genuine and imaginary parts of $x(n)=\mathrm{Re}[x(n)]+j\,\mathrm{Im}[x(n)]$ and then making its transmission to one OFDM symbol.

PAPR is calculated as ratio of maximum power of a signal to its average power:

$$PAPR=\frac{\max\left(|x(n)|^2\right)}{E\left(|x(n)|^2\right)}. \quad (10)$$

In this work we have proposed a hybrid scheme where both µ-law companding scheme and clipping and filtering based scheme is proposed.

IV. RESULTS

In figure 3, µ-law commanding scheme for different µ values is shown. In this figure input and output relationship is shown for various values of µ is shown. In case of µ=1, a linear relationship between input and output is observed. As the value of µ is increased a non-linear relationship between inputs and outputs is observed. Here, gain for lower and moderate values of µ is more as compared to larger values.

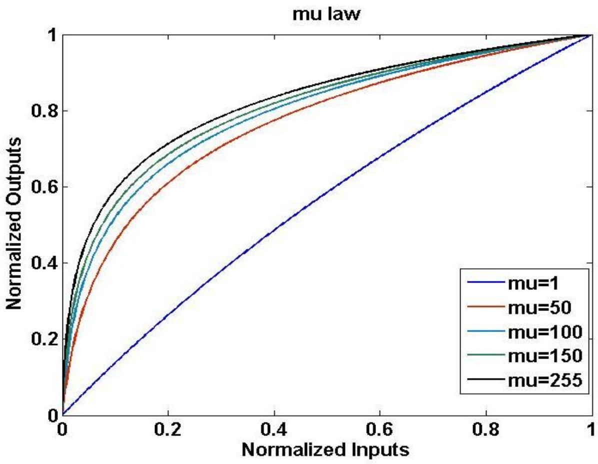

Fig. 3 µ-Law Companding Scheme for Different µ values

In figure 4 PAPR (dB) for different values of µ is shown. Here for lower values of µ, PAPR (dB) is higher. As we increases the value of µ the PAPR (dB) nearly becomes constant. Thus, as a standard the value of µ is considered to be 255.

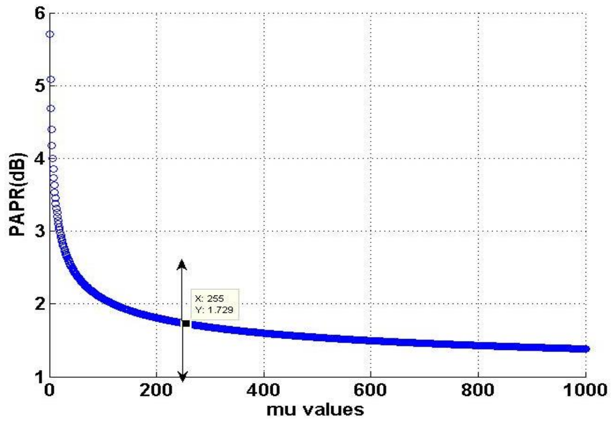

Fig. 4 PAPR (dB) for Different µ Values

In figure 5, normal OOFDM signal plot in terms of amplitude vs. bin is shown. Here, a large variation in amplitude is observed. The maximum observed value is 0.0429 and minimum observed value is 3.7561×10^{-4}. To tackle this large variation clipping is used and observed results are shown in figure 6. Here, if particular bin value is higher than 0.7×maximum amplitude value than it is bring down to 0.7×maximum amplitude value, thus bin values above this are clipped. Now the maximum value is 0.03.

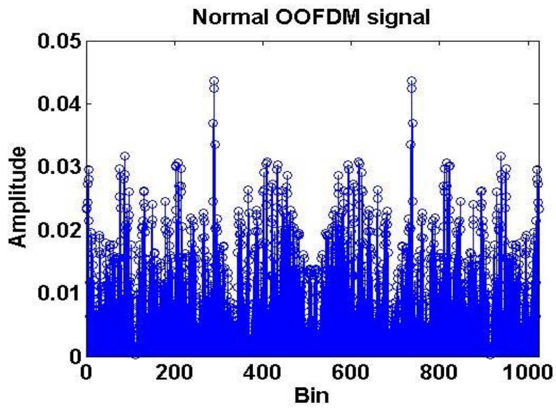

Fig. 5 Normal OOFDM Signal Plot in Terms of Amplitude vs. bin

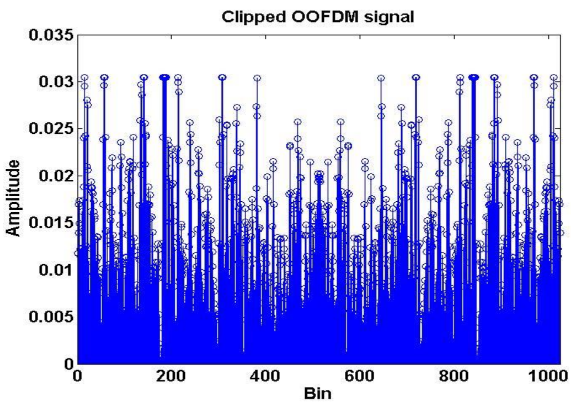

Fig. 6 Clipped OOFDM Signal Plot in Terms of Amplitude vs. bin

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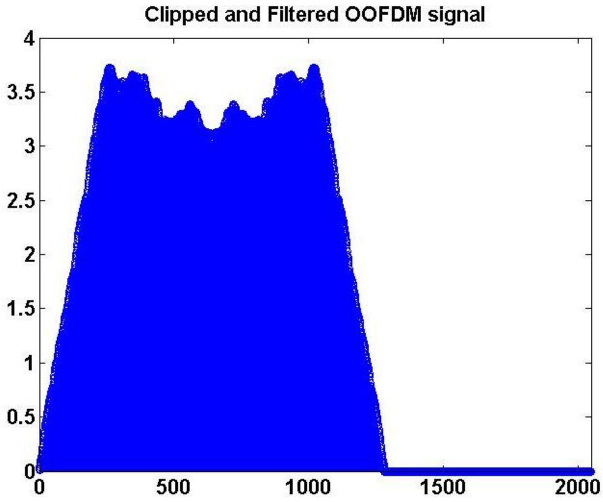

Fig. 7 Clipped and Filtered OOFDM Signal Plot in Terms of Amplitude vs. Bin.

In figure 7, Clipped and filtered OOFDM signal plot in terms of amplitude vs. bin is shown. Here variation in amplitude has been reduced significantly. Due to the convolution gain of the filter, amplitude has increased significantly, now the maximum value is 3.86.

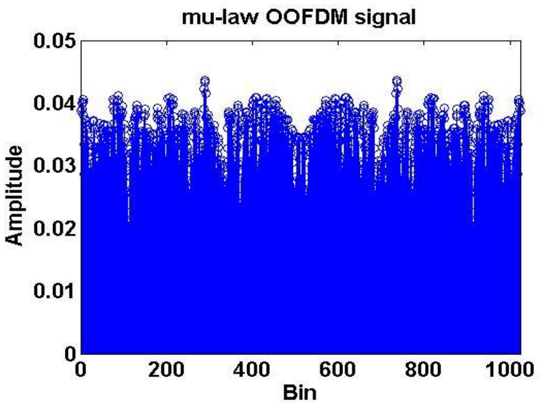

Fig. 8 μ-Law Based OOFDM Signal Plot in Terms of Amplitude vs. Bin

In figure, 8 μ-law based OOFDM signal plot in terms of amplitude vs. bin is shown, with maximum amplitude as 0.0418. However, using μ-law the variation in amplitude gas reduced significantly.

In figure, 9 μ-law, clipped and filtered OOFDM signal plot in terms of amplitude vs. bin is shown. Here, in comparison to figure 7, the variation in amplitude has reduced significantly. Thus, it can be summarized that the performance in terms of PAPR reduction is more in the proposed approach.

The results are also obtained for other values of μ and PAPR in dB are shown in Table 1. For each value of μ, PAPR is obtained under four cases;

1. PAPR of original OOFDM (dB)
2. PAPR of clipped OOFDM (dB)
3. PAPR of μ-Law OOFDM (dB)
4. PAPR of μ-Law + clipping OOFDM (dB)

It is customary to note that Monte-carlo simulation is performed for N×L, values. Thus this number is 1024, which is very less in comparison to steady state values. Therefore, in different set of simulations variations in curve and obtained PAPR can be observed. However, particular μ value, four results are obtained for similar set of 1024 values.

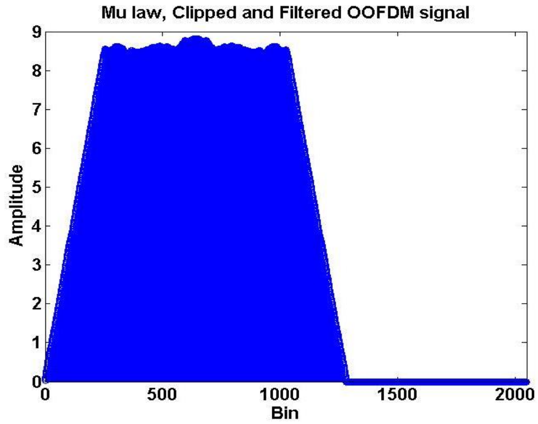

Fig. 9 μ-law, Clipped and Filtered OOFDM Signal Plot in Terms of Amplitude vs. Bin

Table 1 Comparison of Different Schemes

μ	PAPR of original OOFDM (dB)	PAPR of clipped OOFDM (dB)	PAPR of μ-Law OOFDM (dB)	PAPR of μ-Law + clipping OOFDM (dB)
50	16.76	10.01	6.22	1.16
100	18.7	9.54	67	1.09
255	19.46	9.61	4.85	1.04
500	20.21	8.99	4.42	1.03
1000	22.41	9.44	4.59	1.03

It is clear from the table that, the proposed scheme out-performs the previous schemes to a great extend. For all considered values of μ, the improvement in PAPR is more than 3.0 dB, which is very significant improvement.

V. CONCLUSIONS

This chapter deals with PAPR reduction techniques in VLC-OFDM systems. This chapter discusses the clipping and μ-law based scheme is VLC-OFDM system. Simulation study is performed to obtain PAPR under different schemes. It has been found that the proposed scheme is much superior in comparison to other considered schemes. Using μ-law in conjunction with clipping and filtering can reduce papr to a level of nearly 1 dB.

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