

PAPR Reduction in Optical OFDM System using CAZAC-Clipping Technique

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ABSTRACT: With the increasing demand of bandwidth, Optical Orthogonal Frequency division multiplexing (O-OFDM) has attracted a lot of attention in the present era because of several advantages like high spectral efficiency and immunity to dispersion losses. But it suffers from one major shortcoming of high peak-to-average-power ratio (PAPR). Several techniques have been proposed to combat this problem. In this paper, a novel technique has been proposed by combining the Constant Amplitude Zero Autocorrelation (CAZAC) sequence with clipping and implemented in Optical OFDM. Its benefit is that following CAZAC by clipping reduces the probability of peak values, thus further minimizing the PAPR. Simulation results demonstrate that about 3.5 dB PAPR reduction can be achieved by implementing the proposed technique in 10 Gb/s Direct Detection Optical OFDM (DDO-OFDM) system.

KEYWORDS: Optical OFDM (O-OFDM), Peak to Average Power ratio (PAPR), CAZAC Sequence, Clipping.

I. INTRODUCTION

The increasing bandwidth demand in the present era, due to the emergence of several high speed applications like IPTV, YouTube and social media have increased the need of optical communication. But various impairments like fiber dispersion losses, nonlinearities in fiber and transceiver restrict the efficiency of optical systems. To limit these impairments, orthogonal frequency Division Multiplexing (OFDM) plays a very significant role. Hence, the use of OFDM in optical communication networks has made them a suitable candidate for short-range to long-haul high speed networks [1].

The simplest configuration of optical OFDM referred as Direct Detection Optical OFDM (DDO-OFDM) utilizes intensity modulation and direct detection which make it a cost-effective system. It offers various benefits including high spectral efficiency, dispersion management and low complexity. However, it suffers from one major drawback of high Peak to Average Power Ratio (PAPR). It strongly affects the system performance by introducing nonlinear distortions in the transmitted signal, due to nonlinearities inside the fiber and in nonlinear devices such as Analog to Digital Converters (ADC)/Digital to Analog Converters (DAC) as well as Mach-Zehnder Modulator (MZM). Consequently, the maximum power that can be launched is restricted to preserve the linearity of the system [2]. Hence, reducing PAPR has become the need of the hour to improve the system performance as well as transmission distance.

Various researchers have proposed different techniques to combat the problem of PAPR which are broadly categorized into distortion and non-distortion based methods [3]-[9]. The techniques that cause spectral growth lay in signal distortion schemes. On the other hand, in non-distortion schemes, the input OFDM symbols are scrambled by using scrambling sequences and the output scrambled symbol with lowest PAPR is selected to be transmitted. Clipping and filtering [3] [4], Peak Windowing [5] and Companding [6] are incorporated in distortion based techniques whereas selective mapping (SLM) [7], Partial Transmit Sequence (PTS) [8] and encoding [9] are involved in non-distortion category. Apart from these schemes, a very simple and efficient CAZAC matrix transform technique based on autocorrelation properties of Zadoff-Chu sequence has been proposed which has successfully minimized the PAPR problem [10][11].

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A new and improved technique has been proposed in this article, combining the CAZAC matrix transform and clipping to minimize the PAPR of O-OFDM system. It will not only lead to significant reduction in PAPR with low complexity and ease of implementation but also improve the system performance as well as reduce the cost of the system.

II. OPTICAL OFDM

Orthogonal frequency-division multiplexing (OFDM) belongs to a broader class of multicarrier modulation (MCM) in which the data information is carried over many lower rate subcarriers. The subcarriers used are orthogonal to each other. Hence it carries large information with small bandwidth demand. The orthogonality of subcarriers reduces inter-symbol interference and the guard interval present in OFDM prevents inter-carrier interference. In optical communication use of OFDM prevents PMD and chromatic dispersion which make it a desirable technique for fiber-optic communication.

The figure 1 shown below describes the block diagram of Optical OFDM system. At the transmit end of the optical OFDM system, digital data at the high bit rate is parallelized into N data sequences. Each stream is mapped into a symbol using some kind of modulation scheme like quadrature amplitude modulation (QAM), Phase shift keying (PSK) etc. The symbols obtained after mapping are modulated to subcarriers using inverse fast Fourier transform (IFFT) to obtain an OFDM symbol. After IFFT, OFDM symbol is transformed from the frequency domain to time domain. Then to remove ISI and ICI, after IFFT operation, cyclic prefix (CP) is added to the OFDM symbol and then it is converted to analog signal by means of digital-to-analog converter (DAC). The baseband signal obtained at the output of DAC is transmitted after being up-converted in frequency using a local oscillator and a mixer. Then the obtained electrical signal is modulated over optical carrier using Mach-Zehnder modulator (MZM) and is transmitted over optical fiber channel.

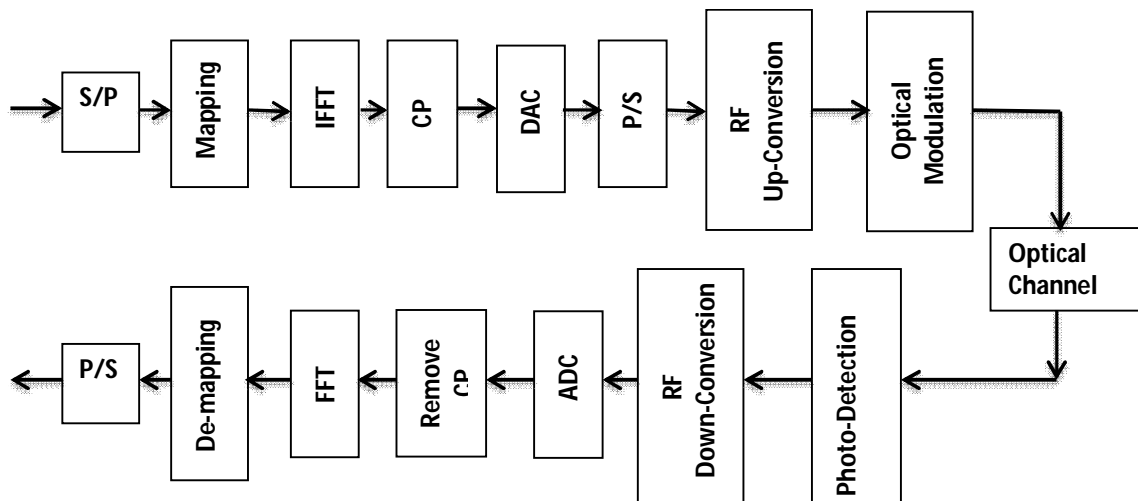


Fig.1 Block Diagram of Optical OFDM System

At the receive end, the optical signal is transformed into electrical signal by means of photodetector which produces electrical current corresponding to optical intensity. the signal is firstly down-converted using same local oscillator frequency as used at the transmitter, to obtain the baseband signal which is then transformed to digital signal using an analog-to-digital converter (ADC). The OFDM symbol obtained is given to the Fast Fourier transform (FFT) to transform it to frequency domain as well as demodulate the symbols from subcarriers. Then the symbols obtained after removing guard interval are de-mapped using de-mapper which retrieves the data transmitted in parallel form which is then converted back to serial form using parallel to serial converter.

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III. PAPR PROBLEM AND PROPOSED ALGORITHM

A) PAPR Definition

OFDM is a multicarrier modulation technique in which large numbers of independently modulated subcarriers are present. These subcarriers can add up coherently, giving a large PAPR. Thus, PAPR of the OFDM signal can be defined as [12]:

$$PAPR\{x(t)\} = \frac{\max|x(t)|^2}{E\{|x(t)|^2\}}, 0 \leq t \leq NT \quad (1)$$

where $x(t)$ is the transmitted OFDM signal given by-

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi f_k t}, 0 \leq t \leq NT \quad (2)$$

where N represents the amount of subcarriers, X_k represents set of N input symbols, $f_k = k/NT$ and T is fundamental symbol period.

If the N signals with the same phase in OFDM are combined, then the resulting peak power of the signal will be N times the average power. Hence, PAPR will be given by [12]-

$$PAPR_{max} = 10 \log_{10} N \quad (3)$$

It implies that on increasing the number of subcarriers, PAPR is also increased.

Since peak amplitude appears rarely in OFDM, thus $\max(x(t))$ is not used to depict peak value in practical applications. Hence, PAPR of OFDM signals is generally depicted by some characterization constants related to probability. The complementary cumulative distribution function (CCDF) is the most commonly utilized method for the measurement of PAPR of optical OFDM signal. To compare the PAPR performance of different techniques also, complementary CDF (CCDF) is used which is given by [12]-

$$CCDF(PAPR_0) = \Pr(PAPR(x[n]) > PAPR_0) = 1 - (1 - \exp(-PAPR_0))^N \quad (4)$$

B) Clipping

Amplitude clipping is the simplest approach to minimize PAPR among all PAPR reduction techniques. In this technique, a threshold value of amplitude is predefined and a soft limiter is employed to clip the peaks of signal which are above the predefined threshold value and the rest of signal is passed unclipped.

If $x[n]$ is the input OFDM signal, then clipping function is defined as:

$$F(x[n]) = \begin{cases} x[n], & \text{if } |x[n]| \leq A \\ A e^{j\angle x[n]}, & \text{if } |x[n]| > A \end{cases} \quad (5)$$

where A is the predefined threshold level and $\angle x[n]$ is the angle of $x[n]$. Thus it reduces high PAPR of signal without any additional power and bandwidth requirement. But clipping is a non-linear process which introduces in-band distortion as well as out of band radiation in the signal which increases BER as well as affects the spectral efficiency [3][4].

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C) CAZAC Matrix Transform

CAZAC matrix is derived from CAZAC sequence which stands for Constant Amplitude Zero Autocorrelation Sequence. The most commonly used CAZAC sequence is Zadoff-Chu sequence. Its main property is that when its cyclically rotated varieties are superimposed on the subcarriers of the signal, then it results in zero cross-correlation with one another at the receiver. In this way, the different subcarriers cannot add coherently, hence reducing peak power of the signal.

A CAZAC sequence is a periodic complex-valued signal with modulus one and out-of-phase cyclic auto correlation equal to zero. The CAZAC sequence $C = [C_0, C_1, C_2, \dots, C_{(L-1)}]$ with length L can be defined as:

$$c_k = \begin{cases} \exp\left(\frac{j\pi k(k+1)p}{L}\right), & L \text{ is odd} \\ \exp\left(\frac{j\pi k^2 p}{L}\right), & L \text{ is even} \end{cases}; \quad k = 0, 1, 2, \dots, (L-1) \quad (6)$$

Here L is a positive number greater than one, and p is any integer which is prime to L [10].

CAZAC sequences are rearranged with length $L=N^2$, $p = 1$, an $N \times N$ complex orthogonal transform matrix A is created as follows:

$$A = \begin{bmatrix} c_0 & c_N & \dots & c_{N(N-1)} \\ c_1 & c_{N+1} & \dots & c_{N(N-1)+1} \\ \vdots & \vdots & \ddots & \vdots \\ c_{N-1} & c_{2N-1} & \dots & c_{N^2-1} \end{bmatrix} \quad (7)$$

Where $c_k = \exp[j\pi k^2/N^2]$, $A_{mn} = c_{m+Nn} = \exp[j\pi(m+Nn)^2/N^2]$, $A^H A = I$, $(.)^H$ denotes conjugate transpose. The obtained matrix A is an orthogonal matrix, because $A^H A = N \cdot I$, hence its inverse matrix will be equal to its conjugate transpose A^H .

After being normalized by \sqrt{N} , the matrix A is then utilized to align the information symbols modulated upon N subcarriers in an OFDM signal. It involves multiplying each information symbol present in an OFDM symbol by a unique CAZAC factor with unevenly dispersed phase defined by equation (7). This equalization of information symbols $X = [X_1, X_2, \dots, X_N]^T$ present in OFDM symbol is done before applying the IFFT operation, resulting in new reduced PAPR vector, $X_M = [X_{mi}]$, where $X_{mi} = [c_i, c_{N+i}, \dots, c_{N(N-1)+i}] [X_1, X_2, \dots, X_N]^T$. From the perspective of statistics, PAPR reduction takes place because the probability of addition of the signal peaks which are of same phase is decreased to a great extent. Since A is an invertible matrix, the distortion less recovery of the original information is possible by multiplying the received signal by inverse of matrix A [11].

Thus the main advantage of CAZAC matrix transform is that it can be implemented with very low complexity. It also does not require transmission of side information which increases spectral efficiency of the system. On the other hand, the main advantage of clipping is that it is very simple to implement and provides large PAPR reduction in optical OFDM systems.

Hence, to improve the performance of the system in terms of PAPR reduction, CAZAC can be employed with clipping technique. It provides large amount of PAPR reduction in optical OFDM systems with very low complexity because both the techniques are very simple to implement. To use the CAZAC-clipping algorithm in optical OFDM systems, the symbols are firstly equalized using CAZAC matrix transform before applying IFFT and then they are clipped using a predefined clipping level.

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IV. EXPERIMENTAL RESULTS

This paper presents combined CAZAC and Clipping based PAPR reduction technique. The Optical OFDM system is simulated using VPI software for data rate of 10 Gb/s. To evaluate PAPR reduction effect, the complementary cumulative distribution function (CCDF) of given PAPR reduction technique is plotted using MATLAB at the transmitter, which demonstrates the probability of PAPR exceeding a particular threshold PAPRO as shown in the figure 2. It is clear from the figure that combined CAZAC-clipping method greatly improves the PAPR performance of the system. As compared to the original system, PAPR is improved by 3.5 dB at the threshold probability of 5×10^{-2} . It also demonstrates that PAPR is improved almost by 1 dB using combined technique as compared to CAZAC Matrix Transform. Hence, this reduction in PAPR of optical OFDM system reduces the nonlinear distortions within the fiber as well as ADC and DAC. Therefore, it improves the system performance as well as reduces overall cost of the system because low cost ADC and DAC can be employed in the system.

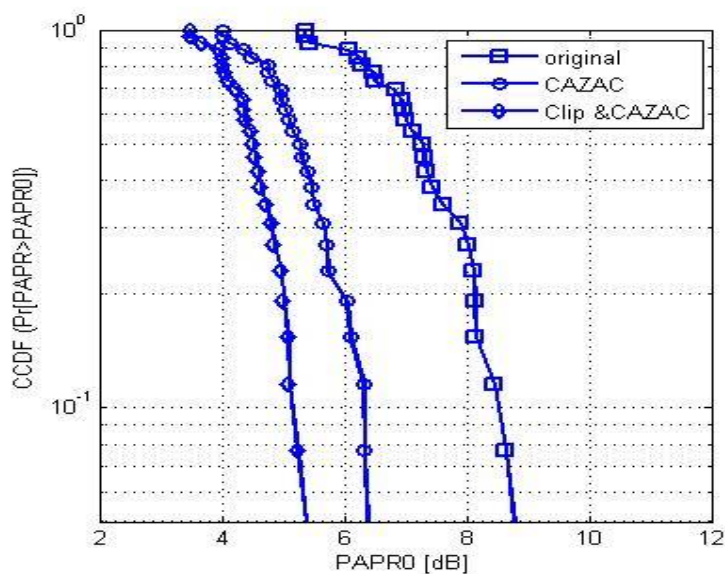


Fig.2 CCDF of OFDM signal with and without PAPR reduction

V. CONCLUSION

In conclusion, improved performance optical OFDM system has been realized with reduced PAPR by the implementation of combined CAZAC-Clipping PAPR Reduction algorithm. The PAPR minimization ability is proved by MATLAB simulation by comparison with original and CAZAC technique which proves that PAPR has been reduced by 3.5 dB compared to original system. It demonstrates 1 dB improvement than CAZAC algorithm. Hence, this technique has improved the performance of the system as well as reduced overall cost of the system.

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