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PAPR Reduction in OFDM System by Using Discrete Cosine Transform and µ-law Companding

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Abstract- Communication is one of the important aspects of human life. With the advancement in age and its growing demands, there has been rapid growth in the field of communication. Multi-carrier modulation is an attractive transmission technique for fourth generation high speed wireless communication. Orthogonal Frequency Division Multiplexing (OFDM) is a promising multicarrier technique used in wireless communication with high data rate and high spectral efficiency.One of the main problems of the OFDM system is the high Peak-to-Average Power Ratio(PAPR) of transmission signal due to the use of many subcarriers. In this paper, a joint Discrete Cosine Transform (DCT) and µ-law companding method is proposed to reduce peak-to-average power ratio of OFDM signal. Simulation results show that this new method is more efficient than the conventional OFDM systems.

Keywords- Multi-carrier modulation, OFDM, PAPR, µ-law companding, DCT Transform

1. Introduction

As a future technology for wireless communications,Orthogonal Frequency Division Multiplexing (OFDM),which is one of the most important multi-carrier modulation (MCM) techniques, offers a high spectral efficiency, multipath propagation tolerance, immunity to the frequency selective fadingchannels and efficient power efficiency [1], [2]. As a result, OFDM hasbeen chosen for high data rate communication system and has been widely used in variouswireless communication systems such asDigital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB) and based mobileworldwide interoperability for microwave access (mobileWiMAX) based on OFDM access technology [3].The concept of OFDM was introduced by R.W. Chang in 1966 and was patented in 1970.

However, though OFDM has many advantages, there alsodisadvantages. One of the major disadvantageof OFDM signal isthe high Peak-to-Average Power Ratio. Thesemulti-carrier systems have a problem that Peak-to-AveragePower Ratio (PAPR) increases with the increase of the number of subcarrier, which causes poor power efficiency or serious performance degradation to RF power amplifier [4].

To reduce the PAPR, many methods have been proposed, such as clipping, coding, partial transmit sequence (PTS), selected mapping (SLM), and nonlinear companding transforms etc. These methods are primarily signal scrambling methods, such as PTS, and signal distortion techniques such as the clipping and companding techniques. Among those PAPR reduction methods, the simplest method is the clipping process. However, use of the clipping processing causes both in-band distortion and out-band radiation, and causes an increased bit error rate (BER) in the system. As an alternative approach, the companding technique shows better performance than the clipping technique, because the inverse companding transform (expanding) can be applied at the receiver end to reduce the distortion of signal. A DCT may also reduce the PAPR of an OFDM signal, but does not improve the BER performance of the system. The idea is to use the different transform to reduce the autocorrelation of the input sequence to reduce the peak to average power problem. In addition, it requires no side information to be transmitted to the receiver.Inspired by the literature [6,7], we propose an efficient PAPR reducing technique based on a joint DCT and µ-law companding method. This method will be compared with the original system with companding technique for reduction PAPR.

The organization of this paper is as follow. Section 2describes system based on OFDM and defines PAPR. µ-law companding and DCT transform are introduced in section 3 and section 4 respectively. In section 5, a PAPR reduction scheme by combing µ-law companding and DCT transform is proposed. Simulation results and analysis are reported in section 6 and conclusions are presented in section 7.

2. PAPR in OFDM signal

2.1 Overview of OFDM-

Orthogonal Frequency Division Multiplexing(OFDM) is an alternative wireless modulationtechnology to CDMA.OFDM has the potential to surpass the capacity ofCDMA systems and provide the fast wireless access technique for 4G communication systems. OFDM is a modulation scheme thatallows digital data to be efficiently transmitted over a radio channel e.g. AWGN channel, even in multipathenvironments. OFDM transmits data by using a largenumber of narrow bandwidth carriers. These carriers areregularly spaced in frequency. The frequency spacing and timesynchronisation of the carriers is chosen in such a waythat the carriers are orthogonal. The word 'orthogonal' indicates that there is a precise mathematical relationship between the frequencies of the carriers in the system. Due to the orthogonality of the subcarriers the transmission bandwidth is used efficiently as the subcarriers are allowed to overlap each other and still be decoded at the receiver.

2.2 PAPR Problem-

In OFDM systems, due to the presence of large no. of modulated subcarriers, the peak value of the system might be very high as compared to the average value of the whole system, resulting in large peak-to-average power ratio (PAPR).

In general, the PAPR of an OFDM signals x(t) is defined as the ratio between the peak powerand its average power during an OFDM symbol.

PAPR is defined as:

$$\text{PAPR} = 10\log_{10}\frac{Peak\ Power}{Average\ Power} \qquad (1)$$

Where,

$$\text{Peak Power} = \max|x(t)^2|$$

$$\text{Average Power} = \frac{1}{T}\int_0^T |x(t)|^2 dt$$

High Peak-to-Average Power Ratio has been termed as one of the major problem involving OFDM system. Low PAPR makes the transmit power amplifier works efficiently, on the other hand, the high PAPR makes the signal peaks move into the non-linear region of the RF power amplifier which reduces the efficiency of the RF power amplifier. In addition, high PAPR requires a high-resolution digital-to-analog converter (DAC) at the transmitter and a high-resolution analog-to-digital converter (ADC) at the receiver, which results in increased cost and comlexity. Any non-linearity in the signal will cause distortion such as inter-carrier interference (ICI) and inter symbol interference (ISI).

The Cumulative Distribution Function (CDF) is one of the most regularly used parameter, which is used to measure the efficiency of any PAPR technique. Normally, the Complementary CDF (CCDF) is used instead of CDF, which helps us to measure the probability that the PAPR of a certain data block exceeds the given threshold.

CCDF is defined as the probability by which the PAPR is greater than the threshold value of given PAPR0. CCDF is mathematically represented as:

$$\text{CCDF} = \Pr[\text{PAPR} > \text{PAPR0}] \qquad (2)$$

3. µ-law Companding

The µ-law algorithm is a companding algorithm,primarily used in 8-bit PCM digital telecommunicationsystems in North America and Japan. Companding algorithmsreduce the dynamic range of an audio signal.In analog systems, this can increase the signal-to-noiseratio (SNR) achieved during transmission; in the digitaldomain, it can reduce the quantization error.

Companding is simply a process in which signal data is first compressed, transmitted through a bandwithlimited channel, and expanded at the receiving end. In this research work µ-law companding is used. In which compression is used at the transmitter end afterthe IFFT process and expansion is used at the receiverend prior to the FFT process.

For a given input x, the equation for µ-law encoding is [8].

$$F(x) = \text{sgn}(x)\,\frac{\ln(1+\mu|x|)}{\ln(1+\mu)}\ \ -1\le x \le 1 \qquad (3)$$

Where companding parameter µ = 255 (8 bits) in the North American and Japanese standards. It is important to note that the range of this function is −1 to 1.

This companding transform reduces the PAPR of OFDM signal by amplifying the small signal and attenuating the period of large signal.

4. Discrete Cosine Transform

In particular, a DCT is a Fourier-related transform similar to the Discrete Fourier transform (DFT), but using only real numbers. DCT is equivalent to DFT with twice the length, operating on real data with even symmetry (since the Fourier transform of a real and even function is real and even), where in some variants the input and/or output data are shifted by half a sample.

Like other transforms, the DCT de-correlates the data sequence. To reduce the PAPR in an OFDM signal, a DCT is applied to reduce the autocorrelation of the input sequence before the IFFT operation [9]. In this section, we will discuss about DCT transform. The definition of a one-dimensional DCT of length N is given by the following equation:

$$X_c(k) = \alpha(k)\sum_{n=0}^{N-1} x(n)\cos\left[\frac{\pi(2n+1)k}{2N}\right] \quad (4)$$

For k = 0, 1, 2, …………………….. N-1

Similarly, the inverse transformation is defined as

$$x(n) = \sum_{n=0}^{N-1} \alpha(k) X_c(k)\cos\left[\frac{\pi(2n+1)k}{2N}\right] \quad (5)$$

for n = 0, 1, 2, ……………………… N-1

For both equations (4) and (5) α(k) is defined as-

$$\alpha(k) = \begin{cases} \frac{1}{\sqrt{N}} \; for \;\; k = 0 \\ \frac{2}{\sqrt{N}} \; for \; k \neq 0 \end{cases} \quad (6)$$

Equation (4.6) can be expressed in matrix form as:

$$X_C = C_N x \quad (7)$$

Where Xc and x are both vectors of dimension N*1 and C_N is a DCT matrix of dimension of N*N. The rows (or column) of the DCT matrix, C_N, are orthogonal matrix vectors. This property of the DCT matrix can be used to reduce the peak power of OFDM signal.

5. Proposed method-

To reduce the PAPR of an OFDM signal, a scheme involving the combination of a DCT and µ-law companding technique is proposed. The block diagram of proposed combined approach system is shown in fig. 1.

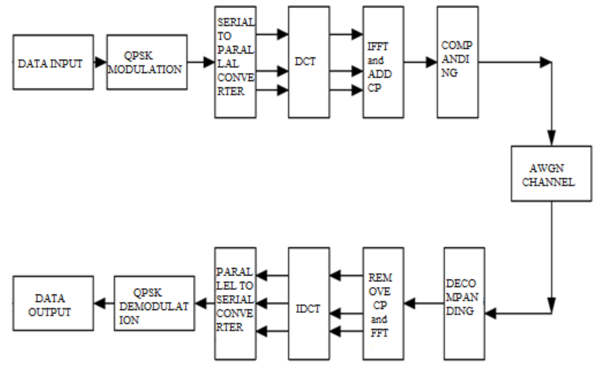

Fig. 1 Block Diagram of Proposed Method for PAPR Reduction

Fig.1 describes the block diagram of our proposed method. An input data from a data source is first modulated by a QPSK modulation technique. Then it will be converted into parallel stream from serial one and then transformed by DCT method. After that, it will beprocessed by the IFFT block to form an OFMD symbol.The last one is then compressed by a companding technique.The inverse operations are performed at the receiver side.

6. Simulation results and analysis

In this section, we present the results of computer simulations used to evaluate PAPR reduction capability of the proposedscheme. The channel was considered as Additive White Gaussian Noise (AWGN). In the simulation, an OFDM system with a sub-carrier of N = 128 and QPSK modulation was considered. Our PAPR reduction results are presented as Complementary Cumulative Distribution Function(CCDF) graph. TheCCDF shows the probability of an OFDM frameexceeding a given PAPR (dB). In general, the closer the CCDF graph to the vertical axis, the better its PAPRreduction performance.

6.1 PAPR Calculation of Proposed method

Fig. 2 shows the PAPR Performance of the proposed method and other existing methods. The PAPRvalue of proposed method is reduced by 7.8 dB at CCDF = $10^{-3}$for companding parameterfactor, µ=100 when compared with the case of original OFDM system.The results obtained in this section compare the proposed method with original OFDM system, companding only and RS coding with Discrete Cosine Transform (DCT) approach.

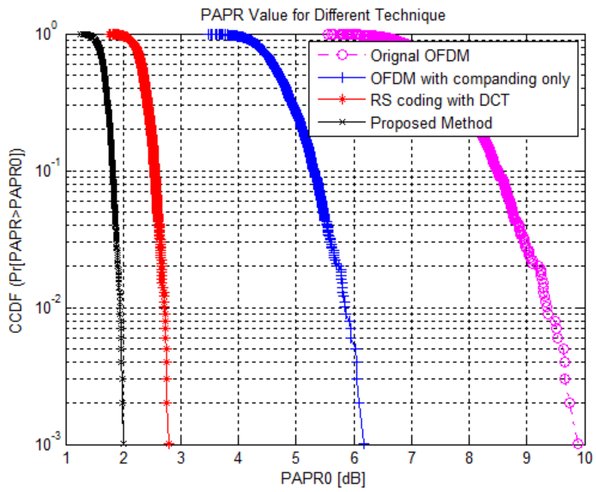

Fig. 2 Comparison of the PAPR calculation of Proposed Method

6.2 PAPR Calculation For Different Companding Parameter

In our work, we decided to use μ-law companding technique. In this section we use different values of μ-law companding parameters and 128 sub-carriers. We can see that μ = 255 give better performances. This is due to compression rate. More it compresses the signal and more thepeaks are reduced. Companding parameter μ = 255 is the value used in practice in USA and Japan. The PAPR of OFDM system at CCDF=10^{-3} is reduced by 7.7 dB, 8.0 dB, and 8.2 dB corresponding to the value of compandingparameter μ=100, 200,255 when compared with thecase of original system.

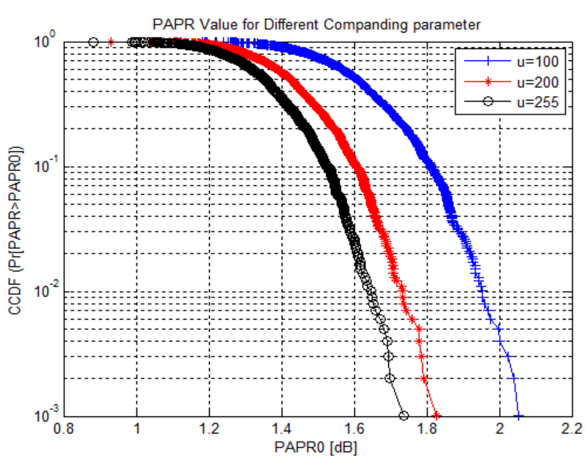

Fig. 3 PAPR calculation of proposed method for μ= 100, 200, 255.

7. Conclusions

In this paper we have considered the problem of the PAPR and there reduction in OFDM system. The proposed PAPR reduction method is based on combining DCT and the μ-law companding method. The performances of the proposed method are evaluated using QPSK modulation.The simulation results have been carried out in terms of reduction of PAPR value of the system for different methods, and variouscompandingparameter.Simulation results indicate that the proposed method provided better results when compared with existing work.

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