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Modified Peak To Average Power Ratio (PAPR) Reduction Scheme For Orthogonal Frequency Division Multiplexing (OFDM) Signals

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Abstract

Orthogonal frequency division multiplexing (OFDM) is an efficient parallel data transmission scheme, in which high data rates can be achieved by transmitting a number of orthogonal subcarriers. The main reason for increasing interest in the OFDM system is the way it handles multipath fading phenomenon that is inherent with the wireless channels. OFDM has been considered for fourth generation (4G) transmission technique. One major disadvantage of OFDM is that the time domain OFDM signal which is a sum of several sinusoids leads to high peak to average power ratio (PAPR). High PAPR involves the development of non-linear distortions .The work done is a joint companding transform and hadamard transform method is proposed to reduce peak-to-average of OFDM signal. Simulation results show that the proposed scheme obtain significant PAPR reduction while maintaining good performance in the BER compared to ordinary companding method.

1. Introduction

Orthogonal frequency division multiplexing (OFDM) has been recently seen rising popularity in wireless applications. For wireless communications, an OFDM-based system can provide greater immunity to multi-path fading and reduce the complexity of equalizers [1]. Now OFDM have been included in digital audio/video broadcasting (DAB/DVB) standard in Europe, and IEEE 802.11, IEEE 802.16 wireless broad band access systems, etc. On the other hand, the major drawback of OFDM signal is its large peak-to-average power ratio (PAPR), which causes poor power efficiency or serious performance degradation to transmit power amplifier [2].To reduce the PAPR, many techniques have been proposed. Such as clipping, coding, partial transmit sequence (PTS),selected mapping (SLM), interleaving [3][4], nonlinear companding transforms[5] [6], hadamard transforms[7] and other techniques etc. these schemes can mainly be categorized into signal scrambling techniques, such as PTS, and signal distortion techniques such as clipping, companding techniques. Among those PAPR reduction methods, the simplest schemes to use the clipping process. However, using clipping, processing causes both in-band distortion and out-of-band distortion and further causes an increasing of error bit rate of system. As an alternative approach, a companding shows better performance than clipping technique because the inverse companding transform (expanding) is applied in receiver end to reduce the distortion of signal. Hadamard transform may reduce PAPR of OFDM signal while the error probability of system is not increased [8]. In this paper, an efficient reducing PAPR technique based on joint companding and hadamard transform method is proposed. This scheme will be compared with the original system with companding technique for reduction PAPR.

The organization of this paper is as follow. Section 2 presents the PAPR problem in OFDM systems. Companding transform and hadamard transform are introduced in section 3 and section 4. In section 5, a PAPR reduction scheme by combing companding transform and hadamard transform is proposed. Simulation results are reported in section 6 and conclusions are presented in section 7.

2. Peak to Average Power Ratio (PAPR)

OFDM is one of the many multicarrier modulation techniques, which provides high spectral efficiency, low implementation complexity, less vulnerability to echoes and non – linear distortion. Due to these advantages of the OFDM system, it is vastly used in various communication systems. But the major problem one faces while implementing this system is the high peak – to – average power ratio of this system. A large PAPR increases the complexity of the analog – to – digital and digital – to – analog converter and reduces the efficiency of the radio – frequency (RF) power amplifier. Regulatory and application constraints can be implemented to reduce the peak transmitted power which in turn reduces the range of multi carrier transmission. This leads to the prevention of spectral growth and the transmitter power amplifier is no longer confined to linear region in which it should operate. This has a harmful effect on the battery lifetime. Thus in communication system, it is observed that all the potential benefits of multi carrier transmission can be out - weighed by a high PAPR value.

2.1 Problems of high PAPR

Presence of large number of independently modulated sub-carriers in an OFDM system the peak value of the system can be very high as compared to the average of the whole system. This ratio of the peak to average power value is termed as Peak-to-Average Power Ratio. Coherent addition of N signals of same phase produces a peak which is N times the average signal.

The major disadvantages of a high PAPR are-

1. Increased complexity in the analog to digital and digital to analog converter.
2. Reduction is efficiency of RF amplifiers.

2.2 PAPR of a Multicarrier Signal

Let the data block of length *N* be represented by a vector. Duration of any symbol in the set ***X*** is *T* and represents one of the sub – carriers set. As the *N* sub – carriers chosen to transmit the signal are orthogonal to each other, so we can have where and *NT* is the duration of the OFDM data block ***X***.

The complex data block for the OFDM signal to be transmitted is given by,

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} Xne^{j2\pi n\Delta ft} \quad 0 \le t \le NT \tag{2.1}$$

The PAPR of the transmitted signal is defined as,

$$PAPR = \frac{\max\limits_{0 \le t \le NT} |x(t)|^2}{\frac{1}{NT}\int_0^{NT} |x(t)|^2 dt} \tag{2.2}$$

Reducing the *max*|*x(t)*| is the principle goal of PAPR reduction techniques. Since, discrete- time signals are dealt with in most systems, many PAPR techniques are implemented to deal with amplitudes of various samples of *x(t)*. Due to symbol spaced output in the first equation we find some of the peaks missing which can be compensated by over sampling the equation by some factor to give the true PAPR value.

3. Companding Scheme

Companding technique is the combination of compression and expansion. Companding is widely used in speech processing where high peaks occur infrequently. OFDM signal also exhibit similar characteristics where high peaks occur infrequently. Companding technique improves the quantization resolution of small signals at the price of the reduction of the resolution of large signals, since small signals occur more frequently than large ones. PAPR is decreasing exponentially with increasing value of the companding parameters μ. In μ-law compander, the signals with lower amplitudes are amplified with greater gain. In OFDM systems, the occurrence of subcarriers having very large peak amplitudes is less frequent, since most of the subcarriers have low peak amplitudes. Because of less frequent high amplitude subcarriers, the average power is low resulting in high PAPR. Companding techniques are used to decrease dynamic range of the signal in order to prevent it from distortions caused by channel with limited range.

Many researches investigating use of the companding technique to reduce PAPR in the OFDM systems were made in recent time. The bottleneck of the OFDM system in terms of high PAPR is power amplifiers and AD/DA converters. Power amplifiers have nonlinear characteristic with some saturation level. High peaks of the OFDM signal usually exceed this maximum amplification level, which result in clipping of high peaks by the amplifier. Clipping distorts the signal by increasing the BER and widen its spectrum. The second bottleneck comes from the limited number of quantization levels in AD/DA converters. High rare peaks will waste quantization resolution by reducing the range of mapping for the main signal. Thus the quantization error will be increased. This becomes especially critical when we have a system with small quantization resolution. 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 companding scheme is claimed to have better performance than clipping method, due to absence of clipping noise.

The advantages of companding are as follows:

1. Due to compression in dynamic range peak power is reduced.
2. The expansion at receiver side will reduce the distortion.

In μ-law companding, the compander squeezes the signal at the transmitter using the formula

$$S_n^{'} = \frac{V \ln\left(\frac{1+\mu|S_n|}{V}\right)}{\ln(1+\mu)} \operatorname{sgn}(S_n) \quad (3.1)$$

Where *v* is the average amplitude of signal and *u* the companding parameter. Specifically, the companding transform should satisfy the following two conditions:

$$E\left(\left|S_n^{'}\right|^2\right) \approx E\left(\left|S_n\right|^2\right) \quad (3.2)$$

$$\left|S_n^{'}\right| \geq \left|S_n\right| when \left|S_n \leq V\right|$$
$$\left|S_n^{'}\right| \leq \left|S_n\right| when \left|S_n \geq V\right| \quad (3.3)$$

At the receiver side, the µ-law expander restores the original signal by

$$S_n = \frac{V}{\mu}\left(e^{\frac{|S'_n|\ln(1+\mu)}{V}} - 1\right)\operatorname{sgn}(S_n') \quad (3.4)$$

4. Hadamard Transform

In Hadamard transform scheme, the mapped and modulated data is been Hadamard transformed before IFFT operation and at the receiver end the data can be decoded after demapping, demodulation and FFT operation performing Inverse Hadamard transform. Hadamard Transform is a matrix, the hadamard transform (scaled by normalization factors) that transform real numbers X_n into real numbers X_k. Hadamard transform can be defined in two ways recursively or by using binary (Base 2) representation of indices n and k

$$H_m = \frac{1}{\sqrt{2}}\begin{bmatrix} H_{m-1} & H_{m-1} \\ H_{m-1} & -H_{m-1} \end{bmatrix}$$

Where, the 1/√2 is a normalization that is sometimes omitted. Thus, other than this normalization factor, the Hadamard matrices are made up entirely of 1 and −1.

$$(H_n)_{i,j} = \frac{1}{2^{\frac{n}{2}}}(-1)^{i \bullet j}$$

where $i \bullet j$ is the bit wise dot product of binary representation of numbers i and j.

The proposed hadamard transform scheme may reduce the occurrence of the high peaks comparing the original OFDM system. The idea to use the hadamard transform is to reduce the autocorrelation of the input sequence to reduce the peak to average power problem and it requires no side information to be transmitted to the receiver. In the section, we briefly review hadamard transform. We assume **H** is the hadamard transform matrix of N orders, and hadamard matrix is standard orthogonal matrix. Every element of hadamard matrix only is 1 or -1. The hadamard matrix of 2 orders is stated by

$$H_2 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \quad (4.1)$$

Hadmard matrix of 2N order may be constructed by

$$H_{2N} = \frac{1}{\sqrt{2N}}\begin{bmatrix} H_N & H_N \\ H_N & -H_N \end{bmatrix} \quad (4.2)$$

Where $-H_N$ is the complementary of H_N . Hadamard matrix satisfy the relation

$$H_{2N}H_{2N}^T = H_{2N}^T H_{2N} = I_{2N} \quad (4.3)$$

Where H_{2N}^T is the transport matrix, I_{2N} is the unit matrix of 2N order.

After the sequence $X = [X_1 X_2 \ldots\ldots X_N]^T$ is transformed by hadamard matrix of N order, the new sequence is

Y = HX

5. Proposed Scheme

To reduce the PAPR of OFDM signal, in this paper we proposed a reduction PAPR scheme that companding transform and hadamard transform are combined to adopt. The incoming input data stream is firstly transform by hadamard transform then the transformed data stream is as input to IFFT signal processing unit. The system block is show in the Figure 1

The signal processing step is below:

Step1: The X is transformed

Y = HX

Step2: y=IFFT (Y), where $y=[y(1)\ \ y(2)\ y(N)]^T$

Step3: do companding transform to y, i.e.
s(n) = C{y(n)}

Step4: do inverse companding transform to received signal
r(n) , i.e. $y\hat{}(n) = C^{-1}\{r(n)\}$.

Step5: do FFT transform to the signal yˆ(n) , ie
$Y^{\wedge}$= FFT(yˆ) , where yˆ $[y\hat{}(1)\ y\hat{}(2)\ y\hat{}(N)]^T$

Setp6: do inverse hadamard transform to the signal $Y^{\wedge}$, ie $X^{\wedge} = H^T Y^{\wedge}$

Then the signal X^ is demaped to bitstream.

In Figure 1 the data source and data sink is available with the transmitted and received data. From these the BER performance, PAPR and other parameters are calculated and performance evaluation is done on comparing with previous methods.

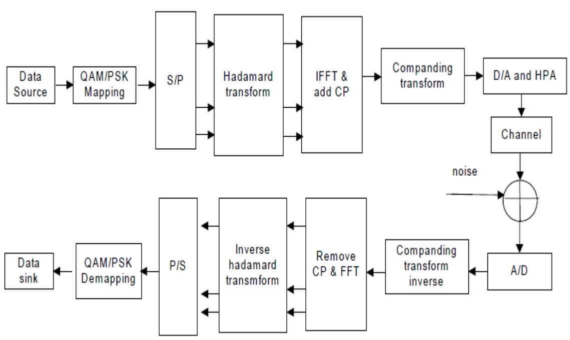

Figure 1. Block diagram of the Proposed System

In Figure 1 we propose a PAPR reduction scheme that involves compandingtransform and hadamard transform combined to adopt PAPR reduction. The incoming input data stream is firstly transformed by hadamardtransform then the transformed data stream is as input to IFFTsignal processing unit.The detailed discussion of the work done is given in upcoming pages. The input data to be transmitted is taken. The data are modulated by any modulation scheme PSK/QAM.The modulation scheme is chosen based on the application. In this work BPSK modulation is used. The subcarriers are chosen .The modulated data is given to the serial to parallel convertor to get the parallel data that has to be given to the Hadamard Transform block. The IFFT operation and addition of cyclic prefix are done over the output of the Hadamard block .The algorithm for ifft(X) is the same as the algorithm for fft(X), except for a sign change and a scale factor of n = length(X). As for FFT, the execution time for ifft depends on the length of the transform. It is fastest for powers of two. It is almost as fast for lengths that have only small prime factors. It is typically several times slower for lengths that are prime or which have large prime factors. Then companding transform is applied to the IFFT and CP data. The companded output is passed to the HPA and then through a Noisy AWGN channel.

The receiver operation is the inverse of the transmitted part. The companded data is expanded which is followed by FFT and removing CP. The inverse Hadamard transform operation is done and it is followed by parallel to serial conversion and demodulation .Finally the transmitted data is obtained. The PAPR and BER performance were calculated.

6. Results and Discussion

The Cumulative Distribution Function (CDF) is one of the most regularly used parameters, 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. By implementing the Central Limit Theorem for a multi – carrier signal with a large number of sub-carriers, the real and imaginary part of the time – domain signals have a mean of zero and a variance of 0.5 and follow a Gaussian distribution. So Rayleigh distribution is followed for the amplitude of the multi – carrier signal, where as a central chi-square distribution with two degrees of freedom is followed for the power distribution of the system.

The CDF of the amplitude of a signal sample is given by

$$F(z) = 1 - \exp(z) \qquad (4.6)$$

The CCDF of the PAPR of the data block is desired is our case to compare outputs of various reduction techniques. This is given by

$$P(PAPR \succ z) = 1 - (1 - \exp(-z))^N \qquad (4.7)$$

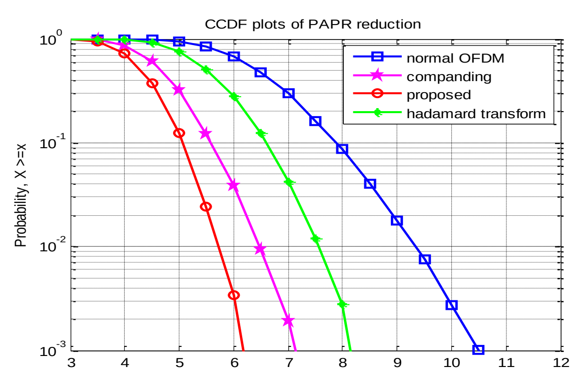

Figure 2 Comparisons of CCDF of PAPR

In Figure 2 at CCDF=10-3,the PAPR of proposed scheme is almost 1dB smaller than that of companding technique. The Hadamard matrix transform may reduce 2dB PAPR compared to that of original OFDM signal.

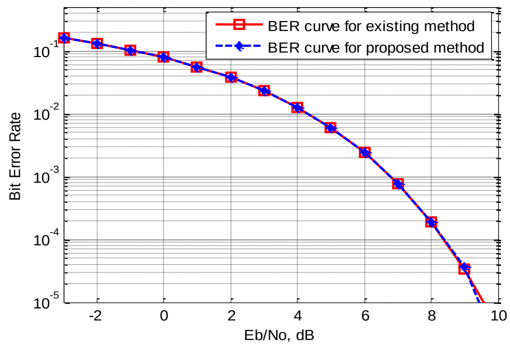

Figure3: BER Comparisons for different PAPR reduction schemes

Figure 3 shows the BER performances of OFDM system with proposed PAPR reduction scheme. The value of u is also 1. We can see that the performance of system is not degraded compared to the system with simple companding transform.

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