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Combined DCT and Companding for PAPR Reduction in OFDM Signals

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Abstract

The high peak-to-average (PAPR) is one of the serious problems in the application of OFDM technology. The Companding transform approach is a very attractive technique to reduce PAPR in that high bit error rate will occurred.in this paper we can combined both companding and dct(discrete cosine transforms) the proposed scheme may obtain about 1 dB PAPR reduction compared with the conventional Companding algorithm.
Keywords: OFDM,Companding, DCT Transform, PAPR,ICI

I. Introduction

OFDM (orthogonal-frequency-division multiplexing) is a promising technique that is able to provide high data rates over multipath fading channels. But in ofdm signal main problem is PAPR. It causes the poor power efficiency, serious performance degradation. To reduce many techniques have been proposed like clipping, coding, Selective mapping(slm),partial transforms(PTS) etc. Among those PAPR reduction methods, the simplest scheme to use is the clipping process. However, use of the clipping processing causes both in-band distortion and out-of-band distortion, 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 reduce the PAPR of an OFDM signal, but does not increase the BER of system.

II. OFDM

A. *OFDM Overview*

The fundamental principle of OFDM is a division of high data rate streams into a number of lower data rate streams and then transmitted these streams in parallel using several orthogonal sub-carriers (parallel transmission). Due to this parallel transmission, the symbol duration increases, thus decrease the prorated amount of dispersion in time resulting from the multipath delay spread. OFDM can be seen as either a modulation technique or a multiplexing technique. OFDM uses the principles of FDM to allow multiple messages to be sent over a single radio channel. It is however in a much more controlled manner, allowing an improved spectral efficiency.

B. *Orthogonality of the Subcarriers and OFDM:*

Two functions or signals are said to be orthogonal if they are mutually independent of each other. Orthogonality is a feature that lets multiple information signals to be transmitted skillfully over a common channel with the successful detection. The subcarrier spacing is chosen so that the waveforms transmitted on different sub carriers are orthogonal in time, but overlap in frequency. The principle of orthogonality state that if the time-averaged integral of the product of any two functions from a set of functions $\{g_1(t), g_2(t), g_3(t), \ldots\ldots g_N(t)\}$ over a joint existence time interval $[t_1, t_1+T]$ is equal to zero.

$$\frac{1}{T}\int_{t_1}^{t_1+T} g_i(t)\,.\,g_k(t)\,dt = 0 \qquad \forall\, i \neq k$$

C. *Guard Interval:*

Individual sub channels can be perfectly separated by the FFT at the receiver when there are no ISI and Inter-channel Interference (ICI) introduced by channel distortion. the Guard Interval or CP is a periodic addition of the final part of an OFDM symbol that is added to the front of the symbol in the transmitter, and at the receiver the CP is removed before demodulation.
CP insertion implies the copying of the last part of the OFDM data symbol and attaching it to the timing at the beginning of the symbol, creating a break between signals (hence: guarding-period).

D. Advantages OF OFDM System:

The advantages of OFDM system are given as

1) Saving of Bandwidth

The OFDM system is more bandwidth efficient in comparison to Frequency Division Multiplexing (FDM). In FDM technique numerous distinct carriers are spaced apart without overlapping where in OFDM system the sub-carrier overlap each other due to orthogonality features. Due to overlapping of sub-carriers the usage of bandwidth reduced drastically and also reduced the guard bands for the separation of sub-carriers.

2) Easy to implement modulation and demodulation

The challenging problem in a MCM system is to implement bank of modulators at the transmitter side and demodulators at the receiver side. The concept of "Data transmission" can be efficiently implemented using IFFT and FFT instead of bank of modulators at the transmitter side and demodulators at the receiver side respectively

3) Easy Equalization

In a single carrier system, equalization make frequency channel flat but equalization amplify noise greatly in frequencies domain where channel response is poor. In OFDM system, wideband channel are divided into flat fading sub-channels, it reduces the equalization complexity in the receiver. So, it is possible to use maximum likelihood decoding with reasonable complexity.

E. Major Problems OF OFDM Signal:

Despite of several advantages, the OFDM systems also have some major problems like

1) High Peak to Average Power Ratio (PAPR) of transmitted signal

Presence of a large number of subcarriers with varying amplitude results in a high peak to average power ratio (PAPR) of the system with large dynamic range, which in turn effects on the efficiency of the RF amplifier.

2) Synchronization (timing and frequency) at the receiver

Symbol Timing Offset (STO) and Carrier Frequency Offset (CFO) affects on the performance of OFDM system. Correct timing between FFT and IFFT is required at the receiver side. OFDM system is highly sensitive to Doppler shifts which affect the carrier frequency offset, resulting in ICI. This thesis is mainly focused on the PAPR problem in OFDM system.

F. Applications

The applications of OFDM are divided into two categories-wire-line and wireless application.The wire-line application such as Asymmetric Digital Subscriber Line (ADSL) broadband access through plain old telephone service (POTS) copper wiring.

G. Peak-to-Average Power Ratio

High PAPR of transmitted signals is one of the major issues of the OFDM system. A large dynamic range of input data symbols is the main cause of getting high PAPR. OFDM signal consists *N* of independent data symbols modulated on N orthogonal subcarriers, and when these *N* signals are added to the same phase, higher peak amplitude is observed. The value of this peak may be times of the average amplitude .The PAPR of any signal is defined as the proportion of the maximum instantaneous power of the signal and its average power. If x (t) is a transmitted baseband OFDM signal, then PAPR is defined as:

$$\text{PAPR} = \frac{\max_{0 \le t \le NT}\left[|x(t)|^2\right]}{1/(NT)\int_0^{NT}|x(t)|^2\,dt}$$

III. PAPR REDUCTION TECHNIQUES

A. Clipping and Filtering:

The clipping is the simplest method of PAPR reduction. Clipping limits the maximum amplitude of OFDM signal to a pre-specified level. 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 .For example; using HPA with saturation level below the signal span will automatically cause the signal to be clipped.

It has following drawbacks:

1) It causes in-band signal distortion, resulting in BER performance degradation.
2) It also causes out-of-band radiation, which imposes out-of-band interference signals to adjacent channels. The out-of-band radiation can be reduced by filtering, but the filtering may affect high-frequency components of in-band signal (aliasing) when the clipping is performed with the Nyquist sampling rate.
3) Filtering after clipping can reduce out-of-band radiation at the cost of peak re-growth. The signal after filtering operation may exceed the clipping level specified for the clipping operation.

B. Companding Technique:

Non-linear Companding is an especial clipping technique which offers good PAPR reduction with better BER performance, low implementation complexity, and no bandwidth expansion.

The difference between clipping and companding is that the clipping process deliberately clips the large amplitude signals; therefore the signal cannot be recovered exactly. The companded signals can be recovered correctly through the corresponding inversion of companding transform at the receiver.

C. Coding Techniques:

The basic premise of coding is to insert redundant bits into the data stream which can be used for error correction at the receiver. Their application to PAPR reduction is in creating sequences of bits which will exhibit low PAPR after the IFFT.
There are 2 types of error detection and correction codes, block codes and convolution codes.

The basic idea of all coding schemes for the reduction of PAPR is to reduce the occurrence probability of the same phase of N signals. The coding method selects such code words that minimize or reduce the PAPR. It causes no distortion and creates no out-of-band radiation, but it suffers from bandwidth efficiency as the code rate is reduced. It also suffers from complexity to find the best codes and to store large lookup tables for encoding and decoding, especially for a large number of subcarriers.

D. Selective Mapping (SLM):

In SLM, the basic idea is to generate a set of OFDM signals, all of them representing the same data block, and then transmitting the one with the lowest PAPR. The major drawback of SLM method is that it is more computationally complex because more than one IFFT blocks are used It also decreases the data rate because the selected signal index, called *side information*, must also be transmitted to allow for the recovery of the original data block at the receiver side

E. Partial Transmit Sequence (PTS):

In PTS, the original data block is divided into multiple non-overlapping sub-blocks. Then these sub-blocks are rotated with rotation factors which are statistically independent. After that, the signal with the lowest PAPR is chosen for transmission
There are several ways for the partition of the data sequence into multiple sub-blocks, including adjacent partition, interleaved partition and pseudorandom partition. Among them, pseudo-random partitioning has been found to be the best choice.

Similar to SLM, the major drawback of PTS is also the computational complexity (search complexity for optimal phase factor, and more than one IFFT blocks) and low data rate (required side information). Several techniques have been proposed in the literature to reduce the search complexity and overhead (by reducing/avoiding the usage of side information)**.** The complexity of PTS is less than SLM.

F. Discrete Cosine Transform:

Like other transforms, such as the Hadamard transform, the DCT decorrelates 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 is applied . In this section, we briefly review the DCT. The formal definition of a one-dimensional DCT of length *N* is given by the following formula

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

IV. PROPOSED TECHNIQUE FOR PAPR REDUCTION

A. System Model:

To reduce the PAPR an OFDM signal, we propose a scheme involving the combination of a Companding transform and DCT. The input data stream is processed with a DCT then with an IFFT signal processing unit. A block diagram of the system is shown in Figure 1.

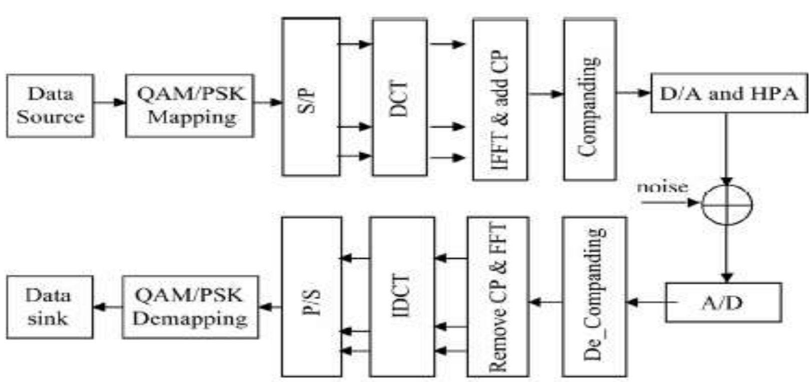

Fig. 1: OFDM system block with DCT-companding

The key signal processing step is described as below:

Step 1:
The sequence X is transformed using the DCT matrix, i.e.
Y = HX
Step 2:
An IFFT(Y) is applied, yielding:
$Y=[y(1),y(2),y(3)-----y(n)]^T$
Step 3: A companding transform is then applied to y
i.e s(n)=c{y(n)}
step 4: An inverse companding transform is applied to the received signal,r(n)
step 5: A FFT transform is applied to the signal,$y^{\wedge}(n)$
i.e $Y=FFT(y^{\wedge}(n)$
where $y^{\wedge} = [y^{\wedge}(1),y^{\wedge}(2)-----y^{\wedge}(n)]$
Step 6: An inverse DCT transforms applied to the signal y i.e $X=H^TY^{\wedge}$ Then, the signal, ˆX, is de-maped from the bit stream.

B. Simulation Results

The Cumulative Distribution Function (CDF) is one of the most regularly used parameters to measure the efficiency of any PAPR technique. Normally, the Complementary Cumulative Distribution Function (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.The CCDF is generally used to estimate the bounds of the PAPR and as well as performance evaluation parameter for most of the PAPR reduction schemes.

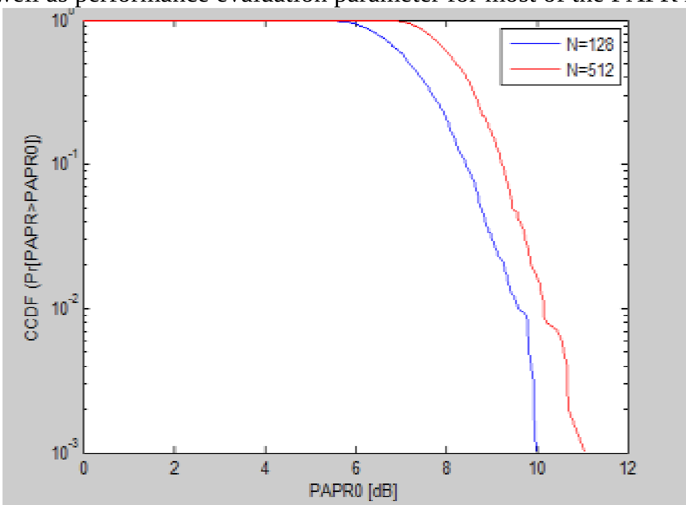

Fig. 2: CCDF of different FFT values

The most obvious trend in the graph is that PAPR goes on increasing as the number of sub-carriers increases. The theoretical value of CCDF is almost same as simulated value of CCDF. The deviation of simulated value is negligible to the calculated or theoretical value for small sub-carriers (i.e. N=64). As,N becomes large the simulated and theoretical values of the CCDF align in the same line.

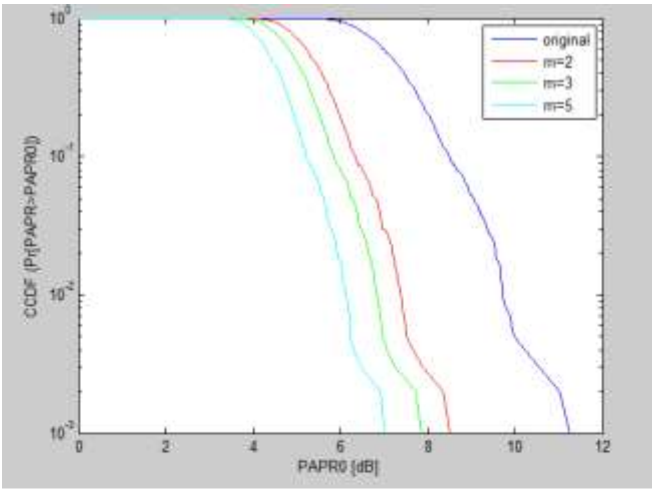

Fig. 2: CCDF of different μ values

The values of the Companding factor, *u*, for the Companding procedure of the second step were fixed to 2, 3, and 5. With this Companding method, the peak power at CCDF = 10–3 is reduced by 3.5 dB, 5 dB and 5.5 dB when compared with the case of original system.

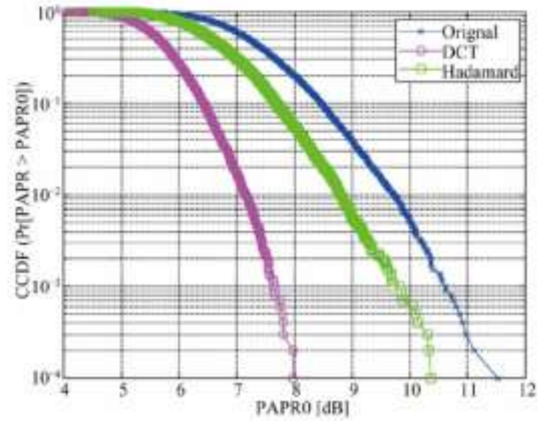

Fig. 3: CCDFs of the matrix transformations

Figure3 shows the CCDF performance of the DCT scheme compared with that of the original and Hadamard transform techniques. At CCDF = 10–3, the DCT scheme reduces the PAPR by 3 dB over original system, but the Hadamard transform only reduced the PAPR by 1 dB.

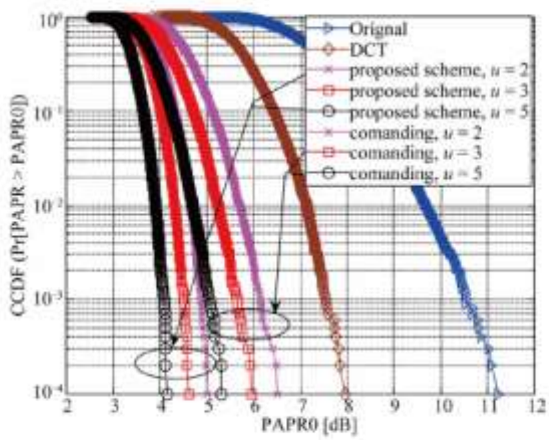

Fig. 4: Compatisons of the CCDF of different PAPR reduction schemes

Figure 4 shows the CCDF performance of the pro-posed PAPR reduction scheme. In the simulation OFDM system, the number of sub carrier is 128. At CCDF = 10–3

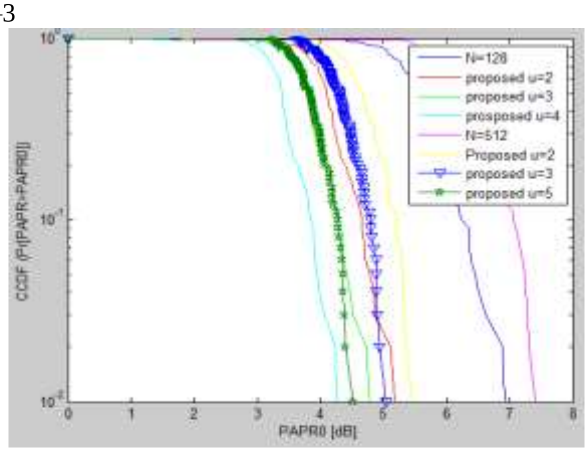

Fig. 5: shows the CCDF performance of proposed reduction PAPR scheme at difference subcarriers

We can see from Figure 5, the effect of difference subcarriers to PAPR performance of OFDM signals is very small.

V. CONCLUSION

In this paper, while taking both PAPR performance and BER performance into account, we proposed a combined DCT and companding scheme for the reduction of the PAPR of OFDM signals. The proposed scheme is com-posed of the DCT transform followed by the companding transform. The DCT, used in the first step, does not influence the BER. The PAPR reduction performance of the proposed scheme was evaluated using a computer simulation. The simulation results show that the PAPR reduction is improved when compared with those of a Companding transform.

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