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Research Article

Low Noise Technique for Reduction of Peak Power and BER in High Rate Wireless Communication System

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Abstract

Orthogonal Frequency Division Multiplexing (OFDM) provides an attractive solution to high rate wireless communication which provides robustness to interference and multipath fading. Large peak to average power ratio (PAPR) is one of the greatest challenges in multicarrier communication. This paper proposes a comparatively simple, low noise technique for transmission of a multicarrier signal in high rate wireless communication. Clipping based active constellation is one of the commonly used techniques for reducing large peaks. But this technique results in peak regrowth, which degrades the bit error rate (BER) performance and increase in in-band noise and out-of band noise. This paper proposes a technique that reduces computational complexity and gives better performance with respect to Bit-error-rate. The improvement on BER performance is studied for various compression profiles. The proposed method effectively reduces nonlinear distortion and BER resulting in low noise system. This simplifies design of transmitter and receiver. The simulation results show that the proposed technique results in lower PAPR and gives simple solution.

Keywords: *Orthogonal Frequency Division Multiplexing(OFDM), Exponential Companding, Peak to Average power ratio(PAPR), Bit Error Rate (BER).*

1. Introduction

Wireless communication is characterized by various phenomenon such as path loss attenuation with distance, shadowing, multipath-fading, interference, noise etc. Each of these not only restricts the data rate over available bandwidth but also affects quality of service. Multi-carrier communication allows transmission of data at high rate and has been applied in many radio communication applications such as digital audio broadcasting (DAB), Digital Terrestrial Broadcast (DVBT), Hyperlan-2 and IEEE802.11a etc. Due to its robustness against multipath fading and due to large symbol duration. One of the frequently cited drawbacks of multi-carrier signal is occurrence of large peak values due to superimposition of large number of subcarriers. Large PAPR values result in increased complexity of transmitter and receiver. This gives rise to reduction in RF power amplifier efficiency. Moreover nonlinear characteristics of transmission system (transmitting media and high power transmitting amplifiers) cause spectral widening of the transmit signal which leads to in-band noise and out-of-band noise. Therefore it is very essential to reduce in-band-noise and out-of-band noise. This is possible only if large peaks are avoided. PAPR reduction techniques can be divided in to three categories. Signal predistortion technique such as clipping and filtering in which signal peaks are reduced by clipping the signal; Coding techniques exclude some of the combinations resulting in large peak; Distortionless techniques reduce large peaks at the cost of reduced bandwidth efficiency and increased computational complexity. In this paper we propose a technique which has advantages of both predistortion techniques as well as distortionless techniques. Use of coding techniques will further improve system performance with respect to BER.

When a multicarrier signal is passed through high power transmitting amplifier, it suffers nonlinear distortion giving rise to in-band noise and spectral widening. If the amplifier is modeled as 3dB clipper, then it is responsible for 14dB inband noise and 22dB adjacent channel interference. Therefore it is very essential to avoid nonlinear distortion and a technique is proposed that avoids signal peaks thereby avoiding nonlinear distortion.

2. OFDM System

Orthogonal Frequency Division Multiplexing is a multi-carrier modulation technique in which data symbols modulate a parallel set of regularly spaced orthogonal sub-carriers. An OFDM modulator is implemented as an N-point inverse discrete Fourier transform (IDFT) on a block of N information symbols followed by digital-to-analog converter (DAC) on the IDFT samples as shown in Fig.1. The IDFT of the data block is

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$$S_n = \sum s_k \exp\{j2\pi nk/N\},\ n = 0, 1, 2, \ldots N-1, \quad (1)$$

yielding time domain sequence $\{S_n: n = 1, 2, \ldots, N\}$. Each block of N IDFT coefficients is typically preceded by a cyclic prefix (CP) or a guard interval to mitigate effect of ISI caused by delay spread or multipath signal. The output of OFDM transmitter is a multi-carrier complex signal consisting of in phase component s_I (t) and quadrature component s_Q (t) as shown in Fig. 1.

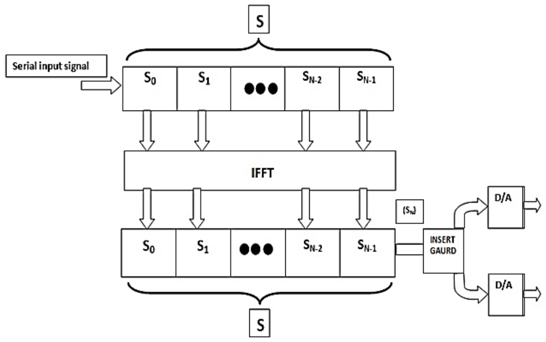

Fig 1: Block diagram of basic OFDM transmitter.

At the receiver, the received complex baseband signal is sampled with an analog-to-digital converter (ADC), with sampling interval of $\Delta T = T_s/N$. After removal of the guard interval, each block of N received samples is converted back to the frequency domain using FFT as shown in Fig 2. The discrete Fourier transform performs baseband demodulation. Thus due to large symbol duration the effect of ISI and multipath propagation is overcome. Another advantage of large symbol duration is that it requires very simple equalizers. The N frequency domain samples are each processed with a simple one tap Frequency Domain Equalizer and applied to a decision device to recover the data symbols.

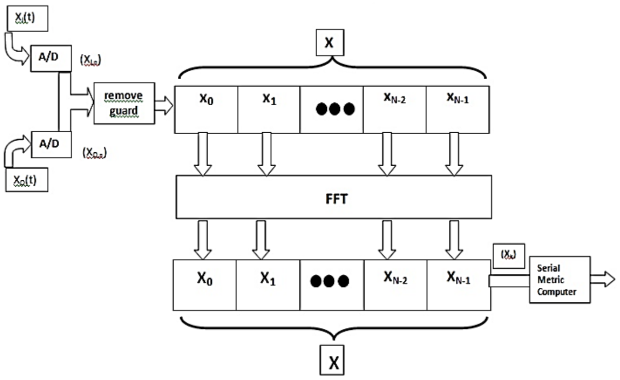

Fig 2 Block diagram of basic OFDM receiver

3. Compression of Large Peaks

Peak to average power ratio in OFDM system can be improved by either distortionless technique such as selective mapping, partial transmit technique, tone injection or tone reservation etc. Peak power reduction can also be achieved with techniques that give rise to distortion such as clipping and filtering technique. Distortionless technique has the advantage of very low BER but these techniques are very complex and needs side information to be transmitted. And hence reduces bandwidth efficiency. Clipping and filtering technique has the advantage of simplicity but clipping gives rise to distortion and hence increased BER. In this paper we compare the performance of existing technique and propose a technique that has the advantages of both with distortion and distortionless technique.

3.1 Clipping-Based Active Constellation Extension (CB-ACE) Algorithm

Clipping peaks of the signal is the simplest method but results in distortion of the original OFDM signal resulting in noise, which results in increased BER. CB-ACE algorithm removes the Out-of-Band Interference (OBI), by filtering the signal. It has been observed that the CB-ACE technique has low clipping ratio this means, the minimum PAPR cannot be achieved when the target clipping level is set below certain level.

The clipping signal, denoted by $c_n^{(i)}$, is given by the equation (2)

$$c_n^{(i)} = \begin{cases} (|x_n^{(i)}| - A)e^{j\theta_n}, & |x_n^{(i)}| > A \\ 0, & |x_n^{(i)}| \le A \end{cases} \quad (2)$$

Where, $c_n^{(i)}$ – Clipping Sample

A – Predetermined Clipping Level θ_n – arg(- $x_n^{(i)}$)

The CB-ACE cannot achieve the minimum PAPR for low target clipping ratios, because the reduced power by low clipping decreases the PAPR reduction gain in ACE. The clipping method suffers from the three major problems like in-band distortion, out-of-band radiation & peak re-growth after filtering the signal for removing out of band noise.

3.2 Exponential Compression Technique.

PAPR of a multi-carrier signal can also be reduced by enlarging smaller amplitudes and keeping large amplitudes unaltered. This technique improves the quantization resolution of small signals at the cost of reduction in resolution of large peaks. Peak-to-Average Power Ratio (PAPR) of the Orthogonal Frequency Division Multiplexing (OFDM) signals can also be reduced using Nonlinear Companding Transform. As the companding increases the number of the quantization intervals for small signals, while maintaining the average power unchanged by properly choosing the transform parameters. The number of the quantization intervals available for large signal will inevitably be reduced since the total number of the quantization intervals remains unchanged after companding. Therefore, there exists an optimal companding coefficient. The key idea of the Nonlinear Companding Transform is to exploit statistical distribution of OFDM transmit signals, which is well modeled by Gaussian distribution for large number of sub-carriers. For OFDM systems, the proposed companding scheme transforms the distribution of the transmitted signals into quasi-uniform distribution. The nonlinear characteristics of the Nonlinear Companding Transform, denoted by y, are given by the equation (3)

$$y = k_1.\mathrm{erf}(k_2 x) \tag{3}$$

Where, y – Nonlinear Characteristics of the Nonlinear Companding Transform erf (x) – An Error Function, k_1 – Positive Number, and k_2 – Positive Number. The Error Function used in the nonlinear characteristic of the Nonlinear Companding Transform is given by the equation (4).

$$\mathrm{erf}(x) = \frac{2}{\sqrt{\Pi}} \int_0^x e^{-t^2} dt \tag{4}$$

Where, erf(x) – Error Function

The companding scheme can be implemented with low complexity, without any iterative computations, as compared with other techniques.

3.3 Exponential Companding Transform Technique

The scheme based on exponential companding technique adjusts both large and small signals and can keep the average power at the same level. By transforming the original OFDM signals into uniformly distributed signals (with a specific degree), the exponential companding scheme can effectively reduce PAPR for different modulation formats and sub-carrier sizes. Moreover, many PAPR reduction schemes, such as µ-law companding scheme, cause spectrum side-lobes generation, but the exponential companding schemes cause less spectrum side-lobes.

The Exponential Companding Transform can effectively transform the original Gaussian-distributed OFDM signals into uniform-distributed i.e., companded signal without changing the average power level. Unlike the µ-law companding scheme, which mainly focuses on enlarging small signals, exponential companding schemes adjust both small and large signals without bias, so that the companding transform is able to offer better performance in terms of Peak-to-Average Power Ratio (PAPR) reduction, Bit-Error-Rate (BER) and phase error for Orthogonal Frequency Division Multiplexing (OFDM) systems.

The Exponential Companding Transform can effectively reduce the PAPR of transmitted signal by transforming the statistics of the amplitudes of these signals into uniform distribution with constant average power level.

These novel schemes also have the advantage of maintaining a constant average power level in the nonlinear companding operation.

3.4. Nonlinear Companding Transform Algorithm.

The process of companding enlarges the amplitudes of the small signals, while the peaks remain unchanged. Therefore, the average power is increased and thus the Peak-to-Average Power Ratio (PAPR) of the Orthogonal Frequency Division Multiplexing (OFDM) systems can be reduced, which in turn helps in increasing the efficiency of the power amplifiers and also reduces the complexity of the Analog-to-Digital Converter (ADC) and Digital-to-Analog Converter (DAC).

The proposed transform appears to be the most attractive technique among various Companding Transforms like µ-Law Companding Transform, Nonlinear Companding Transform because of its simplicity and effectiveness. Large peaks of an OFDM signal under consideration is compressed at the transmitting end and expanded at the receiving end. In µ-law compression technique at the transmitting end compression is performed according to µ-law viz equation (7).

$$y = V \frac{\ln[1+\mu\frac{|x|}{V}]}{\ln(1+\mu)}\, sgn(x) \quad -1 \le x \le 1, \tag{5}$$

Where V = peak amplitude of signal, and x = instantaneous amplitude of the input signal. Decompression is simply inverse of (5) i.e.

$$x = \frac{v}{\mu}\left[exp^{\left(\frac{|y|\log(1+\mu)}{v}\right)} - 1\right] sgn(y) \quad -1 \le y \le 1 \tag{6}$$

Compression of rarely occurring peaks improves resolution of smaller amplitudes which are occurring more frequently as compared larger amplitudes. Compression of larger amplitudes gives rise to quantization noise; however, the effect of the quantization noise due to reduction in resolution of the peaks is relatively small as the peaks occur less frequently.

Exponential companding transform not only reduces out of band noise but also maintains constant average power level. In addition number of side lobes is also reduced. The proposed scheme reduces PAPR without increasing system complexity as no side information needs to be transmitted. The companded signal obtained by using exponential compression is given by equation (7)

$$\mathrm{H(x)=sgn(x)}\sqrt[d]{\propto [1 - \exp(-\frac{x2}{\sigma 2})} \tag{7}$$

Where, H(x) is companded signal

$\propto$ is Average power of output signal
X is original OFDM signal.

The average power of the output signal is given by

$$\propto = \frac{E[|Sn|2]}{E\left[\sqrt[d]{\left[1-exp\left(-\frac{|Sn|2}{\sigma 2}\right)2\right]}\right]} \tag{8}$$

Where d is power of the amplitude of the companded signal.

4. Results

Peak to average power ratio can be quantified by a complimentary cumulative distribution function (CCDF). Fig4.1 shows CCDF plot for 128 channel (Subcarrier)

OFDM signal. 128 subcarrier system has a PAPR of 11.8dB at a CCDF of 10^{-2} of a multicarrier signal without any corrective measure. Fig 4.1 shows that an OFDM system is resulting in large PAPR which affect performance of high rate communication system resulting in increased BER and interference. This also makes system design more complex.

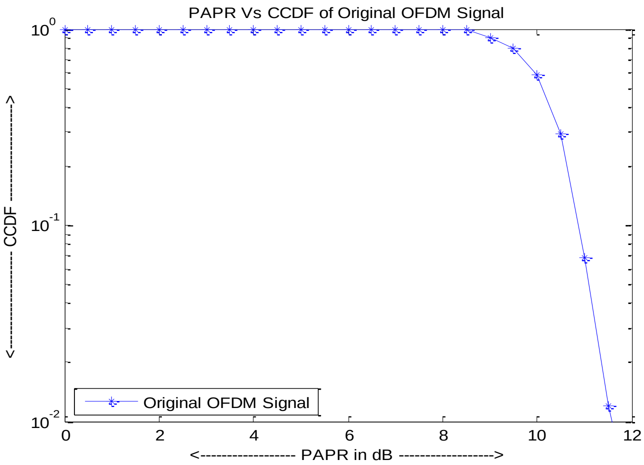

Fig 4.1 PAPR vs CCDF of Original Signal

Signal to Noise Ratio and Bit Error Rate for 128 subcarrier OFDM signal is plotted in Fig 4.2. From the simulation result 4.2, the Signal-to-Noise Ratio (SNR) of the original Orthogonal Frequency Division Multiplexing (OFDM) signal is equal to 11.8 dB at a Bit Error Rate (BER) of 10^{-2} or 0.01 without coding.

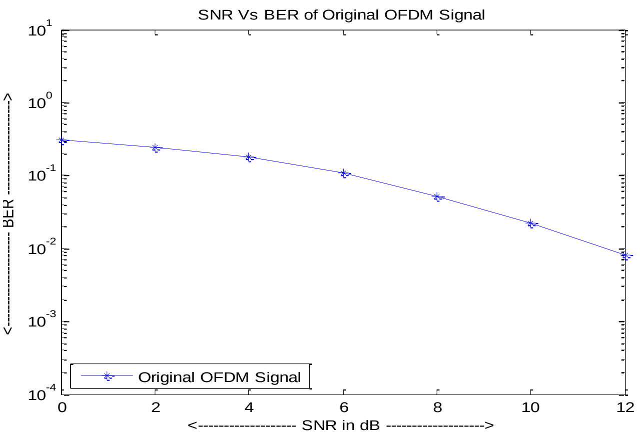

Fig 4.2 BER vs SNR for 128 subcarrier system without coding

PAPR Vs CCDF by using CB-ACE Algorithm for Target Clipping Ratios of 0dB, 3dB and 6db is plotted in Fig 4.3. The Average Power Ratio (PAPR) of the Orthogonal Frequency Division Multiplexing (OFDM) signal obtained by using the Clipping-Based Active Constellation Extension (CB-ACE) algorithm is equal to 10 dB, 8.5 dB and 8.0 dB for the target clipping ratios of 0 dB, 3 dB and 6dB respectively with a Complimentary Cumulative Distribution Function (CCDF) of 10^{-2} or 0.01. This shows an improvement in PAPR of an OFDM system. Results also show that increase in clipping target ratio from 3db to 6dB does not show improvement in the PAPR ratio.

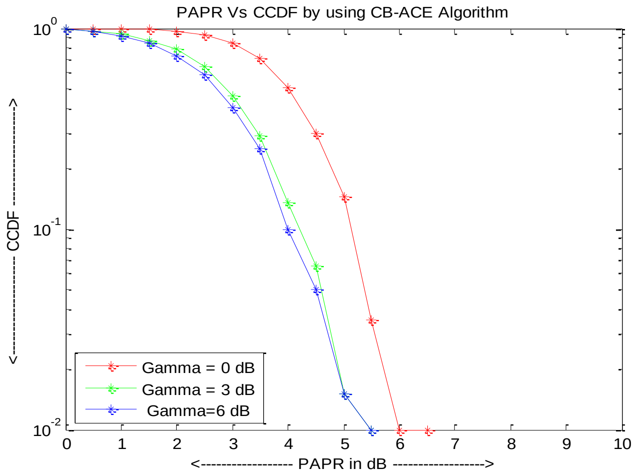

Fig 4.3 PAPR vs. CCDF by using CB-ACE

PAPR vs. CCDF of Proposed Technique (Nonlinear Companding Technique) is plotted in Fig 4.4. Fig shows that there is considerable improvement in PAPR. This reduces system complexity. Any errors that may result in increased BER can be reduced by various coding algorithms.

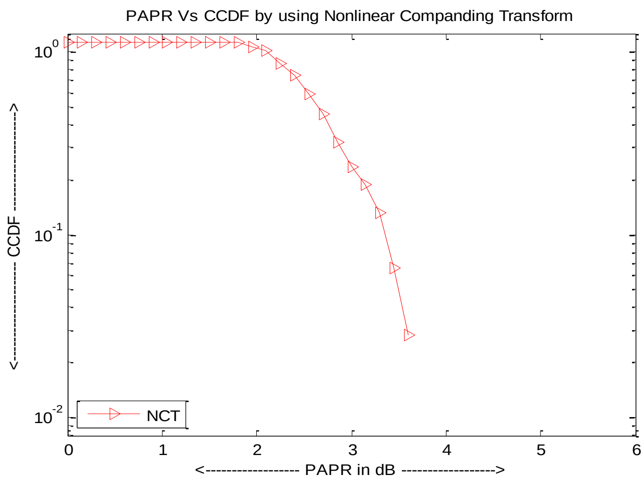

Fig 4.4 PAPR Vs CCDF by using Nonlinear Companding Transform

From the Simulation Result 4.4, the Peak-to-Average Power Ratio (PAPR) of the Orthogonal Frequency Division Multiplexing (OFDM) signals obtained by using the Exponential Companding Transform is reduced to 3.5 dB with a Complimentary Cumulative Distribution Function (CCDF) of 10^{-2} or 0.01. Hence we see that an improvement of the order of 3 o 4db can be obtained with the proposed technique.

5. Conclusion

Reduced PAPR systems make design of transmitting and receiving equipments simple. The exponential companding transform improves Bit Error Rate and considerable decrease in out-of-band noise. For 128 subcarrier multi-carrier signal and over 100000 symbols it is observed that the Peak-to-Average Power Ratio (PAPR) of OFDM signal is of the order of12dB at a Complimentary Cumulative Distribution Function (CCDF) of 10^{-2} or 0.01.

The Signal-to-Noise Ratio (SNR) of the original OFDM signal observed is equal to 16 dB. Thus an improvement of 4dB is observed. The Clipping-Based Active Constellation Extension (CB-ACE) Algorithm reduces the high Peak-to-Average Power Ratio (PAPR) by clipping and filtering the original OFDM signal. The CB-ACE Algorithm results to peak re-growth, Out-of-Band Interference (OBI), low clipping ratio problem, increase in the Bit Error Rate (BER) and decrease in the Signal-to-Noise Ratio (SNR).

The Exponential Companding Transform improves the Bit Error Rate (BER) and minimizes the Out-of-Band Interference (OBI) in the process of reducing the Peak-to-Average Power Ratio (PAPR) effectively by compressing the peak signals and expanding the small signals. The improved BER transmits the data via a transmission channel with fewer errors, while the minimized OBI reduces the effects caused by clipping.

Hence, by reducing the Peak-to-Average Power Ratio (PAPR), the complexity of the Analog-to-Digital Converter (ADC) and Digital-to-Analog Converter (DAC) can be reduced. The reduced Peak-to-Average Power Ratio (PAPR) also increases the efficiency of the Power Amplifiers.

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