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REDUCTION OF PEAK-TO-AVERAGE POWER RATIO IN OFDM SYSTEMS

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Abstract

Orthogonal Frequency Division Multiplexing (OFDM) is a widely used modulation technique in modern wireless communication systems due to its high spectral efficiency and robustness against multipath fading. However, one of the major drawbacks of OFDM systems is the high Peak-to-Average Power Ratio (PAPR) of the transmitted signal, which can lead to performance degradation and nonlinear distortion.

This work presents a novel PAPR reduction scheme for OFDM systems by utilizing a companding transform. The proposed technique offers several advantages, including efficiency, signal independence, distortion-less operation, and the elimination of the need for optimization algorithms. By applying the companding transform to the OFDM signal, the dynamic range of the signal is effectively compressed, reducing the high PAPR.

Simulation results demonstrate the effectiveness of the proposed companding transform-based algorithm in mitigating the PAPR issue in OFDM systems. A comparative analysis with a non-companded OFDM system reveals that the proposed scheme achieves superior performance in terms of PAPR reduction. The results indicate that the proposed algorithm can significantly enhance the performance of OFDM systems by reducing the high PAPR without introducing distortion or requiring additional optimization algorithms.

Overall, this study highlights the potential of the companding transform as a promising technique for PAPR reduction in OFDM systems. The proposed algorithm offers a practical and efficient solution to address the high PAPR issue, improving the performance and reliability of OFDM-based wireless communication systems.

Keywords: OFDM systems, PAPR (Peak-to-Average Power Ratio), PAPR reduction.

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission scheme that has become the technology of choice for next generation wireless and wire line digital communication systems because of its high-speed data rates, high spectral efficiency, high quality service and robustness against narrow band interference and frequency selective fading. OFDM thwarts Inter Symbol Interference (ISI) by inserting a Guard Interval (GI) using a Cyclic Prefix (CP) and moderates the frequency selectivity of the Multi Path (MP) channel with a simple equalizer. This leads to cheap hardware implementation and makes simpler the design of the receiver. OFDM is widely adopted in various communication standards like Digital Audio Broad casting (DAB), Digital Video Broadcasting (DVB), Digital Subscriber Lines (DSL), Wireless Local Area Networks(WLAN), Wireless Metropolitan Area Networks (WMAN),Wireless Personal Area Networks (WPAN) and even in the beyond 3G Wide Area Networks (WAN) etc. Additionally, OFDM is a strong candidate for Wireless Asynchronous Transfer Mode (WATM). However, among others, the Peak to Average Power Ratio (PAPR) is still one of the major drawbacks in the transmitted OFDM signal. Therefore, for zero distortion of the OFDM signal, the HPA must not only operate in its linear region but also with sufficient back-off. Thus, the RF High Power Amplifier (HPA) with a large dynamic range is required for OFDM system. These amplifiers are very expensive and are a major cost component of the OFDM has been attracting substantial attention due to its excellent performance under severe channel condition. The rapidly growing application of OFDM includes Wi-MAX, DVB/DAB and 4G wireless systems.

Overview

Initial proposals for OFDM were made in the 60s and the 70s. It has taken more than a quarter of a century for this technology to move from the research domain to the industry. The concept of OFDM is quite simple but the practicality of implementing it has many complexities. So, it is a fully software project. OFDM depends on Orthogonality principle. Orthogonality means, it allows the sub carriers, which are orthogonal to each other, meaning that cross talk between co-channels is eliminated and inter-carrier guard bands are not required. This greatly simplifies the design of both the transmitter and receiver, unlike conventional FDM; a separate filter for each sub channel is not required.

Orthogonal Frequency Division Multiplexing (OFDM) is a digital multi carrier modulation scheme, which uses a large number of closely spaced orthogonal sub-carriers. A single stream of data is split into parallel streams each of which is coded and modulated on to a subcarrier, a term commonly used in OFDM systems. Each sub-carrier is modulated with a conventional modulation scheme (such as Quadrature amplitude modulation) at a low symbol rate, maintaining data rates similar to conventional single carrier modulation schemes in the same bandwidth. Thus the high bit rates seen before on a single carrier is reduced to lower bit rates on the subcarrier.

In practice, OFDM signals are generated and detected using the Fast Fourier Transform algorithm. OFDM has developed into a popular scheme for wideband digital communication, wireless as well as copper wires. Actually FDM systems have been common for many decades. However, in FDM, the carriers are all independent of each other. There is a guard period in between them and no overlap whatsoever. This works well because in FDM system each carrier carries data meant for a different user or application. FM radio is an FDM system. FDM systems are not ideal for what we want for wideband systems. Using FDM would waste too much bandwidth. This is where OFDM makes sense. In OFDM, subcarriers overlap. They are orthogonal because the peak of one subcarrier occurs when other subcarriers are at zero. This is achieved by realizing all the subcarriers together using Inverse Fast Fourier Transform (IFFT).The demodulator at the receiver parallel channels from an FFT block. Note that each subcarrier can still be modulated independently.

As a multicarrier modulation technique, orthogonal frequency division multiplexing (OFDM) has gained popularity in a number of applications including digital audio broadcasting (DAB), terrestrial digital video broadcasting (DVB-T), the IEEE 802.11a standard for wireless local area networks (WLAN) and the IEEE 802.16d standard for wireless metropolitan area networks (WMAN), owing to its high bandwidth efficiency and robustness to multipath fading.

However, some drawbacks are still unresolved in the design of OFDM system. One of the major problems of OFDM system is the high peak-to-average power ratio (PAPR), which may result in significant distortion when the transmitted signals passed through a nonlinear device such as the power amplifier. To deal with this problem, many PAPR reduction schemes have been proposed, such as block coding, clipping, companding transform schemes, selective mapping (SLM), and partial transmit sequence (PTS). Among which, PTS is a distortion less phase optimization scheme that provides excellent PAPR reduction with a small amount of redundancy. In PTS, an input data sequence is divided into a number of disjoint sub blocks, which are then weighted by a set of phase factors to create a set of candidate signals. Finally, the candidate with the lowest PAPR is chosen for transmission. Nevertheless, finding the optimum candidate requires the exhaustive search over all combinations of allowed phase factors, and the search complexity increases exponentially with the number of sub blocks. To reduce the computational complexity, some modified techniques have been presented. Most of them focus on reducing the number of candidate signals.

For example, iterative flipping with a preset threshold algorithm has been introduced to reduce the PAPR with less complexity and easier implementation. However, the combination of its phase factors is suboptimal and there is some performance gap between the conventional PTS scheme and the iterative flipping algorithm.

1.1 Problems Outline

The 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. Therefore the major problem one faces while implementing this system is the high peak – to – average power ratio (PAPR). 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.

1.2 Motivation

Due to large number of subcarriers, the OFDM signal has large dynamic range with large Peak to Average Power Ratio (PAPR). When considering a system with transmitting power amplifier, the nonlinear distortions and peak amplitude limiting introduced by the High Power Amplifier (HPA) will produce inter modulation between the different carriers and introduce additional interference into the system. This additional interference leads to an increase in Bit Error Rate (BER) of the system. One way to avoid such non-linear distortions and keep a low BER is by forcing the amplifier to work in its linear region. Unfortunately such solution is not power efficient and thus not suitable for wireless communications. Hence there is need for reducing PAPR of transmitted signal.

Currently Global System for Mobile telecommunications (GSM) technology is being applied to fixed wireless phone systems in rural areas. However, GSM uses time division multiple access (TDMA), which has a high symbol rate leading to problems with multipath causing inter-symbol interference. Several techniques are under consideration for the next generation of digital phone systems, with the aim of improving cell capacity, multipath immunity, and flexibility. These include CDMA and OFDM. Among those OFDM can be used because of its effectiveness.

1.3 Objective

There are several methods are proposed to reduce the PAPR. In this, the PAPR analysis in OFDM system is proposed using new companding transform and disclosed the effectiveness of proposed PAPR reduction system as compared to without companding.

2. Related Work

From the past decades many PAPR reduction techniques have been proposed to improve the digital communication system efficiency, and still the researchers are focusing on developing extended PAPR reduction schemes with more effective results. Among them, few techniques like block coding schemes [8], Tone Reservation (TR), Tone Injection (TI) [10-12], iterative clipping and filtering [16], Partial Transmit Sequence (PTS) [9], Active Constellation Extension (ACE) [11], Adaptive ACE [12-14], Select Level Mapping (SLM) [19], companding techniques such as linear [10], non-linear, exponential companding [15] are more popular. The letter proposed in [8] gives a block coding technique for PAPR reduction of multi carrier transmission methods such as OFDM. However, block coding scheme has got reduced peak to mean envelop power ratio (PMEPR) but it has the limitation in number of carriers, hence does not suit for longer data sequences. X. Li *et. al.* in [9] proposed a new PAPR reduction scheme which is based on clipping and filtering, which reduces the peak to mean envelop power ratio by clipping the transmitted sequence to certain extent and afterwards filters the clipped data to reduce the PAPR. Although it reduces the PAPR to some extent but while clipping the input data we are losing the original data bits, which in results the poor system efficiency.

Wattanasuwakull *et. al.* proposed tone reservation (TR) and tone injection (TI) method [10] to reduce the PAPR of the OFDM signal. Main idea of the approach in [11] is to produce a surplus and linear signal which will reduce the peak-power by reservation of number of subcarriers. However, due to the surplus symbols and the larger signal constellation usage it slows down the data rate and increases transmitter power. Sang *et. al.* in [13] proposed a modified selective mapping scheme (SLM) to reduce the PAPR which performs better than conventional SLM and PTS. Algorithm in [13] proposes a modified SLM in which the subcarriers which are predefined will be inserted by the dummy or complementary sequence taken from flipping method. Partial Transmit Sequences (PTS) is an efficient technique for reduction of Peak-to-Average Power Ratio (PAPR) Orthogonal Frequency Division Multiplexing (OFDM) system. However, higher computational complexity is the major drawback of PTS. To overcome this many PTS methods have been proposed. The paper proposed in [14] discusses the optimized PTS (O-PTS) scheme with super imposed training, in which the O-PTS method reduces the PAPR to 7.25 dB from 10 dB of conventional PTS scheme. In [15] transformation-based approach for PAPR reduction has been proposed, which uses linear companding transform. Another approach of PAPR reduction proposed in [16], which presents a new hybrid peak-to-average power ratio reduction technique with the combination of ACE and TR. Recently, adaptive active constellation extension (AACE) method has been proposed in [17-18]. In this approach AACE overcomes the drawbacks of the existed ACE and clipping based active constellation extension (CB-ACE). In [20] the author tried to explain the companding OFDM techniques to reduce the PAPR. Companding techniques have got the better performance than the ACE, AACE but it supports limited modulation schemes and it suffers from large degree of companding value.

However, all the methods which have been discussed above have many drawbacks. To overcome all the drawbacks of conventional schemes, a novel and low complexity partial transmit sequence scheme has been proposed in [22], in which the author has achieved the minimum PAPR of 5.04 dB, but it takes more computations and more CPU time to calculate the phase vectors.

3. PROPOSED IMPLEMENTATION

3.1 PAPR in OFDM Systems

Input data sequence to be transmitted with N subcarriers in an OFDM symbol is (0),(1), $\cdots$,$X(N$ -1). The baseband representation of the OFDM symbol is given by:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X(n) e^{\frac{j2\pi nt}{N}} \qquad 0 \le t \le T \tag{1}$$

T is OFDM symbol duration. When N value will be increased then both the real and imaginary parts of $x(t)$would become Gaussian distributed and each with zero mean with a variance of$E[|x(t)^2|]/2$, and the OFDM symbol amplitude follows a Rayleigh distribution. Therefore, it is possible that the OFDM symbol amplitude will be exceeds than the maximum amplitude. Practical hardware such as A/D and D/A converters, high power amplifiers (HPA) has finite dynamic range; therefore, the maximum amplitude of OFDM signal should be limited.

PAPR of an OFDM signal has been defined as:

$$PAPR = \frac{max[|x(t)^2|]}{\frac{1}{T}\int_0^T |x(t)|^2 dt} \quad (2)$$

In dB value the PAPR can be written as$PAPR = 10log_{10}(PAPR)$. It is easy to see from (2) that reduction of PAPR can be achieved by reducing the numerator and increasing the denominator, or both. Complementary cumulative distributed function (CCDF) will be used as a measurement of PAPR effectiveness, which is the probability that PAPR exceeds some threshold, i.e.,

$$CCDF = Probability\ (PAPR > p_0) \quad (3)$$

where $p_0$is the threshold.

3.2 New companding transform

OBI is the spectral leakage into alien channels. Quantification of the OBI caused by companding requires the knowledge of the power spectral density (PSD) of the companded signal. Unfortunately, analytical expression of the PSD is in general mathematically intractable, because of the nonlinear companding transform involved. Here we take an alternative approach to estimate the OBI. Let (x) be a nonlinear companding function, and (t) = sin(ωt) be the input to the compander. The companded signal (t) is: (t) = [(t))] = f [sin(ωt)] . Since (t) is a periodic function with the same period as (t), (t) can then be expanded into the following Fourier series:

$$y(t) = \sum_{k=-\infty}^{+\infty} c(k)e^{jkwt}$$

where the coefficients $c(k)$ is calculated as:

$$c(k) = c(-k) = \frac{1}{T}\int_0^T y(t)e^{-jkwt}dt \qquad T = \frac{2\pi}{w}$$

Notice that the input x in this case is a pure sinusoidal signal, any $(k) \neq 0$ for $|k| > 1$ is the OBI produced by the nonlinear companding process. Therefore, to minimize the OBI, (k) must approach to zero fast enough as k increases. It has been shown that $(k) \cdot k-(m+1)$ tends to zero if $y(t)$ and its derivative up to the m-th order are continuous [8], or in other words, $c(k)$ converges at the rate of $k-(m+1)$. Given an arbitrary number n, the n-th order derivative of $y(t)$, dny/dtn, is a function of $dif(x)/dxi$, (i = 1, 2, · · · , n), as well as sin(ωt) and cos(ωt), i.e.:

$$\frac{d^n y}{dt^n} = g\left(\frac{d^n f(x)}{dx^n}, \frac{d^{n-1} f(x)}{dx^{n-1}}, \ldots\ldots, \frac{df(x)}{dx}, \sin(wt), \cos(wt)\right)$$

Sin (ωt) and and cos (ωt) are continuous functions $\frac{d^n y}{dt^n}$, is continuous if and only if $(x)/dxi$ (i = 1, 2, · · · , n) are continuous. Based on this observation we can conclude:

Companding introduces minimum amount of OBI if the companding function (x) is infinitely differentiable. The functions that meet the above condition are the smooth functions. We now propose a new companding algorithm using a smooth function, namely the airy special function. The companding function is as follows:

$$f(x) = \beta . sign(x) . [airy(0) - airy(\alpha . |x|)]$$

where airy(·) is the airy function of the first kind. α is the parameter that controls the degree of companding (and ultimately PAPR). β is the factor adjusting the average output power of the compander to the same level as the average input power:

$$\beta = \sqrt{\frac{E[|x|^2]}{E[|airy(0) - airy(\alpha . |x|)|^2]}}$$

Where [·] denotes the expectation. The decompanding function is the inverse of (x):

$$f^{-1}(x) = \frac{1}{\alpha} . \mathrm{sign(x)} .airy^{-1}\left[\mathrm{airy}(0) - \frac{|x|}{\beta}\right]$$

Where the superscript -1 represents the inverse operation. Notice that the input to the deco pander is a quantized signal with finite set of values. We can therefore numerically pre-compute $f-1(x)$ and use table look-up to perform the decompounding in practice. Next we examine the BER performance of the algorithm. Let (t) denote the output signal of the compander, (t) the white Gaussian noise. The received signal can be expressed as:

$$z(t) = y(t) + w(t)$$

The decompanded signal ˜(t) simply is:

$$x\tilde{}(t) = f^{-1}[z(t)] = f^{-1}[y(t) + w(t)] \dots \dots \dots \dots$$

Notice that the signal-to-noise ratio (SNR) in a typical additive white Gaussian noise (AWGN) channel is much greater than 1.

4. SIMULATION ANALYSIS

In this sub section, we illustrate the performance of our proposed algorithm which has been compared with the existing PAPR reduction methods using MALAB simulations.

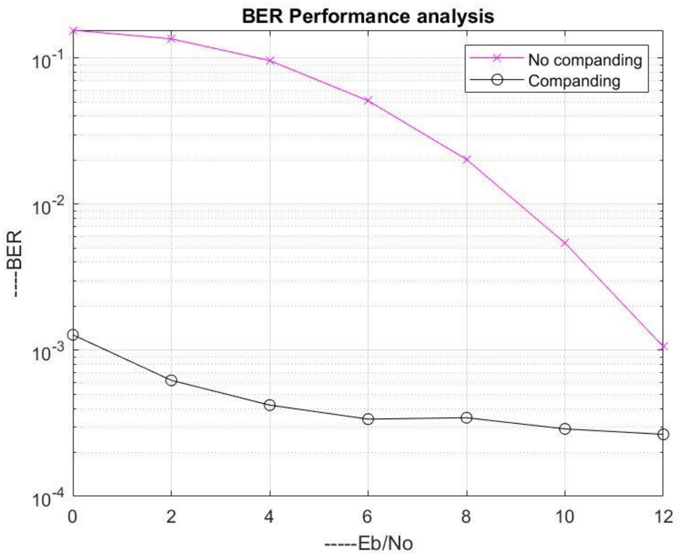

Fig. 1: BER performance analysis.

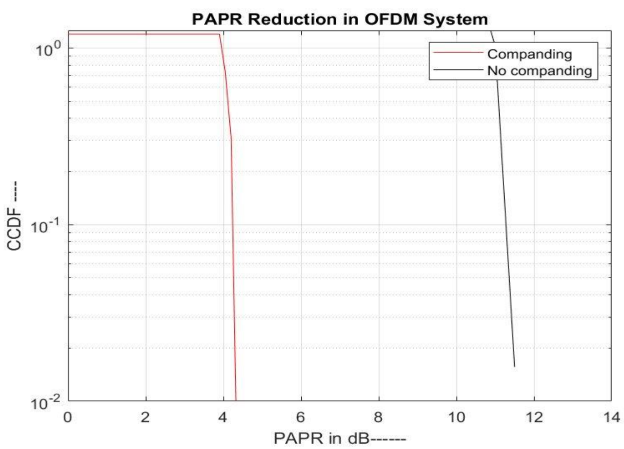

Fig. 2: PAPR reduction in OFDM system.

5. CONCLUSIONS

One of the major drawbacks of OFDM systems are High PAPR of transmitted signal, which in results the degradation of the performance of the system. Here in this proposal, we introduced a novel PAPR reduction scheme using companding transform. This technique is efficient, signal independent, distortion less and does not require any optimization algorithm. Simulation results shown that the proposed algorithm has got better results than without companding.

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