RESEARCH ARTICLE OPEN ACCESS

The PAPR Reduction in OFDM System with the help of Companding Technique

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Abstract
Orthogonal Frequency Division Multiplexing or OFDM is a form of multi-carrier modulation technique. High spectral efficiency, robustness to channel fading, immunity to impulse interference, uniform average spectral density, capability of handling very strong echoes and less nonlinear distortion are among the favorite properties of OFDM. Even though there are many advantages of OFDM, it has two main drawbacks; high Peak to Average Power Ratio (PAPR) and frequency offset. In this paper, the issue of PAPR in OFDM system is discussed. Companding technique is used to reduce the PAPR. In this paper, the simulation results of PAPR without any reduction technique and with the companding technique are compared.
Keywords- OFDM, PAPR, DSP, IFFT, BPSK, QPSK, 16PSK.

I. INTRODUCTION

After more than thirty years of research and developments carried out at different places, orthogonal frequency division multiplexing (OFDM) has been widely implemented in high speed digital communication.

Due to the recent advancements in digital signal processing (DSP) and very large scale integration (VLSI) technologies, the initial obstacles of OFDM implementation do not exit any more. Mean while, the use of Fast Fourier Transform (FFT) algorithms has eliminated arrays of sinusoidal generators and coherent demodulation required in parallel data systems and made the implementation of technology cost effective [Weinstein S.].

In recent years OFDM has gained a lot of interest in digital communication applications. This has been due to its favorable properties like high spectral efficiency and robustness to channel fading. Today, OFDM is mainly used in digital audio broadcasting system and digital video broadcasting system enabling an end-to-end digital transmission system, which is spectrally efficient and rugged against channel distortions. This can be used for services such as offering increased capacity for program broadcasting. In the conventional serial data transmission system, the information symbols are transmitted sequentially where each symbol occupies the entire available spectrum bandwidth. But in an OFDM system, the information is converted to N parallel subchannels and sent at lower rates using frequency division multiplexing. The subcarrier frequency spacing is selected on the other subcarriers zero crossing points. This implies that there is overlapping among the subcarriers but will not interfere with each other, if they are sampled at the sub carrier frequencies. This means that all subcarriers are orthogonal.

OFDM is a broadband multicarrier modulation method that offers superior performance and benefits over older, more traditional single-carrier modulation methods because it is a better fit with today's high-speed data requirements and operation in the UHF and microwave spectrum [Manjung Seo].

Mathematical Description of OFDM Signal

An OFDM symbol consists of N subcarriers by the frequency spacing of Δf. The bandwidth will be divided into N equally spaced subcarriers. And all the subcarriers are orthogonal to each other with in a time interval of length T=1/Δf. Each subcarrier can be modulated independently with the complex modulation symbol $X_{m,n}$ where m is a time index and n is a subcarrier index. Then within the time interval T the following signal of the m-th OFDM block period can be described by equation (1) as:

$$x_m(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_{m,n}\, g_n(t-mT) \qquad \ldots(1)$$

where, $g_n(t)$ is defined through equation (2):

$$g_n(t) = \begin{cases} \exp(j2\pi\Delta f t), & 0 \le t \le \Delta T \\ 0 & \text{else} \end{cases} \qquad \ldots(2)$$

where, $g_n(t)$ is a rectangular pulse applied to each subcarrier. The total continuous time signal x(t) consisting of all the OFDM blocks is given by equation (3):

$$x(t) = \frac{1}{\sqrt{N}} \sum_{m=0}^{\infty} \sum_{n=o}^{N-1} X_{m,n}\, g_n(t-mT) \qquad \ldots(3)$$

Now, consider a single OFDM symbol (m = 0) without loss of generality. This can be shown because there is no overlap between different OFDM symbols.

Since m = 0, $X_{m,n}$ can be replaced by X_n . Then, the OFDM signal can be described as follows:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n \, e^{j2\pi n\Delta ft} \quad \dots (4)$$

If the bandwidth of the OFDM signal is B = N × Δf and the signal x(t) is sampled by the sampling time of $\Delta t = \frac{1}{B} = \frac{1}{N\Delta f}$, then the OFDM signal is in discrete time form and can be written as shown in equation (5):

$$x_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n \, e^{j2\pi kn / N} , \quad k = 0, 1, \dots\dots, N-1 \quad ...(5)$$

Where, n denotes the index in frequency domain and X_n is the complex symbol in frequency domain [Aron Gulliver].

II. PAPR PROBLEM

The OFDM symbols are obtained by summing up of a number of modulated sub carriers, so the synthesized signal has a relatively large peak power, which will brings high PAPR.

A brief mathematical analysis for PAPR is presented below. The root mean square (RMS) magnitude of the OFDM signal is defined as the "root of the time average of the envelop power ($\sqrt{}$P), where P is defined by equation (7):

$$P = \frac{1}{T} \int_{t=0}^{T} |x(t)|^2 dt \quad = \quad \frac{1}{N} \sum_{n=0}^{N-1} |X(n)|^2 \quad ...(7)$$

Where, x(t) is the OFDM signal defined by equation (3). The value P in this case corresponds to a single OFDM symbol, and depends on the sequence of information carrying coefficients $\{X_n\}$. The average power of OFDM symbols can be written as P_{av} = E{P}. Thus, the PAPR of an OFDM signal can be defined as:

$$\zeta = \max |x(t)|^2 / P_{av} \quad ...(8)$$
$$\zeta = \max |x(t)|^2 / E\{|x(t)|^2\} \quad ...(9)$$

III. COMPANDING TECHNIQUE

Companding is a signal processing technique used in the digital systems primary in audio such as microphones (more effectively in wireless) to reduce the noise levels in the sound quality mainly owing to low-level radio frequency interference in the frequency channel. Literally, the term "companding" is composed of the words "compressing" and "expanding".

In a wireless system using the companding technique, the audio signal is compressed in the transmitter and expanded in the receiver. The compression process reduces the deviation in the frequency ranges of the audio before it is transmitted and that is restored to the original frequency ranges by the expansion process at the receiver's end.

The objective of the companding process is to preserve the signal-to-noise ratio of the original audio. The companding is also used in the digital systems by compressing the signals before input to an analog-to-digital converter, and then expanding after a digital-to-analog converter. The T-carrier telephone system implements the companding that follows A-law or μ-law. This technique is also used in the digital file formats for better signal-to-noise ratio (SNR) at very low bit rates.

The compander consists of compressor and expander. The compressor is a simple logarithm computation. The reverse computation of a compressor is called an expander. The compression at the transmit end after the IFFT process and expansion at the receiver end prior to FFT process are used. There are two types of companders, these two types are μ-law and A-law companders [Jianping Wang]. In this dissertation work, the μ law companding is used.

a) μ-law Companding

The μ-law compander employs the logarithmic function at the transmitting side.

In general a μ law compression characteristic:

$$y = \{ v\log_e(1+\mu|x|/v) / \log_e(1+\mu)\} \, \mathrm{sgn}(x) \quad \dots(10)$$

where μ is the μ-law parameter of the compander.

x: input signal.

v : is the maximum value of the signal x.

μ : parameter controls the amount of compression.

The maximum value of output y is the same maximum of input x is equal v.

For normalized input signal with $|x| \leq 1$, the characteristic becomes:

$$y = \{ \log_e(1+\mu|x|) / \log_e(1+\mu)\} \, \mathrm{sgn}(x) \quad \dots(11)$$

The μ-law expander is the inverse of the compressor:

$$x = \frac{v}{\mu}(e^{|y|\log(1+\mu)/V} - 1)\mathrm{sgn}(y) \quad \dots(12)$$

b) A-law Companding

The characteristic of this compander is given by:

$$y = \frac{1+lnA\,|x|}{1+lnA} \, \mathrm{sgn}(x) \qquad \frac{1}{A} \leq |x| \leq 1 \quad \dots(13)$$

A : parameter controls the amount of compression.

Simulation Results

In this section the comparison for PAPR values of BPSK, QPSK and 16PSK modulation schemes for different reduction techniques such as, without any technique and with companding technique are evaluated. The results are plotted in figure 1.2 and 1.3 respectively.

PAPR evaluation without any reduction technique

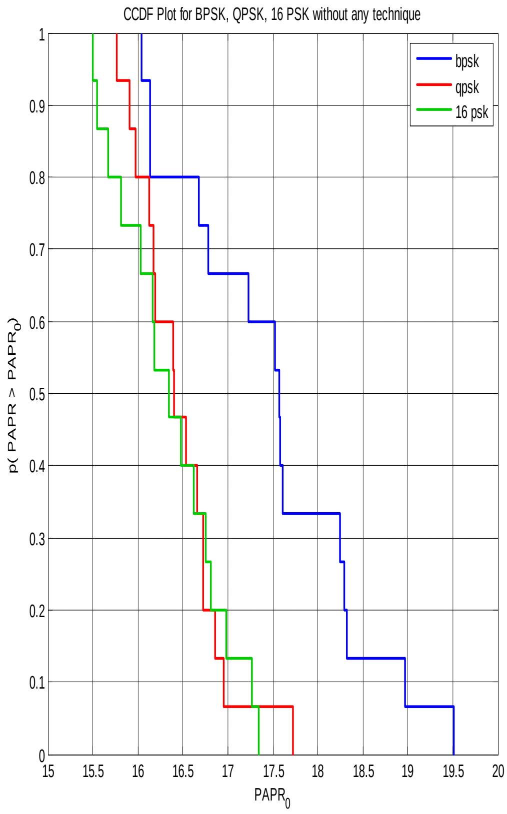

Fig. 1.2 CCDF Plot for BPSK, QPSK & 16PSK without any reduction technique.

In figure 1.2, the maximum value of PAPR is 19.5 dB for BPSK modulation scheme and value of PAPR is 17.75 dB and 17.25 dB respectively for QPSK and 16PSK modulation scheme in case of without any reduction technique. The above graph concludes that QPSK or 16PSK modulation schemes are better than the BPSK modulation scheme by an amount of 2 dB in concern with the peak to average power ratio (without any reduction technique).

PAPR evaluation for companding technique

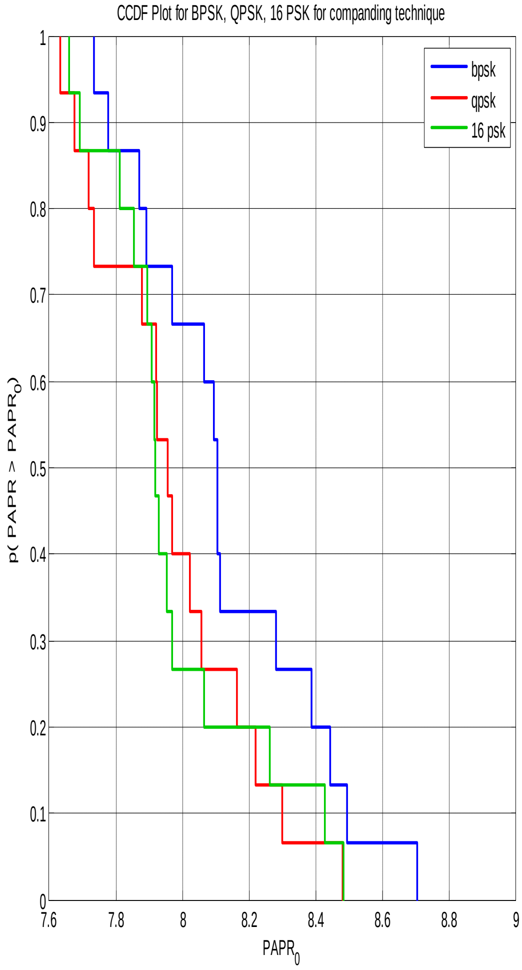

Fig. 6 CCDF plot for BPSK, QPSK & 16PSK with companding technique

In companding technique figure 1.6, value of PAPR is 8.7 dB while using along with of BPSK modulation scheme, the value of PAPR is 8.5 dB in case of QPSK and 16PSK modulation scheme. So there is no significant change in the value of PAPR while changing the modulation schemes. The above graph concludes that any modulation scheme BPSK, QPSK & 16PSK is used in case of companding technique. By using this method the PAPR get reduced to 8.5 dB from 19.5 dB (without any reduction technique).

IV. CONCLUSION

In this paper we compare the result of without any reduction technique of PAPR with companding technique on the performance of OFDM system. In order to analyze the effect of different modulation schemes also on PAPR values, simulation was carried out. It was observed that QPSK and 16PSK modulation schemes are better than the BPSK. The value of PAPR without any reduction technique is 19.5 db and the value of PAPR with companding technique is 8.7db for BPSK modulation scheme. So there is the reduction of 10.8db in the value of PAPR while using companding technique.

In future, some more sophisticated methods such as Active Constellation Extension (ACE) and Tone Reservation Technique (TR) may be implemented and evaluated for further improvements in PAPR reduction of the OFDM system.

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