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Enhancement of BER and PSD of OFDM Signals with PAPR Reduction Using Linear Companding Transform

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Abstract

Orthogonal frequency division multiplexing (OFDM) is a popular modulation/multiplexing scheme offers high data rates It is considered as multicarrier transmission scheme supports future generation wireless as well as wire line communication systems.. OFDM frequently suffers from high Peak to Average Power Ratio (PAPR) which eventually increases the Analogue to Digital and Digital to Analogue convertors complexity levels and reduces HPA (RF) efficiency. Various Peak to average power ratio (PAPR) reduction schemes have been proposed in the past and companding is the popular PAPR reduction which is inserted after modulation in the OFDM system. Although companding scheme provides better results but simultaneously its presence as extra operation increases the bit error rate. In this paper a novel piecewise linear companding scheme is implemented to reduce the PAPR impact and control the companding distortion in the OFDM system. The piecewise linear companding scheme reduces the peak to average power ratio by clipping the amplitudes over the companded peak amplitude and compensate the power by linearly transform the signal amplitudes which are close to the companded peak amplitude. Finally the simulation result yields the better spectral efficiency and batter BER performance while mitigating the companding distortion better way the PAPR is reduced in accurate way.

Keywords: OFDM, PAPR, BER, HPA

1. INTRODUCTION

The next generation wireless communications systems are based on the important factor namely high data rates and traditional communication schemes fails to offer high data rates to meet the demand of high data rates for high speed communications. Initially meeting the requirement of the high data rates is a challenging task in the area of the wireless communications because of the unpredictable wireless channel. Although tremendous progress has been reported in the literature in the literature in the area of wireless communications but introduction of the multi carrier transmission is only proves to be ideal solution to introduce the high rates in the wireless communications.

Multi carrier transmission has wide range of advantages over traditional approaches but it too suffers from some limitations and orthogonal frequency division multiplexing (OFDM) introduction in the wireless communication industry has introduced revolutionary changes by supporting wide range of applications both in terms of indoor and as well as outdoor communications and all this happens in real time because of the maintenance of the Orthogonality among the sub carriers. Orthogonality makes the orthogonal frequency division multiplexing (OFDM) as a special form of multi carrier scheme which can handle the real time limitations such as interferences, multi path fading etc. Traditional communications schemes and multi carrier transmission schemes fails to offer the communication without low complexity and precision while orthogonal frequency division multiplexing (OFDM) successful in offering the low complexity and precision which proves to be vital in the hassle free communication in different applications.

The two important points to be remembered in the high data rates are channel distortion of the data to be transmitted in channel and using simple receiver for recovery of the transmitted data is not possible in the real time scenario. The channel design is an important step in the total system in order to receive data which is transmitted without any distortions and channel design should include the following parameters (a) The receiver should have equalization algorithms which are computationally expensive, (b) The receiver section should include high standard channel estimation algorithms it helps in prediction of the channel in the correct way to recover the transmitted data without any problems, (c) The receiver should have complex structure to tackle all issues in reliable way. Compare to the traditional multi carrier transmission techniques OFDM has inbuilt system to resolve the issue of the equalization problem by changing original frequency selective channel to the flat fading channels which is the important in the multi carrier transmission missing in the traditional schemes. The channel estimation issue can be handled in better way by one tap equalizer to receive the data at the receiver in simple way.

Multiple access systems from FDMA to CDMA has offered wide range of services but none of them are successful to provide better spectral efficiency which is considered as important aspect in serving the more number users with high data rates. OFDM is a special case of multi carrier transmission scheme which provides better spectral efficiency to support the more number of users with high data rates.

The 21^{st} century generation is dominated by the multimedia communications but spectral utilization plays important role to meet the demand and provide the good services. OFDM utilizes available spectrum in effective way and wide range of multimedia communications which are using in the daily needs are based on the OFDM and it is accepted as future generation communication system to support wide range of application ranging from daily needs to high level applications.

Communication through delay dispersive environments is a challenging task in high speed digital communications and OFDM, which is also known as multiple frequency-shift keying (MFSK) is consider has relevant technique to communicate even in the delay dispersive environments with reliability and better accuracy. Orthogonal frequency division multiplexing (OFDM) is basically a multi carrier modulation scheme which supports wide range of applications both in indoor and outdoor environment.

The information sending over multiple carriers is an idea proposed by Chang in 1966 and the messages should be send in a linear band limited channel without interferences both in terms of symbols and carriers. The principle of transmitting information through linear channel came into reality in 1971 and this initial implementation of OFDM consists of demodulators (which are coherent in nature) and oscillators in large numbers. In the late 1971 two noted researchers Weinstein and Ebert develop the OFDM mechanism with modulators and demodulators along with the DFT and after this work a drawback is observed namely interferences. Interferences are successfully resolved to some extent after inserting the cyclic prefix guard interval in order to maintain the orthogonality by Peled & Ruiz in the year 1980.

FDMA, TDMA and CDMA are successful in offering hassle free communication with decent data rate but these approaches fails to offer data rate beyond the 3G scenario. OFDM is a promising modulation scheme supports data rate beyond the 3G wireless communication to give high speed communication. In OFDM terminology the subcarriers are the elements which carry the multiple carriers and sub band is defined as band occupied by the respective signal. OFDM orthogonality is the crucial aspect which notates the signal behavior and it successfully achieves the orthogonality both in terms of time as well as frequency domain. Unlike traditional multi access a scheme which fails to resist against the multi path fading where OFDM offers good robustness against the multipath fading and low complexity in the absence of complex time domain channel equalizer.

2. BACKGROUND

Exchanging the information from one entity to anther is called as communications and from the early ages communication is one of the predominant part of the science from ancient times. Communications has great importance in the human daily needs to high equipped applications and it replaces the traditional telegram, letters etc. The wireless communications discovery has revolutionized the communication scenario by introducing the innovative applications which are once imagination of the 19th century. The wireless communication has moved one step ahead by implementing the mobile communication introduction to the human daily needs and as time passes on the mobile communication has became integral part of modern society to communicate the different people around the globe. The mobile applications and its applications have improved the way of living in the metropolitan cities along with rural remote areas.

2.1 History

Wireless communication usage has predominant evidences from ancient times but along with the time wireless communications has changed its face. The pigeons and smoke are used as primary elements to communicate people at different locations with different signs and in modern world in place of pigeons and smoke usage of mobiles, radars and satellites are witnessed.

The research on the communication is seriously started in the 16th century by the popular inventions like large mobile panels coding by the renowned mathematician and scientist Robert Hooke for alphabetical coding based on the early coding schemes and the research carried on by Robert Hooke paves way for the invention of the optical telegraph by the French physicist Claude Chappe in 17th century. The invention of the optical telegraph results in the long distance communication based on the transmission codes transmitted from the large signaling towers and along with the time the technology related to the communication changing frequently with rapid pace. With the immense development based on the past inventions results in the large network over major cities in France and surrounding countries which are considered as one of the most innovative invention by the historians. The Electromagnetic spectrum invention and its usage in the communication applications have increased the speed and accuracy from ultra short range to ultra high range applications. Noted physicists like James Clerk Maxwell and Heinrich Hertz are important persons behind the foundation of the EM spectrum and its associated applications.

2.2 Power spectral density

Power Spectral Density function (PSD) shows the strength of the variations (energy) as a function of frequency. It shows at which frequencies variations are strong and at which frequencies variations are weak. The unit of power spectral density is energy per frequency (width) and energy can be obtained within a specific frequency range by integrating Power spectral density within that frequency range. The power spectral density is averaged across 20 MHz bandwidth as specified by WLAN. Number of data symbols that constitute the envelope of power spectrum, spread over frequency bins. Power spectral density depends on levels of modulation as it increases with increase in levels of modulation.

3. PAPR REDUCTION TECHNIQUES

In literature different PAPR reduction has reported to improve the efficiency of the system in th transmitter medium and successfully removes the noise related content from the transmission line. Some of the popular PAPR reduction techniques are reviewed in this section

Partial Transmit Sequence

Diminishing the PAPR to improve the efficiency at the transmitter end has been considered as the concerned area from two decades. Partial transmit sequence (PTS) is a popular and most efficient PAPR reduction scheme which is designed to diminish the PAPR impact from OFDM system.

The design behind the partial transmit scheme is based how efficiently the sub block division is performed from the original OFDM signal. Another new thing implemented in this approach is phase rotation which helps the candidate to choose the signal with the lowest PAPR. Original OFDM sequences are divided into disjoint symbol subsequence by using the partition process and in the latter step each subsequent subcarrier is applied by IFFT and another process named distinct rotating vectors is used to make sum of all blocks after multiplied by using the rotating vectors in efficient way.

Tone Reservation Approach

Till now various PAPR reduction have proposed in the literature but majority of the schemes are approximate while tone reservation approach is an accurate scheme proposed to diminish PAPR in effective manner. The idea behind the tone reservation approach is to design a reliable system to control the PAPR impact on the OFDM transmitter side.

The important factors used to mitigate PAPR impact in OFDM modulation scheme are reserved tones locations, complexity levels, reserved tones power and number of reserved tones. The beauty of the tone reservation approach is controlling the large amount of PAPR using small tones which decreases run time complexity and increases performance drastically. In traditional schemes additional operations and information needs to include at the receiver end while in the tone reservation approach no side information and no additional operation is required at receiver end. The design of tone reservation approach is based on the data block summation and signal in terms of time domain. The data block helps in minimizing high PAPR based on original multi carrier signal and note that data block which is used in this approach are termed as the depended block signal.

4. PROPOSED METHOD

Orthogonal frequency division multiplexing (OFDM) is a modulation scheme specially designed to offer high speed wireless communications for supporting wide range of applications ranging from ultra short range to ultra high range. Wireless communications are changing with great pace with technological advancements and OFDM too suffers from drawbacks like Peak to average power ratio (PAPR), Delay, Interferences and fading effect.

The PAPR reduction is a concerned area in OFDM modulation scheme and in literature various PAPR reduction algorithms have reported in the literature but majority of the algorithms focuses on the PAPR reduction only few works focus on the PAPR reduction with distortion but none can meet the desired results. PAPR reduction by companding technique is most successful and in the proposed method a new piecewise linear companding scheme is presented which deals with the companding distortion mitigation along with the PAPR reduction.

The companding distortion mitigation is the primary aim of piecewise linear companding. Initially investigation of companding distortion effects is characterized in theoretical way based on the bit error rate (BER) analysis. Bit error rate (BER) performance is improved gradually by reducing the companding distortion based on the companding expressions and the main motto of the companding technique is to avoid the unnecessary compressions in peak power reduction and control the large signals expansion with respect to the small amplitude increments. A new piecewise liner companding transform is initialized to clip peak amplitudes of companding signal to reduce the impact of the companding distortion in an effective way.

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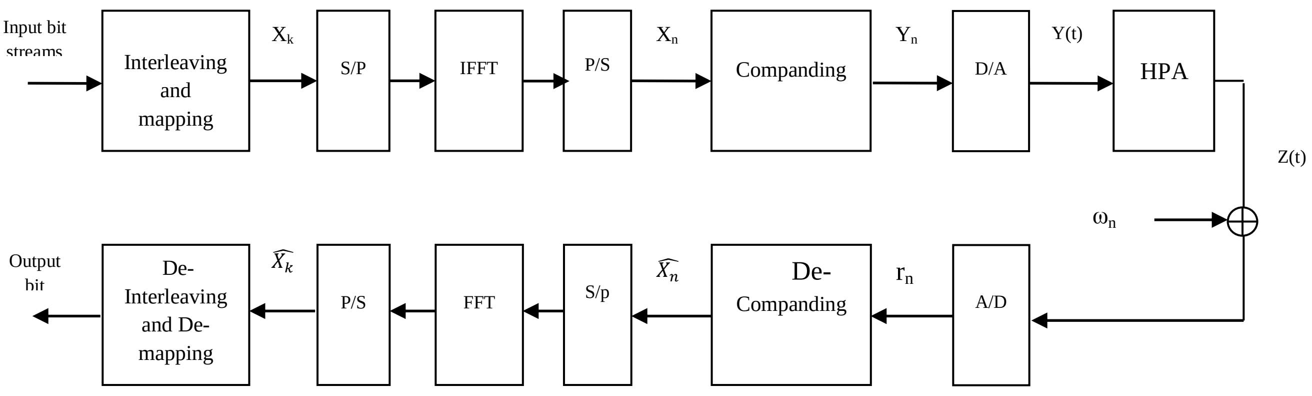

Figure 1: OFDM modulation scheme with companding transform

The amplitudes of the OFDM signal plays an important role in assessing the signal quality, if the amplitudes of the signal increases beyond the threshold limit then it results in peak to average power ratio (PAPR). The proposed piecewise linear companding design implementation depends on the two important factors (1) linear transform scaling design and (2) companding peak amplitude design. Finally experimental results examined that piecewise linear companding achieves better bit error rate (BER) than conventional companding schemes and enhanced power spectral density (PSD) in the process of reducing the PAPR.

4.1 SYSTEM MODEL

The above demonstrated block diagram of OFDM-Companding transform show the inclusion of companding transform as additional block to the original default OFDM block diagram. The basic OFDM transmitted signal in terms of discrete time is illustrated as follow equation

$$x_n = \frac{1}{\sqrt{NL}} \sum_{k=0}^{NL-1} X_k e^{j2\pi\frac{kn}{NL}}, \quad 0 \le n \le NL, \quad (6.1)$$

In the above equation different factors are taken into consideration as follows

Th term X represents $X=\left[X_0, X_{1,\ldots\ldots,} X_{\frac{N}{2}-1},\ 0, \ldots, 0, X_{\frac{N}{2}}, \ldots, X_N\right]$ represents OFDM input signal vector and the symbols which are going to insert in the input signal vector needs modulated in a linear way. The modulation process makes the carriers to accept the symbols in reliable way. Here each individual symbol are modulated by QAM or QPSK modulation schemes.

Here two important aspects are important namely sampling factor L and the number of subcarriers N. Author has inspired from central limit theory where the complex Gaussian process of x_n is estimated in approximated way and the statistics are revealed once the N is large enough. Subsequently the probability density function (PDF) is used to know the x_n amplitudes and x_n has Rayleigh distribution as follows

$$. \quad f|x_n|(x) = \frac{2x}{\sigma_x^2} e^{\frac{-x^2}{\sigma_x^2}} \quad x \geq 0, \quad (6.2)$$

Generally the term σ is defined as standard deviation of variation factor and in above notation the term σ_x^2 is used to represent the variance ofx_n.

Where σ_x^2=$E[X_k]^2$ denotes the two factors as follows

$E[.]$ =represents mathematical function

$|.|$= represents the modulus

The PAPR of OFDM signal represented in (1) is given by:

$$\text{PAPR}=\frac{\text{Peak power}}{\text{Average Power}} = \frac{max|x(t)|^2}{E[|x(t)|^2]} \quad (6.3)$$

4.2 COMPANDING TRANSFORM DESIGN CRITERIA

Orthogonal frequency division multiplexing (OFDM) scheme has standard block diagram with composed of parameters in the transmission end as Analog to digital conversion (A/D), Serial to parallel (S/P), modulation scheme (QPSK, BPSK or QAM) and then IFFT followed by channel and receiver section. But in proposed work along with all parameters an extra operation called companding operation is added after OFDM modulation process to reduce PAPR impact on the OFDM signal. Although companding transform has ability to reduce to reduce the PAPR impact on the OFDM signal but subsequently thee extra operation is a third party approach which results in the companding distortion. The companding operation design criterion is based on BER performance and BER is the key factor in analyzing the companding distortion in reliable way. Both theoretical and practical approaches used by the companding transform to analyze the PAPR impact but initially PAPR impact is analyzed by theoretical in approximately.

The companding transform design depends on how efficiently companding distortion can be mitigated and reduced. The theoretical analysis to reduce the companding distortion based on the BER is the key factor to design the companding transform. The design of the companding transform require the following factors as follows

y_n= represents the companded signal,

x_n= represents the original OFDM modulation scheme,

c_n= represents the companding distortion.

The companding signal y_n can be expressed as

$$y_n = x_n + c_n \quad (6.3)$$

Note that companding distortion c_n has the same phase as original OFDM signal x_n. The power of the companding transform is notated as follows and the power of y_n of the companded signal based on equation

4.3 NOVEL LINEAR COMPANDING APPROACH

A novel piecewise linear companding approach has been proposed in this section and the design of the new piecewise linear companding scheme is designed in effective way based on transform parameters in a theoretical analysis.

The proposed pricewise linear companding scheme is implemented on OFDM signal to mitigate the companding distortion and reducing the PAPR impact on the signal. The reduction of the peak power is followed by companding the original signal x_n with respect to the peak amplitude A_c

The following figures shows the respective signal clips over peak amplitude A_c for peak power reduction and then power compensation process is carried on by a linearly transformation of the signals which are close to the A_c.. The proposed companding function representation is represented as follows

$$h(x) = \begin{cases} x & |x| \le A_i \\ kx + (1-k)A_c & A_i < |x| \le A_c, \\ sgn(x)A_c & |x| > A_c \end{cases}$$

(6.4)

The proposed companding function is represented as above and $sgn(x)$ represents sign function and subsequently the respective de companding function at the receiver section is as follows

$$h^{-1}(x) = \begin{cases} x & |x| \le A_i \\ x - (1-k)A_c & A_i < |x| \le A_c, \\ sgn(x)A_c & |x| > A_c \end{cases}$$

(6.5)

The proposed linear companding scheme is different from traditional PAPR reduction schemes and the design of linear companding scheme is based on the peak amplitude companding signal parameters as A_c, A_i and k. The reduction of the PAPR in the OFDM modulation scheme is done when the power allocated to the carriers is goes beyond the average power limit and according to the definition of PAPR the peak power can be reduced can be achieved by peak amplitude A_c in theoretical PAPR value. The preset PAPR reduction is determined as A_c=$\sigma_x 10^{PAPR}$ $preset/20$. Based on the above parameters the PAPR reduction can be solved as follows

$$\int_{A_i}^{A_c} kx + (1-k){A_c}^2 f_{|x_n|}(x)dx + \int_{A_c}^{\infty} A_c^2 f(x)dx = dx = X^2 f_{|x_n|}(x)dx. \quad (6.6)$$

The above equation modified into quadratic equation about k. The motto behind implementation of the above equation is to keep the average signal power in constant mode. The constant K needs to be smaller than value 1 and constant K is taken in the interval [0, 1]. To keep the expanded signal peak amplitude not larger than A_c and in order to keep the limit constant K should not be a real number.

4.4 SELECTION OF THE COMPANDING TRANSFORM CRITERION

The companding distortion selection is aimed to minimize the companding distortion is derived in the sequel section. The calculation of the companding distortion according to (13) is

$$\sigma_c^2 = \int_0^{+\infty} |y_n - x_n|^2 f_{|x_n|}(x)dx = \left((A_c - A_i)^2 e^{-\frac{A_i^2}{\sigma_x^2}} - \sqrt{\pi}\sigma_x A_c \left(erf\left(\frac{A_c}{\sigma_x}\right) erf\left(\frac{A_i}{\sigma_x}\right)\right) + \sigma_x^2 \left(e^{-\frac{A_i^2}{\sigma_x^2}} - e^{-\frac{A_c^2}{\sigma_x^2}} \right) \right) - \sqrt{\pi}\sigma_x A_c erf\left(\frac{A_c}{\sigma_x}\right) + \sigma_x^2 e^{-\frac{A_c^2}{\sigma_x^2}} \quad (6.7)$$

Here we observe the cost function in the form of convex which plots the contour plot in the first constraint of the above equation and consequently usage of the optimal parameter k is witnessed in the above equation which results in the companding distortion in the form of mini approach. Finally this mini companding approach is used for the determination of the A_c

5. SIMULATION RESULTS

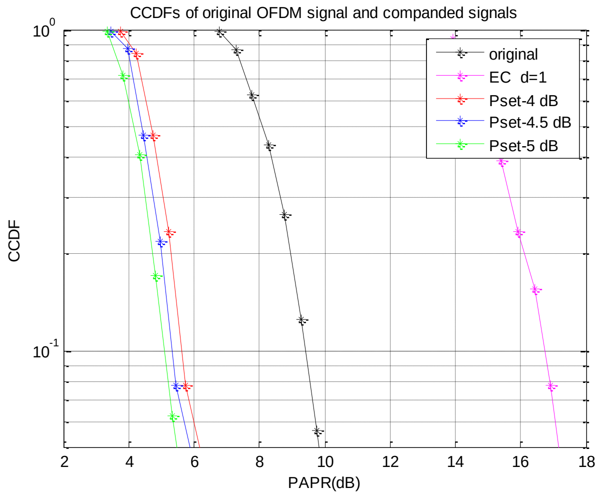

Figure 2: CCDF of original OFDM signal and companded signals

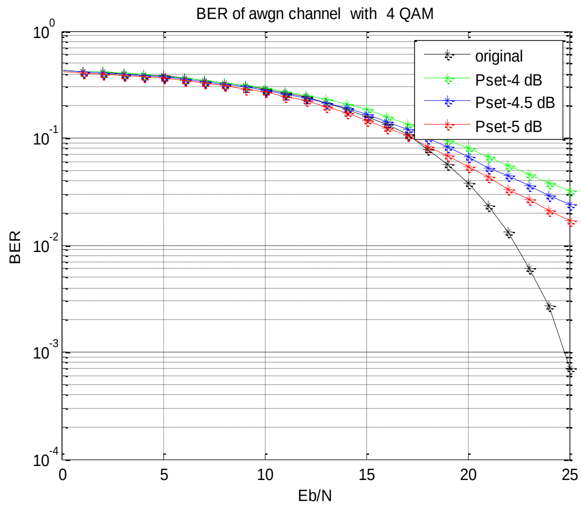

Figure 3: BER of AWGN channel with 4 QAM

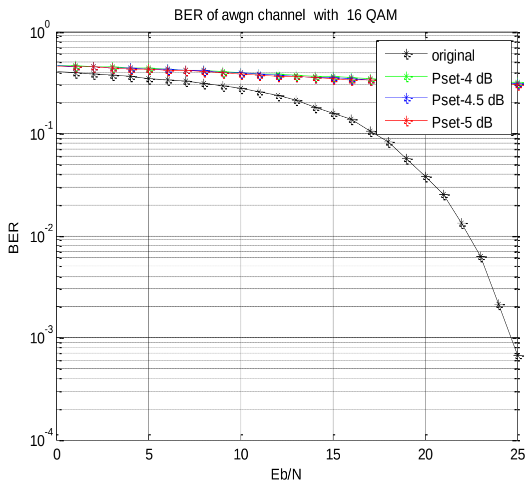

Figure 4: BER of AWGN channel with 16 QAM

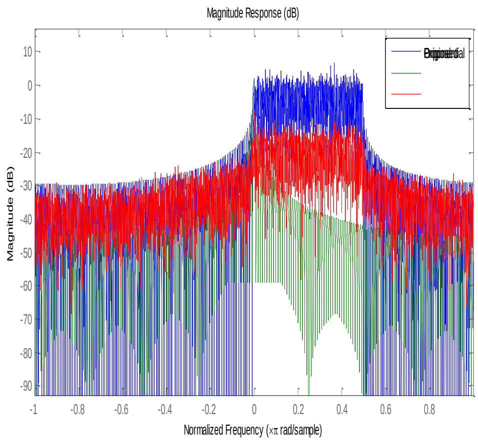

Figure 5: magnitude response

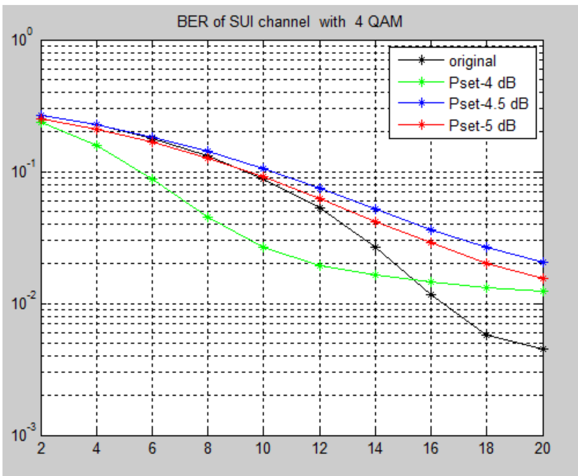

Figure 6: BER of SUI-4 channel with 4QAM

PAPR reduction is challenging task in the orthogonal frequency division multiplexing, in our proposed work we use piecewise linear companding algorithm for improved BER using SUI channel. PAPR reduction is done by using SUI channel for better performance and low run time complexity

6. CONCLUSION

A new piecewise companding scheme proposed for improve the BER performance by mitigate the companding distortion in optimum level. The companding scheme aims to reduce the impact of the PAPR but results in the companding distortion which dramatically decreases the bit error performance and increases the complexity levels. A new Piecewise linear companding scheme is designed to reduce PAPR and companding distortion mitigation in OFDM system by avoiding the unnecessary compression and expand larger signals with smaller amplitude increments. The experimental results show better BER performance, enhanced power spectral density and better spectral efficiency.

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