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Enhancing the Performance of OFDM Signal Based on PAPR Reduction Using Precoder and Combined Distortion Techniques

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A B S T R A C T

In this paper, PAPR in Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system is reduced by initially coding the OFDM signal using discrete Fourier transformation (DFT) matrix algorithm before introducing repeated clipping and filtering (RCF) plus logarithm function techniques, which are a combination of distortion schemes (CDS). The algorithm of conventional OFDM signal was obtained and subsequently evaluated. Then DFT precoding technique was introduced to code the OFDM signal resulting in coded-OFDM signal. The algorithms of RCF and logarithm function (or log companding) were studied and presented in the form of mathematical equations. The algorithms of DFT, RCF and log companding were transformed into MATLAB codes and incorporated into OFDM system to improve PAPR performance. Simulations were carried out with respect to conventional OFDM, DFT coded OFDM with RCF, and DFT coded OFDM with RCF plus log companding. The results of the simulations revealed that the proposed DFT coded OFDM with RCF and log companding scheme (PCCDS) was able to reduce the value of PAPR to as low as 0.640 dB, which is 94 % improvement from the original value, 10.6 dB for conventional OFDM at complementary cumulative distribution function (CCDF) of 10-3.

Keywords: DFT, OFDM, PAPR, RCF, Log-companding

1. Introduction

The output of OFDM system is formed from the superposition of multiple subcarriers. This can results in some instantaneous power outputs to largely increase and thus become enormously higher than the average power of the OFDM signal when the multiple carriers are of the same phase. This is regarded as high peak-to-average power ratio (PAPR). Large PAPR is one of the most critical problems of wireless communication system using OFDM technique.

Nomenclature

A_c is the amplitude of the subcarrier

ω_c is the frequency of subcarrier in radian per second (rad/s)

$\phi_c(t)$ is phase of difference of the subcarrier

t is time in second

f_c is the subcarrier frequency in hertz

N is the number of symbols

T represents the original symbol period

NT is data block period

X_k is the transmitted symbol on $k-th$ subcarrier

L is the oversampled factor

High peak power can cause linear power amplifier to be push beyond its capacity. This results in nonlinear distortion and in so doing changes the signal spectrum superposition leading to degradation in the system performance. The presence of high PAPR can increase the complexity of OFDM system, reduce performance efficiency, makes OFDM to be sensitive to linear nonlinear distortion, and causes degradation in BER performance

Prior to this time, various methods classified as signal scrambling techniques such as selective level mapping (SLM) and partial transmit sequence (PTS), and signal distortion techniques such as clipping and filtering and companding algorithm have been developed in literature that caused significant improvement in the minimization of PAPR in OFDM signal. Nevertheless, these techniques have their respective weakness such as computational complexity due to the sub-blocks related to signal scrambling techniques(PTS and SLM) and in-band noise common among the distortion techniques, has attracted the attention of researchers into employing other strategies in addressing this challenge and providing improved PAPR performance in OFDM system. This paper is concerned with reducing the effect of PAPR in OFDM system using combination of distortion techniques with coded OFDM signal rather than using conventional OFDM signal.

2. Empirical review

With techniques in PAPR reduction moving towards combination of algorithms, several approaches have been applied in recent time, which involve the use biological inspired algorithm with signal scrambling techniques, or a combination of signal scrambling and signal distortion techniques, or a combination of two or more signal distortion/scrembling techniques. For instance, to reduce the computational complexity associated with PTS technique, a novel swarm intelligence model called firework algorithm (FWA) was implemented together with it to minimize PAPR in OFDM system (Amhaimar et al., 2018). In order to effectively reduce PAPR of OFDM signal in MIMO-OFDM system, a combination of tone reservation (TR) scheme and phase information of the pilot tones were implemented (Manasseh et al., 2011). Performance comparison of FWA based PTS, genetic algorithm (GA) based PTS, simulated annealing (SA) based PTS, standard particle swarm optimization (SPSO) based PTS, SLM and conventional PTS for PAPR reduction was conducted in Amhaimar et al. (2019). A root-based Mu-law companding was employed in precoded OFDM signal to reduce PAPR by Anoh et al., (2017). For PAPR reduction in OFDM signal a variation of repeated clipping and filtering (RCF) and tone reservation/injection techniques was implemented in Singh et al. (2013). A combination of signal distortion and scrambling using RCF and SLM was applied in OFDM system to reduced PAPR (Manjula and Muralidhara, 2017). In Dubey and Gupta (2016) and Agwah et al. (2020a), PAPR reduction was achieved using discrete Fourier transform (DFT) precoder plus RCF algorithm. The performance of PAPR in MIMO-OFDM long term evaluation (LTE) network was minimized using hybrid technique that involves DFT with RCF plus Mu-law companding (Agwah et al., 2020b),. Similarly, discrete cosine transform (DCT) with RCF plus Mu-law companding was used was employed for reducing PAPR in OFDM signal by Ekengwu et al. (2020). Singh and Sarin (2018) introduced primal-dual hybrid gradient (PDHG) technique for saddle point optimization of PAPR and multiuser cancellation in multiuser MIMO-OFDM downlink system. Two signal scrambling schemes, SLM and PTS, were combined for PAPR reduction in MIMO-OFDM system in Zahra et al. (2014). In Ali and Hamza (2016), GA based SLM technique was employed to carry out PAPR reduction in OFDM. A suboptimal metaheuristic technique for phase optimization of PTS algorithm based improved harmony search (HIS) was employed in reducing PAPR (Singh and Patra, 2017). Parallel ant colony optimization (parallel-ACO) based PTS was proposed for PAPR reduction in Taşpinar et al. (2016). Two optimization algorithms, social spider optimization (SSO) and adaptive artificial bee colony (ABC) algorithm with SLM scheme was employed to reduce PAPR in OFDM signal in VijayaLakshmi and Reddy (2018). A combination of clipping technique and SLM scheme was applied for PAPR in Sudha and Kumar (2016). A generalized oppositional biogeography based optimization (GOBBO) which was enhanced by oppositional based learning (OBL) techniques were applied to solve the search complexity problem of PTS in order to reduce PAPR of OFDM signal in Goudos (2016).

Considering the technological trend in this aspect of wireless communication, the study carried out by Agwah et al. (2020b) is modified by using Log companding technique rather than Mu-law companding for OFDM system since from the study by Mounir and El_Mashade (2019), log companding technique offers the best practical companding transform compared to Tanh, exponential, linear symmetric transform (LST), μ - Law, and linear asymmetric transform (LAST), which is impracticable.

3. System design

The block diagrams of proposed OFDM model is presented in Fig.1. The model will be used for the simulation analysis that will be conducted in this paper.

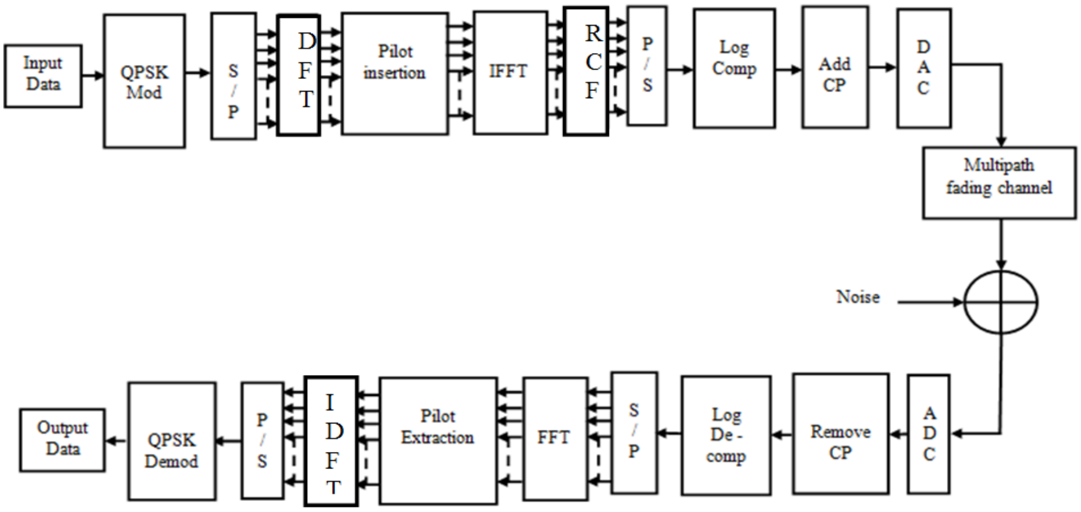

Fig. 1 – Proposed OFDM system model with RCF and log companding

3.1 Mathematical model of OFDM signal and PAPR problem

An OFDM is a multicarrier modulation scheme in which each subcarrier can be described as a complex waveform given by:

$$x(t) = A_c(t)e^{j(\omega_c t+\varphi_c t)} \quad (1)$$

where A_c is the amplitude of the subcarrier, ω_c is the frequency of subcarrier in radian per second (rad/s), $\varphi_c(t)$ is phase of difference of the subcarrier, t is time in second. The frequency in rad/s can be expressed in terms of subcarrier frequency f_c in hertz is given by:

$$\omega_c = 2\pi f_c \quad (2)$$

Now, consider an OFDM signal comprising *N* subcarriers. Given a block of *N* symbols, $X = \{X_k, k = 0,1,\cdots,N-1\}$ that represents a data block formed with each symbol modulating one of a set of subcarriers ($\{f_k, k = 0,1,\cdots,N-1\}$. The *N* subcarriers are taken to be orthogonal such that:

$$f_k = k\Delta f \quad (3)$$

where X_k is the transmitted symbol on $k-th$ subcarrier, $\Delta f = 1/NT$ and *T* represents the original symbol period while *NT* is data block period. Thus, the complex band OFDM signal consisting of *N* subcarrier with *NT* data block period is given by:

$$x(t) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} X_k e^{j2\pi f_k t},\ 0 \le t \le NT \quad (4)$$

Since modulation technique such as QPSK use in this work is a digital modulating scheme, the OFDM signal can be expressed in the discrete time domain as complex envelope with oversampled factor *L* given by Amhaimar et al. (2018):

$$x[n] = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} X_k e^{(j2\pi nk/LN)},\ 0 \le n \le LN-1 \quad (5)$$

Considering the Eq. (5), the generated signal by IFFT comprises *N* number of separately modulated and orthogonal subcarriers with high values of PAPR when added up at the output of the IFFT block. The definition of PAPR of OFDM signal in discrete time is given by Amhaimar et al. (2018):

$$\text{PAPR}\{\text{x[n]}\} = \frac{\max\left\{|x[n]|^2\right\}}{E\left\{|x[n]|^2\right\}},\ 0 \le n \le LN-1 \quad (6)$$

where $x[n]$ is the discrete time OFDM signal as in Eq. (5) and $E\{\cdot\}$ stands for the required value (of average power).

OFDM systems are considered as generalized case of MIMO-OFDM based on space time block code (STBC) [1, 20] for two, three, and four antennas. Using Alamouti code and an input signal $X = [X(0), X(1), ..., X(N-1)]$, the encoder signal with two transmitting antenna is given by Agwah et al. (2020b):

$$X_1 = [X(0), -X^*(1), ..., X(N-1), -X^*(N-1)]^T$$
$$X_2 = [X(1), X^*(0), ..., X(N-1), -X^*(N-2)]^T \quad (7)$$

The signals X_1 and X_2 are respectively transmitted by antennas 1 and 2. Thus, the PAPR at each MIMO-OFDM antenna is given by:

$$\mathrm{PAPR}\{x_i\} = \frac{\max\left\{|x_i(n)|^2\right\}}{E\left\{|x_i(n)|^2\right\}}, \quad 0 \le n \le LN-1 \tag{8}$$

where $i = 1, 2, ..., N_T$ number of transmit antennas. The discrete time domain signal at each transmit antennas is described by:

$$x_i(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k^i e^{(j2\pi nk/LN)} \tag{9}$$

The peak power variation of OFDM signal in MIMO-OFDM system can be represented mathematically by Amhaimar et al. (2018):

$$\mathrm{PAPR}_{\mathrm{MIMO-OFDM}} = \max\{\mathrm{PAPR}(x_i)\}, \ \ i = 1,.....,N_T \tag{10}$$

In the analysis of peak power of signal in modern communication, the statistical tool usually used is the Complementary Cumulative Distribution Function (CCDF) measurement (Manjula and Muralidhara, 2017). The measurement index for the probability of PAPR not greater than a threshold in practice is CCDF (Yi and linfeng, 2009) and is defined mathematically as:

$$P(PAPR > Z) = 1 - P(PAPR \le \ ) = 1 - f(z)^N$$
$$= 1 - (1 - \exp(\ - Z))^N$$
(11)

where N is statistically independent uncorrelated signal samples (Ekengwu et al., 2020).

3.2 Discrete Fourier Transform Precoder

In the application of precoder as a means of coding OFDM signal, the modulated baseband stream of data is clustered into blocks of length $(N - N_p)$ symbols each [23]. Normally, $N \times (N - N_p)$ precoding matrix ***P*** is used to multiply every block symbols. The expression for ***P*** is given by:

$$\mathrm{P} = \begin{bmatrix} P_{1,1} & P_{1,2} & \cdots & P_{1,(N-N_p)} \\ P_{2,1} & P_{2,2} & \cdots & P_{2,(N-N_p)} \\ \vdots & \vdots & \cdots & \vdots \\ P_{N,1} & P_{N,2} & \cdots & P_{N,(N-N_p)} \end{bmatrix} \tag{12}$$

where $P_{n,m}$ are the precoding matrix elements, N is the number of subcarriers, and $(N - N_p)$ represents the length of data block before precoding with $0 \le N_p < N.$ When $N_P = 0$ and the rate loss decreases to zero, the precoding matrix becomes $(N \times N)$ matrix (Mounir et al., 2018; Slimane, 2013).

3.3 Repeated clipping and filtering

In this scheme, the input vector $A_i = a_0, a_1, a_2, ...a_{N-1}$ is initially transformed using an oversized IFFT, where N is number of subcarriers in each OFDM symbol. For each L time oversampling, the input vector A_i is extended by adding $N(l-1)$ zeros in the middle of the input vector as shown in Fig. 2 (the structure of clipping and filtering process in OFDM system).

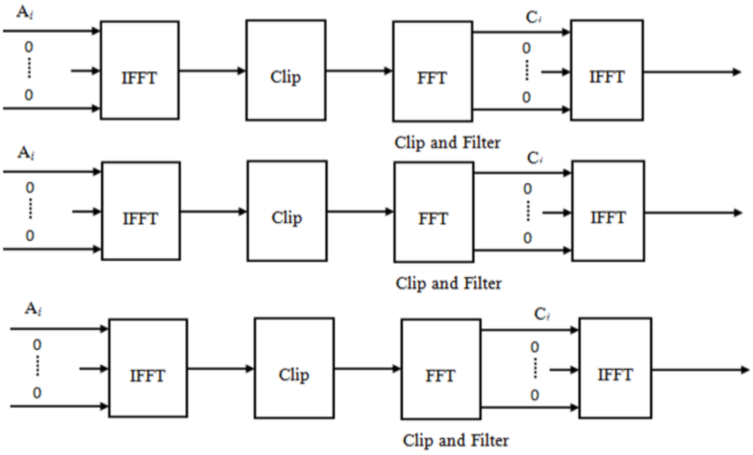

Fig. 2 – Structure of clipping and filtering iterations

The amplitude clipping is described mathematically by (Jolania and Toshniwal, 2013):

$$C(x) = \begin{cases} x, & x \leq A \\ A, & x > A \end{cases} \qquad (13)$$

where A is a positive real number, which is a predetermined clipping level [25].

3.4 Logarithm companding

In companding technique, OFDM signal is compressed at the transmitter while it is expanded at the receiver. Logarithm function companding or simply Log companding is used in this work. The Log companding algorithm is defined by (Jolania and Toshniwal, 2013):

$$C(x) = \begin{cases} x_n, & |x_n| \leq x_{th} \\ K_1 Log_e[1 + (x_n K_2)], & |x_n| > x_{th} \end{cases} \qquad (14)$$

where x_{th} is the threshold, before compression is performed. $K_1$and K_2 are positive integers controlling the level of compression or amount of companding such that $0 \leq K_1 K_2 \leq 1$.

3.5 Simulation Parameter

In order to effectively examine the OFDM system proposed in this work for reducing PAPR with the BER performance, the parameters of MIMO-OFDM used in this work are that of LTE standard given in Table 1.

Table 1 – System parameter

Parameter	Value
Modulation	QPSK
FFT size	256
Spacing ($f_{spacing}$)	15000 Hz
Sampling frequency (f_s)	15000*256
Sampling period (T_s)	$1/f_s$(μs)
Maximum Doppler frequency	0.01 Hz
Cyclic prefix	¼ of FFT size
Oversampling factor	4
Clipping ratio (CR)	1.2
SNR	0 to 30
$K_1 = 1/K_2$	1

4. Results

This section presents the results of the simulations carried out in MATLAB so as to examine the performance of conventional (uncoded) OFDM system and coded OFDM system (using DFT precoding technique) with RCF and coded OFDM system with RCF plus logarithm companding for PAPR reduction. In carrying out the simulation analysis, the RCF technique was studied by choosing clipping ratio (CR) = 1.2, number of iterations = 4 (1-

C&F, 2-C&F, 3-C&F, and 4-C&F), and sampling factor = 4 considered as optimal values. Furthermore, the coefficients (K_1 and K_2) of the logarithm companding scheme were assigned unity each for effective performance.

4.1 Analysis of conventional OFDM system

The simulation curve of conventional OFDM system is shown in Fig. 3. In this scenario, the simulated OFDM system is assumed to having no PAPR reduction technique introduced and the OFDM signal is not precoded. This was carried out to ease the understanding of the PAPR performance regarding the original OFDM system. The value of the system PAPR obtained from the simulation result as shown in Fig. 3.

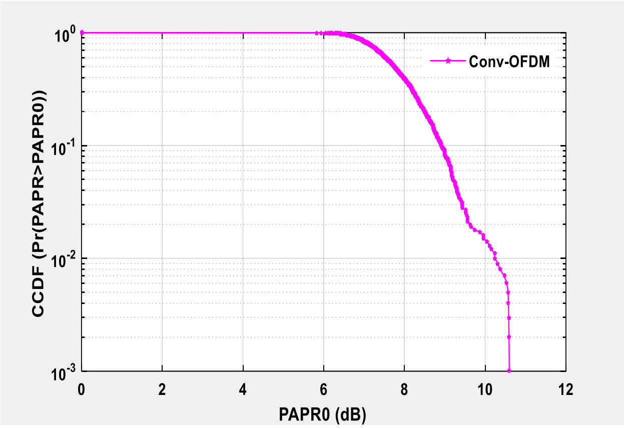

Fig. 3 – PAPR curve of conventional OFDM system

For the simulation analysis, QPSK modulation technique and 256 data points were utilized. The OFDM symbol size used was 256. With the CCDF plotted against PAPR in dB as shown in Fig. 3, the result of the simulation of conventional OFDM system reveals a PAPR effect of magnitude 10.6 dB at CCDF of 10^{-3}.

4.2 Analysis of DFT coded OFDM with RCF

In this simulation scenario, discrete Fourier transform (DFT) precoder is used to code original OFDM signal in order to enhance its PAPR performance. Then clipping and filtering processes take place for four iterations after which the resulting OFDM signal is passed onward to the transmit antenna. This simulation was conducted to analyze the effectiveness of coding OFDM signal prior to clipping and filtering operation in reducing PAPR of OFDM signal. Figure 4 shows the simulation results of DFT coded OFDM signal with four clipping and filtering iterations.

In order to analyze the percentage improvement of PAPR with the respect to the level of reduction due to introduction of RCF algorithm, the value (10.6 dB) which is obtained from conventional OFDM system is taken as the reference value. Hence, the calculation is performed using the expression given by:

$$\%PAPR = \frac{PAPR_{ConvOFDM} - PAPR_{ModOFDM}}{PAPR_{ConvOFDM}} \times 100 \quad (15)$$

Where $PAPR_{ConvOFDM}$ is the PAPR of conventional OFDM signal, and $PAPR_{ModOFDM}$ is the augmented PAPR. Therefore using $PAPR_{ConvOFDM}$ = 10.6 dB, the numerical performance of the system is shown in Table 2.

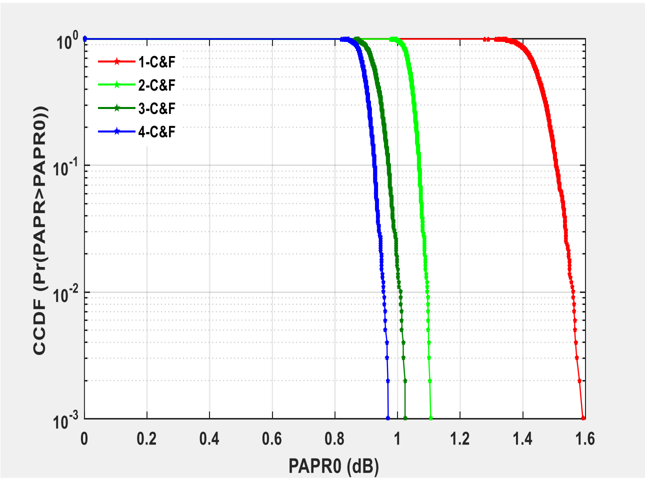

Fig. 4 – PAPR of coded OFDM with RCF

Table 2 – Performance analysis of DFT coded OFDM signal with RCF

Process	PAPR value (dB)	PAPR improvement (%)
One clipping and filtering (1-C&F)	1.591	85.0
Two clipping and filtering (2-C&F)	1.106	89.6
Three clipping and filtering (3-C&F)	1.024	90.3
Four clipping and filtering (4-C&F)	0.970	90.8

Figure 4 shows the simulation curves of CCDF against PAPR in dB for DFT coded OFDM signal with four clipping and filtering iteration process. The figure shows that the value of PAPR was very much reduced because the OFDM signal was initially coded prior to introduction of repeated clipping and filtering (RCF). It can be deduced from Table 2 that the addition of DFT precoder makes the achieved PAPR reduction of OFDM signal to be largely reduced compared to conventional OFDM signal. Therefore, looking at Table 2, the achieved improvement in PAPR reduction due to coded OFDM signal with RCF is 90.8% after fourth iteration before signal is transmitted.

4.3 Analysis of the proposed system

The proposed system utilizes DFT coded OFDM signal with RCF plus log companding techniques and it is tagged proposed coded combined distortion scheme (PCCDS). The simulation curves for the iterations stage including the final stage of PAPR reduction that involves the application of log companding after the fourth clipping and filtering iteration is shown in Fig. 5. The numerical analysis of the simulation plots is presented in Table 3.

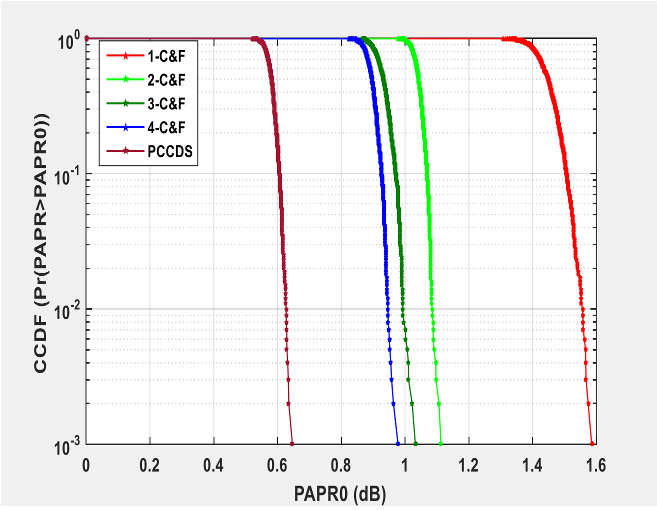

Fig. 5 – PAPR of OFDM signal with PCCDS

Table 3 – Performance analysis of coded OFDM signal with RCF plus log companding

Process	PAPR value (dB)	PAPR improvement (%)
One clipping and filtering (1-C&F)	1.591	85.0
Two clipping and filtering (2-C&F)	1.106	89.6
Three clipping and filtering (3-C&F)	1.024	90.3
Four clipping and filtering (4-C&F)	0.970	90.8
Proposed coded combined distortion scheme (PCCDS)	0.640	94.0

While the earlier approach involving the coding of OFDM signal using DFT before applying the RCF technique seemed to be promising in reduction of PAPR in OFDM system, the proposed technique that utilizes DFT coded OFDM with RCF and log companding (called PCCDS) appeared to be even more effective in largely minimizing of PAPR as shown in Fig. 5. Numerical analysis of PAPR curve for each iteration process and with the log companding revealed that the proposed scheme reduced PAPR to 0.640 dB, which is 94% improvement from the original value of 10.6 dB as shown in Table 3.

This paper has presented logarithm companding/repeated clipping and filtering (RCF) optimization techniques for peak to average power ratio (PAPR) reduction in orthogonal frequency division multiplexing-multiple input multiple output (OFDM-MIMO) system. In order to carry out simulations to examine and analyze the performance of the proposed scheme, codes of OFDM system were created as MATLAB extension files for conventional and DFT coded OFDM signal with RCF plus log companding. The system utilizes QPSK modulation and 256 number of subcarriers. Optimal values of oversampling factor (L = 4), clipping ratio (C.R = 1.2), and coefficients of logarithm function ($k_1 = 1$ and $k_2 = 1$) presented in literature were used for the simulation of the proposed system. Generally, simulation results showed that PAPR reduces more on using the coded OFDM with RCF plus log companding such that reduction of 0.640 dB was achieved at CCDF of 10^{-3}, which is 94% improvement from the original OFDM signal.

Acknowledgements

An example appendix

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