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Minimizing Peak-to-Average Power Ration in OFDM Based Cognitive Radio using Combined Distortion Technique

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A B S T R A C T

Orthogonal Frequency Division Multiplexing (OFDM) technique is considered a good candidate for cognitive radio (CR) systems regarding flexibility and adaptability. This work presents application of precoded algorithm with distortion technique for minimizing peak-to-average power ratio in OFDM based Cognitive Radio (CR). The main objective of this work was to apply precoding algorithm with combined distortion technique for minimizing peak-to-average power ratio in OFDM based CR in order to reduce the effect of PAPR. The proposed scheme was modelled in MATLAB environment. Simulation was initially conducted for conventional OFDM and the PAPR was observed to be 10.33 dB at CCDF of 10-3. The resulting value of BER was 0.0002818 at SNR of 11.2 dB. The next approach was to introduce repeated clipping and filtering (RCF) in to the OFDM system. With the addition of RCF algorithm, the simulation results indicated that at the same CCDF of 10-3, a less PAPR of 3.32 dB was achieved which was69.1% reduction of PAPR values after fourth iteration. The BER against SNR plot achieved at the receiver in this case was 0.002098 at 30 dB. The next approach involves reducing the PAPR value further by addition of DCT precoder with RCF. Maintaining the same CCDF of 10-3, the PAPR was further reduced to 1.36 dB after fourth iterations, which was 84.3% reduction. The BER performance of the system was improved by the introduction of the precoder such that a value of 0.0006693 at 30 dB. The performance comparison plots revealed that the proposed system using DCT and RCF achieved better PAPR reduction than the system using DFT and RCF. Generally, the results obtained from the performance analysis carried out via simulations showed that the proposed system largely reduced PAPR while compensating for degradation effect on received signal performance in terms of BER assuming RCF algorithm was use alone at the transmitter.

Keywords: BER, Cognitive radio, OFDM, DFT, RCF

1. Introduction

Cognitive Radio (CR) is being employed on proper use of spectrum due to its fast adaptability and flexibility. Cognitive Radio is an intelligent wireless system, which is always aware of its environment through sensing and should be able to dynamically adjust the parameters of its radio operation. It is expected that the physical layer (PHY) of CR be adaptable and flexible. Conversely, one promising technique for flexible spectrum grouping in communication systems is Orthogonal Frequency Division Multiplexing (OFDM) (Rajbanshi et al., 2006).

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation scheme in which available spectrum is divided into subcarriers such that individual subcarrier contains a low rate stream of data. It has largely gained tremendous popularity in recent times as a result of its robustness in the presence of harsh multipath channel conditions. Nevertheless, OFDM application is faced with the problem of PAPR, which is a major drawback. Besides, for flexibility and adaptability, the OFDM is a promising scheme for CR systems. Hence, there is need to reduce PAPR of OFDM signal in CR system to improve spectrum efficiency and achieve high data rate. With some techniques in the form of signal scrambling and signal distortion algorithms already introduced and have shown good performance in reduction of high PAPR. These techniques have their separate weakness such that research direction is focused on integrating two or more of these techniques to achieving more efficient PAPR reduction scheme. This paper is designed to use precoded algorithm based on combined distortion technique to minimise PAPR in OFDM based CR.

2. Literature review

Anitha and Satheesh (2021) discussed the effect of reducing PAPR in the spectrum of OFDM based cognitive radio systems. The study applied a technique that utilized Hadamard encoded OFDM signal and Partial Transmit Sequence (PTS) based estimation used in the system to realize much reduced PAPR. The digital modulation technique used with OFDM was Offset Quadrature Amplitude Modulation (OQAM).The study did not provide any numerical figure to substantiate the simulated results.

Kalikiet al. (2021) applied an optimization scheme to simultaneously reduce PAPR and out-of-band power (OBP) in noncontiguous OFDM (NC-OFDM) based CR systems. It reported that NC-OFDM based CR systems provide very much efficient utilization of spectrum by transmitting data of unlicensed users on subcarriers of data of licensed users when they are free. In the study, despite this benefit, the disadvantages of NC-OFDM were highlighted to include OBP and PAPR. The OBP it was reported to be caused by side lobes of NC-OFDM signal in frequency domain, which interferes with the spectrum for unlicensed users whereas PAPR is as a result of the inverse fast Fourier transform (IFFT) block employed in NC-OFDM system that causes distortion (nonlinear) effect in power amplifier (PA). The study implemented a scheme called alternative projections onto convex and non-convex sets (APOCNCS) to reduce OBP and PAPR at the same time. It carried out alternative projections onto these sets to form iteration such that the NC-OFDM signal converged to the limits specified for in-band-power, peak amplitude, and OBP. The study employed 64 subcarriers, which were numbered 0 to 15, 24 to 39, and 48 to 63 as active subcarriers while others were numbered 16 to 23 and 40 to 47 as null subcarriers by assumption. The modulation technique used to modulate the binary data in the study was Quadrature Phase Shift Keying (QPSK). The results from simulations were reported to indicate that the error rate performance was not degraded in the course of minimizing OBP and PAPR and did not alter the modulated data. The problem of APOCNCS algorithm is its computational complexity which increased as compared to previous algorithm as reported in the study.

Parvez et al. (2012) developed a scheme for PAPR reduction in noncontiguous (NC) bands spectrum of OFDM based CR. The system was designed to achieve high data rate of noncontiguous subcarriers while at the same time avoiding interference to the transmissions. In the study, the NC-OFDM transceiver considered employed bandwidth of 10 MHz, FFT block size of 256, and clipping ratio of 4. The modulation schemes used were Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), and 16 Quadrature Amplitude Modulation (16-QAM). It also employed Additive White Gaussian Noise (AGWN) and Rayleigh fading channel as the channel modes for simulation study. The system was examined in terms of two performance parameters namely PAPR and BER. The study reported that the QAM 16 outperform BPSK and QPSK in terms of PAPR reduction.

Sheikh et al. (2016) stated that multicarrier communication is potential candidate for 4G-LTE network, but has the problem of PAPR because of the addition of various carriers via Inverse Fast Fourier Frequency (IFFT). The study developed a new hybrid scheme that integrates filtering and companding schemes with Selective Level Mapping (SLM) to significantly reduce PAPR. Multicarrier signal was generated in the study using Digital Video Broadcasting (DVB-T2) parameters. It used an available bandwidth of 8 MHz and IFFT/FFT length of 4096 for simulation. The result reported in the study revealed that the hybrid scheme achieved a PAPR reduction of nearly 9.1 dB with FFT block size of 256.

Nair et al. (2017) used signal cancelation and tone reservation technique to reduce PAPR in NC-OFDM based CR system. The concept of the developed scheme was to dynamically extend part of the constellation points on the secondary user subcarriers and combine many signal cancellation symbols on the primary user subcarriers in order to create the proper cancelation signal for joint PAPR minimization and sidelobe suppression. In the study, the number of subcarrier used was 64 and the subcarrier interval was 22.5 kHz. The modulation techniques employed were 4-QAM and 16-QAM. The scheme achieved reduced PAPR value of 9, 10.6 and 11 dB by varying the parameter to control the maximum sidelobe power in the values 0.5, 0.4, 0 respectively. The study reported that the PAPR improves by increasing the value of the maximum sidelobe power control parameter.

Rady et al. (2016) discussed the use of joint suppression and various techniques for PAPR reduction in OFDM based CRs. The study focused on the general performance improvement of PAPR and BER problems. The performance of the various techniques was examined and comparison made based on theoretical analysis and numerical simulation. In the study, six different techniques were investigated namely, selective level mapping with multiple choice sequence (SLM-MCS), advanced constellation expansion with peak reduction (ACEPR),interleaver with SLM-MCS (I-SLM-MCS), hybrid precoding technique that involves combination of two similar schemes (Zadoff-Chu technique and precoding technique), multi-stages of partial transmit sequence (MS-PTS), and noncontiguous technique and serial peak cancellation (NC-SPC). The results obtained from the simulation were presented in terms of these metrics: PAPR, BER, sidelobe power, and system complexity. The study revealed that hybrid precoding scheme outperformed all the other techniques.

Sarvani and Neeraja (2015) applied signal cancellation technique for reduction of PAPR and suppression of sidelobe in NC-OFDM based CR system. The idea behind the technique was for the signal cancellation scheme to dynamically extends some parts of constellation points on the secondary user subcarriers and add a few signal cancellation symbols on the primary user subcarriers so as to generate appropriate cancellation signal for PAPR reduction and sidelobe suppression. The study reported significant reduction of PAPR and suppression of sidelobe, but without numerical values to substantiate the claim made regarding to the developed technique.

Zaki et al. (2019) described NC-OFDM as an appropriate transmission scheme for CR system. The authors stated that an efficient utilization of spectrum for high data rate wireless systems is guaranteed by NC-OFDM. However, two main challenges are common with NC-OFDM system namely, high sidelobe level and PAPR. Two schemes were proposed to jointly suppress the out-of-band (OOB) radiation caused by high sidelobe levels and minimize PAPR. The two proposed schemes employed an inverse discrete wavelet packet transform (IDWPT).The first approach involved the use of signal IDWPT with cancellation (SC) (IDWPT-SC) for PAPR reduction and in the second method IDWPT was used with the sub-signal cancellation (IDWPT-Sub-SC). The results indicated that the use of IDWPT helped in reducing fluctuations in the transmitted signal, and as such minimize PAPR and OOB radiation.

Chaudhari and Durvesh (2015) described CR as an emerging technology that reduces the problem of spectrum scarcity. It regarded OFDM is an ideal transmission scheme for CR networks due to its flexibility in supporting dynamic spectrum access (DSA). However, with challenges of OOB and PAPR, the study surveyed different methods that have proposed for addressing either or both problems using precoding techniques.

Mahajan et al. (2017) regarded CR as a technology that permits unlicensed user to use the free licensed band intelligently to address the challenge of scarcity in available spectrum. It maintained that CR is capable to learn and adapt it wireless transmission in relation to the surrounding radio environment. OFDM is utilized as multicarrier scheme in CR because it can provide high data rate. Nevertheless the problem of PAPR is still present. The authors proposed a hybrid technique that combined partial transmit sequence (PTS) and clipping technique to reduce PAPR in OFDM based CR. Simulation results indicated using subcarrier of 64 and 128 with clipping ratio of 0.7, the hybrid scheme reduced PAPR to 4.44 dB and 4.65 dB with QPSK modulation scheme, 4.43 dB and 4.85 dB with 16-QAM modulation, and 4.3 dB and 4.62 dB with 32-QAM modulation scheme respectively.

3. System design

So far some of the related studies on PAPR reduction in NC-OFDM based CR have been examined. The review has shown that system with hybrid scheme provides improved PAPR compared to others using individual techniques separately. In this paper, a discrete cosine transform (DCT) precoding with repeated clipping and frequency domain filtering (RCF) is proposed to reduce PAPR in noncontiguous OFDM (NC-OFDM) based cognitive radio (CR). In order to minimize the presence of high peak-to-average power ratio (PAPR) associated with OFDM based CR, a discrete cosine precoding is introduced with RCF. The system structure is shown in Fig. 1.

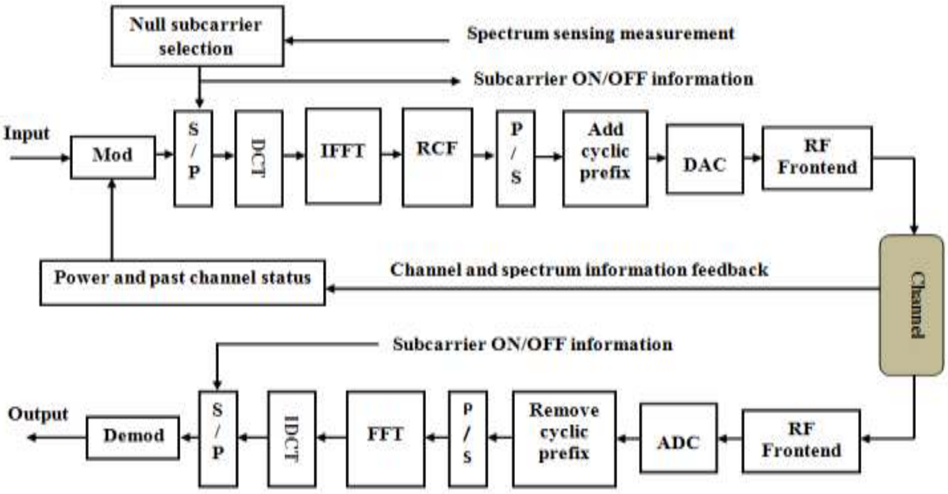

Fig. 1 – Block diagram of proposed system

In Fig. 1, the previous channel information in non contiguous OFDM (NC-OFDM) based CRs under dynamic spectrum sharing environments is utilized by the system. Conventional OFDM has resource allocation problem where there is fixed transmission spectrum allocation. In the case of CR system, the spectrum is co-shared and the operating bandwidth is not all the time fixed with respect to time, frequency, and geographical domains. It should be noted that the IFFT is at the transmitter side of the OFDM system because as a multicarrier modulation scheme, the OFDM symbol (or signal) is constructed in the frequency domain. Thus, to transmit the OFDM symbol, the signal must be represented in time domain and this is achieved using the IFFT.

3.1 Mathematical description of OFDM signal and PAPR

Assuming a continuous spectrum consisting of N subcarriers belonging to primary users, vacant subcarriers that are not utilized by the primary users are sensed by sensing detector, and NC-OFDM allows the use of these subcarriers in sending the transmission of data by the secondary users via the communication channel. These subcarriers are usually referred to active subcarriers in NC-OFDM systems, while the others are called null subcarriers. In general, a discrete-time NC-OFDM signal can be defined by (Kaliki et al., 2021):

$$x[\mathrm{n}] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi \frac{kn}{N}}, \quad n = 0, 1, \cdots, N-1 \tag{1}$$

and the subcarrier spacing is given by:

$$\text{Subcarrier spacing} = \frac{1}{NT_s} \tag{2}$$

where X_k is the data of secondary users to be transmitted on active subcarriers, N is the number of symbols and T_s is the sampling periods, respectively. The discrete-time NC-OFDM signal is converted to a continuous time NC-OFDM signal using interpolation filter $h_1(t)$ for accurate calculation of out-of band power (OBP) and input band power (IBP). Thus, the continuous time NC-OFDM signal is given by (Kaliki et al., 2020):

$$x(t) = h_1(t)\left(\sum_{n=-N_{cp}}^{N-1} x_n \delta(t - nT_s)\right) \tag{3}$$

where N_{cp} is the length of the cyclic prefix (CP). The energy spectrum of the continuous time NC-OFDM signal is given by (Kaliki et al., 2021):

$$E(f)=\frac{L^2}{N}\left|H_1(f)\sum_{k=0}^{N-1}X_k \text{sinc}_{\text{L}}(f-f_k)e^{-j\pi(f-f_k)T_S(L-N_{cp}-1)}\right|^2 \tag{4}$$

where $L=N+N_{cp},\ f_k=k/NT_s,\ H_1(f)$ *is the Fourier transform of the interpolation filter, and the function* sinc_{L} *is defined by:*

$$\text{sinc}_{\text{L}}=\begin{cases}\dfrac{\sin(\pi L T_s f)}{\sin(\pi T_s f)}, & T_s f\notin Z,\\ (-1)^{T_s f(L-1)}, & \text{otherwise},\end{cases} \tag{5}$$

where Z is the set of integers.

The sum of the energy of the NC-OFDM signal can be defined in terms of the energy spectrum given by:

$$E_{total}=\int E(f)df. \tag{6}$$

In the case in which the NC-OFDM signal is sampled *J* times to obtain accurate peak amplitude and the PAPR of the signal, the resulting oversampled NC-OFDM signal is expressed as in:

$$x[\text{n}]=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}X_k e^{j2\pi\frac{kn}{JN}},\quad n=0,1,\cdots,JN-1 \tag{7}$$

Considering the Equation (7), 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 NC-OFDM signal in discrete time is given by:

$$\text{PAPR}=\frac{\text{Peak power}}{\text{Average power}}=\frac{\max|x[n]|^2}{E[|x[n]|^2]} \tag{8}$$

where $x[n]$ is the discrete time OFDM signal as in Equation (3.8) and $E\{\cdot\}$ stands for the required value (of average power). Typical value taken for oversampling factor *J* is within an integer of $J\geq 4$ so as to accurately estimate PAPR (Kaliki et al., 2021).

3.2 Discrete cosine transform precoding

A standard $N\times(N-N_p)$ precoding matrix ***P*** is employed in multiplying each block symbols. The mathematical description of ***P*** is given by:

$$\text{P}=\begin{bmatrix}P_{1,1} & P_{1,2} & \cdots & P_{1,(N-N_p)}\\ P_{2,1} & P_{2,2} & \cdots & P_{2,(N-N_p)}\\ \vdots & \vdots & \cdots & \vdots\\ P_{N,1} & P_{N,2} & \cdots & P_{N,(N-N_p)}\end{bmatrix} \tag{9}$$

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 $0\leq N_p<N.$ When $N_P=0$ and the rate loss decreases to zero, the precoding matrix becomes $(N\times N)$ matrix (Mounir et al., 2018). Thus the DCT precoding algorithm in terms of $(N\times N)$ is given by Ekengwu et al. (2020):

$$P_{n,m}=\begin{cases}\sqrt{\dfrac{1}{N}}, & n=0 \quad and \quad 0\leq m\leq(N-1)\\ \sqrt{\dfrac{2}{N}}\cos\left(\dfrac{2\pi nm+\pi n}{N}\right), & 1\leq n\leq(N-1) \quad and \quad 0\leq m\leq(N-1)\end{cases} \tag{10}$$

3.3 Repeated clipping and filtering

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

$$C(x) = \begin{cases} x, & x \leq A \\ A, & x > A \end{cases} \quad (11)$$

where A is a positive real number, which is a predetermined clipping level (Jolania and Toshniwal, 2013).

In this paper, RCF is employed because it ensures that re-grow effect of filtering is addressed by performing the process in an iterative or a repeated fashion until a significant level of PAPR is achieved. Furthermore, the use of precoding offers improved bit to error ratio (BER) than conventional OFDM with RCF technique.

3.4 Channel Model

In implementing a typical real life experience of transmitted signal over wireless communication channel, the Rayleigh fading channel model is implemented given by Clarke as cited in Parvez and Al Baki (2010):

$$P(t) = \begin{cases} \frac{r}{\sigma^2} \exp\left[\frac{-r^2}{2\sigma^2}\right], & 0 \leq r \leq \infty \\ 0, & r < 0 \end{cases} \quad (12)$$

where σ^2 is the variance of the Rayleigh distributed variables.

4. Simulation results

The system is NC-OFDM transceiver using 10 MHz bandwidth, 64 FFT block size, a clipping ratio (CR) of 1.2., number of iteration for RCF is 4, signal to noise ratio of 3 dB, oversampling factor of 4. Length of cycling is 0.25 x 64 FFT block size, and modulation is QPSK (signal constellation is 4). For the analysis, the complementary cumulative distribution function (CCDF) of the peak to average power ratio (PAPR) for the transmitted symbol is plotted against the PAPR in dB. At the receiver, the received signal is analyzed in terms of the bit error ratio (BER) against SNR.

The results of the simulation carried out using the conventional OFDM system as shown in Fig. 2 and 3 for PAPR and BER respectively. In this case, the system is assumed to be operating without a technique to offset the effect of PAPR on the power amplifier (PA) of the transmitter.

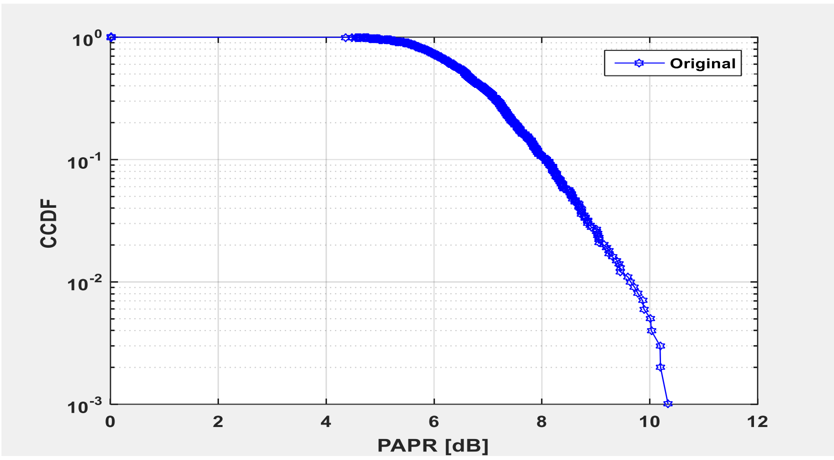

Fig. 2 – PAPR plot of conventional OFDM

In Fig. 2, the simulation result showed that at CCDF of 10^{-3}, the PAPR of the system was 10.33 dB. Also, an obvious observation is that as the probability function (that is CCDF) decreases the PAPR increases.

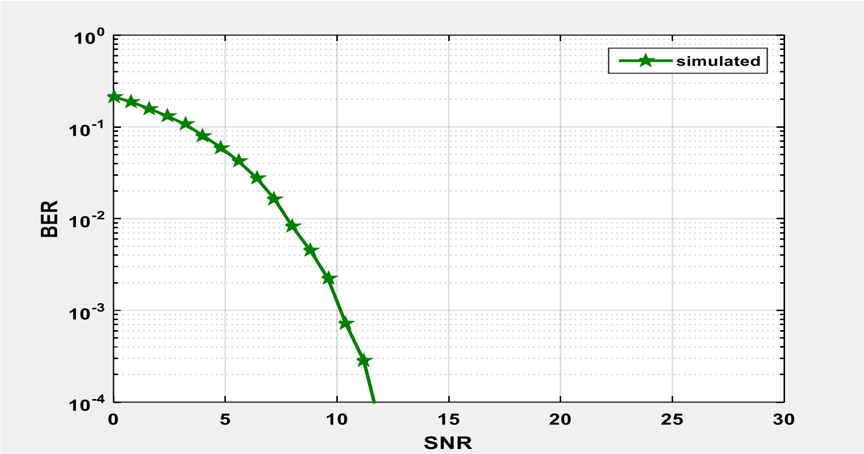

Fig. 3 – BER plot of conventional OFDM

The simulated BER performance of the OFDM signal is shown in Fig. 3, revealed a value of 0.0002818 at SNR of 11.2 dB. Looking at the BER performance simulation curve, it can be seen that as BER decreases SNR increases.

The simulation analysis regarding the proposed system with RCF algorithm is presented in this section in terms of PAPR performance at the transmitter and BER performance at the receiver as shown in Fig. 4 and 5.

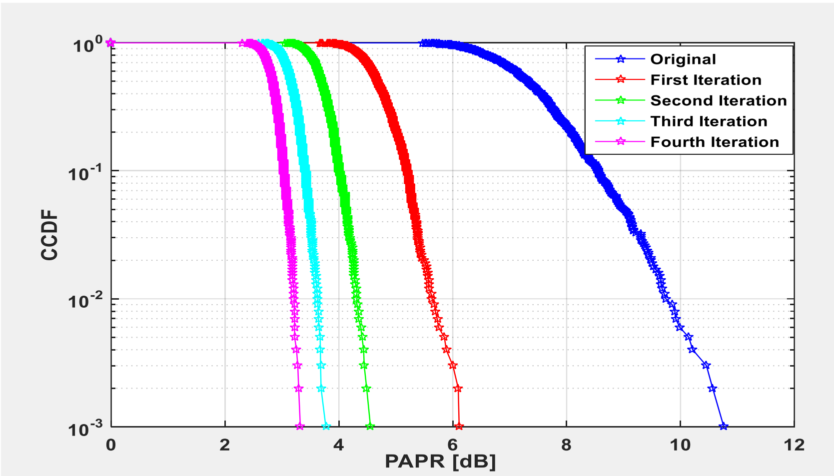

Fig. 4 – PAPR reduction with RCF

As shown in Fig. 4, it can be seen that the CCDF is 10^{-3} while the PAPR increased to a value of 10.76 dB. The numerical analysis of the system is shown in Table 1

Table 1 PAPR performance of system with RCF at CCDF of 10^{-3}

Simulation Scenario	PAPR (dB)	Reduction (%)
Original	10.76	-
First iteration	6.112	43.2
Second iteration	4.56	57.6
Third iteration	3.77	65.0
Fourth iteration	3.32	69.1

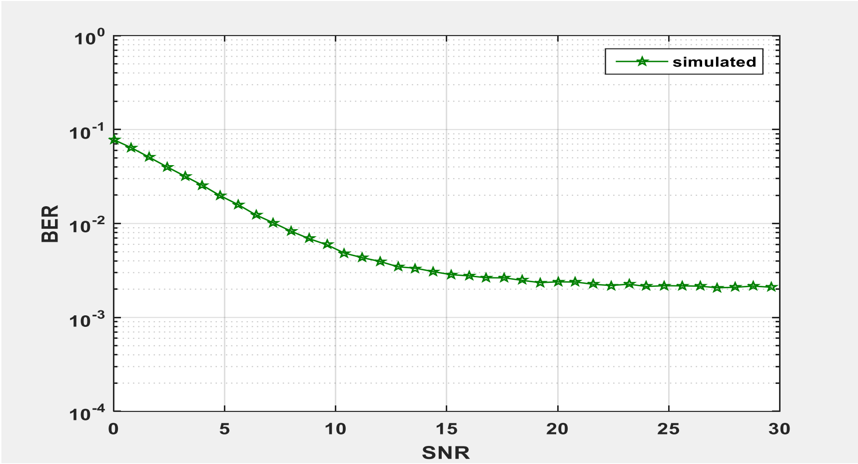

Fig. 5 – BER performance of system with RCF

The simulated BER against SNR plot shown in Fig. 5 revealed 0.002098 at SNR of 30 dB. The system performance is presented in this section in terms of PAPR and BER using DCT precoding algorithm and RCF scheme as shown in Fig. 6 and 7.

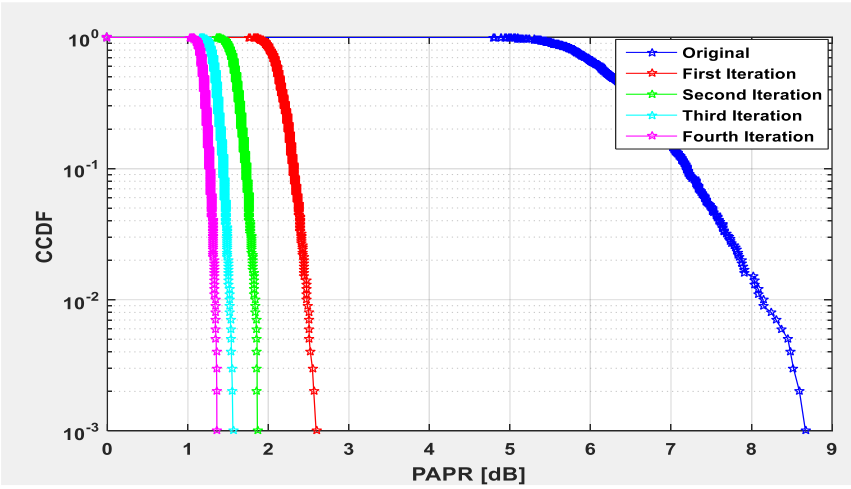

Fig. 6 – PAPR reduction with precoder and RCF

The performance of the system is shown in Fig. 6 with precoder and RCF combined to reduce PAPR at the transmitter. As shown in the figure, it can be observed that at CCDF of 10^{-3}, the PAPR increased to 8.67 dB. The numerical analysis of the curves at different number of iterations is presented in Table 2.

Table 2 PAPR performance of system with precoder and RCF at CCDF of 10^{-3}

Simulation Scenario	PAPR (dB)	Reduction (%)
Original	8.67	-
First iteration	2.59	70.5
Second iteration	1.63	81.2
Third iteration	1.56	82.0
Fourth iteration	1.36	84.3

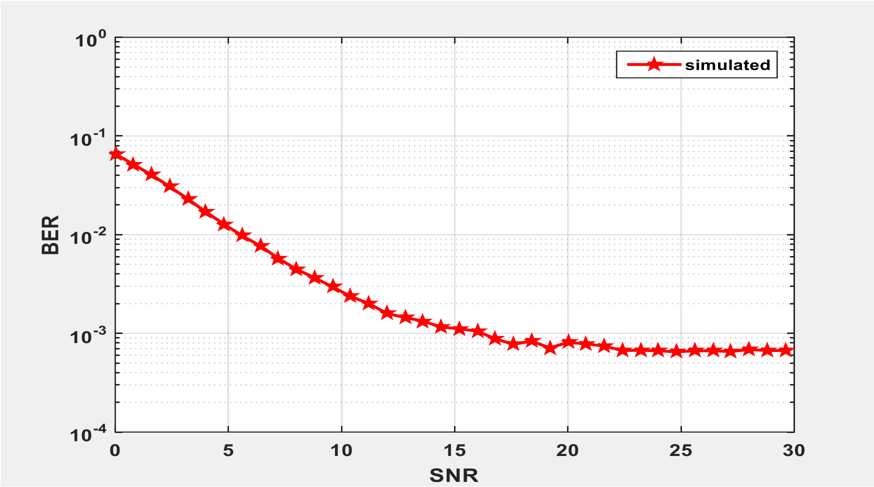

Fig. 7 – BER performance of system with precoder and RCF

The simulation result shown in Fig. 7 indicates that the introduction of precoder together with RCF provided a BER of 0.0006693 at SNR of 30 dB. Performance comparison is carried considering the proposed system with DCT and RCF algorithm and system with discrete Fourier Transform (DFT) and RCF for PAPR reduction in OFDM based Cognitive Radio (CR). Figure 8 shows the PAPR simulation curves. It should be noted that only fourth iteration plots are shown in the figure.

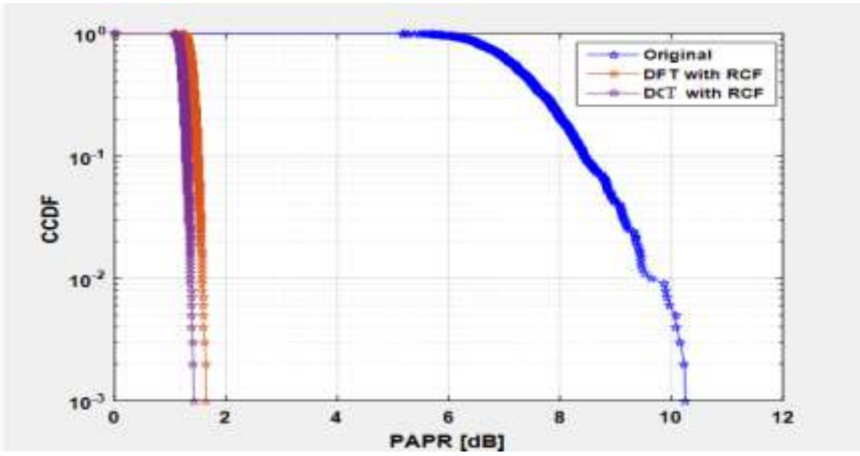

Fig. 8 – Performance comparison of PAPR

In Fig. 8, by increasing PAPR, it was observed that at CCDF of 10^{-3}, a PAPR of 10.33 dB was recorded; but after the fourth iterations of both systems, the PAPR of the proposed DCT with RCF was 1.424 dB while PAPR of DFT with RCF was 1.635 dB, which are 84.2% and82.8% respectively.

Generally, from the MATLAB simulation analysis carried out regarding the proposed system, the following conclusion can be drawn. In Fig. 2, the value of the conventional PAPR was observed to be 10.33 dB at CCDF of 10^{-3}.The resulting value of BER obtained from the plot in Fig. 3 was 0.0002818 at SNR of 11.2 dB. With the addition of RCF algorithm, the simulation results indicated that at the first iteration, the same 10^{-3} is accomplished at less PAPR of 6.112 dB (i.e. 43.2% reduction in PAPR value). In the second iteration, the PAPR was further reduced to 4.56 dB (i.e. 57.6% reduction in PAPR value). At third and fourth iterations, the PAPR reduces even further to 3.77 dB and 3.32 dB respectively, which are 65% and 69.1% reduction of PAPR values as shown in Fig. 4. The BER against SNR plot achieved at the receiver as shown in Fig. 5 is 0.002098 at 30 dB. The next approach involves reducing the PAPR value further by addition of DCT precoder with RCF. The analysis revealed as shown in Fig. 4 and Table 2 that by increasing PAPR, at CCDF of 10^{-3}, the value was 8.67 dB. However, during the first iteration, the same value of CCDF at reduced PAPR value of 2.59 dB was achieved. Maintaining the same CCDF of 10^{-3}, the PAPR was further reduced to 1.63 dB, 1.56 dB, and 1.36 dB during second, third, and fourth iterations that stand for 70.5%, 81.2%, 82 %, and 84.3% reduction respectively. The BER performance of the system was improved by the introduction of the precoder such that a value of 0.0006693 at 30 dB. Finally, performance comparison plots shown in Fig. 8 revealed that the proposed system using DCT and RCF achieved better PAPR reduction than the system using DFT and RCF.

In conclusion, this paper has provided a general concept of the orthogonal frequency division multiplexing (OFDM) and cognitive radio (CR). The flexibility and adaptability of OFDM has made it attractive multicarrier modulation scheme in many wireless communication system including CR systems. In this work, a scheme that combines precoding scheme and repeated clpping and filtering (RCF) to effectively reduce PAPR at high proportion in non-contiguous OFDM (NC-OFDM) was proposed. The main objective of this work was to apply precoding algorithm with combined distortion technique for minimizing peak-to-average power ratio in OFDM based CR in order to reduce the effect of PAPR. The proposed scheme was modelled in

MATLAB environment. The results obtained from the performance analysis carried out via simulations showed that the proposed largely reduced PAPR while compensating for degradation effect on received signal performance in terms of BER assuming RCF algorithm was use alone at the transmitter.

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