A HYBRID PRECODING TECHNIQUE FOR REDUCING BOTH PAPR AND SIDELOBE POWER IN COGNITIVE RADIO NETWORKS

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ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is a recognized transmission technique for Cognitive Radio (CR) networks, which is called non-contiguous OFDM (NC-OFDM). While this technique has two major drawbacks, Out OF Band (OOB) leakage due to high spectral sidelobe and high Peak to Average Power Ratio (PAPR), which cause interference with Primary Users (PU). Many solutions were proposed for solving either of these problems individually or together. In this paper, a hybrid precoding technique for reducing both PAPR and sidelobe power is proposed. This technique is based on using Zadoff-Chu sequences with Singular Value Decomposition (SVD) optimization method to minimize the power interference with PU. Simulation results cover the PAPR, sidelobe reduction, and Bit Error Rate (BER) for the proposed technique.

Keywords

NC-OFDM, CR, PAPR, ISI, and BER.

1.INTRODUCTION

Cognitive radio [1] is a system used to improve the throughput of wireless communication. Because of the fact that most of the permanently allocated (PU) spectrum is not utilized all the time hence this results as spectrum holes and the spectrum is underutilization [2]. Cognitive radio utilizes the spectrum in opportunistic manner which basically works on the principle of detect-and-avoid (DAA). The main issue in CR is dynamic spectrum sensing used to activate and deactivate the spectrum. NC-OFDM technique proved to be a suitable candidate for cognitive radios due to its impact on facing frequency-selective channel and capability to support high data.

The problems of NC-OFDM have collected into two categories, high peak to average power ratio (PAPR) and high sidelobe power. Most radio systems employ High Power Amplifiers (HPA) in the transmitter to obtain sufficient transmission power. When the OFDM signal has high PAPR, this obliges the power amplifier to work in nonlinear region. This non linearity makes the HPA very sensitive to the variations of the signal amplitude and makes out of band distortion and Inter carrier Interference (ICI). While the output of the IFFT is Sinc function, OOB radiation occurs out of the main lobe of OFDM spectrum because of the decay of this Sinc function. This OOB radiation causes interaction between PU and CR users. The two problems reduce power amplifier efficiency and increase BER.

The techniques for reducing sidelobe power are presented. Windowing technique [3], such as raised cosine windowing, is applied in time domain waveform to reduce sidelobe power while the spectrum efficiency may be significantly decreases. To improve the spectral efficiency various advanced techniques have been proposed [4]-[14] such as subcarrier weighting (SW) [4], adaptive symbol transition [5]. Among them two classes of techniques, that have received a wide attention recently and achieve more reduction on sidelobe power while retaining spectrum efficiency, are cancellation [6]-[8] and precoding [9]-[14]. Cancellation techniques such as active interference cancellation (AIC) [6], cancellation carrier (CC) [7], and extended AIC [8] can achieve good sidelobe suppression but suffer from Signal to Noise Ratio (SNR) degradation and also extra power is wasted in cancellation subcarrier. Precoding techniques optimize a precoding matrix to minimize sidelobe power. In [9], new basis sets are developed to improve both sidelobe suppression and error performance but the complexity is increased. Orthogonal precoders [10] and [11] approaches have the advantage of maintaining the receiver SNR, but their computation complexity is increased with increasing of the number of subcarriers. In [12], the designed precoders minimize the discontinuity between consecutive OFDM symbols. Sidelobe suppression with orthogonal projection is presented in [13]. Adaptive precoder [14] is a simple technique while it maintains the receiver SNR.

Another techniques for reducing PAPR problem [15] are investigated such as clipping, interleaving [16], compander , selective mapping (SLM), partial transmit sequence (PTS), tone reservation, adaptive mode with low complexity [17], signal set expansion, active constellation expansion, and precoding technique [18] and [19]. Clipping method causes distortion to the signal and BER degradation, while both SLM and PTS techniques need additional complexity. All the above studies consider either PAPR reduction alone or sidelobe suppression alone. Therefore some techniques are presented to reduce sidelobe with PAPR together such as SLM with MCS [20], advanced constellation expansion [21], and phase adjustment [22].

In this paper, a hybrid precoding technique for reducing sidelobe power and PAPR together in OFDM based on cognitive radio is proposed. This technique is a combination between two similar techniques, Zadoff-Chu technique which reduces the PAPR and precoding technique which reduces the sidelobe suppression. The two techniques are considered precoding techniques while a different precoding matrix are multiplied in each technique therefore, the proposed technique is considered a simple one. In the proposed technique, the performance of the sidelobe suppression can be adaptively adjusted according to the external radio environment to improve the precoding efficiency.

The rest of the paper is organized as follows: In Section II, the system model of NC-OFDM with the proposed technique is investigated. The details of the proposed hybrid precoding technique are presented in Section III. The performance and simulation results are discussed in Section IV. Finally, the conclusions are included in Section V, followed by references.

2. SYSTEM MODEL

In a CR system employing OFDM as the main modulation scheme, it is assumed that the system is familiar with the radio scenario and the channel state information (CSI). The dynamic spectrum sensing is the basic stages in cognitive radio networks, which detects the occupancy of the PU. This sensing deactivates the subcarriers that are occupied with PU and activates the other free subcarrier to be used easily with any SU. After the spectrum sensing step, it is a critical challenge to mitigate the interference between the PUs and secondary users (SUs).

In a general CR system based on OFDM, it divides the total subcarriers into a few subbands. Each subband contains a block of continuous subcarriers with different number. To keep complexity low, suppressing the sidelobe for each subband independently is presented. NC-OFDM model with proposed precoding technique is shown in Figure1. The serial input bits are mapped to complex data symbol vector $\mathrm{X} = [X_0, X_1, \ldots, X_{N-1}]^T$by M-ary phase shift keying (MPSK) where [.]T denotes subcarriers. Then two precoding stages are presented, the first stage is Zadoff-Chu transform (ZCT) which transform the original vector to a new vector with low PAPR and the second precoding stage is applied to produce another vector with reducing sidelobe power.

Therefore, the resulting vector with low PAPR and also low sidelobe power is produced. Then IFFT is applied to this vector then the serial data is produced from serial to parallel converter. Cyclic prefix (CP) is applied at the beginning of each symbol with guard interval exceeding delay spread of the multipath channel to reduce the effect of inter symbol interference (ISI). After that, the spectrum of the transmitted signal is tested instantaneously by monitoring the channel status. The precoder operates adaptively with the feedback from the test results and channel status. When the channel require to reduce the sidelobe power of the OFDM signal, the precoder will be recalculated to achieve more suppression and insure that there is no interference with PUs. Thus, the spectrum resource which is related to the complexity of algorithm can be fully utilized with the channel requirement achieved.

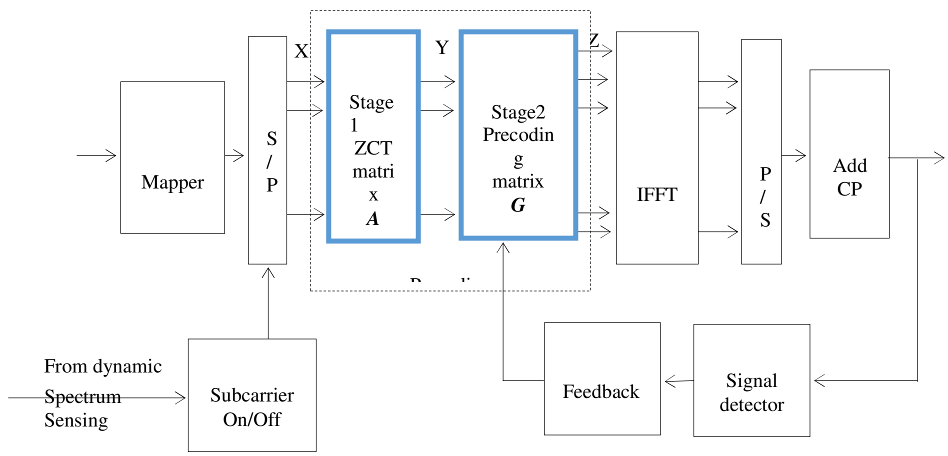


Figure 1. Block diagram of an NC-OFDM with proposed technique.

3. PROPOSED TECHNIQUE

3.1. Zadoff-Chu sequence for PAPR reduction:

Zadoff-Chu sequences are class of poly phase sequences which have optimum correlation properties. Zadoff-Chu sequences have an ideal periodic autocorrelation and constant magnitude. The Zadoff-Chu sequences of length L is defined according to [19] as:

$$a(k) = \begin{cases} e^{\frac{j2\pi r}{L}\left(\frac{k^2}{2} + qk\right)} \text{for } L \text{ even} \\ e^{\frac{j2\pi r}{L}\left(\frac{k(k+1)}{2} + qk\right)} \text{for } L \text{ odd} \end{cases} \quad (1)$$

where $k = 0, 1, \ldots\ldots, L-1$, q is any integer number, r is any integer relatively prime to L

In this system, the kernel of the ZCT acts as a column-wise ZCT matrix $\boldsymbol{A}$ of dimension $L = N \times N$ which is obtained by reshaping the ZC sequence with $k = r + nN$ as hereunder:

$$\boldsymbol{A} = \begin{bmatrix} a_{00} & a_{01} & \cdots & a_{0(N-1)} \\ a_{10} & a_{11} & \cdots & a_{1(N-1)} \\ \vdots & \vdots & a_{rn} & \vdots \\ a_{(N-1)0} & a_{(N-1)1} & \cdots & a_{(N-1)(N-1)} \end{bmatrix} \tag{2}$$

Here r is the row variable and n is the column variable. In other words, the $L = N^2$ points long ZC sequence fill the kernel of the matrix. This matrix is multiplied with the original vector X as this equation:

$$\mathrm{Y} = \boldsymbol{A}\mathrm{X} \tag{3}$$

where the vector $\mathrm{Y} = [y_0, y_1, \ldots, y_r, \ldots, y_{N-1}]^T$ is produced with the same length N and y_r it can be written as :

$$y_r = \sum_{n=0}^{N-1} a_{r,n} X_n, \quad r = 0, 1, \ldots\ldots, N-1 \tag{4}$$

where $a_{r,n}$ means rth row and nth column of the ZCT matrix. $a_{r,n}$are computed from eq. (1) by using column wise reshaping $k = r + nN$ and putting $r = 1$ and $q = 0$. Therefore, the resulting vector Y has less PAPR but it still has high sidelobe power.

3.2. Precoding technique for reducing sidelobe power:

This is the second stage which is used for reducing the sidelobe power and also converts the vector Y to another vector $\mathrm{Z} = [z_0, z_1, \ldots, z_m \ldots, z_{M-1}]^T$.

$$\mathrm{Z} = \boldsymbol{G}\mathrm{Y} \tag{5}$$

where $\boldsymbol{G}$ is $M \times N$ complex valued orthogonal precoding matrix with $M \geq N$, i.e. $\boldsymbol{G}^H\boldsymbol{G} = \boldsymbol{I}$. The subscript [.]H denotes conjugate transposition. $R = M - N$ is defined as precoding redundancy and also $\rho = N/M$ is precoding efficiency.

The resulting vector is modulated onto M subcarrier by IFFT, the OFDM symbol $S = [s_0, s_1, \ldots, s_p \ldots, s_{P-1}]^T$ after insertion CP with length v, where $P = M + v$ is generated. Where s_p is pth component of S is given by,

$$s_p = \frac{1}{N} \sum_{m=0}^{M-1} z_m \, e^{j2\pi m(p-v)/M} \tag{6}$$

The frequency domain representation of OFDM symbol $S'(f)$ is obtained by Fourier transform of S and is defined as:

$$S'(f) = \sum_{p=0}^{P-1} s_p \, e^{-j2\pi f p T_0} \tag{7}$$

Where T_0 is the duration of OFDM symbol. This equation is converted to the vector form to be easy used which is written as:

$$S'(f) = \frac{1}{N} E\, \boldsymbol{F}^H \boldsymbol{D}\, \boldsymbol{G}\, Y = \frac{1}{N} E\, \boldsymbol{F}^H \boldsymbol{D}\, \boldsymbol{G}\, \boldsymbol{A}\, X \qquad (8)$$

Where $E = (1, e^{-j2\pi f T_0}, e^{-j2\pi 2 f T_0}, \dots\dots\dots\dots, e^{-j2\pi(P-1) f T_0})$ is $1 \times P$vector, F is an $M \times P$ Fourier matrix with (m, p)th entry of $e^{j2\pi mp/M}$, and $\boldsymbol{D}$ is diagonal matrix which denotes CP matrix $\boldsymbol{D} = \text{diag}\,(1, e^{-j2\pi v/M}, \dots\dots\dots\dots, e^{-j2\pi(M-1)v/M})$. Assume the frequency region $B_C = [f_D, f_U]$ assigned to PU is detected which is a part from the CR spectrum. The main goal is to exploit the spectrum with high efficiency and less interference to PU. The key factor which determine the interference to PU is the matrix E and also the pth component of $e^{-j2\pi f p T_0}$ in the frequency region $f \in [f_D, f_U]$ is considered the key interference factor from the pth subcarrier to the PUs band. The interference spectral leakage of the vector S in B_C can be evaluated by two times sampling the frequency $f$in matrix E in B_C which is collected in $\varphi = \{f_0, f_1, \dots\dots\dots, f_{C-1}\} \in B_C$. The Fourier transform of each OFDM symbol at these frequencies are forced to be zero in order to reduce the interference to PU.

$$S'(f_c) = 0 \qquad\qquad c = 0, 1, \dots\dots, C-1. \qquad (9)$$

The OFDM spectrum can cancel each other with the help of the precoding matrix $\boldsymbol{G}$ by introducing the correlation to subcarrier if well designed. From Eq. 8, Eq. 9 can be written as:

$$\gamma\, \boldsymbol{G}\, \boldsymbol{A}\, X = 0, \qquad \gamma = E\, \boldsymbol{F}^H \boldsymbol{D} \qquad (10)$$

The average power spectrum of OFDM symbol will also exhibit zeros at these frequency samples and their vicinity. Therefore, the power spectrum of precoded OFDM symbol should be the same as that of uncoded symbol. Due to the orthogonality of the precoding matrix, it should satisfy:

$$\boldsymbol{G}^H\ \boldsymbol{G} = \boldsymbol{I}_N \qquad (11)$$

From this equation, each precoded OFDM symbol has the same amplitude as that before precoded. This means that the PAPR does not change before and after the precoding process and it still be in the lower range.

The main idea in this proposed technique is using singular value decomposition to solve the problem of the last two equations by decomposing γ into:

$$\gamma = \boldsymbol{U}\, \boldsymbol{\Sigma}\ \boldsymbol{V}^H \qquad (12)$$

where $\boldsymbol{U}, \boldsymbol{V}$ are two unitary matrices with size $C \times C$ and $M \times M$, respectively which means that $\boldsymbol{U}^H\ \boldsymbol{U} = \boldsymbol{I}_C$ and $\boldsymbol{V}^H \boldsymbol{V} = \boldsymbol{I}_M$. While $\boldsymbol{\Sigma}$ is $C \times M$ diagonal matrix with singular values filled in its diagonal in non-increasing order. Therefore the optimal precoding matrix can be considered as orthogonal basis of null space of γ

$$\boldsymbol{G} = \boldsymbol{V}_G \boldsymbol{Q} \qquad (13)$$

where $\boldsymbol{V}_G$ is $M \times N$ submatrix of $\boldsymbol{V}$ while $\boldsymbol{V}_1$ is consist of the last N columns in $\boldsymbol{V}$, and $\boldsymbol{Q}$ is an arbitrary $N \times N$ unitary matrix. While the $\boldsymbol{V}_G$ is orthogonal to satisfy the constrain in Eq. (11). The sidelobe power leakage after precoding is defined as:

$$W_G = \delta \sum_{i=R}^{M-1} \boldsymbol{\Sigma}_{i,i} \qquad (14)$$

where δ is constant coefficient, the sidelobe power leakage is related to singular value of $\boldsymbol{A}$ while more interference can be suppressed with discarding more singular values of matrix $\boldsymbol{A}$ by precoding matrix $\boldsymbol{G}$. The sidelobe power decreases with increasing the precoding redundancy R. The first R biggest singular values can be discarded adaptively due to the feedback from channel statues.

The PAPR is the ratio between maximum instantaneous power to the average power, and is defined as

$$\mathrm{PAPR} = \frac{\max|s_p|^2}{E\left[|s_p|^2\right]} \tag{15}$$

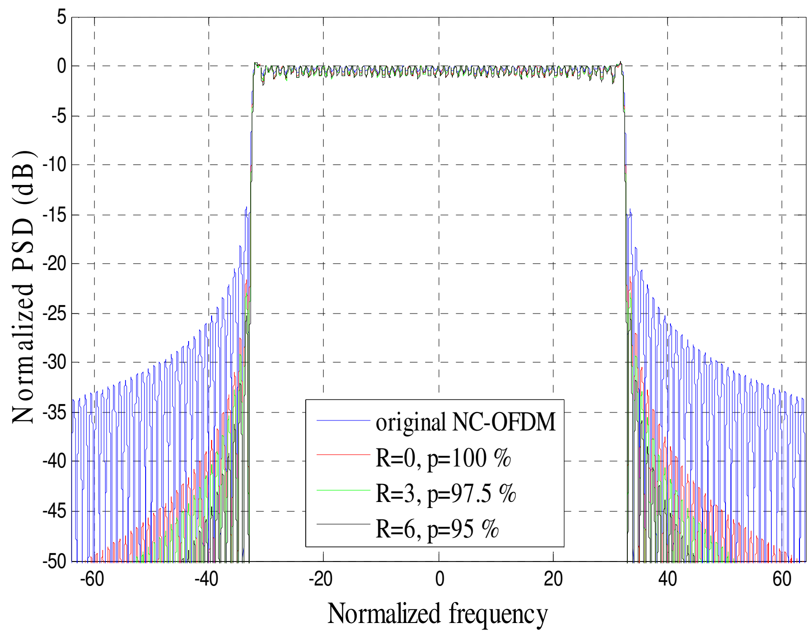
4. SIMULATION RESULTS

NC-OFDM signal with random distributions of 64 subcarriers are used in this simulation. Table (1) shows the simulation parameters for the system under consideration. The aim is to compare the simulation results of the proposed hybrid technique with the original NC-OFDM technique.

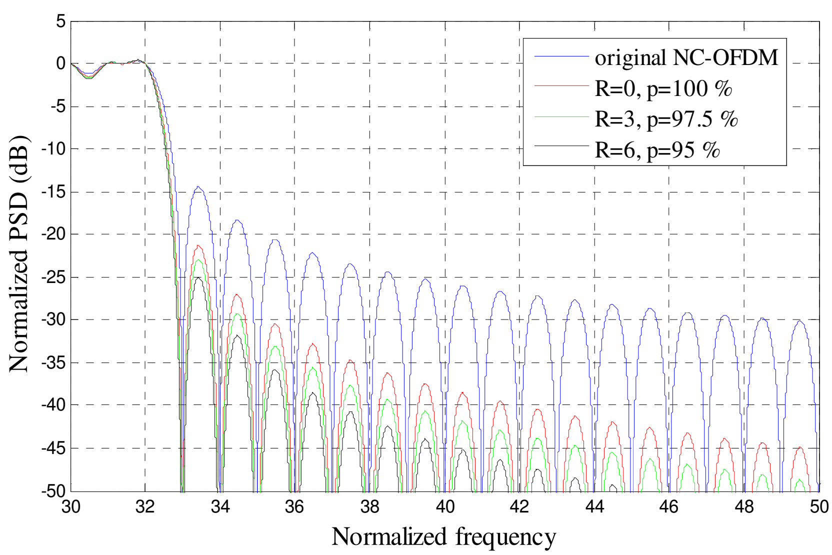
Table 1. Implementation parameters of the proposed technique.

Parameter	**Value**
Number of subcarriers	64
Pilot subcarriers	4
Modulation scheme	QPSK
Number of iteration	1000
f_c (GHz)	5.003
Sampling time	2 µsec
T_g/T_0	1/8
redundancy R	0

The comparison between the performance of the original NC-OFDM and the proposed technique with different number of redundancy R is shown in Figure 2. It is shown that more significant suppression is obtained than the conventional NC-OFDM system. It is also found that the sidelobe power decreases dramatically with increasing R. This is because more singular values of the matrix A are discarded by the precoding matrix G. While increasing the value of redundancy R leads to decreasing the precoding efficiency, but the precoding efficiency can be really high if the M is much larger than R. Therefore, the value of R should be decided adaptively due to the system's requirement and wireless condition. The power of the sidelobes that lays outside the transmission bandwidth averaged over 64 sidelobe can be suppressed by about 19.3, 21.9, and 24.5 dB for R=0, 3, and 6, respectively from original NC-OFDM as shown in Figure 2 (b).



(a)



(b)

Figure 2. Comparison between the original NC-OFDM and the proposed technique (a) the total figure (b) its zoom.

The performance of the proposed technique is presented in terms of the Complementary Cumulative Distribution Function (CCDF). The CCDF is defined as the probability of exceeding the PAPR of an NC-OFDM signal over a given threshold PAPRth is expressed as,

$$\mathrm{CCDF}(\mathrm{PAPR}(S)) = \Pr(\mathrm{PAPR}(S) > \mathrm{PAPR}_{th}). \tag{10}$$

The simulations of PAPR that are given in terms of CCDF is shown Figure 3 which shows the variation of CCDF with PAPR for 64 subcarrier. This Figure shows the performance of the original NC-OFDM technique and the proposed technique. The PAPR reduction for the proposed technique at CCDF = 10-3 is about 5.1 dB from the original NC-OFDM.

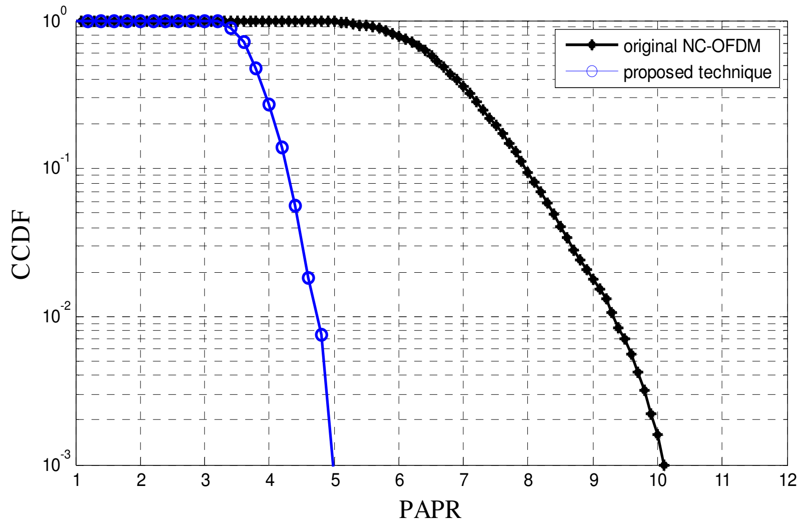


Figure 3. CCDF PAPR for the original NC-OFDM and the proposed technique.

The performance of the signal to noise ratio (SNR) with BER under Additive White Gaussian Noise (AWGN) channel for the original NC-OFDM and the proposed technique is shown in Figure 4. It shows that the BER performance of the proposed precoding technique with (R = 0) is similar to the conventional OFDM system. However, increasing the value of R, improves the BER performance of proposed system. That is because the proposed technique can spread the power of individual original data onto all the active tones.

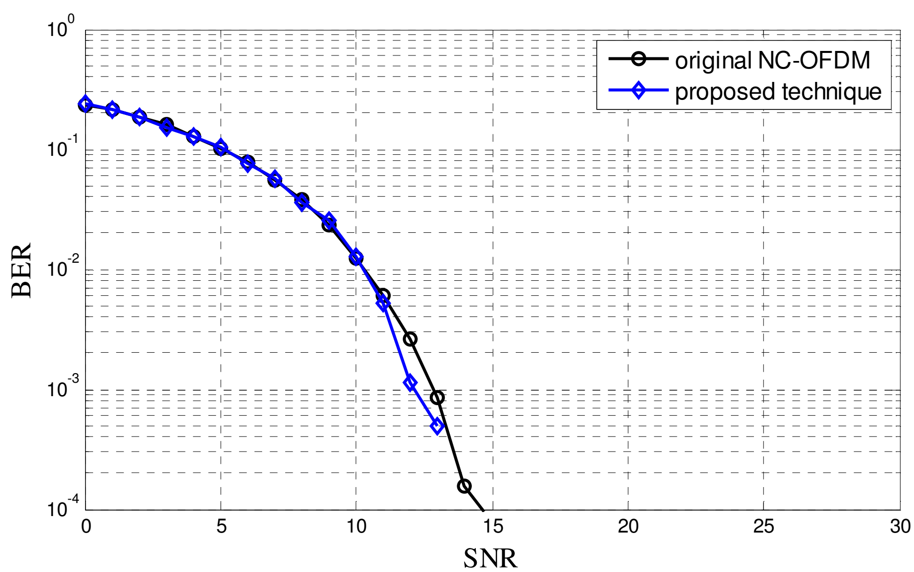


Figure 4. SNR Vs. BER for the original NC-OFDM and the proposed technique.

4.CONCLUSIONS

In this paper, an efficient technique was proposed to reduce both the PAPR and the sidelobe power for cognitive radio. This technique combines two precoding techniques which reduced the PAPR by 5.1 dB at CCDF = 10-3 for 64 subcarriers compared with original NC-OFDM. At different redundancy, the precoding matrix can provide different sidelobe suppression performance. Therefore, it can meet the requirements of different wireless condition. Simulation results show that the precoding matrix can significantly reduce the sidelobe power with a little precoding efficiency and does not increase the PAPR of the signal. The proposed technique does not affect the BER performance over AWGN.

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