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Signal Cancellation Method for Simultaneous Reduction of PAPR and Sidelobe Power in NC-OFDM based CR system

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Abstract-Non-Contiguous Orthogonal Frequency Division Multiplexing (NC-OFDM) based Cognitive Radio (CR) system has two main drawbacks. They are high Peak-to-Average Power Ratio (PAPR) and large spectrum sidelobe power. Due to high PAPR, amplifiers will enter into the saturation region and leads to non-linear distortion, and large spectrum sidelobe power causes interference to the adjacent sub-carriers. To overcome these drawbacks Signal Cancellation (SC) method is introduced, which will dynamically extend part of constellation points on Secondary User (SU) sub-carriers. This in-turn reduces the PAPR values and add several signal cancellation symbols on Primary User (PU) sub-carriers that reduces the sidelobe power. This ultimately reaches our aim of joint PAPR reduction and sidelobe suppression. To reduce the computational complexity of Signal Cancellation (SC) method another joint reduction technique is introduced i.e., sub-optimal SC method. Both of these methods can provide significant performance of PAPR reduction and sidelobe suppression simultaneously.

Index Terms-NC-OFDM; Cognitive Radio (CR); sidelobe suppression; Peak-to-Average Power Ratio (PAPR).

1. INTRODUCTION

Bandwidth requirement for wireless communication increases exponentially as the number of wireless network services increases. The basic necessity of all wireless service is spectrum availability. Cognitive Radio (CR) has drawn significant attention from academic and industrial communities to meet the ever growing needs for spectrum resources and high data rate communication [1]. In CR systems, Cognitive (Secondary) and licensed (Primary) users are allowed to identify and exploit local and instantaneous spectrum white space where licensed users are not present for data transmission.

The co-existence of the NC-OFDM based CR system with both secondary users (SUs) and primary users (PUs) is shown in Fig.1. Whenever SUs transmit data through unused sub-carriers an interference will be created to the PUs in the conventional NC-OFDM based system [2]. To avoid this interference, spectrum notches are created in the PU region.

Along with many advantages, there exists two major drawbacks for NC-OFDM based CR system. They are high Peak-to-Average-Power-Ratio (PAPR) and large spectrum side lobe power values. Due to high PAPR the High Power Amplifiers (HPA) used in the transmitter will enter in to saturation region and the signal will clips off and non-linear distortion occurs and subsequently degrades the BER performance of the system and also create out-of band power interfering the adjacent sub-carriers [3]. Another major drawback is the large spectrum sidelobe power that introduces interference to the adjacent PUs, resulting performance degradation of

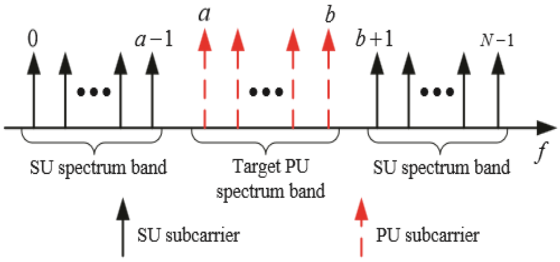


Fig.1: NC-OFDM based CR System coexisting with PUs and SUs.

Pus [4]. Hence there is need to suppress the sidelobe power of the secondary users.

In this context, the existing techniques to reduce PAPR included in the literature are Clipping, Partial Transmit Sequence [5], Active Constellation Extension (ACE), Tone Reservation [6]. All these techniques concentrates only on how to reduce PAPR but do not take care of the large spectrum sidelobes. Apart from this, there is an increase in out-of-band power if any one among the above mentioned techniques are implemented.

Many schemes have been proposed in the literature in order to suppress the large spectrum sidelobe power, such as Active Interference Cancellation (AIC) which utilizes some sub-carriers as the guard bands to suppress the sidelobes results the reduction of spectrum efficiency. Another technique is Extended Active Interference Cancellation (EAIC) [2] utilizes tones spaced closer than the interval of sub-carriers to generate the cancellation signals for the sidelobe suppression that leads to the destruction in orthogonality introducing interference. Hence this method leads to the degradation of BER Performance of the system. Constellation Adjustment (CA) [7] is another method in which some sub-carriers are multiplied with some weights to generate alternate signal among which with minimum sidelobe power is transmitted. For the purpose of retrieving the original data, the receiver must know the weights with which the data is multiplied. So, we must send the selected weights to the receiver by using some subcarriers which results in decreasing the data rates. Pulse Shaping (PS) and Spectral Precoding (SP) [8] are the two similar techniques which will efficiently suppress the sidelobes of the system by shaping the waveform of the signal. But the drawback of these techniques is their computational complexity. Here comes the next one i.e., Sidelobe Suppression with Orthogonal Projection (SSOP) [9] utilizes an orthogonal projection matrix for sidelobe suppression, and uses some reserved sub-carrier to transmit the projection matrix to the receiver side for recovering the distorted signal in the receiver. Thus, the SSOP method suffers from the decrease of data rate. Adaptive Symbol Transmission (AST) is another technique that adds AST blocks between OFDM symbols, which leads to a considerable degradation of the system throughput. All these sidelobe suppression techniques will deal only with suppressing the sidelobe power and will not concentrate on the reduction of high PAPR of the NC-OFDM based CR system.

All these techniques individually concentrate on either sidelobe suppression or PAPR reduction. To reduce both the drawbacks i.e.,PAPR and sidelobe suppression of the NC-OFDM system simultaneously there exists a technique like Selected Mapping (SLM) [10]. In SLM, several alternative signals are generated and selects one signal among them with low PAPR and sidelobe power as its transmitter signal. Several sub-carriers are reserved to send information about alternative signals which reduces the data rates. However SLM technique cannot achieve the better PAPR and sidelobe suppression. So, the SC method is introduced for better performance of joint reduction of PAPR and sidelobe power. In SC method, part of the outer constellation points on SU sub-carriers are dynamically extended while several signal cancellation symbols are added on the PU sub-carriers to generate the appropriate cancellation signal for joint PAPR reduction and sidelobe suppression. The problem can be formulated as a quadratically constrained quadratic program (QCQP) [11], and the optimal cancellation signal can be obtained by convex optimization. To solve the QCQP problem with low complexity, we go for Sub-Optimal SC method.

The rest of this paper is organized as follows. We briefly describe the NC-OFDM based CR system, and introduce PAPR and spectrum sidelobe in Section II. In Section III, we propose a technique that jointly reduces the PAPR and suppress the sidelobe power in detail. Simulation results are shown in Section IV, followed by conclusions in Section V.

2. SYSTEM MODEL

In this section we will discuss about NC-OFDM based CR system by converting input data bits to OFDM symbol by following steps as shown in

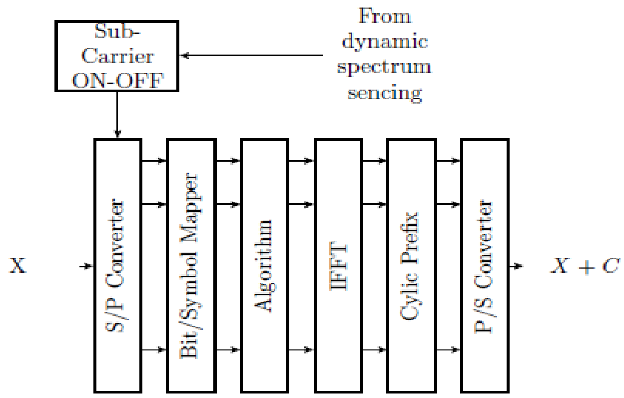


Fig:2 Block Diagram of NC-OFDM Transmitter

Fig.2. Consider the input data bits for OFDM system as: $\mathbf{X}$={X_0, X_1, X_2, ….}.

Here we consider NC-OFDM system with N Sub-Carriers, among which L=b-a+1 i.e., from a^{th} to b^{th} sub-carriers are accommodated with PUs and remaining N-L i.e., from 0^{th} to $(a-1)^{th}$ and $(b+1)^{th}$ to $(N-1)^{th}$ sub-carriers are detected and utilized by SUs for data transmission. Consider two sub sets, R={0,1,....a-1,b+1,...N-1} and R_c={a,....,b} consists of indexes of secondary and Primary users subcarriers respectively. Here we concentrate on how the PAPR and sidelobe power can be calculate for our system. Fig.1 depicts the coexistence of the NC-OFDM based CR system with both SUs and PUs at their allocated positions.

2.1. Peak-to-Average Power Ratio

Consider the symbol vector of an NC-OFDM system as $\mathbf{X} = [\mathrm{X}(0), \mathrm{X}(1), \ldots\ldots \mathrm{X}(\mathrm{N}-1)]^T$of size N, in which X(k)=0 for k ∈ R, as these sub-carriers are occupied by the PUs. The time-domain OFDM signal can be obtained by applying N-Point Inverse Discrete Fourier Transform (IDFT) to $\mathbf{X}$, can be defined as

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j2\pi kn\Delta f/f_s}$$

$$= \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j2\pi kn/N}, n = 0,1, \ldots N-1 \quad (1)$$

where Δf is frequency gap between adjacent sub-carriers in the spectrum and f_s represents total bandwidth given by NΔf. Then NC-OFDM signal samples are obtained by J-times oversampling the original signal for the purpose approximation of the PAPR of continuous time NC-OFDM signals. we can rewrite (1) a

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j2\pi kn\Delta f/Jf_s}$$

$$= \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j2\pi kn/JN}, n = 0,1, \ldots JN-1 \quad (2)$$

Matrix form representation of (2) is

$$\mathbf{x = FX} \qquad \mathbf{(3)}$$

where F is the IDFT Matrix of size JNxN with $(i,k)^{th}$ element as

$$F(i,k) = \frac{1}{\sqrt{N}} e^{j2\pi ik/JN}$$

In an NC-OFDM system PAPR can be defined as the ratio of maximum or peak instantaneous power to the average power of that signal and can be given as

$$PAPR = \frac{\max_{0 \le n \le JN-1} |x(n)|^2}{E[|x(n)|^2]} = \frac{||X||_\infty^2}{\frac{1}{JN}||X||_2^2} \quad (4)$$

where E[.] represents expectation or mean of the symbol, $||.||_2$ and $||.||_\infty$ represents l_2 norm and Infinity norm respectively.

As in NC-OFDM systems very large PAPR values lead to non-linear distortions and a power efficiency degradation of high power amplifiers, there is need to overcome this problem. In order to measure the PAPR values of a system, the Complementary Cumulative Distribution Function (CCDF) is used which is the probability of PAPR that exceeds the given threshold value(P_0) and can be given as

$$CCDF = Pr\{PAPR > P_0\} \quad (5)$$

2.2. Spectrum Sidelobe

In an NC-OFDM system to measure the spectrum sidelobe power of a SU that extends in the PU band, we need to calculate the spectrum at M sample points of frequencies $\{f_0, f_1, \ldots f_{M-1}\}$. The sampled sidelobe power at the frequency f_m can be defined as

$$S(m) = \frac{1}{N} \sum_{n=0}^{N-1} \sum_{k=0}^{N-1} x(n) e^{-j2\pi n f_m/f_s}, m = 0,1, \ldots M-1 \quad (6)$$

Replacing Time-domain signal x(n) with X(k) i.e., (1) into (6), we get

$$S(m) = \frac{1}{N} \sum_{n=0}^{N-1} \sum_{k=0}^{N-1} X(k) e^{j2\pi n(k\Delta f - f_m)}, m = 0,1, \ldots M-1 \quad (7)$$

The Matrix form of (7) can be given as

$$\mathbf{S=PX} \qquad \mathbf{(8)}$$

where the sampled sidelobe matrix **S** is denoted as $S = [S(0), S(1), \ldots s(M-1)]^T$ of size M-1. P is a matrix with the $((m,k)^{th}$ element as $\frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi kn/N} e^{-j2\pi n f_m/f_s}$.

The sum of the sampled energy at frequency points $\{f_0, f_1, \ldots, f_{M-1}\}$ gives the measure of the total sidelobe power S_t in the target spectrum band that can be expressed as

$$S_t = \sum_{m=0}^{M-1} |S(m)|^2 = ||S||_2^2 \quad (9)$$

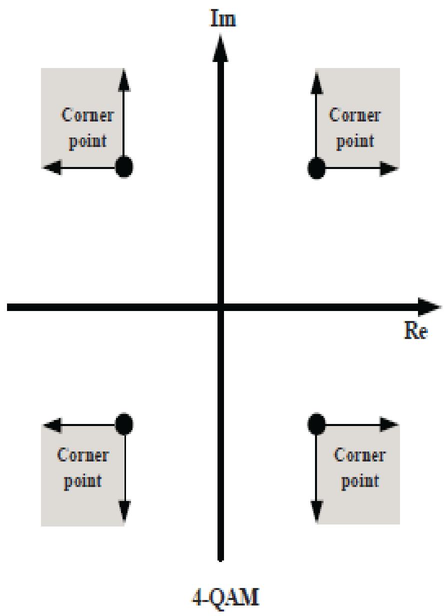


Fig:3 Constellation extended region on SU sub-carriers with 4QAM

For the conventional NC-OFDM based CR system, the PU sub-carriers can be turned off at the occupied SU band, that creates spectrum notches to limit the interference to the PUs. Even though there exist a non-negligible interference to the PUs with turn-off technique also [2]. Thus, some techniques have been proposed to jointly suppress the sidelobe power and PAPR of the NC-OFDM based CR system, such as SC Method and sub-optimal SC Methods.

3. PROPOSED MODEL

3.1. Signal Cancellation (SC) Method

In this section, we discuss about a Signal Cancellation (SC) method for simultaneous reduction of PAPR and sidelobe power in the NC-OFDM system. Here sub-carriers of both PU's and SU's are utilized to generate the cancellation signals to solve the considered problem. Moreover, in this method part of the outer constellation points are dynamically extends on SU sub-carriers, while several signal cancellation symbols are added on PU sub-carriers. It is notable that SUs cannot utilize PU sub-carriers for data transmission. As it adds some signal cancellation symbols on sub-carriers it provides better sidelobe power suppression and reduction of PAPR simultaneously when compared to that of all the previous techniques.

The constellation adjustment symbols $\mathbf{C_s} = [\mathrm{C_s}(0), \mathrm{C_s}(1), \ldots.., \mathrm{C_s}(\mathrm{N}-1)]$ are added to the SU sub-carriers of original data **X** which has to obey the principle rules for modified constellation points as shown in Fig.3, Cs(k) ∈ M for k ∈ R and Cs = 0 for k∈ R^c. At the same time signal cancellation symbols $\mathbf{C_p} = [\mathrm{C_p}(0), \mathrm{C_p}(1), \ldots., \mathrm{C_p}(\mathrm{N}-1)]$ are added on PU sub-carriers, where Cp = 0 for k ∈ R. The overall signal cancellation symbol in SC method is given by

$$\mathbf{C} = \mathbf{C_s} + \mathbf{C_p} \qquad (\mathbf{10})$$

$$\mathrm{C(k)} = \begin{cases} \mathrm{C_s(k)}, & \mathrm{k} \in \mathrm{R} \\ \mathrm{C_p(k)}, & \mathrm{k} \in \mathrm{R^c} \end{cases} \qquad (11)$$

The original data **X** can be modified by adding **C** and get data $\overline{\mathbf{X}}$ with less PAPR and sidelobe power values and given by

$$\overline{\mathrm{X}} = \mathrm{X} + \mathrm{C_s} + \mathrm{C_p} = \mathrm{X} + \mathrm{C} \qquad (12)$$

The time-domain signal of $\bar{X}$can be given by,

$$\bar{\mathrm{x}} = \mathrm{FX} + \mathrm{FC_s} + \mathrm{FC_P} = \mathrm{FX} + \mathrm{FC} \qquad (13)$$

The convex optimization problem for SC method can be formulated as below

$$\min_{C} \ \|FX + FC\|_\infty \qquad (14a)$$

$$\text{subject to: } \|\mathrm{PX} + \mathrm{PC}\|_2 \ \le \ \beta\|\mathrm{PX}\|_2 \qquad (14b)$$

$$\|X + C\|_2^2 \ \le \ \epsilon_0 \qquad (14c)$$

$$\mathrm{C(k)} \in \mathrm{M}, \text{ for } \mathrm{k} \in \mathrm{R} \qquad (14d)$$

where the parameter β is to control the maximum sidelobe power constraint of the system and ϵ_0 is maximum power. Each of the above equations has their individual objectives. Equation (14a) function represents PAPR minimization with the proposed SC method. Equation (14b) defines that the sidelobe power of SC method system must be less than or equal to the conventional system, β decides the suppression level of the system. Equation (14c) is power limiting constraint of the system. Equation (14d) represents the constellation extension constraint for subcarriers. For 4-QAM (14d) can be given by

$$\mathrm{Real(X(k))}*\mathrm{Real(X(k))} \ \ge 0; \ \mathrm{k} \in \mathrm{R}$$
$$\mathrm{Imag(X(k))}*\mathrm{Imag(C(k))} \ge \ 0; \ \mathrm{k} \in \ \mathrm{R} \qquad (15)$$

where Real() and Imag() are the real and imaginary part of a complex number respectively. The above defined convex optimization problem can be reformulated as a second order cone program (SOCP) for better performance as below

$$\min_{\mathrm{C}} \ \mathrm{q} \qquad (16a)$$

$$\text{subject to: } \bar{\mathrm{x}} = \mathrm{FX} + \mathrm{FC} \qquad (16b)$$

$$\|\bar{\mathrm{x}}(\mathrm{n})\|_2 \le \mathrm{q}, \ \mathrm{n} = 0{,}1 \ldots., \mathrm{JN}-1 \qquad (16c)$$

$$\|\mathrm{PX} + \mathrm{PC}\|_2 \ \le \ \beta\|\mathrm{PX}\|_2 \qquad (16d)$$

$$\|X + C\|_2^2 \ \le \ \epsilon_0 \qquad (16e)$$

$$\mathrm{C(k)} \in \mathrm{M}, \text{ for } \mathrm{k} \in \mathrm{R} \qquad (16f)$$

$$q \ge 0 \qquad (16g)$$

The above SOCP problem can be solved by standard interior point method with complexity of O(N^3) during each iteration and one IDFT operation is used for each iteration in our method, which has complexity of JN log JN. The overall complexity of SC method is O(N^3+JN log JN).

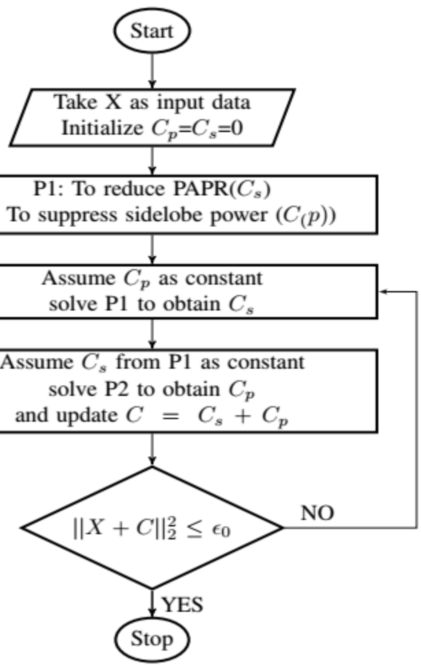


Fig:4 Flow chart for sub-optimal SC method

3.2. Sub-optimal SC Method

In previous section, we discussed about SC method which can effectively solve the PAPR and sidelobe power problems in NC-OFDM system. But its computational complexity is very high. So, another method is introduced to reduce the computational complexity of the system i.e., is sub-optima SC method.

In the SC method the symbols Cs and Cp are for joint reduction of PAPR and sidelobe power of the system. But here in the sub-optimal SC method, constellation adjustment symbol $\mathbf{C_s}$ on SU sub-carriers is to generate peak cancellations signals which will reduces only PAPR and not sidelobe power. In the same way the signal cancellation symbol **Cp** on PU sub-carriers is used only for sidelobe suppression and not take care about PAPR reduction.

Hence, the joint reduction of PAPR and sidelobe power can be reformulated in two problems. The first one is to reduce the PAPR by extending the constellation points on SU sub-carriers by following the principle rules as shown in Fig.3. And the second one is to suppress the sidelobe power by adding signal cancellation symbols on PU subcarriers. By solving these two problems individually by ignoring the other one will show impact on the performance of the second parameter i.e., if PAPR is reduced by solving first problem the sidelobe power will be affected. So, in single step we can't achieve the joint reduction. Hence, the sub-optimal SC method is designed as an iterative algorithm in which it solves two problems in each iteration. The power constraint (16e) is considered to terminate the iterative process.

3.2.1. PAPR Reduction

In sub-optimal SC method, in each iteration PAPR problem is solved first and then the sidelobe power, and the first problem is solved by obtaining Cs. For that purpose, firstly initialize Cp = 0 Cs = 0 and start the first iteration. In first problem Cp is make as constant parameter. The Cs on SU sub-carriers are employed to generate the peak cancellation symbols for the purpose of PAPR reduction and it can be formulated as convex optimization as below

$$\mathbf{P1}: \quad \min_{C_s} \|FX + FC_s + FC_P\|_\infty \qquad (17a)$$

$$C(k) \in M, \quad \text{for } k \in R \qquad (17b)$$

To solve P1 by Projection on to Convex Sets (POCS) method by following the below sequence of steps

1) Take JN-Point IDFT to the data block **X+Cp** to get discrete time-domain signal
   $\tilde{x} = [\tilde{x}(0), \tilde{x}(1), \ldots \ldots, \tilde{x}(JN-1)]$
2) Clip any signal whose amplitudes are larger than A_t where A_t is clipping threshold level. The clipped time-domain signal $\tilde{x}$ is

$$\bar{x} = \begin{cases} \tilde{x}(n), & |\tilde{x}| < A_t \\ A_t e^{j\theta(n)}, & |\tilde{x}| \geq A_t \end{cases} \qquad (18)$$

3) Calculate the clipping noise d = [d(0),d(1),….,d(JN-1)] using

$$d(n) = \bar{x}(n) - \tilde{x}(n) \qquad (19)$$

4) To get Frequency domain clipping noise apply JN-point DFT to d(n). D = [D(0),D(1),…..,D(N-1)]
5) Cs(n) can be obtained by

$$Cs(n) = \begin{cases} D(n), & n \in R, Cs(n) \in M \\ 0, & \text{else where} \end{cases} \qquad (20)$$

This obtained Cs(n) can be used for the purpose of reducing PAPR of the NC-OFDM based CR system.

3.2.2. Sidelobe Power Suppression

In each iteration, after solving _rst problem (PAPR reduction) by obtaining **Cs**, then we go for the second problem to obtain **Cp** by making the parameter **Cs** from solution of **P1** as constant. Sidelobe power suppression problem can be formulated as

$$\mathbf{P2}: \quad \min_{C_p} \|PX + PC_s + PC_p\|_2 \qquad (21a)$$

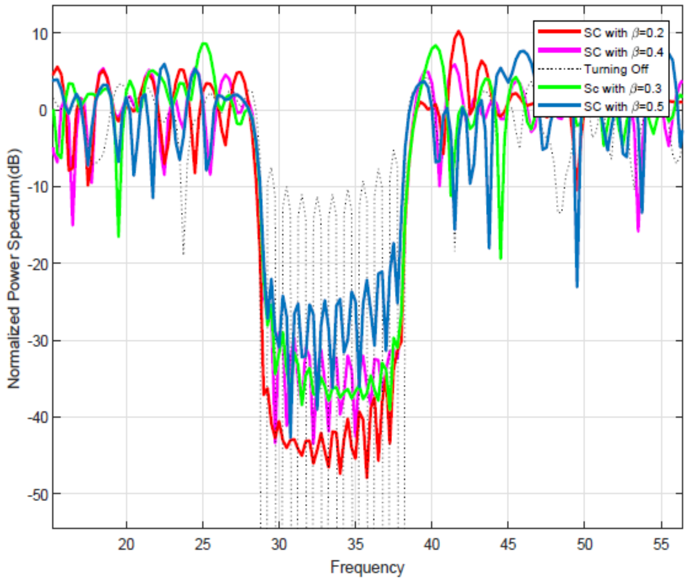
$$C_s(k) \in M, \text{for } k \in R \qquad (21b)$$

By squeezing out the zeros from Cp of size N x 1 by leaving weights on R_c sub-carrier positions, we get a Lx1 vector $\tilde{C}_p$. To get$\tilde{C}_p$ from Cp a T_w matrix is designed in such a way that

$$C_p = T_w \tilde{C}_p \qquad (22)$$

The solution of P2 can be expressed as

$$\tilde{C}_p = -(U^H U)^{-1} U^H P(X + C_s) \qquad (23)$$



Fg.5. Normalized Power spectrum of SC method

where U=PT_w and U^H is complex conjugate matrix of U.
By substituting (22) in (23) we get

$$C_p = -T_w (U^H U)^{-1} U^H P(X + C_s) = V(X + C_s) \qquad (24)$$

where $V=-T_w(U^H U)^{-1}U^H P$
Finally C_p is obtained and modified OFDM signal is

$$X=X+C_s+C_p \quad (25)$$

Since the sub-optimal SC method also increases the power of the system it should also follow the power constraint in (16e). Terminate the iteration when ever the system doesn't the power constraint. So, this method can jointly reduces PAPR and also suppress the sidelobe power by following the restrictions in power. The ow graph in Fig.4 show the sequential order of steps that are followed in sub-optimal SC method.

When comes to the computational complexity of the sub-optimal SC method it depends on solving P1 and P2 in each iteration. In P1 for one iteration one DFT and one IDFT operations are needed. so, computational complexity of solving P1 is given by O(2 JN log JN). To solve P2 there is matrix multiplication operation in each iteration matrix of size NxN. Thus, the computational complexity to solve P2 can be given by $O(N^2)$. The total computational complexity of sub-optimal SC method is $O(N^2 + 2\text{ JN log JN})$. It is less when compared with that of SC method as mentioned earlier.

4. SIMULATION RESULTS

In this section, simulations are performed to evaluate the capability of the proposed method that includes the PAPR reduction, the sidelobe suppression and BER Performance for the considered NC-OFDM

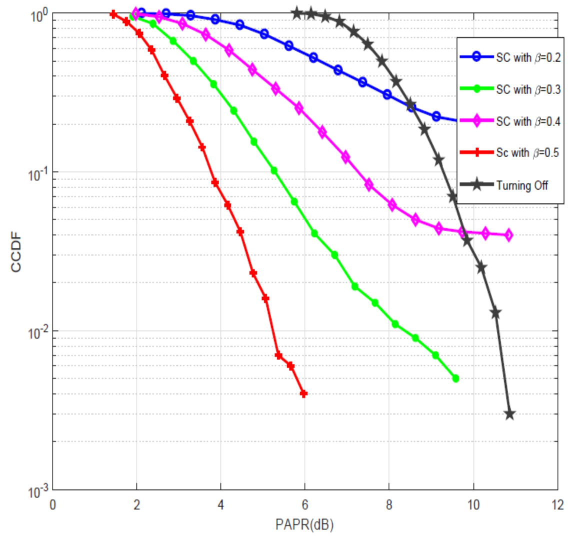


Fig.6. PAPR of SC method with different β values

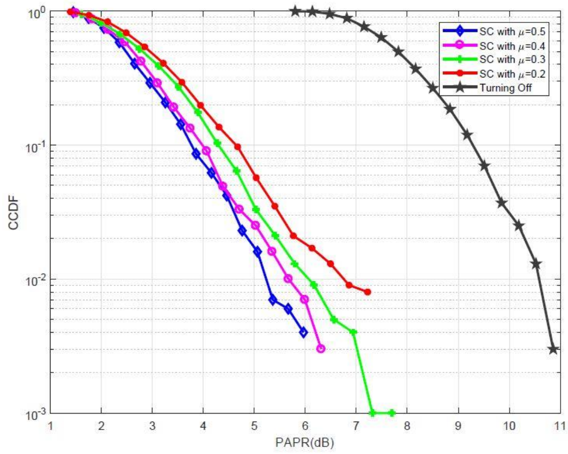


Fig.7. PAPR of SC method with different μ values

based CR system with N=64 with each sub-carrier interval $\Delta f = 22.5$KHz. The target Spectrum band occupied by the PUs is from 29Δf to 38Δf, in which 37 sampling points for the evaluation space of $\frac{\Delta f}{4}$. Thus a=29, b=38 and M=37 and remaining spectrum band is utilized by the SUs. In addition, 10^4 symbols are modulated by 4-QAM with the oversampling factor J=2. In the implementation of SC and sub-optimal SC methods the power constraint parameter is set to$\epsilon_0 = (1+\mu)\|\mathbf{X}\|_2^2$, where ϵ_0 is a parameter which adjusts the power threshold ϵ_0. For comparison we simulate for conventional method which turns off the sub-carriers in the target band i.e., in PU sub-carrier region. The convex optimization problem formulated in SC method can be solved using a public software CVX [12].

The normalized power spectrum of the NC-OFDM system with implementation of SC method is depicted in Fig.5. The power spectrum is simulated by

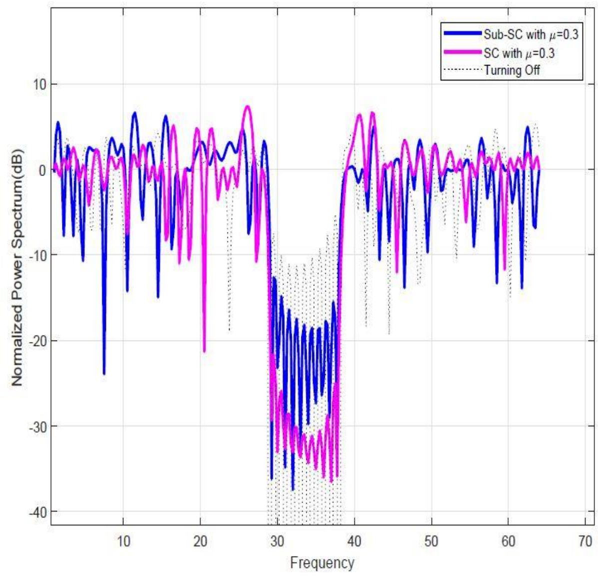


Fig.8. Normalized power spectrum of sub-optimal SC method

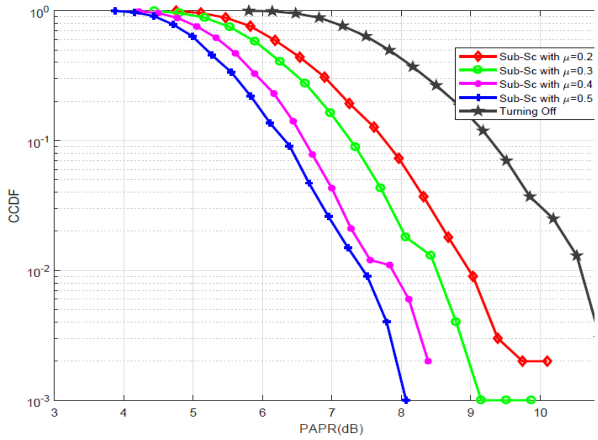


Fig.9. PAPR of sub-optimal SC method with different μ values

varying the parameter β which decides the reduction of sidelobe power in PU region, making the power constraint parameter μ as constant to 0.5. The suppression of sidelobe power increase with decrease in β value. For β=0.5, 0.4, 0.3, 0.2 the sidelobe power suppression levels are -25dB, -32dB, -38dB and -42dB respectively. The suppression levels are very much better when compared with that of the conventional method whose sidelobe power level is of -12dB.

The PAPR of SC method by varying the β values and considering the power controlling parameter μ= 0.5 is shown in Fig.6. Generally for an NC-OFDM system there exist trade off between PAPR reduction and sidelobe power suppression, i.e., reduction in sidelobe power reflects increase in the PAPR values and vice-versa. As mentioned earlier, as β value decrease suppression level increases i.e., better suppression is achieved which degrades the PAPR reduction of the system. The PAPR values for =0.5, 0.4, 0.3 at CCDF=10^{-1} are 3.9dB, 5.2dB, 7.1dB respectively. For the convention method the PAPR is 9.4dB. There is reduction in both the parameters for different βvalues when compared with the conventional method.

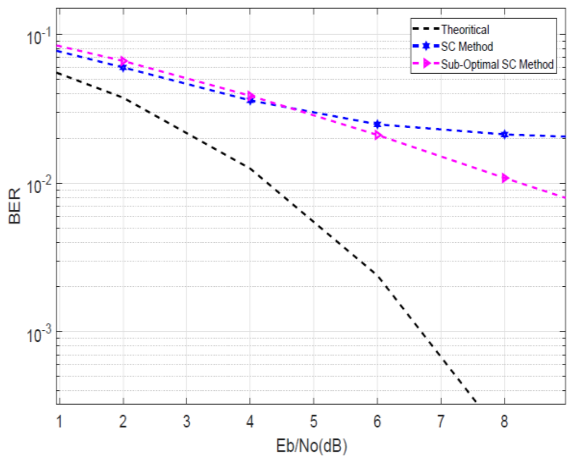


Fig.10. BER performance of SC and sub-optimal SC methods

The PAPR of SC method with different μ values and β= 0.5 is illustrated in Fig.7. As μ is the parameter which directly effects the power of the system the PAPR reduction levels are very much improved by varying it. The PAPR values for μ=0.5, 0.4, 0.3, 0.2 at CCDF=10^{-2} are 5.1dB, 5.6dB, 6dB and 6.8dB respectively. It is clear from the simulations that, as μ value increases the performance of PAPR is also improved.

The normalized power spectrum of the sub-optimal SC method is depicted in Fig.8. The termination of the iterative process of sub-optimal SC method is done by setting μ = 0.5 and number of iterations is set to K=6. As this technique is designed to overcome the computational complexity in SC method, the performance does'nt reach the SC method's performance. The suppression level reaches to -29dB. For all μ values suppression is same as the variation in μ does'nt vary the sidelobe power.

The PAPR of sub-optimal SC method for different μ values is shown in Fig.9. As we discussed earlier, the parameter μ directly show impact on power of the system. So, if _ increases the PAPR performance of the sub-optimal SC method also increases. The PAPR at CCDF=$10^{-2}$for _=0.5, 0.4, 0.3, 0.2 are 7.3dB, 7.9dB, 8.5dB and 9dB respectively. All the numerical results are listed in Table.1 and Table.2.

The BER performance of both SC and sub-optimal SC method is illustrated in Fig.10. As both techniques concentrate only on reduction of PAPR and sidelobe power simultaneously, their performance regarding these two parameters is appreciable. Due to addition of signal cancellation symbol (C) to the original data that leads to the degradation in the BER performance, which is not acceptable for effective

Table 1: Normalized Power Spectrum Results

Name of the Algorithm	Parameter	Suppression levels(dB)
SC Method	$\beta = 0.5$	-25dB
	$\beta = 0.4$	-32dB
	$\beta = 0.3$	-38dB
	$\beta = 0.2$	-42dB
Sub-optimal SC Method	-	-29dB

Table 2: PAPR vs CCDF Results

Name of the Algorithm	Parameter	Suppression levels(dB
SC Method at CCDF=10^{-1}	$\beta = 0.5$	3.9dB
	$\beta = 0.4$	5.2dB
	$\beta = 0.3$	7.1dB
SC Method at CCDF=10^{-2}	$\mu = 0.5$	5.1dB
	$\mu = 0.4$	5.6dB
	$\mu = 0.3$	6dB
	$\mu = 0.2$	6.8dB
Sub-optimal SC Method at CCDF=10^{-2}	$\mu = 0.5$	7.3dB
	$\mu = 0.4$	7.9dB
	$\mu = 0.3$	8.5dB
	$\mu = 0.2$	9dB

communication. So, there is a need to consider the BER performance as an extra constraint for our considered problem.

5. CONCLUSION

In this paper, a Signal Cancellation (SC) method for simultaneous reduction of PAPR and sidelobe power of secondary users in NC-OFDM based CR System is proposed. This method dynamically extends the constellation points on SU sub-carrier for PAPR reduction and generates signal cancellation symbols on PU sub-carriers for sidelobe power suppression. Simulation results show that this provides significant PAPR reduction upto 6.8dB (μ= 0.2), sidelobe power suppression level of -42dB (β = 0.2). Considering the computational complexity of the SC method another method called sub-optimal SC method is introduced which solves the considered problem with less complexity and PAPR reduction upto 9dB (μ = 0.2) and sidelobe power suppression level of -29dB. According to our considerations, the order of computation complexities of SC and sub-optimal SC method are O(2.62 x10^5) and O(4.635x 10^3) respectively. But in these two techniques the BER performance is degraded, which affects the efficient communication and need to overcome this problem.

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