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# PAPR Reduction in NC-OFDM Based Cognitive Radio System Using Signal Cancelation and Tone Reservation

***Revathy G Nair[1], Aswathy Anilkumar[2], Jismi Babu[3]***
[1] PG student, College of engineering kidangoor,
Kidangoor,kottayam,kerala
*ammugopalakrishnan93@gmail.com*
[2]PG student, College of engineering kidangoor,
Kidangoor,kottayam,kerala
*aswathy7740@gmail.com*
[3]Assistant Professor, College of engineering kidangoor,
Kidangoor,kottayam,kerala
*jismibabu@yahoo.com*

**Abstract: High data rate wireless access is demanded by many applications. It requires more bandwidth for higher data rate transmission in any of the system. With promising technology and ever-increasing wireless devices, the spectrum is becoming scarcer day by day. In this case, using noncontiguous orthogonal frequency division multiplexing(NC-OFDM) and cognitive radio(CR) for spectrally efficient transmission are an alternative solution. High peak-to-average power ratio (PAPR) and large spectrum sidelobe power are two main drawbacks of this system. In this paper, we propose a novel signal cancelation (SC) method followed by tone reservation for joint PAPR reduction and sidelobe suppression in NC-OFDM-based CR systems. The key idea of the proposed method is to dynamically extend part of the constellation points on the secondary user (SU) subcarriers and add several SC symbols on the primary user (PU) subcarriers to generate the appropriate cancelation signal for joint PAPR reduction and sidelobe suppression. The joint PAPR reduction and sidelobe suppression can be consider as quadratically constrained quadratic program (QCQP) in SC method to obtain its optimal cancelation signal. The main idea of tone reservation method is to keep a small set of tones for PAPR reduction.**

*Index Terms*— **Cognitive radio (CR), noncontiguous orthogonal frequency-division multiplexing (NC-OFDM), peak-to-average power ratio (PAPR)**

## 1. Introduction

The term wireless communication was introduced in 19$^{th}$ century and wireless communication technology has developed over the subsequent years. Wireless services have been growing rapidly with each passing year. Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique that divides the available spectrum into subcarriers, with each subcarrier containing a low rate data stream. In OFDM system, the achievement of large number of non-contiguous subcarriers by collective usage for the high data rate transmission is referred as Non-Contiguous OFDM (NC-OFDM) [1]. NC-OFDM can provide the necessary agile spectrum usage for the target licensed spectrum if spectrum can be occupied by primary and secondary users. The spectrum sensing measurements are deactivated during the subcarriers corresponding to the spectrum occupied by primary user. Noncontiguous orthogonal frequency-division multiplexing (NCOFDM) is an attractive physical-layer technology due to its robustness in multipath propagation environment, more tolerant of delay spread, more resistant to frequency selective fading than single carrier transmission systems and gives good protection against co-channel interference and impulsive parasitic noise.[2-4]

The demand of spectrum is increasing day by day. A CR is an emerging technology for the efficient use of the spectrum. It can discover unused spectrum by spectrum sensing and can adjust its transmission setting accordingly without causing interference to licensed users. Cognitive Radio (CR) is an intelligent wireless communication system that is self-aware of its surrounding environment and identifies unused portion of radio spectrum on the basis of observed spectrum usage and able to make decision itself and efficiently uses spectrum in a dynamically adaptive way. The features of CR are frequency agility, dynamic frequency selection, adaptive modulation, transmit power control ,location awareness and negotiated use.

The major drawbacks of the NC-OFDM based CR system is high PAPR and large spectrum sidelobe. OFDM system has high peak values in time domain since many subcarrier components are added via an inverse discrete Fourier transform operation. Therefore, OFDM systems are known to have a high PAPR. High PAPR in NC-OFDM cause RF power amplifiers should be operated in a very linear region. Otherwise the signal peak gets into non-linear region of the power amplifier causing signal distortions.[2] This signal distortion introduces intermodulation among the subcarriers and out of band radiation. On other hand lead this lead to very inefficient amplification and expensive transmitters. The PAPR problem important in the uplink since the efficiency of power amplifier is critical due to the limited battery power in a mobile terminal. The selection of PAPR reduction technique is based on following factors.

i) PAPR reduction technique with as few harmful side effects such as in-band and out-of-band radiation.

ii)Low average power: PAPR can be reduced by increasing average power of original signal then it requires a large linear operation region in high power amplifier and thus resulting in the degradation of BER performance.

iii) Low implementation complexity: The time and hardware requirements for the PAPR reduction should be minimal.
iv) No bandwidth expansion: The bandwidth expansion effect the data code rate loss due to side information.
v) No BER performance degradation
vi)Power requirement: the PAPR reduction technique should be design without any additional power.
The large spectrum sidelobe introduces interference to the adjacent PUs, resulting in the serious performance degradation of the adjacent PUs [9].Then it required desirable to suppress the spectrum sidelobe as much as possible in the NC-OFDM-based CR system.

PAPR reduction techniques can be broadly divided into three major classes.[2]. First one is signal distortion techniques, it reduce the PAPR by distorting the transmitted OFDM signal before it passes through the power amplifier. Second one is multiple signalling and probabilistic techniques. This method either generate multiple permutation of the OFDM signal and transmit the one with minimum PAPR or to modify the OFDM signal by introducing phase shift, adding peak reduction carrier or changing constellation points. Third one is coding techniques. This technique is to select the code word that reduces the PAPR for transmission. PAPR can be reduced by different techniques and each technique have their own advantages and disadvantages. The selection criteria for PAPR reduction techniques mainly depend on the transmission requirements. [3]In clipping technique, clipping is done around the predefined peaks value but at the cost of increased distortion. The probabilistic scrambling techniques do not suffer from the out-of-band radiation but spectral efficiency decreases and complexity increases with increase in number of subcarrier. These techniques include selective mapping (SLM), partial transmit sequence (PTS), interleaved OFDM, Tone Reservation (TR) and Tone Injection (TI). SLM algorithm adapted to any length of route number that means it can be used for different OFDM systems with different number of carriers. It is particularly suitable for the OFDM system with a large number of sub-carriers.PAPR reduction using coding technique results high complexity and lower band width efficiency.[4] All of proposed techniques have the ability to reduce PAPR effectively but at the cost of loss in data rate, transmit signal power increase, BER increase, computational complexity increase and so on. Thus, the PAPR reduction technique should be chosen carefully according to various system requirements.

In this paper, we propose a novel scheme, which is the combination of signal cancelation (SC)and tone resevation for PAPR reduction in the NC-OFDM-based system. For the proposed SC method, part of the outer constellation points on SU subcarriers is dynamically extended, whereas several SC symbols are added on the PU subcarriers, to generate the appropriate cancelation signal for joint PAPR reduction and sidelobe suppression. Tone reservation for further PAPR reduction in the system.Then, the SC method formulates the problem of the joint PAPR reduction and sidelobe suppression as a quadratically constrained quadratic program (QCQP) , and the optimal cancelation signal can be obtained by convex optimization.

## 2.COGNITIVE RADIO

Cognitive Radio (CR) is an intelligent wireless communication system that is self-aware of its surrounding environment and identifies unused portion of radio spectrum on the basis of observed spectrum usage and able to make decision itself and efficiently uses spectrum in a dynamically adaptive way.
The demand of spectrum is increasing day by day. A CR is an emerging technology for the efficient use of the spectrum. It can discover unused spectrum by spectrum sensing and can adjust its transmission setting accordingly without causing interference to licensed users. The inconsistency between allocation and use of spectrum leads to need for the development of intelligent radios. The regulation and more flexible spectrum management techniques are required to increase the efficient use of our natural spectrum resources.
The Federal Communication Commission (FCC) has started considering dynamic approaches for spectrum sharing. [3]The IEEE 802.22 standards have launched the process to use TV band spectrum holes for enabling wide area Internet service. The IEEE 802.22 working group is developing a standard for cognitive wireless regional area networks (WRAN) for use by license-exempt devices on a non-interfering basis in spectrum that is allocated to the TV Broadcast Service [1].
The CR has the ability to dynamically adjust its certain operating parameters (e.g. transmit power, carrier frequency, and modulation strategy) in real-time, with two primary objects in mind: to provide highly reliable communications and efficient utilization of the radio spectrum.

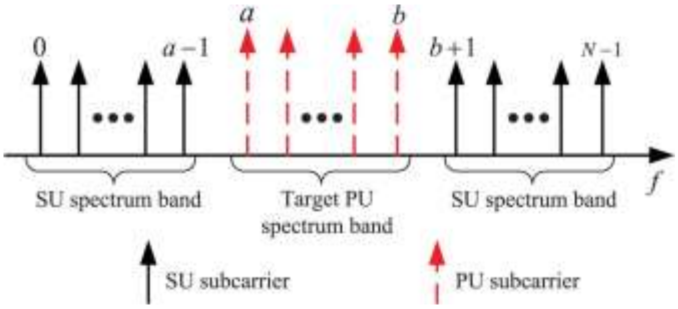


FIG.1. NC-OFDM-BASED CR SYSTEM COEXISTING WITH THE PU AND SUS

For the NC-OFDM-based CR system, the PUs utilize the PU spectrum band for data transmission, whereas the SUs can detect and utilize the unoccupied spectrum band of the Pus (i.e., SU spectrum band) for data transmission[11]. Thus, the SUs
utilize the SU subcarriers located in the SU spectrum band for data transmission.[15] Moreover, in the conventional NC-OFDM based CR system, the SUs must deactivate the PU subcarriers that are located in the PU spectrum band to create spectrum notches to limit the interference to the PUs. shown in Fig. 1, for a conventional NC-OFDM-based CR system with $N$ subcarriers, among which $L = (b - a + 1)$ subcarriers are occupied by the PUs (from the $a$th to the $b$th subcarriers) and the remaining $N - L$ subcarriers (from the zeroth to the $(a - 1)$th subcarriers, and from the $(b + 1)$th to the $(N - 1)$th subcarriers) are utilized by the SUs for data transmission.
Denote $R = \{0, 1, . . . , a - 1, b + 1, b + 2, . . . , N - 1\}$ as the subset that consists of indexes of the SU subcarriers and $Rc = \{a, . . . , b\}$ as the subset that consists of indexes of the PU subcarriers. In OFDM system, the achievement of large number of non-contiguous subcarriers by collective usage for the high data rate transmission is referred as Non-Contiguous OFDM (NC-OFDM) [6]. NC-OFDM can provide the necessary

agile spectrum usage for the target licensed spectrum if spectrum can be occupied by primary and secondary users. The spectrum sensing measurements are deactivated during the subcarriers corresponding to the spectrum occupied by primary user.[10] Moreover, dynamic spectrum sensing can be determined when the active subcarriers are located in the unoccupied spectrum bands.

## 2.1 PAPR

OFDM signal consists of lot of independent modulated subcarriers, which are created the problem of PAPR. It is impossible to send this high peak amplitude signals to the transmitter without reducing peaks. So we have to reduce high peak amplitude of the signals before transmitting. PAPR can be defined as the relationship between the maximum power of a sample in a transmit OFDM symbol and its average power.
The PAPR of the OFDM signal can be written as:

$$\text{PAPR= PAPR}=10\log_{10}\frac{P_{peak}}{P_{average}}(\text{dB}) \quad (1)$$

The complementary cumulative distribution function(CCDF) is widely employed to measure the PAPR reduction performance, which is defined as the probability that the PAPR exceeds a given threshold $PAPR_0$, i.e.,

$$CCDF = \Pr\{PAPR > PAPR_0\}. \quad (2)$$

Since the high PAPR of NC-OFDM signals leads to serious nonlinear distortion and power efficiency degradation of the HPA, it is necessary to reduce the PAPR of the NC-OFDM signals.

## 3. PROPOSED SIGNAL CANCELLATION METHOD AND TONE RESERVATION

Here, we propose a novel SC method for joint PAPR reduction and sidelobe suppression in the NC-OFDM-based CR system. Proposed method different to the conventional NC-OFDM-based CR scheme, which turns off the PU subcarriers to create spectrum notches to limit the interference to PUs, the SC method utilizes both the SU and PU subcarriers to generate the cancelation signals for joint PAPR reduction and sidelobe suppression. Tone Reservation (TR) method is proposed for PAPR reduction [15]. The main idea of this method is to keep a small set of tones for PAPR reduction. This can be originated as a convex problem and this problem can be solved accurately. The amount of PAPR reduction depends on some factors such as number of reserved tones, location of the reserved tones, amount of complexity and allowed power on reserved tones.
method achieves better PAPR reduction and sidelobe suppression performances than the conventional turning-off method. Fig. 2 shows the constellation extension regions when the quadrature amplitude modulation (QAM) is employed for the SC method. For the SU subcarriers, the constellation points are classified as inner points, boundary points, and corner points. Inner points cannot be extended, boundary points can be extended only outward in one direction along the arrowed lines, and corner points can be extended to the shaded regions[8].

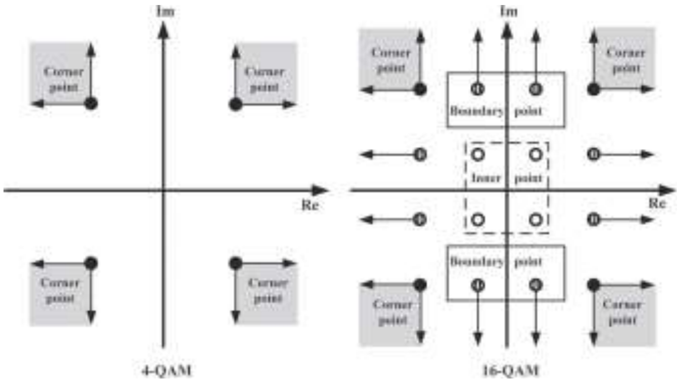


Fig. 2. Constellation region on SU subcarriers with 4-QAM and 16-QAM, respectively.

SC method, on the SU subcarriers, the constellation adjustment symbol $\mathbf{C}_s = [C_s(0), C_s(1), \ldots, C_s(N-1)]$ is added to the original data symbol $\mathbf{X}$, where $C_s(k) = 0$ for $k \notin R$ and the constellation adjustment symbol $C_s(k)$ must obey the principle rule shown in Fig. 2. Denote $M$ as the constrained space for $C_s(k)$, it is obvious that $C_s(k) \in M$ for $k \in R$. Moreover, on the PU subcarriers, the SC symbol $\mathbf{C}_p = [C_p(0), C_p(1), \ldots, C_p(N-1)]$ is added, where $C_p(k) = 0$ for $k \in R$. If we denote $\mathbf{C} = \mathbf{C}_s + \mathbf{C}_p$ as the total SC symbol of the SC method, then we have

$$C(k)=\begin{cases} C_s(k) & R \in k \\ C_p(k) & R \notin k \end{cases} \quad (3)$$

joint PAPR reduction and sidelobesuppression problem can be formulated as an optimization problem, i.e.,[9]

$$\min_{C} \|FX + FC\|_\infty \quad (4.a)$$

$$\text{subject to} \quad \|P_d X + P_d C\|_2 \leq \beta\|P\_d X\|_2 \quad (4.b)$$

$$\|X + C\|_2^2 \quad (4.c)$$

$$C(k) \in M, \text{ for } k \in R \quad (4.d)$$

Equation (4b) represents the sidelobe power constraint of the NC-OFDMbased CR system, and $\beta$ denotes the parameter to control the maximum sidelobe power, which is calculated according to desired system characteristics. In (4b), the sidelobe power of the proposed SC method should be equal to or less than $\beta$ times the sidelobe power of the conventional NC-OFDM-based CR system. Since the total SC symbol **C** is added to the original data block **X**,. Thus, the total power of the SC method must be restrained, and (4c) represents the power constraint of the SC method, where ∈ denotes the maximum power. Equation (4d) represents the constellation modification constraint, and the extended points on SU subcarriers must obey the principle rule shown in Fig. 2.

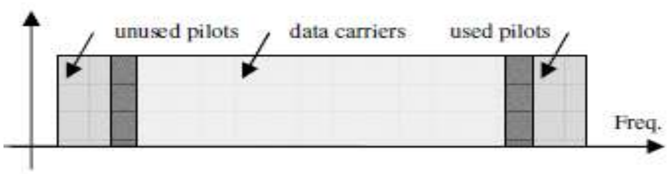


Fig3. Allocation of reserved tones within an NC -OFDM symbol

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Tone Reservation (TR) is a technique designed to combat this problem by reserving a number of carriers (tones) in the frequency domain to generate a cancellation signal in the time domain to remove high peaks. However TR can have a high associated computational cost due to the difficulties in finding an effective cancellation signal in the time domain by using only a few tones in the frequency domain. In Tone Reservation ,a small number of subchannels( tones), which do not carry any information data ,are reserved for peak cancellation. Since symbol demodulation is performed in the frequency domain on a tone-by-tone basic, the reserved sub-channels can be discarded at the receiver, and only the data-bearing sub-channels are used to determine the transmitted bit
stream.

4. SIMULATION RESULTS

Here, some simulations have been conducted to evaluate
the capability of the proposed combination of SC method and TR. where the NC-OFDM-based CR system is considered with $N$ = 64 subcarriers, and the subcarrier interval is $\Delta f$ =22.5 kHz. Moreover, the target spectrum band occupied by Pus is from $29\Delta f$ to $38\Delta f$, in which 37 frequency sampling points for the evaluation of the total sidelobe power are placed with the equivalent space of $(\Delta f)/4$. Thus, $a$ = 29, $b$ = 38, $M$ = 37, and the remaining spectrum band is utilized by SUs. In addition, $10^4$ independent NC-OFDM symbols modulated by 4-QAM and 16-QAM are randomly generated with the oversampling factor $J$ = 2.

Fig. 4 shows the PAPR reduction of the proposed SC method
. The proposed SC method with different $\beta$ values also achieves significant PAPR reduction. For example, when $CCDF$ = 0.01, for $\beta$ = 0.5, 0.4, 0., and 0.5, the PAPR of the proposed SC method is 9, 10.6, and 11 dB, respectively. Moreover, the PAPR reduction performance of the SC method improves when the value of $\beta$ increases. Because there is a tradeoff between PAPR reduction and sidelobe suppression, and the sidelobe suppression constraint becomes more relaxed with the increase of $\beta$, this leads to the improvement of the PAPR reduction performance and the degradation of the sidelobe suppression performance. PRT tones are not carrying any information it is considered as overhead thus in this case25 to 29and 40to 46 consider as peak reduction tones.

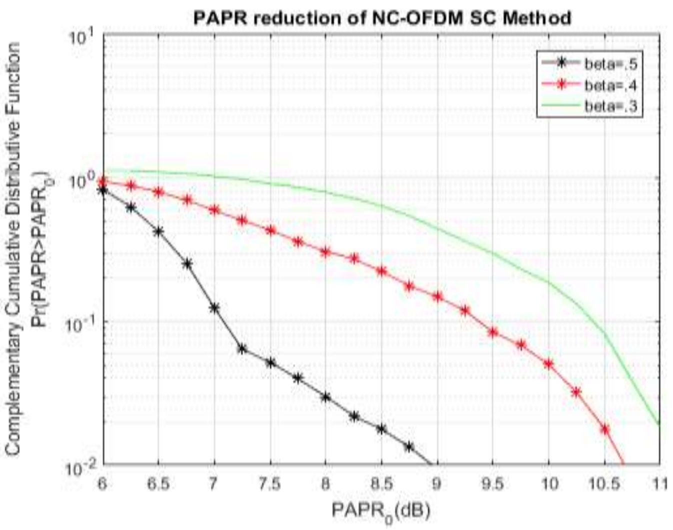


Fig4. PAPR reduction with the SC method when $\beta$ different for 4-QAM.

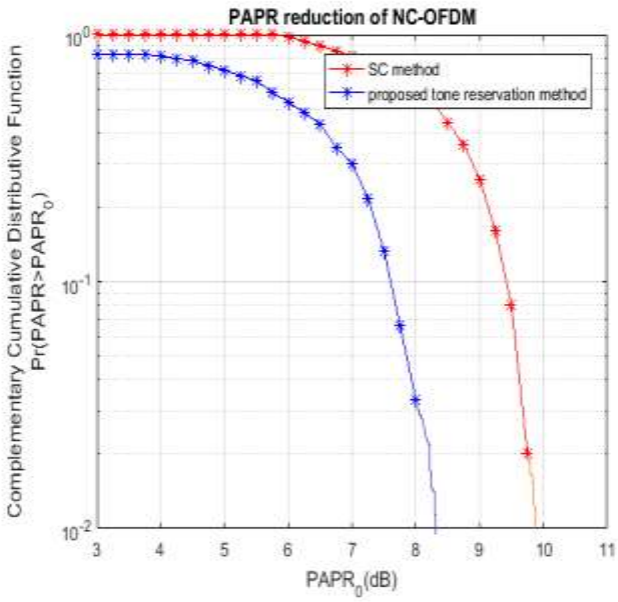


Fig5. PAPR reduction with the SC and tone reservation method for 4-QAM.

5. CONCLUSION

In this paper, we have proposed an SC method for joint PAPR reduction and sidelobe suppression in NC-OFDM-based CR systems. The proposed SC method dynamically extends part of constellation points on the SU tones and adds several SC symbols on the PU tones to jointly reduce the PAPR and suppress the sidelobe of NC-OFDM signals Significant PAPR reduction can be achieved by using only small number of tones in the frequency domain. Combination of signal cancellation and tone reservation method provide significant PAPR reduction.

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