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Efficient utilization of Spectral Mask in OFDM based Cognitive Radio Networks

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Abstract: *Cognitive Radio (CR) is used to access the unused licensed spectrum by the unlicensed users. While accessing the licensed spectrum by CR user's radiation or signals of Cognitive radio users interfere and disturb the licensed user signal. This problem can be rectified by constructing a spectrum mask across the CR users, which eliminates the Out of Band radiation of CR users. In this paper we propose a method to restrict Cognitive Radio signals within the Spectral mask and proposed new techniques for efficient utilization of spectral mask in Cognitive Radio Networks. Our simulation results show that the Out of band radiation is within the spectral mask without reducing the BER and our proposed techniques will reduce the computational complexity in the Network.*
Keywords: *cognitive Radio, dynamic spectrum access, out of Band radiation, Spectral Mask, Spectral Precoding*

I. Introduction

Cognitive Radio's are intelligent radios which are mainly used for efficient utilization of available Spectrum. It consist primary users (PU) and Secondary Users. Primary users are licensed users of the spectrum and secondary users are unlicensed users that uses cognitive radio also called cognitive radio (CR) users. When the licensed users are not accessing the spectrum Cognitive radio users are free to access the available spectrum. If the licensed user wanted to use the spectrum cognitive radio user automatically switches to nearest available band. Orthogonal Frequency Division Multiplexing (OFDM) is multicarrier modulation technique which is widely used for efficient utilization of spectrum. In this large band is divide into multiple sub bands and each sub band uses a different carrier, in which each carrier frequency is orthogonal to each other, so that Inter Symbol Interference (ISI) can be reduced. As OFDM supports efficient utilization of available bandwidth, it is always used in Cognitive Radio applications.

Initially FCC gave permission to use licensed band by unlicensed users without causing interference to licensed users. But while accessing the licensed band by cognitive radio user some of its radiation caused interference to licensed user signals called as out of band radiation. This problem of Out of Band radiation can be reduced by constructing a spectral mask across the Cognitive radio signal which eliminates the out of band radiation shown in Figure 1. Till now a lot of Techniques are proposed to reduce this problem but they are unable to solve this problem. Some of these are In time domain Cosine window applied to signal to suppress the out of band radiation [2], But the system throughput reduces. Adaptive symbol transition method [3] which inserts extensions between OFDM symbols, which also results in throughput reduction. In frequency domain, a simple tone-nulling scheme[4], map antipodal symbol pairs onto adjacent subcarriers [5],[6], active interference cancellation approach [7], subcarrier weighting [9], multiple-choice sequence [10], and selected mapping all these methods suppress OOB radiation [11], but these are not applicable to multiuser. Spectral mask can be constructing by using spectral precoding approaches which can reduce OOB radiation. Some of these are correlative precoder [12], projection precoder [13], 1-continuous precoder [14], but these methods cause significant bit-error-rate (BER) performance degradation. Existing methods uses notch frequency methods [1] to restrict the out of band radiation in within the spectral mask. In this we select frequencies where radiation crosses the mask and removes those frequencies called notch frequencies. But as the number of notch frequencies increases performance of the system degrades as bit-error-rate increases.

In this paper we construct a spectral method by using spectral precoding approach and removes the OOB radiation by using simple equalization techniques and proposed new techniques on utilization of spectral mask which decreases the complexity of the system.

Rest of the paper organized as follows, Section 2 explains the overview of the procedure, Section 3 explains proposed methods, Section 4 explains our simulation results, and Section 5 concluded the paper.

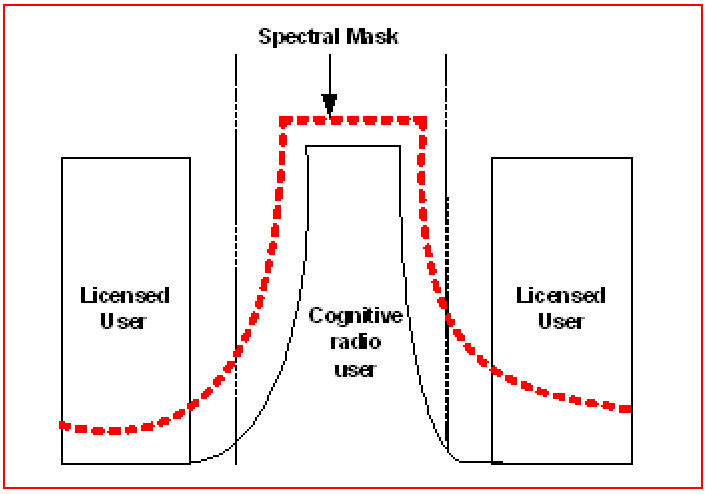

Fig.1. Spectral mask applied to CR user existing with licensed users

II. System Model

In this section we explain the overview of the system procedure. In this first we generate the OFDM signal for the Cognitive radio user and next prepare spectral mask for the CR user and apply the generated spectral mask to the cognitive user to restrict the unwanted radiation.Fig.2 explains the detailed procedure

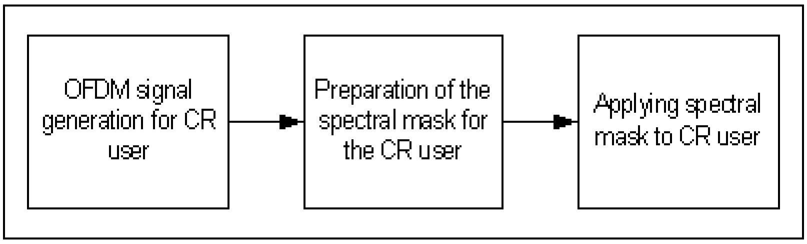

Fig.2. Overview of the system model

We consider K number of OFDM based cognitive radio users using the part of the licensed spectrum unoccupied by the licensed spectrum. The frequency band is divided into set of N sub carriers, $N=\{n_0,n_1,n_2.............n_{N-1}\}$. The k^{th} user $0 \leq k \leq K-1$, utilizes set of subcarriers $N_k \subset N$. In this first we construct an OFDM user signal and next we construct the Spectral mask across the OFDM signal to remove unwanted radiation.

Let d_n denotes the transmitted symbol over the nth subcarrier. Then the Fourier Transform of the OFDM signal can be expressed as [8]

$$S(f) = \sum_{n\in N} dn\, a_n(f) \tag{1}$$

With

$$a_n(f) = T\, e^{-j\pi (Ts - Tg)(f - \frac{n}{Ts})}\, \mathrm{sinc}(T(f - \frac{n}{Ts})), \tag{2}$$

Where $T = Ts + Tg$ is the symbol duration and $\mathrm{sinc}(y) = \frac{\sin(\pi y)}{(\pi y)}$. (3)

The power spectrum density (PSD) of the OFDM signal is

$$P(f) = \frac{1}{T} E\{|S(f)|^2\} = \frac{1}{T} a^T(f)\, E\{dd^H\}\, a^*(f), \tag{4}$$

Where $a(f) = [a_{n0}(f)\ \ a_{n1}(f)\ \ a_{n2}(f)\ \ ....\ a_{nN-1}(f)]^T$ and $d=[\ d_{n0}\ d_{n1}\ ....d_{nN-1}]^T$.

Here the superscripts, T, *, and H, denote the transpose, conjugate, and conjugate transpose of a vector or matrix, respectively.

We construct A_k matrix using a(f) as $[a_0(f_0)\ \ a_0(f_1)\ ....\ a_0(f_{M-1})]^T$, Let the singular value decomposition (SVD) of A_k be

$$A_k = U_k \sum k\, V_k^H \tag{5}$$

Where U_k is an M_k X M_k unitary matrix, $\sum k$ is an M_k X N_k diagonal matrix, and V_k is an N_kX N_k unitary matrix. From these spectral mask can be composed by using V_k matrix.

Spectral precoding matrix G=V. Then power spectral density of OFDM signal can be composed as [8]

$$P(f) = \frac{1}{T} a^T(f)\, GG^H\, a^*(f) \tag{6}$$

For the spectral mask generation power spectral density is

$$P(f) = \frac{1}{nT} a^T(f)\, GG^H\, a^*(f), \tag{7}$$

where n is the spectral mask factor factor, by varying n value the position of spectral mask is varying from OFDM signal.
System complexity of the spectral mask can be calculate by using formula

$$\lambda = \frac{S}{Mk} \tag{8}$$

Where S is the number of frequencies utilized to construct spectral mask, and Mk is the total number of frequencies of the user band.

III. Proposed Methods

Cognitive Radio is an intelligent radio which senses the spectrum and checks the availability of the unused licensed spectrum. To avoid Out of Band radiation we use spectral mask. In the current system when cognitive radio detect unused spectrum, spectral mask will applied to full cognitive radio signal, even the Licensed users not present. The main aim of the spectral mask is to restrict the signals which cause interference to licensed users. So if licensed users not present in the surroundings of cognitive radio then we no need to use the spectral mask. Here we proposed some methods to use spectral mask effectively. In this When cognitive radio senses the spectrum it analyzes whether the licensed users present on Left side or Right side or both sides of the Cognitive radio user. With these three conditions the complexity of the system will reduce.Fig.3 explains the detailed model of proposed techniques.

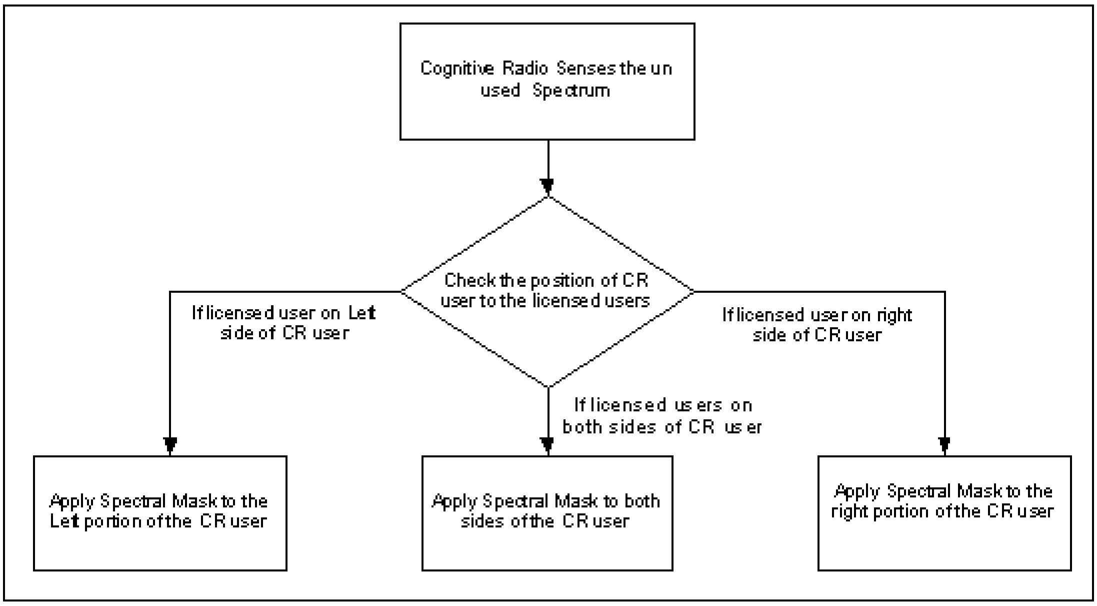

Fig.3.Effieient utilization of spectral mask techniques

A. Condition A

If the Licensed user present on only Left side of the Cognitive radio user, then the spectral mask will apply to only left part of the Cognitive radio signal, because there is no Licensed user on the right side of the system. With this system has to construct the spectral mask using only half the subcarriers, which is easier than using the all subcarriers. Consider M is the total number of frequencies in frequency band

$$A_n(f) = \sum_{f=f0}^{f(\frac{M}{2})-1} \sum_{n=0}^{N-1} T\, e{-}j\pi\, (Ts - Tg)\, (f - \frac{n}{Ts})\, \text{sinc}(T\, (f - \frac{n}{Ts})) \tag{9}$$

Here Cognitive radio system constructs the spectral mask in the frequency range of f_0 (first frequency) to $f(\frac{M}{2}) - 1$ (half of the total frequencies).

B. Condition B

If the Licensed user present on only Right side of the Cognitive radio user, then the spectral mask will apply to only right part of the Cognitive radio signal, because there is no licensed user on the right side of the system. Consider M is the total number of frequencies in frequency band

$$A_n(f) = \sum_{f=f(\frac{M}{2})-1}^{f(M)} \sum_{n=0}^{N-1} T\ e{-}j\pi\ (Ts - Tg)\ (f - \frac{n}{Ts})\ sinc(T\ (f - \frac{n}{Ts})) \quad (10)$$

Here Cognitive radio system constructs the spectral mask in the frequency range of $f(\frac{M}{2})$ (half of the frequency) to f(M) (End of the available frequencies).

C. Condition C

If the Licensed users present on both sides of the Cognitive radio user, then the spectral mask will apply to both sides of Cognitive radio signal.

$$A_n(f) = \sum_{f=f0}^{f(M)} \sum_{n=0}^{N-1} T\ e{-}j\pi\ (Ts - Tg)\ (f - \frac{n}{Ts})\ sinc(T\ (f - \frac{n}{Ts})) \quad (11)$$

In this spectral mask is construct at each frequency from f_0 to f(M).

IV. Simulation Results

In this section we present simulation results of proposed methods. In our simulation, we take Ts = $\frac{1}{15}$ms, Tg = $\frac{3}{640}$ms, f={-15,...15}MHz and N= {-240, ..,-1,1,.........240}.

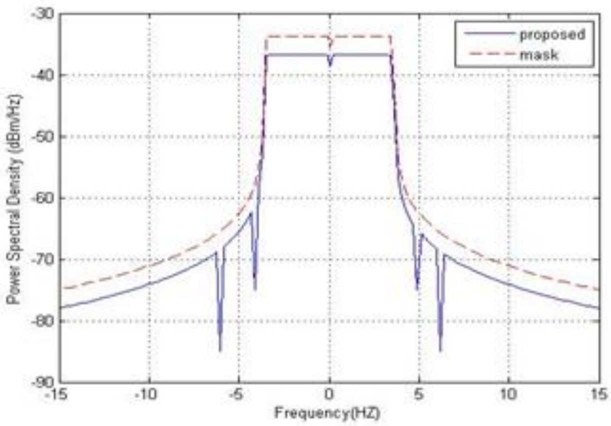

Fig.4. Spectral precoding using notch frequency technique

Fig. 4 shows the existing method of spectral precoding using notch frequencies method, In this method as the number of notch frequencies increases BER performance will reduces. Even it effectively controls the BER performance, The bit error performance and the system complexity while implementing notch frequencies show that this method is not preferable for more number of users.

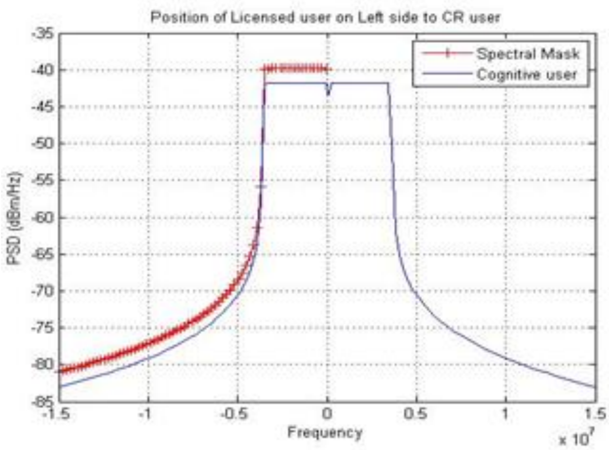

Fig.5. Position of licensed user on left side to Cognitive radio user

We propose a method to reduce out of band radiation without using notch frequencies. In this we use simple equalization technique in which radiation of user signal is checked at each frequency whether it is below the spectral mask or not, if user signal exceeds the spectral mask, then PSD of CR signal reduced below the spectral mask. As we are not removing any frequencies (notch frequencies) Bit error rate is low and efficiency of the system is high.

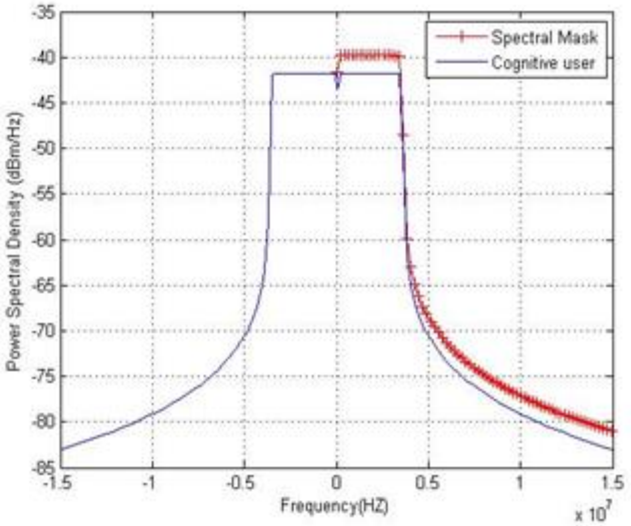

Fig.6. Position of licensed user on left side to Cognitive radio user

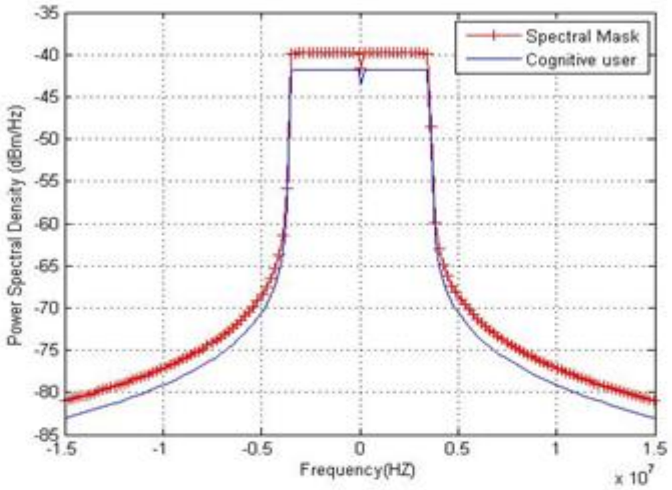

Fig.7 Proposed spectral mask without using notch frequencies

Our simulation results show that proposed new techniques effectively reduce the system complexity.Fig.5 show when the licensed user present on left side to Cognitive radio user. Here we can see that spectral mask applied to only left part of the user signal.Fig.6 shows when the licensed user present of right side of the cognitive radio user. Fig.7 shows if the licensed users present on both sides of the user signal. In this spectral mask applied to whole user signal to reduce out of band radiation. Fig.8 Shows the BER performance of proposed system and compared with previous methods.

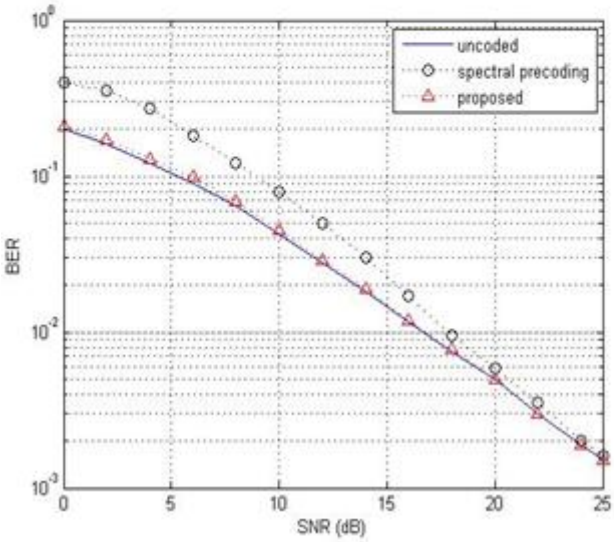

Fig.8. BER performance comparison of the proposed and existing systems.

In our simulation we calculated system complexity using the equation (8) as number of frequencies utilized to build spectral mask tothe total number of frequencies used by the CR user. TABLE.1 shows the system complexity of various spectral mask techniques, in which system complexity is more for previous methods when compared to proposed method.

Table.1. Comparison of system complexity for various spectral mask schemes

Spectral mask scheme	**System complexity**
Projection	1
Continuous OFDM	1
Spectral precoding using notch frequencies	1
Proposed schemes	1/2

V. Conclusion

In this paper we constructed a spectral mask which removes out of band radiation using simple equalization technique and implemented three conditions for efficient utilization of spectral mask based on the position of the licensed user to the cognitive radio. Our simulation results shows that the proposed techniques effectively reduce the BER performance and reduce the system complexity.

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