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Sidelobe Suppression using AIC technique in OFDM-based Cognitive Radios

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Abstract —*Orthogonal frequency division multiplexing (OFDM) is an efficient and effective trans-mission technique for Cognitive radio (CR) systems but it suffers from out-of-band (OOB) radiations due to high spectral sidelobes. This is one of the major drawback of OFDM scheme especially in cognitive radios where it is important to prevent secondary user's interference into the primary licensed user's (LUs) frequency band. In this paper, we investigate the already existing technique called Active Interference Cancellation (AIC]) to overcome the sidelobe problem in OFDM on different parameters. In this technique, a few tones at both edges of the spectrum hole and in the PU band are used to cancel the interference to LUs. Two special tones are called Active interference edge tones. The motto of all this is to cancel interference in that band. Unlike other methods, this technique does not affect receiver and need small alterations in the receiver and also there is no need of side information to be sent to the receiver.*

Keywords*-OFDM, CR, OOB, LUs, AIC*

I. INTRODUCTION

Spectrum is the most valuable but scarce resource in wireless communication.The growing demand on wireless communication systems to provide high data rates has brought with it the need for a flexible and efficient use of the spectrum resource, which is a scarce commodity.The regional spectrum allocation policy counteracts the free mobility of radio communication equipment. The vast majority of the available spectral resources have already been licensed, so it appears that there is little or no room to add any new services, unless some of the existing licenses are discontinued. Static spectrum allocation policies also results in underutilization of the spectrum due to the fact that most of the permanently allocated spectrum is not utilized all the time hence results in spectrum holes in time domain[1]. There comes a new technology named Cognitive radio[2] which shows a new paradigm shift for efficiently utilize the spectrum in an intelligent manner. Cognitive radio tries to utilize the spectrum in opportunistic manner which basically works on the principle of detect-and-avoid (DAA). The basic objective of the new spectrum allocation policy is the promotion of secondary utilization of unused portions of the spectrum in the form of spectrum pooling, wherein, unlicensed users rent licensed portions of the spectrum from a common pool of spectral resources from different owners [2]. OFDM proved to be a suitable candidate for cognitive radios[3] but high spectral sidelobes of OFDM have the tendency to interfere with out-of-band as well as in-band services.Various sidelobe suppression techniques for OFDM-based cognitive systems have been addressed in the literature. These techniques are performed either in time or frequency domain. Time domain windowing[4], adaptive symbol transition[5] are implemented in time domain. Both the techniques result in reduced throughput due to extension of symbol in time domain. In frequency domain, tones nulling[3] can be used but this is not sufficient for interference suppression. More techniques such as spectral precoding[6], subcarrier weighting (SW)[7] multiply data carriers with some weighting factor to reduce sidelobes. Another set of effective techniques to reduce sidelobes is polynomial cancellation coding (PCC) [8], Adjacent frequency coding [9]. These schemes have very less complexity but their throughput suffers. In this paper, we study that out of band radiation suppression can be done by applying active interference cancellation (AIC) [10] technique which introduces two special tones at the edge of the interference band to nullify the sidelobe interference but the scheme is computationally inefficient. The results are compared through simulations done in MATLAB. This paper is organized as follows. In Section II, the system model for the proposed technique is introduced. In Section III, we discuss the Active interference technique along with simulation results. In Section IV, we discuss effect of various system parameters on AIC technique using simulation results. Finally in Section V, we present the Conclusions of this study.

II. AIC System Model

In this paper we consider an OFDM based cognitive radio system with N subcarriers. Since in this system we have both Primary as well as Secondary users. Primary users being licenced don't bother about the knowledge of secondary users, but that is not the case of secondary users. Thus Secondary users in the system are assumed to have the knowledge of spectrum occupied by primary users and make use of suppression techniques to reduce out of band radiation (OOBR). A system model is shown in Figure 1. An input data bit stream d (n) is symbol mapped using phase shift keying (PSK) and is converted to a parallel data stream of N bits. This data stream is passed through the AIC tone introduction block being fed to IFFT block for modulation. This parallel data stream is converted to serial data by P/S block. To overcome the effect of delay dispersive channel, a cyclic prefix is added to this modulated data. This baseband OFDM signal is passed through transmitter's radio frequency chain to amplify the signal and up-convert it to the desired frequency. The focus of our work in this study, is the AIC tone introduction block and how AIC tones will reduce the OOBR.

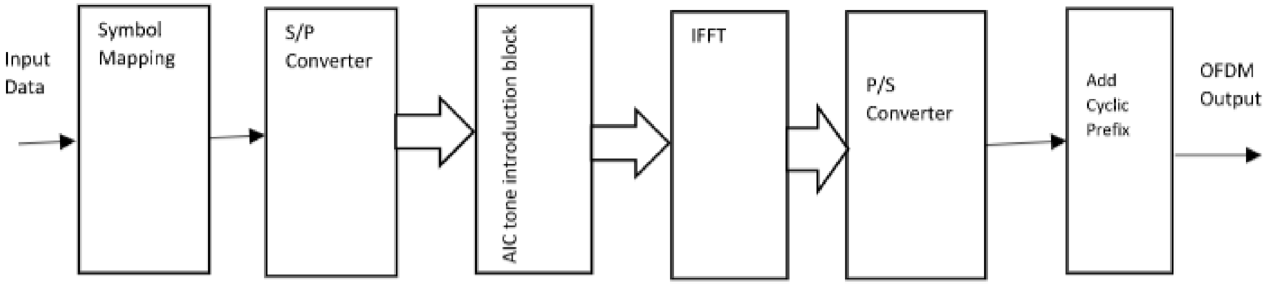

Figure 1. System Model

III. ACTIVE INTERFERENCE CANCELLATION

This approach is based on an assumption that the power values of some subcarriers, not used for carrying data, can be adjusted for each OFDM symbol to reduce the sidelobe of the SU's data subcarriers (DCs) in PU's band. This approach is called the Cancellation Carriers [11]. The spectrum of each subcarrier can be approximated with a sinc pulse. An important feature of such spectrum is that the sidelobes of each subcarrier overlap with the sidelobes of other subcarriers. Moreover, as sidelobes decline slowly, the correlation between sidelobes of adjacent subcarriers can be strong.
A special carrier, called the cancellation carrier (CC), is added at the edge of every block of data subcarriers. The Active Interference Cancellation (AIC) method is a similar technique [12]. The only difference is that the special carriers are also added inside the PU's band (not only on edges). However, it was shown by means of simulation in [12] that the AIC carriers inside PU's band have negligible influence on OOB radiation. Moreover, they can strongly increase computational complexity so the authors of [12] suggest they not be used at all.
The scheme for the Cancellation Carriers method is shown inFigure 2. Where a simplified representation of DCs and CCs is shown.

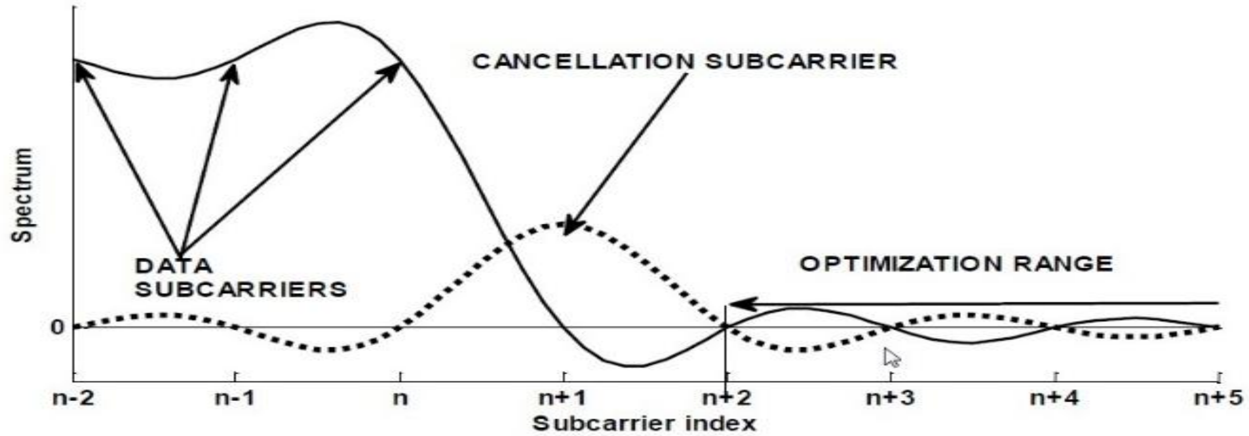

Figure 2. Diagram of spectrum amplitude of data subcarriers (solid line) and cancellation subcarrier (dotted line). Optimization region marked, no CP used.

Active CCs technique was proposed in [13], [14] where a few tones at both edges of the spectrum hole and in the PU band are used to cancel the interference to LUs. Two special tones are called Active interference edge tones. The motto of all this is to cancel interference in that band.When the information data is denoted by *X(k)* k=0,.. .,127, the transmitted OFDM signal is given by

$$x(n) = \sum_{k=0}^{127} X(k) e^{j2\pi n \frac{nk}{128}} \quad (1)$$

In order to evaluate the interference in-between the tone frequencies, we up-sample (we apply four-times up-sampling here) the corresponding spectrum, which is given by *Y(l)* (1=0,. ..4*128-1),

$$Y(l) = \frac{1}{128} \sum_{n=0}^{127} x(n) e^{-j2\pi n \frac{nl}{128}} (2)$$

Combining these two equations, we obtain as the relation between *X* and *Y*

$$Y(l) = \frac{1}{128} \sum_{n=0}^{127} (\sum_{k=0}^{127} X(k) e^{j2\pi n/128(k-l/4)} (3)$$

$$Y(l) = \frac{1}{128}\sum_{k=0}^{127} X(k)P(l,k) \quad (4)$$

where *P(n, I)* is the transform kernel.

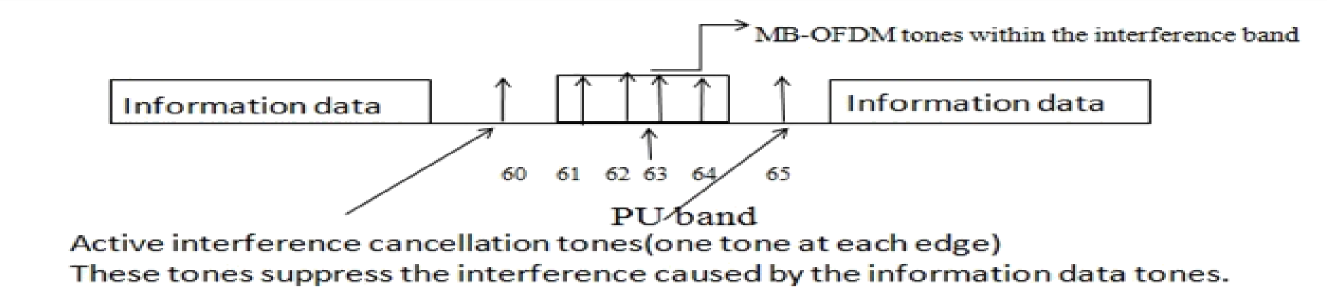

Fig 3. Definition of the AIC tone position

Instead of turning off a large number of tones, we define two special tones at the edge of the interference band as shown above, and would prove that these two tones can sufficiently cancel the interference in the band. The tone values can be arbitrarily determined without affecting the information tones due to the orthogonality relationship. We call these special tones Active Interference Cancellation (AIC) tones. Following the definition of the interfering band position, OFDM tones within the band, and the position of the AIC tones shown in Fig.3, we take up a specific example of the (in-band) UWB interference to the Radio Astronomy service of 3260-3267MHz. The tones #61, 62, 63 and 64 of the MB-OFDM Band#l co-locate with this band as shown in the figure. We then add two tones on the edge outside these three tones, and try to cancel the interference inside the interference band using the total of six tones. It will be shown later that the AIC tones play the dominant role and three 'in-band' tones can be simply 'turned off. It has been found that increasing the number of the AIC tones does not significantly improve the cancellation performance, thus the current solution seems to be near optimum.The vector d_1 is given by

$$d_1 = Pg \quad (5)$$

where *P* is the kernel defined by (4) and *g* is the vector of the information data tones with *X(60)* to *X(65)* turned off. In order to cancel the interference within the band, we need to generate the negative of the interference signal using the tones *X(60)* to *X(65).* Again using the relation (3.4) above, setting all the *X* to zero except for,*X(60)* to *X(65),* the equation to be solved is given by

$$P_1 h = -d_1 \quad (6)$$

where h is the column vector of *(X(60)* to *X(65))* and P_1 is the small kernel derived from P by limiting the index according to *h* and d_1 .

Here, *h* is our desired tone values. However, (6) cannot be solved in the straightforward way because the matrix P_1 is not invertible. Hence, instead, we seek the minimization of

$$e^2 = mod(P_1 h + d_1)^2 \quad (7)$$

Which leads to

$$h = -({P_1}^T P_1)^{-1} {P_1}^T d_1 = -W_1 d_1 \quad (8)$$

This minimum mean-squared solution is also known as the Moore-Penrose generalized inverse[15].

A. Simulation Results

To examine the performance of the AIC technique, an OFDM system with N = 128 is considered. A LU is detected spanning the band between subcarriers X61 and X64. First, the normalized PSD is estimated with disabled subcarriers set to zero and data subcarriers carrying BPSK signals. Next, two, four and six AIC tones are considered, with half of CCs on each side of the gap. The results are shown in Fig. 4. When CCs are not used, the interference level is kept under - 20 dB of the original signal power level. Two and four CCs reduce the interference level to around -42.5 dB and - 71 dB, respectively. Further two, four and six AIC tones with optimization are considered, with half of CCs on each side of the gap. The results are shown in Fig. 5. When CCs are not used, the interference level is kept under - 20 dB of the original signal power level. Two and four CCs reduce the interference level to around -30 dB and - 47 dB, respectively but peak overshoot is reduced considerably as shown in Table 2. Thus, trade-off between interference reduction in the desired band and peak overshoot is considered. AIC technique reduces the interference significantly at the cost of an increase in the computational complexity and symbol energy.

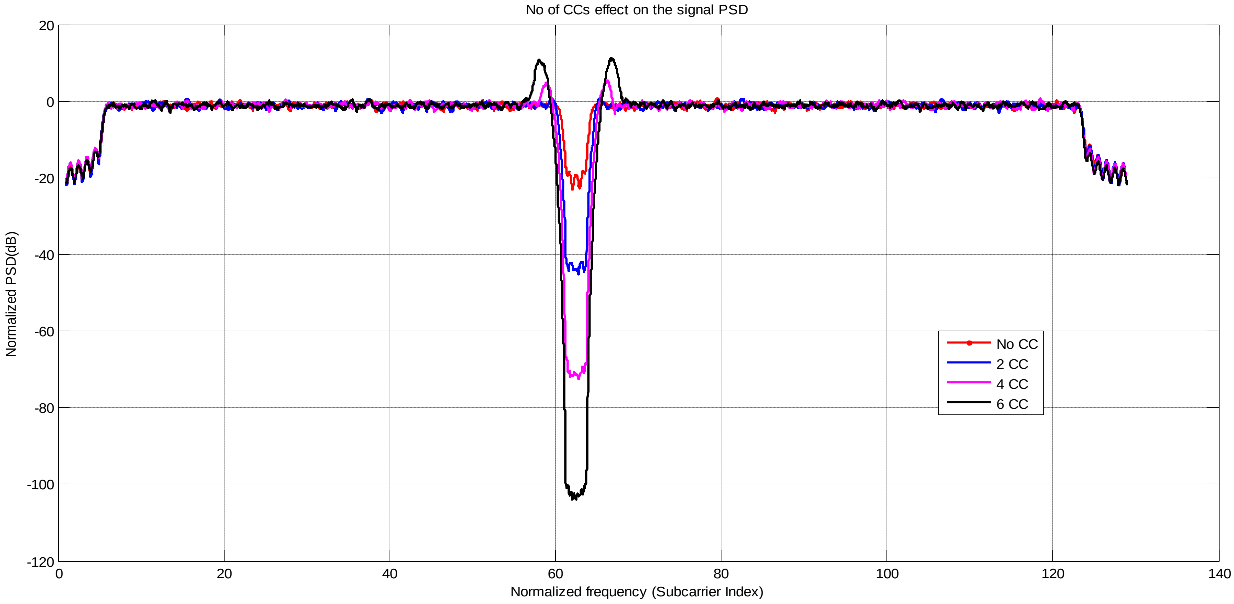

Fig 4. Number of CCs effect on the signal PSD having PU band from 61 to 64 subcarriers

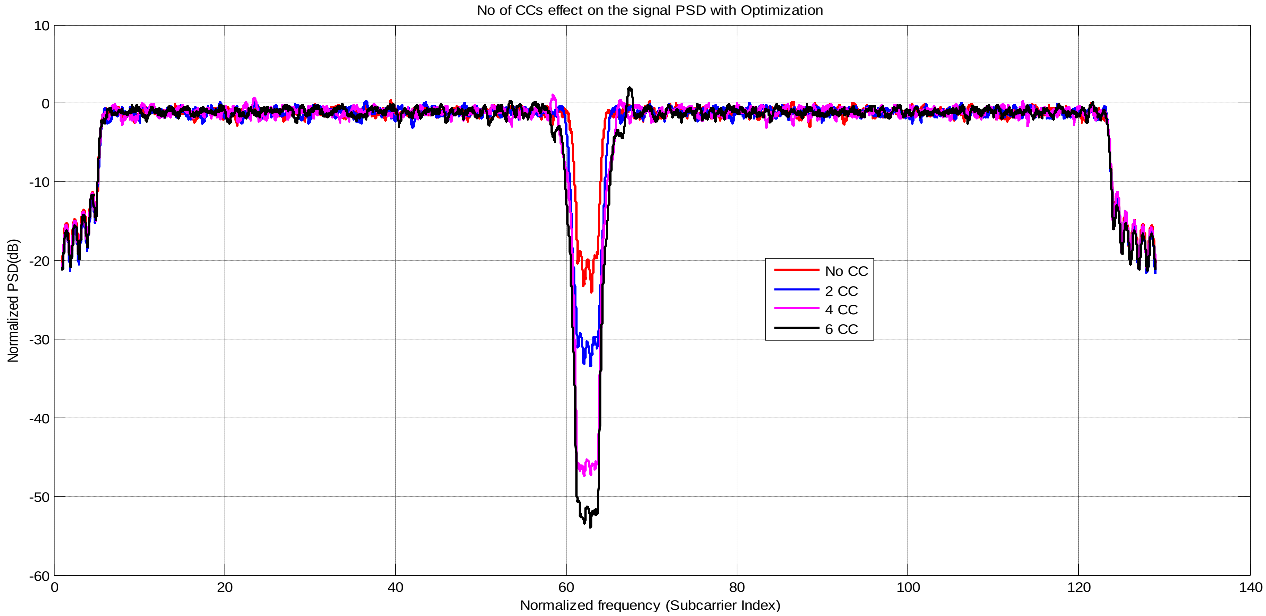

Fig 5. Number of CCs effect with optimization on the signal PSD having PU band from 61 to 64 subcarriers

Table 1. Interference reduction using AIC without using optimization.

No of CCs	Interference Reduction	Peak Overshoot
0	-20	0
2	-42.5	1.5
4	-71	5
6	-103.5dB	11

Table 2. Interference reduction using AIC using optimization.

No of CCs	Interference Reduction	Peak Overshoot
0	-20	0
2	-30	0
4	-47	1
6	-53dB	2

IV. CONCLUSION

Reducing out of band radiation is of prime importance in OFDM based cognitive radios. In this paper, we study AIC technique with and without optimization with zero, two, four and six Cancellation carriers or AIC tones on both side of the PU band. It is observed that more reduction is achieved as we increase the AIC tones. Also, sidelobe suppression is more in AIC technique without optimization but in that case peak overshoot is more compared to the AIC technique with optimization. Thus, depending upon the use we may need optimization in some cases.

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