Suppression of Side-Lobes in Orthogonal Frequency Division Multiplexing based Cognitive Radio System

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Abstract: Out of band radiation is an embedded problem of Orthogonal Frequency Division Multiplexing (OFDM), especially in Cognitive Radio (CR) environment where License Users (LUs) communications are distorted by Cognitive Users (CUs). In this paper, we have worked out the concept of Cancellation Subcarrier (CCs) such that CCs are added at the edges of OFDM spectrum and then use Least Mean Square Algorithm (LMS) – as an adaptive algorithm to find out the weights of the CCs for a resultant signal having an amplitude the same- as that of the out of band radiated signal, but with polarity shift of 180°. And hence the side-lobes of OFDM spectrum are suppressed to an optimized level, which is -32dB in our proposed technique.

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), Cognitive Users (CUs), Cancellation Carries
(CCs) and Least Mean Square (LMS)

1. Introduction

Radio Spectrum is very precious and limited resource used in Radio Communication System where rapid changes occur and hence spectrum demand increases. Further, with traditional fixed band or slot allocation approaches where a particular portion of spectrum is to be used by particular type of radio communication system, accommodating cellphone calls and data traffic that is increasing at an unprecedented rate, the Radio Spectrum has been becoming a rare commodity in many countries.

But, as per spectrum utilization surveys conducted by different bodies in different geographical area reveals that- allocated spectrum is mostly observed as under-utilized most of the time at different geographical area [1-2]. Due to rising popularity of wireless communication and the potential of spectrum shortage, it looks that the actual utilization of the spectrum is spare in practice and the need for its dynamic sharing is being researched. This leads to the concept of spectrum sharing where unlicensed users are allowed to dynamically access the license spectrum or a portion which are under-utilized by the time such that communication of Licensed User (LU) is not affected by unlicensed or Cognitive User (CU) [3-4]. Cognitive Radio (CR) technology or approach is the one of the best approaches that provides more flexibility to effectively utilize the available unused spectrum. Cognitive Radio scans the unused bands with the ability to auto-configure transmission and reception parameters to different frequencies during heavy traffic load thus allowing free slots of the spectrum and to ensure smooth communication [5].

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The most challenging problem to spectral sharing is the effective utilization of the same band such that sharing should not cause to degrade the communication of Licensed User (LU). Orthogonal Frequency Division Multiplexing (OFDM) having a great spectral efficiency makes it an appropriate candidate to be used in spectrum sharing environment [6]. However, the high out of band radiation of CUs in adjacent bands due to side-lobes of OFDM subcarriers are more challenging and needs to be suppressed to an acceptable level [7-10].

To suppress side lobes we use techniques likes Guard band insertions and Windowing transmitted signal- in time domain. Guard band insertion at edges of OFDM signal can minimize or suppress the side-lobes, however, resulting with the wastage of spectral resources. Whereas, multiplying transmission signal (S) with windowing function resulting a prolonged symbol duration and hence spectral efficiency decreases [11-12].

In order to overcome the drawbacks of existing techniques, a new concept of well-defined subcarriers, known as Cancellation Carriers (CCs) is introduced[7], [13-14] where CCs are added at both edges of OFDM signal- shown in Fig. 1.

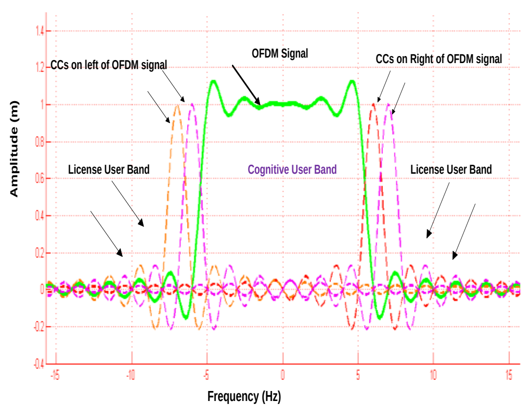

Fig. 1. OFDM Signal with CCs on both Edges of Signal

The weights of CCs are optimized to a level to enabling us to suppress the out band radiations of OFDM signal to maximum possible extent. Though regarded as a suitable technology for the CR physical layer, orthogonal frequency division multiplexing (OFDM) suffers from radiation external to the slot hindering the OFDM's spectrum sharing capabilities [13-14].

The potential application of this work is to suppress the out of band radiations of cognitive users in cognitive radio environment using OFDM platform. In proposed technique we undertake with cancellation subcarriers technique such the weight of CCs are calculated with an irritation technique called Least Mean Square (LMS) Technique.

The paper is organized as follows. In Section II we introduce the system model and formally state the problem of spectral shaping for suppressing the side lobe power. In Section III we discuss the cancellation subcarriers and weight updating technique called a traditional technique. In Section IV the proposed technique of LMS is discussed and the problem is addressed via LMS. In Section V the results weights and waveforms in optimization range are shown graphically and in tubular form. Section VI concludes the paper.

2. Model of OFDM Transmitter

We take a cognitive radio system where LUs and CUs are sharing the same frequency spectrum, in an OFDM platform to share the spectrum more effectively. To reduce the possibility of interference in other user operating band, different techniques like cancellation subcarriers and subcarriers weighting [9-10], [12] etc. are used

As illustrated in Fig. 2, an OFDM system of a data stream bits $ds_{(n)}$, where n = 1, 2, 3,…, n is modulated by a Phase-Shift-Keying (PSK) modulation scheme. The modulated data stream

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$ms_{(n)}$ is then passed on through serial to parallel converter for converting the data bits into parallel slower data stream, such that each bit is then transmitted on one of the N orthogonal sub-carriers in a sinc wave form. The Inverse Fast Fourier Transform (IFFT) of these signals at the receiver side are then passed through parallel to serial converter before being ultimately added to result in a composite single OFDM signal similar to what it was in original. While sending out through subcarriers slots, the scheme generates side-frequency bands, called side-lobes causing interference to the LU band, the suppression of which is desired [13-15].

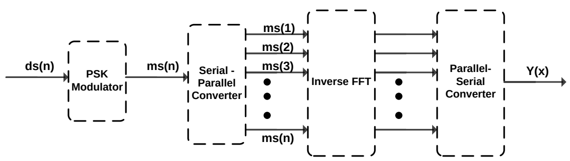

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Fig. 2. Schematic of an OFDM System

The spectrum of each data subcarrier $Y_n(x)$ of an OFDM system [14-15] is

$$Y_n(x) = d(mm)sinc(\pi(f - fshift)) \tag{1}$$

Where n= 0, 1, 2, n-1

$d(mm)$ is the amplitude (m) of a subcarrier and f is the entire frequency band whereas $fshift$ are the frequency slots where sinc wave of a data subcarriers are generated. And hence the spectrum of transmitted signal $Y(x)$ - the superposition of spectra of data carriers are

$$Y(x) = \sum_{n=-(N/2)}^{(N/2)} Yn(x) \tag{2}$$

Where $Y(x)$ is the transmitted signal and $Yn(x)$ is the individual subcarrier spectra taken from $-(N/2)$ to $+(N/2)$.

Fig. 3 illustrates the side lobes of an OFDM based data subcarriers, in other user's band and cause to downgrades the communication in adjacent bands. The more suppress side lobes in optimization range, the efficient to communicate for users in adjacent bands.

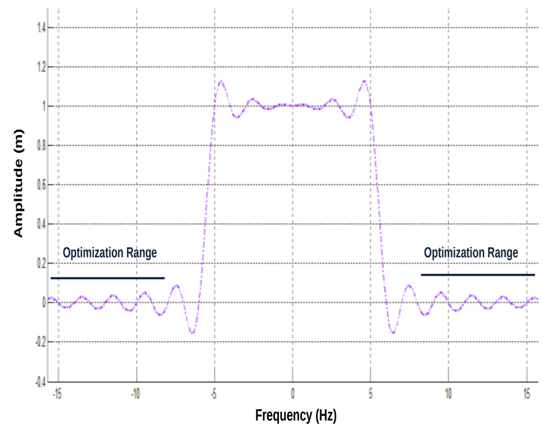

Fig.3. Superposition of data subcarriers and side lobes in adjacent bands

3. Cancellation Sub-carriers and weight optimization

As illustrated in Fig. 3, side lobes of an OFDM based data subcarriers cause service degradation in adjacent bands. These side-lobes are aimed to suppress to an optimized level- for effective communication. Cancelation subcarriers are added at both edges of OFDM data subcarriers spectrum such that CC at left are the same as of right of the spectrum of data subcarriers, as shown in Fig. 4

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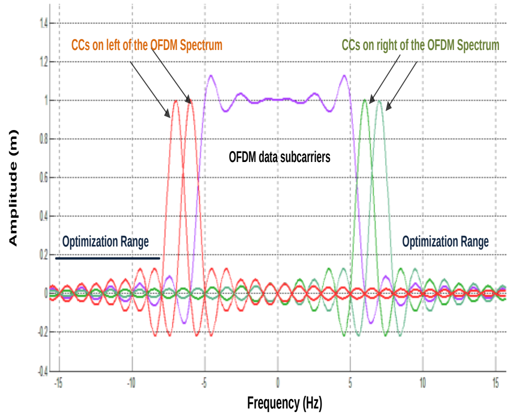

Fig. 4. Cancellation subcarriers on both sides of OFDM spectrum

For Weight Optimization, take sample points $\boldsymbol{p}$, both on left and right in the Optimization Range, such that each sample point is taken at the middle of each side lobe. Further the sample points on the left are equal to the right side in optimization area.

Let $\boldsymbol{p}$ be the total sample points taken in Optimization range [14-15], then vector value of $\boldsymbol{p}$ is given by

$$\boldsymbol{p} = [\boldsymbol{p_1}, \boldsymbol{p_2}, \boldsymbol{p_3}, ... , \boldsymbol{p_n}]^T \quad (3)$$

Where "n" is the total number of sample points taken in optimization range.

As cancellation subcarriers are added at both edges of OFDM spectrum such that the number of CCs at left hand side of the OFDM spectrum is equal to right hand side. Now, find out the vector values of all cancellation subcarrier at sample points $\boldsymbol{p}$.

Hence the **M**atrix value $\mathbf{S}$ of all cancellation subcarriers at sample points $\boldsymbol{p}$ [14-15] are given by

$$\mathbf{S} = [\boldsymbol{s_1}, \boldsymbol{s_2}, \boldsymbol{s_3}, . . \ \boldsymbol{s_n}]^T \quad (4)$$

Where "n" is the number of cancellation subcarrier added on both sides of the OFDM spectrum.

Further, the vector value $\boldsymbol{\partial}$ **o**f the weight of cancellation subcarriers [14-15] are given as

$$\boldsymbol{\partial} = [\boldsymbol{\partial_1}, \boldsymbol{\partial_2}, \boldsymbol{\partial_3} , . , \boldsymbol{\partial_n}]^T \quad (5)$$

Where "n" is equal to total weights of CCs.

To suppress the side-lobes in adjacent bands, the signal waveform of OFDM data subcarriers in optimization range must be the same as that of the cancellation subcarriers (in amplitude) but with polarity shift of 180^0. And hence cancel out the effect of each other in optimization range [13-15].

Mathematically, we have

$$\boldsymbol{p} + \mathbf{S}\boldsymbol{\partial} \cong \mathbf{0} \quad (6)$$

In other word

$$\min \boldsymbol{\partial} = \|\boldsymbol{p} + \boldsymbol{S}\boldsymbol{\partial}\|^2 \quad \text{st: } \|\boldsymbol{\partial}\|^2 \leq \alpha \quad (7)$$

Where α is an additional constraint limiting the power of Cancellation Carriers, so that an optimized cancellation subcarriers power is selected.

After solving Eq. 7, we have

$$\boldsymbol{\partial} = -(\boldsymbol{S}\boldsymbol{S}^T)^{-1}(\boldsymbol{p}\boldsymbol{S}^T) \quad (8)$$

Eq. 8 is the traditional equation used to find out the weights of cancellation subcarriers [13-15]

Updated weights from Eq.8 are put in Eq.6 and hence the side-lobes in optimization range are suppressed as shown in Fig. 5 and Fig. 6.

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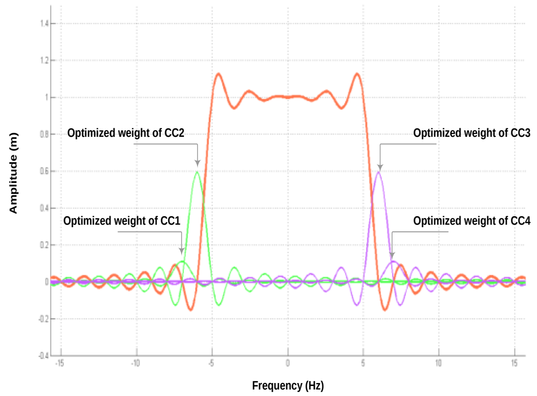


Fig. 5. Optimized Weights of Cancellation Subcarriers

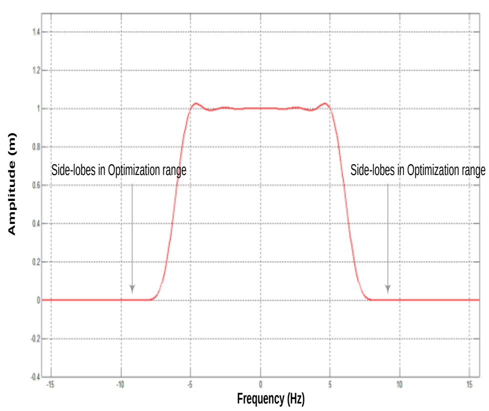


Fig.6. Side-lobes suppressed in Optimization range

4. Proposed Technique

In proposed method the weights of cancellation subcarriers are determine by coefficient updating technique called the Least Mean Square (LMS) Technique.

Weights or filter coefficients in LMS are updated in a way such that the algorithm is initiated by assuming a very small weight (most commonly close to zero) - that has been updated in each step and then error signal e(n) is calculated. The weights are updated till error signal e(n) reach to maximum optimum level. If error signals e(n) is increasing with the same weights after further iterations, then optimum error would never be achieved, so we have to reduce the weights.

Filter coefficient in a standard LMS technique can be updated by performing the following three (3) steps.

Step#.1

$$y(n) = w(n)u(n) \quad (9)$$

Where, $y(n)$ is the output signal of an adaptive filter, $w(n)$ is the system impulse response and $u(n)$ is the system input.

Step#. 2

$$e(n) = d(n) - y(n) \quad (10)$$

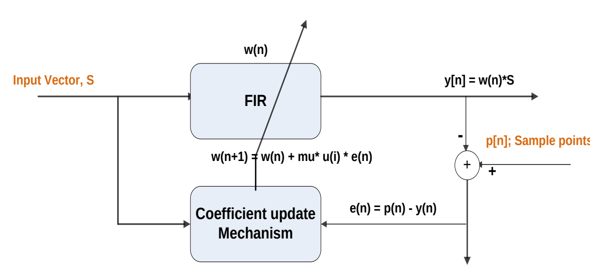
Where $e(n)$ is the error signal, which needs to be minimized to an extent to get required result and $d(n)$ is the desired response or signal.

Step#. 3

$$\bar{w}(n+1) = \bar{w}(n) + \rho \; e(n) \; \bar{u}(n) \quad (11)$$

Where $\bar{w}(n+1)$ the update is filter coefficient or weight- to be calculated and ρ is the step size of an adaptive filter. All these steps are repeated till optimal value of $e(n)$ is produced.

The block diagram of standard LMS Technique as shown in Fig. 7



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Referring to our problem of determining weights of cancellation subcarriers via LMS technique, the Matrix value $\boldsymbol{S}$ of cancellation subcarriers are given at the input of LMS and thus output $\boldsymbol{y}[\boldsymbol{n}]$ is produced after multiply with the vector value of system coefficient.

The vector values sample points $\boldsymbol{p}$ taken in optimization range are then added to the output $\boldsymbol{y}[\boldsymbol{n}]$ of LMS and hence the difference of both produces an error signal $\boldsymbol{e}[\boldsymbol{n}]$, shown in Fig. 7

The coefficient is then updated and applied to the system. The process is repeated till error signal $\boldsymbol{e}[\boldsymbol{n}]$ is minimized to an optimum level. And hence the optimum weights or coefficients are produced.

Then from Eq.6, vector values of the weights $\boldsymbol{w}[\boldsymbol{n}]$ are multiplied with the Matrix value $\boldsymbol{S}$ of cancellation subcarriers and then after adding with the input signal**,** we get suppressed side-lobes in optimization range.

5. Result and Discussion

The weight of cancellation subcarriers are determined by a technique called here a traditional technique deliberated in Eq. (8) [13-15]. The optimized weights thus produced are added with the data sample points after multiplied with the matrix values of cancellation subcarriers Eq. (6).

We get an optimized weight of CCs with proposed technique called the LMS Technique Eq. (11) and hence from Eq. (6) the subcarriers in optimization range are suppressed.

The weights of cancellation subcarriers produce from the traditional technique given in Eq. (8) is almost the same as that from Least Mean Square (LMS) given in Eq. (11) after multiple loops. These are shown as in Fig. 8 and Fig. 9 respectively.

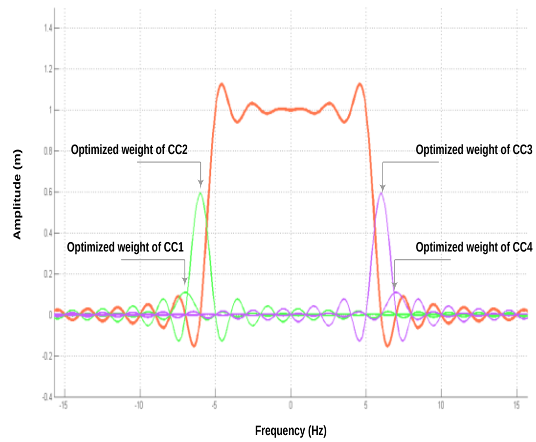

Fig.8. Optimized Weights of Cancellation Subcarriers via Traditional Technique

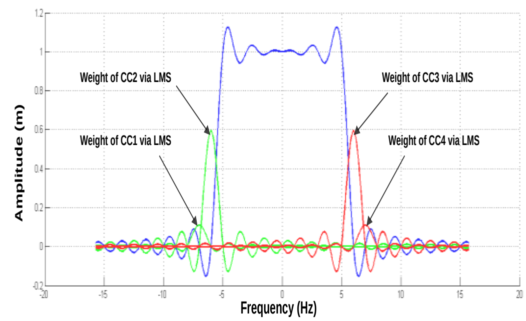

Fig.9. Optimized Weights of Cancellation Subcarriers via Least Mean Square

The resultant waveforms of side-lobes after optimized weighted cancellation subcarriers added with the side lobes of an OFDM spectrum in optimization range in Eq. (6) are shown in Fig. 10 and Fig.11.

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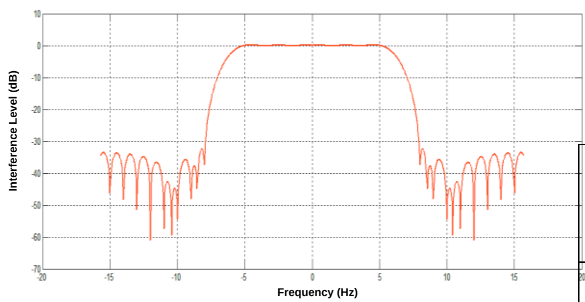

Fig. 10. Side-Lobes Suppressed via Traditional Technique

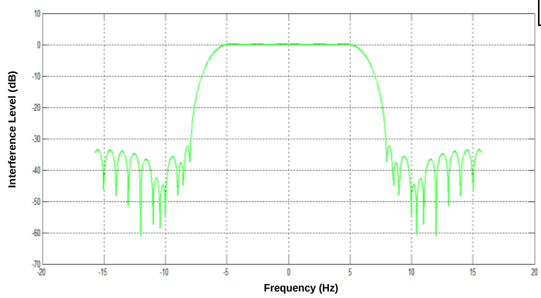

Fig.11. Side-Lobes Suppressed via Least Mean Square

The Fig. 10 and Fig. 11 shows that side lobes in adjacent bands are suppressed to -32dB (in both techniques) that will not cause to interfere to the Licensed Users communicating adjacent to the OFDM band.

The weights of cancellation subcarriers received from both techniques of the traditional [13-15] and those from LMS are almost the same as shown in Fig. 8 and Fig. 9 respectively. Hence the side lobes are suppressed and the results would be the same the same as indicated in plots in Fig. 10 and Fig. 11.

Updated weights of four (4) cancellation subcarriers; such that two (2) on each side; for both the standard and Least Mean Square techniques are shown in table 1

Table 1: Updated weights via Traditional and LM S Technique

Weight Calculation Techniques	$Weight_1$ (L)	$Weight_2$ (L)	$Weight_3$ (R)	$Weight_4$ (R)
Traditional Technique	0.1096	0.5932	0.5932	0.1096
Least Mean Square (LMS)	0.1095	0.5932	0.5932	0.1096

6. Conclusion

The paper has discussed the importance of dynamic career access for making full use of the frequency spectrum, soon would become a rare commodity. The concepts of cognitive recognition are presented for application in OFDM a technique with a potential for MIMO application. OFDM is shown to be associated with the issues of side lobes generation causing interference to the multichannel slots in the spectrum. The cancellation of side lobes is demonstrated by an adaptive cancellation technique the LMS Technique, which is compared with the results from similar cancellation technique. The results of this work have got potential for application in Multiple Input and Multiple Output (MIMO) wireless sensors networks.

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