Efficient High Out of Band Reduction for Cognitive Radio Systems

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Abstract - **Orthogonal frequency division multiplexing (OFDM) a multicarrier method is a best candidate for the physics layer of cognitive radio (CR) system because of its ability to fill the spectral holes by turning ON and OFF the individual subcarriers and accordingly utilizes the spectral resources efficiently. However, the sidelobes of OFDM subcarriers utilized by un-licensed users enters the spectral domain of the licensed users, concludes in high-out-of-band (HOOB) radiation, causes severe interference to the neighboring users. In this paper, a generalized structure of OFDM is presented, that has an ability of categorizing any HOOB radiation techniques, irrespective of whether one or several techniques have been applied. Based on that structure, two novel hybrid techniques have been recommended, that has an ability of reducing the HOOB radiation in two phases. In the first phase the HOOB radiation is reduced by using genetic and firefly algorithm-based cancellation carriers while additional reduction is achieved by utilizing generalized sidelobe canceler in the second phase. Simulations results shows that the recommended techniques reducehigh out of band radiation better in contrary to the available techniques.**

Index Terms **-** cognitive radio, cancellation carriers, dynamic spectrum access, firefly algorithm, genetic algorithm, generalized sidelobe canceller, high-out-of-band radiation, orthogonal frequency division multiplexing, power spectral density.

I.INTRODUCTION

Rapid growth in wireless communication systems and the requirements for high transmission speed and resources during recent decades results in spectrum scarcity[1], [2]. The spectrum measurement done by Federal communication commission (FCC) in several parts of the world in several time intervalsshows that the biggest challenge is accessing a spectrum instead of spectrum shortage. Most often the spectrum is either engaged or partially engaged. The reason behind these conclusions are the conventionalmonitoring and control systems that limits the capable users to get an access. The above situation leads the agencies to the conclusion:The policy related to the spectrum access should be more tractable, second compatible technology should be available for spectrum sharing policy. Based on this conclusion their suggestions were, allocation of spectral resources to several different users operating in a same frequency band dynamically or randomly, and un-restricted access of spectral resources to every user. In the end they haveone thing in common i.e. Dynamic spectrum access(DSA) [2], [3]. A novel spectrum sharing concept that permit the un-licensed users (UL) to gain access to the spectral white spaces. A promising technology that helps in increasing the spectrum consumption. After thatspectrum governing bodies started implementing DSA. In response J. the idea of cognitive radio (CR) have been presented in 1999[4]–[6]. A novel technique of introducingwireless communication systems. The main objective of this scheme is to present the wireless communicationvia DSA, to improve the capabilityand consumption of wireless communicationand solving the problem of spectrum underutilization. Multicarrier techniques are one ofthe best candidate for the physical layer of CR systems [7]. Allocation of the spectrumwhite spaces to the UL users that are co-located with the spectrum used by the licensed users (LU), multicarrier techniqueshave a flexibility to fill in that spaces and thereforeemploys the spectral resources effectively. Orthogonal frequency division multiplexing (OFDM) is an appropriate candidate for this purpose [8]–[10]. The main idea of OFDM is splitting up of the frequency selective channel into multiple frequency flat fading channels that are parallel as well as orthogonal. As the subcarriers of OFDM are overlapping in nature the spectral efficiency of the system becomes high, overcoming the problem of spectrum shortage and achieves the high data rate transmission. As OFDM has capability of modifying its transmitted spectrum according to the situationbyswitching ON and OFF the particular subcarriers, because of this it is the best multicarrier technique for the spectrum sharing systems but the main issue in OFDM systems is the suppression of sidelobes are the transmitter.

The interference suppression from the UL user to the LU is a difficult jobsince the transmission of a LU should not be disrupted from the transmission of neighboring and or UL user. In OFDM-based CR systems, UL users utilize subcarriers that are unoccupied by theLUs.Since the sidelobes of OFDM subcarriers are crumbledas $\frac{1}{x}$, the sidelobes of those subcarriers utilized by UL users enters the spectral domain of LU results in High-out-of-band (HOOB) radiation, causing severe interference to the adjacentusers and limits that use of available spectral resources in an efficient manner. Due to the high sidelobes it is not sufficient to ON and OFF the individual subcarriers in those channels where licensed users are operating. To tackle that problem different techniques are found in the literature that includes cancellation carriers [11]–[17], subcarrier weightings [18], [19], filtering [20], windowing [21], [22], precoding [23]–[28], multiple choice sequence [29] and constellation expansion [30], [31] etc.

In this paper, generalized structure of OFDM is presented, capable of categorizing any HOOB radiation reduction techniques, regardless ifone or various techniques have been applied and in accordance to the place where to apply, this structure is classifiedas: frequency domain and time domain techniques.Frequency domain is further divided into two subgroups, symbol mapping and precoding. Based on this generalized structure, we have proposed two new hybrid techniques that are capable of reducing HOOB radiation in two phases. In first phase, HOOB is reduced using genetic and firefly algorithm-based cancellation carriers while further reduction is achieved using generalized sidelobe canceller (GSC) in the second phase. The usefulness and feasibility of the proposed techniques is shown using computer simulations done in MATLAB, which shows that far superior reduction of HOOB radiation is accomplished in contrary to the available techniques.

The rest of the paper is organized as follows: first section is about the system model followed by proposed techniques and simulation results while conclusion is given in the end of the paper.

II. SYSTEM MODEL

The block diagram of generalized OFDM structure is shown in Fig. 1.

As depicted in the figure 1 the input bit stream mapped with M – PSK / M – QAM modulation followed by serial to parallel (S/P) conversion, whose output $\mathbf{b}_l = \left[b_{1,l}, b_{2,l}, ..., b_{N,l}\right]^T$ represents the modulated symbol vector with N symbols in lth time slot. After that each vector then passes through frequency domain block, where the frequency domain HOOB radiation reduction techniques that includes symbol mapping and precoding are applied. The output of frequency domain block is given by:

$$\mathbf{d}_l = \mathbf{D}\mathbf{c}_l \tag{1}$$

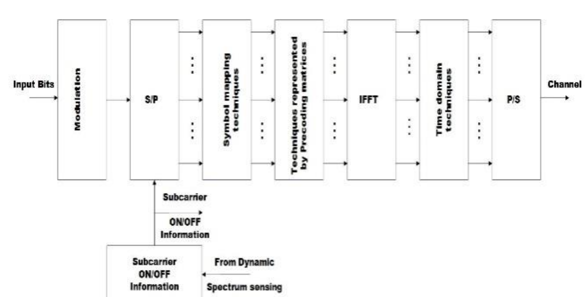

Figure 1: Generalized structure of OFDM

Where **D** represents the precoding matrix while $\mathbf{c}_l$ represents the output of symbol mapping from $\mathbf{b}_l$. It should be noted that here the dimension of vector $\mathbf{d}_l$ is greater than or equal to the dimension of vector $\mathbf{c}_l$ while the dimension of vector $\mathbf{c}_l$ is greater than or equal to the dimension of symbol vector $\mathbf{b}_l$. The output from the frequency domain block is then passed through inverse fast Fourier transformation (IFFT) block and after insertion of cyclic prefix (CP) given by:

$$\mathbf{s}_l = \mathbf{FDc}_l \quad (2)$$

After that the vector $\mathbf{s}_l$ passes through time domain block, where the time domain HOOB radiation reduction techniques are applied whose output is given by:

$$\mathbf{x}_l = \mathbf{HFDc}_l \quad (3)$$

Where the matrix **H** represents windowing, filtering etc.

The *l*th transmitted continuous time domain signal for a given input modulated symbols $\mathbf{d}_l$ given in equation (1) is given by:

$$x_l(t) = \sum_{i=1}^{N} d_{i,l} e^{j2\pi \frac{f_i}{T_d} t}, \ -T_{CP} \le t \le T_d \quad (4)$$

Where $d_{i,l}$ represents the *i*th element of vector bl, N represents the total number of available subcarriers, T_d represents the duration of one OFDM symbol without CP, T_{CP} represents the duration of CP, so therefore $T = T_d + T_{CP}$ will be the duration of one OFDM symbol with CP and f_i represents the center frequency of *i*th subcarrier.

In frequency domain signal in equation (4) is represented as:

$$X_l(f) = \sum_{i=1}^{N} d_{i,l} s_i(f) \quad (5)$$

Where

$$s_i(f) = \frac{e^{j\pi\left(\frac{f_i}{T_d} - f\right)(T_d - T_{CP})}}{\pi\left(\frac{f_i}{T_d} - f\right)T} \sin\left(\pi\left(\frac{f_i}{T_d} - f\right)T\right) \quad (6)$$

The PSD of signal given in equation (5) is:

$$P_l(f) = E\left\{\left|X_l(f)\right|^2\right\} \quad (7)$$

$$P_l(f) = \mathbf{s}(f) E\left(\mathbf{dd}^H\right) \mathbf{s}^*(f) \quad (8)$$

Where $\mathbf{s}(f) = \left[s_1(f), s_2(f), ..., s_N(f)\right]^T$. To protect the licensed users from the HOOB radiation of un-licensed users, the PSD should be minimized.

III.PROPOSED TECHNIQUE

In this section, details about two proposed hybrid techniques is presented. These techniques work in two phases. During first phase the HOOB radiation is reduced using genetic, firefly algorithm based cancellation carriers [32] that are represented by precoding matrices, while further reduction is achieved using GSC[33] in the second phase.

A. Phase I

In this phase genetic and firefly algorithmbased cancellation carriers are used that are represented by precoding matrices. Assuming that the vector $\mathbf{b}_l$ contains the data symbolsall of them are equally probable and mutuallyindependent.

$$E\left[\mathbf{b}_l \mathbf{b}_l^H\right] = \mathbf{I}_{N\times N} \quad (9)$$

Here $\mathbf{I}$ depict identity matrix of size $N \times N$, the vector is then passed through S/P block followed by frequency domain block, whose output is given in equation (1).

In equation (1) $\mathbf{d}_l$ will now represent the precoded vector having dimension $M \times 1$, $\mathbf{c}_l = \mathbf{b}_l$ having dimension $N \times 1$(Remember thatsize of $\mathbf{d}_l$ will be largerthan the size of $\mathbf{c}_l$), where $K = M - N$ depicts the total number of cancellation carriers injected on one and the other end of the OFDM signal and $\mathbf{D}$ depicts the precoding matrix of size $M \times N$ given by:

$$\mathbf{D} = \begin{bmatrix} \mathbf{A}_{\frac{K}{2}\times N} \\ \mathbf{I}_{N\times N} \\ \mathbf{B}_{\frac{K}{2}\times N} \end{bmatrix} \quad (10)$$

The identity matrix $\mathbf{I}$ in the equation (10) shows the amplitudes of information subcarriers while matrix $\mathbf{A}$ and $\mathbf{B}$ contains the optimized amplitudes of left and right handed cancellation carriers, calculated using genetic algorithm and firefly algorithm. The final signal in frequency domain after the phase I having reduced HOOB radiation will be given by:

$$T_l\left(f\right) = \sum_{j=1}^{K/2} d_{l,j} s_j\left(f\right) + \sum_{i=1}^{N} d_{l,i} s_i\left(f\right) + \sum_{j=\frac{K}{2}+1}^{K} d_{l,j} s_j\left(f\right) \quad (11)$$

B. Phase II

In phase II, signal of equation (11) is first divided into $N_k$samples, collected in a vector $\mathbf{z}$ and is then passed through GSC, another frequency domain radiation reduction technique. It is divided into the upper and the lowersections. The upper section consists of a quiescent weight vector $\mathbf{w}_q$ that allow the input signal to pass through it and provides essentialincrease to the specified portion of the signal,fulfilling the constraints, while the lower portion contains the blocking matrix $\mathbf{B}$ and adaptive weight vector $\mathbf{w}_a$.The job of a$\mathbf{B}$ is to blocks that specified portion of the signal and let the rest of the signal to pass, while the function of $\mathbf{w}_a$ is to provide essentialincrease to the rest of the signal. Finally the signal from the two portions of the GSC when subtracted results in the reduction of HOOB radiation.

The expressions for a well-known result of GSC are given as:

$$\mathbf{w}_q^H = \mathbf{g}^H\left(\mathbf{C}^H\mathbf{C}\right)^{-1}\mathbf{C}^H \quad (12)$$

$$\mathbf{B} = null\left(\mathbf{C}^H\right) \quad (13)$$

Where equation (12) depicts the expression for $\mathbf{w}_q^H$ of size $N_k \times 1$, $\mathbf{C}$ depicts the constraint matrix of size $N_k \times N$,with N steering vectors given by:

$$\mathbf{C} = \left[\mathbf{s}_1, \mathbf{s}_2, ..., \mathbf{s}_N\right] \quad (14)$$

Where N depictsthe number of subcarrier frequencies in the specified portion of the signal, $\mathbf{s}_i = \left[s_1, s_2, ..., s_{N_k}\right]^T$ is the ith steering vector of size $N_k \times 1$ whereas $\mathbf{g}$ depicts the gain vector that contain gain associated to each steering vector. Finally $\mathbf{B}$ depicts the null space of size $N_k \times (N_k - N)$ such that:

$$\mathbf{C}^H\mathbf{B} = \mathbf{O} \quad (15)$$

Here $\mathbf{O}$ depicts the null matrix of size $N \times (N_k - N)$. The remaining signal that is preserved in the lower portion of GSC is then subtracted from the signal in the upper portion that contain the full signal. The output of GSC is given by:

$$Y_l(f) = \mathbf{w}_q^H \mathbf{z} - \mathbf{w}_a^H \mathbf{B}\mathbf{z} \qquad (16)$$

$$Y_l(f) = \left(\mathbf{w}_q - \mathbf{B}\mathbf{w}_a\right)^H \mathbf{z} \qquad (17)$$

The optimum adaptive weight vector $\mathbf{w}_a^H$, in the lower portion denoted by $\mathbf{w}_{a(opt)}^H$ is used for minimization the cost function.

$$J(\mathbf{w}_a) = \left(\mathbf{w}_q - \mathbf{B}\mathbf{w}_a\right)^H \mathbf{R}\left(\mathbf{w}_q - \mathbf{B}\mathbf{w}_a\right) \qquad (18)$$

$$\mathbf{w}_{a(opt)}^H = \mathbf{w}_q^H \mathbf{R}\mathbf{B}\left(\mathbf{B}^H \mathbf{R}\mathbf{B}\right)^{-1} \qquad (19)$$

IV.SIMULATIONS & RESULTS

The effectiveness of our proposed techniques in the form of computer simulations in MATLAB are discussed in this section. Here proposed technique I is a combination of genetic algorithm-based cancellation carriers with generalized sidelobe canceller and proposed technique II is a combination of firefly based genetic algorithm with generalized sidelobe canceller. We are assuming that an unlicensed user has detected one spectrum hole and aredivided into 16 subchannels, each of them is modulated using Binary Pulse shift keying with normalized power equal to 1. For reduction of HOOB radiation in phase I, total of $K = 4$ cancellation carries is used on either side of the OFDM signal and total of 16 samples are considered in the optimization region. In phase II, the signal is divided into 501 samples, while the number of frequency subcarriers are taken as 16.

The effectiveness of our proposed techniques in the form of computer simulations is shown in figures 2 – 8, that clearly shows that our proposed techniques reduces the High out of band radiation better as compared to the existing techniques found in the literature and proposed technique II shows slightly better results as compared to proposed technique I.

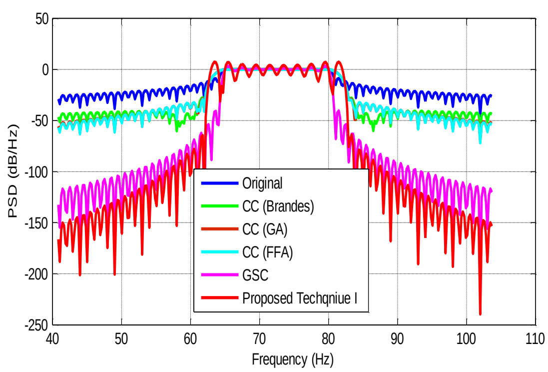

Fig. 2. Comparison of Proposed technique I with others

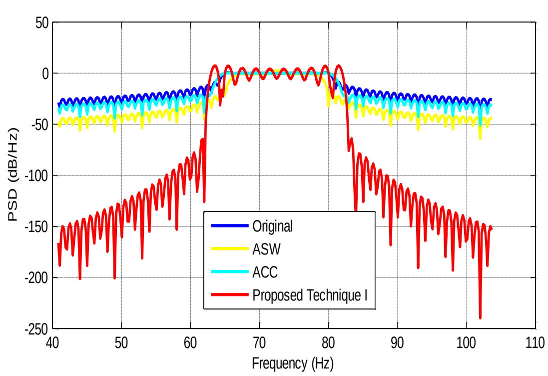

Fig. 3 Comparison of Proposed technique I with others

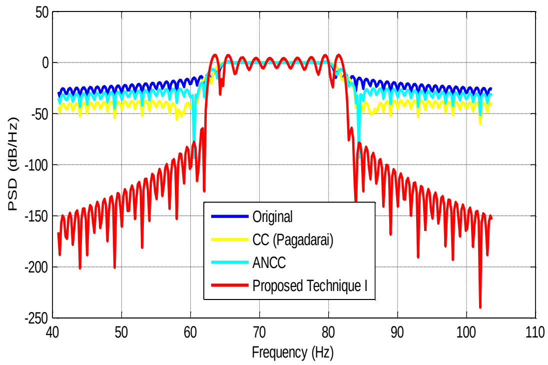

Fig. 4 Comparison of Proposed technique I with others

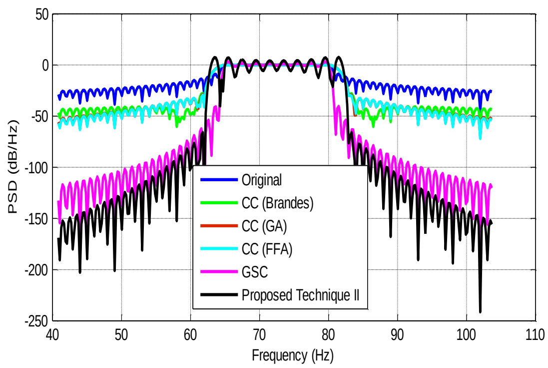

Fig 5. Comparison of Proposed technique II with others

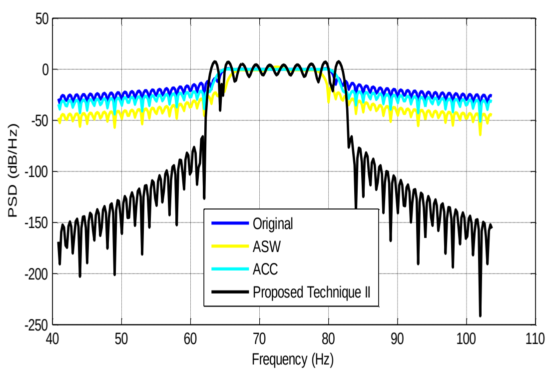

Fig 6. Comparison of Proposed technique II with others

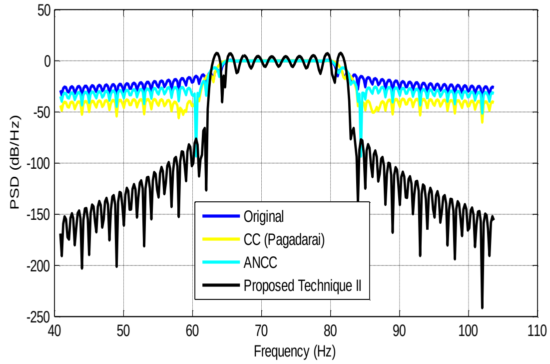

Fig 7. Comparison of Proposed technique II with others

V. CONCLUSION

Generalized structure of orthogonal frequency division multiplexing have been discussed in this paper. It has a capability of implementing any High out of band radiation technique, irrespective of whether one or various techniques are applied.Based on that two hybrid techniques have been proposed for the reduction of High out of band radiation. These techniques works in two phases, In the first phase the radiation is reduced using genetic and firefly algorithm based cancellation carriers, while in the second phase the radiation is further reduced using generalized sidelobe canceller. Computer simulations in MATLAB shows that the proposed techniques reduces the radiation better as compared to the existing technique found in the literature.

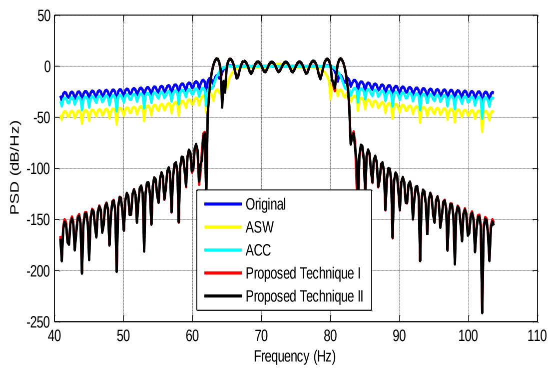

Fig 8. Performance comparison of Proposed technique II with existing techniques

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