Sidelobe Reduction in Cognitive Radio Systems Using Hybrid Technique

Atif Elahi, Ijaz Mansoor Qureshi, Mehreen Atif, Noor Gul

Abstract—Orthogonal frequency division multiplexing (OFDM) is one of the best candidates for dynamic spectrum access due to its flexibility of spectrum shaping. However, the high sidelobes of the OFDM signal that result in high out-of-band radiation, introduce significant interference to the users operating in its vicinity. This problem becomes more critical in cognitive radio (CR) system that enables the secondary users (SUs) users to access the spectrum holes not used by the primary users (PUs) at that time. In this paper, we present a generalized OFDM framework that has a capability of describing any sidelobe suppression techniques, despite of whether one or a number of techniques are used. Based on that framework, we propose cancellation carrier (CC) technique in conjunction with the generalized sidelobe canceller (GSC) to reduce the out-of-band radiation in the region where the licensed users are operating. Simulation results show that the proposed technique can reduce the out-of-band radiation better when compared with the existing techniques found in the literature.

Keywords—Cognitive radio, cancellation carriers, generalized sidelobe canceller, out-of-band radiation, orthogonal frequency division multiplexing.

I. INTRODUCTION

In order to fulfill the increasing demand for high data rate and wireless services and at the same time coming up with the enhanced spectrum utilization, researches from all over the world have given a suggestion to utilize the spectrum resources efficiently [1], [2]. Spectrum policy task force (SPTF) appointed from Federal Communication Commission (FCC) in its report has shown that spectrum in use of licensed resources efficiently [1], [2]. Spectrum policy task force (FCC) in its report has shown that spectrum in use of licensed


given that

\[ \sum_{\kappa=0}^{\kappa-1} g_\kappa \exp \left( j 2 \pi \frac{n}{T_s} \right) I(t) \]

where \( T_s \) is the duration of symbol, and \( I(t) \) represents the windowing function defined as:

Atif Elahi is with the Department of Electrical Engineering, Faculty of Engineering and Technology, International Islamic University, Islamabad, 44000, Pakistan (corresponding author, phone: +92-332-9202-431, +92-310-9532-282, e-mail: atif.phdee40@iiu.edu.pk).

Ijaz Mansoor Qureshi is with Department of Electrical Engineering, Air University Islamabad, 44000, Pakistan (e-mail: imqureshi@mail.au.edu.pk).

Mehreen is with the Department of Statistics, Islamia College University Peshawar, 25000, Pakistan (e-mail: atif.phdee@hotmail.com).

Noor Gul is with Department of Electrical Engineering, Faculty of Engineering and Technology, International Islamic University, Islamabad, 44000, Pakistan (e-mail: noor.phdee51@iiu.edu.pk).
Here, $T_g$ represents the length of guard interval to eliminate the effect of intersymbol interference (ISI).

Frequency domain representation of a signal given in (1) as shown in Fig. 1 is obtained by taking its fast Fourier transformation:

$$X_r(f) = \sum_{n=0}^{N_r-1} g_n^r s_n(f)$$

where $s_n(f) = T \exp \left( -j \pi \left( T_s - T_g \right) \left( f - \frac{n}{T_s} \right) \right) \sin c \left( T \left( f - \frac{n}{T_s} \right) \right)$

and $T$ represents OFDM symbol duration.

Power spectral density of the transmitted OFDM signal given in (3) of $r$th SU is given as:

$$p_r(f) = \frac{1}{T} E \left[ \left| X_r(f) \right|^2 \right] = \frac{1}{T} s^H(f) E(g g^H) s'(f) \tag{4}$$

Here, $g = [g_0, g_1, ..., g_{N_r-1}]^T$ and $s(f) = [s_0(f), s_1(f), ..., s_{N_r-1}(f)]^T$, respectively. As shown in Fig. 1, the sidelobes of the transmitted OFDM signal of $r$th SU are a cause out-of-band radiation which gives severe interference to the neighboring users including PUs and SUs.

To protect the neighboring users from such an interference, the sidelobe should be suppressed effectively.

III. PROPOSED TECHNIQUES

In this section, the proposed technique that consists of CC in conjunction with GSC based on our proposed generalized OFDM framework is presented as shown in Fig. 2.

Suppose that the input bit stream $a_r = [a_0, a_1, ..., a_{N_r-1}]^T$ of $r$th SU is first modulated with Phase shift keying (PSK), $g = [g_0, g_1, ..., g_{N_r-1}]^T$ is passed through serial to parallel (S/P) block.

These modulated symbols are supposed to be identically and independently distributed (iid), i.e.

$$E \left[ gg^H \right] = I_{N_r \times N_r} \tag{5}$$

where $I$ represents the identity matrix having dimension $N_r \times N_r$. After S/P, the symbols are then passed through frequency domain block whose output is given by:

$$d = Qg \tag{6}$$

where $d$ represents the pre-coded symbol vector of $r$th SU.
having dimension $M_r \times 1$ and $M_r > N_r$, where $L = (M_r - N_r)$ represents the number of CCs inserted on either sides of the OFDM signal of the $r$th SU, while $Q$ can be treated as precoding matrix having dimension $M_r \times N_r$ representing CCs technique defined as:

$$Q = \begin{bmatrix} A_{M_r \times N_r} \\ I_{N_r \times N_r} \\ B_{M_r \times N_r} \end{bmatrix}$$  

(7)

Here, in (7), the identity matrix $I$ represents the weights of the data subcarriers, while the two matrices $A$ and $B$ represent the optimized weights of the CCs. The resulting signal of $r$th SU will then be given by:

$$T_r(f) = \sum_{j=1}^{M_r} d_j s_j(f) + \sum_{n=1}^{N_r} d_n s_n(f) + \sum_{j=1}^{M_r} d_j s_j(f)$$  

(8)

The signal given in (8) has a suppressed sidelobe. For further suppression, the signal is then sampled into $W_r$ samples and are collected in vector $y_r$ with dimension $W_r \times 1$ and passed through GSC.

GSC is the straightforward form of linearly constraint minimum variance (LCMV), which converts the minimization problem having some constraint into an unconstraint [20]. It consists of two branches, the upper one and the lower one. The upper one contains a vector called as quiescent weight vector represented by $w_q$ that preserves the incoming signal while the lower branch consists of blocking matrix $C$ followed by adaptive weight vector $w_a$. The blocking matrix $C$ blocks the wanted portion of the signals and allows the un-wanted portion, i.e. allows the sidelobes while blocking the rest of the signal, and the adaptive weight vector $w_a$ adjusts the amplitudes of the sidelobes such that when the signal from the upper branch and lower branch are subtracted, we get a signal with a suppressed sidelobe.

The output of the GSC is given by:

$$Z_r(f) = (w_q^H - w_a^H C)y_r$$  

(9)

Here, in (9), the term $w_a$ is the adaptive weight vector whose function is to minimize the sidelobe that is a cause of out-of-band radiation. This adaptive weight vector modifies the amplitudes of the sidelobes such that, when the signals from the upper and lower branch subtract from each other, it will result in a signal with reduced sidelobes. The expression for $w_q$, $w_a$ and $C$ is found in [19] is given by:

$$w_q = C_a \left( C_a^H C_a \right)^{-1} f$$

$$C = \text{null} \left( C_a^H \right)$$

(10)

The optimized adaptive weight vector $w_{a(\text{opt})}$ is the one that minimizes the cost function given by:

$$J(w_a) = (w_q - Cw_a)^H R_y (w_q - Cw_a)$$  

(11)

i.e. $\min_{w_a} (w_q - Cw_a)^H R_y (w_q - Cw_a)$ and on solving gives:

$$w_{a(\text{opt})} = \left( C^H R_y B \right)^{-1} C^H R_y w_q$$  

(12)

Finally, we get:

$$w_{\text{GSC}} = w_q - Cw_{a(\text{opt})}$$  

(13)

### IV. SIMULATIONS AND RESULTS

In this section, we consider that single SU operating in a spectrum hole detected with the help of DSS. Suppose that this SU divides the available spectrum holes into 16 sub-channels also called as subcarriers, in which e.g. a 64 – point FFT is applied for OFDM modulation. Each sub-channel is BPSK modulated whose power is normalized to 1. Here we are considering two CCs each on the left and right side of the data subcarriers. 20 sidelobes are reserved on both sides of the spectrum with one frequency sample taken in the middle of every sidelobe, resulting in $K_l = K_r = 10$ samples. For GSC, 301 samples of the signals are collected in vector $y$. Figs. 3-5 show the performance comparison of our proposed technique with different existing techniques found in the literature in terms of PSD that shows that our proposed technique gets better reduction of sidelobes as compared to the exiting techniques.

---

**Fig. 3** Comparison of proposed technique with existing techniques
In this paper, we have given a generalized OFDM framework that has an ability of describing any out-of-band radiation reduction techniques whether we are using single or multiple techniques. Based on that framework, we have proposed a technique that is a combination of CCs’ technique which can also be represented with pre-coding matrices with GSC. The usefulness and reliability of the proposed technique in term of power spectral density is compared with the other techniques found in literature, which shows that our proposed technique gets better reduction of sidelobes.

V. CONCLUSION

In this paper, we have given a generalized OFDM framework that has an ability of describing any out-of-band radiation reduction techniques whether we are using single or multiple techniques. Based on that framework, we have proposed a technique that is a combination of CCs’ technique which can also be represented with pre-coding matrices with GSC. The usefulness and reliability of the proposed technique in term of power spectral density is compared with the other techniques found in literature, which shows that our proposed technique gets better reduction of sidelobes.

REFERENCES