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Performance of OFDM-Based Cognitive Radio

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ABSTRACT*: The effect of spectrum sensing errors on the performance of orthogonal frequency division multiplexing based cognitive radio transmission can be evaluated by deriving the expression for the average bit error rate. This depends on various parameters like transmission and spectrum sensing parameters. Here, we consider the case with adding a carrier frequency offset. The spectrum sensing errors of OFDM-based cognitive radio transmission causes performance degradation of the system due to interference and depends on transmission and spectrum sensing parameters. This can be reduced by using a convex optimization technique like beamforming in OFDM-based cognitive radio.*

IndexTerms- *, bit error rate, cognitive radio system, convex optimization , OFDM, signal to interference noise ratio, spectrum sensing.*

I. INTRODUCTION

Cognitive radio is a tempting solution to the spectral crowding problem by introducing the opportunistic usage of frequency bands that are not heavily occupied by licensed users since they cannot be utilized by users other than the license owners at the moment. Orthogonal Frequency Division Multiplexing (OFDM) is one of the most widely used technologies in current wireless communication systems which has the potential of fulfilling the requirements of cognitive radios inherently or with small changes. With this ,the interoperability among the different protocols become easier which is one of the most important requirements in Cognitive radio. Cognitive radio is a solution to the problem of 'spectrum scarcity' caused by the development of wireless services [1]. It reuses the licenced frequency bands that are not occupied by the licenced users at some specific time and in some specific location for the unlicenced users[2]. The cognitive radio has two important functions that can be classified as: spectrum sensing that detects whether the licenced band is free and the transmission of data if the licenced band is free.

According to IEEE 802.22 standard [3], the cognitive radio uses two frame relay. In this, the OFDM transmission on the second period is based on the sensing result from the first period. In first period, it checks whether the licenced user or the primary user is free. If the primary user, hence hereby forth called, is free then that band is being used by the secondary user. Hence, the data transmission occurs. There are also a number of previous works on different aspects of the OFDM-based cognitive radio system . For example, in [5] and [6], interference detection and cancellation for the OFDM-based cognitive radio system was studied. In [7] and [8], resource allocation for the OFDM-based cognitive radio system was studied. In [9], frequency synchronization in the OFDM-based cognitive radio system was considered. In [10] - [13], new spectrum sensing methods based on the characteristics of the OFDM signal were proposed using either energy detection, optimal Neyman-Pearson detection, autocorrelation detection or cyclostationarity feature detection, respectively. However, none of these works have evaluated the effect of the spectrum sensing errors on the performance of the OFDM-based cognitive radio transmission.

According to this paper, the effect of the sensing errors on the performance of the OFDM-based cognitive radio system is analysed in terms of the average bit error rate. The expressions for the average bit error rate was derived for the analysis based on different spectrum sensing and OFDM transmission parameters. Here, we are considering the case by adding a carrier frequency offset. Carrier frequency offset (CFO) can be induced by poor oscillation alignments at the receiver[14], time delay caused by multipath fading or imperfect synchronization[15]. In other words, CFO can be defined as the frequency shift on the received signals in the time domain. As a result, in the frequency domain, the received signal in any subcarrier will depend not only on the transmitted signal from that subcarrier, but also signals from the other subcarriers. The latter is also known as the inter-carrier interference (ICI).

Here, the spectrum sensing errors causes the performance degradation of the OFDM-based cognitive radio system due to interference sensing parameters. The interference caused due to the spectrum sensing errors can be reduced by a convex optimization method like beamforming. For small to medium values of the operating SNR, the interference caused by the sensing errors dominates, while for large values of operating SNR, the interference caused by the carrier frequency offset dominates.

The rest of the paper is organised as follows: Section II deals with the system model describing the spectrum sensing and the OFDM data transmission. Section III deals with the analysis of the paper which describes the addition of carrier frequency offset and a convex optimization method like beamforming. The section IV deals with the results and the discussions. Section V deals with the conclusion and the future work. The above interference calculation depends on the transmission and spectrum sensing parameters.

II. SYSTEM MODEL

Consider an OFDM-based cognitive radio system that operates on W subcarriers and that owned by the licensed users, referred to as the primary user . The cognitive radio user is referred to as the secondary user , will only access these licensed subcarriers when the primary user is detected absent. The secondary transmission is conducted through consecutive frames periods. In each frame period, the first part is the spectrum sensing period and the second part is the OFDM data transmission period. In the spectrum sensing part, all the secondary users stop their data transmission and listen to the W subcarriers to decide whether the primary user is absent. If the primary user is detected in the subcarriers during the sensing period, then the secondary users will not transmit any data in the following data transmission period in those subcarriers but will wait until the next frame arrives to conduct the spectrum sensing of those subcarriers again. If the primary user (licenced) is not detected in the subcarriers during this spectrum sensing period, the secondary users(unlicenced) will transmit their OFDM data in the second part of the data frame period. Assume that among the W subcarriers, N of them are detected free and used for the cognitive radio transmission, where $N \leq W$. Also, assume that the primary activity is semistatic so that the primary users status is not changing during one secondary frame. The cognitive radio can be induced in the OFDM transmission by doing the energy detection method of spectrum sensing on each of the subcarriers of the orthogonal frequency division multiplexing. Hence, the primary user (licenced) and secondary user can be identified separately.

2.1 . Spectrum sensing

Assume that N detected free subcarriers used for cognitive transmission are divided into Q blocks where the q-th block contains Nq subcarriers such that $\sum_{q=1}^{Q} Nq = N$. Each block corresponds to any one channel of the primary user or one primary user. This is also a case when the cognitive radio system operates in the licensed frequency bands of the narrowband system such that the licensed bands from several primary users have to be used in an exact order to achieve high data rate. Let the ordered subcarrier index be named from 1 to N. Denote $\mathbf{ix}q$ be denoted as the $1 \times Nq$ vector that contains the subcarrier indexes in the q-th block. Considering an example of above, if the second block contains the eighth, ninth, tenth, eleventh subcarriers, one has $N2 = 4$ and $\mathbf{ix}2 = [8\ 9\ 10\ 11]$. Denote the probability $Pq(H0)$ as the a priori probability that the q-th block is vacant and where $H0$ represents the hypothesis that the licensed block is free. Also, denote that the probability $Pq(H1)$ as the a priori probability that the q-th block is occupied and where $H1$ represents the hypothesis that the licensed user block is busy. As mentioned before, each block of the radio transmission corresponds to the same channel of one primary user or one narrowband primary user out of several primary users. Therefore, it is assumed that the subcarriers in the same block have the same availability. The values of $Pq(H0)$ and $Pq(H1)$ depends on how busy the primary traffic in the q-th block is.

In the first part of the secondary frame period, the spectrum sensing is performed. The sensing accuracy depends on two important measures: the probability of detection and the probability of false alarm. The probability of detection gives the probability that a licensed band is busy and hence is detected busy. The probability of the false alarm gives the probability that the licensed user band is free while it is detected busy. In this paper, we focus on the effect of the sensing errors on the performance of the OFDM-based cognitive radio transmission, and assumed that the $P_q^d = Pq\{H1|H1\}$ denotes the probability of detection and the $P_q^f = Pq\{H1|H0\}$ denotes the probability of false alarm in the spectrum sensing for the q-th block The OFDM data transmission in the data transmission period of the secondary frame period is based on the sensing result from the primary frame period. The data transmission in the secondary frame period will only proceed when the licensed band is free and it is detected free or when the licensed band is busy but it is detected free. The first case happens with probability.

$$P_q^{idle} = P_q(H_0)(1 - P_q^f)$$

(1)

In this case, the cognitive OFDM data transmission is similar to the conventional OFDM transmission system and it does not suffer from any interference caused by the primary user because the primary user is actually absent. The second case happens when the probability is given by then serial to parallel converted and that results in a complex vector in order to modulate the active. The following figure shows the OFDM-based cognitive radio transmitter. The input symbols are

$$P_q^{busy} = P_q(H_1)(1 - P_q^d)$$

(2)

When the above case is considered, not only the secondary user causes interferences to the primary user, the secondary OFDM data transmission also suffers from interferences caused by the primary user because the primary user is actually present but the spectrum sensing has missed its presence.

2.2. OFDM data transmission

Consider an OFDM-based cognitive radio transmission system with *N* detected subcarriers used in the second part of the secondary frame period. Suppose that $s[m]$ stands for the *m*-th data symbol drawn from *M*-ary QAM (M-QAM) constellation, which is assumed to be independent and distributed with the unit average power. The data symbols can be grouped into blocks of size *N*. Prior to transmission, the *l*-th data block $[s[lN+1], \ldots, s[lN+N]]^T$ is first transformed into the time domain by means of an inverse discrete Fourier transform (IDFT) and then added with a cyclic prefix of length *LCP* with *LCP* < *N*. Denote $b[m]$ as the *m*-th sample resulting from these operations. The data symbol $b[m]$ is transmitted through a time invariant multipath Rayleigh fading channel. This multipath channel as well as the effect of the transceiver filter is jointly modeled in this paper as a finite impulse response (FIR) filter of order of *L* with its *i*-th tap denoted by $g[i]$. This implies that the tap $g[i]$ may only have nonzero values when $1 \leq i \leq L + 1$. Assume a Rayleigh fading channel where all the taps are independent and identically distributed as complex Gaussian random variables with mean zero and variance σ_g^2.

III. ANALYSIS

3.1. With carrier frequency offset

When adding a carrier frequency offset, the *m*-th received sample signal after the matched-filtering can be written as

$$x[m] = e^{j2\pi f0\,(m-1)Ts} \qquad [\textstyle\sum_{i=1}^{L+1} g[i]b[m = i+1] + v[m]] + w[m]$$

(3)

where f_0 is the carrier frequency offset and v[m] and w[m] are complex Gaussian random variables.

Similarly, the decision variables for the *k*-th subcarrier can be derived after grouping the samples into blocks and removing the cyclic prefix and performing the FFT as

$$z_k = m_l \Lambda_k s_k + \textstyle\sum_{j=1, j\neq k}^{N} m_{j-k+1} \Lambda_j s_j + v_k + w_k \qquad i$$

(4)

$$\text{where } m_k = \frac{\sin(\pi(k-1+\epsilon_0)) \quad e^{j\pi(1-\frac{1}{N})(k-1+\epsilon_0}}{N\sin(\pi(k-1+\epsilon_0)/N)}$$

(5)

Λ_j and s_j are the frequency domain channel gain and the data symbol in the *j*-th subcarrier, w_k is the complex Gaussian random variable with zero mean and variance $E\{|w_k^2|\} = \sigma_w^2$, and v_k is the interference from the primary user and is given by,

$$v_k = \textstyle\sum_{i=1}^{N} a_i b_i c_{ik}$$

(6)

where $\epsilon_0 = f_0 T$ is the normalised carrier frequency offset

From above equations, we can see that part of the interference is caused by the primary user while the other part of the interference is caused by the other subcarriers as intercarrier interference. The SINR is the ratio of signal to interference noise ratio. From the above equation of SINR, the value of the average BER for M-QAM can be derived as

$$P_k^{BER}(\alpha_1, \alpha_2, ..., \alpha_N) = \sum_{i=1}^{\sqrt{M}-1} e_i \int_0^\infty Q(\sqrt{\frac{|m_1|2^1}{x\sigma_{ICI,\alpha}^2 + \sigma_{ICI,\beta}^2 + \sigma_w^2} + \sum_{I=1}^{N} a_i^2 |c_{ik}|2^1 \sigma_i^2} \cdot |f_{\Lambda k}|^{2(x)} dx$$

(7)

where $|f_{\Lambda k}|^{2(x)}$ can be given by the following,

$$|f_{\Lambda k}|^{2(x)} = \frac{1}{\sigma_i^2}^1 e^{\frac{-x}{\sigma^2}} \Lambda, \quad x > 0$$

(8)

From the above equations, the following observations can be made. The interference caused by the primary user results in a smaller SINR, that is similar to the case when there is no carrier frequency offset, while the interference caused by carrier frequency offset leads to an upper limit of the SINR. Depending on the values of the frequency shifts of the primary interferers, there may be an increase or reduction in the amount of interference caused by the carrier frequency offset.

3.2. Interference mitigation using beamforming

A downlink cognitive radio network with K secondary user's and L primary user's are considered. Secondary user's base station has multiple antennas and each of the primary user and secondary user has single antenna.

The main considerations of convex optimization for cognitive radio networks can be given by, the interference mitigation using beamforming techniques , SINR balancing based on the quality of service provision, cognitive relaying in overlay networks and cognitive MIMO networks , adaptive bit loading and power allocation for OFDMA based CR networks and robust rate maximization games in spectrum sharing channels are also being considered.

The transmitted signal from the basestation of the radio transmission is given by,

$$x = \sum_{i=1}^{k} \sqrt{p_i} u_i s_i = U_s^{\sim}$$

(9)

The main aim is to determine an optimum set of beamformers and power allocations so that each secondary user attains its target signal to interference plus noise ratio while ensuring interference leakage to primary users is below a certain threshold. The SINR at the ith secondary user terminal is given by,

$$SINR_i = U_i^H R_i \frac{U_i^-}{\sum_{j \neq i} U_i^H R_i U_i^- + \sigma_i^2}$$

(10)

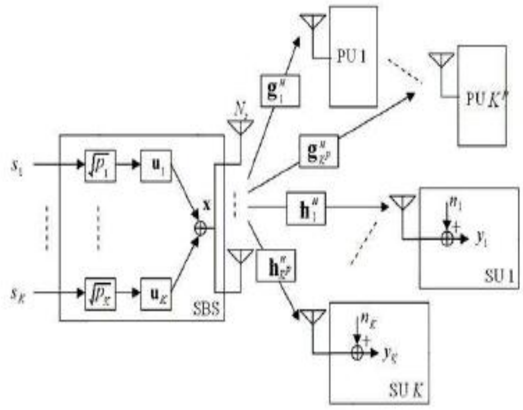

Fig 1: Interference reduction using beamforming method

IV. RESULTS AND DISCUSSIONS

In this section, the simulation results and discussions of OFDM-based cognitive radio has been conducted. First we process cognitive radio user, we use five primary users with different frequency. If any primary user is absent, then the secondary user will occupy the absent areas. The objective of the project is to improve the spectrum sensing errors.

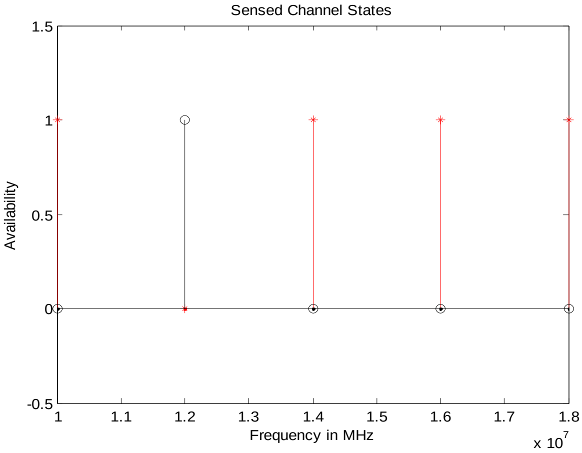

Fig 2: This simulation shows the availability of channel

In figure 2, the channel states are sensed. Here, the available channels(licenced) are estimated. The peak value 1 is assumed as channel availability and 0 is assumed as available channel absent. When a channel is sensed available that is the primary user is absent, then the secondary user starts transmitting in the available channel, till the primary user is detected.

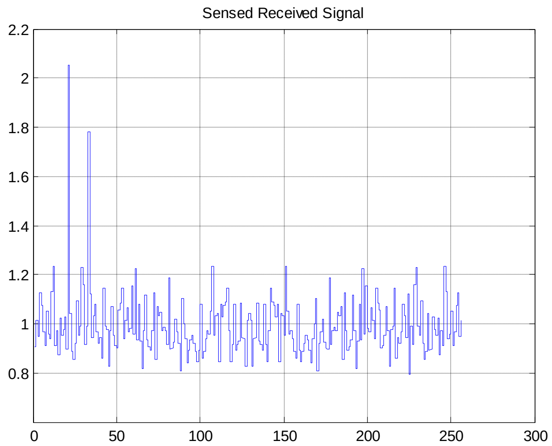

Fig 3: Sensing of the received signal

In figure 3, the received signal is being sensed. The cognitive radio automatically detects the available channels in wireless spectrum.If the licensed band is actually free and is also detected free in the sensing frame period, the OFDM transmission in the second frame period is similar to the conventional OFDM transmission system. On the other hand, if the licensed band is actually busy but is detected free, the OFDM transmission in the second frame period will suffer from interferences caused by the licensed users. . The expressions for the average bit error rate was derived for the analysis based on different spectrum sensing and OFDM transmission parameter. In spectrum sensing part, an additional noise is added to the channel, when the channel is faded using noise and causes any interference then the spectrum sensing error will occur.

We use Carrier frequency offset for causing Interference. So we used Blind Spectrum algorithm to sense the availability and absence of channel. We assumed 0 as absent and 1 as available channel. Using this technique we completely remove the noise and improve sensing rate. Through this channel we send data signal for transmission using OFDM. It is important to evaluate the performance degradation caused by the interferences so that correct parameters for the OFDM-based cognitive radio system can be chosen to meet certain quality of service criterion. According to this paper, the effect of the sensing errors on the performance of the OFDM-based cognitive radio system is analysed in terms of the average bit error rate.

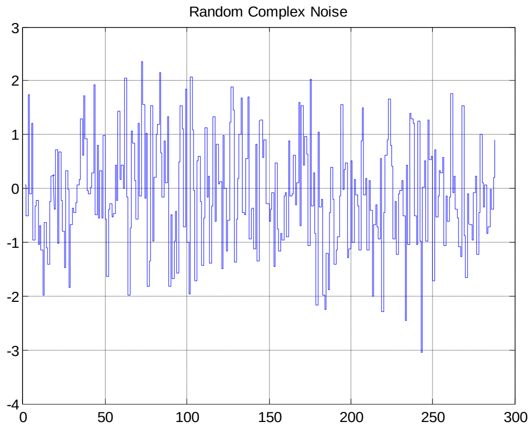

Fig 4: Gaussian complex random noise is generated

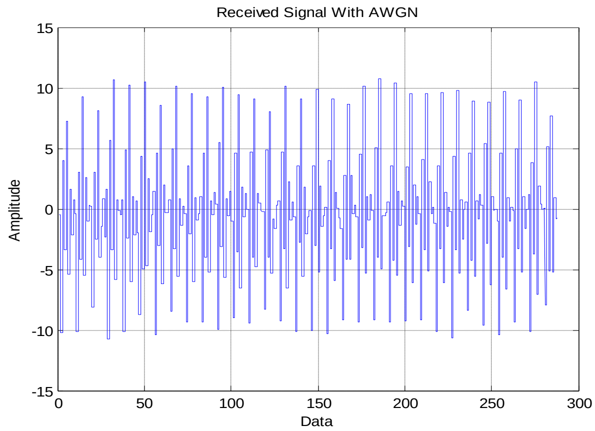

Fig 5: Received signal with AWGN

In the OFDM part, we used 16-QAM modulation method, it is used to modulate by changing (modulating) the amplitudes of two carrier waves and then we apply cyclic prefix and IFFT for generating OFDM Modulation. In OFDM system the detected sampled signal can be broken into frame for transmission. In this project, we used complex multipath channel for transmission and then we added AWGN noise to the received signal.

The effect of the primary user interference can be reduced by increasing the signal-to-noise-ratio, but the effect of the inter-carrier interference cannot be reduced by increasing the signal-to-noise-ratio. For the same carrier frequency offset, the BER performance also degrades when the value of *INR* increases.

V. CONCLUSIONS

The effect of sensing errors on the average BER performances of the OFDM-based cognitive radio transmission has been evaluated by deriving their analysis expressions as functions of the spectrum sensing parameters and the OFDM transmission parameters. Here, the case with carrier frequency offset is considered. The interference from the primary user (licenced) caused by the sensing errors degrades the performance of the OFDM-based cognitive radio transmission. The amount of degradation depends on the spectrum sensing and the OFDM data transmission parameters.

The future work consists of reception part and comparing the transmission and reception and evaluating the BER calculation. After calculating the BER values and evaluating the spectrum errors and it's effect, we devise different methods to reduce the interference caused due to spectrum sensing errors.

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