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Algorithm for Detection of Spectrum Holes for OFDM Based CR in Multipath Environment

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***Abstract*—**Cognitive radio is an intelligent radio which obtains and adjusts its information from its surrounding environment. And by doing so, it leads to more efficient utilization of spectrum. Spectrum sensing is most important parameter in case of cognitive radio. Since OFDM is wideband transmission technique, detecting signals in low signal to noise ratio is major challenge. This paper presents algorithm based on cyclic prefix correlation coefficient (CPCC) which is most important property of OFDM. It is shown that it is simplest and computationally efficient method of spectrum sensing in absence of multipath environment and performance of this algorithm degrades in multipath scenario. Further, by considering multipath correlation in GLRT, a simple and low complexity algorithm is obtained called as (MP based GLRT).

Index Terms*—Cognitive radio, spectrum sensing, OFDM, cyclic prefix, GLRT*

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I. INTRODUCTION

As the technology is improving day by day, number of wireless users is also increasing. And Spectrum is limited source. With the increasing demand of wireless applications, the problem of spectrum utilization has become more critical than earlier. Cognitive radio takes an advantage of licensed spectrum when it is not used by primary users. Cognitive radio is an intelligent radio system that uses spectrum resources opportunistically. Communication quality is improved by avoiding interference to its primary users. Furthermore, quality is improved by learning from previous experience and adapting to immediate local available spectrum [1].The efficient utilization of limited spectrum bands is provided with the help of temporary use of idle licensed frequency bands. As a result, innovative techniques that can offer new ways of exploiting the available spectrum are needed.

Cognitive radio technology works on the principle of "Dynamic spectrum management" which solves the issues of spectrum underutilization in better way. In cognitive radio terminology, primary users are defined as the users having higher priority or legacy rights on the usage of a specific part of the spectrum. On the other hand, secondary users are having lower priority, and they should use this spectrum in such a way that they should not cause any interference to primary users. Therefore, secondary users must have cognitive radio capabilities, like sensing of the spectrum reliably to check whether it is being used by a primary user and to vacate the spectrum band as soon as primary user is detected. Also secondary users need to change the radio parameters to exploit the unused part of the spectrum.

Orthogonal frequency division multiplexing (OFDM) is a special case of multicarrier transmission in which single data stream is transmitted over a multiple number of lower rate data streams [2]. One of the most important reasons to use OFDM in spectrum sensing is its inherent capability to combat multipath fading and interference. Spectrum sensing is a task of finding the unused parts of licensed spectrum. Main aim is to identify the empty channels to reduce the traffic in congested areas. A CR should be designed in such a way that it must be aware of and sensitive to the changes in its surroundings, which is an important requirement for spectrum sensing. Dynamic spectrum access is a key concept in case of cognitive radio. Dynamic spectrum access involves use of licensed spectrum whenever it is available. Spectrum sensing enables CR users to adapt to the environment by detecting spectrum holes without causing interference to the primary network. This can be done with a real-time wideband sensing capability to detect weak primary signals in a wide spectrum range. In OFDM based cognitive radio, sensing can be performed either in time domain or frequency domain.

The likelihood ratio test (LRT) is one of the desirable algorithms for spectrum sensing if exact knowledge of channel state information and noise variance is made available at receiver. But such knowledge is generally difficult to obtain at receiver. Secondly, energy detection is the simplest form of detecting the spectrum holes because of its low computational and implementation complexity. It does not require any knowledge about the primary user's signal. Here, primary transmission is modeled as unknown deterministic signals [2]. The signal is detected by comparing output of energy detector with threshold [3]. This threshold value depends upon the noise floor. However, slight uncertainty in noise floor degrades the performance of algorithm. Furthermore, energy detection algorithm is suitable for the signals which are independent and identically distributed. Therefore, to detect correlated signals, new efficient techniques are needed. In fact, number of techniques has been proposed; among them are cyclostationary based sensing [5], matched filter detection [6], waveform based sensing [7] etc.

Cyclic prefix is most important property of OFDM signals. Cyclic prefix results in nonzero correlation of received signal samples at certain delays. In [8], a method based on the cyclic feature of OFDM blocks in the time domain has been proposed. Although the algorithm shows good performance, the signal correlation induced by multipath propagation is not exploited in such an algorithm.

Detection algorithm decides between the two hypothesis whether the primary user is present or absent. If channel state information and noise variance is not known, then the method is to perform maximum likelihood estimates of unknown parameters. Likelihood ratio test (LRT) expresses how many times data is under one model than other. Then these unknown parameters are used in LRT as if they are correct values, and this result in generalized likelihood ratio test (GLRT). GLRT is implemented in many hypothesis testing problems. GLRT is also used in spectrum sensing applications to detect the presence of primary user.

Here, two algorithms are devised for spectrum sensing. First, cyclic prefix correlation coefficient (CPCC) based algorithm is obtained. It is shown that this algorithm performs well in absence of multipath fading. Also it is shown that the performance of this algorithm degrades in multipath environment. So to have the better efficiency in multipath environment, multipath based GLRT (MP based GLRT) algorithm is obtained. In both the cases it is assumed that there is synchronization between primary user and secondary user.

The rest of the paper is organized as follows:
Section II describes the system model, in which OFDM transmission is considered. Section III gives the mathematical expressions for calculating maximum likelihood estimates of transmitted signal as well as noise variance and presents the main concept about GLRT. Section IV shows the algorithm based on cyclic prefix correlation coefficient in absence of multipath environment. Section V presents multipath based GLRT algorithm. Section VI gives simulation results.

II. SYSTEM MODEL

The OFDM model considered here assumes that there is perfect synchronization between primary users and secondary users. OFDM model consists of L subcarriers [8]. The baseband modulated OFDM signal can be mathematically expressed as,

$$S_n(m) = \frac{1}{\sqrt{L}} \sum_{k=0}^{L-1} S_{n,k}\, e^{\frac{2\Pi mk}{L}} \;,\; m = 0 \ldots \ldots L-1 \qquad (1)$$

Where, $S_{n,k}$ are the complex symbols to be transmitted in nth OFDM block with$k = 0 \ldots \ldots L-1$.

$$S_n = \left[S_{n(L-1)\ldots\ldots}\, S_{n(0)} S_{n(L-1)\ldots\ldots} S_{n(L-L_p)}\right]^T \qquad (2)$$

L_p denotes the number of symbols in the guard interval i.e. length of the cyclic prefix. Then the received signal and noise vector can be represented by,

$$X_n = \left[x_{n(L-1),} x_{n(L-2)\ldots\ldots}\, x_{n(0)} x_{n(-1)\ldots\ldots} x_{n(-L_p)}\right]^T \qquad (3)$$

$$V_n = \left[v_{n(L-1),} v_{n(L-2)\ldots\ldots}\, v_{n(0)} v_{n(-1)\ldots\ldots} v_{n(-L_p)}\right]^T \qquad (4)$$

The primary signal is received through multipath fading channel and its baseband model is given by channel filter taps, h_i where, $i = 0 \ldots \ldots L_c$. And L_c denotes the number of multipath components. The relation between X_n, V_n, h_n is given by,

$$X_n = hS_n + V_n \qquad (5)$$

The variance of X_n is $\sigma_x{}^2$ and based on eq. (5) it can be represented as,

$$\sigma_x{}^2 = \sigma_s{}^2 \sum_{i=1}^{L_c} |h_i|^2 + \sigma_v{}^2 \qquad (6)$$

Equation (6) is the variance of X_n in presence of primary user signal otherwise, $\sigma_x{}^2 = \sigma_v{}^2$.

Depending upon the state of primary user, two binary hypotheses are defined in spectrum sensing i.e. H_0 and H_1. If primary user is in idle state then it is represented by H_0 and if primary user is in active state then it is represented as H_1. Then test statistics T is given by,

$$\text{Decide } H_0, \text{ if } T \leq \in$$
$$\text{Decide } H_1, \text{ if } T > \in \qquad (7)$$

Where, $\in$ is some threshold value and it depends upon probability of false alarm. Two probabilities are defined in case of spectrum sensing.; P_d is probability of detection, which states that primary user is correctly detected i.e. it is detected when it is in its active state and P_f is probability of false alarm i.e. false detection of primary user when it is in idle state.

$$P_f = P_r\{T > \in |H_0\} \qquad (8)$$
$$P_f = P_r\{T > \in |H_1\} \qquad (9)$$

P_r is any distribution function like cumulative distribution function (CDF)

III. GENERALIZED LIKELIHOOD RATIO TEST (GLRT)

GLRT based on spectrum sensing based has been presented in [8], in which different tests are obtained under different parameter assumptions, i.e., unknown noise variance and/or signal covariance matrix. Here GLRT is reviewed in its general form for detection of OFDM signals. If noise variance $\sigma_z{}^2$ and signal covariance matrix R_y are not known then the GLRT is given by [8],

$$L_G(y) = \frac{f_{y|H_1,\widehat{R_y}}(y\ |H_1,\ \widehat{R_y})}{f_{y|H_0,\widehat{\sigma^2}_z}(y\ |H_0, \widehat{\sigma^2}_z)} \qquad (10)$$

y=$[y_1, \ldots\ldots y_N]$ is a collection of N received blocks. $\widehat{R_y}$ and $\widehat{\sigma^2}_z$ are the maximum likelihood estimates of R_y and $\sigma_z{}^2$ under the hypothesis H_1 and H_0 respectively.

The maximum likelihood estimate of $\sigma_z{}^2$ can be written as

$$\widehat{\sigma^2}_z = \max_{\sigma_z{}^2}\{\ln f_{y|H_0,\sigma_z{}^2}(y\ |H_0, \sigma_z{}^2)\} \qquad (11)$$

Where,

$$f_{y|H_0,\sigma_z{}^2}(y\ \ |H_0, \sigma_z{}^2) = \prod_{n=1}^{N} \frac{1}{(\pi\sigma_z{}^2)^M} \exp\left(-\frac{1}{\sigma_z{}^2}\ ||y_N{}^2||\right) \qquad (12)$$

Where, $||.||$ denotes the vector Euclidian norm.

In the same way, maximum likelihood estimate of R_y can be calculated as,

$$\widehat{R_y} = \max_{R_y} \{\ln f_{y|H_1,R_y}(y \mid H_1, R_y)\} \quad (13)$$

Where,

$$f_{y|H_1,R_y}(y \mid H_1, R_y) = \prod_{n=1}^{N} \frac{1}{\pi^M \det(R_y)} \exp(-y_n{}^H R_y{}^{-1} y_n) \quad (14)$$

After simplification of equation (12) and (13) we get GLRT as [9],

$$T_G(y) = \frac{\frac{1}{M} tr(\widehat{R_y})}{det^{\frac{1}{M}}(\widehat{R_y})} \underset{H_1}{\overset{H_0}{\gtrless}} \epsilon \quad (15)$$

IV. GLRT BASED ON CYCLIC PREFIX CORRELATION COEFFICIENT

A CPCC based spectrum sensing algorithm is proposed in [7] with the focus on AWGN channel. Here only head and tail of each received OFDM block is considered.

$$\dot{X}_n = \left[x_{n(L-1)}, x_{n(L-2)} \ldots\ldots x_{n(0)} x_{n(-1)} \ldots\ldots x_{n(-L_p)}\right]^T \quad (16)$$

Then corresponding transmitted signal and AWGN vectors are defined as

$$\dot{S}_n = \left[S_{n(L-1)} \ldots\ldots S_{n(L-(L_{p+L_{c-1}})} S_{n(L-1)} \ldots S_{n-1(L-L_{c+1})}\right]^T \quad (17)$$

Then,

$$\dot{X}_n = h\dot{S}_n + \dot{V}_n \quad (16)$$

Further signal covariance matrix and noise variance is given in [7]. Then by considering multipath correlation in GLRT, it is shown that performance of CPCC based algorithm degrades in multipath environment.

V. MULTIPATH CORRELATION FOR GLRT

The CPCC-based algorithm only uses observation in the head and tail of an OFDM block to exploit the correlation structure, which results from the use of the cyclic prefix. On the other hand, multipath also introduces strong correlation to the received OFDM samples. The developed algorithm uses the portion of the received OFDM symbol that does not include the ISI part.

In this way, the known structure of the observation can be taken into account to improve the estimation of the signal covariance matrix. Furthermore, a simplified test statistics is derived as a function of the received signal correlation coefficients [1].

VI. FLOW GRAPH

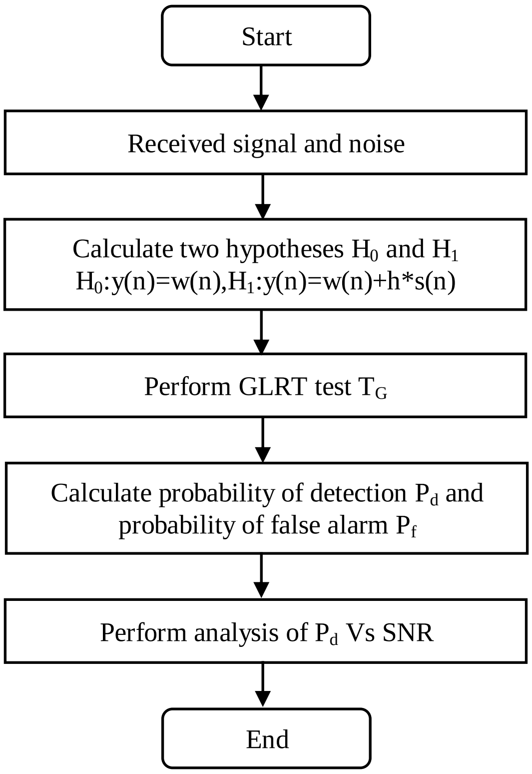

Figure (1) Flow chart for the proposed system

OFDM transmission is considered in the system. OFDM signal is received along with noise (V_n). Here noise variance and channel state information are not known. So, maximum likelihood estimates are calculated. Depending upon estimated values of signal (R_y) and and Then to detect whether the primary user is present or not, two hypotheses tests are performed called H_0 and H_1.Then GLRT is applied for both the algorithms. And then their performance is evaluated on the basis of test T_G. Probability of detection and probability of false alarm is calculated on the basis threshold ϵ. Finally, performance is evaluated for different values of SNR's.

VII. SIMULATION RESULTS AND DISCUSSION

Simulation is done with the help of MATLAB Simulink. The simulation is performed for L=64 subcarriers, and modulation used is 16 QAM. The performance is evaluated for CPCC based and MP based GLRT algorithm. SNR range chosen is from -20dB to 0dB. Then for different values of SNR's, probability of detection is plotted.

Figure (2) shows the comparison for both CPCC and MP based GLRT. It shows that performance of MP based GLRT is better than that of CPCC based GLRT. It also shows that for high values of SNR's probability of detection is higher.

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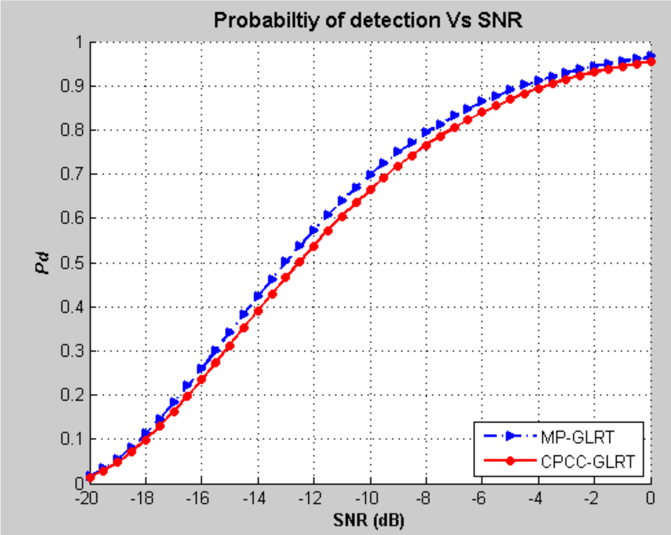

Figure (2) Performance comparison of CPCC and MP based GLRT

VIII. Conclusion

In this paper spectrum sensing algorithms for OFDM based cognitive radio are given. The key feature is to explicitly take into account the structure (constraint) of the covariance matrix of the underlying OFDM signal so that the ML estimations of unknown parameters are improved, which leads to robust and efficient spectrum-sensing tests. CPCC algorithm is simple and low complexity algorithm. But its performance degrades in multipath environment. This drawback is overcome by MP based GLRT.

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