Improvement in Probability of Detection Using Diversity Techniques in Cognitive Radio

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Abstract : **The scarcity of radio spectrum is tour de force by the capability of Cognitive radio technology. Cognitive radio system's most important challenge is to perform Diversity is used to scrimmage with fading and shadowing in spectrum sensing. Among many diversity techniques, the equal gain combining technique provides the maximum performance and less complexity as it uses equal importance in each branch. This paper, mainly focused on Equal gain combining diversity technique and the technique is applied to the Weighted-covariance-based detector (WCD) and Information theoretic criteria (ITC) based spectrum sensing to improve the detection performance over AWGN fading channel. Simulation results shows that the Equal gain combining technique can improve probability of detection at low SNR.**

***IndexTerms* - Cognitive radio, Spectrum sensing, Equal gain combining, Weighted-covariance-based detector, Information theoretic criteria.**

I. INTRODUCTION

In present days, due to the increasing in the number of wireless communication services, the uses of radio spectrum have become crowded. But as per the report of Federal Communication Commission(FCC), 90% of the existing licensed spectrum remains idle and the usage varies from geographically and temporally. Cognitive radio(CR) deals with irrational frequency regulation policy. In cognitive radio networks, the spectrum utilization of existing wireless communication networks can be tremendously improved by reliably sensing the primary (licensed) channel by the secondary users (unlicensed) and then opportunistically accessing it without causing harmful interference to primary users.By doing this, the spectrum utilization of existing wireless communication networks can be tremendously improved [2]. . For cognitive radio (CR) network, sensing of vacant spectrum is very important task. However, there are several factors that make sensing the presence of primary users in a complicated communication environment, especially a CR-based network, is still a challenging problem from the practice perspective [2]. In this paper, we study a blind spectrum sensing methods based on weighted covariance-based detector (WCD) and information theoretic criteria (ITC). A weighted covariance-based detector is proposed by introducing data-aided weights to the covariance matrix. The weighting operation reduces the overlap between the distributions of test statistic with and without primary signals, thereby leading to a considerable performance improvement over CAV. It is worth mentioning that the weights can be easily calculated from the estimated covariance matrix [4]. Information theoretic criteria (ITC) sensing method was introduced by Akaike [5] and by Schwartz [6] and Rissanen [7]. Applying ITC for spectrum sensing was firstly introduced in [8]–[11]. This work provides a more intensive study on the ITC sensing algorithm and its performance. First of all, to make the information theoretic criteria applicable, a new over-determined channel model is constructed by introducing multiple antennas. Then, simplified information theoretic criteria (SITC) sensing algorithm which only involves the computation of two decision values is presented. Compared to the original information theoretic criteria (OITC) sensing algorithm in [8], SITC is much less complex and yet almost has no performance loss [2]. However, sensing the spectrum is a hard task because of shadowing and fading in wireless communication. In many scenarios the cognitive radio is deployed in a multipath fading environment and hence must cope with the fading effects on the unknown primary signal [12]. We have considered the problem of spectrum sensing in a fading environment, we have investigated several diversity techniques in order to improve the performance of the energy detectors. Equal Gain Diversity technique is considered as an important tool to enhance wireless link performance by alleviating the effects of radio channels' fading process [8]. Diversity techniques are based on redundancy of transmitted information. On the receiver side, the used diversity combining technique plays an important role on the system performance [13]. In this paper equal gain combining was studied and it was applied to the WCD and ITC. The comparative analysis is done for SNR vs. Pd . The Rest of this paper is organized as follows. Section II describes the System model. Section III describes Average probability of detection with diversity reception. Section IV presents Simulation results. Section V concludes the paper.

II . System model

The problem of sensing primary signals that arrive at a secondary user as - M sensing antennas through AWGN fading channels. Let H_0 and H_1 represent the absence and presence of primary signals, respectively. With the above binary hypotheses, the received signal vector **x**(k) from the M antennas at time instant k is given by [14,15].

$X(k) = \eta h(k)s(k) + n(k),$

k=1,2,…,K where $\eta = 0$ under H_0, and $\eta = 1$ under H_1;

$n(k) = [n_1(k), n_2(k), \ldots \ldots nM(k)]^T$ denotes the independent and identically distributed, $s(k)$ denotes the primary signal.

$h(k) = [h_1(k), h_2(k), \ldots \ldots hM(k)]^T$ denotes the AWGN fading channel at time instant k.

A. *Weighted Covariance-Based Detection:*

Here, we propose a weighted covariance-based detector (WCD). The test statistic of WCD is given by

$$T_W = \sum_{i=1}^{M-1}\left(w_i \sum_{|m-n|=i} |r'_{mn}|\right)$$ Where the weights

$$w_i = \sum_{|m-n|=i} |r'_{mn}|$$

$$r'_{mn} = \frac{\hat{r}_{mn}}{\hat{\sigma}^2}$$

With $\hat{\sigma}^2$being the estimated power of the received signal

$$\hat{\sigma}^2 = \frac{1}{M}\sum_{m=n} \hat{r}_{mn}$$

We can see that CAV is a special case of WCD when $W_i = 1/M$, i = 1, 2, …. M − 1. The use of weights $\{W_i\}$ in WCD is crucial to improve the detection performance.WCD is a variant of CAV, which exploits the correlation of primary signals [4]. Hence, WCD can also be extended to exploit both temporal correlation and spatial correlation for spectrum sensing. We derive the variance of $T_w|H_0$.

Let

$$T_i|H_0 = w_i \sum_{|m-n|=i} |r'_{mn}|$$

$$= \sum_{|m-n|=i} r'_{mn} \sum_{|m-n|=i} |r'_{mn}|$$

$$T_i|H_1 = w_i \sum_{|m-n|=i} |r'_{mn}|$$

Then

$$T_w|H_1 = \sum_{i=1}^{M-1} T_i|H_1$$

B. Information theoretic criteria:

ITC is an approach that was originally implemented for model selection and was introduced by Akaike [5], and by Schwartz [6] and Rissanen [7]. There are two well-known criteria that have been widely used: the Akaike information criterion (AIC) and the minimum description length (MDL) criterion. One of the most important applications of ITC is to estimate the number of source signals in array signal processing [16]. Consider a system model described as

$$x = As + \mu$$

Where $\boldsymbol{x}$ is the $p \times 1$ complex observation vector, $\mathbf{A}$ is a $p \times q$ $(p > q)$ complex system matrix, $\boldsymbol{s}$ denotes the $q \times 1$ complex source modulated signals, and $\boldsymbol{\mu}$ is the additive complex white Gaussian noise vector. It is noted that the definite parameters q, $\mathbf{A}$, and σ^2 are all unknown. The resulting cost functions of the AIC and the MDL have the following form [16].

$$AIC(k) = -2\log\left(\frac{\prod_{i=k+1}^{p} l_i^{1/(p-k)}}{\frac{1}{p-k}\sum_{i=k+1}^{p} l_i}\right)^{N(p-k)} + 2k(2p-k) + 2$$

$$MDL(k) = -\log\left(\frac{\prod_{i=k+1}^{p} l_i^{1/(p-k)}}{\frac{1}{p-k}\sum_{i=k+1}^{p} l_i}\right)^{N(p-k)} + \left(\frac{1}{2}k(2p-k) + \frac{1}{2}\right)\log N$$

Where N signifies the observation times, and $l_i$denotes the i^{th} decreasing ordered eigen value of the sampled covariance matrix. The estimated number of source signals is determined by choosing the minimum (2) or (3). That is

$$\hat{\mathrm{k}}_{\mathrm{AIC}} = \mathrm{arg}_{\mathrm{j}=0,1,..,\mathrm{p}-1} \min \mathrm{AIC(j)}$$

$$\hat{\mathrm{k}}_{\mathrm{MDL}} = \mathrm{arg}_{\mathrm{j}=0,1,..,\mathrm{p}-1} \min \mathrm{MDL(j)}$$

We consider a multipath fading channel model and assuming that there is only one primary user in the cogitative radio network. Let $x(t)$ be a continuous-time baseband received signal at the secondary user's receiver. Spectrum sensing can be formulated as a binary hypothesis test between the following two hypotheses:

$$H_0: x(t) = \mu(t)$$

$$H_1: x(t) = \int_0^T h(l)s(t-l)dl + \mu(t)$$

Where $s(t)$ denotes the signal that is transmitted by the primary user, $h(t)$ is the continuous channel response between the primary transmitter and the secondary receiver, $\mu(t)$ denotes the additive white noise, and the parameter T signifies the duration of the channel. The channel response is also assumed to remain invariant during each observation [17]. To obtain the discrete representation, we assume that the received signal is sampled at ratef_s, which is equal to the reciprocal of the baseband symbol durationT_0. For notation simplicity, we define

$x(n) = x(nT_0), s(n) = s(nT_0), and\ \mu(n) = \mu(nT_0).$

Hence, the corresponding received signal samples under the two hypotheses are described as

$$H_0: x(n) = \mu(n)$$

$$H_1: x(n) = \sum_{i=0}^{L-1} h(i)s(n-i) + \mu(n)$$

Where $h(i)$ $(0 \le i \le L-1)$ denotes the discrete channel response of $h(t)$, and L denotes the order of the discrete channel (L taps). Let each observation consist of M received signal samples. Then, (8) and (9) can be rewritten in a matrix form as

$$H_0: x_i = \mu_i$$

$$H_1: x_i = Hs_i + \mu_i$$

Where $\mathbf{H}$ is an $M \times (L + M - 1)$ circular channel matrix, which is defined as

$$H = \begin{bmatrix} h(L-1) & h(L-2) & \dots & h(0) & \\ & h(L-1) & h(L-2) & \dots & h(0) \\ & & \ddots & & \ddots \end{bmatrix}$$

$x_i, s_i,$ and μ_i are the $M \times 1$ observation vector, the $(L+M-1) \times 1$ source signal vector, and the $M \times 1$ noise vector, respectively, and are defined as

$$x_i = [x(iM-M+1), x(iM-M+2), \dots, x(iM)]^T$$
$$s_i = [s(iM-M-L+2), s(iM-M-L+3), \dots, s(iM)]^T$$
$$\mu_i = [\mu(iM-M+1), \mu(iM-M+2), \dots, \mu(iM)]^T$$

ITC needs very little prior information about the primary user. In particular, it does not require the knowledge of channel state information, synchronization, pilot design, or modulation strategy. Moreover, it does not need the estimation of noise power. Hence, we argue that the ITC method is a blind spectrum sensing.

III. Average probability of detection with diversity reception

In case of more than one antenna used at receiver, diversity combining techniques are used. This section presents the probability of detection for Equal gain combining (EGC) in AWGN channel [18].

A. *Equal Gain Combining:*

The Maximal Ratio combining technique provides the maximum performance relative to all other diversity combining techniques, but at the same time it provides the highest complexity of all the combining techniques because MRC requires knowledge of the fading amplitude in each signal branch. Whereas in equal gain combining complexity is very much reduced as it uses equal weights in each branch and so it does not require estimation of the channel (path) fading amplitudes. The total conditional SNR per symbol at the output is given by

$$\gamma_{EGC} = \frac{(\sum_{l=1}^{L} \alpha l)^2 E_S}{\sum_{l=1}^{L} Nl}$$

Where E_s is the energy (in joules) per symbol and Nl is the AWGN power spectral density on the l^{th} path. The probability of detection at the EGC output for AWGN channel can be calculated by

$$P_d = Q_{LN/2}(\sqrt{\gamma_{EGC}}, \sqrt{\lambda})$$

IV. Simulation Results

Here, the results for SNR (dB) vs. probability of detection for Equal Gain Combining (EGC) with WCD and ITC have been given. All simulations on this subject are executed on MATLAB (release R2017a), Monte Carlo(MC) method,which is a stochastic technique (based on the use of random numbers) forms the basis of these simulations.

A. *Simulation results for WCD and WCD with equal gain:*

In Fig.1 Probability of detection is compared with WCD and WCD with Equal Gain combining. It is observed from the fig. that, performance is considerable in case of Equal Gain combining. Hence, it may be concluded that the detection performance of Spectrum sensing may be enhanced by using WCD and also considerable for applying EGC case.

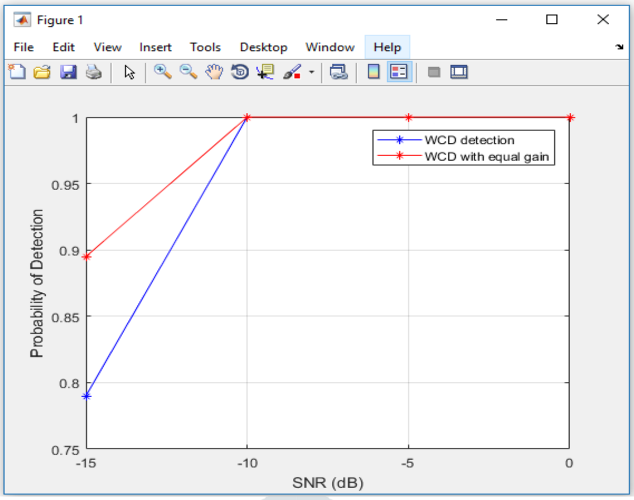

Fig.1 SNR (dB) vs. Pd for WCD and WCD with EGC

A. results for ITC and ITC with equal gain:

In Fig.2 Probability of detection is compared with ITC and ITC with Equal Gain combining. It is observed from the fig. that, performance is considerable in case of Equal Gain combining. Hence, it may be concluded that the detection performance of Spectrum sensing may be enhanced by using ITC and also considerable for applying EGC case.

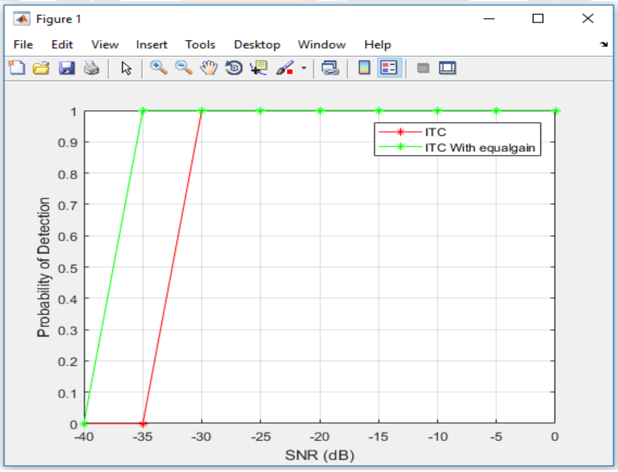

Fig.2 SNR (dB) vs. Pd for ITC and ITC with EGC

It is observed from the Table.1 that, performance is considerable in case of Equal Gain combining. Hence, it may be concluded that the detection performance of WCD and ITC may be enhanced by using equal gain combining technique.

It may be concluded that EGC diversity shows considerable results. The probability of detection Pd increases even on the same SNR value, if it is applied equal gain combining to the WCD and ITC.

	Probability of detection(P_d)

SNR(dB)	WCD	WCD with EGC	ITC	ITC with EGC
-35	---	---	0	1
-30	---	---	1	1
-15	0.79	0.89	1	1
-10	1	1	1	1

Table 1: Shows the simulation results of WCD, WCD

V. Conclusion

Cognitive Radio has emerged as an intelligent network that fulfills the increasing demand of bandwidth for effective communication. In this paper WCD and ITC based spectrum sensing in cognitive radio is analysed over AWGN fading channel. The results shows that the performance of spectrum sensing using WCD and ITC under equal gain diversity reception scheme. Equal gain combining technique is applied to the WCD and ITC spectrum sensing algorithms to improve the detection performance over AWGN fading channel. It is concluded that EGC diversity shows better results. The probability of detection Pd increases even on the same SNR value if we apply equal gain combining to the WCD and ITC.

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