Indonesian Journal of Electrical Engineering and Computer Science
Vol. 1, No. 2, February 2016, pp. 341 ~ 348
DOI: 10.11591/ijeecs.v1.i2.pp341-348

Noise Uncertainty Effect on a Modified Two-Stage Spectrum Sensing Technique

Heba A.Tag El-Dien[1*], Rokaia M. Zaki[1], Mohsen M. Tantawy[2], Hala M. Abdel-Kader[1]
[1]Shoubra Faculty of Engineering, Benha University
[2] National Telecommunication Institute, Cairo, Egypt
*Corresponding author, e-mail: hebaallah.shahat@feng.bu.edu.eg

Abstract

Detecting the presence or absence of primary user is the key task of cognitive radio networks. However, relying on single detector reduces the probability of detection and increases the probability of missed detection. Combining two conventional spectrum sensing techniques by integrating their individual features improves the probability of detection especially under noise uncertainty. This paper introduces a modified two-stage detection technique that depends on the energy detection as a first stage due to its ease and speed of detection, and the proposed Modified Combinational Maximum-Minimum Eigenvalue based detection as a second stage under noise uncertainty and comperes it with the case of using Maximum-Minimum Eigenvalue and Combinational Maximum-Minimum Eigenvalue as a second stage.

Keywords*: Cognitive radio, Noise uncertainty, Two-Stage Detector.*

1. Introduction

According to Federal Communication Commission (FCC), large amount of unused spectrum is available in licensed spectrum which is not effectively used due to non-uniform spectral demand in time, frequency and space. This reveals that the inadequate spectrum management policies are the main reason for spectrum scarcity. To overcome this, the FCC approved to allow existing unlicensed radio services in the licensed TV White Space (TVWS) through Cognitive Radio (CR) [1]. In CR, the secondary users need to opportunistically sense the idle channels. Once an idle channel is sensed, the secondary users will access the channel. Hence, spectrum sensing requests the secondary users to efficiently and effectively detect the presence of the primary signals, and is a fundamental problem in CR [2]. Spectrum sensing can be classified into two main categories, namely cooperative detection technique and non-cooperative detection technique. The non-cooperative detection can be further divided into two classes: (i) blind sensing which does not need any information about the primary user's signal such as Eigenvalue based detector and Energy Detector (ED), (ii) signal specific sensing which needs information about the primary user's signal such as Matched Filter (MF) and The Feature detector or Cyclostationary Feature detector (CFD) [3].

ED is simple and fast technique, which works better in high Signal to Noise Ratio (SNR), but it is not robust at low SNR and cannot differentiate between noise and signal [4]. MF is an optimal detector in white Gaussian noise, but it needs more information about the transmitted signal. CFD operates in the mid-way between ED and MF. In one hand it needs less information about the primary user's signal than the MF; in the other hand it has better performance than the ED. CFD relies on the fact that most signals exhibit periodic features, present in pilots, cyclic prefixes, modulations, carriers, and other repetitive characteristics. Because the noise is not periodic, the signal can be successfully detected. In [5-7], the eigenvalue based detection designed as a blind sensing technique with high probability of detection in low SNR environments. So for efficient sensing IEEE 802.22 standard prefers two-stage sensing that is coarse sensing which covers large bandwidth and small sensing time and fine sensing that concentrates on lower bandwidth and uses very robust sensing techniques like eigenvalue based techniques [4, 8].

Received September 19, 2015; Revised December 30, 2015; Accepted January 25, 2016

Spectrum sensing faces some challenges such as low SNR for primary users, time dispersion, channel fading, and noise uncertainty. In this paper, the noise uncertainty effect on the modified two-stage combinational maximum-minimum eigenvalue detector is investigated.

Various sensing techniques and their characteristics are described in [3]. In [1], a semi blind method which is based on minimum eigenvalue of a covariance matrix is proposed. In [2] a novel detector is proposed based on the entropy of spectrum power density. The two-stage sensing techniques and there different algorithms are discussed in [4] and [8]. The authors in [13] discusses different spectrum sensing algorithm and focuses on sensing algorithm based on the eigenvalues of received signal, [13] also introduces a Matlab code for simulating Tracy-widom distribution function. The authors in [10, 12] defines different eigenvalue algorithms such as maximum- minimum eigenvalue and energy to minimum eigenvalue algorithms. The effect of noise correlation on eigenvalue based Spectrum Sensing is studied analytically under both the noise only and the signal plus noise hypotheses in [14]. In [15] a unified comparison of the performance of energy detection, maximum eigenvalue based detection and maximum-minimum eigenvalue detection techniques for centralized data-fusion cooperative spectrum sensing under impulsive noise, is presented.

The paper is organized as following, sec II investigates the previous work in the detection algorithms in CRN, sec III discusses the system model of the proposed algorithms, and finally the paper is concluded in sec IV.

2. Previous Work

The detection problem can be summarized using two binary hypotheses that indicate the absence and the presence of primary user's signal. In practice, due to the noise uncertainty, the estimated noise power may be different from the actual noise power. And the estimated noise power changed in the interval $\sigma_v^2 \in [\sigma_v^2/\beta, \beta \sigma_v^2]$ where $\beta > 1$ is the noise fluctuation factor which is normally ranges from 1 to 2 dB [10].

2.1. Energy Detection

The energy detector is the simplest detector as it doesn't need any information about the primary user signal. It compares the received signal power to the noise power [5].

The effect of noise uncertainty β on the energy detection probability of false alarm P_{fa} and probability of detection P_d is shown in Equation (1) and (2) respectively.

$$p_{fa} = Q\left(\frac{\Upsilon - N\beta\sigma_v^2}{\beta\sigma_v^2\sqrt{2N}}\right) \tag{2}$$

$$P_d = Q\left(\frac{\Upsilon - N\frac{\sigma_v^2}{\beta} - NP}{\frac{\sigma_v}{\sqrt{\beta}}\sqrt{2N\frac{\sigma_v^2}{\beta} + 4NP}}\right) \tag{2}$$

Solving (1) and (2) results in:

$$P_d = Q\left(\frac{Q^{-1}\left(P_{fa}\right)\beta^2 - \sqrt{\frac{N}{2}}\left(1 + \beta SNR - \beta^2\right)}{\sqrt{1 + 2\beta SNR}}\right) \tag{3}$$

Where Q(.) is the Q function, Υ is the threshold value, σ_v^2 is the noise variance, P is received signal power, N is the number of samples, and β is the noise fluctuation factor.

2.2. Maximum-minimum Eigenvalue Based Detection

The Maximum-minimum eigenvalue based detection (MME) technique is one of the eigenvalue blind sensing detection techniques. MME improves the performance of detection at low SNRs, but the improvement of sensing performance also comes at a cost of computational complexity and long-time processing [8]. It compares the ratio between maximum and minimum eigenvalues of the received signal covariance matrix to a predefined threshold value Υ_1 as shown in Equation (4).

$$T_{MME} = \lambda_{max} / \lambda_{min} \tag{4}$$

The probability of detection and probability of false alarm of the MME can be written according to [10, 12] as following:

$$P_{fa} = 1 - F_1\left(\frac{\Upsilon_1 \left(\sqrt{N} - \sqrt{ML}\right)^2 - \mu}{v}\right) \tag{5}$$

$$P_d = 1 - F_1\left(\frac{\Upsilon_1 N + N\left(\Upsilon_1 Þ_{ML} - Þ_1\right) / \sigma_v^2 - \mu}{v}\right) \tag{6}$$

Where F1 (.) is the tracy-widom distribution of the first order, M is the number of the received antennas, L is the smoothing factor, $\mu = \left(\sqrt{N-1} - \sqrt{ML}\right)^2$, $v = \left(\sqrt{N-1} - \sqrt{ML}\right)\left(\frac{1}{\sqrt{N-1}} + \frac{1}{\sqrt{ML}}\right)^{1/3}$, $Þ_1$ is the max eigenvalue, and $ÞML$ is the minimum eigenvalue of the received signal matrix, [10, 12].

To study the effect of noise uncertainty β on the MME ROC, the probability of detection must be written as in (7).

$$P_d = 1 - F_1\left(\frac{\Upsilon_1 N + N\left(\Upsilon_1 Þ_{ML} - Þ_1\right) / \beta\sigma_v^2 - \mu}{v}\right) \tag{7}$$

The relation between P_d and P_{fa} for the MME with and without noise uncertainty at β =1, β =1.05& β =1.1 respectively is shown in Figure 1.

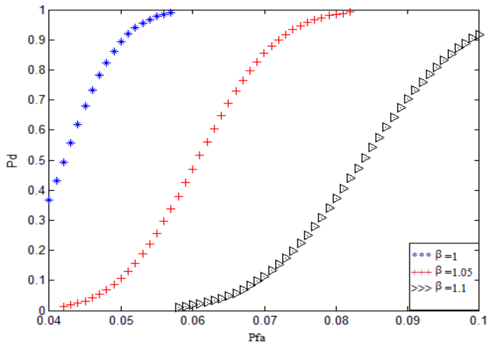


Figure 1. The ROC of MME with and without noise fluctuation at β =1, β =1.05 and β =1.1

3. System Model

3.1. Combinational Maximum-Minimum Eigenvalue

According to [4], the Combinational Maximum-Minimum eigenvalue Technique CMME is another form of the eigenvalue blind sensing detection techniques .It compares the ratio between maximum eigenvalue and the difference between maximum and minimum eigenvalues of the received signal covariance matrix to a predefined threshold value Υ_2 as shown in Equation (8).

$$T_{MME} = \lambda_{max} / \left(\lambda_{max} - \lambda_{min} \right) \tag{8}$$

The probability of detection and probability of false alarm of the CMME can be written as following:

$$P_{fa} = 1 - F_1 \left(\frac{\Upsilon' \left(\sqrt{N} - \sqrt{ML} \right)^2 - \mu}{v} \right) \tag{9}$$

$$\mathrm{P_d} = 1 - \mathrm{F_1} \left(\frac{\Upsilon' \mathrm{N} + \mathrm{N} \left(\Upsilon' \text{Þ}_{\mathrm{ML}} - \text{Þ}_1 \right) / \sigma_v^2 - \mu}{\mathrm{v}} \right) \tag{10}$$

Where $\Upsilon' = \Upsilon_2 / (\Upsilon_2 - 1)$. The effect of noise uncertainty β on the CMME produces probability of detection written as:

$$P_d = 1 - F_1 \left(\frac{\Upsilon' N + N \left(\Upsilon' \text{Þ}_{ML} - \text{Þ}_1 \right) / \beta \sigma_v^2 - \mu}{v} \right) \tag{11}$$

The relation between P_d and P_{fa} for the CMME with and without noise uncertainty at β =1, β =1.05& β =1.1 respectively is shown in Figure 2.

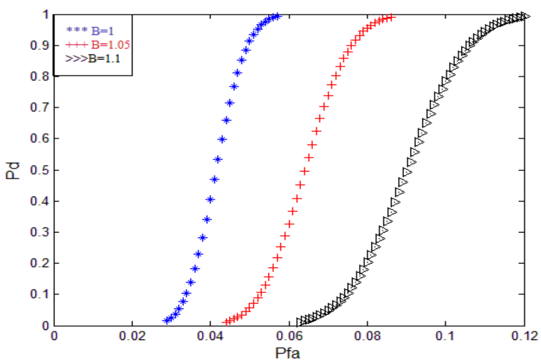


Figure 2. The ROC of CMME with and without noise fluctuation at β =1, β =1.05 and β =1.1

3.2. Proposed Modified CMME Algorithm

The modified CMME technique (MCMME) is a new form of using maximum and minimum eigenvalues. It compares the ratio between the sum and the difference of maximum and minimum eigenvalue of the received signal covariance matrix to a predefined threshold value Υ_3 as shown in Equation (12).

$$T_{MME} = \left(\lambda_{max} + \lambda_{min} \right) / \left(\lambda_{max} - \lambda_{min} \right) \tag{12}$$

The probability of detection and probability of false alarm of the MCMME can be written as following:

$$P_{fa} = 1 - F_1 \left(\frac{\Upsilon'' \left(\sqrt{N} - \sqrt{ML} \right)^2 - \mu}{v} \right) \tag{13}$$

$$P_d = 1 - F_1\left(\frac{\Upsilon''N + N\left(\Upsilon''\text{Þ}_{ML} - \text{Þ}_1\right)/\sigma_v^2 - \mu}{v}\right) \tag{14}$$

Where $\Upsilon'' = (\Upsilon_3 + 1)/(\Upsilon_3 - 1)$. The effect of noise uncertainty β on the MCMME produces probability of detection written as:

$$P_d = 1 - F_1\left(\frac{\Upsilon''N + N\left(\Upsilon''\text{Þ}_{ML} - \text{Þ}_1\right)/\beta\sigma_v^2 - \mu}{v}\right) \tag{15}$$

The relation between P_d and P_{fa} for the MCMME without noise uncertainty at β =1, and with noise uncertainty at β =1.05 and β =1.1 respectively is shown in Figure 3.

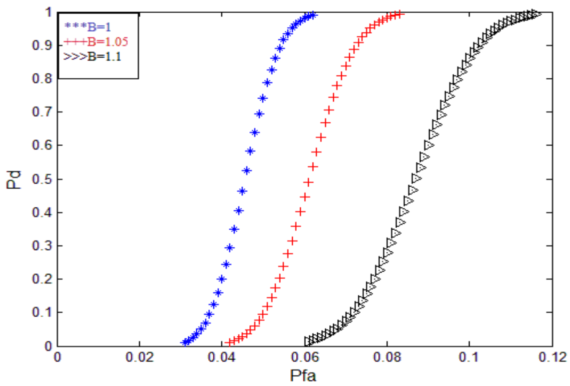
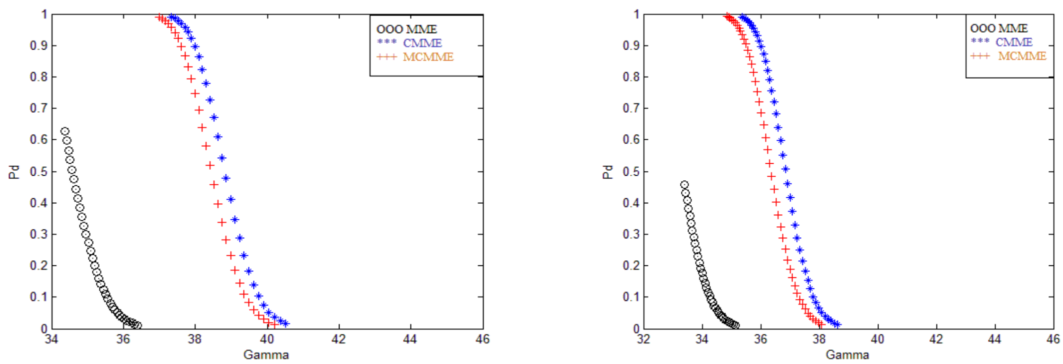


Figure 3. The ROC of MCMME with and without noise fluctuation at β =1, β =1.05 and β =1.1

Figure 4(a) and (b) show the relation between the Probability of detection and threshold value for MME, CMME, and MCMME at β =1 and β =1.05 respectively.We note that to get the same probability of detection at high noise fluctuations, the threshold value must be decreased. Fig.5 shows the relation between β and the Probability of detection for MME, CMME, and MCMME at P_{fa}=0.07, to ensure that as the noise fluctuation increased the probability of detection decreased.



(a) (b)

Figure 4. The relation between the Probability of detection and threshold value for MME, CMME, and MCMME (a) at β =1, (b) at β =1.05

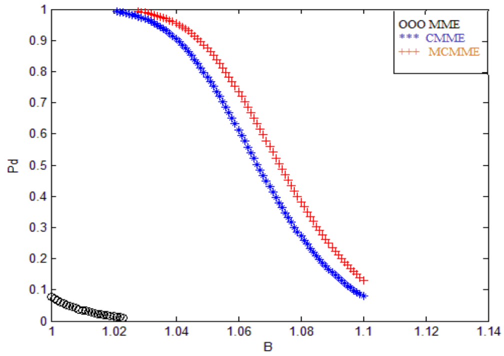


Figure 5. The relation between the Probability of detection and β for MME, CMME, and MCMME at $P_{fa} = 0.07$

3.3. Two-Stage System

This section explains the two-stage detection algorithm that exploits the merits of ED and one of the previous eigenvalue detection techniques. In this system the first stage, i.e., coarse sensing stage, tests the channel using ED technique. If the decision in coarse sensing (Dc) is greater than the threshold Υ_{Dc}, then the channel is declared as occupied. Else the received signal is sensed by using the second stage, i.e., fine sensing stage by using MME, CMME, or MCMME. If the decision in fine sensing (D_f) is greater than the threshold value Υ_{Df}, then the channel is considered as occupied else, it is empty [4].

The overall probability of detection P_{dT} and probability of false alarm P_{faT} are given as [8]:

$$P_{faT} = P_{faC} + \left(1 - P_{faC}\right) P_{faF} \tag{16}$$

$$P_{dT} = P_{dC} + \left(1 - P_{dC}\right) P_{dF} \tag{17}$$

Substituting (2) and (7) in (17) results the overall probability of detection of two-stage ED-MME detection technique as shown in (18).

$$P_{dT}\left(ED - MME\right) = 1 - F_1\left(Z\right) + F_1\left(Z\right) Q\left(Y\right) \tag{18}$$

Where $Y = \dfrac{\Upsilon - N\dfrac{\sigma_v^2}{\beta} - NP}{\dfrac{\sigma_v}{\sqrt{\beta}}\sqrt{2N\dfrac{\sigma_v^2}{\beta} + 4NP}}$ and $Z = \dfrac{\Upsilon_1 N + N\left(\Upsilon_1 Þ_{ML} - Þ_1\right)/\beta\sigma_v^2 - \mu}{v}$.

Similarly from (2) and (11) the overall probability of detection of two-stage ED-CMME detection technique as shown in (19).

$$P_{dT}\left(ED - CMME\right) = 1 - F_1\left(Z'\right) + F_1\left(Z'\right) Q\left(Y\right) \tag{19}$$

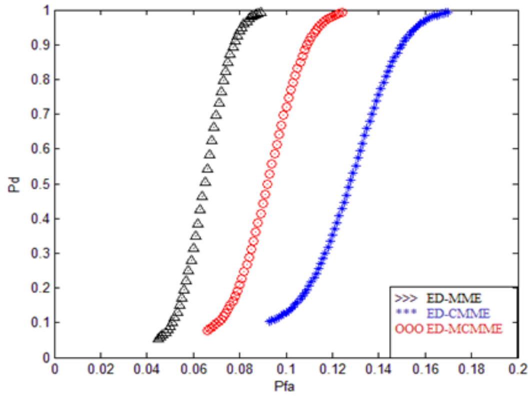
Where $Z' = \dfrac{\Upsilon' N + N\left(\Upsilon' Þ_{ML} - Þ_1\right)/\beta\sigma_v^2 - \mu}{v}$.

And from (2) and (15) the overall probability of detection of two-stage ED-MCMME detection technique as shown in (20).

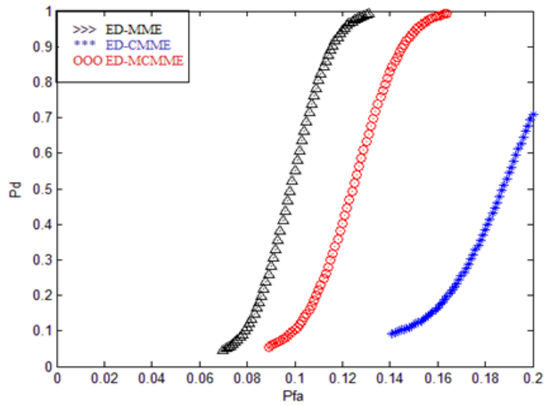
$$P_{dT}\left(ED - MCMME\right) = 1 - F_1\left(Z''\right) + F_1\left(Z''\right) Q\left(Y\right) \tag{20}$$

Where $Z'' = \dfrac{\Upsilon'' N + N\left(\Upsilon'' Þ_{ML} - Þ_1\right)/\beta\sigma_v^2 - \mu}{\nu}$.

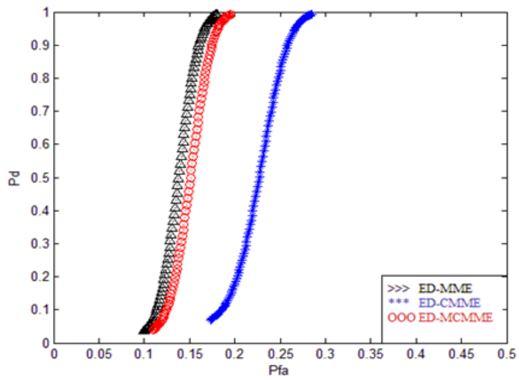
The compared ROC of the Two-stage ED-MME, ED-CMME and ED-MCMME detection techniques with and without noise fluctuation at β =1, β =1.05& β =1.1 are shown in Figure 6(a), (b), and(c) respectively.



(a)



(b)



(c)

Figure 6. The ROC of the Two-stage ED-MME, ED-CMME and ED-MCMME detection technique with and without noise fluctuation (a) at β =1, (b) at β =1.05& (c) at β =1.1

4. Conclusion

In this paper we have studied the effect of noise uncertainty on the Proposed modified two-stage combinational maximum-minimum eigenvalue detector (ED-MCMME), and compare it with the two-stage ED-CMME and ED-MME. The results showed that with and without noise fluctuations, ED-MCMME has better performance than ED-CMME and worse than ED-MME. But for a noise fluctuation of about 10%, the probability of detection of ED-MCMME closes to it for ED-MME.

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