International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 11, Issue 04 (April 2015), PP.66-71

An Optimized Energy Detection Scheme For Spectrum Sensing In Cognitive Radio

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Abstract:- With rapid growth of wireless devices, the Scarcity of Spectrum resources arises ,due to the improper and inefficient usage of available spectrum band. This problem can be alleviated by Cognitive radio . The major function of the cognitive radio rely on efficient sensing of available spectrum and Spectrum sensing techniques have been used to enhance the detection performance. Among these techniques, Energy detection is considered to be the implemented in practice because of less complexity. In this paper we propose an Adaptive threshold scheme which improves the detection performance under low SNR region. In this paper, noise uncertainty factor is considered wherein the Probability of error is minimized in various SNR regions.

Keywords:- Cognitive Radio, Spectrum Sensing, Energy detection, Noise Uncertainty, SNR(Signal to Noise Ratio)

I. INTRODUCTION

The immense growth in the wireless technology in the recent decades increase the need for spectrum resources. The available spectrum is underutilized due to the static allocation of the spectrum. To meet the rising demand of the spectrum resources and to overcome the underutilization of spectrum bands, Cognitive radio technology was introduced.

Cognitive Radio is a promising technology which was initially proposed by Joseph Mitola III, and it is derived from software defined radio the Software Defined Radio which enhances the flexibility of personal wireless services through a new language called Radio Knowledge Representation Language[1].Cognitive radio allows the wireless terminal to dynamically access the available spectral opportunities[2]. It allows the Unlicensed user(Secondary user) to access the spectrum bands allocated to the Licensed User(Primary User) without causing interference, hence improves spectrum utilization.

The main functions of Cognitive radio includes Spectrum Sensing, Spectrum Management, Spectrum Mobility and Spectrum Sharing. Of all these functions, Spectrum Sensing plays a vital role as it deals with the efficient detection of unused spectrum bands for the allocation of the bands to Secondary User[3].

Various Spectrum Sensing techniques are Energy Detection, Matched Filter, Cyclostationary detection, Cooperative Spectrum Sensing etc[5-7]. In Energy detection, the secondary user doesn't require prior knowledge about the Primary user signal whereas in Matched filter, the secondary user must have the prior knowledge about the Primary User. Signal detection at the low SNR region is dealt in [4]. In this paper energy detection mechanism is used.

Cognitive radio must have the capability to detect the weak signal in even in the low SNR region to avoid the interference with the Primary user. Energy detection method is considered to be the most practical method because of its less complexity and ease of implementation.

During the detection of Primary User, noise is considered and in reality noise power is varied from time to time, noise uncertainty arises[10]. TO reduce the noise uncertainty problem various methods have been proposed[11-13].

In this paper, we present a new method to enhance the sensing performance under the noise uncertainty environment. An adaptive threshold method is adopted that performs well under the low SNR region. In Section II, System Model and threshold value under No noise uncertainty and Section III describes the effect of Noise uncertainty and Section IV deals with the proposed Adaptive Threshold Scheme. Section V presents the Simulation results. Finally the References are followed by Conclusion.

II. SYSTEM MODEL

The energy detection method[8-9]calculates the energy of the primary user signal and compares it with the threshold value in the decision device. The block diagram of energy detector is given by,

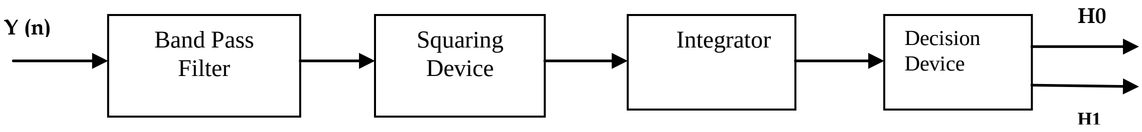

Figure 1 Block Diagram Of Energy Detection

To estimate the power energy of the primary user signal, the input signal is filtered using band pass filter and then passed through a squaring device. It is then integrated using Integrator and sent to the decision device where the threshold value is preloaded. The incoming signal from the integrator is compared with the threshold value and the decision is made.

The performance of the sensing is based on three parameters,

Probability of detection(Pd): When the channel is vacant, the detection is declared as vacant. The hypothesis for the Probability of detection is given by P($H_1|H_1$) where H_1 turns to be true in case of presence of the primary user which should be as high as possible for better detection.

Probability of False Alarm(Pf): The channel is declared as occupied when the channel is vacant. The Hypothesis for the probability of false alarm is given by P($H_1|H_0$) which should be as low as possible for better detection.

Probability of Misdetection(Pm): The channel is declared as vacant when the channel is occupied. The Hypothesis for probability of misdetection is given by P($H_0|H_1$).

The aim of the spectrum sensing is to maximize the detection probability and reduce the false alarm probability.

Energy detection is based on the Hypothesis

$$y(n) = \begin{cases} x(n) + w(n)\,, n = 1,2,\ldots..N & H_1, Signal\ is\ present \\ w(n)\,, n = 1,2,\ldots..N & H_0, Signal\ is\ absent \end{cases} \quad (1)$$

Here x(n) denotes the transmitted signal from the primary user, w(n) represents the noise signal which is assumed to be independent and it is additive white Gaussian Noise with zero mean and variance σ_n^2, N denotes the number of samples. H_0 represents null hypothesis which denote the absence of primary user in the band and hence the spectrum is free for the access to the secondary user and H_1 represents the presence of the primary user signal.

The energy of the primary user signal is done by the following equation

$$E = \sum_{n=0}^{N-1} |y(n)|^2 \quad (2)$$

In case of optimal energy detector, the test statistics is given by,

$$T_s = \sum_{k=1}^{N} |Y[k]|^2 \gtrless_{H_0}^{H_1} \lambda \quad (3)$$

where D(y) is the decision variable and λ is the decision threshold and N is the number of Samples.

When N is large, the test statistic in (3) can be approximated as Gaussian Distribution

$$T_s \sim \begin{cases} Normal(\mu_0,\ {\sigma_0}^2) & H_0 \\ Normal(\mu_1,\ {\sigma_1}^2) & H_1 \end{cases} \quad (4)$$

Where µ is defined as $\begin{cases} \mu_0 = N{\sigma_n}^2 & H_0 \\ \mu_1 = N{\sigma_n}^2(\gamma + 1) & H_1 \end{cases}$ (5)

and σ is defined as $\begin{cases} {\sigma_0}^2 = 2N{\sigma_n}^4 & H_0 \\ {\sigma_1}^2 = 2N{\sigma_n}^4(\gamma + 1)^2 & H_1 \end{cases}$ (6)

Where γ is the average power signal to noise ratio(SNR) and is given by $\gamma = \left(\frac{\sigma_s^2}{\sigma_n^2}\right)$.

The probability of detection and false alarm over AWGN channel is given by,

$$P_d = Prob\{D > \lambda|H_1\}; \quad P_d = \frac{1}{2} erfc\left[\frac{\lambda - \mu_1}{\sqrt{2}\,\sigma_1}\right] \quad (7)$$

$$P_f = Prob\{D > \lambda|H_0\}; \quad P_f = \frac{1}{2} erfc\left[\frac{\lambda - \mu_0}{\sqrt{2}\,\sigma_0}\right] \quad (8)$$

Where erfc is the complementary error function.

The probability of mis-detection is given by,

$$P_m = 1 - P_d \quad (9)$$

The prior information about the presence or absence of the primary is known, then the probabilities of it is assumed to be PH1 and PH0 and hence the total probability is given by PH0+PH1=1. The probability of error is now given by,

$$P_e = PH_0 P_f + PH_1\, P_m \quad (10)$$

The main aim of spectrum sensing is to minimize the probability of error and probability of false alarm hence increase the probability of detection. Without considering the noise uncertainty problem, assuming N is very large and hence approximated to Gaussian distribution, the optimal threshold is represented as,

$\lambda^{opt} = \arg min_{\lambda}(PH_0Pf + PH_1Pm)$ (11)

The closed form of above expression is given by,

$\lambda^{opt} = \frac{-B+\sqrt{B^2-AC}}{A}$ (12)

Where $A = \sigma_1^2 - \sigma_0^2$; $B = \sigma_0^2\mu_1 - \sigma_1^2\mu_0$; $C = \sigma_1^2\mu_0^2 - \sigma_0^2\mu_1 - 2\sigma_1^2\sigma_0^2 \ln\left(\frac{\sigma_1}{\sigma_0}\right)$
columns.

III. UNDER NOISE UNCERTAINTY

The system without noise is practically impossible. Noise is a combination of unwanted disturbances, interferences and various types of noises. Fluctuation of Noise power is considered to be noise uncertainty .

Channel is prone to noise and it is of great importance to determine the detection performance in the presence of noise uncertainty. The true noise power is considered as σ_n^2 and average noise power is considered as σ^2, then at a specific time average noise power is assumed to be

$\sigma^2 = \rho\sigma_n^2$ (13)

where ρ is the noise uncertainty factor.

Based on Central Limit theorem, the test statistics under noise uncertainty is approximated as Gaussian and is given by,

$$T_s \sim \begin{cases} Normal(N\rho\sigma_n^2,\quad 2N\rho^2\sigma_n^4) & H_0 \\ Normal\left(N\sigma_n^2\left(\frac{1}{\rho}+\gamma\right), 2N\sigma_n^4\left(\frac{1}{\rho}+\gamma\right)^2\right) & H_1 \end{cases} \quad (14)$$

The probability and detection and false alarm under noise uncertainty is modified and is represented as

$$P_d = \frac{1}{2}erfc\left[\frac{\lambda - N\sigma_n^2\left(\frac{1}{\rho}+\gamma\right)}{\sqrt{4N}\sigma_n^2\left(\frac{1}{\rho}+\gamma\right)}\right] \quad (15)$$

$$P_f = \frac{1}{2}erfc\left[\frac{\lambda - N\rho\sigma_n^2}{\sqrt{4N}\rho\,\sigma_n^2}\right] \quad (16)$$

P_m= 1-P_d (17)

The Probability of error is obtained by substituting the above equations in

$$P_e = PH_0P_f + PH_1\,P_m \quad (18)$$

and the SNR range is given by,

$SNR_{Range} = \rho - \left(\frac{1}{\rho}\right)$ (19)

IV. ADAPTIVE THRESHOLD UNDER NOISE UNCERTAINTY

To protect the primary users from secondary user interferences, choosing a proper threshold value is necessary. Under fixed threshold, Noise power fluctuates which declines the detection accuracy and hence introduces interference in the system. In order to alleviate the above problem, the threshold should be chosen flexible and hence dynamic threshold is proposed. In this threshold value is set dynamically

$\lambda^* \in (\lambda/\rho^*, \rho^*\lambda)$ where ρ^* is the dynamic threshold factor and it should be greater than or equal to 1 to indicate the dynamic factor(ρ^* >=1)

.By considering the noise uncertainty and dynamic threshold factor the detection and false alarm probabilities are given as

$$P_d = \min_{\lambda^*\in\left(\frac{\lambda}{\rho^*},\rho^*\lambda\right)} \min_{\sigma^2\in\left(\frac{\sigma_n^2}{\rho},\rho\sigma_n^2\right)} \frac{1}{2}erfc\left[\frac{\lambda^* - \mu_1}{\sqrt{2}\sigma_1}\right]$$

$$P_d = \frac{1}{2}erfc\left[\frac{\frac{\lambda}{\rho^*} - \mu_1}{\sqrt{2}\sigma_1}\right] \quad (20)$$

$$P_f = \max_{\lambda^*\in\left(\frac{\lambda}{\rho^*},\rho^*\lambda\right)} \max_{\sigma^2\in\left(\frac{\sigma_n^2}{\rho},\rho\sigma_n^2\right)} \frac{1}{2}erfc\left[\frac{\lambda^* - \mu_0}{\sqrt{2}\sigma_0}\right]$$

$$P_f = \frac{1}{2}erfc\left[\frac{\rho^*\lambda - \mu_0}{\sqrt{2}\sigma_0}\right] \quad (21)$$

The modified parameters for threshold calculation A, B and C are given by,

$$A = \rho^{*2}\sigma_1^2 - \left(\frac{1}{\rho^{*2}}\right)\sigma_0^2;$$

$$B = \left(\frac{1}{\rho^*}\right)\sigma_0^2\mu_1 - \rho^*\sigma_1^2\mu_0\ ;$$

$$C = \sigma_1^2\mu_0^2 - \sigma_0^2\mu_1^2 - 2\sigma_1^2\sigma_0^2\ln(\rho^{*2}\sigma_1/\sigma_0)$$

The SNR range is given by,

$$SNR_{Range} = \frac{\rho}{\rho^*} - \left(\frac{1}{\rho}\right) \tag{22}$$

V. SIMULATION RESULTS

Simulation results shoows the performance of proposed method under various scenarios with different SNR values.

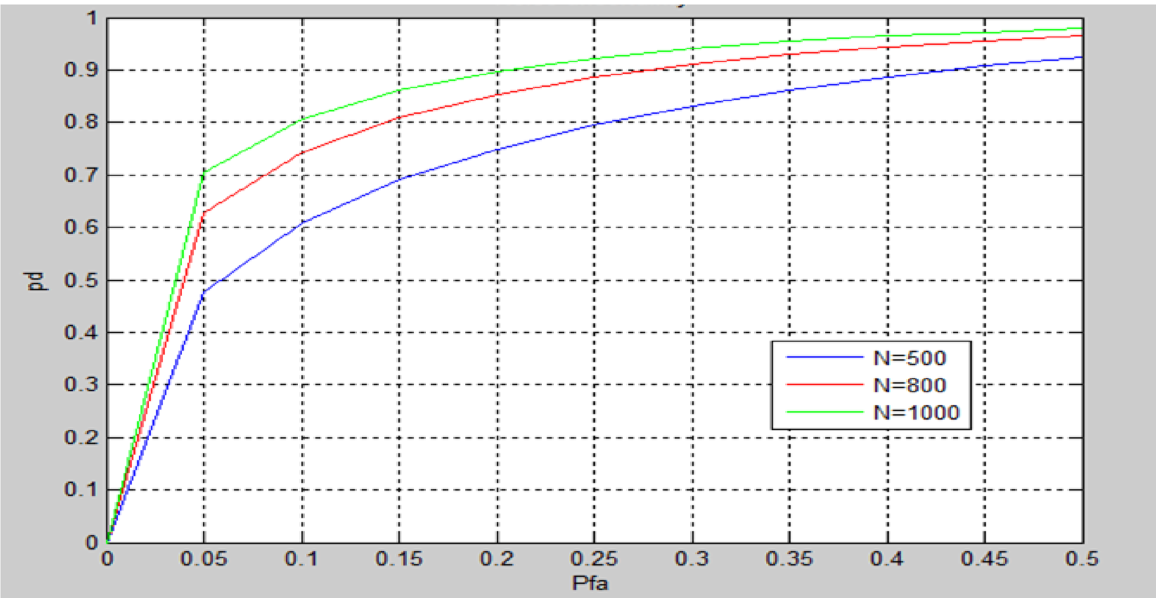

Fig 2: Probability of Detection by varying N

Figure 2 represents the probability of detection under without noise uncertainty. It is shown that the probability of detection increases with the increase in number of samples.

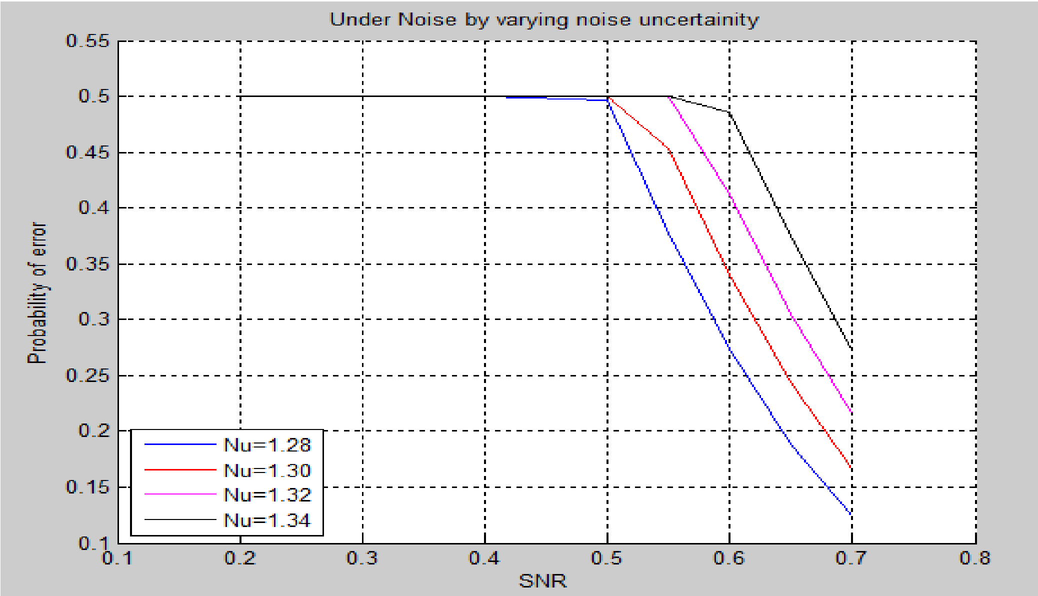

Fig 3: Probability of error under Noise Uncertainty

Figure 3 shows the effect of noise uncertainty in the probability of error. When the noise uncertainty factor increases the probability of error increases and SNR bound also gets increased.

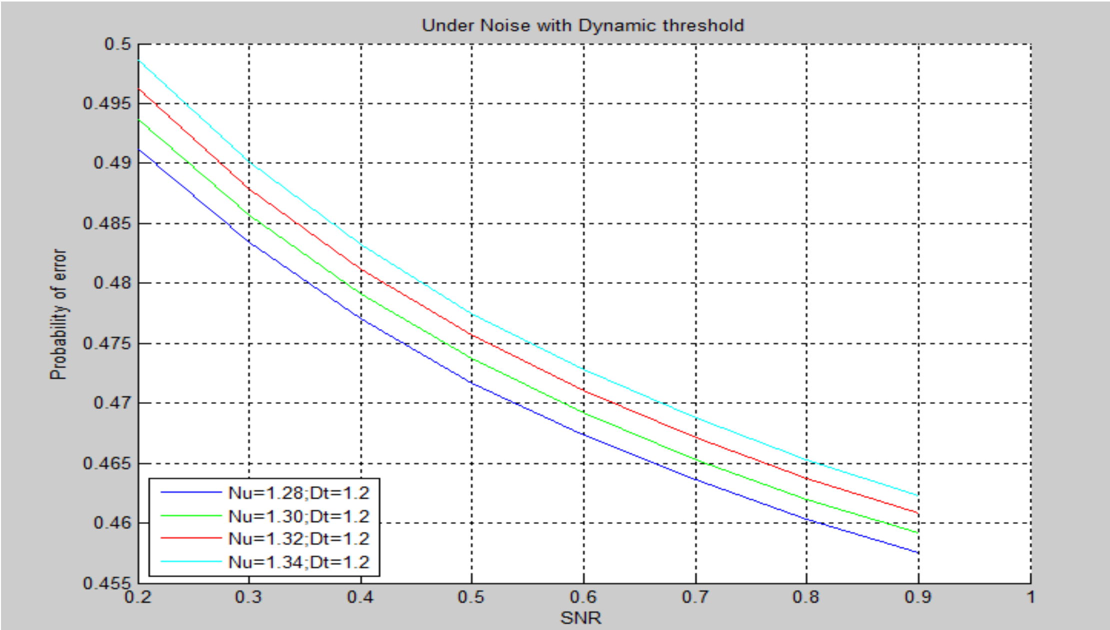

Fig 4: Probability Of Error under Noise Uncertainty with Dynamic Threshold=1.2

Figure 4 explains the probability of sensing error for different SNR values with noise uncertainty factor ρ and adaptive threshold factor ρ* as 1.2. In the figure Nu represents Noise uncertainty factor and Dt represents Dynamic threshold. The probability of error is minimized compared to figure 3

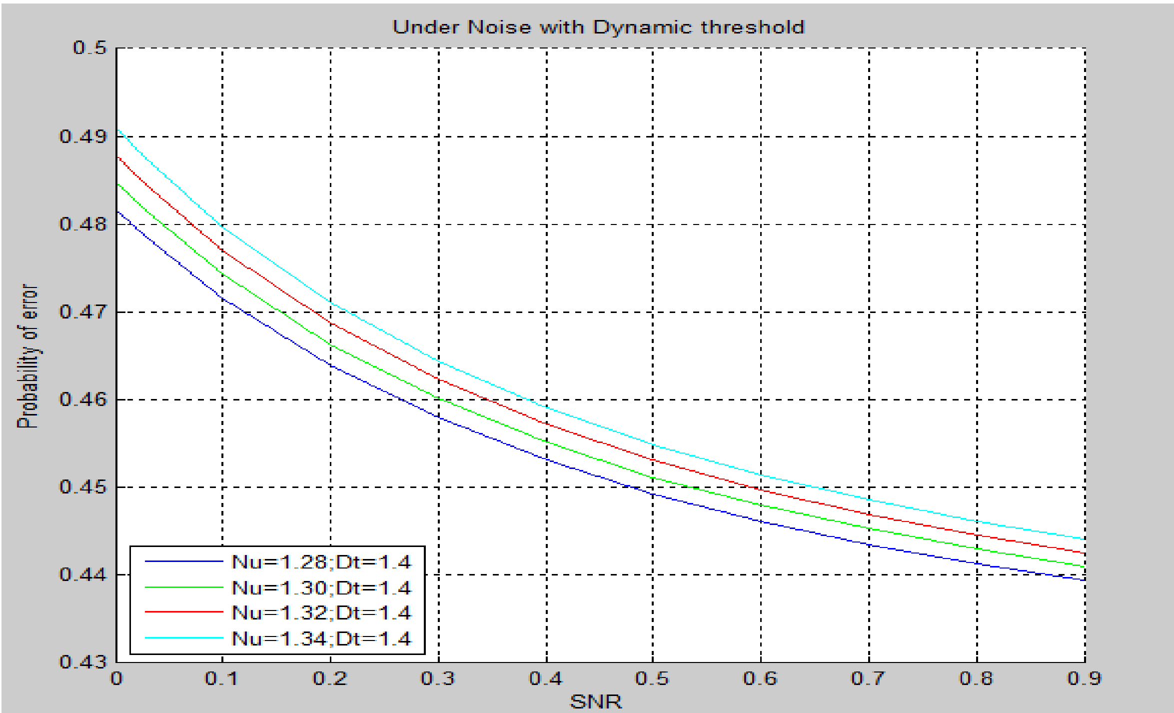

Fig 5: Probability Of Error under Noise Uncertainty with Dynamic Threshold=1.4

Figure 5 explains the probability of sensing error for different SNR values with noise uncertainty factor ρ and adaptive threshold factor ρ* as 1.2. In the figure Nu represents Noise uncertainty factor and Dt represents Dynamic threshold. When the adaptive threshold factor increases the performance of sensing error increases and the probability of error reduces greatly even at very low SNR.

VI. CONCLUSIONS

The energy detection technique has been considered as the simple and easy to implement method in spectrum sensing compared to other methods. The effect of noise uncertainty is the major concern in energy detection method. To overcome that constraints,the adaptive threshold scheme has been proposed and discussed which provides better performance in terms of error minimization in the low SNR region results.

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