Energy Detection Using Min-Max Technique in Uncertain Noise Environment in Cognitive Radio Network

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Abstract- This paper considers the detection of presence or absence of signals in low SNR medium with uncertainty in noise spectral density. In traditional energy detector, we have assumed that the channel and noise power should be constant during sensing period.ROC (receiver operating characteristic) degrades very badly with the increase in fluctuation in noise power and it goes worse in low SNR medium. The proposed min-max algorithm eliminates the effect of this degradation by adopting a suitable value for threshold. Simulation results are also matched with the theoretical results.

***Index Term*- Cognitive Radio, Energy Detector, Noise power, Uncertainty Parameter, SNR Threshold.**

I. INTRODUCTION

The most challenging task in cognitive radio networks is spectrum sensing [1]. In the IEEE 802.22 Wireless Regional area networks (WRAN) has not specified any spectrum sensing technique. So any secondary user may select any specific technique as per given condition. Among the available spectrum sensing technique such as matched filter, Energy Detector, Cyclostationary Feature Detection, Eigen Value Detection, Energy Detection is used widely due to its low complexity [6]. The Traditional Energy Detector measures the energy associated with received signal over a specific time period and a Bandwidth [4].

In spectrum sensing, the goal is to meet a given receiver operating characteristic (ROC) constraint at very low SNR. Classical detection theory suggests that degradation in the ROC due to reduced SNR can be countered by increasing the sensing time. Most Energy detection schemes are based on constant noise power. But it is not possible because of thermal noise, Interference between Primary and secondary users, Quantization noise, Interference between secondary users. Thus the noise in detection time cannot be always constant.

In this paper we first analyze the effect on ROC for different values of variance of noise and then try to eliminate this degradation upto a level by varying the threshold within certain limit. The rest of this paper is organized as follow. Sections II briefly discuss the Energy Detection and its low SNR model. Section III gives the effect when we consider the effect of fluctuation in noise variance. In Section IV we consider the case for variable threshold within certain limit. Section V presents numerical and simulation results followed by concluding remark in Section VI.

II. ENERGY DETECTION AND LOW SNR MODEL

The Spectrum sensing in Cognitive Radio network follows a binary hypothesis testing problem: Hypothesis $H0$ (signal absent, only noise present) and Hypothesis $H1$ (signal present). The Received signal for binary hypothesis can be given as:

$$H0: Y(n) = W(n), \qquad n = 1,2,3 \ldots\ldots, N;$$
$$H1: Y(n) = hX(n) + W(n) \; n = 1,2,3 \ldots\; N; \tag{1}$$

Where $X(n)$ is the transmitted signal, h is wireless channel gain, $W(n)$ is AWGN with mean zero and variance σ^2.

In this sensing technique secondary user does not have any deterministic knowledge about the signal $X(n)$, besides average power of the signal. The traditional analog energy consists of a pre-filter followed by a square-law device and a finite time integrator [2], [4]. The output of integrator is called the decision statics. It may be proportional to the received signal energy and can be given as

$$D(Y) = \frac{1}{N}\sum_{n=0}^{N-1} |Y(n)|^2 \underset{H0}{\overset{H1}{\gtrless}} \gamma \tag{2}$$

Where γ is decision threshold. N is the total number of samples [5]. As we have considered the case of constant variance of noise, the CLT gives the following approximation:

$$D(Y)\,|\,H0 = \mathcal{N}\left(\sigma^2, \frac{2}{N}\sigma^4\right)$$

$$D(Y)\,|\,H1 = \mathcal{N}\left(P + \sigma^2, \frac{2}{N}(P + \sigma^2)^2\right) \tag{3}$$

Where P is the average signal power. With this approximation we write the value of detection probability P_d and false alarm probability P_f.

$$P_d = Prob\,(D(Y) > \gamma \mid H1)$$
$$= \frac{1}{2} erfc\left(\frac{\gamma - (P+\sigma^2)}{\sqrt{\frac{4}{N}}\;(P+\sigma^2)}\right)$$

$$P_f = Prob\,(D(Y) > \gamma \mid H0)$$
$$= \frac{1}{2} erfc\left(\frac{(\gamma-\sigma^2)}{\sqrt{\frac{4}{N}}\sigma^2}\right)$$
$$Pm = 1 - Pd$$

Where P_m is Probability of miss-detection. By combining equation (4) and (5), we may get the formula for N

$$N = 4\left[erfc^{-1}(2P_f) - erfc^{-1}(2P_d)(1+SNR)\right]^2 SNR^{-2} \tag{6}$$

Where $SNR = P/\sigma^2$. From equation (6), it is clear that; signal may be detected in low SNR medium by increasing the detection time.

III. UNCERTAINITY IN NOISE POWER

Till now we have discussed the case of constant noise power, now consider the case for noise with uncertainty [5]. As this Uncertainty will lie within certain limit as $\sigma^2 \epsilon (\frac{\sigma^2}{r}, r\sigma^2]$, Where r is uncertainty parameter and r>1.

Now apply these uncertainties in equation (4) and (5), and we get new value of P_d and P_f as:

$$P_d = \min_{\sigma^2 \epsilon [\sigma^2/r,\, r\sigma^2]} \text{Prob}\,(\text{D(Y)} > \gamma|\text{H}_1)$$

$$= \frac{1}{2}\text{erfc}\left(\frac{\gamma - \left(P + \frac{\sigma^2}{r}\right)}{\sqrt{\frac{4}{N}}\left(P + \frac{\sigma^2}{r}\right)}\right) \tag{7}$$

$$P_f = \max_{\sigma^2 \epsilon [\sigma^2/r,\, r\sigma^2]} \text{Prob}\,(\text{D(Y)} > \gamma|\text{H}_0)$$
$$= \frac{1}{2}\text{erfc}\left(\frac{(\gamma - r\sigma^2)}{\sqrt{\frac{4}{N}}\; r\sigma^2}\right) \tag{8}$$

$$P_m = 1 - P_d$$

By combining the equation (7) and (8), we may get the value of N in case of noise uncertainty as

$$N = 4\left[r\, erfc^{-1} - \left(\text{SNR} + \frac{1}{r}\right) erfc^{-1}(2P_d)\right]\left[\text{SNR} - \left(r - \frac{1}{r}\right)\right]^{-2} \tag{9}$$

By comparing equation (6) and (9), it is clear that the main difference is SNR^{-2} and $SNR - (r - \frac{1}{r})^{-2}$ .As from equation (9), it is clear that when SNR is equal to the$(r - \frac{1}{r})$, then N equal to infinite. In other words to detect such a signal, sensing time should be infinite which is impractical. It means SNR should always higher than $(r - 1/r)$, which kept a limit of minimum SNR for detecting a signal. This limit is considered as SNR threshold, means signal received with SNR lower than SNR threshold will be treated as noise [5].

IV. VARIATION IN THRESHOLD

As due to variation in noise power, detection probability degrades. To recover this loss in P_d, threshold value must be changed accordingly. Now we will consider a new uncertainty parameter r' for threshold variation. The value of this new parameter will also vary within some limits as $\gamma \epsilon (\gamma/r', \gamma r']$, where r'>1.

Now consider the effect of this new parameter r', P_d and P_f will get new value as

$$Pd = \min_{\gamma \epsilon [\gamma/r',\, r'\gamma]} \; \min_{\sigma^2 \epsilon [\sigma^2/r,\, r\sigma^2]} Prob\,(D(Y) > \gamma \mid H1)$$

$$= \frac{1}{2}\text{erfc}\left(\frac{\gamma/r' - (P + \sigma^2/r)}{\sqrt{\frac{4}{N}}\;(P+\sigma^2/r)}\right) \tag{10}$$

$$P_f = \max_{\gamma \epsilon [\gamma/r',\, r'\gamma]} \; \max_{\sigma^2 \epsilon [\sigma^2/r,\, r\sigma^2]} Prob\,(D(Y) > \gamma \mid H0)$$

$$= \frac{1}{2}\text{erfc}\left(\frac{r'\gamma - r\sigma^2}{\sqrt{\frac{4}{N}}\; r\sigma^2}\right) \tag{11}$$

By combining equation (10) and (11), we get

$$N = \frac{4[(r'/r)\text{erfc}^{-1}(2P_f) - r'(1/r + \text{SNR})\text{erfc}^{-1}(2P_f)]^2}{(r'SNR + \frac{r'}{r} - \frac{r}{r'})^2} \tag{12}$$

Now compare equation (6) and (12), at r $= r'$, both equations are same. Thus by selecting the proper value of r', the effect of degradation in detection performance may be reduced.

V. NUMERICALS AND SIMULATION

This section provides the numerical and simulation result. All the simulations are done on MATLAB 7.8.0(R2009a). Here Input signal is taken as BPSK signal. Fig. 1 shows a curve between P_d and P_f for different value of SNR as -10dB, -15dB, -20dB, assume N=500. From fig. 1 it is clear as the value of SNR goes on decrease, the value of detection probability also decreased. Fig. 2, shows as total no of samples increase from N=500 to 2000, there is significant improvement in the value of detection probability.

Fig. 3 considered the effect of noise fluctuation. As noise variance change for 1 to some other value (as r changes 1.01, 1.03, 1.05), there is large amount of decay in detection probability, here N=1500 and SNR= -15dB is assumed. Fig. 4 shows the relationship between SNR threshold and uncertainty parameter. If r = 1.01, SNR threshold = $r - \frac{1}{r}$ will be approximately -17dB. It means when the cognitive user receives the signal to noise ratio below -17dB, this channel will be considered as vacant and may be used by secondary user. Similarly as r = 1.03, SNR threshold will be -12.28dB, means any signal having SNR below -12.28, will considered as noise. Fig. 5 compared all the cases, as r=1 and r'=1 is the condition for no fluctuation in noise or threshold. In second condition r=1.05 and r'=1 is the case when only fluctuation in noise is considered. Other cases count the effect of variable threshold with noise fluctuation.

VI. CONCLUSION

In this paper, we have discussed the energy detection performance with noise power fluctuation. A small fluctuation in noise power gives a large degradation in spectrum detection performance. In low SNR medium, this fluctuation affects a lot to the detection performance. So here we have used min-max criteria to compensate this degradation in performance. Theoretical and simulated results show that proposed scheme improves the detection in fluctuating noise environment

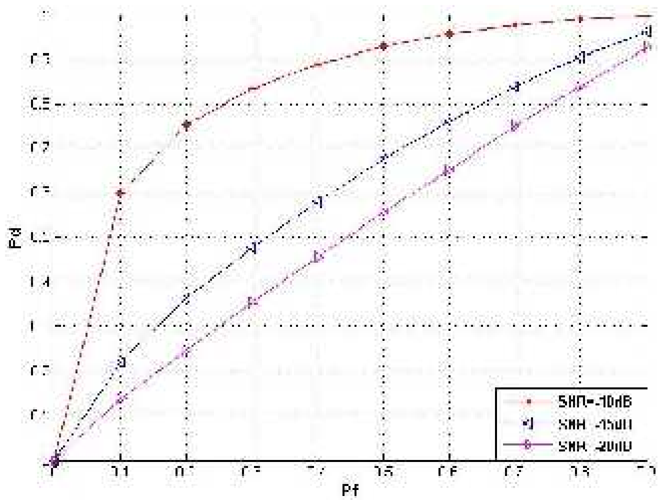

Fig.1.ROC curves for different SNR at N=500

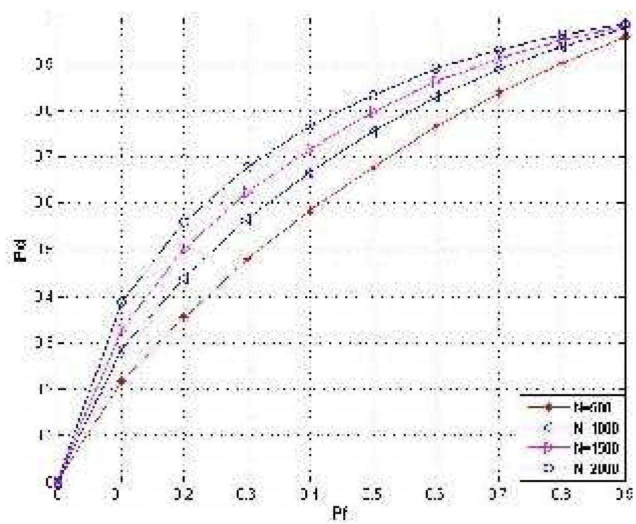

Fig.2. ROC curves for different N at SNR= -15dB

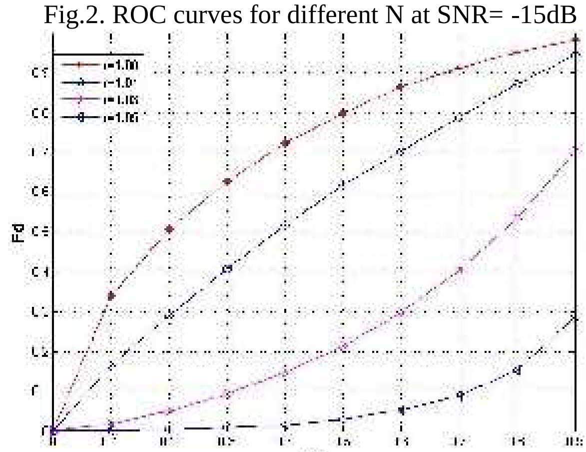

Fig.3.ROC curves for different noise uncertainties at SNR=-15dB and N=1500

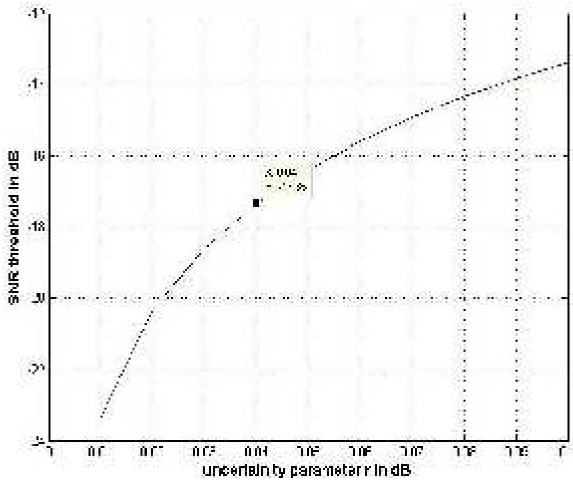

Fig.4. Curve for SNR Threshold at r =1.01 (.04dB) at point given in figure.

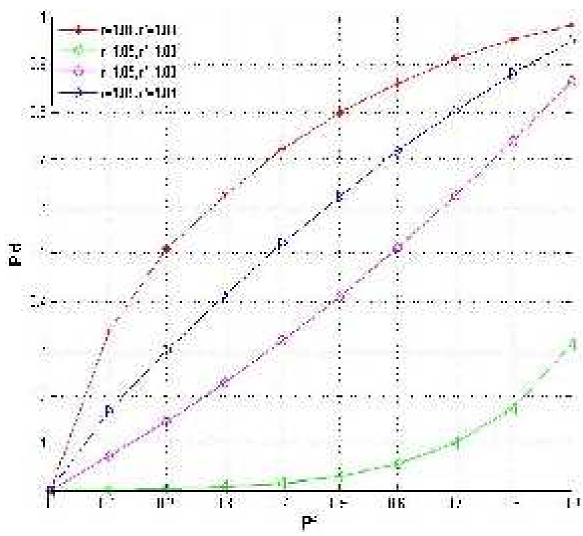

Fig.5.ROC curves with different noise uncertainty and different variable thresholds

REFRENCES

[1] S.Haykin, "Cognitive radio: brain-empowered wireless communications," *IEEE J,Select.Areas in Commun*, vol. 23, no. 2, pp. 201–220, february 2005.

[2] H.Urkowitz,''Energy Detection of Unknown Deterministic Signals,'' IEEE,vol,55,No. 4,april 1967.

[3] ''A Comparison of Fusion Rules for Cooperative Spectrum Sensing in Fading Channels'', G&PS Research Labs, Motorola Inc., Plantation, FL 33322 USA

[4] F.F. Digham and M.K.Simon, "On energy detection of unknown signal over fading channel," *Proceedings of IEEE International Conference on Communications (ICC03)*, pp. 3575–3579, May 2003.

[5] R. Tandra and A. Sahai, "SNR walls for signal detection," *EEE Journal of Selected Topics in Signal Processing*, vol. 2, no. 1, pp. 4–17, February 2008.

[6] T.Yucek and H.Arslan,''A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications'', *IEEE COMMUNICATIONS SURVEYS & TUTORIALS, VOL. 11, NO. 1, FIRST QUARTER 2009.*

[7] J.G.Prokis,Digital Communication, 4th ed. McGraw-Hill,2001.