International Journal of Future Generation Communication and Networking
Vol.7, No.3 (2014), pp.61-68
http://dx.doi.org/10.14257/ijfgcn.2014.7.3.06

An Algorithm for Spectrum Sensing in Cognitive Radio under Noise Uncertainty

Deep Raman[1] and N. P. Singh[2]

Department of Electronics and Communication
NIT Kurukshetra, INDIA
[1]mr.deepraman@gmail.com, [2]nirajatnitkkr@gmail.com

Abstract

With increasing demand of new wireless applications and increasing number of wireless user's problem of spectrum scarcity arises. Cognitive Radio technology supports dynamic spectrum access to address spectrum scarcity problem. Reliability of cognitive operation entirely depends upon how effectively task of spectrum sensing has been performed. Spectrum sensing is a process of discovering voids in spectrum which can be allocated to cognitive users opportunistically. There exists number of traditional spectrum sensing methods in literature for constant noise floor. Practically, noise spectrum density is uncertain under which performance of spectrum sensing scheme degrades. In this paper a new spectrum sensing adaptive algorithm considering noise uncertainty has been proposed. Simulation results of proposed scheme shows a constant detection probability has been achieved under noise uncertainty.

Keywords: *Cognitive Radio; Energy detection; Noise uncertainty; SNR estimation; Adaptive threshold*

1. Introduction

Quality of service and higher data rate are two most important parameters in emerging wireless technologies. With increasing demand of service quality and date rate, wireless communication system is developing quickly and many new communication paradigms are emerging. These new application require more utilization of frequency, leading to the scarcity of spectrum resources. Cognitive radio (CR), as a new technology to solve this problem by allocating frequency among different users. Opportunistically access to the idle spectrum without interfering on primary users is the main task of CR to increase the frequency spectrum utilization efficiency [1, 2].

In CR system, authorized or licensed user is called primary user and has the priority to occupy the frequency band. While second user or cognitive user, can only use spectrum opportunistically i.e. when spectrum is idle the idle without interference to the primary user. Cognitive user must monitor spectrum changes every time. Like, if primary user begins to transmit message, cognitive user on that particular bad has to vacate. This monitoring process is called Spectrum Sensing. Common methods of spectrum sensing involves energy detection, cyclostationary detection and matching filtering detection. Matching filter detection provide optimal detection but, require parameter of primary user in advance. However, in practical, it is very hard to convey parameter of licensed user to cognitive user, as of primary user privacy concerns [3]. Cyclostationary detection is unable to real-time search white space in wireless spectrum band since its computation complexity is too high [4].

Energy detection is the most common way due to its implementation simplicity and higher speed, But, a slight variation in noise variance cause great degradation in performance of energy detector. Performance of energy detection algorithm depends upon mainly sensitivity and specificity. These two mainly depend upon selection of threshold

ISSN: 2233-7857 IJFGCN

value which differentiates between the presence and absence of primary user. Hence, a careful trade-off is considered while setting the threshold for detection scheme [5, 6]. There exist many variation of two threshold setting scheme in literature, one when spectrum re-use probability of unused spectrum is targeted, probability of false alarm (P_f) is fixed to a small value and probability of detection (P_d) is maximized. This is referred to as constant false alarm rate (CFAR) detection principle. Second, when It is required to guarantee a given non-interference probability, Miss detection probability (P_m) is set at a minimum value or equivalently P_d is fixed to a high value and Pf is minimized. This approach is known as constant detection rate (CDR) principle. But, both of these scheme depends their operation on predefined value of parameters [7]. For real time application performance of all static threshold schemes degrades as of dynamically changing environmental conditions. To improve detection under noise uncertainty collaborated sensing gain is considered in [8]. In [9], an analytic model for noise power estimation is presented. A fixed threshold scheme providing more robust and more reliable detection than conventional energy detection is presented in [10]. Also, Bayesian estimation [11] and sliding window [12] techniques are investigated for detection under varying noise floor.

In this paper to address this problem, a new algorithm has been proposed which track changing environment condition in terms of Signal to Noise Ratio (SNR) and change parameters accordingly to yield a constant required probability of detection. The rest of the paper is organized as follows. In section II, a comprehensive system model is presented and performance parameters are described. Section III contains problem formulation. Section IV presents proposed adaptive threshold scheme. Section V composed of discussion of the results obtained with proposed approach. Finally conclusions is presented in section VI.

2. System Model

In any detection scheme it is required to detect a primary user signal of duration T and bandwidth of W. in energy detection, it is considered that only the transmitted power of the primary system during interval T is known, therefore, this power will be detected first in desired spectrum W, and then compared with a predefined threshold to determine whether the spectrum band is available or not. When the energy of the received signal is greater than threshold λ, the detector indicate that the primary user is present, which will be represented by hypothesis H_1, else, there is no primary user, which is represented by null hypothesis H_0 [13]. Overall method of energy detection has been illustrated in Figure 1.

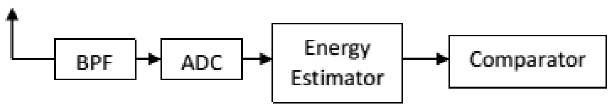

Figure 1. Sensing Model of Energy Detection

Mathematically, it can be represented as:

$$x(n) = \begin{cases} w(n) & H_0 \\ s(n) + w(n) & H_1 \end{cases} \quad (1)$$

Where n = 0,1,2,3... N, which represents the number of samples. x(n) represent received signal at the secondary user, s(n) is the licensed user signal, and is considered to be independent and identically distributed random process having zero mean and variance σ^2. w(n) denotes the noise signal and is also assumed to be stationary, independent and identically distributed random process of zero mean Additive White Gaussian Noise (AWGN) with power spectrum density N_0. The test statistic for the radiometric detection can be represented as a series of Fast Fourier Transformer (FFT) components. This test statistics represent energy of signal

$$T_D = \begin{cases} \sum_{k=0}^{n} (X[k])^2 < \lambda & H_0 \\ \sum_{k=0}^{n} (X[k])^2 \geq \lambda & H_1 \end{cases} \quad (2)$$

Here, X(k) is FFT series of signal x(n), and λ is the detection threshold value. According to the central limit theorem and as long as N is large enough, the decision statistic in (2) can be approximated as a Gaussian distribution [13, 14].

$$T_D = \begin{cases} Normal\left(\mu_0, \sigma_0^2\right) & H_0 \\ Normal\left(\mu_1, \sigma_1^2\right) & H_1 \end{cases} \quad (3)$$

Where

$$\left.\begin{aligned} \mu_0 &= \sigma_n^2 \\ \sigma_0 &= \frac{\sigma_n^2}{\sqrt{N}} \end{aligned}\right\} \quad (4)$$

$$\left.\begin{aligned} \mu_1 &= \sigma_0^2 * (\gamma + 1)^2 \\ \sigma_1 &= \sigma_0 * \sqrt{(2 * \gamma + 1)} \end{aligned}\right\} \quad (5)$$

Where γ is SNR.

The performance of spectrum sensing is measured by two parameters: the detection probability (P_d) which indicates that the primary user exists, here this parameter should be as big as possible to protect the primary users from the interference, and false alarm probability (P_f) which signifies that the primary user is present while in reality there is no primary user. This probability should be as small as possible to increase the spectrum utilization.

$$P_d = P_r\left(\text{signal is detected} \mid H1\right)$$

P_f is the probability that the detection algorithm falsely decides that PU is present in the scanned frequency band when it actually is absent, and it is written as

$$P_f = P_r\left(\text{signal is detected} \mid H0\right)$$

Thus, we target at maximizing P_d while minimizing P_f. Another important parameter of interest is the probability of missed detection P_m which is the complement of P_d. P_m indicates the probability of not detecting the primary transmission when primary user is active in the band of interest and can be formulated as

$$P_m = 1 - P_d = P_r\left(\text{signal is not detected} \mid H1\right)$$

In AWGN channel probabilities of detection and false detection are represented as

$$P_f = Q\left(\frac{\lambda - \mu_0}{\sigma_0}\right) \quad (6)$$

And

$$P_d = Q\left(\frac{\lambda - \mu_1}{\sigma_1}\right) \quad (7)$$

Where Q denote complementary error function which can be expressed by

$$Q(x) = \frac{1}{\sqrt{2\Pi}}\int_x^\infty e^{(-y^2/2)}dy \quad (8)$$

3. Problem Formulation

In traditional threshold setting schemes *i.e.*, CFAR and CDR threshold values is based upon a constant noise variance. But actually in real time applications noise variance keep on changing between maximum and minimum values given by

$$\sigma_l = \sigma_n * 10^{\frac{-\rho}{10}}, \sigma_h = \sigma_n * 10^{\frac{\rho}{10}} \quad (9)$$

Here ρ denote the uncertainty factor, whose value lies between 0 and 1. Where 0 denote no uncertainty in noise variance and 1 denote maximum uncertainty. In these schemes performance of the system highly degrades as noise uncertainty factor increases and desired value of P_d is not achieved. In such situations real time sensing is not possible and system find it hard to search white spaces for cognitive users operation. Figure 2 shows probability function of variation in noise variance. This suggest noise is bounded by low and high values which depends upon environmental conditions. This degradation in performance is basically because of changing noise variance and fixed static threshold value which don't changes with changing scenario. So the task here for system is to provide desired detection probability even in changing noise variance.

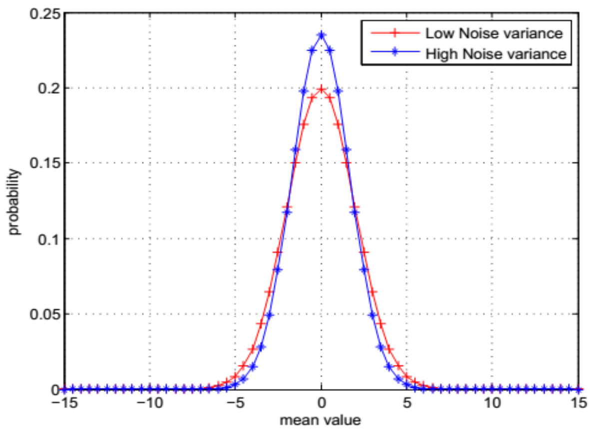

Figure 2. Variation in Noise Variance

4. Proposed Algorithm

As noise variance changes SNR of channel changes, so the proposed algorithm works on the basis of channels SNR estimation. SNR estimation has been discussed extensively in literature [15, 16]. Maximum Likelihood estimator, Second and Fourth Order Moments techniques are used for SNR estimation in [15]. SNR estimation of non-uniform variance is discussed in [16-18]. Based upon estimated SNR value threshold value has been set by varying number of samples accordingly. This threshold value keep track of any change in estimated SNR which is keep on changing based upon environment conditions. Proposed scheme has been shown as under in Figure 3.

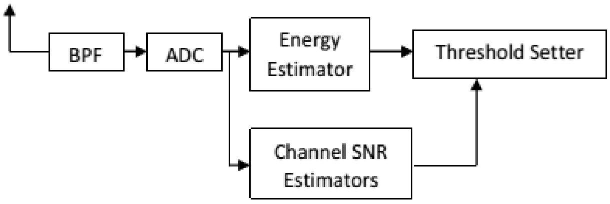

Figure 3. Proposed Adaptive Threshold Scheme

Threshold based upon for a particular Pf is given by

$$\lambda = \sigma_0 * Q^{-1}(P_f) + \mu_1 \tag{10}$$

Detection probability for this threshold value is

$$P_d = Q\left(\frac{\sigma_0 * Q^{-1}(P_f) + \mu_0 - \mu_1}{\sigma_1}\right) \tag{11}$$

Putting value of all parameter we get

$$\gamma = \frac{\sqrt{2} * [Q^{-1}(P_f) + Q^{-1}(P_d)]}{\sqrt{N} - Q^{-1}(P_d) * \sqrt{2}} \tag{12}$$

Above result yield us number of samples required to have a desired probability at a particular SNR value.

Steps in algorithm

1. Channel SNR estimation.
2. Compute number of samples required to achieve desired P_d and P_f.
3. Set threshold based upon estimated SNR and number of samples.
4. Compute test statistics.
5. Compare test statistics with proposed threshold value to make decision about presence or absence of primary user.

5. Results and Discussion

In this section results obtained with CFAR scheme, CDR scheme and proposed scheme are given. For static threshold schemes which are based upon fixed noise variance i.e. CFAR and CDR. Number of samples, i.e. N is considered to be 1000. Channel is considered to be corrupted by AWGN with variance equal to 1.

Figure 4 shows P_f variations at different SNR values based upon CDR scheme. It is evident from figure that when environment parameters changes i.e. SNR value changes P_f changes for a desired P_d and this effect is more severe at lower P_d.

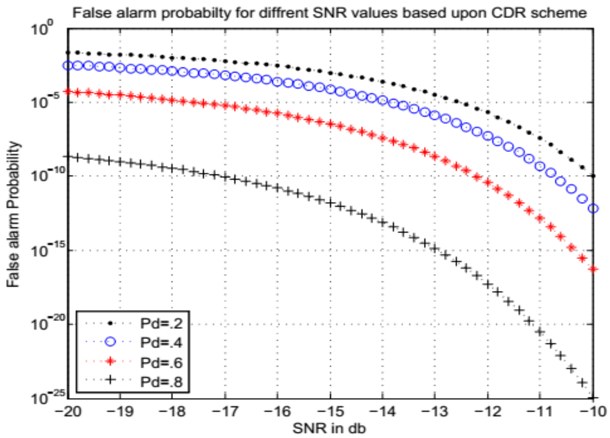

Figure 4. False Alarm Probability for Different SNR Values Based upon CDR Scheme

Figure 5 shows for CFAR scheme P_d changes when SNR value changes i.e. dynamic environment. For higher P_f like P_f=.5, change in P_d is noticeable even for small change in environment parameters. Value of P_d equals to .9 at SNR -10 reduced to just .1 at SNR equal to -14.

Results based upon CDR and CFAR scheme explore the dynamic environment conditions where noise variance keep on changing. This suggest to have reliable operation in changing environment threshold value must be varied accordingly. Figure 6 and figure 7 shows result obtained with adaptive threshold scheme. These results clearly shows to have a constant desired P_d in dynamic scenario number of samples are varied. Like in Figure 6 to have a constant P_d over 0db to -5db, number of samples should be increased by 30%. This increase gets high for greater noise levels.

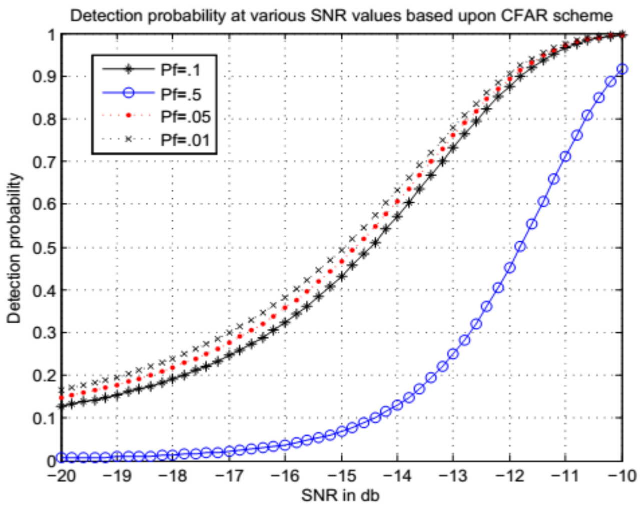

Figure 5. Detection Probability for Different SNR Values based Upon CFAR Scheme

Results obtained suggest two very important things, one number of samples required are more to have more P_d, and second variation in number of samples is less at lower desired P_d. It can be concluded from discussion that to combat effect of noise variations in system performance number of samples are varied, this in turn provide constant detection probability among changing environment.

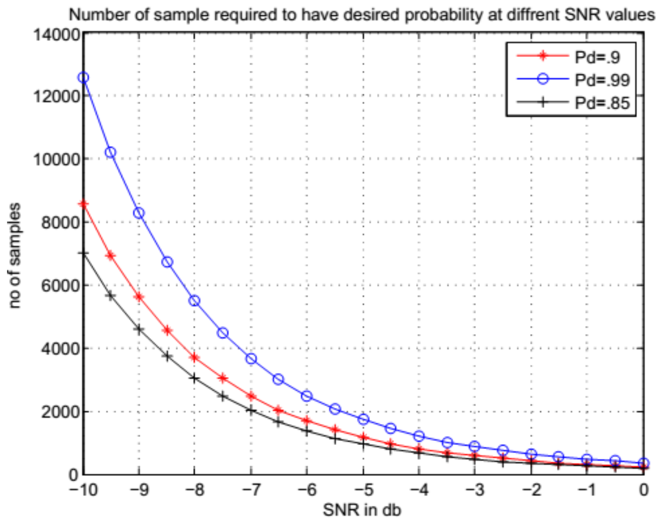

Figure 6. Number of Samples Required to Have Desired Probability at Different SNR Values

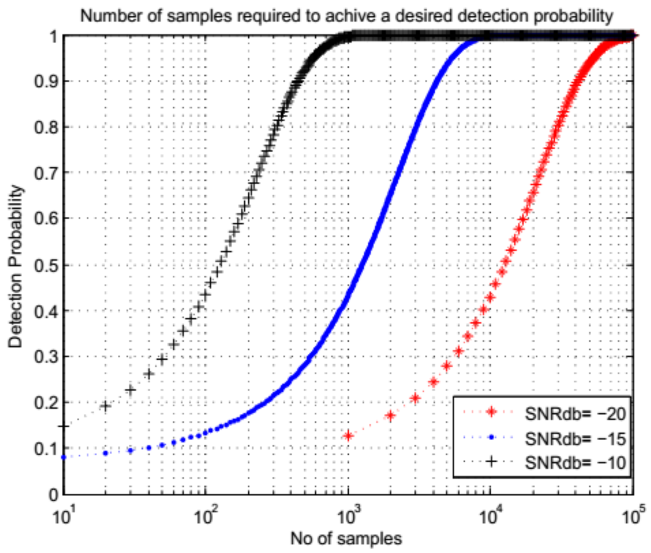

Figure 7. Number of Samples Required to Achieve a Desired Detection Probability

6. Conclusion

In any sensing scheme probability of correct detection entirely depends upon appropriate value of threshold. In this paper an adaptive threshold algorithm scheme is proposed as a solution to changing P_d when noise floor keep on changing. The proposed scheme track the dynamically changing environment in terms of SNR and set threshold accordingly. Analytical analysis and result obtained shows that a constant desired P_d can be achieved even in changing environment using proposed scheme.

References

[1] S. Haykin, "Cognitive Radio: Brain Empowered Wireless Communications", IEEE Journal on Selected Areas in Communications, vol. 23, no. 2, **(2005)**, pp. 201-220.
[2] I. F Akyildiz, W.-Y. Lee and M. C. Vuran, "Next Generation/ Dynamic Spectrum Access/ Cognitive Radio Wireless Networks: A survey", Computer Networks, vol. 50, no.5, **(2006)**, pp. 2127-2159.
[3] N. Devroye, P. Mitran and Y. Tarokh, "Limits on Communications in a Cognitive Radio Channel", IEEE Communications Magazine, **(2006)** June, pp. 44-49.
[4] K. W. Choi, W. S. Jeon and D. G. Jeong,"Sequential Detection of Cyclostationary Signal for Cognitive Radio Systems", IEEE Transactions on Wireless Communications, , vol. 8, no. 9, **(2004)**, pp. 4480-4485.
[5] J. J. Lehtomäki, M. Juntti, H. Saarnisaari and S. Koivu, "Threshold Setting Strategies for a Quantized Total Power Radiometer", IEEE Signal Processing Letters, **(2005)**, pp. 796–799.
[6] R. Garello, "Comparisons of Spectrum Sensing Methods for Cognitive Radio under Low SNR", Antenna and Propagation Wireless Communication (APWC) Tropical Conference, IEEE-APS, **(2011)**, pp. 886-889.
[7] Z. Shibing and B. Zhihua, "An Adaptive Spectrum Sensing Algorithm under Noise Uncertainty", IEEE International Conference on Communication (ICC), **(2011)**, pp. 1-5.
[8] B. Shen, L. Huang, C. Zhao, Z. Zhou and K. Kwak, "Energy Detection based Spectrum Sensing for Cognitive Radios in Noise of Uncertain Power", IEEE International Symposium Communications and Information Technologies, Vientiane, Lao PDR, **(2008)**.
[9] Z. Ye, G. Memik and J. Grosspietsch, "Energy Detection Using Estimated Noise Variance for Spectrum Sensing in Cognitive Radio Networks", IEEE Conference on Wireless Communications & Networking, March; Las Vegas, America, **(2008)**.
[10] J. W. Lee, J. H. Kim, H. J. Oh, and S. H. Hwang, "Energy Detector Using Adaptive-fixed Thresholds in Cognitive Radio Systems", 14th Asia Pacific Conference on Communications, October; Tokyo, Japan, **(2008)**.
[11] J. Shen, S. Liu and Y. Wang, "Robust Energy Detection in Cognitive Radio", IET Commun., vol. 3, no. 6, **(2009)**, pp. 1016-1023.
[12] Y. M. Kim, G. Zheng and S. H. Sohn, "An Alternative Energy Detection Using Sliding Window for Cognitive Radio System", IEEE Conference on Advanced Communication Technology, Korea, **(2008)** February.
[13] Y. C. Liang, Y. Zeng, E. C. Y. Peh and A. T. Hoang, "Sensing Throughput Trade-Off for Cognitive Radio Networks", IEEE Transactions on Wireless Communications, vol. 7, no.4, **(2008)**, pp. 1326-1337.
[14] A. Sonnenschien and P. M. Fishman, "Radiometric Detection of Spread Spectrum Signals in Noise of Uncertain Power", IEEE Transactions on Aerospace and Electronic Systems, vol. 28, no 3, **(1992)**, pp. 654–660.
[15] D. R. Pauluzzi, N. C. Beaulieu, "A Comparison of SNR Estimation Techniques for the AWGN Channel", IEEE Transaction on Communication., vol. 48, **(2000)**, pp.1681-1691.
[16] D. H. Johnson and D. E. Dudgeon, "Array Signal Processing", Prentice Hall, Englewood Cliffs, NJ, **(1993)**.
[17] S. M. Kay, "Fundamental of Statistical Signal Processing", Detection Theory. Prentice Hall, Upper Saddle River, NJ, **(1993)**.
[18] S. M. Kay, "Fundamental of Statistical Signal Processing", Detection Theory. Prentice Hall, Upper Saddle River, NJ, **(1998)**.

Author

Deep Raman received B.Tech (Gold Medallist, 2011) degree in Electronics and Communication from Govt. Engineering Collage Sirsa, INDIA. Currently he is pursuing his M.Tech in Communication engineering at National Institute of Technology Kurukshetra, INDIA. His research interest includes wireless communication, signal processing and cognitive radio.

