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Two-Phase Detector for Spectrum Sensing in Cognitive Radio Networks

Jyotshana Kanti[1] and Geetam Singh Tomar[2]

[1]Department of Computer Science and Engineering
Uttarakhand Technical University, Dehradun, INDIA,
[2]Machine Intelligence Research Labs, Gwalior, INDIA
[1]jyotshanakanti@gmail.com, [2]gstomar@ieee.org

Abstract

Spectrum sensing is one of the key functions of cognitive radio networks (CRN), which senses licensed band for CR users. This paper introduces a two phase detector, carries a weighted-energy detector (W-ED) and a correlated-generalized likelihood ratio test (C-GLRT). In first phase, we identify the energy and then if required, the C-GLRT makes the final decision in second phase. Performance of the proposed two phase detector is compared with the existing energy detector (ED), generalized likelihood ratio test (GLRT), and adaptive spectrum Sensing (ASS) detectors.

Keywords*: Cognitive Radio, C-GLRT, GLRT, W-ED*

1. Introduction

There is tremendous increase in wireless services, which has increased the demand of the radio spectrum. However, the radio spectrum is a limited resource and its efficient utilization is essential. The licensed spectrum users are referred to as primary users. Most of the spectrum is wasted because it is not being used by the primary user at all the times and also at all geographical locations. Cognitive Radio (CR) is used to detect such situation in order to make use of the spectrum when it is not used by the primary users. Spectrum Sensing (SS) Techniques are used to allocated the spectrum to the secondary unlicensed users for the specific time being and geographical location [1]. The SS here is performed by the two phase detector. The proposed two phase detector makes use of the W-ED as the first phase and C-GLRT as the second phase of the detector [2]. When the noise variance is known the energy detector (ED) is a simple and robust SS technique [3-4]. However if we do not have exact knowledge of the noise variance it leads to incorrect evaluation of the threshold and hence leads to increase in the false alarm probability [5]. When the noise variance is unknown the eigen value based detector GLRT can be used [6]. These detectors are based on the correlated multiple antennas and hence are suitable for the practical use. Further, in [7], authors presented two-phase detection scheme known as ASS, where out of two phases only one phase detector performs sensing operation at a time. But it does not perform well at low SNR.

The rest of the paper is organized as follows: Section II shows system description. Section III presents system model. Section IV describes the numerical results and analysis. Finally, Section V concludes the paper.

2. System Description

Suppose that the secondary user is deployed with *M* antenna then the exponential correlation model is generally used to define the correlation among the antennas. The

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correlation matrix *'C'* of antennas is a symmetric toeplitz matrix. The components of correlation matrix *'C'* can be written as

$$C_{ij} = \begin{cases} \rho^{j-i}, & i \le j \\ C_{ji}^*, & i > j \end{cases} \quad (1)$$

Where, $i, j = 1, 2 \ldots M$, and $0 \le \rho \le 1$, ρ is the antenna correlation coefficient between two adjacent antennas, and defined as $\rho = exp^{-23\Lambda^2\left(\frac{d}{\lambda c}\right)^2}$, It relies on the angular spread Λ, wavelength λ_c, and the distance d between two adjacent antennas. Angular spread Λ is an important propagation parameter which determines how spread out multipath power is about the horizon. Angular spread Λ ranges from 0 to 1, with 0 denoting the case of a single multipath component from a single direction, and 1 denoting no clear bias in the angular distribution of received power.

3. Proposed System Model

We consider the scenario where multiple antennas are deployed at the single secondary node in order to detect the primary signal. The number of antennas which are used at secondary node is being represented by M. Then in order to detect the signal with a very low signal to noise ratio (SNR) In the proposed method various time instants have been considered, which is represented by N. Firstly considering the noise signal represented by $w(n)$ having Gaussian distribution with mean zero and co-variance matrix $\sigma_n^2 I$. The signal being transmitted by the primary user is represented by $s(n)$ and is complex phase shift keying modulated having an average power equal to p which we have assumed to be 1. The signal is transmitted over a channel which can be white Gaussian channel or Rayleigh fading channel. The channel gain is represented by $h(n)$ and have Gaussian distribution with mean as zero and variance as σ_h^2.The received signal is represented by $x(n)$. Since M antennas are considered at the secondary user in this case, the received signal vector $x(n)$ is a $M \times 1$ vector. The entire received signal matrix being represented by $X(n)$ which is formed by considering the received signals at each antenna at different instants of time. Therefore $X(n)$ is given as:

$$X(n) = [x(1)\, x(2) \ldots\ldots\ldots . x(N)] \quad (2)$$

The SS problem can be formulated on the basis of two hypothesis test: H_0 and H_1. In the hypothesis H_0 we assume that we are receiving only the noise signal. Hence the received signal $x(n)$ is equal to the noise signal *i.e.*,

$$H_0 : \; x_i(n) = \; w_i(n) \quad (3)$$

In the hypothesis H_1 it is assumed that signal and noise both are received. Hence the received signal here is given as

$$H_1 : \; x_i(n) = \; h_i(n) \times s(n) + \; w_i(n) \quad (4)$$

$i = 1,2 \ldots . M, \quad n = 1, 2, \ldots, N$

Therefore, the distribution of $X(n)$ is given as

$$X \approx \begin{cases} C_N(0, \sigma_w^2 I) & under\ H_0 \\ C_N(0, P\sigma_h^2 C + \sigma_w^2 I) & under\ H_1 \end{cases}$$

Then, likelihood functions under H_0 and H_1 are:

$$p(X|H_0, \sigma_w^2) = \prod_{n=1}^{N} \frac{1}{\pi^M \sigma_w^{2M}} \times \exp\left(\frac{-x(n)^H x(n)}{\sigma_w^2}\right)$$

$$p(X|H_1, \sigma_w^2) = \prod_{n=1}^{N} \frac{1}{\pi^M\, det(P\sigma_h^2 C + \sigma_w^2 I)} \times \exp\left(-x(n)^H \left(P\sigma_h^2 C + \sigma_w^2 I\right)^{-1} x(n)\right) \quad (7)$$

The novelty of this paper is that it utilizes the property of both W-ED and C-GLRT detectors. Due to W-ED it assigns the higher weight coefficients to the signal component, which corresponds to larger eigen values, while according to C-GLRT it considers the correlation effect of the multiple antennas being used at the secondary user, hence this arrangement significantly improves the detection performance.

The ED being used at the first phase; performs the coarse detection. If it declares that the channel is occupied the result is simply accepted however if the ED declares the channel to be unoccupied the result is given to the second phase of the detector. The C-GLRT forms the second phase of the detector which performs the final detection. The first phase W-ED is based on the Neyman Pearson theorem when the noise variance is known, the W-ED is given as:

$$L(X) = \frac{p(X|H_1,\sigma_w^2)}{p(X|H_0,\sigma_w^2)} \tag{8}$$

The test statistic is then given as:

$$T_{W-ED}(X) = \ lnL(X) \gtrless_{H_0}^{H_1} \ \varepsilon \tag{9}$$

Where, ε is the decision threshold. It is seen that for a W-ED, the observed data *x(n)* is first linearly transformed to *y(n)*, then the transformed signal component corresponding to the larger eigen value is used with a higher weight coefficients. When the antennas are independent, *C* is a diagonal matrix, all the eigen values are the same, and the W-ED becomes the ED. When the constraint on probability of detection is given, the threshold ε is calculated on the basis of the false alarm probability.
The probability of false alarm is given as

$$P_F^{ED} = \ P_r\{T_{ED} > \ \tau|H_0\} = \ 1 - \ F_{T_{ED|H_0}}(\tau) \tag{10}$$

The probabilty of detection is given as

$$P_D^{ED} = \ P_r\{T_{ED} > \ \tau|H_1\} \tag{11}$$

Algorithm: Propose Two-Phase detector for Spectrum sensing

1: Given $\{x_1,x_2,x_3,...,x_N\}$
2: Given $\{M, \rho, P\}$
3: Given $\{ \varepsilon, \lambda_2\}$
4: X = 1; Z = 0;
  Y = 0; λ_{Rx} = 0;
5: **for** i = 1,2,...,N
    X = -X*x_i^H;
    Z = exp (X/sigma);
    Y = Z/(pi^M*sigma^M);
  endfor
6: **if** ln (Y) ≥ ε
    LF = H_1;
  else if X < ε
    LF = H_0;
7: else
8:   Z = 0;
9: **for** i = 1,2,...,N
    $\lambda_{Rx} = (\lambda_{Rx}+\lambda_{R_x}^i)/M$;
  endfor
10: **if** ln[Y(λ_{Rx})] ≥ ε

m = H_1;
else if Z < ε
m = H_0;
endif
endif

The Second phase C-GLRT based method first obtains the maximum likelihood estimate (MLE) of the unknown parameter Θ under H_0 and H_1, then it forms the GLRT test statistic as:

$$L_G(X) = \frac{p(X|H_1,\Theta_1)}{p(X|H_0,\Theta_1)} \tag{12}$$

Based on the likelihood functions under H_0 and H_1; The MLE of σ_w^2 is obtained as:

$$\sigma_{w0}^2 = \frac{1}{MN}\sum_{n=1}^{N}\frac{x(n)^H x(n)}{\sigma_w^2} = \frac{1}{M}\sum_{i=1}^{M}\lambda_{R_x}^i \tag{13}$$

Where $\lambda_{R_x}^i$ is the eigen value of the sample covariance matrix R_x defined as $R_x = 1/NXX^H$. The derivative is set to zero and the MLE of σ_w^2 is derived under H_1 as:

$$\sigma_{w1}^2 = \max\left(0, \ \frac{1}{M}\sum_{i=1}^{M}\lambda_{R_x}^i - \frac{P\sigma_h^2}{M}\sum_{i=1}^{M}\lambda_i\right) \tag{14}$$

Using the MLE of σ_{w0}^2 and σ_{w1}^2 in the likelihood functions of H_0 and H_1 the test statistic of C-GLRT is derived as:

$$T_{C-GLRT}(X) = lnL_G(X) \gtrless_{H_0}^{H_1} \ \varepsilon \tag{15}$$

The probability of false alarm is given as

$$P_F^{C-GLRT} = P_r\{T_{C-GLRT} > \tau|H_0\} \tag{16}$$

$$P_F^{C-GLRT} = 1 - F_{T_{C-GLRT|H_0}}(\tau) \tag{17}$$

The probabilty of detection is given as

$$P_D^{C-GLRT} = P_r\{T_{C-GLRT} > \tau|H_1\} \tag{18}$$

4. Numerical Results and Analysis

In the proposed two phase detection scheme, the overall false alarm probability is calculated by using the false alarm probabilities of both the W-ED and C-GLRT detectors. False decision is made when the decision statistic is greater than the threshold under H_0 and when the decision statistic is smaller than the threshold under H_1. When the W-ED makes a false decision the result is given to the C-GLRT, based on this the decision of the second phase becomes the final result. The transmitted power is taken as P which is assumed to be 1 and the channel parameter is taken as 1.

The numbers of samples considered are 20 and the numbers of antennas used are 6. The constraint on the false alarm probability is 0.01. The detection performance of the proposed two phase detector is compared with existing ED, GLRT, and ASS detectors. Figure 2 shows the graph between the probability of detection and SNR. Numerical results show that the proposed two phase detector scheme optimizes detection performance and outperforms the GLRT, ASS, and ED sensing techniques by 6.0%, 23.0%, and 63.0% at – 5 dB SNR respectively.

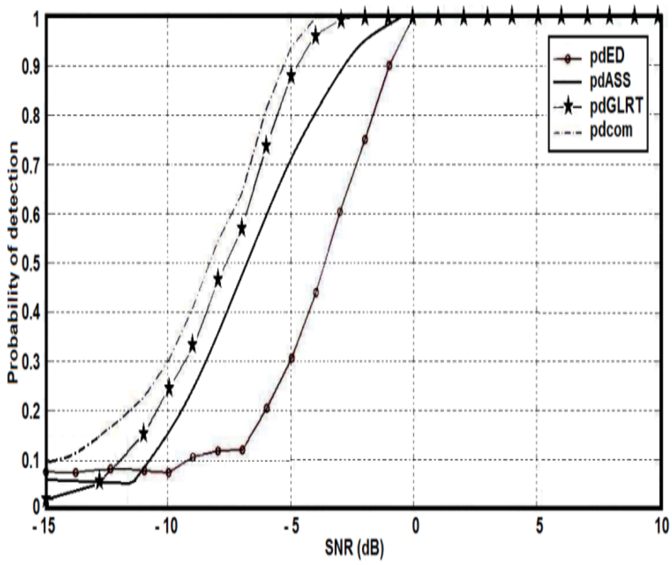

Figure 2. Detection Performance Comparison between ED, GLRT, ASS, and Presented Two Phase Detector

5. Conclusion

In this paper, we have introduced SNR based spectrum sensing technique for WRAN. - The detection performance of proposed two phase detector compared with the existing ED, GLRT, and ASS. Analyzing Figure 2, we can state that proposed two-phase detection scheme detects signal approximately - 6 SNR. While other takes - 4.7 dB for GLRT, - 3 dB for ASS, and -1 dB for ED detectors. It is shown that the proposed detector performance better than other existing detectors. Hence it is suitable to be used in present conditions.

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References

[1] A. Bagwari and B. Singh, "Comparative performance evaluation of Spectrum Sensing Techniques for Cognitive Radio Networks," Fourth IEEE International Conference on Computational Intelligence and Communication Networks (CICN- 2012), vol. 1, **(2012)**, pp. 98-105.
[2] L. P. Luo, P. Zhang, G. C. Zhang and J. Y. Qin, "Spectrum sensing for cognitive radio networks with correlated multiple antennas", Electronics Letters, vol. 47, no. 23, **(2011)** November, pp.1297-1298.
[3] L. Lu, X. Zhou, U. Onunkwo and G. Y. Li, "Ten years of research in spectrum sensing and sharing in cognitive radio," EURASIP Journal on Wireless Communications and Networking, **(2012)** January, pp. 1-16.
[4] A. Bagwari and G. S. Tomar, "Cooperative Spectrum Sensing with Multiple Antennas Using Adaptive Double-Threshold Based Energy Detector in Cognitive Radio Networks", Springer Journal of The Institution of Engineers (India): Series B, vol. 95, no. 2, **(2014)**, pp. 107-112.
[5] P. Wang, J. Fang, N. Han and H. Li, "Multi antenna- assisted spectrum sensing for cognitive radios", IEEE Trans. Veh. Technol., vol. 59, no. 4, **(2010)**, pp. 1791–1800.
[6] T. J. Lim, R. Zhang, Y. C. Liang and Y. Zeng, "GLRT- based spectrum sensing for cognitive radio", Proc. IEEE Global Telecommun. Conf. , **(2008)**, pp. 1–5.
[7] W. Ejaz, N. U. Hasan and H. S. Kim, "SNR-based adaptive spectrum sensing for cognitive radio networks," International Journal of Innovative Computing, Information and Control, vol. 8, no. 9, **(2012)** September, pp. 6095-6105

