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Adaptive Threshold for Spectrum Sensing in Cognitive Radio

Ganem A.B.O. Ganem and Mohiedin Wainakh
Department of Telecommunication, Higher Institute of Applied Science and Technology, Damascus, Syria

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Corresponding Author:
Ganem A.B.O. Ganem
Department of Telecommunication, Higher Institute of Applied Science and Technology, Damascus, Syria

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Abstract: Cognitive radio has been considered as a solution to the problem of radio spectrum scarcity and spectral ineffectiveness. Spectrum sensing is one of the most important topics in cognitive radio. Many spectrum sensing algorithms have been presented with differences in methodology and accordingly their performance. In this study, we select spectrum sensing algorithm based on correlation coefficient in the OFDM signals. The detection threshold corresponding to the test statistic has been calculated using constant false alarm rate and a method for calculating the SNR-adapted detection threshold has been suggested throw minimizing the average of total error probability. A numeric simulation has been made in addition to plotting the changes of detection probability over SNR which resulted in significant enhancement in the performance of the detector using adaptive threshold compared to fixed one, where the gain was about 6 dB at probability of detection equals to 0.6 when using the adaptive threshold compared to the use of the fixed threshold.

INTRODUCTION

The radio frequency spectrum is a scarce resource and it is typically licensed by governments. The demand for wireless applications and communications is increasing which causes increase in demand of radio spectrum band and their utilization. According to Federal Communication Commission (FCC) the usage of frequency band from 0-6 GHz varies from 15-85%[1]. This shows that there is high probability that the licensed user is most of the time likely to be idle which causes decrease in spectrum efficiency.

Static spectrum access is the main policy for current wireless communication technologies. Under this policy, fixed channels are assigned to licensed users or Primary Users (PUs) for exclusive use while unlicensed users or Secondary Users (SUs) are prohibited from accessing those channels even when they are unoccupied. The concept of cognitive radio is introduced to overcome the above problem.

Cognitive Radio (CR)[2] is a smart wireless communication technology which is aware of its surrounding environment and searches the spectrum holes which are unused by primary users to make them available to secondary users for transmission.

Spectrum sensing[3] is the key step to implement the cognitive radio system. Spectrum sensing is used to finding the spectrum hole in spectrum band. Spectrum hole are temporarily band which is currently not used by primary user. If these bands are further used by primary users then the cognitive radio moves to another band. Many conventional detectors have been emerged for the spectrum sensing in cognitive radio including Energy Detector (ED), matched filter, feature detector[4]. Each detector has its own advantages and disadvantages in terms of accuracy, computational complexity, sensing duration time and detection performance[5].

Energy detection algorithms do not make any assumption on the PU signal statistics while matched lter detection algorithms make explicit assumptions on the known pilot waveform or the preamble to design the detectors[4]. Feature detectors lie in middle of these two extremes and only make certain assumptions on the structural or statistical properties of the PU signal while designing the detectors[5]. For example, almost all man-made signals exhibit distinct cyclostationary features which can be used to detect the signals. Again, the presence of CP induces a particular auto correlation structure in an OFDM signal that can be used to design detectors for such signals. Circularity and non-circularity of complex-valued signals is also a distinguishing feature as the noise is typically circular. These kinds of algorithms may also be useful to detect and distinguish different kinds of signals.

The main challenge in any detector is the setting of an appropriate detection threshold. Most of the threshold setting algorithms based on the Constant False Alarm Rate (CFAR)[6]. In CFAR, the threshold is calculated by adjusting the constant value of a false alarm probability that makes it difficult to obtain a specific detection probability on a wide SNR range, especially in low SNR regions. In this study, a threshold setting is proposed for minimizing the average total error probability and maximizing the entire spectrum utilization.

System model: The OFDM Model considered in our work is the same as that by Bokharaiee *et al*.[7] and Chaudhari *et al*.[8] which assumes that the primary user PU employs L subcarriers. Let $\{S_k\}_{k=0}^{L-1}$ be the complex symbols to be transmitted. The baseband OFDM modulated signal can be expressed as:

$$s(m) = \frac{1}{\sqrt{L}}\sum_{k=0}^{L-1} S_k e^{\frac{j2\pi mk}{L}},\ m = 0, ...,\ L\text{-}1 \quad (1)$$

For large L number of subcarriers, s(m) can be approximately modeled as a zero-mean complex Gaussian random variable of variance σ_s^2, i.e., $s(m) \sim N(0, \sigma_s^2)$. The received signal can be expressed as:

$$x(n) = s(n) + v(n) \quad (2)$$

where v(n) is additive white Gaussian noise AWGN and can be modeled as i.i.d. $N(0, \sigma_s^2)$ complex random variable.

Let H_0 be the null hypothesis, i.e., an OFDM based primary user is absent and H_1 be the alternate hypothesis, i.e., an OFDM based primary user is active. Therefore, the hypothesis testing problem may be written as:

$$H_0 : x(n) = v(n);\ H_1 : x(n) = s(n) + v(n) \quad (3)$$

By Bokharaiee *et al*.[7] and Chaudhari *et al*.[8] proposed the autocorrelation coefficient as a test statistic, under the assumption that the conditional distribution of x(n) is Gaussian under either of hypothesis, the ML estimate of autocorrelation coefficient is shown to be Log-Likelihood Ratio Test (LLRT) statistic in low SNR regime and given by:

$$\hat{\rho}ML = \frac{\frac{1}{M}\sum_{n=0}^{M-1} R\{x(n)\, x^*(n+T_d)\}}{\frac{1}{2M}\sum_{n=0}^{M-1}|x(n)|^2} \underset{<H_0}{>} H_1\eta \quad (4)$$

where T_d is length of the data in OFDM block (i.e., number of subcarriers L), M denote of the number of received samples and η is detection threshold. By Chaudhari *et al*.[8] approximate the distribution of the test statistic for sufficiently large M as:

$$H_0 : \hat{\rho}_{ML} \sim N_r\left(0,\ \frac{1}{2M}\right) H_1 : \hat{\rho}_{ML} \sim N_r\left(\rho_1,\ \frac{\left(1\text{-}\rho_1^2\right)^2}{2M}\right) \quad (5)$$

where:

$$\rho_1 = \frac{T_c}{T_c + T_d}\frac{\sigma_s^2}{\sigma_s^2 + \sigma_v^2} = \frac{T_c}{T_c + T_d}\frac{SNR}{1 + SNR}$$

T_c is length of cyclic prefix. This is a classical detection problem with test statistic $\hat{\rho}_{ML}$. Different detection strategies like Neyman-Pearson (NP), Min-Max, Bayes, etc. can be used depending on the prior information available and error constraints to be satisfied. For NP detector to satisfy a Constant False Alarm Rate (CFAR) constraint at the local detector. For a Gaussian random variable $r \sim N_r(\mu_r, \sigma_r^2)$ we have:

$$P(r > \eta_r) = \frac{1}{2}\text{erfc}\left(\frac{\eta_r\text{-}\mu_r}{\sqrt{2}\sigma_r}\right) \quad (6)$$

where, erfc (.) is the complementary error function. Using (Eq. 6), the false alarm probability P_{fa} is given by:

$$P_{fa} = P(\hat{\rho}_{ML} > \eta\,|\,H_0) = \frac{1}{2}\text{erfc}\left(\sqrt{M}.\eta\right) \quad (7)$$

Thus, the threshold at the local detector can be calculated as:

$$\eta = \frac{1}{\sqrt{M}}.\text{erfc}^{-1}(2P_{fa}) \quad (8)$$

Similarly, the probability of detection P_d is given by:

$$P_d = P(\hat{\rho}_{ML} > \eta | H_1) = \frac{1}{2} \text{erfc}\left(\sqrt{M}.\frac{\eta-\rho_1}{1-\rho_1^2}\right) \quad (9)$$

Probability of miss detection would be given as $P_{md} = 1-P_d$.

MATERIALS AND METHODS

Proposed method: Our aim is to derive an expression for adaptive threshold to minimize the probability of error. Each spectrum sensing algorithm has characterized by its performance which described in detection probability against SNR[9]. In other hand, there is other parameters which effect on performance of detector, the first parameter is probability of false alarm P_{fa} (error type I), and the second one is probability of miss detection P_{md} (error type II)[6]. These two probabilities are consisted in probability of error P_e. We can write probability of error for two hypothesis test as following[9]:

$$P_e = \lambda P_{fa} + (1-\pi) P_{md} \quad (10)$$

Or we can rewrite (Eq. 10) like:

$$P_e = \lambda P_{fa} + (1-\lambda)(1-P_d) \quad (11)$$

where, $\lambda = P(H_0)$ is the prior about the absence of PU signal. With substitution (Eq. 7 and 9) in Eq. 11, we obtained:

$$P_e = \frac{\lambda}{2}\text{erfc}\left(\sqrt{M}\eta\right) + (1-\lambda)\left(1-0.5\,\text{erfc}\left(\sqrt{M}\,\frac{\eta-\rho_1}{1-\rho_1^2}\right)\right) \quad (12)$$

erfc function is a concave function. Since, P_e is a linear combination of two concave functions, therefore, it is a concave function. Then it can be differentiated with respect to threshold and making it equal to zero to obtain a minimum probability of error, i.e., $\partial P_e/\partial\eta = 0$:

$$\frac{\partial P_e}{\partial\eta} = \lambda\frac{\partial P_{fa}}{\partial\eta} - (1-\lambda)\frac{\partial P_d}{\partial\eta} = 0 \quad (13)$$

$$\lambda\frac{\partial P_{fa}}{\partial\eta} = (1-\lambda)\frac{\partial P_d}{\partial\eta} \quad (14)$$

$$\lambda\frac{\partial}{\partial\eta}\left[0.5\,\text{erfc}\left(\sqrt{M}\eta\right)\right] = (1-\lambda)\frac{\partial}{\partial\eta}\left[\sqrt{M}\,\frac{\eta-\rho_1}{1-\rho_1^2}\right] \quad (15)$$

$$\lambda e^{-M\eta^2} = \frac{1-\lambda}{1-\rho^2} e^{-M\left(\frac{\eta-\rho_1}{1-\rho_1^2}\right)^2} \frac{\lambda\left(1-\rho^2\right)^2}{1-\lambda} \text{In}\left(\frac{\lambda\left(1-\rho^2\right)}{1-\lambda}\right) = 0 \quad (16)$$

Further, simplification yields a quadratic equation as:

$$\rho^2\left(2-\rho^2\right)\eta^2 - 2\rho\eta + \rho^2 + \frac{\left(1-\rho^2\right)^2}{M}\text{In}\left(\frac{\lambda\left(1-\rho^2\right)}{1-\lambda}\right) = 0 \quad (17)$$

As a solution of the quadratic equation, we get two solutions:

$$\eta_{1,2} = \frac{1 \pm \sqrt{1-\left[\left(2-\rho^2\right)\left(\rho^2+\frac{1-\rho^2}{M}\right)^2 \text{In}\frac{\left(\lambda\left(1-\rho^2\right)\right)}{1-\lambda}\right]}}{\rho\left(2-\rho^2\right)} \quad (18)$$

Since, that the values of correlation coefficient are between -1 and +1, therefore appropriate threshold is given:

$$\eta^* = \frac{1-\sqrt{1-\left(2-\rho^2\right)\left(\rho^2+\frac{\left(1-\rho^2\right)^2}{M}\text{In}\left(\frac{\left(\lambda-\rho^2\right)}{1-\lambda}\right)\right)}}{\rho\left(2-\rho^2\right)} \quad (19)$$

RESULTS AND DISCUSSION

Simulation results and analysis: The simulation parameters are chosen similarly to those by Bokharaiee *et al*.[7]. In particular, the primary user's OFDM system has L = 32 subcarriers. Therefore, $T_d = 32$. The CP is chosen as $Tc = T_d/4 = 8$. For each secondary user the detection period is assumed to be 100 OFDM block. Therefore, the number of samples for the autocorrelation estimate at secondary user is $M = 100(T_d+T_c) = 4000$. The sensing time for an OFDM system having a bandwidth of B = 5 MHz is roughly $M\backslash B = 100(32+8)/5{*}10^6 = 0.8$ msec. This approximately corresponds to sensing time of 1 msec. The frame duration is For fixed threshold, similarly to Bokharaiee *et al*.[7] and Chaudhari *et al*.[8], $P_{fa} = 0.05$.

Figure 1 shows the Receiver Operating Characteristic (ROC) plot for different values of SNR. Notice that for fixed value for probability of false alarm $P_{fa} = 0.1$, detection probability varies from 0.3-0.8 for SNR = -15, -10 dB, respectively. We also notice that, smaller SNR values are closer to diagonal line the curve is. This curve fulfills all required features of ROC curve[10].

Figure 2 shows effect of CP length on probability of detection for different values of SNR. Observe that as the length of CP increases, the probability of detection enhances because correlation samples increases. It should also be noted that the value of the change in probability of detection by the change of length of CP varies depending on SNR value because in environments where SNR is high, correlation samples can be better distinguished.

Figure 3 shows the relationship of adaptive threshold to SNR for different values of λ. Note that the threshold value changes with λ and SNR. In environments where

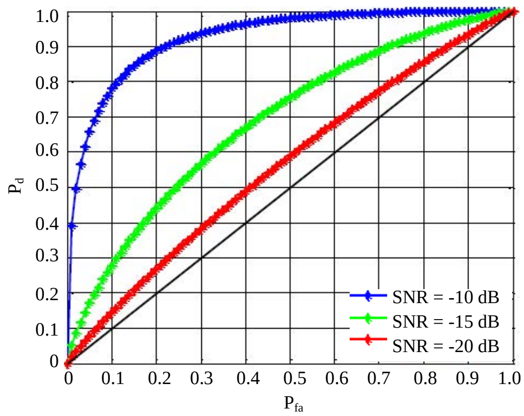

Fig. 1: ROC plot for different values of SNR

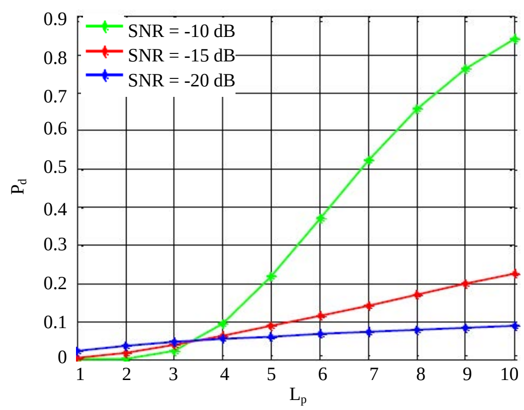

Fig. 2: Effect of CP length on probability of detection for different values of SNR

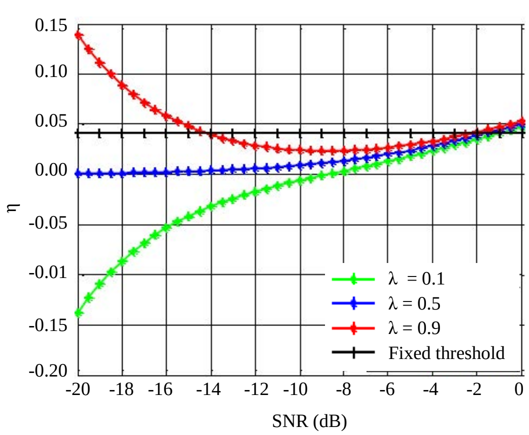

Fig. 3: The relationship of adaptive threshold to SNR for different values of λ

SNR is low, the threshold is large in absolute terms for λ greater/less than 0.5. In order to minimize the noise effect, the threshold is increased in high noise environments.

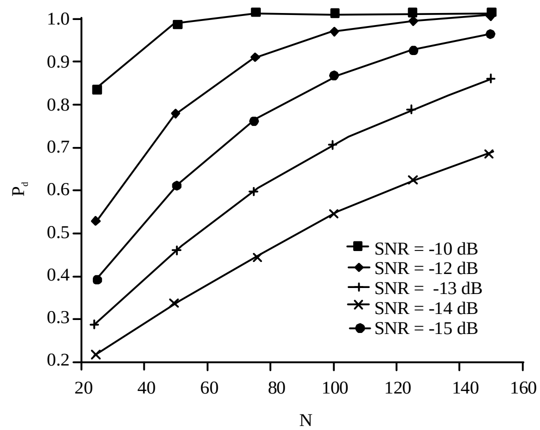

Fig. 4: The relationship between the probability of detection and number of received OFDM blocks

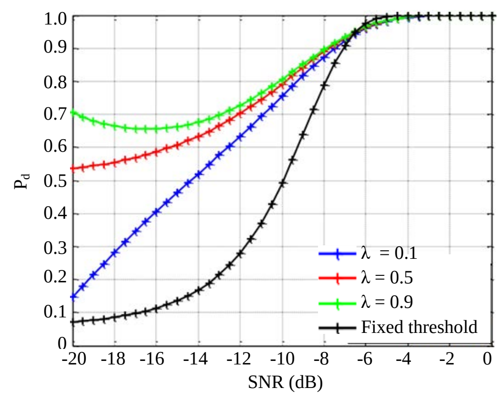

Fig. 5: Performance of detection algorithm for the fixed threshold and adaptive one for different values of λ

On the other hand, the adaptive threshold is very close to the constant one at high SNR, whatever the value of λ.

Figure 4 shows the relationship between the probability of detection and number of received OFDM blocks or number of observation samples. Note that the probability of detection enhances for specified number of received OFDM blocks as the SNR increases. As can be seen from the figure for each SNR value the probability of detection can be made close to 1 by increasing the number of received OFDM blocks but on the other hand we cannot increase this number because this will increase the sensing time and thus decrease the data transmission time. In this simulation the number of OFDM blocks can be increased from 100-125 without increasing the sensing time.

Figure 5 shows the performance of detection algorithm for the fixed threshold and adaptive one for different values of λ. Note that the performance of algorithm is significantly enhanced for adaptive threshold compared to the fixed one for different values of λ. Note also that the probability of detection increases as the value of decreases because at low values of the probability of existing PU's signal is high where $\lambda = P(H_0)$ and as a result detection probability is better. Observe that there is a gain about 4 dB at probability of detection 0.6 for λ = 0.5 and λ = 0.7.

CONCLUSION

In this study, we introduce adaptive threshold for correlation test statistic in term of minimizing the average of total error. The numerical analysis shows that the performance of sensing algorithm enhances about 4 dB at probability of detection 0.6 for λ = 0.5 and λ = 0.7 and the probability of detection enhances from 0.18-0.62 at SNR = -14 dB when using adaptive threshold compared with fixed one.

REFERENCES

01. Chaudhari, S., 2012. Spectrum sensing for cognitive radios: Algorithms, performance and limitations. Ph.D. Thesis, Aalto University, Espoo, Finland.
02. Mitola III, J., 1999. Cognitive radio for flexible mobile multimedia communications. Mobile Networks Appl., 6: 435-441.
03. Axell, E. and E.G. Larsson, 2011. Optimal and sub-optimal spectrum sensing of OFDM signals in known and unknown noise variance. IEEE. J. Selected Areas Commun., 29: 290-304.
04. Suseela, B. and D. Sivakumar, 2015. Non-cooperative spectrum sensing techniques in cognitive radio-a survey. Proceedings of the IEEE Technological Innovation in ICT for Agriculture and Rural Development, July 10-12, 2015, Chennai, India, pp: 127-133.
05. Ali, A. and W. Hamouda, 2017. Advances on spectrum sensing for cognitive radio networks: Theory and applications. IEEE. Commun. Surv. Tutorials, 19: 1277-1304.
06. Kay, S.M., 1998. Fundamentals of Statistical Signal Processing: Estimation Theory. Prentice-Hall, Englewood Cliffs, New Jersy.
07. Bokharaiee, S., H.H. Nguyen and E. Shwedyk, 2011. Blind spectrum sensing for OFDM-based cognitive radio systems. IEEE. Trans. Veh. Technol., 60: 858-871.
08. Chaudhari, S., V. Koivunen and H.V. Poor, 2009. Autocorrelation-based decentralized sequential detection of OFDM signals in cognitive radios. IEEE. Trans. Signal Process., 57: 2690-2700.
09. Boudjellal, A., K. Abed-Meraim, A. Belouchrani and P. Ravier, 2017. Minimum error rate detection: An adaptive Bayesian approach. Signal Process., 140: 1-11.
10. Stirling, W.C. and T.K. Moon, 2000. Mathematical Methods and Algorithms for Signal Processing. Prentice Hall, Upper Saddle River, New Jersey, USA., Pages: 937.