Review on the Performance of Non-Cooperative Spectrum Sensing Based on Energy Detection

Muhanned AL-Rawi

***Abstract*— In cognitive radio, spectrum sensing is an emerging technology to exploit the underutilized spectrum so as to overcome the problem of spectrum scarcity. One of the important spectrum sensing technique is energy detection. This paper studies the performance of energy detection based on non-cooperative spectrum sensing in cognitive radio over Rayleigh fading channel with additive white Gaussian noise. The simulation results show that the probability of detection increases with the increase of probability of false alarm, and signal to noise ratio.**

***Index Terms*— Cognitive radio; spectrum sensing; energy detection**

I. INTRODUCTION

Cognitive radio (CR) is a novel technology, which improves the spectrum utilization by allowing secondary users (CR users) to borrow unused radio spectrum from primary licensed users (PUs) or to share the spectrum with the PUs. As an intelligent wireless communication system, cognitive radio is aware of the radio frequency environment, selects the communication parameters (such as carrier frequency, bandwidth and transmission power) to optimize the spectrum usage and adapts its transmission and reception accordingly. By sensing and adapting to the environment, a CR is able to fill in spectrum holes and serve its users without causing harmful interference to the PU. Basically, at a given time and location, CR aims to avoid the existence of portions of the spectrum going underutilized while other portions are crowded. Therefore, the two main concerns of this recent networking paradigm are increasing the performance and protecting PUs from any harmful interference. The main four functions of CR are

- Spectrum sensing.
- Spectrum management.
- Spectrum mobility.
- Spectrum sharing.

Spectrum sensing is the major task of CR as it should be firstly performed before allowing unlicensed users to access a vacant licensed channel. Spectrum sensing involves obtaining the spectrum usage characteristics across multiple dimensions such as time, space, frequency, and the code and determining what type of signals are occupying the spectrum. It is defined as the task of finding spectrum holes by sensing the radio spectrum in the local neighborhood of the cognitive radio receiver in an unsupervised manner. Cognitive radio provides a number of ways to perform spectrum sensing. Mainly it is categorized into three as follows

- Non-Cooperative spectrum sensing in which cognitive radio works on its own, then it will be utilizing this type of non-cooperative spectrum sensing. It will automatically configure itself according to the signals it can detect the information with which it is previously loaded.
- Cooperative spectrum sensing in which number of different CRs with CR network cooperate with each other to perform sensing.
- Interference based sensing which is intended to quantify and manage the sources of interference in a radio environment.

Spectrum sensing is in need of various information before a decision is taken, which involves which part of the spectrum, it should sense & how, its bandwidth of spectrum of interest, when to sense and to see any priori information is available or not. The task of spectrum sensing involves the following subtasks:

- Detection of spectrum holes.
- Spectral resolution of each spectrum hole.
- Estimation of the spatial directions of incoming interferes.
- Signal classification.

II. SPECTRUM SENSING TECHNIQUES

In this paper, only non-cooperative spectrum sensing techniques are considered. Here, PUs signal is detected independently by CR user. Each user determines the presence and absence of PUs individually and acts accordingly. This technique is based on the detection of the weak signal from a primary transmitter. In primary transmitter based detection technique, a cognitive user determines signal strength generated from the PU. In this method, the location of the primary receivers are not known to the cognitive users because there is no signaling between the primary users and the cognitive users. Non-cooperative sensing is performed by many sensing methods as mentioned below.

- The energy detection is the simplest method to sense the environment in a blind manner.
- The cyclostationary based sensing may require some information about the spectral user signal characteristics.
- The matched filter-based sensing requires the complete information of the spectral-user signal.
- Waveform based-sensing only applicable to systems with known signal patterns.

Waveform-based sensing is more robust than energy detection and cyclostationarity based methods because of the coherent processing that comes from using deterministic signal component. However, there should be a priori information about the PU's characteristics and PUs should transmit known patterns or pilots. The performance of an energy detector based sensing is limited when two common assumptions do not hold. The noise may not be stationary and its variance may not be known. Other problems with the energy detector include baseband filter effects and spurious tones. It is stated in literature that cyclostationary based methods perform worse than energy detector based sensing methods when the noise is stationary. However, in the presence of co-channel or adjacent channel interferers, noise becomes non-stationary. Hence, energy detector based schemes fail while cyclostationarity based algorithms are not affected. On the other hand, cyclostationary features may be completely lost due to channel fading. While selecting a sensing method, some tradeoffs should be considered. The characteristics of primary users are the main factor in selecting a method. Cyclostationary features contained in the waveform, existence of regularly transmitted pilots, and timing/frequency characteristics are all important. Other factors include required accuracy, sensing duration requirements, computational complexity, and network requirements. Several works have considered these four methods[1-20]. In this paper, only energy detection method is considered.

III. DETECTION THEORY AND HYPOTHESIS TESTING

When the receiver receives the signal, it has to differentiate between two cases. These are: the received signal is noise only or it includes a signal and a noise. The theory behind this decision is known as detection theory in communication or decision theory or hypothesis test.

In Cognitive Radio networks, receivers have to distinguish between two hypotheses H_0, and H_1. H_0 indicates PU absence and H_1 indicates PU presence. On other words, H_0 indicates a spectrum hole and H_1 indicates the band occupation. Spectrum hole can be defined as "A spectrum hole is a band of frequencies assigned to a PU, but, at a particular time and specific geographical location, the band is not being utilized by that user". Let $x(m)$ be a sequence of M receiving samples, where $m \in \{1, 2 \ldots . M\}$ then, the two hypotheses cab written as:

$$x(m) = \begin{cases} w(m) & H_0 \\ h * s(m) + w(m) & H_1 \end{cases} \qquad (1)$$

Where $s(m)$ is the PU transmitted signal, $w(m)$ is the Additive White Gaussian Noise (AWGN) of variance σ^2, and h is the amplitude gain of the channel.

When the decision is based on a noise present, there is always a probability that a decision is incorrect. In this case, where two hypotheses only present (H_1 and H_0), the receiver decision has four possibilities:

- Receiver decides the band is occupied (H_1), when the PU using the band truly. In this case, the probability is called probability of detection(p_d):

$$p_d = prob\{Decision = H_1/H_1\}$$

- Receiver decides a spectrum hole (H_0), when the PU using the band truly. In this case, the probability is called probability of miss-detection(p_m):

$$p_m = prob\{Decision = H_0/H_1\}$$

- Receiver decides the band is occupied (H_1), when the PU does not use the band truly. In this case, the probability is called probability of false alarm(p_f):

$$p_f = prob\{Decision = H_1/H_0\}$$

- Receiver decides a spectrum hole (H_0), when the PU does not use the band truly. In this case, the probability is called probability of spectrum hole detection(p_h):

$$p_h = prob\{Decision = H_0/H_0\}$$

IV. ENERGY DETECTION

The system model for energy detection is shown in Fig.1. In order to measure the energy of the received signal, the output signal of bandpass filter (this filter selects the specific band of frequency to which user wants to sense) with bandwidth W is squared and integrated over the observation interval T. Finally, the output of the Integrator, Y, is compared with a threshold, λ, to decide whether a licensed user is present or not.

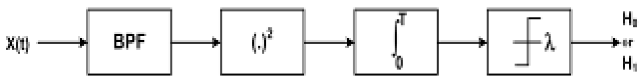

Fig.1 Energy detector

Analytically, based on Eq.1, the decision rule can be stated as:

H_0…… if $\varepsilon < \lambda$

H_1…… if $\varepsilon > \lambda$ (2)

Where $\varepsilon = E\,|x(m)|^2$ is the estimated energy of the received signal and λ is chosen to be the noise variance σ^2

If the energy detection can be applied in a non-fading environment, then the probability of detection (P_d), false alarm probability (P_f), and missed detection probability (P_m) are given as follows:

$$P_d = Pr(Y > \lambda | H_1) = Q_m\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \qquad (3)$$

$$P_f = Pr(Y > \lambda | H_0) = \frac{\Gamma(n, \lambda/2)}{\Gamma(n)} \qquad (4)$$

$$P_m = 1 - P_d \qquad (5)$$

Where γ is the signal-to-noise-ratio(SNR), n is being degrees of freedom, $\Gamma(.)$ and $\Gamma(.,.)$ are complete and incomplete gamma functions and $Q_m(\ )$ is the generalized Marcum Q-function.

If the energy detection is considered for Rayleigh fading channel, then detection probability over Rayleigh fading channel must be obtained. Note that the probability of false alarm, however, remains the same under any fading channel since it is considered for the case of no signal transmission and as such is independent of SNR. When the channel is varying due to fading effect, the previously given equation for probability of detection represents the probability of detection conditioned on the instantaneous SNR. Therefore, by averaging the conditional probability of detection over the SNR fading distribution, then the expression in closed form of detection probability in fading channels is given by.

$$P_d = \int_{\gamma} Q(\sqrt{2B\gamma}, \sqrt{\lambda}) f_\gamma(x)\, dx \quad (6)$$

Where B is the time-bandwidth product and $f\gamma(x)$ is the probability of distribution function of SNR under fading. Under Rayleigh fading, the signal amplitude follows a Rayleigh distribution. In this case, the SNR follows an exponential PDF.

$$f(\gamma) = \frac{1}{\bar{\gamma}} \exp\left(-\frac{\gamma}{\bar{\gamma}}\right) \quad (7)$$

Where $\bar{\gamma}$ is the average SNR. Therefore, in Rayleigh fading, a closed-form formula for detection probability over Rayleigh fading channels may be obtained as follows.

$$P_{d,Ray,Fading} = \exp\left(-\frac{\lambda}{2(1+B\bar{\gamma})}\right)\left(1+\frac{1}{B\bar{\gamma}}\right)^{B-1} * \left|1-\frac{\Gamma\left(B-1,\frac{\lambda B\bar{\gamma}}{2(1+B\bar{\gamma})}\right)}{\Gamma(B-1)}\right| + \frac{\Gamma\left(B-1,\frac{\lambda}{2}\right)}{\Gamma(B-1)} \quad (8)$$

where $\Gamma(.)$ is the gamma function

V. COMPUTER SIMULATION TEST

A series of computer simulation tests have been carried out to measure the performance of non-cooperative spectrum sensing based on energy detection over Rayleigh fading channel with AWGN. The performance was measured using complementary receiver operating characteristic (ROC). The ROC has been widely employed in the signal detection theory due to the fact that it is an ideal technique to measure the trade-off between the probability of detection (P_d) and the probability of false alarm (P_f). Two measures were considered including the effect of false alarm probability, and effect of SNR as follows:

A. *Effect of false alarm probability*

Fig.2 shows P_d versus average SNR for P_f = 0.01, 0.05, and 0.1 with number of samples M=6. It can be concluded that as P_f increases, P_d increases. Also, P_d increases almost linearly with the increase of average SNR.

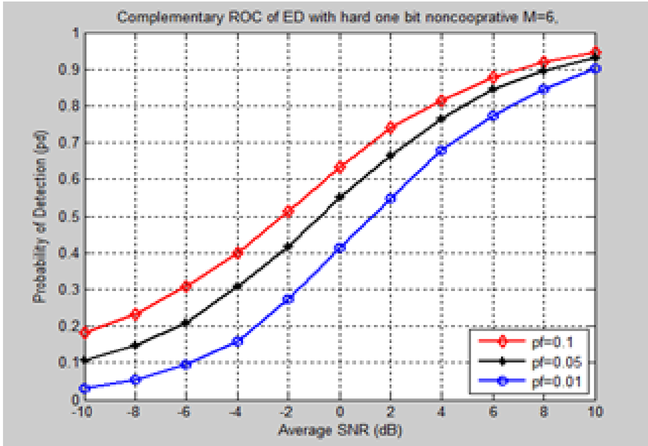

Fig.2 P_d versus SNR for different

B. *Effect of average SNR*

Fig.3 shows P_d versus P_f for SNR= -2dB, 0dB, 2dB, while M=6. It can be concluded that the P_d increases as SNR increases. Also, P_d increases almost logarithmically with the increase of P_f.

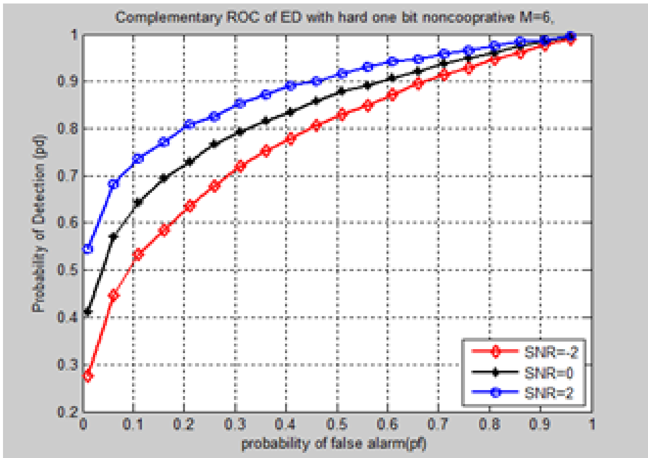

Fig.3 P_d versus P_f for different SNR

VI. SUMMARY AND CONCLUSION

The performance of energy detection based on non-cooperative spectrum sensing was measured over Rayleigh fading channel with AWGN. Simulation results show that P_d increases with the increase of P_f and SNR.

REFRENCES

[1] S. Haykin, D. Thomson, and J. Reed," Spectrum sensing for

cognitive radio," *Proceeding of IEEE*, Vol.97, No.5, 2009.

[2] Y. Zeng, and Y. Liang, "Spectrum-sensing algorithms for cognitive radio based on statistical covariances," *IEEE Transactions On Vehicular Technology*, Vol.58, No.4, 2009.

[3] T. Yucek, and H. Arslan,"A survey of spectrum sensing algorithms for cognitive radio application," IEEE Communications Surveys & Tutorials, Vol.11, No.1, 2009.

[4] A. El-Sherif and K. Liu, "Joint design of spectrum sensing and channel access in cognitive radio networks," *IEEE Transactions on Wireless Communications*, Vol.10, No.6, 2011.

[5] D. Mercedes, and A. Gabriel, "Evaluation of energy detection for spectrum sensing based on the dynamic selection of detection-threshold," *Procedia Engineering*, Vol.35, 2012.

[6] A. Decker," A review paper based on spectrum sensing techniques in cognitive radio networks," *Network and Complex Systems*, Vol.3, No.9, 2013.

[7] M. Babil,"Spectrum sensing in cognitive radio system," B.Sc. Project, University of Ibb, Yemen, 2014.

[8] K. Kumar, and V. Sindhu,"Comparison of non-cooperative spectrum sensing techniques in cognitive radio," *International Journal of Wired and Wireless Communications*, Vol.4, Issue 1, 2015.

[9] V. Divyapraba, K. Kishore, R. Pratheepa, and V. Elamaran,"Spectrum sensing based on energy detection using MATLAB_Simulink," *Indian Journal of Science and Technology*, Vol.8, No.29, 2015.

[10] P. Semba and J. Wei, "Performance evaluation of matched filter detection based on non-cooperative spectrum sensing in cognitive radio network," *International Journal of Computer Networks and Communications Security*, Vol.3, No.12, 2015.

[11] F. Al-gomai," Cooperative communication for cognitive radio system", B.Sc. Project, University of Ibb, Yemen, 2015.

[12] A. Nadeem, M. Khan, and K. Han ,"Non-cooperative spectrum sensing in context of primary user detection: A review," *IETE Technical Review*, PP.1-13, 2016.

[13] A. Patel, and S. Pareyani,"Analysis of spectrum sensing techniques in cognitive radio to enhance spectral efficiency," *International Journal of Advanced Research in Computer and Communication Engineering*, Vol.5, Special Issue.3, 2016.

[14] A. Marathe, S. Nikam, and N. Netrawali,"Performance evaluation of spectrum sensing methods for cognitive radio," *International Journal of Current Engineering and Technology*, Vol.6, No.5, 2016.

[15] A. Barman, and A. Chouksey,"Spectrum sensing techniques in CR networks: comparative study," *International Journal of Advanced Research in Computer and Communication Engineering*, Vol.5, Special Issue.3, 2016.

[16] G. Korde ,and C. Rawat,"Comparative evaluation of spectrum sensing techniques for cognitive radio," *The International Journal of Engineering and Science*, Vol.5, Issue 2 , 2016.

[17] P. Kumari,"Spectrum sensing techniques for cognitive radio networks: A review," *International Journal of Innovative Research in Computer and Communication Engineering*, Vol. 4, Issue 3, 2016.

[18] N. Giweli, S. Shahrestani, and H. Cheung, "Selection of spectrum sensing method to enhance QoS in cognitive radio networks," *International Journal of Wireless & Mobile Networks* ,Vol.8, No.1, 2016.

[19] K. Pawar, and T. Dhope,"Performance evaluation of spectrum sensing using multiple antenna in cognitive radio," *International Journal of Innovative Research in Computer and Communication Engineering*, Vol. 4, Issue 5, 2016.

[20] R. Garg, and N. Saluja,"Spectrum sensing in cognitive radio: components and methodologies," *In Proc. of the World Congress on Engineering and Computer Science*, San Francisco, USA, 2016.

Muhanned AL-Rawi was born in Iraq,1969. He received B.Sc. degree in electrical engineering from AL-Mustansiryia University, Iraq, in 1990, M.Sc. degree in communication and electronics engineering from Baghdad University, Iraq, in 1993, and Ph.D. degree in telecommunication engineering from Bandung Institute of Technology, Indonesia, in 1999.

He is currently with the department of electrical engineering, University of Ibb, Yemen. His research interests include digital communications, and digital signal processing. E-mail: muhrawi@yahoo.com