Cognitive Radio Spectrum Sensing Based on Energy

Oualid Khatbi, Ahmed Mouhsen and Zakaria Hachkar

Abstract The surveys that have been done on the use spectrum shows that some frequency bands are less busy compared with others. Cognitive radio has come to give the possibility to use the free band of a primary user for a secondary user. Confirmation of the presence of the primary user is typically performed by a spectrum sensing. A function of cognitive radio based on the ability to find unoccupied spectrum without interference. The cognitive radio spectrum sensing method considered in this work is Energy detection method based on the central limit theorem and the sensing performance of this scheme is quantified by the receiver operating characteristic (ROC), such as between the probability of detection versus the probability of false alarm. A simulation is carried out in the Matlab environment to show the relation between Pd and Pf with various SNR values.

Keywords Cognitive radio · Spectrum sensing · Energy detection method · The probability of detection and probability of false alarm

1 Introduction

The Wireless communication saw a very fast growth in these last years. The growth of the systems and the wireless services showed that the availability of spectrum became severely limited; it becomes obvious that the increasing number of data cannot be satisfied by the current statistical plans of frequency assignment. As a

O. Khatbi (✉) · A. Mouhsen · Z. Hachkar
Faculté des Sciences et Techniques, Ingénierie Mécanique, Management Industriel et Innovation (IMMII), Université Hassan 1er, BP 577 26000 Settat, Morocco
e-mail: o.khatbi@gmail.com

A. Mouhsen
e-mail: mouhsen.ahmed@gmail.com

Z. Hachkar
e-mail: zhachkar2000ster@gmail.com

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consequence, the need to have a new way of exploitation of the spectrum became essential. The cognitive radio appears to be a solution of temptation of the problem of spectral congestion by presenting the opportunist use of the frequency bands which are not heavily occupied by authorized users [1]. Whereas there is no agreement on the formal definition of cognitive radio from now on, the concept developed recently to include diverse meanings in several contexts [2]. In this paper, we use the definition adopted by Federal Communications Commission (FCC): "Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets." [3]. In the terminology of the cognitive radio, primary users PU can be defined as the users who have the capacity and the priority to use a specific party of the spectrum. Examples of licensed technology are global system for mobile communications (GSM) [4], worldwide interoperability for microwave access (WiMax) [5, 6], and long term evolution (LTE) [6]. On the other hand, secondary users SU, who have a lower priority to exploit this spectrum so that they do not cause interference to the primary users. Thus, the secondary users must be capable of detecting the unused specters by the primary users in a reliable way and of exploiting them. The reliability of the spectral detection is the most important factor which determines the performance of the cognitive radio, and it is at present based on three techniques different [7]: matched filter detection, energy detection and cyclo-stationary detection.

The matched filter based detection requires a perfect knowledge of the PU signal for synchronization and a dedicated receiver for each kind of PU signal but it is very good at low SNR region. In cyclo-stationary detection, we require exact information about the cyclic frequencies of the PU signal which is not an easy task. Energy detection (also denoted as non-coherent detection), is the signal detection mechanism using an energy detector (also known as radiometer) to specify the presence or absence of signal in the band. The most often used approaches in the energy detection are based on the Neyman-Pearson (NP) lemma. The NP detection criterion enlarges the probability of detection Pd for a given probability of false alarm fa [8] It is an essential and a common approach to spectrum sensing since it has moderate computational complexities, and can be implemented in both time domain and frequency domain [9, 10]. To adjust the threshold of detection, energy detector requires knowledge of the power of noise in the band to be sensed [11]. The signal is detected by comparing the output of energy detector with threshold which depends on the noise floor.

In this paper with the help of Central Limit Theorem we have proposed new threshold based energy detector to improve the performance of spectrum sensing for CR. Simulation results shows that our proposed scheme based on this threshold depend the SNR values and better for higher SNR. The rest of the paper is organized as follows. System model is presented in Sect. 2. Spectrum sensing has been done in Sect. 3. Energy Detection, Central limit theorem approach, in Sects. 4 and 5 respectively, Simulation results are shown in Sect. 6 and finally our conclusion is drawn in Sect. 7.

2 System Model

The cognitive radio is the system of wireless communication where a transmitter-receiver can intelligently detect the communication channels which are not used and to reach it without creating interferences. This property gives the possibility to use the frequency spectrum. The availability of the idle spectrum of radio is generally varied according to time, the frequency and the location. The spectral detection allows the secondary users Known how to have a dynamic spectral access and get such idle spectrum in a opportunist way. It also allows knowing if the primary user decided to take back his band once again.

2.1 Types of CR

There are two types of Cognitive Radios:

- Full Cognitive Radio: Full Cognitive Radio (CR) considers all parameters. A wireless Node or network can be conscious of every possible parameter observable [12].
- Spectrum Sensing Cognitive Radio: Detects channels in the radio frequency spectrum. Fundamental requirement in cognitive radio network is spectrum sensing. To enhance the detection probability [13] many signal detection techniques are used in spectrum sensing.

2.2 Characteristics of CR

There are two main characteristics [14] of the cognitive radio and can be defined

- Cognitive capability: Cognitive Capability defines the ability to capture or sense the information from its radio environment of the radio technology. Joseph Mitola first explained the cognitive capability in term of the cognitive cycle "a cognitive radio continually observes the environment, orients itself, creates plans, decides, and then acts"
- Reconfigurability: Cognitive capability offers the spectrum awareness, Reconfigurability refers to radio capability to change the functions, enables the cognitive radio to be programmed dynamically in accordance with radio environment (frequency, transmission power, modulation scheme, communication protocol).

2.3 Functions of CR

There are four major functions of Cognitive Radio:

- Spectrum Sensing: The goal of spectrum sensing is to find and determine the presence of primary users on a band.
- Spectrum management: Supply and choose by the cognitive radio the just spectrum immediately after its detection.
- Spectrum Sharing: Cognitive Radio assigns the unused spectrum (spectrum hole) to the secondary user (SU) as long as primary user (PU) does not use it. This property of cognitive radio is described as spectrum sharing.
- Spectrum Mobility: When a licensed (Primary) user is detected the Cognitive Radio (CR) vacates the channel.

3 Spectrum Sensing

Spectrum sensing is the most important function in the cognitive radio; it is always in the study shift and development. Secondary user (SU) should be able to detect spectrum in a continuous and real time way and must be equipped with highly reliable spectrum sensing functions [15]. Many different methods are proposed to identify the presence of signal transmission and can be used to enhance the detection probability.

3.1 System Model

The problem of detecting the presence or absence of the PU transmission is formulated as a binary hypothesis testing problem. The null hypothesis denoted by H0 corresponds to the received signal being only noise. On the other hand, the alternative hypothesis denoted by H1 indicates that the received signal contains the PU signal along with noise. As an example, a simple binary hypothesis test for detecting the PU transmission in an AWGN channel is given by:

$$\begin{aligned} &\mathrm{H0}:\ x(n) = w(n) \\ &\mathrm{H1}:\ x(n) = s(n) + w(n) \end{aligned} \tag{1}$$

where n = 1, 2, 3, ……. N is the number of samples of received signal, x(n) is the received sample signal by the SU, w(n) is the white Gaussian noise with mean zero and variance σ_n^2, s(n) is the received PU signal with mean zero and variance σ_s^2.

3.2 Performance Criteria

Performance of spectrum sensing algorithms may differ in different scenarios. It is therefore important to compare and choose the best scheme for a given scenario. At the same time, it is necessary to choose proper performance criteria for a fair comparison. In this section, we briefly present important performance parameters which can be used to evaluate the sensing algorithms:

- False alarm probability: It is defined as the probability that the detector declares the presence of PU, when the PU is actually absent.
- Missed detection probability: It is defined as the probability that the detector declares the absence of PU, when the PU is actually present.
- Sensing time: If the receiver chain is time-duplexed for reception and sensing, it is desirable that the sensing durations are shorter and the data transmission durations are longer.
- SNR: The SNR of the received PU signal at the sensor depends on the PU transmitted power and the propagation environment. The detection performance improves with an increase in the SNR.

3.3 Detection Techniques

Fundamental to the theory of detecting the signal in noise is the theory of statistical decision, where the decision making depends on the hypothesis testing. In binary hypothesis testing, the problem resides in defining a decision rule that indicates which of two hypotheses should be chosen: the null hypothesis (H0) or the alternative hypothesis (H1). If the null and alternative hypotheses are defined in terms of signal(s), hypothesis H0 (signal absent) and hypothesis H1 (signal present). The decision rule can be represented as:

$$\begin{aligned} &\mathrm{H1}: \Lambda(y) > \lambda \\ &\mathrm{H0}: \Lambda(y) < \lambda \end{aligned} \tag{2}$$

where λ is the threshold and $\Lambda(y)$ is a function that depends on the measurements. If it exceeds the threshold, then H1 is selected; otherwise, H0 is decided. The aim of the detection theory is, hence, to design the most effective detector by definition $\Lambda(y)$ and λ. Let $y = [y_0, \ldots, y_{N-1}]$ be the observation vector and $P(y/H_i)$, $i = 0, 1$, denote the joint probability density function (PDF) of these N elements of observing y given that H_i was true, is often referred to as the likelihood function of the observation vector y. Thus, we can define the $\Lambda(y)$ is the likelihood ratio test (LRT) as

$$\Lambda(y) = \frac{p(y/H_1)}{p(y/H_0)} \tag{3}$$

4 Energy Detection

Energy detection is a signal detection mechanism in which the presence or absence of primary user is determined by measuring the radio frequency energy in the channel [16]. Then this calculated energy of the received signal over specified time duration is compared with the threshold value (chosen) and decision about the occupancy of channel is made accordingly. The energy detection technique is quite simple as it does not require any prior knowledge about the primary user. The test statistics for energy detection is given as:

$$T(x) = \frac{1}{N}\sum_{n=1}^{N} |x(n)|^2 \tag{4}$$

where $T(x)$ is received signal energy and N is sampling, If the threshold value is less than the calculated energy, decision is made that primary user is present and if the calculated energy value comes out to be less than threshold value than the decision is made that primary user is absent and the band is free and can be allotted to secondary user [17]. The performance of the detection can be characterized with two probabilities: probability of detection P_d and probability of false alarm P_f. It can be formulated as:

$$\begin{aligned} P_d &= P\{T(x) > \lambda/H_1\} \\ P_d &= Q\left(\frac{\lambda - (\sigma_S^2 + \sigma_n^2)}{(\sigma_S^2 + \sigma_n^2)/(\sqrt{N/2})}\right) \end{aligned} \tag{5}$$

$$\begin{aligned} P_f &= P\{T(x) > \lambda/H_0\} \\ P_f &= Q\left(\frac{\lambda - \sigma_n^2}{\sigma_n^2/(\sqrt{N/2})}\right) \end{aligned} \tag{6}$$

where

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{\frac{t^2}{2}} dt \tag{7}$$

The detection threshold for a fixed P_f can be given as:

$$\lambda = \sigma_n^2 \sqrt{(N/2)Q^{-1}(P_f) + \sigma_n^2} \tag{8}$$

5 Central Limit Theorem Approach

The CLT shows that the sum of N random variable N with a finite mean and variance approaches a normal distribution when N is large enough. Using the CLT, the distribution of the test statistic (4) can be accurately approximated with a normal distribution for a sufficiently large number of samples as:

$$\Lambda \sim \begin{cases} N\left(N\left(2\sigma_n^2\right), N\left(2\sigma_n^2\right)^2\right) : H_0 \\ N\left(N\left(2\sigma_n^2\right)(1+\gamma), N\left(2\sigma_n^2\right)^2(1+\gamma)^2\right) : H_1 \end{cases} \tag{9}$$

where γ is the SNR, By using each mean and variance in (9), an approximated false alarm probability is:

$$P_f = Q\left(\frac{\lambda - N(2\sigma_n^2)}{(\sqrt{N}(2\sigma_n^2)}\right) \tag{10}$$

Similarly, approximated detection probabilities are:

$$P_d = Q\left(\frac{\lambda - N\left(2\sigma_n^2\right)(1+\gamma)}{\sqrt{N}(1+\gamma)\left(2\sigma_n^2\right)}\right) \tag{11}$$

6 Simulations Results

To observe the detection performance of the CR under the CLT theorem, simulation results are shown in this section to evaluate the CLT approach in energy detection scheme.

Figure 1 shows the probability of detection versus SNR curves for simulated case. We have taken 1000 samples and probability of false alarm is fixed to 0.01. As it can be easily observed from the Fig. 1 that the probability of detection is better from SNR = −10 dB.

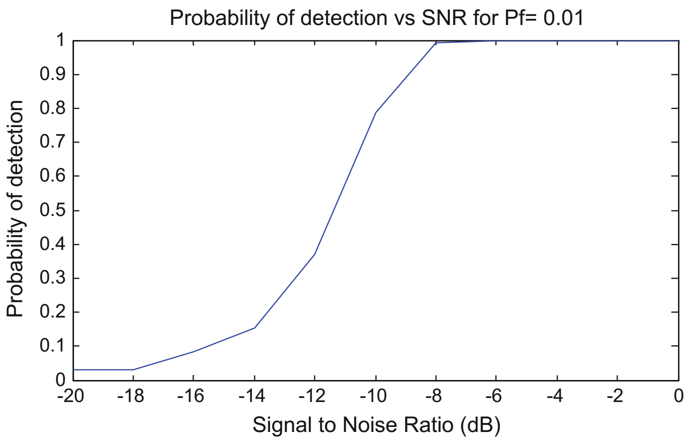

Fig. 1 Probability of detection vs SNR for $P_f = 0.01$

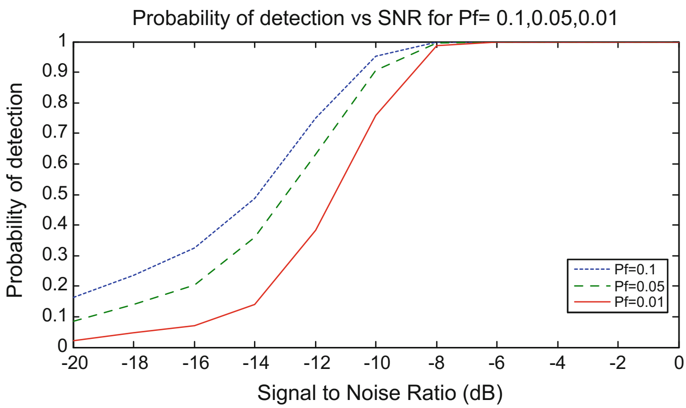

Fig. 2 Probability of detection vs SNR for $P_f = 0.1, 0.05, 0.01$

The graphs are drawn between probability of detection and SNR under various probability of false alarm. From Fig. 2 it is clear that for low SNR region probability of detection increases with increase in the probability of false alarm and for higher SNR graphs are converged.

It clear that with the increasing of the SNR (from –20 dB to 0) the detections we get also increased. It indicates that with the increasing of the SNR, the more spectrums which are occupied we can detect. By changing the value of the SNR, we get the relationship between the SNR and the detections, from the diagram, we can see from −10 dB to 0, SNR makes the energy detector performs best.

7 Conclusion

This paper proposes a threshold based on the central limit theorem and the sensing performance of this scheme is quantified by the receiver operating characteristic (ROC), such as between the probability of detection versus the probability of false alarm. Simulation results demonstrates that the increasing of the SNR increase the detections and the more spectrums which are occupied is detected, and also the relationship between the SNR and the detections, from SNR = -10 dB, the energy detector performs best.

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