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Abstract: The recent and rapid evolution of wireless technologies has led to a strong demand in terms of resources. To solve the problem the idea of cognitive radio has been introduced to facilitate a good spectrum management and efficient use of the spectrum. In this article we present the spectrum sensing techniques which is a very important step in cognitive radio. The energy detection method used in this paper through the simulation result represented by the ROC curve (Receiver Operating Characteristic) shows that the performance of this method is simple and effective. In this paper, we made the description of this method and also show the mathematical form thereof. The simulation was made using the MATLAB based on the AWGN channel.

Keywords: Performance, Cognitive Radio, Energy Detection, Spectrum sensing, AWGN channel.

1. Introduction

Wireless communication systems continue to proliferate [1] to become indispensable to our days. This growth has been accompanied by an increase in the request of spectral resources accessible by the wireless technology, which has become more and more rare not allowing those more to respond to the request. To compensate for this problem of shortage of frequencies, the famous researcher Joseph Mitola III [2], in 2000 introduced the idea of dynamic allocation of the spectrum. It thus defines the term Cognitive Radio, which is widely tipped to be the next technology in future wireless communications [3]. In 2002, the Federal Communications Commission (FCC), body of regulation and spectrum management in the United States, published a report [4] on the use of frequencies in which it is noted that, in more than 70% of cases, the spectrum is under-used next time or space. The problem of shortage of frequencies is therefore an artificial problem and the current policy of static management of the spectrum is responsible. This policy of the spectrum management is headed by the World Administrative Radio Conference, which write up the radio regulations which assign the use of the radio spectrum electric on a global basis. Thus, in order to solve the current problem of spectrum management, new approaches to dynamic access to the radio spectrum have developed, or the access opportunistic is the most widespread because it attacks was the cause of the shortage of frequencies. The main motivation of the cognitive radio is the sharing of frequencies with other users called secondary that can access at any moment in the frequency band supposed to be free and a user called primary which has the priority on the band. The detection of the spectrum is the crucial task for the success of the opportunistic access. It is a cardinal feature of cognitive radio to avoid harmful
interference with authorized users and recognize the spectrum available to improve the use of the spectrum.

The main functions of the Cognitive Radio are the following [5]:

**Spectrum Detection:** Detect the spectrum not used and the share without interference with other users. The detection of primary users is the most effective way to detect the holes of spectrum. The detection of the spectrum is an important phase, in particular for the detection of interference, with the aim of obtaining the status of the spectrum (free /occupied), so that the spectrum can be consulted by a secondary user under the compulsion of interference. The challenge lies in the fact of measure the interference at the primary receiver caused by the transmissions of secondary users.

**Spectrum Management:** the free Band is dispersed throughout the radio spectrum available to the terminal. To ensure that the terminal is able to choose a free band, among those which exist, to meet the requirements of quality of service of its communication, a characterization of these free bands is necessary. This characterization consist to measure a certain number of parameters such as the width of this band, the level d interference, the quality of the radio link, the error rate channel, etc.

**Spectrum Sharing:** other than the vertical sharing of radio resources with the primary users, secondary users will necessarily need to manage them the horizontal sharing of resources left available by the primary systems. According to the architecture of the secondary network, several sharing solutions exist: centralized, distributed, cooperative, non-cooperative.

**Mobility Spectrum:** The dynamic access to spectrum stipulates that the device has no more resources of dedicated frequencies. On the contrary, the terminal has resources that it can recover on a broad spectral coverage. Because of this, the radio device opportunistic (RO) must be able to frequently change of channel either because the channel has just d be taken over by his UP or because the quality of the radio link d another channel is better than his own.

There are several spectrum detection techniques namely: Matched Filter, Cyclostationary and Energy Detections [6]. These methods have at the same time good points and bad points depend of the framework. The main objective of this paper is to study energy detection technique and evaluate performance. We are going to organize that paper as follows: section II provides a description of the matched filter, energy detection of detection and detection techniques Cyclostationary function used for the spectrum of the detection.

The system model used is presented in the section III. We are going to present the results of the simulation in section IV. At the end we have section V as conclusion.

### 2. Spectrum Techniques for the Detection

One of the major challenges for cognitive radio is the detection of the spectrum. It is to find the spectrum holes in the radio environment for users of CR. However, it is difficult for the CR to have a direct measurement of the channel between the transmitter and receiver main [7]. A CR cannot transmit and detect the radio environment simultaneously, and thus, we need such detection techniques of the spectrum which take less time for the detection of the radio environment. The spectrum of detection techniques have been class is shown in figure 1 below.
In transmitter detection each Cognitive radio (CR) must by itself have the ability to determine in a specified spectrum the absence or presence of the Primary user (PU). The transmitter detection techniques most used are:

- Detection with Matched Filter Method
- Cyclostationary Detection
- Energy Detection

Each one of those techniques has its own advantages and own Consequences.

**The Detection with Matched Filter Method:** It is well known that matched filter realized in the performance of optimal detection allowing AWGN results channel, as shown and Tandra Sahai in [8] because it maximizes the signal-to-noise ratio (SNR). A perfect knowledge of the transmitted waveform is required for the use of matched filters technique, for example: bandwidth, the kind of modulation and order, the carrier frequency, pulse shape [9, 10]. Such a coherent detection has need of a very short duration of observation [9] compared to other techniques in this section. Despite the advantages of the pairing of the filter, it is important to note, however, that, in the context of the cognitive radio, the transmission of the signal and its characteristics are generally known or available knowledge are not accurate. In this case, the filter performance suits degrade rapidly, resulting in missed detections. [11] Moreover, this approach is not suitable for applications of cognitive radio, or different transmission standards can be adopted by the main users. [10] Indeed, in these cases, the secondary user require a matched filter for each signal dedicated which may be present in the environment considered, leading to prohibitive costs and high implementation complexity [10], more such architecture is not scalable.

**The Cyclostationary Detection:** On this techniques we can see, modulated signals are coupled with sine wave carriers, repeated spreading, pulse trains, cyclic prefixes or hopping sequences. That technique gives us better performance, even on low SNR regions. This method has good signal classification capacity. However, It is more complex than that of the energy detection and detection of high speed cannot be reached. This cannot work if the target the signal characteristics are unknown.

**The method Energy Detection:** In the past, the most often method used to detect the presence of signal was more focus on the energy detector (radiometer) approach [12], which performs a measurement of the energy received in a time limit and a specific frequency band [12]. The radiometer is a sub-optimal approach since the probability distribution of the signal to be detected is unknown,
making it impossible to use the conventional likelihood ratio (LRT) [13]. Energy detection is widely used because of its low complexity implementation and calculation. The radiometer requires no knowledge regarding the signal to be detected allowing it to intervene in many applications. However, this technique has several inconvenient [9, 14], which may limit its worked-up in the context of cognitive radio. Indeed, the calculation of the threshold used for the detection of the signal is very sensitive of the high level of noise which is unknown and in some cases the variables, so that a small error in the estimate of the level of noise caused a high loss of efficiency [15] as an under-estimate of the level of noise (thus at the limit of detection) can trigger false alarms therefore of missed opportunities for the secondary users, secondly the overestimation of the level of noise has the effect of reducing the probability of detection. In this case, if one is under $H_1$, the secondary user can assume that the channel is free while it is occupied, so it can be transmitted over this channel and cause interference to the primary user.

3. The model of system

The method of detection of energy calculates the energy of the primary user signal and compares the result with the threshold value in the operative part of the decision. The diagram of the energy detector is given by figure 2. To estimate the power of the primary user of energy signal, the input signal is filtered by using band-pass filter and then passes through a side pressure device. It is then integrated using an integrator and sent to the device of decision or the threshold value is preloaded. The signal from the integrator is compared with the threshold value and the decision is taken.

![Fig.2: The block diagram of energy detector](image)

3.1 The hypothesis Test

The problem that arises is whether there is a signal present or not i.e. chooses the hypothesis $H_0$ or $H_1$.

$$y(n) = \begin{cases} w(n) : H_0 \\ hs(n) + w(n) : H_1 \end{cases}$$  (1)

With $y(n)$ is the signal received by the CR user. $s(n)$ is the transmitted signal of the primary user, is a complex signal, it has real component $s_r$ and imaginary component $s_i$ denoted $S = s_r + js_i$. $w(n) = w_r(n) + jw_i(n)$ is (AWGN) the additive white Gaussian noise samples are supposed to be circularly symmetric complex Gaussian (CSCG) non-constant variable with mean zero ($E[w(n)] = 0$) and variance $2\sigma_w^2$ ($\text{Var}[w(n)] = 2\sigma_w^2$), i.e., $w(n) \sim \mathcal{N}(0, 2\sigma_w^2)$, in this case $\text{Var}[.]$ is the variance operations and $E[.]$ is consider as an variable expected, $\mathcal{N}(, , )$ is consider as a complex Gaussian distribution. Further, $w_r(n)$ and $w_i(n)$ are value-valued Gaussian random variables with means zero and variance $\sigma_w^2$, i.e., $w_r(n), w_i(n) \sim \mathcal{N}(0, \sigma_w^2)$, where $\mathcal{N}(, , )$ is consider as a real Gaussian distribution.
h is considered as the channel gain denotes as h= h, +jh, is constant within each detection period of spectrum.

\( \mathcal{H}_0 \) corresponds to presence of only noise and the absence of the signal. 
\( \mathcal{H}_1 \) corresponds to the presence of the signal and the noise.

### 3.2 Statistic of the Decision

When the Neyman-Pearson criterion is applied to the hypothesis problem in (1), the likelihood report for the binary hypothesis test given in (1) can be given as [16].

\[
T_{LR}(Y) = \frac{f_{Y/\mathcal{H}_0}(x)}{f_{Y/\mathcal{H}_1}(x)}
\]  

Where the probability density function (PDF) of the received signal \( y \) under hypotheses \( \mathcal{H} \) is \( f_{y/\mathcal{H}_0}(x) \) where \( \mathcal{H} \in \{\mathcal{H}_0, \mathcal{H}_1\} \). Then, the log-likelihood ratio (LLR) can be written as the form \( a + b = \sum_{n=1}^{N}|y(n)|^2 \) where parameters \( a \) and \( b \) are independent of the signal value \( y(n) \) and \( N \) is the number of samples. Therefore, the LLR is proportional to \( \sum_{n=1}^{N}|y(n)|^2 \) which is energy detector statistic test. In the case where \( s(n) \) is Gaussian , this part show us that the receiver is just aware of the signal power \( s(n) \), and for an unknown signal , the energy detector is uncorrelated , it does not depend on the uncorrelated background noise , it's the optimal non-coherent detector [17]. After proper filtering, squaring, integration and sampling, the test statistic of energy detector is given by:

\[
T(Y) = \sum_{n=1}^{N}|y(n)|^2 = \sum_{n=1}^{N}(e_r(n)^2 + e_i(n)^2)
\]  

### 3.3 The Indicators of Performance

The performance of an energy detector is based on the following indicators keys. 
The performance of the energy detector is characterized using following indicators, those which have been introduced on the statistical basis of the test under the hypothesis binary:

**Probability of False Alarm (\( P_{fa} \))**: The probability to decide whether the signal is present while \( \mathcal{H}_0 \) is true, i.e., \( P_{fa} = P(\mathcal{H}_1/\mathcal{H}_0) = P\{T(Y) > \lambda/\mathcal{H}_0\} \) where and \( P\{.\} \) stands for an event probability and \( \mathcal{H} \) is the detection threshold. In the framework of cognitive radio networks, undetected spectrum holes are induced due to the false alarm in the system. This means that a large \( P_{fa} \) promotes a low level of use of the spectrum by a secondary user.

**Probability of Detection**: The probability to decide whether the signal is present when \( \mathcal{H}_1 \) is true, i.e., \( P_d = P(\mathcal{H}_1/\mathcal{H}_1) = P\{T(Y) > \lambda/\mathcal{H}_1\} \)

### 3.4 The Test Statistics Distribution

The probability density function (PDFs) of \( T(Y) \) under hypotheses \( \mathcal{H}_0 \) and \( \mathcal{H}_1 \) are denotes as \( f_{T/\mathcal{H}_0}(x) \) and \( f_{T/\mathcal{H}_1}(x) \), respectively. 
Under \( \mathcal{H}_0 \), In this case, \( e_r(n) = w_r(n) \) and \( e_i(n) = w_i(n) \) follow \( \mathcal{N}(0, \sigma_w^2) \). Thus, \( T(Y) \) is a sum of \( 2N \) squares of independent \( \mathcal{N}(0, \sigma_w^2) \) random variables, and it follows central chi-square distribution is given by PDF [18]

\[
f_{T/\mathcal{H}_0}(x) = \frac{x^{N-1} e^{-\frac{x}{2\sigma_w^2}}}{(2\sigma_w^2)^N N!}
\]
Where $I(n) = \int_0^\infty t^{n-1} e^{-t} dt$ is the gamma function [19]. With, the false-alarm probability which can be derived, $P\{T(Y) > \lambda/\mathcal{H}_0\}$, by using (4) as

$$P_{fa} = \frac{I(N \frac{\lambda}{2\sigma_w^2})}{I(N)} \quad (5)$$

Where $I(n, x) = \int_x^\infty t^{n-1} e^{-t} dt$ is the upper incomplete gamma function [19].

Under $\mathcal{H}_1$, $e_r(n)$ follows $\mathcal{N}(h_r s_r(n) - h_l s_l(n), \sigma_w^2)$. $e_i$ follows $\mathcal{N}(h_r s_i(n) + h_l s_r(n), \sigma_w^2)$. Since $T(Y)$ is the a sum of $2N$ Square Feet of independent and non-identically the Gaussian distribution random variables with non-zero means, $T(Y)$ follows the non-chi-square distribution center is given by PDF [18]

$$f_{T/\mathcal{H}_1}(x) = \frac{(x/N_{\sigma_w^2}) e^{-1/2(x/N_{\sigma_w^2})}}{\sqrt{\pi}} I_{N-1}\left(\sqrt{\mu x/\sigma_w^2}\right), 0 \leq x \leq \infty \quad (6)$$

Where $I_v(.)$ is the modified function of Bessel the first kind of order $v$, 

$$\mu = \sum_{n=1}^N \left[\frac{(h_r s_r(n) - h_l s_l(n))^2}{\sigma_w^2} + \frac{(h_r s_i(n) + h_l s_r(n))^2}{\sigma_w^2}\right] = 2N\gamma$$

Which is the non-centrality parameter, and $\gamma = \frac{|h_l|^2 \sum_{n=1}^N |s(n)|^2}{2\sigma_w^2}$. Thus, the detection probability, $P\{T(Y) > \lambda/\mathcal{H}_1\}$, can be derived by using (6) as

$$P_d = Q_N\left(\sqrt{2N\gamma}, \frac{\sqrt{N}}{\sigma_w}\right) \quad (7)$$

Where $Q_N(a, b) \int_0^\infty x^{N-1} e^{-x^2/2} I_{N-1}(ax) dx$ Is the version generalized of Marcum-Q function [20].

4. Simulation Result

As announced above, the energy detector performance is focused on two parameters $P_d$ and $P_{fa}$. Performance is shown by the curve $P_d$ vs SNR and the curve of the Receiver Operating Characteristic (ROC). The simulation was based on AWGN Channel. The performance of energy detector for the three values of $P_{fa}$ is shown in Figure 3. For these three $P_{fa}$ values and the values of SNRs between -10 dB -5 dB, the $P_d$ is low but the cons for values of SNRs between -5 to 5 $P_d$ is high.
Figure 4 describes the ROC curve for different values of SNR in dB. The probability of detection, we notice that the energy detector performance increases when the SNR also augment.

5. Conclusion
In this paper, we present the technique for detection of the spectrum in networks of cognitive radio based on the method of detection of the energy. The result of this article through the curve of the Receiver Operating Characteristic (ROC) shows that the energy detection method is simple and effective, which does not need any prior information of primary user's signal (PU). The detection of
the spectrum in cognitive radio is a very important step to prevent interference between the primary and secondary user and facilitates the proper operation of the spectrum.

In our future work, we will be evidence estimation and overestimation of the noise level in the energy detection method.

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7. References