IMPLEMENTATION OF A BPSK MODULATION BASED COGNITIVE RADIO SYSTEM USING THE ENERGY DETECTION TECHNIQUE

Sid Ahmed Chouakri[1], Mohammed El Amine Slamat[1,*]
and Abdelmalik Taleb-Ahmed[2]

[1]Laboratoire de Télécommunications et Traitement Numérique du Signal,
University of Sidi Bel Abbes, ALGERIA
sa_chouakri@hotmail.com
* aimenslamat20@gmail.com
[2]Laboratoire LAMIH, Université de Valenciennes et du Hainaut Cambrésis,
FRANCE
taleb@univ-valenciennes.fr

ABSTRACT

We present in this work an energy detection algorithm, based on spectral power estimation, in the context of cognitive radio. The algorithm is based on the Neyman-Pearson test where the robustness of the appropriate spectral bands identification, is based, at one hand, on the 'judicious' choice of the probability of detection (P_D) and false alarm probability (P_F). First, we accomplish a comparative study between two techniques for estimation of PSD (Power Spectral Density): the periodogram and Welch methods. Also, the interest is focused on the choice of the optimal duration of observation where we can state that this latter one should be inversely proportional to the level of the SNR of the transmitted signal to be sensed. The developed algorithm is applied in the context of cognitive radio. The algorithm aims to identify the free spectral bands representing, reserved for the primary user, of the signal carrying information, issued from an ASCII encoding alphanumeric message and utilizing the BPSK modulation, transmitted through an AWGN (Added White Gaussian Noise) channel. The algorithm succeeds in identifying the free spectral bands even for low SNR levels (e.g. to -2 dB) and allocate them to the informative signal representing the secondary user.

KEYWORDS

Radio cognitive, energy detection, spectrum sensing, power spectral density, BPSK modulation, primary/secondary user

1. INTRODUCTION

It is widely recognized that wireless digital communications systems do not exploit the entire available frequency band. Future wireless generations' systems will therefore have to take advantage of the existence of such unoccupied frequency bands, thanks to their ability to listen and adapt to their environment [1]. The recent rapid evolution of wireless leads a strong demand in terms of spectrum resources. To overcome this problem it must be a good spectrum management and therefore a more efficient use of it [2-4]. The recent researches show that, 80%

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to 85% of the total spectrum is unused, while only 15% to 20% of the spectrum is used for the maximum period of time [5-6].

Cognitive radio has emerged as a key technology, which allows opportunistic spectrum access and respond directly to the needs related to the management of the environment of the radio terminal [7-8]. Cognitive radio (CR) is basically software-defined radio SDR with artificial intelligence, able to sense and react to their changing environment [9-11]. In 1998, at the royal Institute of technology KTH, Joseph Mitola III exhibited his work on a radio that is aware of the electromagnetic environment, which is able to change the behavior of its physical layer and which can adopt complex strategies. Cognitive radio (CR) is the name of this new approach to communication in wireless networks [12].

The paper is organized as follows: In the second section of this work we will present the basic concepts of cognitive radio, as well as its main features. In the third section we will introduce a so important topic in the radio cognitive RC system which is the technique for the detection of 'available' spectrum band that is the energy detection technique based on spectral power estimation.

In the fourth section, we will discuss two main statistical tests, upon which is based the energy detection technique, that are the Bayesian test and the Neyman-Pearson test. The latter one is based on the calculation of the probability of false alarm P_F and the probability of detection P_D. In the fifth and last section we will introduce the technique of detection of energy in the context of a cognitive radio scenario, articulated on the QPSK modulation, and a procedure that allows inserting the secondary user in the unoccupied band.

2. OVERVIEW ON COGNITIVE RADIO

2.1. Architecture of Cognitive Radio Networks

A detailed description of the architecture of the cognitive radio networks is vital to develop effective communication protocols. The elements that compose the CRN cognitive radio networks are represented in figure 1 [13].The architecture of the cognitive radio systems is articulated upon two distinct networks: primary and secondary [14]. The primary network is licensed to use certain spectral bands. The primary network acquired that right through the purchase of licenses from government agencies, e.g. cellular networks, the broadcast TV networks, etc. The secondary network (known as cognitive radio, dynamic access networks, or unlicensed network) is a network that has no license to operate on the spectral band. However, thanks to the additional features they have, these users can share the spectral bandwidth with the primary users provided they do not harm their transmissions or take advantage of their absence to transmit.

2.2. Functions of Cognitive Radio

The main functions of cognitive radios are:

2.2.1. Spectrum sensing:

It is a fundamental function allowing the cognitive radio users to detect the spectrum used by primary systems and improve the efficiency of the total spectrum [5].

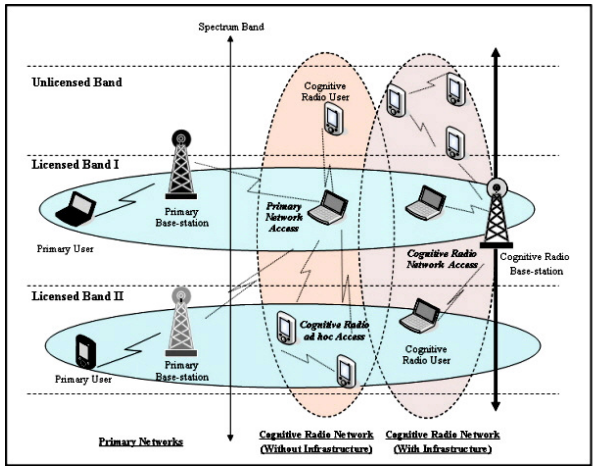


Figure 1. Coexistence between two network types: primary and secondary network [13].

2.2.2. Spectrum management:

The unused spectral bands have different characteristics from the others. All of this information changes over time given the dynamic nature of the radio environment.

2.2.3. Spectrum mobility:

The definition of mobility of the spectrum is to maintain the requirement of communication seamless during the transition to a better spectrum.

3. THE SPECTRUM SENSING BASED ENERGY DETECTION

Figure 2 represents the details of the classification of the spectrum sensing techniques.

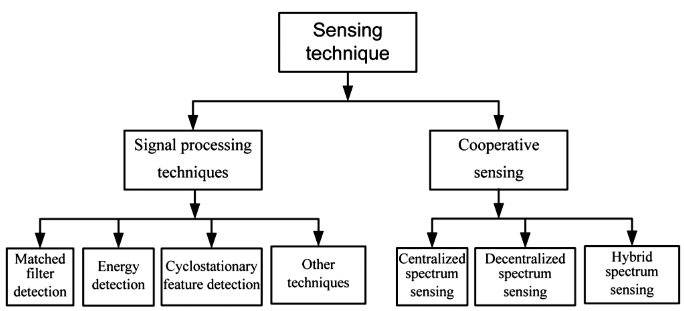


Figure 2. Classification of the spectrum sensing techniques [15]

3.1. Mathematical Basis

When information about the presence of the Gaussian noise is available, the energy detection approach is a suitable technique for spectrum sensing. Receivers do not need an exhaustive knowledge of primary users. The energy detection (ED) simply deals with the primary signal as noise and decides the presence or absence of the primary signal based on the energy of the observed signal [5]. This technique measures the received energy of primary user. If the energy is less than a certain threshold value then it decides as free band. Figure 3 illustrates the energy detection technique methodology block diagram [16]. The band pass filter BPF selects the center frequency and the bandwidth of interest. The filter is followed by a squared rising to measure the energy of the received signal. Subsequently, it is the integration phase. Finally the integrator output is compared with a threshold to decide if the primary user is present or not.

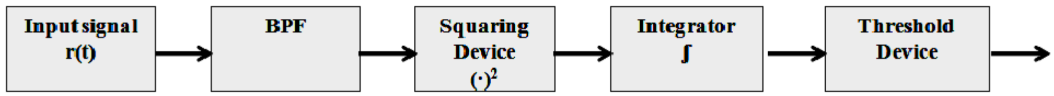


Figure 3. Energy detection technique methodology block diagram [16].

The sample of the signal received by the secondary user can be represented by [5-6]:

$$\begin{array}{ll} H_0: & y(n)=w(n) \\ H_1: & y(n)=s(n)+w(n) \end{array} \qquad (1)$$

where s(n) is the signal to be detected, w(n) is the added white Gaussian noise (AWGN), and n is the index of sample. H_0 is the hypothesis that the primary user is absent and H_1 represents the hypothesis that the primary user is present. Metric decision for the detection of energy may be written by [5-6]:

$$T=\sum_{i=1}^{N} {y_i}^2 \underset{H_0}{\overset{H_1}{\gtrless}} \gamma \qquad (2)$$

where N is the dimension of the observation vector. The decision on the occupation of a band can be obtained by comparing the T metric decision against a threshold λ.

The performance of the detection algorithm can be summarized by two probabilities: the detection probability P_D and false alarm probability P_F. It can be formulated as [2]:

$$P_D=P_r(T>\lambda \backslash H_1) \qquad (3)$$

P_F is the probability that the test decides incorrectly that the reporting frequency is occupied when actually is not, and it can be written by:

$$P_F=P_r(T>\lambda \backslash H_0) \qquad (4)$$

3.2. The Calculation of the Threshold

Let us assume the model of the received signal given by equation (1); where s (n) is with zero mean value and a variance of ${\sigma_s}^2$, w (n) is with zero mean value and a variance of ${\sigma_w}^2$, and n = 1, 2, 3... N is the observation sample.

Let us suppose: *cov* $(w_i, w_j)=0 \ \forall i \neq j$, *cov* $(s_i, s_j)=0 \ \forall i \neq j$ *and cov* $(w_i, s_j)=0 \ \forall i, j$.
so :

$$\begin{cases} f_0(y) = P(y/H_0) = \prod_{i=1}^{N} \frac{1}{\sqrt{2\pi{\sigma_s}^2}} e^{-\frac{1}{2}\frac{{y_i}^2}{{\sigma_s}^2}} \\ f_1(y) = P(y/H_1) = \prod_{i=1}^{N} \frac{1}{\sqrt{2\pi({\sigma_s}^2+{\sigma_w}^2)}} e^{-\frac{1}{2}\frac{{y_i}^2}{{\sigma_s}^2+{\sigma_w}^2}} \end{cases} \qquad (5)$$

$$P_F = P_r\left(\sum_{i=1}^{N} {y_i}^2 > \gamma \backslash H_0\right) = P_r\left\{\sum_{i=1}^{N} \left(\frac{y_i}{\sigma_w}\right)^2 > \frac{\gamma}{\sigma_w^2}/H_0\right\} \qquad (6)$$

where $\sum_{i=1}^{N}\left(\frac{y_i}{\sigma_w}\right)^2$ follows a noncentral chi-squared distribution with N degrees of freedom. Let us make: $X=\sum_{i=1}^{N}\left(\frac{y_i}{\sigma_w}\right)^2$ then the distribution probability is given by:

$$P(X/H_0) = \frac{1}{2^{\frac{N}{2}}.\Gamma\left(\frac{N}{2}\right)} X^{\frac{N}{2}-1} e^{-\frac{X}{2}} \quad (7)$$

where $\Gamma(a) = \int_0^{+\infty} t^{a-1} e^{-t}\, dt$ is the gamma function.

Similarly for P_D:

$$P_D = P_r\{\sum_{i=1}^{N} {y_i}^2 > \gamma \,|H_1\} = P_r\left\{\sum_{i=1}^{N}\left(\frac{y_i}{\sqrt{\sigma_w^2+\sigma_s^2}}\right)^2 > \frac{\gamma}{\sigma_w^2+\sigma_s^2}/H_1\right\} \quad (8)$$

where $\sum_{i=1}^{N}\left(\frac{y_i}{\sqrt{\sigma_w^2+\sigma_s^2}}\right)^2$ follows a noncentral chi-squared distribution with N degrees of freedom. Also, the distribution probability is given by:

$$P_D = 1 - \Gamma_{inc}\left(\frac{\gamma}{2(\sigma_w^2+\sigma_s^2)}, \frac{N}{2}\right) \quad (9)$$

We will define the incomplete gamma used by Matlab function:

$$\Gamma_{inc}(x,a) = gammainc(x,a) = \frac{1}{\Gamma(a)}\int_0^x t^{a-1} e^{-t} dt$$

This allowed derive, analytically, the minimum number of samples that are required to complete a prescribed performance (P_F, P_d) for a given SNR, the expression of N is given as follows [18]:

$$N \approx \lceil [SNR^{-1}\, Q^{-1}(P_F) - (1+SNR^{-1})Q^{-1}(P_D)]^2 \rceil \quad (10)$$

for sufficiently large number N [17].

3.3. Power Spectral Estimation

The energy detection is the common used tool for spectrum sensing due its low computational cost and implementation complexity. It is designed to decide the presence or the absence of UP without a priori knowledge of statistical characteristics of the primary signal [19].

There exist two domains for implementing the energy detection technique, in time as well as frequency domain by the use of the Fast Fourier transform (FFT).

If the Fourier transform X (f) of x(t) signal exists then according to the theorem of Perceval:

$$\int_{-\infty}^{+\infty} |x(t)|^2 dt = \int_{-\infty}^{+\infty} |X(f)|^2\, df \quad (11)$$

Signal energy is conserved in both time and frequency domains however the representation in the frequency domain is more flexible [20].

3.3.1. The Periodogram:

It is the simplest non-parametric method of power spectral estimation. The spectral power density (PSD) of length L of the signal $x_L(n)$ is defined by [21-22]:

$$P_{xx}(f)=\frac{1}{L}\left|\sum_{n=0}^{L-1} x_L(n)e^{-j2\pi fn}\right|^2 \quad (12)$$

3.3.2. The average Periodogram (Welch):

The main problem with the Periodogram is high variance (inconsistency). A simple solution for this is to apply the average of a set of estimates (assumed to be independent). The signal of length N is divided into k segments overlapped with length L, and then each segment periodogram is calculated; the average Periodogram I estimated as follows [8]:

$$P_{AVER}(f)=\frac{1}{K}\sum_{m=0}^{K-1} P_{PER}(f)^{(m)} \quad (13)$$

Where

$$P_{PER}(f)^{(m)}=\frac{1}{L}\left|\sum_{n=0}^{L-1} x_L(n)e^{-j2\pi fn}\right|^2 \quad (14)$$

4. THE ENERGY DETECTION ALGORITHM

4.1. The Implementation of Energy Detection Algorithm

It includes 5 main phases:

1) Initialization: entering the values of P_D and P_F, the duration and the number of signals and the sampling frequency.

2) The primary signal generation: entering the F_i frequency and make the summation of primary signals by adding white Gaussian noise of diverse SNR values;

3) Calculation of the threshold according to the equations (2) and (10);

4) Estimation of the PSD: by using the 2 techniques of spectral estimation of power (Periodogram and Welch);

5) Evaluation: Comparison with the threshold calculated in step 3) and decision making.

4.2. Simulation and Result

We generate at maximum 6 sinusoidal signals with frequencies 1 kHz, 2 kHz, 3 kHz, 4 kHz, 5 kHz, and 6 KHz. The sampling frequency is F_s = 14KHz. In this work we have taken the respective values of P_D and P_F equal to 0.95 and 0.05. The following table 1 shows the results obtained for different values of SNR and durations of observation.

The Periodogram method can be a useful tool for spectral estimation in case of high SNR more specifically where there data is longer; where it arises the importance of the observation period. Table 2 below shows the results of the study of the detection performance depending on the duration of observation (Figure 4).

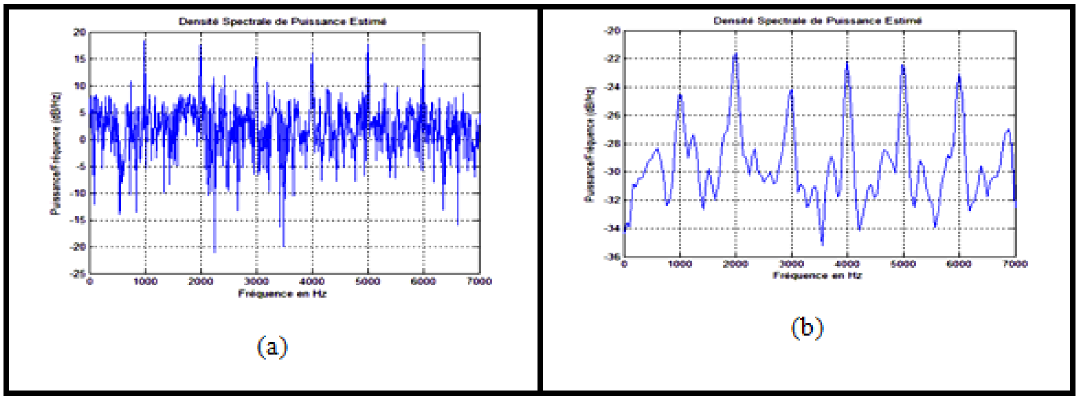


Figure 4. Power spectral density PSD estimation for an SNR of -4 dB using:
(a) Periodogram; (b) the Welch method

Table 1. Estimation of the DSP for Welch VS. Periodogram.

SNR (dB)	Duration (ms)	Estimation of PSD	True Detection	False Detection
-4	0.0651	Welch	4/6	2/6
		Periodogram	5/6	1/6
	0.1	Welch	5/6	1/6
		Periodogram	5/6	1/6
4	0.0651	Welch	5/6	1/6
		Periodogram	4/6	2/6
	0.1	Welch	5/6	1/6
		Periodogram	6/6	0/6

Table 2. The performance of detection on the basis of the observation period.

SNR (dB)	Duration	True Detection	False Detection
-4	0.9 ms	4/6	2/6
	1.6 ms	6/6	0
0	0.1 ms	6/6	0
	0.6 ms	6/6	0
4	0.1 ms	6/6	0
	0.6 ms	5/6	1/6

The previous synthesis shows that the detection performance depend not only on the probability of false alarm and detection, but it also depends on the optimal duration of observation T_{opt}. We note that the time required for a low SNR is wider than that for a high SNR. Thus, we can confirm that the required observation period is inversely proportional to the level of the SNR.

5. COGNITIVE RADIO BASED ON THE DETECTION OF ENERGY

After the implementation of the algorithm of the identification of the free spectral bands, for a given scenario, based energy detection technique; we proceed, in the present phase, to the context of cognitive radio. In other words, we simulate a transmission chain of an alphanumeric message via a noisy Gaussian channel by identifying free spectral bands to be allocated by secondary users (cognitive radio).

5.1. Description of the Algorithm

In our example, we generate an alphanumeric message converted to 8 bit ASCII encoding. Next initialization phase comprises the duration of the signal T, carrier frequencies, the value of P_D and P_F and the secondary signal. The used modulation is BPSK (Binary Phase Shift Keing).

The modulated primary signal is transmitted through an AWGN channel. Primary signals are determined by the technique of the ED and as the detector output is above the threshold then it says that the UP is present and vice versa. The insertion of secondary user is introduced in the band where the primary user is absent. Figure 5 illustrates the methodology for implementing the detection technique in the context of cognitive radio.

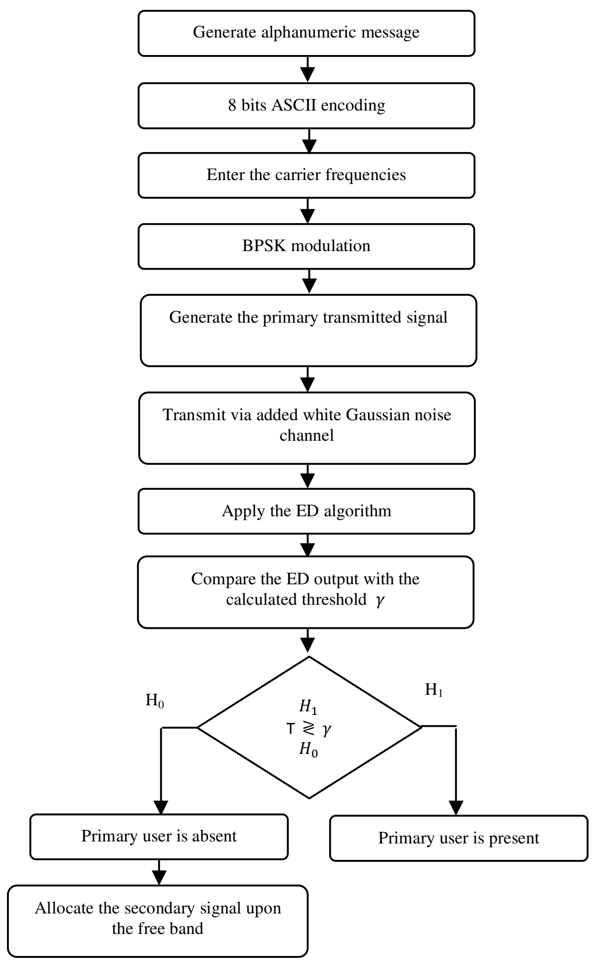


Figure 5. Methodology for implementing ED in the context of RC.

5.2. Results and discussions

In our example, we generate a randomly alphanumeric message of 19 characters; this message will be ASCII-encoded 8-bit. Considering 3 BPSK modulated primary signals with carrier frequencies of 2.5 KHz, 6.5 KHz and 10.5 KHz. The sampling frequency is F_s = 24 kHz and the duration of signal is t = 0.08ms. Assuming that there are two primary users 2.5 KHz and 10.5KHz frequencies are present and the primary user with a frequency of 6.5KHz is absent. The signal is transmitted through an AWGN channel.

Calculation of the threshold: The threshold is calculated based on equation (2). The number of observed samples N is calculated from (5). We choose P_D = 0.95, P_F = 0.05, SNR = - 2DB and duration of signal is t = 0.08ms. The cognitive radio system looks permanently for the hole of the spectrum where the primary user is absent which is determined by the method of energy detection. When it finds the hole of the spectrum, immediately it attributes it to the secondary user (US). Figure 6 shows the occupation of the unused bandwidth by secondary user.

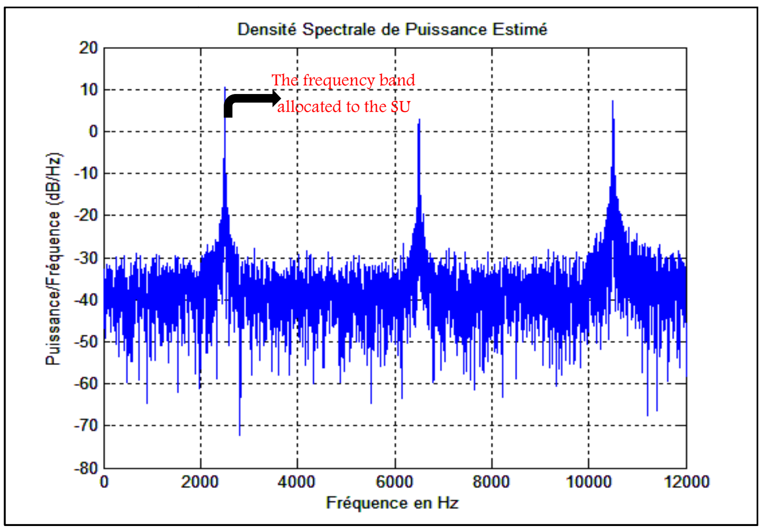


Figure. 6 Allocation of secondary user in the free band

Figure 7 shows the estimation of the spectral power density by the technique of Periodogram for an SNR = - 30dB. Unfortunately, for this very low level SNR, the algorithm of the ED fails to identify the free spectral bands due the high number of representative noise within the informative signal peaks.

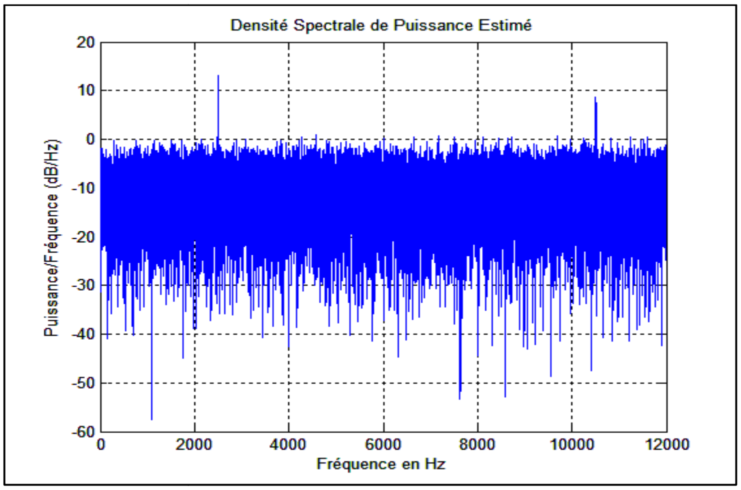


Figure 7. The PSD estimated by the technique of periodogram for an SNR =-30dB

6. CONCLUSIONS

In this paper, the technique of detection of energy has been introduced in the context of cognitive radio. The realized algorithm is based on the Neyman-Pearson test and calculation of P_F and P_F. we have implemented an energy detection algorithm. In our example it was shown that the detection of energy performance also depends on the optimal observation duration, and the method chosen for the estimation of the power spectral density (PSD). An example of telecommunications systems that provides a scenario for the RC system was exposed, and also was given a developed procedure that allows to insert the secondary user in the unoccupied band of opportunistically in a dynamic way allowing better allocation of available frequency resources. The signal to emit, is modulated in BPSK is transmitted through an AWGN channel. The presence / absence of primary user is determined by the technique of energy detection (ED), when the primary user is absent, the band is assigned to the secondary user.

REFERENCES

[1] Lee, S.hyun. & Kim Mi Na, (2008) “This is my paper”, ABC Transactions on ECE, Vol. 10, No. 5, pp120-122.

[2] Gizem, Aksahya & Ayese, Ozcan (2009) Coomunications & Networks, Network Books, ABC Publishers.

[1] J. Mitola, A. Attar, H. Zhang, O. Holland, H. Harada, and H. Aghvami, “Special issue on achievements and the road ahead: the first decade of cognitive radio,” IEEE Trans. Veh. Technol., vol. 59, no. 4, May 2010.

[2] J. Ma, G. Y. Li, and B. H. Juang, “Signal processing in cognitive radio,” Proc. IEEE, vol. 97, no. 5, pp. 805–823, May 2010.

[3] S. Haykin, D. J. Thomson, and J. H. Reed, “Spectrum sensing for cognitive radio,” Proc. IEEE, vol. 97, no. 5, pp. 849–877, May 2010.

[4] S. H. Song, K. Hamdi, and K. B. Letaief, “Spectrum sensing with active cognitive systems,” IEEE Trans. Wireless Commun., vol. 9, pp. 1849–1854, June 2010.

[5] Ian F. Akyildiz, Won-Yeol Lee, Mehmet C. Vuran, and Shantidev MohantyA, « Survey on Spectrum Management in Cognitive Radio Networks », Georgia Institute of Technology, IEEE Communications Magazine, April 2008.

[6] Tevfik Yucek and Huseyin Arslan, «A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications », IEEE Communications Surveys & Tutorials, Vol. 11, No. 1, First Quarter 2009.

[7] Christophe MOY "Evolution de la conception radio : de la radio logicielle à la radio intelligente" Habilitation à Diriger des Recherches (HDR), Université de Rennes 1, 8 octobre 2008

[8] B. Wang and K. J. R. Liu, "Advances in cognitive radio networks: a survey," IEEE J. Sel. Topics Signal Process., vol. 5, no. 1, pp. 5–23, Feb 2011.

[9] Mansi Subhedar et Gajanan B, «Spectrum Sensing Techniques in cognitive radio network: A survey », International Journal of Next Generation Network Vol.3, No.2, 37-51 June 2011.

[10] Phunchongharn, P.; Hossain, E.; Niyato, D.; Camorlinga, S. A cognitive radio system for e-health applications in a hospital environment Wireless Communications, IEEE February 2010 Volume: 17 Issue:1 On page(s): 20 - 28 ISSN: 1536-1284

[11] Chavez-Santiago, R.; Balasingham, I.; 2011 IEEE 16th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), 10-11 June 2011 ; 148 – 152 Kyoto E-ISBN: 978-1-61284-280-6 Print ISBN: 978-1-61284-281-3

[12] Joseph Mitola III, « Cognitive Radio an Integrated Agent Architecture for Software Defined Radio », Royal Institute of Technology (KTH), May 2000.

[13] Architecture for Cognitive Radio Networks Broadband Wireless Networking Lab School of Electrical and Computer Engineering Georgia Institute of Technology http://www.ece.gatech.edu/research/labs/bwn/CR/projectdescription.html

[14] I. F. Akyildiz, W. Y. Lee, M.C. Vuran and S. Mohanty, "NeXt Generation / Dynamic Spectrum Access / Cognitive Radio Wireless Networks: A Survey,"Computer Networks Journal (Elsevier), Vol. 50, pp. 2127-2159, September 2006

[15] Gyanendra Prasad Joshi , Seung Yeob Nam and Sung Won Kim Review Cognitive Radio Wireless Sensor Networks: Applications, Challenges and Research Trends Sensors 2013, 13(9), 11196-11228; doi:10.3390/s130911196
http://www.mdpi.com/1424-8220/13/9/11196/htm

[16] Mahmood A. Abdulsattar and Zahir A. Hussein, «Energy detection technique for Spectrum sensing in cognitive radio: a survey», International Journal of Computer Networks & Communications (IJCNC) Vol.4, No.5, September 2012.

[17] Ratsirarson s. a, Rakotonirina t, Ravonimanantsoa n.m.v, «Analyse Des Différents Types Des Fonctions De La Radio Cognitive », Université d'Antananarivo BP 1500, Ankatso – Antananarivo 101 – Madagascar.

[18] H. Urkowitz, «Energy Detection of Unknown Deterministic Signals», Proc. of the IEEE, vol. 55, no. 4, pp. 523-531, 1967.

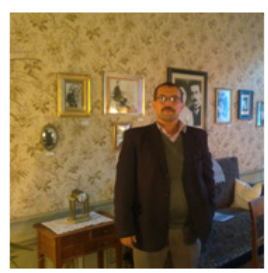
[19] A.M. Fanan, N.G. Riley, M. Mehdawi, M. Ammar, and M. Zolfaghari, «Survey: A Comparison of Spectrum Sensing Techniques in Cognitive Radio», Int'l Conference Image Processing, Computers and Industrial Engineering (ICICIE'2014) Jan. 15-16, 2014 Kuala Lumpur (Malaysia).

[20] Ahmad Ali Tabassam et Muhammad Uzair Suleman, «Building Cognitive Radios in MATLAB Simulink – A Step Towards Future Wireless Technology », Wireless Advanced, IEEE,2011.

[21] J.McNames, «Spectral Estimation », Portland State University ECE 538/638Ver. 1.15.

[22] Shan He et Hongmei Gou, «Spectral Estimation», ENEE 624 Advanced Digital Signal Processing, University of Maryland at College Park, Dec. 16, 2002.

AUTHORS



Professor CHOUAKRI, SID AHMED, engineering educator, researcher; married. PhD (hon.), U. Tlemcen, Algeria, 2008. Rschr., Prof. U. Sidi Bel Abbès, Algeria, since 1997. Member of Laboratory of Telecommunications and Digital Signal Processing at the University of Sidi Bel Abbès, Algeria. He received the engineering degree in Computer Science from the National Institute of electricity and electronics of Boumerdes, Algeria in 1992 and the Master degree and PhD in Electronics from the University of Tlemcen, Algeria in respectively, 1997 and 2008.

Domains of interest: biomedical engineering, signal processing (digital filtering, time-frequency analysis, wavelet transform…), Hardware systems, real time systems, wireless for telemedicine, telecardiology, RFID systems, Cognitive radio…