Implementation of the Energy Detector by Software Defined Radio for Spectrum Detection

Monica Alcaraz* and Fatima Mountadi
*Corresponding author email id: monicaalcaraz@yahoo.com

Abstract – The spectrum detection stage in cognitive radio presents major challenges, since the devices used require precision and a high coordination to exchange data between the nodes that form a network. This article uses the energy detection technique, which consists of measuring the power of a signal and comparing it with a threshold to detect whether or not a primary user exists, in addition to monitoring the transmission time. The project is based on the Software Defined Radio Technology (SDR); this technology allows implementing with the same hardware a lot of signals with different parameters avoiding great costs in equipment and real material. The results presented confirm the validation of the method using a simulated test signal in the GNU Radio environment, the power of the signal can be mathematically calculated and then verify if the designed threshold is capable of detecting the presence or absence of a primary signal.

Keywords – Energy Detection, Monitoring, Primary User, Software Defined Radio, Spectrum Detection, Threshold.

I. INTRODUCTION

Nowadays, broadband services in rural communities are a problem, as there is a lack of infrastructure for access to information. The radio spectrum is granted to primary services, generating a shortage of frequencies, which could be used for the evolution of new wireless technologies.

The concept of cognitive radio allows maximizing the use of the radio spectrum, enabling dynamic access of unlicensed users (secondary or cognitive users) to frequency bands assigned to licensed users (primary users), there are frequencies below 3 GHz that practically are congested and others that may be partially unoccupied for some time lapses, therefore it is necessary to start looking for new communication technologies that allow to exploit the wireless spectrum in a more intelligent and flexible way.

The analysis of the spectrum includes the information obtained by the detection, considering aspects such as interference, attenuations and variability in the availability of the spectral resource for subsequent decision making [1].

The signal processing algorithms to monitor the electromagnetic spectrum allow locating if there is available spectrum holes and verify which ones are adapted for the communication needs of a cognitive user. However, the evaluation of the performance of these algorithms are carried out by computer simulations, assuming that data is known, but are not available to the radios, which can deteriorate the performance of the algorithms in a real environment.

Dynamic access to the spectrum requires four phases of the cognitive cycle [2]:

A. Spectrum Detection
   Identify spectrum gaps and maintain low interference levels for licensed users.

B. Spectrum Decision
   Select an available channel and appropriate band for the communication of cognitive users.

C. Resource Sharing
   Cognitive users must implement spectrum planning methods to share it impartially with each other.

D. Mobility
   The user must abandon the channel in case the primary user initiates a data transmission and must be able to resume its transmission in another free space of the spectrum.

The applications that can be given to cognitive radio have a great boom in the military, public and private sectors to mention some [3].

In military usage, due to hostile environmental conditions there are interference and connectivity problems, so that cognitive radios can mitigate this problem using free frequencies.

In the public sector in issues such as efficient use of available spectrum, this would increase new wireless communication services and thus the development of new technology, as well as the interoperability of systems as emergency services, providing secure, efficient and accessible communication.

For the private sector, telephony and mobile internet access could exploit unused bands with more space to operate; services would be cheaper and with more applications such as video calls, and mobile phones would be able to change its operating frequency without too much additional hardware.

II. SOFTWARE DEFINED RADIO (SDR)

The Cognitive Radio has as antecedent the Software Defined Radio, since it allows to analyze the radio electric environment and to make decisions autonomously, reconfiguring the parameters of communication according to the demands of the network and of the users, always trying that the energy levels consumed for these actions be as low as possible.

The term Software Defined Radio (SDR) was introduced by Joseph Mitola III in 1991 to refer to a type of reprogrammable radios where the same hardware component could be used to perform different functions, at different instants of time; changes in configuration are applied through software, thus reducing costs by manufacturing hardware and facilitates the availability of applications.
GNU Radio is free software created by Eric Blossom in 2001 and whose main objectives is to provide signal processing functions to implement Software Defined Radios and support the investigation of wireless communications and radio systems based on SDR technology [4].

The creation of an application in GNU Radio is carried out by programming in high level; in this project the Python programming language is used. However, there is the possibility of using a graphical interface, called GNU Radio Companion (GRC), which allows complete designs without writing lines of code, simplifying the level of complexity and eliminating the need for knowledge of programming languages by the user.

### III. SENSITIVE MODEL

**Power Detector**

It is the most common way of detecting opportunities in the spectrum due to its low level of complexity in computational and implementation terms.

\[
y[n] = x[n] + r[n]
\]

"n" is the number of samples in the time domain and the samples x [n] are independent, so the correlation of these samples as shown in equation (2) improves the performance of the method.

\[
M = \sum_{n=1}^{N} y(n)
\]

"N" is the number of samples that will fit into the primary user detector buffer.

There are two hypotheses for detecting opportunities in the spectrum:

\[
H_0 = y[n] = r[n] \quad (\text{Missing primary user})
\]

\[
H_1 = y[n] = x[n] + r[n] \quad (\text{Primary user present})
\]

Where:

\[
y[n] = \text{signal received}
\]

\[
x[n] = \text{primary user}
\]

\[
r[n] = \text{noise}
\]

A threshold (\(\lambda\)) must be defined and each reading obtained will be compared to that threshold, to evaluate the performance of the spectrum detection are defined:

\[
P_D = P(M > \lambda) \big| H_1 \quad (\text{Successful detection})
\]

\[
P_{FA} = P(M > \lambda) \big| H_0 \quad (\text{False alarm detection})
\]

The balance between \(P_D\) and \(P_{FA}\) will have an optimal \(\lambda\) threshold.

The Energy Detector method does not require prior knowledge of the primary signal, the signals are detected by comparing the output level of an energy detector respecting to a threshold that depends on the noise floor, but one of the disadvantages is that it lacks of accuracy in differentiating noise or interference produced by licensed users and has low signal-to-noise ratio.

Then, \(\lambda\) depends on the variance of the noise; a small error in the estimation of noise power produces a significant drop in performance.

The probability of false alarm occurs when the user is detected as active when it is not, which results in the loss of a transmission opportunity of a secondary user. The goal of detection by this analysis is to maximize the probability of detection by maintaining a given false alarm probability [5]. Clearly, it is more important to limit interference to a primary user than to miss spectrum opportunities, thereby maximizing the probability of detection. In practice the threshold level is generally set based on the requirement in the false alarm probability [6] (this being independent of any measured SNR levels of a primary user), but then also a condition on the probability is imposed detection.

### IV. DESIGN PARAMETERS

**Wireless Regional Area Network (WRAN)**

In July of 2011 the IEEE organization published the 802.22-2011 standard [7], which specifies the air interface including the cognitive layers of access to the medium (MAC) and physical (PHY) of point-multipoint networks type Wireless Regional Area Network (WRAN) composed of fixed base stations (BS) and fixed or mobile user terminals (CPE) operating in TV bands (VHF / UHF) between 54 MHz and 862 MHz [8].

The standard contains the specifications needed to deploy a cognitive network that provides broadband data services using the licensed spectrum of the TV bands but without interfering with the licensed services. Each CPE performs spectrum sensing and then sends the reports (in an established format) to the BS who makes the decisions of the parameters that will be used for the communication and whether or not it can be carried out under the non-interference constraint [9].

To sense the spectrum inputs must specify the type of signal to be sensed (DVB-T, ISDB-T, NTSC, IEEE 802.22, etc.), the bandwidth (6, 7 or 8 MHz), the duration of the sensing, the Interval between senses and the maximum probability of false alarm allowed (with a range of 0.001 and 0.255) [10].

<table>
<thead>
<tr>
<th>Parameter Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection time</td>
</tr>
<tr>
<td>Probability of Detection</td>
</tr>
<tr>
<td>Probability of false alarm</td>
</tr>
<tr>
<td>Bandpass time</td>
</tr>
</tbody>
</table>

Table I. Sensing requirements - IEEE 802.22 standard [10]

The practical considerations that have been taken for the implementation of this sensing block in the GNU Radio platform have been programmed in C++ language and then concatenated to a flow graph of tests.
The design consisted in calculating an average energy of the traditional form and therefore adding a quantity $N$ of point energies $e[i]$ and then dividing by $N$.

Where:

$$e[i] = |x[i]|^2$$  \hspace{1cm} (7)

$$x = \text{complex signal received}$$

$$i = \text{samples}$$

$$e = \text{punctual energy}$$

The final solution implemented in GNU Radio consists of a decimator system where each element or sample of the detector block is calculated based on a finite and configurable number of elements of the input. When choosing some detector design parameters, it was decided to take into account the sensing requirements contained in the IEEE 802.22 standard, the number of samples $N$ as a function of $P_d$, $P_{fa}$ and SNR is obtained for an SNR $= -21\, \text{dB}$ with $P_d = 0.9$ and $P_{fa} = 0.1$, the number of samples is $N = 210072$.

It is clarified that the chosen SNR value corresponds to the sensing requirement value mentioned in the draft of the IEEE 802.22 standard [11]. In the final rule of 2011 several values of SNR requirements are presented depending on the chosen method.

V. SIMULATION RESULTS

To validate the method, it is decided to use a simulated test signal in GNU whose power can be calculated mathematically and then first check if the power calculation is done correctly. The following validations consist of checking that the threshold is correctly calculated from the input parameters and that the comparison step is also correct. The simulated signal chosen is a complex cosine of amplitude $A$ and frequency $f_c$, according to Euler’s formula:

$$x_{\cos}(t) = A \times \cos(2\pi f_c t) + i \sin(2\pi f_c t)$$  \hspace{1cm} (8)

Making the calculation of power of the signal gives:

$$P_{x_{\cos}} = \frac{1}{T} \int_{0}^{T} |Ae^{j(2\pi f_c t)}}|^2 \, dt = |A|^2$$  \hspace{1cm} (9)

Fig. 2 shows the signal generation blocks in GRC. In Fig. 3 and Fig. 4 the parameters of the test signal ($A = 3\), $f_c = 2\, \text{kHz}$), their representation in time and frequency are observed.

The results obtained in Fig. 5 indicate that the signal strength increases its value according to the amplitude of the input signal, (a) without adding Additive White Gaussian Noise (AWGN), the threshold detects that there is a primary user and sends the output “1”, Primary user present.

The signal strength is squared resulting in 9 units which exceed the defined threshold at 2.20967 units, this threshold calculated based on the input parameters is consistent, the noise uncertainty and the have a value of 100m, the which is mentioned in the IEEE 802.22 standard, is considered a noise power of 2 units and the SNR obtained of 5.4407 dB.

When Additive White Gaussian Noise (AWGN) is added in (b), the threshold and noise floor increase, so the signal-to-noise ratio decreases and it is difficult to detect a primary user, so the output has a “0”, Primary user absent.

The noise uncertainty is maintained at 0.1, the SNR has a decrease to $-14.1519\, \text{dB}$, the signal strength increases to 133,193 units but does not exceed the threshold calculated at 139,787 units therefore results in an unoccupied channel, is say without transmission from a primary user.
The values obtained in this simulation are only to show that the programmed threshold works correctly, the test values in actual practice will change depending on the received signal.

![FFT Plot](image1)
a) Without AWGN noise.

![FFT Plot](image2)
(b) With AWGN noise.

Fig. 5. Validation of the energy detector

**VI. CONCLUSION**

After connecting the test signal with the detector block the following results were observed:
1. The power of the signal is unit 9 as expected.
2. The threshold calculated based on the input parameters is consistent.
3. Adding AWGN noise to the existing cosine shows that the noise floor power level (and hence the threshold) increases, and the block output becomes 0 because the total power of the signal is less than threshold.

**REFERENCES**


**AUTHORS’ PROFILES**

**Monica Alcaraz**
(Mexican, 1992), She studied engineering in Telecommunications, graduated from the National Autonomous University of Mexico. She is currently doing master's degree studies in Telecommunications and researching of TV White Spaces.

**Fatima Moumtadi**
(Mexican, 1967), holds a Master's degree in Satellite Broadcasting Systems and a Doctoral degree in Television Systems, Faculty of Broadcasting and Television at the Technical University of Communications and Information Technology in Moscow, Russia (MTUCI). She is a career professor in the Department of Electronics at the Faculty of Engineering of the National Autonomous University of Mexico (UNAM). Her research interests include the areas of radiofrequency and biomedical, has published articles in congresses, national and international magazines and has a recognition as responsible of the thesis "Mobile Wireless Electrocardiograph Warning System", the winner of TR35 Mexico Magazine 2012 by MIT Innovation.