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Model for Energy Detection with Software-Defined Radios in Cognitive Radio Networks

Ahmed M. El Khateeb[1,2], Tamer A. Moniem[2], Ashraf Mohamed Ali Hassan[2], Rania Ahmed Abul Seoud[1]

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Abstract: In recent years, a lot of interest has been shown in cognitive radio as a potentially useful method for dynamic spectrum allocation. One useful technique for optimizing the utilization of spectrum resources is cognitive radio (CR). A key component in locating open channels for CR use is spectrum sensing. One of the fundamental roles of the cognitive radio is spectrum sensing, which is essential to all other roles. Because of their extreme flexibility, software-defined radios, or SDRs, are being used more often to deploy CR in place of more costly spectrum analyzers. This work provides a thorough explanation of the wide-band sensing technology, as well as a real-time swept spectrum sensing solution and energy detection idea. Lastly, FFT graphs are used to analyze the suggested sensing solution's performance. The findings demonstrated that the suggested sensing method could achieve excellent resolution in the wide band measured frequency domain, suggesting that wide bands with heterogeneous signals may be accurately resolved and analyzed. In this paper, we successfully developed and implemented a cognitive radio-based communication system. It is inevitable that the spectrum access policy will be changed in light of the growing demand for radio spectrum and the inadequate usage of the allowed bands. As the signal-to-noise ratio increases, the probability of missed detection PMD and false alarm PFA decreases and the probability of detection PD increases.

***Index Terms**: Cognitive radio, Spectrum sensing, primary users, Secondary Users, spectrum hole, energy detection*.

I. Introduction

The Federal Communication Commission (FCC) survey on spectrum has revealed that improper use of the licensed spectrum occurs at different times, frequencies, and geographical regions [1]. The increased number of wireless applications is also driving up demand for allocating and using radio frequency spectrum [2]. When a licensed user is not present, a secondary user or an unlicensed user may use this band. In an effort to promote efficient spectrum utilization, the notion of cognitive radio (CR) has been put forth [3]. The principles of CR are covered, along with the difficulties of dynamic spectrum sharing and allocation in CR [4]. When permitted users are not using certain frequency channels, CR permits opportunistic use of such frequencies. Hence, in order to identify open spectrum bands, CR depends on effective spectrum sensing. In order to handle various kinds of signal processing, the deployment of new wireless devices and applications has also led to an increase in the cost of hardware infrastructure. Reconfigurable hardware platforms are therefore needed for this. The best way to address these issues is via SDR platforms. SDR in conjunction with GNU radio offers an affordable and adaptable platform. To match the capabilities of solely hardware solutions while delivering intelligence that software can provide is a significant problem for software defined radios. discusses the use of Universal Software Radio Peripheral (USRP) and GNU radio to construct software-based wireless transmission systems, or software defined radios [5-8].

1Department of Electrical Engineering, Faculty of Engineering, Fayoum University, Fayoum, 63514, Egypt
2October High Institute for Engineering and Technology, 6thof october,12596, Egypt
Corresponding author: Ahmed M. Khateeb (am3589@fayoum.edu.eg).

CR is able to adjust its operational parameters to best suit the trade-offs of the surrounding radio environment. When a part of the frequency band is not in use by the primary users (licensed users), it is known as spectrum white space. CR can identify this space and use it for secondary user (SU) transmission[9]. However, CR can utilize spectrum sensing to identify licensed users when they re-use the spectrum and can pause transmissions created by secondary users. Furthermore, by identifying and using the unutilized frequency band, CR may coexist with existing radio systems, maximizing spectrum use without negatively affecting main users (PU). Thus, there are primarily two kinds of users in CR. The first is PU, who is authorized to use the designated frequency band; the second is SU, who is not authorized to use the designated frequency band but is permitted to use it if it becomes available. The SU must leave the frequency band and search another open frequency band as soon as the PU or licensed user returns to it. Spectrum sensing is required by SU in order to determine if a given frequency band is in use or not. Sensing is therefore one of a CR's primary features, meaning that a CR has to be able to recognize the unoccupied spectrum band[10-12].

SDR and CR competencies are integrated. By employing a clever approach that uses GNU radio to automatically adjust radio parameters and sense the spectrum, SDR improves the usefulness of CR.For spectrum sensing, a variety of detection techniques are available. Considerable research is done on spectrum sensing for CR-based systems [13]. Energy detection is a preferred method for spectrum sensing in CR because of its adaptability and ease of use.Due to its set threshold design, the classic energy detection technique [14] is susceptible to noise uncertainty, which is an inevitable occurrence in real-world scenarios. Therefore, for the best CR performance, an effective energy detector is suggested in this study. The threshold of the energy-based sensing approach is determined by measuring certain parameters in the suggested system, which is then utilized to an actual scenario. The goal of calculating thresholds is to reduce the likelihood of false alarms (PFA) and increase the likelihood of detections (PD). Based on theoretical analysis and simulation results, the suggested technique is more efficient than the conventional energy detection approach while requiring less complexity increase[15-16].

Spectrum sensing in CR is now the focus of most study, however theoretical detection techniques are insufficient. As covered in [17], SDR is a crucial and practical foundational technology for the context-aware, adaptive, and learning radio units, or CRs, of the future. Software-based signal processing and the necessary hardware components must be combined for SDR to function.[18] presents an overview of the requirements for these platforms, as well as the state of development and future directions in this field.

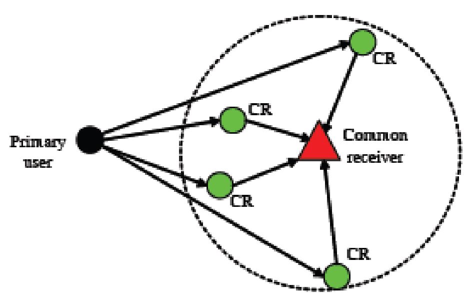

Figure1 spectrum sensing structure in a cognitive radio network

To test and verify the CR's performances, a hardware test platform is needed. The solution to this issue is to use SDR's emerging technology, which offers cost-effectiveness and ease of implementation by substituting software for hardware. SDR offers a number of advantages, including quicker execution times and adaptability to new demands. To assist with unique research initiatives, a multitude of experimental SDR platforms are available [19]. One of the most well-liked and intriguing software platforms for radio networks is GNU radio [20], which Blossom launched. It is a free software toolkit that works with SDR kits to build software radios [21]. The GNU license allows unrestricted use of

GNU radio components in research projects, and the entire GNU radio project is available under it. This GNU radio project includes a big library of functions for the SDR system developed in Python and C++ as well as a library of numerous fundamental parts for creating basic DAB radio receiver functions. Moreover, GNU radio is made to function with a low-cost piece of hardware. The modulation system known as Gaussian Minimum Shift Keying (GMSK) has shown to be successful in wireless scenarios. Maximum Shift Keying (MSK), which substitutes a sinusoidal pulse for the rectangular pulse, is the source of GMSK. This technique will shape pulses using a Gaussian filter. An advantage of a Gaussian-shaped impulse response filter is that, in comparison to a rectangular pulse, it produces a signal with lower side lobes and a narrower main lobe. This modulation technique is known as GMSK modulation because it shapes pulses using a Gaussian filter[22,23].

II. Methodology

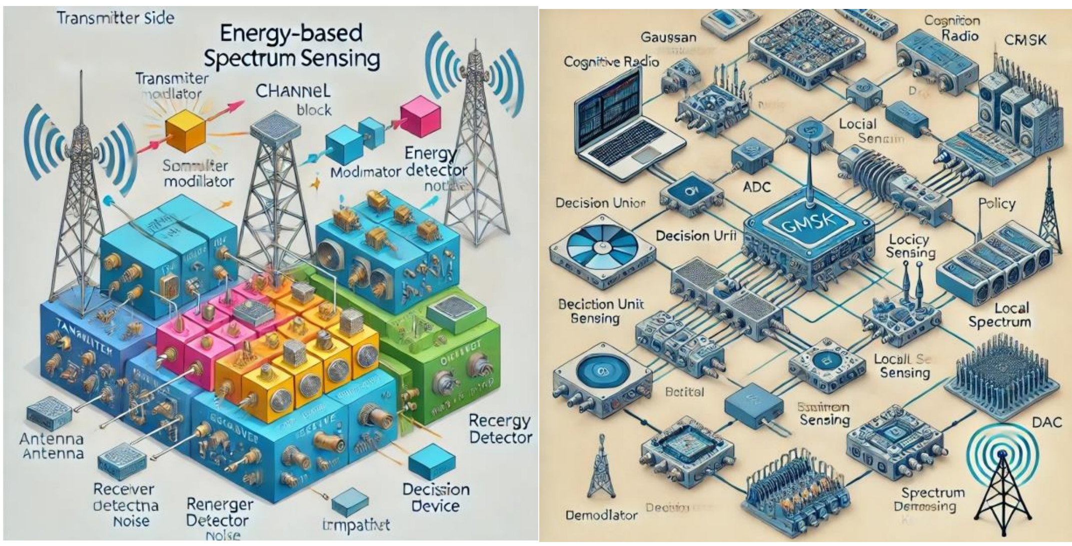

Figure 2: Overall system block diagram.

Figure 2 displays a block schematic of the CR-GMSK system that is the subject of this research. The cognitive engine is in charge of setting the radio and physical layer (PHY) parameters as well as making intelligent judgments. The decision unit uses data from the policy engine, local and network spectrum sensing, and other sources to identify the transmission opportunities. Regarding the PHY layer, CR can interact with a range of radio-access technologies in the surrounding environment or, depending on the conditions, can enhance communication quality by adjusting the GMSK system and SDR interface's configuration parameters. Take note that just one carrier frequency is used for spectrum sensing and detection.

III. Design Procedures

Figure 3 displays the total transmitter and receiver block diagram for energy-based spectrum sensing. A real-time signal modulated by GMSK is the system's input. It is processed using GNU radio tools and programming written in the Python language. Following this processing, an SDR-LAB device is used to transmit it wirelessly. The transmitted frequency is set on the receiver. A second SDR-LAB transceiver used for modeling and simulation in engineering receives the sent signal. It then transfers the incoming data to GNU radio software, which consists of two components: energy-based spectrum sensing and GMSK demodulation, which are utilized to detect signals. This provides the signal to noise ratio and detection output (SNR) computations.

Figure 3a: block diagram transmitter for energy based spectrum sensing

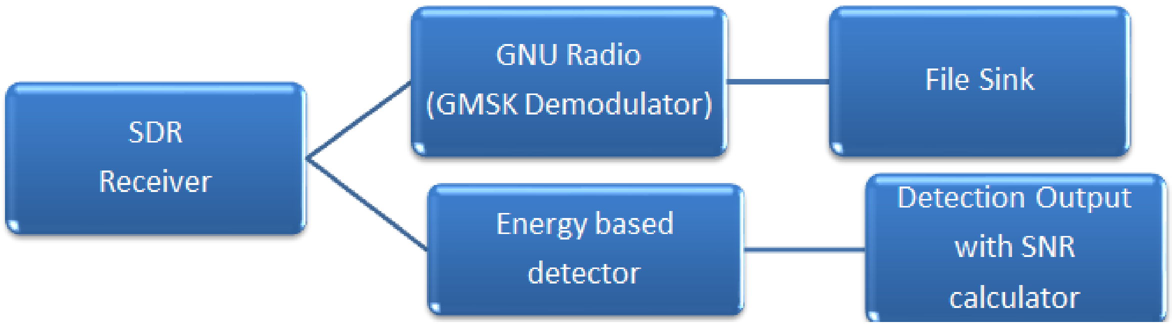

Figure 3b: block diagram receiver for energy based spectrum sensing.

The straightforward spectrum sensing technique is energy detection as it's simple to utilize and doesn't require any prior understanding of the main signal. Assume for the moment that the received signal fits the following hypothesis model[25]:

$$S(i) = \begin{cases} n(i), & H_0 \\ y(i) + n(i), & H_1 \end{cases} \quad (1)$$

Where the signals received at CR nodes, the signals transmitted at main nodes, and the white noise samples are denoted by the variables S(i), y(i), and n(i), respectively. We use the two aforementioned theories to determine whether or not the signal is present. It is assumed that the n(i) noise is a random process and is additive white Gaussian noise (AWGN) with zero mean. The ratio of signal to noise is

$$SNR = \frac{G_{power}}{I_{power}} \quad (2)$$

where I_{power} is the noise power and G_{power} is the signal power.

Assuming complete deterministic ignorance of the signal y(i), the energy detection algorithm operates in a semiblind manner. Assume for the moment that all we know about the signal is its average power. The correlation detector is the best type of detector [14]. The model of decision-making is

$$Z(i) = \begin{cases} \frac{1}{M}\sum_{i=0}^{i-1} S(i)y(i) < \lambda & H_0 \\ \frac{1}{M}\sum_{i=0}^{i-1} S(i)y(i) > \lambda & H_1 \end{cases} \quad (3)$$

Where λ is the threshold and Z(i) is the decision variable. The following approximation can be made using the Central Limit Theorem if the noise variance is fully understood.

$$Z\left(\frac{i}{H_0}\right) = U\left(€^2 \frac{2€^4}{M}\right)$$

$$Z\left(\frac{i}{H_1}\right) = U\left(A + €^2 \frac{2(A + €^2)^2}{M}\right) \quad (4)$$

Where M is the number of samples, A is the average signal strength, and $€^2$ is the noise variance.A symbol for approximation is $U()$.

By comparing the detection statistics with a predefined threshold (λ), the occupancy of the spectrum is decided. The two probabilities that are used to describe the detector's performance are P_{FA} (the probability of false alarm) and P_D (the probability of detection). The probability that the test determines H_1 when it is actually H_0 is indicated by P_{FA}.

$$P_{FA} = P_r(Z > \lambda \mid H_0) . \quad (5)$$

P_D denotes the likelihood that the test will correctly determine H1, which is determined by

$$P_D = P_r(Z > \lambda \mid H_1) . \quad (6)$$

The noise term can be obtained from (3) and (4) if it is considered to be a circularly symmetric complex Gaussian and the probability density function of P_M is approximated using the Gaussian distribution approximation.

$$P_{FA} = F(\frac{\lambda - 2M}{\sqrt{4M}}) \quad (7)$$

$$P_D = F(\frac{\lambda - 2M(SNR + 1)}{\sqrt{4M}(2SNR + 1)}) \quad (8)$$

Where F( ) and SNR stand for the F-function and the signal-to-noise ratio, respectively. Choosing between the two hypotheses with sufficient reliability to obtain high P_D for effective PU protection and low P_{FA} for SU access is a challenge in local spectrum sensing.

A good detector should maximize the efficiency of spectrum consumption or guarantee a high detection probability (P_D) and a low false alarm (P_{FA}). The development of many methodologies can enhance the efficiency of spectrum sensing based on energy detectors.

An effective energy detector is proposed, in which the threshold for this system is determined by measuring certain parameters under real-world conditions.

The decision variable is obtained from the output of an integrator, which comes after a squaring device in the design of this energy detecting system. The output of the detector indicates the presence of a PU if this variable is above the predetermined threshold after it has been compared to it. An energy detector compares the energy of the input data stream with a threshold that is defined based on the noise floor. A band pass filter is used to select the necessary bandwidth from the input signal before sampling it. The Fast Fourier Transform (FFT) is used in the digital implementation of this approach, which squares and integrates the absolute value of the samples over the observation band. Ultimately, the presence or absence of the primary user can be determined by comparing the integrator's output to the threshold. Figure 4 shows the block diagram for this technique.

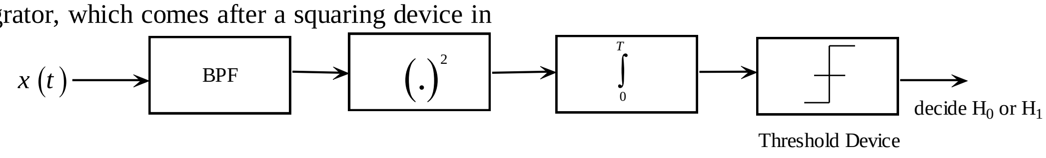

Figure 4 Block diagram of an energy detector

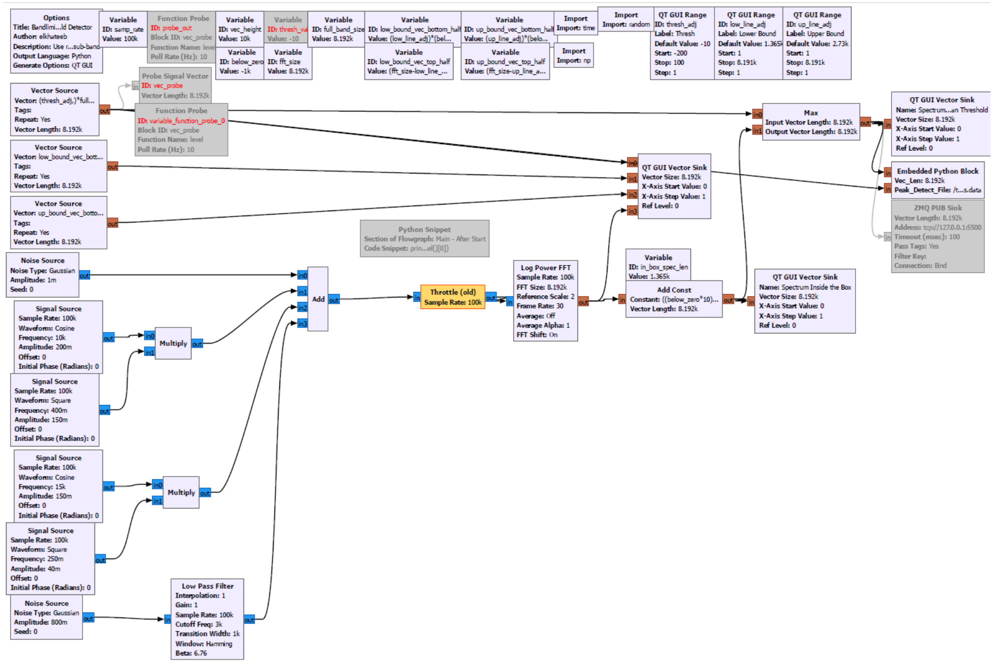

Figure 5 GNU Radio Companion (GRC) implementing the energy detection method with FFT.

Data reduction and display of the measured band X require additional processing. A spectrogram that accounts for the measurement period or a single sweep spectrum plot are the two ways in which the measured band is displayed. To create a clean FFT frame for each windowed block, the FFT samples are averaged over several FFT frames that are gathered for a center frequency. The spectrogram data is then created using the final FFT findings from each block, along with the measurement timeframe. Operating the spectrum analyzer requires a few parameters.The bandwidth that has to be measured is represented by the span and center frequency. It can also be stated as the frequency of start and stop. To create a clean trace, the VBW modifies the smoothness of the trace of the measured samples in the same way that each measured block is averaged.

IV. Discussion and Analysis of Results

The output of signal detection from an energy-based spectrum sensing block is a flag known as the detection output. When a signal is present, its energy surpasses the threshold and the detected output equals one. However, the signal's energy falls below the threshold and the observed output is zero if the signal's transmission stops. In this case, signal is the main user. This demonstrates the effective usage of an energy-based detector that sets the detection output to detect the presence of the primary user on a specified frequency. Scope plots and Fast Fourier Transforms (FFT) are used to view the signals at each point.

In Figure 6, power transfer is displayed. The sensing data on the receiving end. We may view received signals in GNU Radio by using the FFT sink block. Additionally, the signal processed at the SU is saved in a data file that is integrated into the Detect upload block. We then utilized MATLAB to analyze the data file. The likelihood of detection in relation to the quantity of sensing samples is displayed in Figure 7. It demonstrates that the energy detector performs better when increasing SNR. The likelihood of detection and false alarm based on SNR is displayed in Figure 8. The performance in terms of detection probability and false alarm probability improves significantly with increasing SNR.

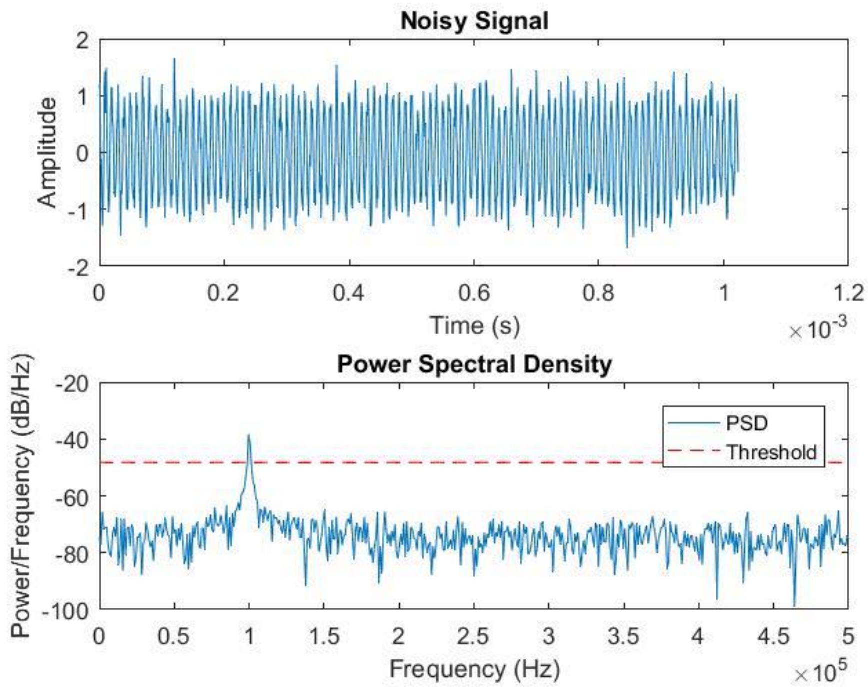

Figure 6a Comparison on spectra for power transmitted at 1x10^{5}Hz

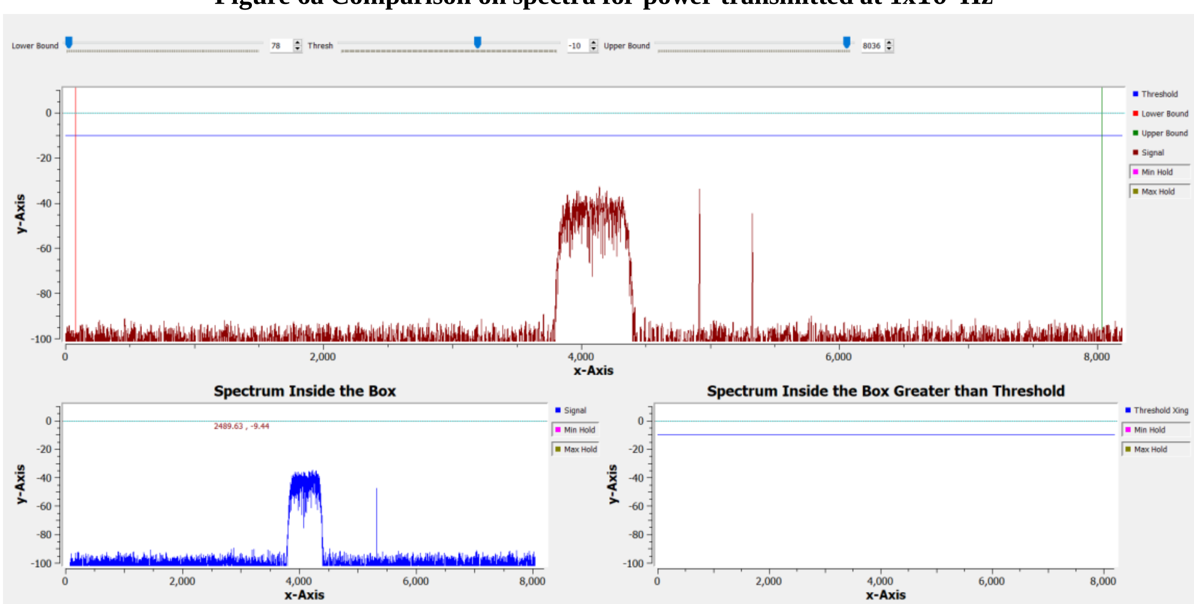

Figure 6b Comparison on spectra for power transmitted

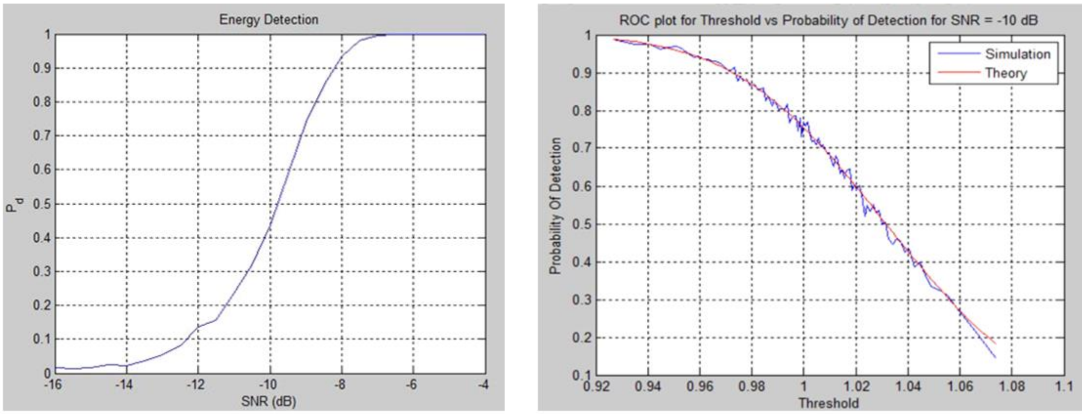

Figure 7 **a-Relation between P_D and SNR   b- Relation between P_D and Threshold at SNR=-10dB**

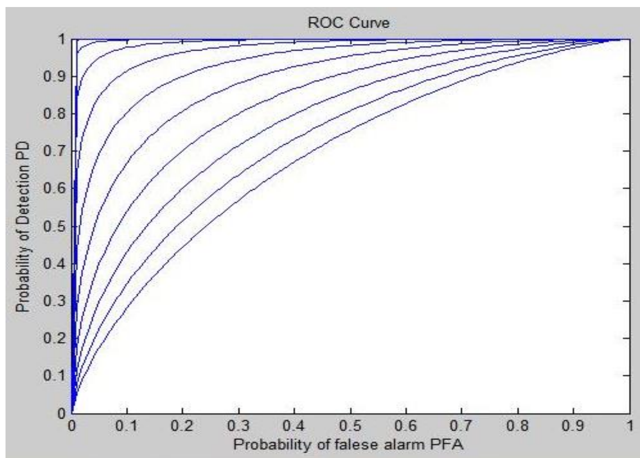

Figure 8 Relation between P_D and P_{FA} at SNR=-15:1:5

VII. Conclusion

An unique GNU radio method has been developed and deployed on software defined radios platform to detect transmitted signal by energy-based spectrum sensing of cognitive radio. Averaging blocks are used to successfully implement an energy detector, and the transmitted signal is modulated using GMSK. To sum up, a substantial number of theoretical and algorithmic results for energy detector have been created by this effort; also, the software defined radios implementation in conjunction with GNU radio provides a set of tools that enable the development of a practical cognitive radio system with real-time spectrum sensing capabilities. Thus, we have created and executed a cognitive radio based communication system with success. Given the increasing demand for radio spectrum and the poor use of the permitted bands, a reform in the spectrum access policy becomes inevitable. The likelihood of missed detection P_{MD} and false alarm P_{FA} declines and the likelihood of detection P_D improves as the signal-to-noise ratio rises.

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Data availability No Availability Data in this research paper

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