Spectrum Sensing for Cognitive Radio Users using Constant Threshold Range in Energy Detector

Tallataf Rasheed[1], Adnan Rashdi[2] and Ahmad Naeem Akhtar[3]

[1,2,3] Department of Electrical Engineering, National University of Sciences and Technology, Military College of Signals, Rawalpindi, 46000, Pakistan

Abstract

Spectrum Sensing has an important role in Cognitive Radio Network (CRN). Different methodologies have been proposed in the literature for spectrum sensing. Energy detector method is more practical and less in complexity. This paper presents analysis of energy detection algorithm in different scenarios with different parameters to detect presence or absence of Primary User (PU). The energy detection threshold has been used as Constant Threshold Range (CTR) to reduce the trade-off between Probability of False Alarm P_{fa} and Probability of miss detection P_{md}. The Receiver Operating Curves (ROC) has been presented by simulating Spectrum Sensing scenarios under fading and non-fading environments. It is also shown that theses curves can be further improved by Cooperative Spectrum Sensing (CSS) technique. The hardware implementation has also been presented by receiving real time signals using Universal Software Radio Peripheral (USRP) and GNU Radio, which has verified the simulated results.

Keywords: *Cognitive Radio, Spectrum Sensing, Energy Detection, Constant False Alarm Rate, Constant Threshold Range.*

1. Introduction

In wireless communication, CR has gained significant importance for spectrum management to avoid the inescapable spectrum scarcity. Cognitive Radio is a smart radio which acquires knowledge about available spectrum through process called Spectrum Sensing. Any licensed user known as Primary User (PU) do not utilize the spectrum all the time. Thus policy of Opportunistic Spectrum Access (OSA) has emerged in CR, so that any secondary user known as Cognitive Radio User (CRU) can access the spare band opportunistically without causing any interference with PU [1]. Ideally a CRU should not cause any interference with PU but wireless channels are always random in nature due to which a CRU at times make wrong decision about absence or presence of PU [2]. A reliable wireless communication can be described in terms of ROC which includes Probability of detection P_d, Probability of false alarm P_{fa} and Probability of miss detection P_{md} [3]. The optimization of these stochastic parameters is the work being targeted.

Transmitter spectrum sensing techniques can be categorized as coherent detection and non-coherent detection. The widely used methods of coherent detection are Matched Filter detection [4] and Cyclostationary feature detection [5] whereas Energy Detection [6] is a non-coherent detection technique. The basic key points for an appropriate selection of spectrum sensing techniques are speed of estimation, accuracy and complexity. Matched Filter and Cyclostationary detection are more accurate methods than energy detection. But these methods require priori knowledge about the signal so are complex too. The least complex and more practical technique for spectrum sensing is Energy Detection which works as a blind detector [7].

The credibility of energy detector depends on signal to noise ratio (SNR δ) and the value of threshold (τ) which is used to make decision about the presence or absence of PU. The combination of these techniques with different threshold values has been implemented in the literature [8]. The Constant False Alarm Rate (CFAR) has been used by the researchers over the ancient past to derive τ which requires trade-off between P_{fa} and P_{md}. In order to reduce this trade-off and probability of error [9], different threshold values are used in this paper.

However spectrum sensing result of a single CRU is not reliable due to shadowing and fading environments. So by cooperation among different CRU we can get even better results. In CSS a CRU makes its local decision and sends it to the CR Controller (CRC) known as Fusion Center (FC) where data from every CRU is aggregated for final and accurate decision. But this cooperation brought the additional communication overhead by increasing the P_d [10].

A comparative analysis has been carried out in this paper using simulations in terms of P_{fa}, P_d and P_{md} by changing different parameters of energy detector under both AWGN and Rayleigh fading wireless communication models. We have taken results by considering CFAR and CTR for comparison using simulations. The improved results by CSS have also been modulated in this paper using simulations. To verify the simulation results a data set has been prepared and demonstrated in a Hardware environment using USRP and the comparison results have been analyzed.

This paper is organized in different sections. Our system model with an energy detector is explained in section II. The description of CSS is given in section III. Then section IV will show the simulations and analysis. The Hardware implementation using USRP has been demonstrated in section V, which also contains analysis of its comparison with the simulations. The conclusion and future work of paper is in section VI.

2. System Model

The system model consists of a single CRU, sensing the presence of PU with hypothesis $\mathcal{H}0$ and $\mathcal{H}1$ defined as,

$$x(t) = n(t) \quad \mathcal{H}0 \text{ defining signal is absent} \tag{1}$$

$$x(t) = s(t) + n(t) \quad \mathcal{H}1 \text{ defining signal is present} \tag{2}$$

Where s(t) source signal, x(t) is received signal, and n(t) is an AWGN. The energy of the signal is compared with threshold τ values as,

$$\gamma < \tau \quad \text{Signal is absent} \tag{3}$$

$$\gamma > \tau \quad \text{Signal is present} \tag{4}$$

The approximated formulae of P_d, P_{fa} and P_{md} for energy detector can be given by [11].

$$P_{fa} = \Gamma(N, \tau/2)/\Gamma(u) \tag{5}$$

$$P_d = Q(\sqrt{2\delta}, \sqrt{2\tau}) \tag{6}$$

$$P_{md} = 1 - P_d \tag{7}$$

Where the δ represent the SNR, time bandwidth product is given by u, Γ (.,.) and Γ(.) are incomplete and complete gamma functions respectively. When we set a τ according to the CFAR, a trade-off between P_{md} and P_{fa} is required [12] which is shown by Fig. 1. The targeted task of our system model is to reduce this trade-off, thus we set the τ range from τ(1) to τ(N) as Constant Threshold Range (CTR) which is shown in Fig. 2, to reduce both P_{md} and P_{fa}.

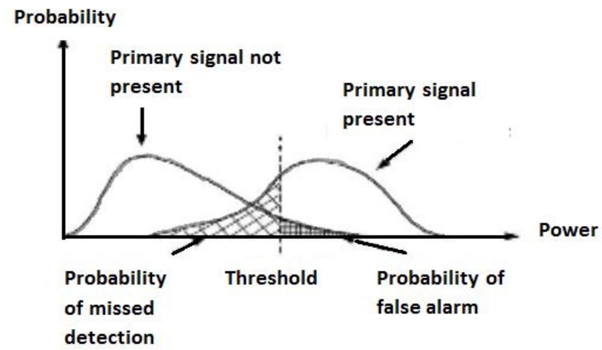

Fig. 1 Tradeoff between P_{fa} and P_{md} with CFAR

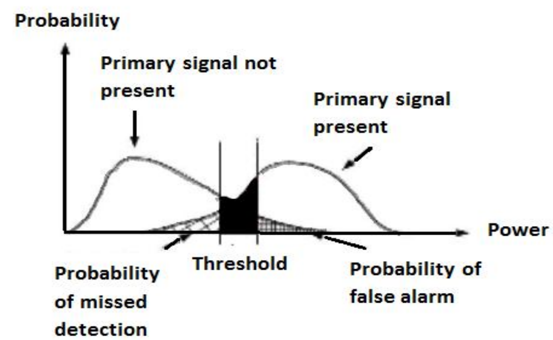

Fig. 2 Tradeoff between P_{fa} and P_{md} with CTR

$$P_d = e^{-(\tau/2)} \sum_{k=0}^{u-2} (1/k!)(\tau/2)^k + \{(1+\delta_a)/\delta_a\}^{u-1} \{e^{-(\tau/2(1+\delta_a))} - e^{-(\tau/2)} \sum_{k=0}^{u-2} (1/k!)(\tau\delta_a/2(1+\delta_a))\} \tag{8}$$

Although an Energy Detector does not detect a signal below certain limit of δ which is known as δ wall, yet it is more practical, as energy of signal can easily be detected. In any communication system model we make an assumption that the noise is Additive White Gaussian. However, practically different kinds of noises added in the signal during its path [13]. In this paper we have taken results under more practical fading channel i.e, Rayleigh Fading.

3. Cooperative Spectrum Sensing

The first objective of CRU is to detect the presence of PU in a particular spectrum band, to be used by CRU, in case found vacant. Any CRU, in isolation does not sense the presence of PU. Therefore CSS is adopted as a reliable and efficient method of spectrum sensing. Cooperative Spectrum Sensing has two stages; sensing and reporting. A CRU makes its local decision in sensing stage and forward that to the FC where final decision has been made using different rules [14].

We have considered the Cooperative Spectrum Sensing to guarantee the higher probability of detection. The performance analysis of Spectrum sensing can be made by Receiver Operating Curves (ROC). We use AND rule for making final decision at FU. Now the probabilities, detection and false alarm can be given by [15].

$$P_d = \prod_{1}^{k_i} (P_d) \tag{9}$$

$$P_{fa} = \prod_{1}^{k_i} (P_{fa}) \tag{10}$$

In CSS all the CRUs will send their local decisions, '1' representing presence of PU and '0' representing absence of PU, then final decision will be taken by FC using AND rule. In AND rule, if all CRUs give their local decision as '1' then final decision will be '1'. This whole process is shown in Fig. 3.

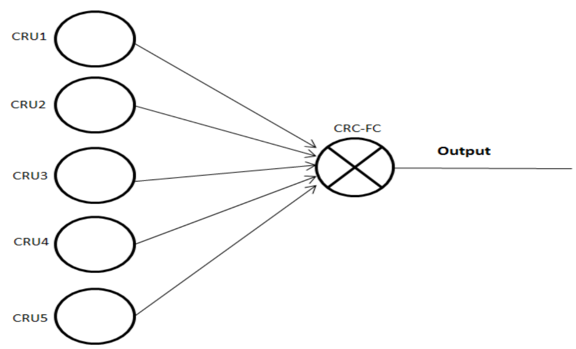

Fig. 3 Model of Cooperative Spectrum Sensing

The final decision will come back to every CRU about presence or absence of PU. Clearly, this will overcome any wrong decision made by any of CRU due to environmental conditions but causes additional overhead.

4. Simulation and Analysis

The detection performance of single CRU and CSS will be evaluated in this section using ROC. The most important parameter contributing in accurate results is SNR (δ). The Fig. 4 shows that detection performance of energy detector is improved by increasing the δ under both AWGN and Rayleigh fading environments with CFAR. The resultant decrease in P_{md} is shown in Fig. 5.

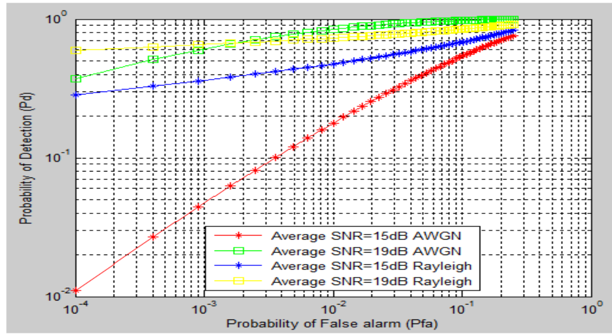

Fig. 4 P_d with different SNR using CFAR

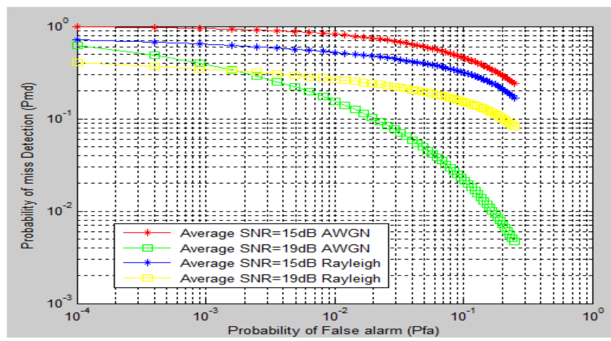

Fig. 5 P_{md} with different SNR using CFAR

It is evident from the result shown in Fig. 4 and Fig. 5 that decrease in P_{md} with higher δ, P_{fa} increases which warrants the trade-off between P_{fa} and P_{md}. Infect, increase in P_{md} means CRU is causing interference for a PU and increasing P_{fa} means a CRU is not utilizing the free spectrum efficiently. However, it is required to avoid interference for a CRN. We prefer low P_{md} over low P_{fa}. P_{fa} approaches to 1 even at very low P_{md}. So to improve the P_{fa} if we avoid CFAR and use CTR in (5), better results of P_{fa} are expected.

An ideal sensing case i.e, P_d become 1 in AWGN channel at 19dB (δ) is shown in Fig. 6 and P_{fa} decreases by taking CTR with an acceptable increase in P_{md} too as shown in Fig. 7. Actually, we have to set our τ such as to get both P_{md} and P_{fa} as low as possible by the applied algorithm

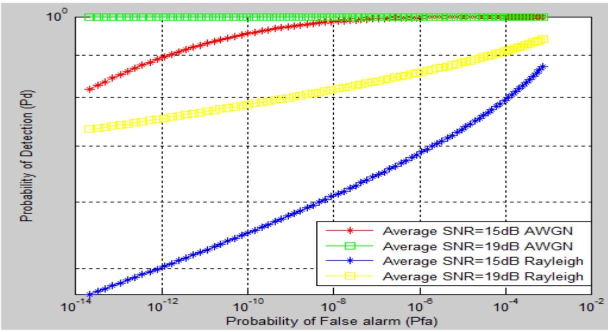

Fig. 6 P_d with different SNR using CTR

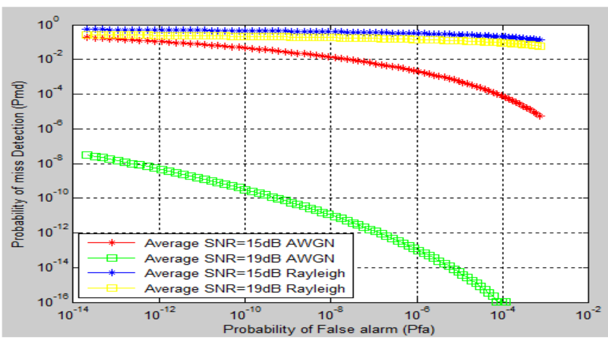

Fig. 7 P_{md} with different SNR using CTR

As explained earlier, with cooperation among nodes we improve the detection performance which is shown in Fig. 8 and Fig. 9. Here also the P_d is nearly equal to 1 by applying CSS in AWGN channel.

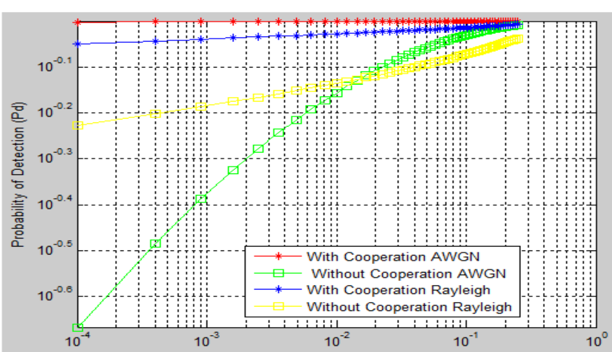

Fig. 8 P_d with Cooperative Sensing

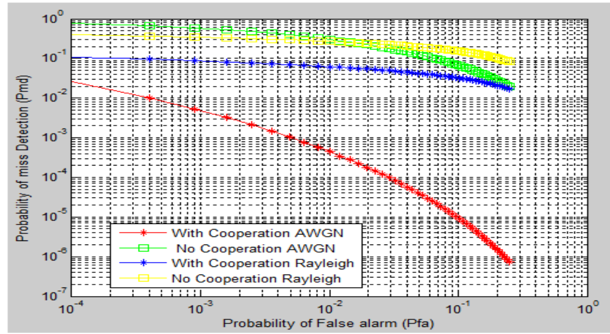

Fig. 9 P_{md} with Cooperative Sensing

From the simulations we can see that the proposed technique of CTR instead of using CFAR provides P_{fa} as low as 10^{-2} as compared to almost 1 for CFAR.

5. Experimental Setup

To verify and validate the simulation results, an experimental setup was arranged. The experimental setup consists of a signal generator, USRP and a Personal Computer (PC). The daughter board of USRP is XCVR2450 which covers the dual band frequency ranges from 2.3GHz to 2.4GHz and 4.9 to 5.9GHz. The whole work is done on 2.4GHz frequency band. A SME06 Signal Generator is connected with an antenna via RF cable for signal transmission and USRP connected with PC using Ethernet cable is our receiver. A GNU Radio software toolkit is used for signal processing of received signal on PC. This is shown in Fig. 10.

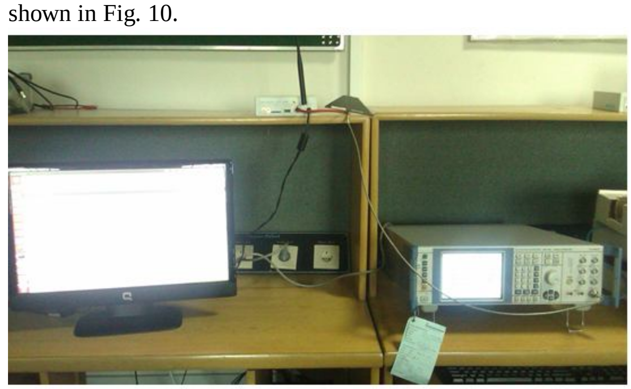

Fig. 10 Experimental test bed

A sine wave with PSK modulation is transmitted by the signal generator using an antenna to USRP, which is seen by GNU Radio on PC. We have taken a USRP source block on GNU Radio at 2.4GHz frequency with 32k sampling rate and makes a FFT plot of received signal with GUI FFT Sink from GNU Radio signal processing blocks. Later the real time input signals and noise are evaluated using Matlab. Similar results are obtained by real time data using USRP.

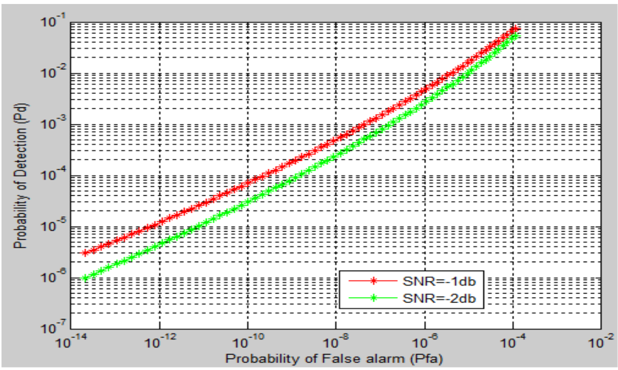

Fig. 11 P_d with different SNR using USRP

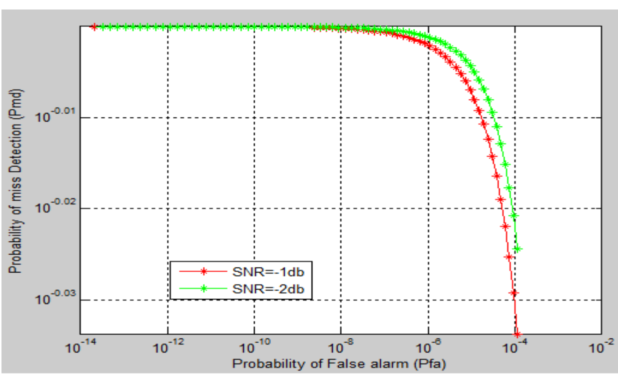

Fig. 11 P_{md} with different SNR using USRP

The δ of received signal is improved by increasing the power level of input signal from transmitter, by which the detection performance increases [16] under AWGN and Rayleigh channel as shown in Fig. 11 which effects decrease in P_{md} in Fig. 12.

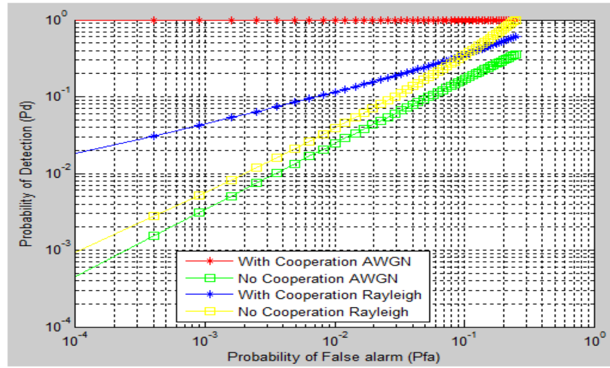

Fig. 13 P_d with CSS using USRP

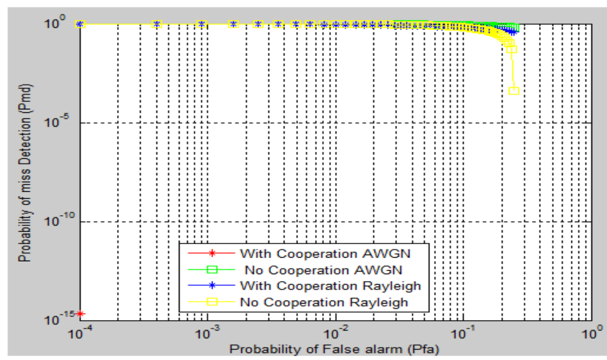

Fig. 14 P_{md} with CSS using USRP

By applying the CSS on real time date, the P_d increases and becomes ideal in AWGN channel as shown in Fig. 13. The P_{md} decreases too, which is shown in Fig. 14.

6. Conclusions and Future Work

The performance of CRN has been evaluated for Spectrum Sensing using energy detector in different environments. It is shown that if δ of a signal is improved then detection performance also enhances but at the same time P_{fa} increases. Then that P_{fa} can be reduced in an ideal environment with filtering and no temperature change at receiver end with CTR. However, practically it is difficult and requires a long sensing time. Thus, CSS has been implemented which provide good results as shown by ROC in our paper. All this comparative analysis has shown that trade-off between P_{md} and P_{fa} is made according to a required practical environment but we can get a reasonable decrease in P_{fa} with an acceptable increase in P_{md} by avoiding the CFAR method.

In future the researchers may find a way to estimate the noise variance with low estimation error to validate the results. The combination of different techniques may also be used for Spectrum Sensing in parallel with CTR technique and then use both the results in Spectrum Allocation process to specific users. We want to get an accurate and more reliable result with low sensing time in order to avoid interference with PU and efficiently utilize the available spectrum.

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Tallataf Rasheed has received her B.S. degree in Electrical Engineering from Government College University Faisalabad and currently has enrolled in M.S. Electrical Engineering in National University of Sciences and Technology, Military College of Signals, Rawalpindi, Pakistan. Her current research interest includes Software Defined Radio and Cognitive Radio.

Adnan Rashdi received his B.Sc, M.Sc and Ph.D degrees in Electrical Engineering from the University of Engineering & Technology (UET), Lahore, Pakistan in 1994, 2003 and 2008 respectively. His research interest includes software defined radios, cognitive radios, wired and wireless multiuser communication systems, signal processing and optimization techniques. He has published many research papers in international journals and conference proceedings. He is a member of IEEE USA.

Ahmad Naeem Akhtar received his B.S. and M.S degree from National University of Sciences and Technology, Military College of Signals, Rawalpindi, Pakistan. He is currently enrolled in Ph. D at same university. His research interests are Software defined radio and Cognitive Radio.