Receiver Operating Characteristic for Variable Threshold and Sample Values using Energy Detection for Secondary user in Cognitive Environment

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ABSTRACT
A cognitive Radio is a current area of research for modern day communication systems design in which spectrum availability is becoming scarcity. In the current scenario various spectrum sensing techniques have been evolved, but till today energy detection remains the most common amongst of the all. In this paper the receiver operating characteristics of the receiver is being studied using the spectrum sensing method in energy detection. The receiver operating characteristic of the receiver is an important parameter to identify the spectrum availability in the cognitive environment and is being studied under the parameters of the probability of detection which is measured with the adaptive threshold values and samples values under various signal to noise ratio.

Keywords
Cognitive Radio, Probability of Detection, Energy Detection.

1. INTRODUCTION
In the current development of the conception of the Cognitive Radio (CR) and the cognitive radio networks there are new areas of research, development, evolution and elaboration. The communication systems have improved drastically due to capabilities of CR and cognitive radio networks. The CR is an ultra smart, nimble device or scheme that senses and detects the environment on its own with the help of sensors and then autonomously adapts and changes the parameters of communication accordingly. This device can be used in the dynamic spectrum access and existence of different wireless networks at same the time, management of interference, intelligent communication, etc. CR presents an answer by using the void holes known as spectrum holes in the spectrum that defines the capable opportunities for the usage of spectrum, in a non-interference manner. This process requires three principle stages: sensing of spectrum, analysis of spectrum and allocation of the spectrum. By spectrum sensing we mean to obtain the characteristics and usage of spectrum in various dimensions such as space, time, frequency, coding and many more. Thus finding out which and what types of signals occupy the spectrum band at that time. Clearly, the CR model and paradigm presents a lot of new challenges and hindrances in the design of protocols, power efficiency and management of spectrum, quality of service, security etc.[15] The job of sensing the spectrum proves a very cumbersome process. In current times, in order to sense the spectrum which exists, we do have a number of techniques available. Some of these spectrum sensing techniques and methods are energy detection method, cyclo-stationary technique, feature detection technique, wavelet transform method etc.[1]

In the paper the emphasis is being given to the approach that the probability of detection of the secondary user which has been have defined is compared with the theoretical probability of detection. In this process two approaches for laying the focus on the topic are taken for building up the hypothesis for the probability of detection. In the first approach the method calculates the probability of detection of the user keeping the number of samples/cycle (N) same and changing the threshold value which has been made adaptive. The number of samples for which the incoming signal is sensed under the different signal to noise ratio scenarios is taken as 200 for which are the calculation has been done.

In the next approach the number of samples/cycle of the signal are changed and calculated the probability of detection of the user under a fixed signal to noise ratio level. The results obtained are promising in the nature as the variation in the threshold value has increased the probability of detection for the secondary user in the changing signal to noise ration environment. Moreover the results also lays a strong statement that the number of samples/cycle of the signal also changes the probability of detection which is very well established from the results which has been discussed in the paper. The main focus of this paper is to discuss the receiver operating characteristics of the energy detector under various conditions. The receiver operating characteristics are plotted between the probability of detection Vs the probability of false alarm under two conditions. In the first condition the signal to noise ratio is changed from -10 dB to +10 dB and in the second phase the number of samples/cycle N are changed from 10, 6 and 14. The probability of detection is calculated for the above and is plotted Vs the probability of false alarm to check the receiver operating characteristics of the approach used.

2. RECEIVER OPERATING CHARACTERISTICS
In statistics, a receiver operating characteristic (ROC), or ROC curve, is a graphical plot that illustrates the performance of a receiver system with the change is the threshold value and its signal to noise ratio.

In a Receiver Operating Characteristic (ROC) curve the true positive rate is plotted in function of the false positive rate for different scenarios. The receiver operating characteristic curve represents a pair corresponding to a particular decision threshold. In order to transmit a valid information from one place to another we make use of different devices, various devices, various medium of transportation, different ranges of frequency and a lot many factors and parameters are taken into account.[One of the most important factors is the probability of detection while using the energy detector method along with the signal to noise ratio in the communication systems while transmitting the information from the sender to receiver. Signal to Noise may be defined as a measure that compares the level of a desired signal to the level of background noise. It may be also defined as the ratio of power of signal to the power of noise. It is measured in decibels (dB).

$$\text{SNR} = \mathbf{P}_{\text{signal}} / \mathbf{P}_{\text{noise}} \quad (1)$$

where P is the average power.

The SNR can be also defined in terms of amplitude of signal or the variance parameters.

$$\text{SNR}=\boldsymbol{\sigma}^2_{\text{signal}}/\boldsymbol{\sigma}^2_{\text{noise}} \quad (2)$$

where σ is the variance.

$$\text{SNR}=\mathbf{A}^2_{\text{signal}}/\mathbf{A}^2_{\text{noise}}. \quad (3)$$

where A is the amplitude of the signal.

All the calculations and measurements in real are affected by the noise. This noise is called the electronics noise but the source of the noise can also be included and taken into consideration from other external events and processes. These include wind, vibrations, and gravitational attractions of the moon, variations of temperature, variations in humidity and some other variations. Effect of noise also depends on what quantity is measured and also on the sensitivity of the measuring device. The noise can often be controlled by simply controlling the environment[9]. However, it can be greatly reduced when the characteristic of the noise are known to us or when the noise characteristics are different from the signal characteristics then it is possible to filter it out or alternatively we can process the signal. If the noise present is random in nature and the signal that needs to be measured is constant or periodic in nature, then it is possible to increase the SNR by taking the average value of the measurement. Here, by doing so the noise is reduced as the square root of the number of averaged samples. Ideally any spectrum sensing algorithm should select the hypothesis (H_0) when the primary user is absent and hypothesis (H_1) when it is present. Practically, spectrum sensing algorithms are prone to errors and their performance depends on various factors such as the decision threshold, received SNR, Total number of sample values (sensing time), channel conditions etc.

Probability of false alarm is the probability that the spectrum sensing algorithm declares that H_1 is true, when the primary user is actually absent. From the secondary user perspective, increase in false alarm will reduce the spectrum opportunities for them. Therefore, it is important to control the probability of false alarm for efficient secondary user spectrum utilization. In this paper the probability of detection for the secondary user Vs the probability of false alarm which is ROC curve is plotted for the adaptive threshold values and number of samples/cycle.

3. SPECCTRUM SENSING USING ENERGY DETECTION

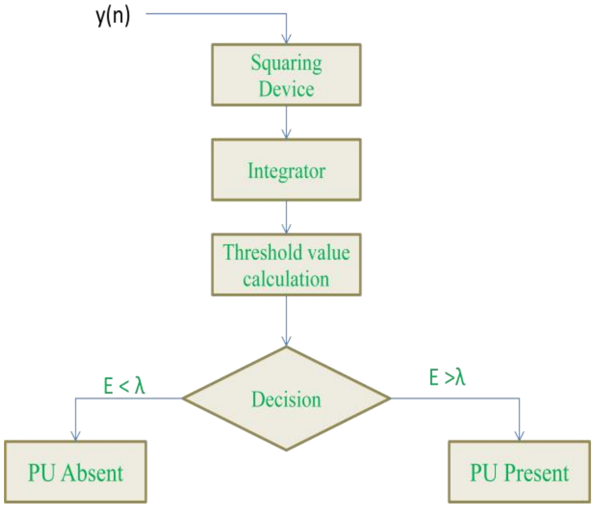

Figure 1 Spectrum sensing using energy detector

The received signal is of the following form:

$$Y(n) = S(n) + N(n) \quad (4)$$

Where, S is the signal component, N is the noise component in the signal received.

The energy calculated by the Energy Detector is given as below:

$$\text{Energy} = \text{abs(Y)}^{\wedge 2} \quad (5)$$

This energy is then given to integrator to obtain the average values which are then compared with the threshold value to make the decision. The principle of the working here is simple that the number of samples per cycle can be changed for the signal and can be increased or decreased [5]. The number of samples per cycle of the signal is important in the analysis of the probability of detection. The effect on the change on the number of samples per cycle is studied in this thesis and a conclusion has been drawn [8]. The number of samples per cycle of the signal has clearly been investigated with the variable signal to noise ratio at the receiver.

3.1 Threshold Value Calculation

The threshold value is an important parameter for decision making in the energy detection method. The receiver's output depends upon how accurate the decision has been made for the received signal. The received signal is of the form:

$$y(n) = w(n); \qquad for\ Ho$$
$$= s(n) + w(n); \qquad for\ H1$$

where w(n) is the noise, s(n) is the signal from PU, H_o is the hypothesis corresponding to absence of Primary User, H_1 is the hypothesis corresponding to presence of Primary User. The basis of calculation starts with the measurement of energy obtained over the band of interest which is given by:

$$〚T〛\_N\,(y) = 1/N\ \{[\sum〚|\,Y(n)|^2]〛 \quad (6)$$

and which lays the foundation for the hypothesis H_o and H_1.

The equation for probability of false alarm is given as:

$$P\_f = P\,[T\_N\,(y) > \lambda\,;\,Ho] \quad (7)$$

This can be rewritten in terms of Q-function as

$$P\_f \;=\; Q[(\lambda - 1)\sqrt{N}] \qquad (8)$$

P_f , N are known and value of λ (threshold is obtained which is adaptive and depends on the number of samples.

The equation for probability of detection is given as:

$$P\_d \;=\; P[T\_N(y) \;>\; \lambda;\; H1] \qquad (9)$$

This can be rewritten in terms of Q-function as

$$P\_d \;=\; Q[(\lambda - S - 1)\sqrt{(N/(2S+1))}] \qquad (10)$$

N and S are known and value of P_d is obtained. The probability of detection is compared with the theoretical probability of detections which is the standard equation of the probability of detection under AWGN channel.

$$Pd_{theory\,(i)} = marcumq\big(sqrt(snr_{avg} * 2 * m), sqrt(Th(i)), m\big) \qquad (11)$$

The results which are simulated probability of detection and theoretical probability of detection under the adaptive threshold and variable number of samples/cycle are obtained and are plotted.

4. SIMULATION RESULTS

The Receiver operating characteristic of the energy detector is important for the analysis of the spectrum availability. The ROC curve is plotted between the probabilities of detection Vs probability of false alarm. In the results obtained the simulated probability of detection and theoretical probability of detection is plotted against the probability of false alarm. The approach followed for plotting the ROC curve is plotting the above probabilities under the condition of changing number of samples/cycle (N) and keeping the signal to noise ratio fixed for one set of results. The figure 2, 3 & 4 are plotted for the SNR value which is constant at -10 dB for the number of samples/cycle N= 10, 6 & 14 respectively. These graphs are also plotted for the same conditions of simulated and theoretical values of the probability of detection. The probability of false alarm is incremented in the steps from 0 to 1. The probability of detection is plotted against probability of false alarm for analyzing the performance of the receiver under the conditions of adaptive threshold and variable number of samples/cycle.

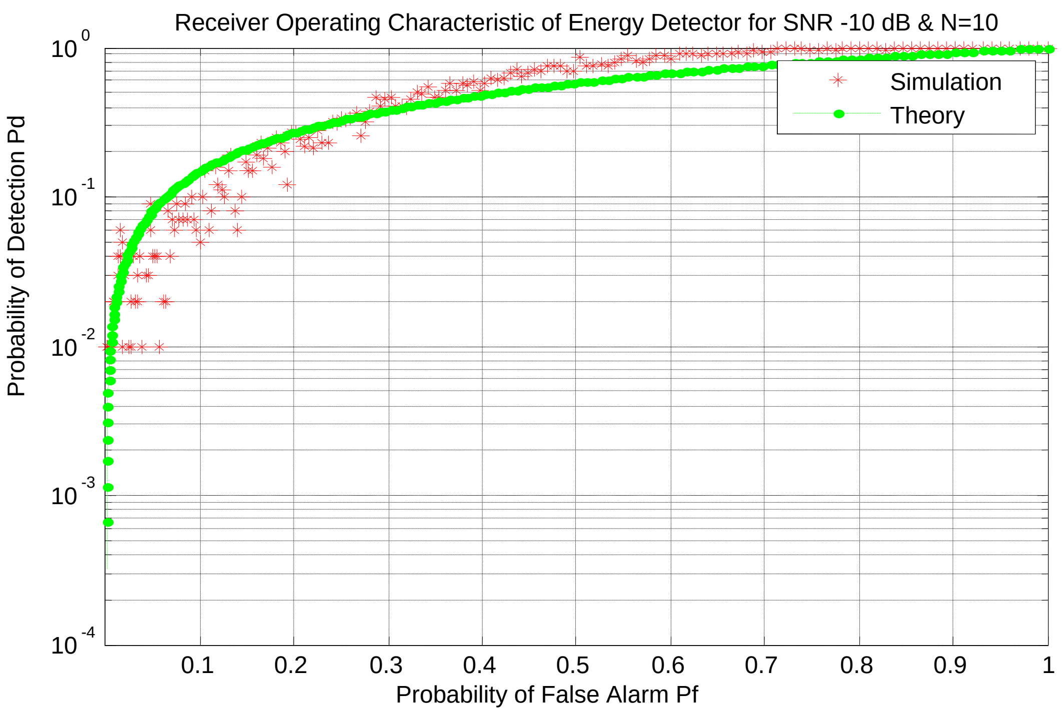

Figure 2 Probability of Detection Vs Probability of False alarm for SNR =-10 dB and N=10

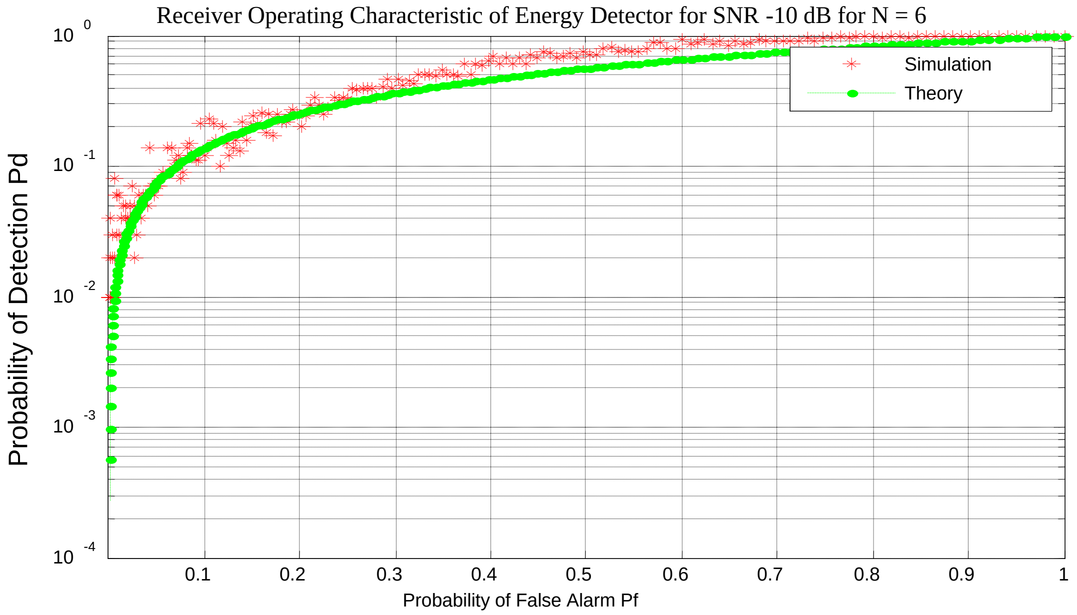

Figure 3 Probability of Detection Vs Probability of False alarm for SNR =-10 dB and N=6

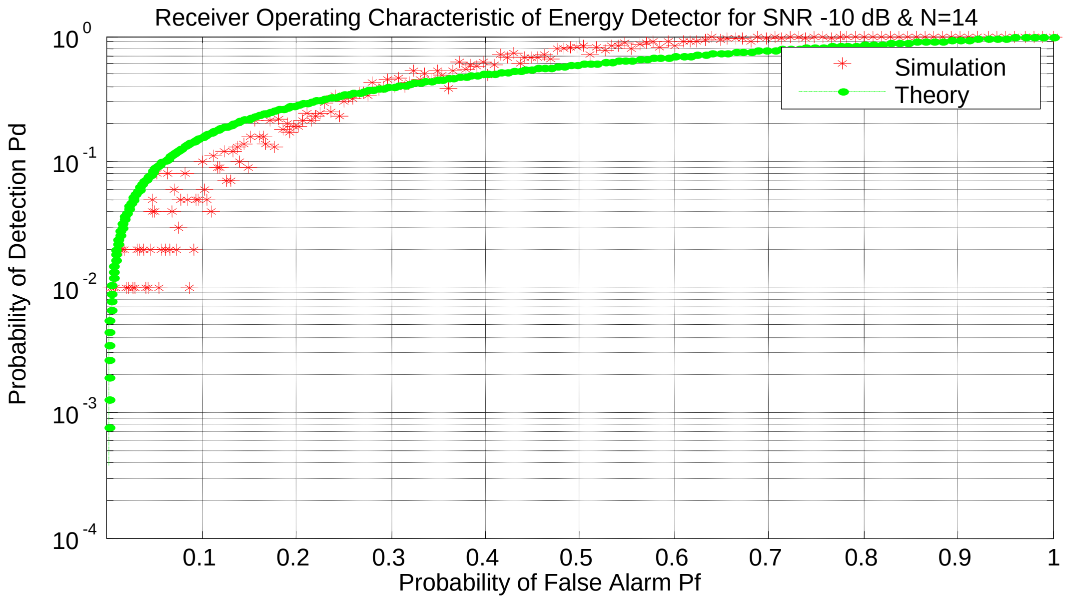

Figure 4 Probability of Detection Vs Probability of False alarm for SNR =-10 dB and N=14

The ROC curve in the following figures from 5 to 7 are plotted for the SNR values = -5 dB for the same conditions of samples/cycle N= 10,6,14 respectively.

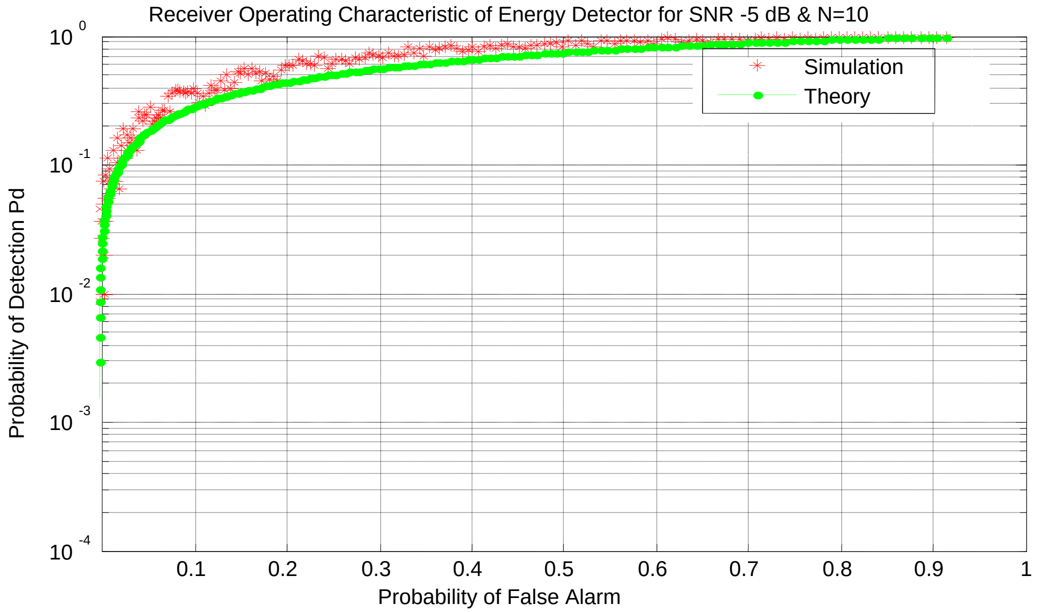

Figure 5 Probability of Detection Vs Probability of False alarm for SNR =-5 dB and N=10

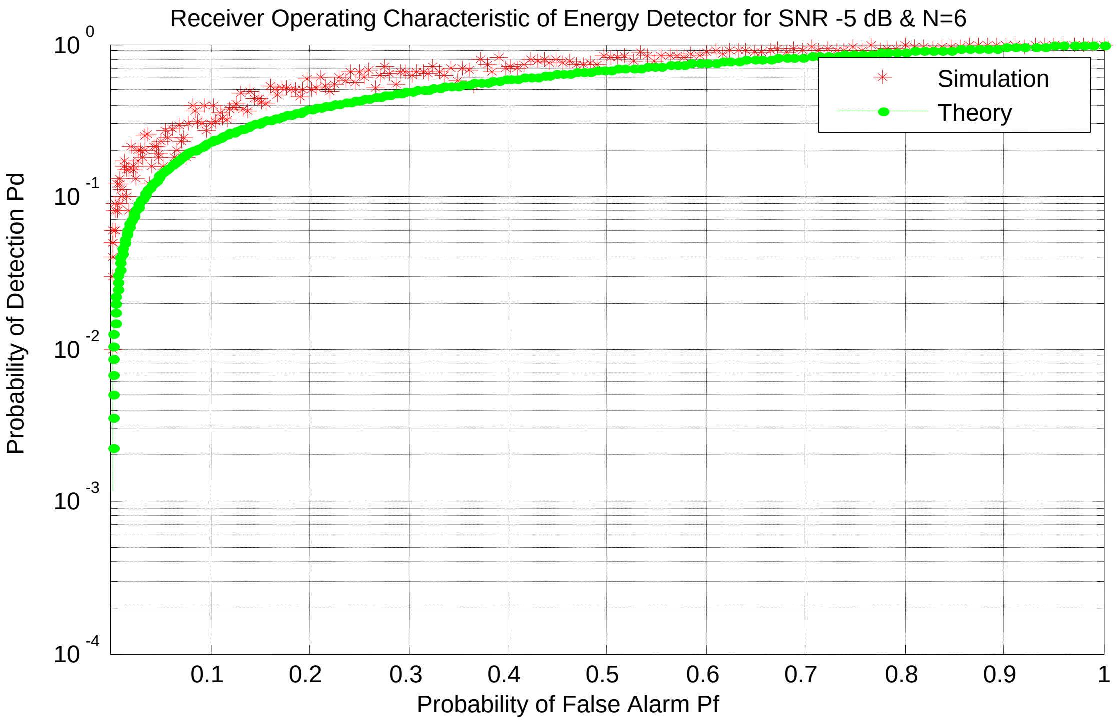

Figure 6 Probability of Detection Vs Probability of False alarm for SNR =-5 dB and N=6

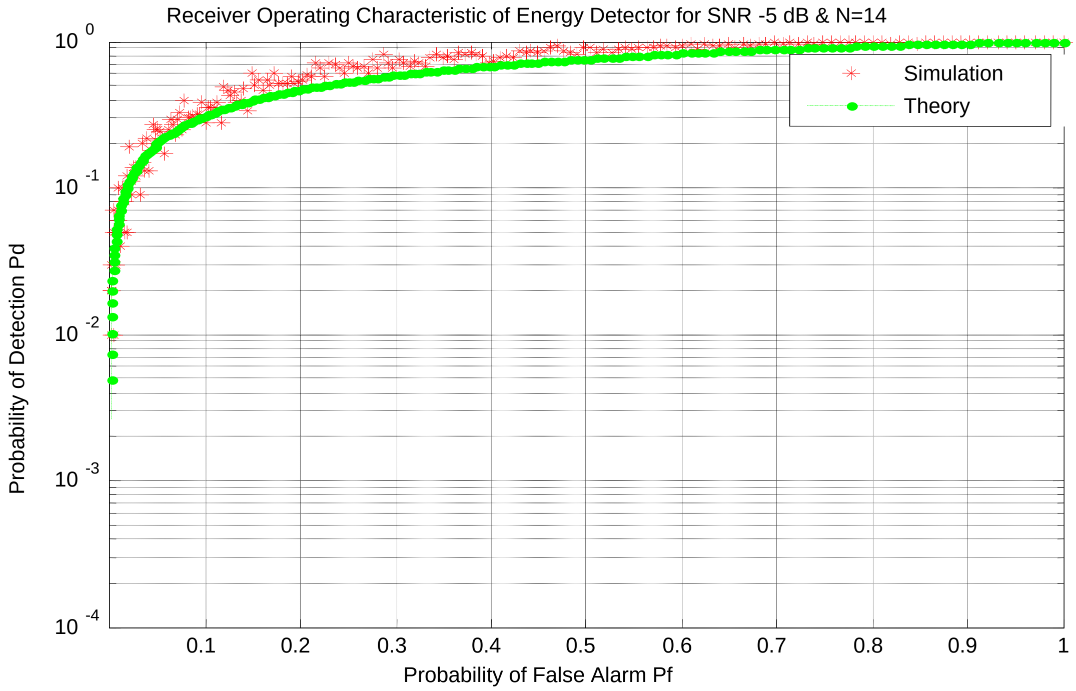

Figure 7 Probability of Detection Vs Probability of False alarm for SNR =-5 dB and N=14

The ROC curve in the following figures from 8 to 10 are plotted for the SNR values = -3 dB for the same conditions of samples/cycle N= 10,6,14 respectively.

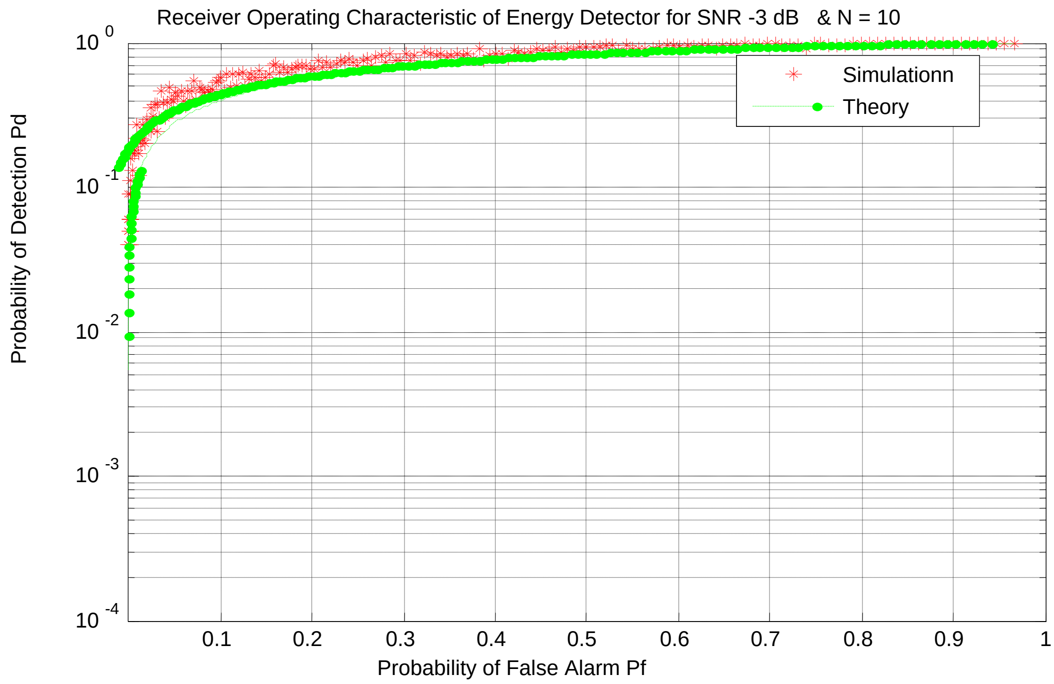

Figure 8 Probability of Detection Vs Probability of False alarm for SNR =-3 dB and N=10

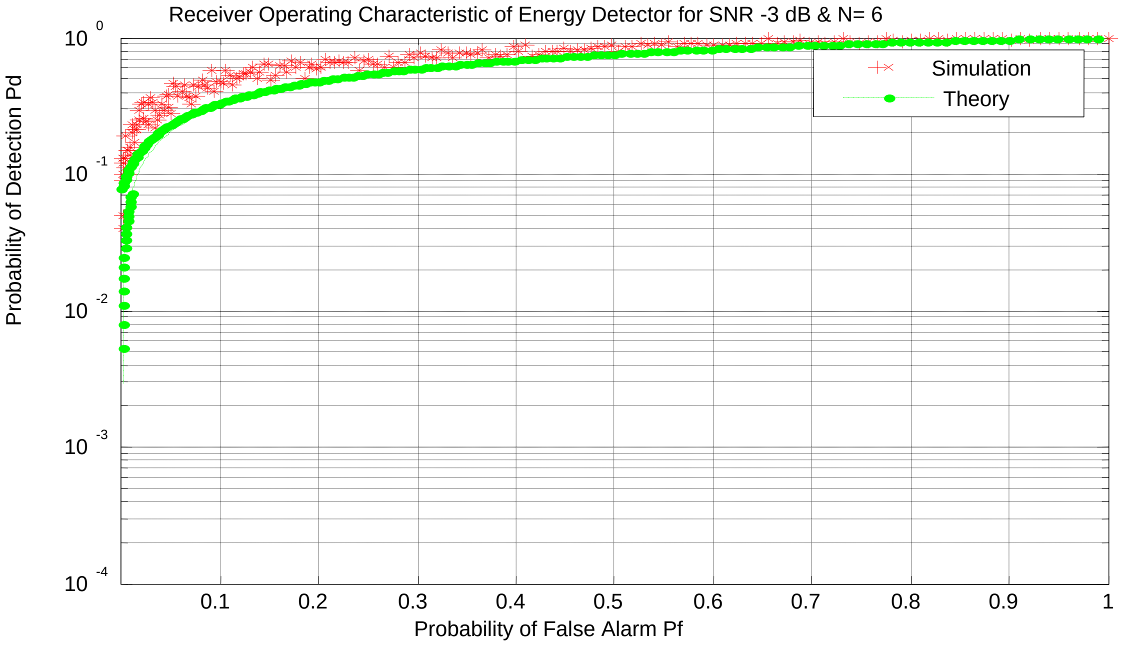

Figure 9 Probability of Detection Vs Probability of False alarm for SNR =-3 dB and N=6

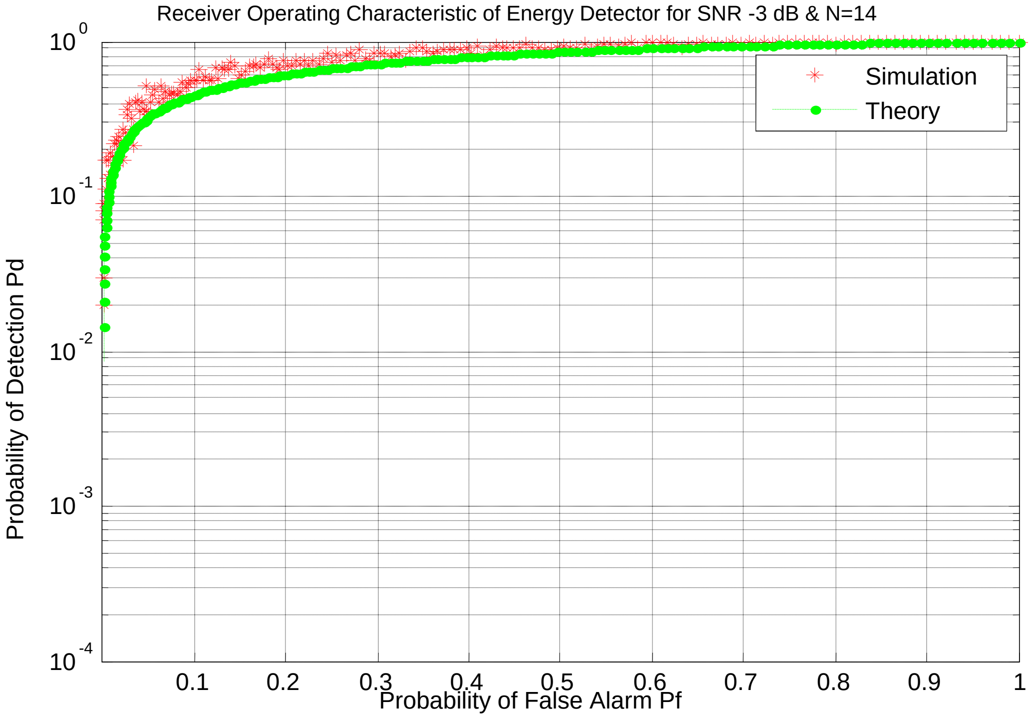

Figure 10 Probability of Detection Vs Probability of False alarm for SNR =-3 dB and N=14

The ROC curve in the following figures from 11 to 13are plotted for the SNR values = 3 dB for the same conditions of samples/cycle N= 10,6,14 respectively.

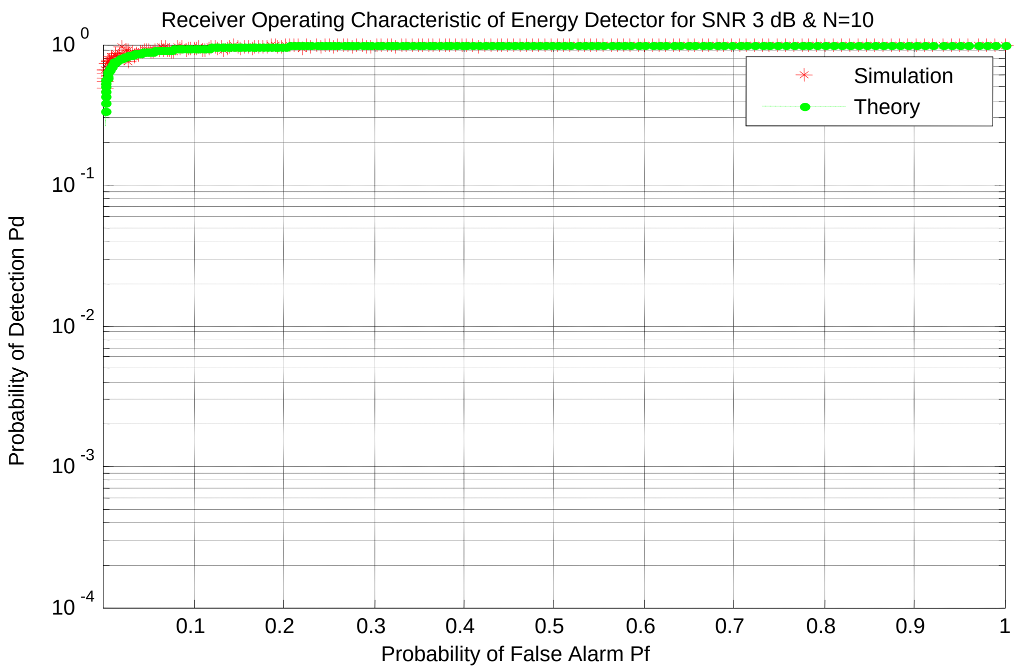

Figure 11 Probability of Detection Vs Probability of False alarm for SNR =3 dB and N=10

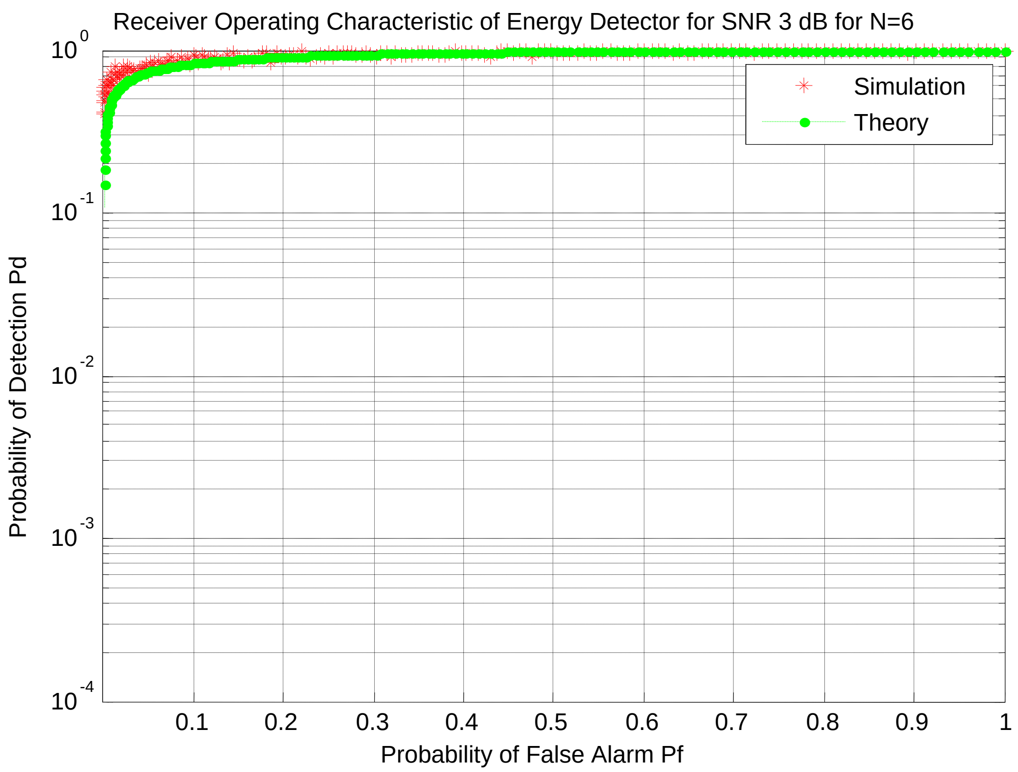

Figure 12 Probability of Detection Vs Probability of False alarm for SNR =3 dB and N=6

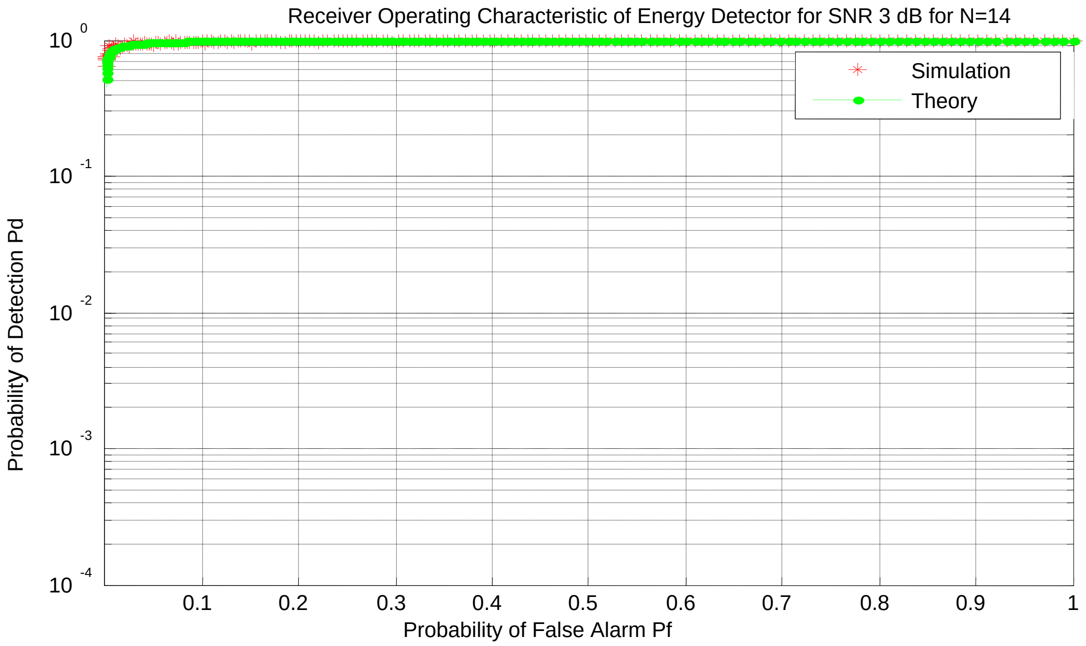

Figure 13 Probability of Detection Vs Probability of False alarm for SNR =3 dB and N=14

The ROC curve in the following figures from 14 is plotted for the SNR values = 5 dB for the same conditions of samples/cycle N= 10

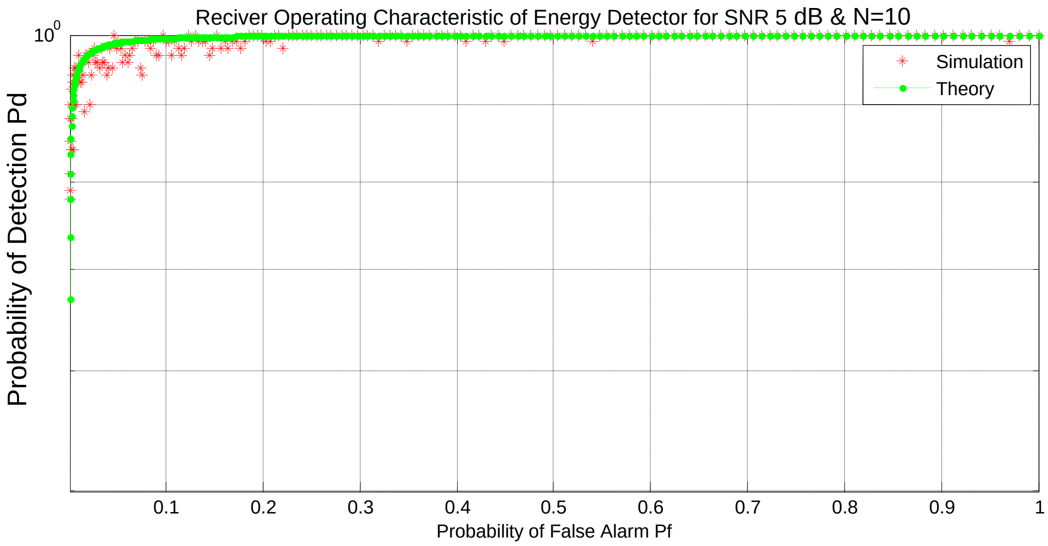

Figure 14 Probability of Detection Vs Probability of False alarm for SNR =5 dB and N=10

The ROC curve in the following is plotted for the SNR values = 10 dB for the same conditions of samples/cycle N= 10.

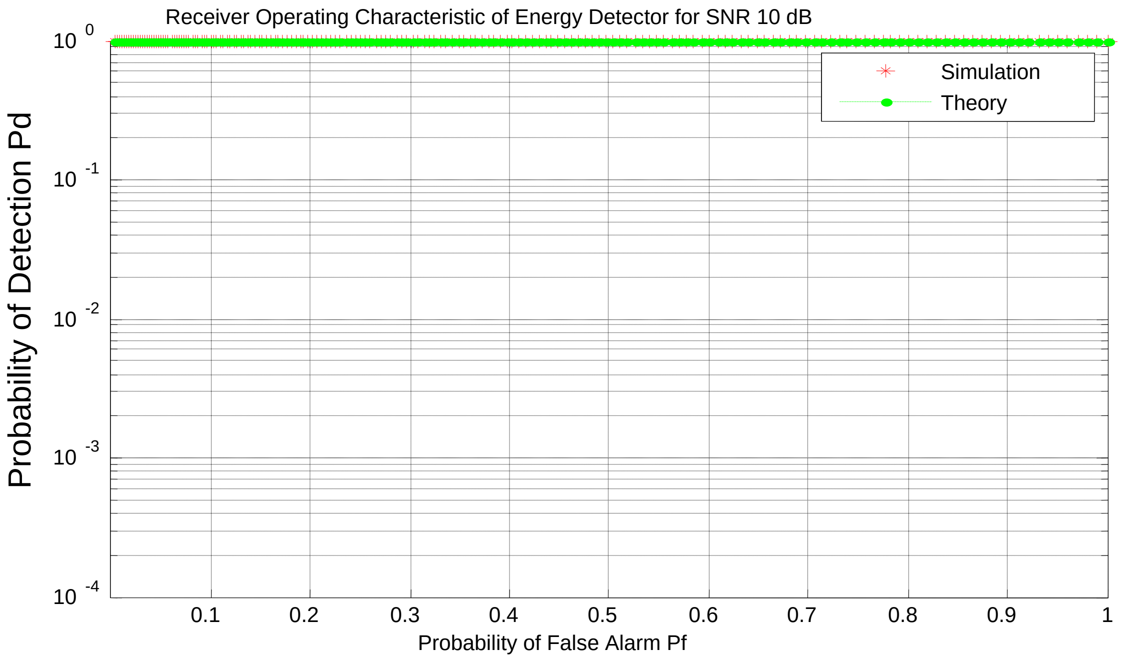

Figure 15 Probability of Detection Vs Probability of False alarm for SNR =10 dB and N=10

5. CONCLUSION

It has been observed in this paper that the simulated probability of detection show better response to the theoretical probability of detection for low number of sample/cycle values and lower SNR values. The simulation done for N=6 sample/cycle shows that the simulated probability of detection has better result than the theoretical probability of detection for lower SNR values at lower probability of false alarm which is evident from the figures 3, 6, 9, 12 and is an indicator of the spectrum availability for that channel. It is also shown that if the number of sample/cycle N are increased from N=10 to 14 than the simulated probability of detection show poor response to the theoretical probability of detection at lower probability of false alarm for the lower SNR values. However, if the SNR value is increased from -10 dB to + 3 dB than the simulated probability of detection show better response than the theoretical probability of detection at low level of probability of false alarm. The probability of false alarm checks the hypothesis H_o which lays that the primary user is absent and the signal received is a noise for the secondary receiver. The probability of detection attains its maximum value for low values of probability of false alarm in case of higher values of SNR. This observation leads to the conclusion that the number of samples/cycle is an important parameter for the detection of the signal in case of changing threshold values. The sensing time plays an important role in the detection of probability but the noise uncertainties and simulation of the spectrum creates a bound, which can be future work to improve the probability of detection. The future scope which can be laid down here is that the number of samples/cycle are increased than how the probability of detection can be improved for the low level of the probability of false alarm. The future scope can be comparison of different probability of detection methods for various spectrum sensing algorithms where the numbers of samples and threshold value are made adaptive.

6. REFERENCES

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