# CSS using Energy Detector in AWGN and Flat-Fading Channels in Cognitive Radio Networks: A Complete Analysis

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***Abstract: In this work, various spectrum sensing methods and algorithms are analyzed and their performance is been evaluated based on the different values of probabilities as obtained through MATLAB simulations. The work is been started from the analysis of the simplest single user sensing to advanced cooperative spectrum sensing and is further extended to CSS in AWGN noise and flat-fading channels. The results indicates that advanced cooperative spectrum sensing gives much better sensing decisions as compared to the results obtained by simulating single user sensing method. Simulation results obtained shows that Pd increases with Pf and also shows good values for SNR more than 0 dB. Also the Pd increases from 0.7 to 0.84 as we go from single user detection to CSS.***

***Keywords: Cognitive Radio Networks (CRN), Co-operative Spectrum Sensing (CSS), Energy Detector (ED), Primary User (PU), Secondary User (SU), Signal Noise Ratio (SNR).***

## I. INTRODUCTION

Optimum utilization of overall spectrum is major necessity for wireless systems, since spectrum is a finite resource. The electromagnetic wave frequency between 10 MHz and 6 GHz are utilized for wireless communications purposes. For greater demand and excessive usage utilization of radio spectrum, economical use of available licensed spectrum is becoming more and more decisive. To solve the problem of the regular requirement for spectrum under-utilization, cognitive radio (CR) is the upcoming modern trend that realizes the dynamic allocation of the spectrum problem. As per the increasing demand of wireless technology in the current scenario, more spectrum is required. But recently there is scarcity of the spectrum for meeting the new challenge of requirement. However, different researches shows, the actual licensed spectrum is not utilized properly and this blank unused part of the spectrum is known as *white spaces* or *spectrum holes.* Cognitive radio defines two types of spectrum users- PU and SU.

- *Primary users* – they are the legal owners of the assigned spectrum. Such users are the main subscribers of the spectrum. [2]
- *Secondary users* – they are the unauthorized users who are not the legal owners of the spectrum. However, they can access the channel, whenever it is free, such that they don't disturb the primary users. [2]

To use the free available channel, the SUs should be capable enough to sense the spectrum whether it is occupied by the PU or it is free to be used by the SU. It should be able to change its radio parameters accordingly in order to use the free space.

In 1999, Mitola and Maguire invented Cognitive Radio. The cognitive radio may be defined as follows:

"Cognitive radios are smart wireless devices which knows its surrounding parameters very well and act accordingly through learning from its environment and adapt to the changes in the incoming RF signal by adjusting its corresponding operating parameters. It deals with two primary jobs- highly reliable communication and optimum utilization of the overall spectrum.

In fact cognitive radios are the means of utilizing the spectrum to its whole by exploring the existence of spectrum holes. Cognitive radio is also defined to be devices which do radio spectrum sensing, analyze and identify the spectrum holes and finally operate in the identified holes.

The FCC recently conducted studies and found that the available bandwidth is assigned to some primary servers, which they never utilize to their fullest. The studies further showed that the percentage utilization of the 0-6 GHz bandwidth ranges from 15 % to 85%. The research indicates that many bands of the radio spectrum are not completely occupied at different times in different physical areas of the world.

The Principles of Cognitive Radios are as follows:

- *Spectrum Sensing:* It is to sense whether there are other users present on the channel or not. This spectrum sensing give required information for spectrum sharing.
- *Spectrum Decision*: It is done in the presence of noise, the secondary users decide which part of the unused spectrum it will use from the sensing information provided by the secondary users however it is not an easy task as the secondary users provide only casual knowledge of the spectrum usage.

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- *Spectrum Management*: It is to select the best available free spectrum to facilitate the user requirements.
- *Spectrum Sharing*: Finally the decision is taken to allot the free spectrum among the secondary users. Spectrum sharing completely relies on the spectrum management as a free slot may be usable for a specific secondary user and not for the others.

The cognitive radio recognizes the free time slot when a particular licensed band of the spectrum is blank at certain point and to use this time slot for the transmission of the CR user without disturbing or interfering to the license holder.

The sensing of the spectrum is done by a limited number of CRs that send their local decisions (about the availability of the PU) to a common hub called the decision fusion (DF) centre.

The DF selects the channel for sensing and combines the received local decision to decide about the availability PU. After arriving at the decision about whether the PU is present or absent, the DF reports back the same to the CR users. Normally the CRs are shadowed and their performance is degraded by severe multipath fading. Due to which sometimes the CR is not able to see that a PU is present and tries to use the channel which primary user is already using this is known as *hidden primary user problem*. To overcome this problem and to improve the sensing accuracy, a technique known as *Co-operative Spectrum Sensing* (CSS) is used. CSS increases the probability of detection of PU signal.

*Cluster based CSS*: A group of CRs in a network is known as a cluster. Each cluster has a cluster leader which takes the local sensing decisions from the CRs in its cluster and reports it to the DF.

## II. TYPES OF DETECTORS

There are several types of spectrum detecting methods used for deciding whether the primary user is using the channel or not.

A number of detection methods are explained in literature to search for the blank holes. However spectrum sensing is highly challenging due to the following reasons.

- The required SNR may be very low for detection.
- Shadowing and Multipath fading are the limiting factors for wireless channels.
- The noise is random and changes with time and place which makes it difficult to predict the noise power.

These challenging factors give a wide range of research in this field. The generally used spectrum detectors are signal are Energy Detection (ED), Matched Filter Detection (MFD), Cyclostationary Feature Detection (CFD), Wavelet Detection (WD), Covariance Detection (CD) etc.

### A. Energy Detector

- Energy detector is the easiest method of sensing the spectrum as a prior knowledge of the PU signal is not necessary in this case.
- It is non-coherent sensing technique.
- The received samples are compared to a predefined threshold. If the energy of the received incoming signal is above the threshold, the decision is taken in the favor of the occupancy of the channel. While if energy of the received incoming signal is below the threshold, it is assumed that the channel is idle.

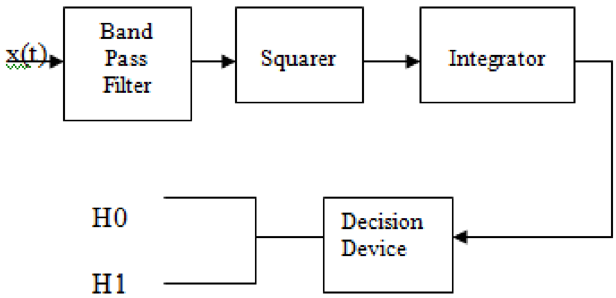


**Fig. 1 Block Diagram for Energy Detection [7]**

Fig. 1 shows the basic diagram for energy detector. Here input signal at the receiver is passed over a band pass filter to decide the desired frequency. The output from the band pass filter is squared and then integrated over the time interval. The output from the integrator is compared with the predefined threshold and the decision is taken whether the PU signal is present or not.

**Other Spectrum Sensing Techniques:**

Multi-taper spectrum estimation, Collaborative spectrum sensing, Multi- hop spectrum sensing, OFDM and MIMO spectrum sensing techniques are also used.

The primary focus of this paper is to analyze and measure the performance metrics for energy detection sensing technique.

## III. SYSTEM MODEL

### A. Energy Detection by Single User

When the CR sensor knows nothing about the signal transmitted by other PUs in a particular frequency band of concern, the best it can do, is to measure the energy present in that band. If no PU is present, the CR sensor measures only the noise energy, whereas if the PU is present, the CR sensor will measure signal plus noise energy. The decision whether a signal is present or not can be formulated as a hypothesis testing problem. In a particular channel, the received signal is measured as

$r_n = n_n$ H0: noise received (Eq. 1)

$r_n = hs_n + n_n$ H1:noise-plus-signal received (Eq. 2)

Furthermore, h is channel gain and $n_n$ is the observed noise and $s_n$ is the signal.

H0 and H1 are two hypotheses between which the sensor has to decide. The received signal samples can be averaged over a number of time instances N, so that the decision variables

$$y = \sum_{n-1}^{N} |r_n|^2 \qquad \text{(Eq. 3)}$$

are used. If the number of samples are large, y tend to be Gaussian random variables, with mean and variance given as below:

$$E\{ y \} = \begin{cases} N\sigma_n^2 & ,H0 \\ N[\,|h|^2 + \sigma_n^2\,] & ,H1 \end{cases}$$

$$\sigma_y^2 = \begin{cases} 2N\sigma_n^4 & ,H0 \\ 2N\sigma_n^4\,[2\,|h|^2 + \sigma_n^2\,] & ,H1 \end{cases}$$

The decision rule is $y \underset{H0}{\overset{H1}{\gtrless}} \lambda$, (Eq. 4) where λ is the threshold.

Based on this decision, the following parameters are defined:

- **Probability of Detection (Pd)**: If the decision variable y is above the threshold, it means the PU signal is present. The probability of this event is called Pd.
- **Probability of False Alarms (Pf)**: If the decision variable y is above the threshold and it appears that the PU signal is present, when only noise is present, it is known as *false alarms*. The probability of such an event is called Pf.
- **Probability of Miss Detection (Pm)**: if the PU signal is present but the decision variable y remains below the threshold and it appears as if the PU signal is not present, it is known as *missed detection*. The probability of such an event is called Pm.
- **Probability of Error (Pe) or Total Error Rate**: It is the sum of Pm and Pf.

Let $\sigma_s^2$ and $\sigma_n^2$ be the transmitted and signal power and noise power respectively and assuming $\sigma_n^2 = 1$

$$\gamma = \sigma_s^2 / \sigma_n^2 = SNR \qquad \text{(Eq. 5)}$$

then

from [14], it can be seen that

$$Pf = P(Y > \lambda | H0) = \frac{\Gamma(m, \lambda/2)}{\Gamma m} \qquad \text{(Eq. 6)}$$

$$Pd = P(Y < \lambda | H0) = Q(\sqrt{2\gamma}, \sqrt{\lambda}) \qquad \text{(Eq. 7)}$$

$$Pm = 1 - Pd \qquad \text{(Eq. 8)}$$

$$Pe = Pm + Pf \qquad \text{(Eq. 9)}$$

Where Γ = gamma function and

Q = Marcum Q-function.

### B. Cooperative Spectrum Sensing (CSS)

Suppose a CRN consists of K number of secondary users (SU), a primary user (PU) and a fusion centre (FC). Each CR does individual sensing and decides whether the PU is using the channel or not. The individual sensing decisions are reported to the hub, which takes the final decision about whether the PU is present or not.

## IV. SIMULATION DETAILS

### A. Simulation Parameters

Following assumptions are made for the simulation.

**Table 1: Simulation Parameters**

| S.N. | Parameters | Specification |
|---|---|---|
| 1. | Number of Samples | 1000 |
| 2. | Number of Iterations | 10,000 |
| 3. | SNR (dB) (γ) | -25 to 25 |
| 4. | Noise | AWGN |
| 5. | Fading | Rayleigh |
| 6. | Number of SU | 5 |
| 7. | Number of PU | 1 |
| 8. | Number of FC | 1 |
| 9. | Modulation | BPSK |
| 10. | Prob. of False Alarm (Pf) | 0 to 1 |
| 11. | Threshold (λ) | Depends on Pf |

### B. Simulation Model

To demonstrate, the above system model is simulated in MATLAB. The implementation follows the following steps:

- Generated a random signal $s_n$ with 1000 samples.
- Generated a random noise signal $n_n$ with 1000 samples.
- Transmitted the signal and the received signal at a single CR: $r_n = hs_n + n_n$ is determined.
- The threshold λ is calculated using a fixed value of Pf.
- The decision variable Y is calculated according to Eq. 4.
- The decision is taken whether the channel is busy with the PU or idle.
- The process is repeated 10,000 times to get the required probabilities.
- Various graphs between the different parameters (Pd, Pf, Pm, Pe, SNR) are plotted.
- Above steps are repeated for 5 CRs to demonstrate the effect of cooperative spectrum sensing.
- Various plots are drawn for CSS and single user energy detection techniques.
- The energy detection is also evaluated considering flat fading channel: Rayleigh fading as is compared with AWGN channel.
- At every instant the simulated results are compared with the theoretical results obtained by using the analytical formulae.

## V. RESULTS AND ANALYSIS

The algorithm based on above model is simulated in MATLAB. For the performance evaluation, we have assumed that the CRN consists of 1 PU, 5 SU and 1 FC. The number of samples handled by each SU is 1000, also 10,000 simulations are done and the following results are obtained. Firstly, we present the results for single user energy detection. Secondly, to show the difference between single user sensing and co-operative spectrum sensing, the results are plotted between the two. Finally, CSS in AWGN noise and flat-fading channel is considered and the results are as follows.

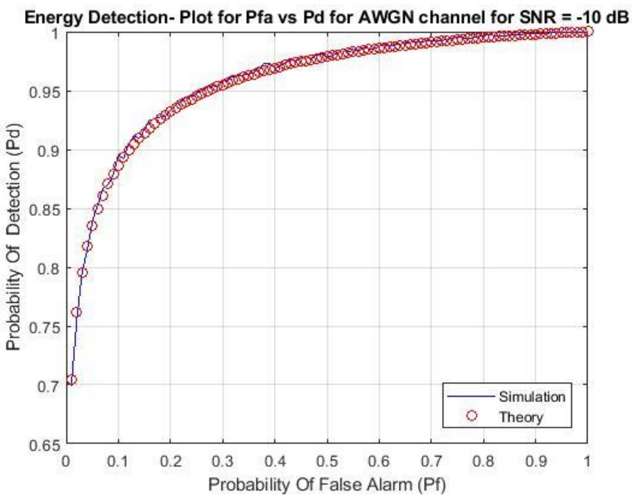


**Fig. 2 Plot between Pd and Pf for Energy Detector**

Fig 2 shows that the Pd increases with Pf. This is for the case when a single user is trying to sense the channel at SNR = -10 dB. From the plot, we can say that as detection capability increases the false alarms, indicating wrong sensing information, which may be upto 1.

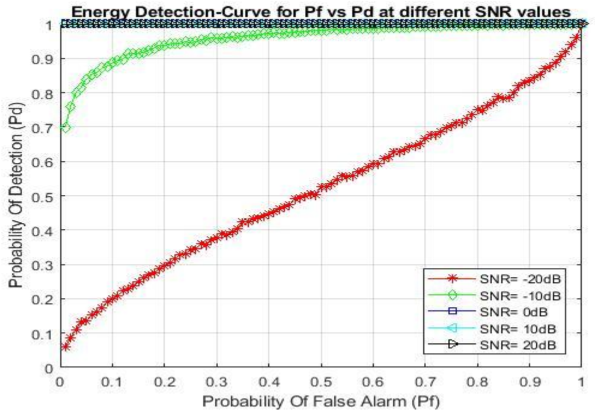


**Fig 3 Plot between Pd and Pf at different values of SNR**

Fig 3 shows that at SNRs below 0 dB, the Pd increases as Pf increases, which is satisfactory at SNR=-10 dB. At SNR = 0 dB, it approaches 1, even if Pf = 0. Above 0 dB, the value of Pd remains unchanged and the graphs overlaps for SNR = 10 dB, SNR = 20 dB and positive values of SNR.

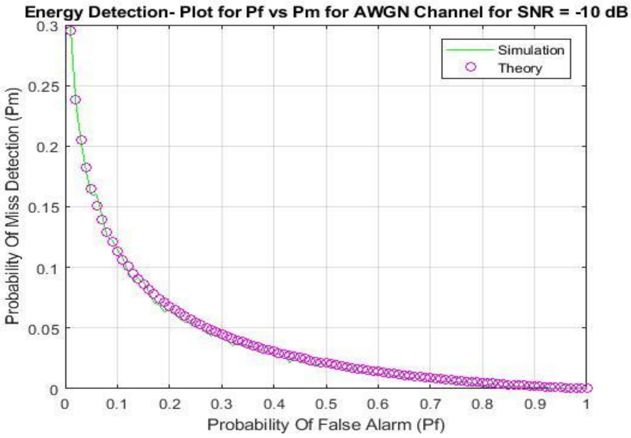


**Fig. 4 Plot between Pm and Pf for Energy Detector**

It is clear from Fig. 4 that as Pf increases, the Pm decreases. This is the complementary curve of Pf vs Pd curve. It is clear that as Pf tends to 1, Pm becomes zero. Also the curve verifies the fact that Pm = 1 – Pd.

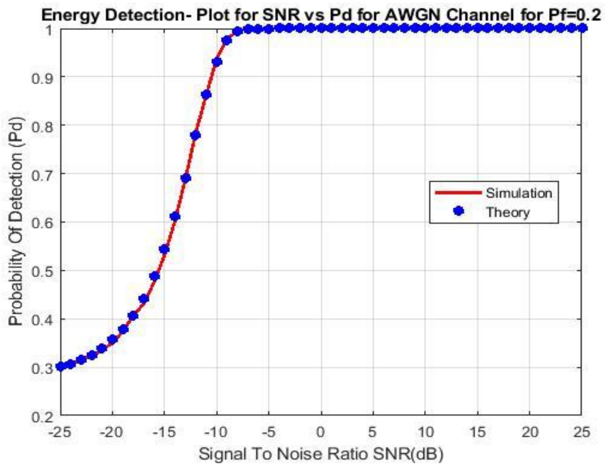


**Fig. 5 Plot between Pd and SNR for AWGN channel for Pf=0.2**

The simulation is done with the targeted SNR from -25 to 25 dB. Fig. 5 shows that Pd increases as SNR increases at a fixed value of Pf = 0.2.

Also SNR vs Pd is also plotted for various values of Pf. Here it is observed, as the value of Pf increases, the sensing capability (Pd) also increases. Graph at Pf = 0.4 is much better than the graph at Pf = 0.1.

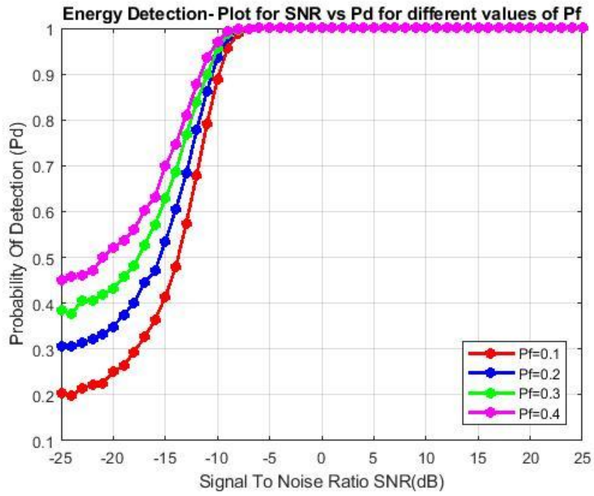


**Fig 6 Plot between Pd and SNR for different values of Pf**

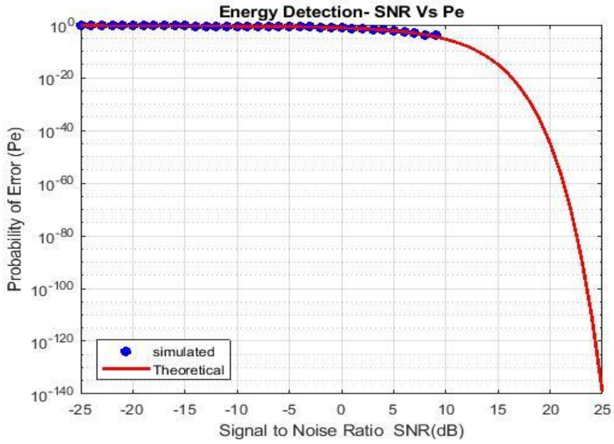


**Fig 7 Plot between Pe and SNR for Energy Detection**

The performance of energy detector is best analyzed by the help of SNR vs Pe diagram. Fig 7 shows that the energy detector performs well even at small values of SNR.

We have used the fact that Pe = Pf + Pm.

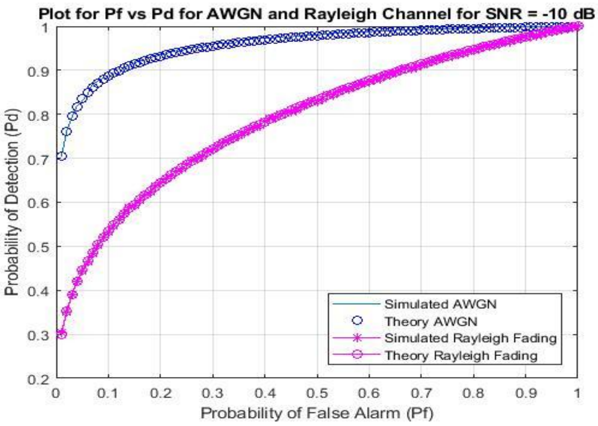


**Fig. 8 Plot between Pd and Pf for Energy Detection in AWGN and Rayleigh Channel**

All the above graphs (Fig.2 to Fig. 7) are been analyzed and plotted in the presence of AWGN channel. However the analysis is been extended to Rayleigh fading channel also and the comparative results are plotted in Fig. 8. Here we can see that the sensing degrades in fading channel.

It is clear that the detection probability is Pd = 0.3 for Rayleigh channel, which was Pd = 0.7 for AWGN channel.

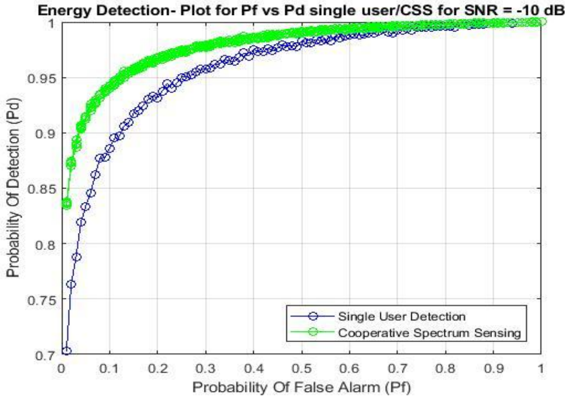


**Fig 9 Plot between Pd and Pf for Single User Detection and Cooperative Spectrum Sensing**

Finally, going from single user sensing to cooperative spectrum sensing, we see that even when Pf = 0, the value of Pd = 0.7 (for single SU sensing) increases to Pd = 0.84 (for SUs = 5). This indicates that the sensing is much better in case of multiple SUs as compared with 1 SU.

## VI. CONCLUSION

In this research paper, we have presented the detailed analysis of Energy Detector. It is one of the most extensively used detector for sensing the spectrum occupancy, as it need not require any prior information of the incoming signal coming through the channel. The only thing is to calculate the energy of the signal available in the channel and to decide whether the channel is free or busy. The sensing probability is good as it starts from 0.7 even if single SU senses the channel. We have evaluated the values of Pd, Pm and Pe by fixing and varying the values of Pf and SNR. It is observed that the sensing upgrades as we increase the values of Pf. Also, the sensing is satisfactory at SNRs below 0 dB and improves at SNRs > 0 dB. Also the graphs show that CSS outperforms single SU sensing.

Energy Detection is simplest to implement and has low cost of computation. However, it shows low sensing performance under low values of SNR due to the random noise available in the channel. It is unable to differentiate whether the interference is due to the SUs of the same channel or the PU is also a limiting factor for it.

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