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Evaluation of Energy Detection at various SNR values and optimal Cooperative Spectrum Sensing

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Abstract--- The world is moving towards a digital generation and more number of users are being added to the wireless technologies. The spectrum availability is being reduced with the increase in number of users. The problem of spectrum scarcity can be addressed by using cognitive radio, a comparatively newer technology. Spectrum sensing is the core part of cognitive radio which helps us in identifying the unused frequencies or part of the spectrum that can be allocated to new users without any disturbance to the ongoing transmission. Energy detection is such a spectrum sensing technique which is simple to implement, and we do not require to have the prior knowledge of the primary user signal. In this paper, we will implement and analyze energy detection with various values of SNR. We will investigate the optimal threshold in cooperative sensing also.

Keywords--- Cognitive Radio; Spectrum Sensing; Energy Detection; SNR; Spectrum Access

I. INTRODUCTION

Wireless communication has become an essential part of our life. We need a spectrum or a set of frequencies to establish a wireless communication system. As the demand of wireless communication is increasing, the spectrum scarcity is also getting increased. One of the main reason of spectrum scarcity is the high bandwidth usage. We are not limited to voice communication now. Large size data including videos, documents, software, games, utilities etc. is being transferred over the wireless communication. This leads us to look for a new-generation technology in cognitive radio.

Cognitive Radio first came into the picture in late 1990s when it was mentioned by Mitola in his thesis. Cognitive Radio intelligently sense the environment and finds the unused portions of the spectrum by means of spectrum sensing. The areas that are not being used are called white spaces. The new users which are known as the cognitive radio users, can do the transmission in the white spaces [1]. The users with license are known as the primary users. Cognitive radio users are allocated the spectrum in such a way that there is no disturbance to the ongoing communication between the primary users, and if there is any interference, that remains in the tolerable limits. Spectrum sensing plays a vital role in cognitive radio as it informs about the bands that are ready to occupy new users and start transmission.

The I section of this paper gives introduction of the proposed work and paper study, the II section gives us the theoretical development. III section describing methodology used in the paper, IV section contains the implementation and results and V section concludes the proposed work.

II. THEORETICAL DEVELOPMENT

A. Spectrum Sensing

Spectrum Sensing is the fundamental function in Cognitive Radio in which white space availability is found. The unutilized or the underutilized spectrum is identified in spectrum sensing that can be used to accommodate the secondary users for better utilization of the frequency bands. It identifies the tolerable limits of interference to the primary users so that the ongoing transmissions remain unaffected while the secondary users are introduced in the white spaces.

The white spaces and the interference levels are checked firstly in the communication system and then SNR (Signal to Noise Ratio) is measured. Channel capacity is also measured to detect the suitable number of connections without any disturbance to the primary users and without any failure to the secondary users' transmission. Secondary users need to regularly detect the presence of licensed users and if a primary user comes into the white space, the secondary user which is using the white space, needs to vacant the band or lower down the transmission rate with limited interference [2].

The principle of spectrum sensing is illustrated in the fig. 2. A Licensed transmitter is trying to communicate with the licensed receiver and there are secondary users that try to make connections in a licensed band. The secondary transmitter must perform spectrum sensing to avoid the disturbance to the primary transmission. A secondary transmitter must find whether there is an active primary receiver in its exposure. If a primary receiver is not present, then the secondary transmitter can start communication else it should not be allowed. It is called *direct spectrum sensing* as the primary receiver is searched.

We know that it is not an easy task to detect a primary receiver as the receiver doesn't send signals most of the time. It forces us to find its alternatives in the form of primary transmitter detection. Looking at the fig. 1, the communication coverage of the primary transmitter is denoted by D, and the interfering coverage of secondary transmitter is denoted by R. The active primary transmitter needs to be detected in the zone of D + R. If there is distance larger than D + R in between the primary and the secondary transmitter, this indicates that there is no primary receiver in the range and the secondary user communication can be done successfully. Interference may occur if the distance is less than D+R. Thus, identifying nearby primary transmitters can give us the fair idea of spectrum holes and it is known as *indirect spectrum sensing*.

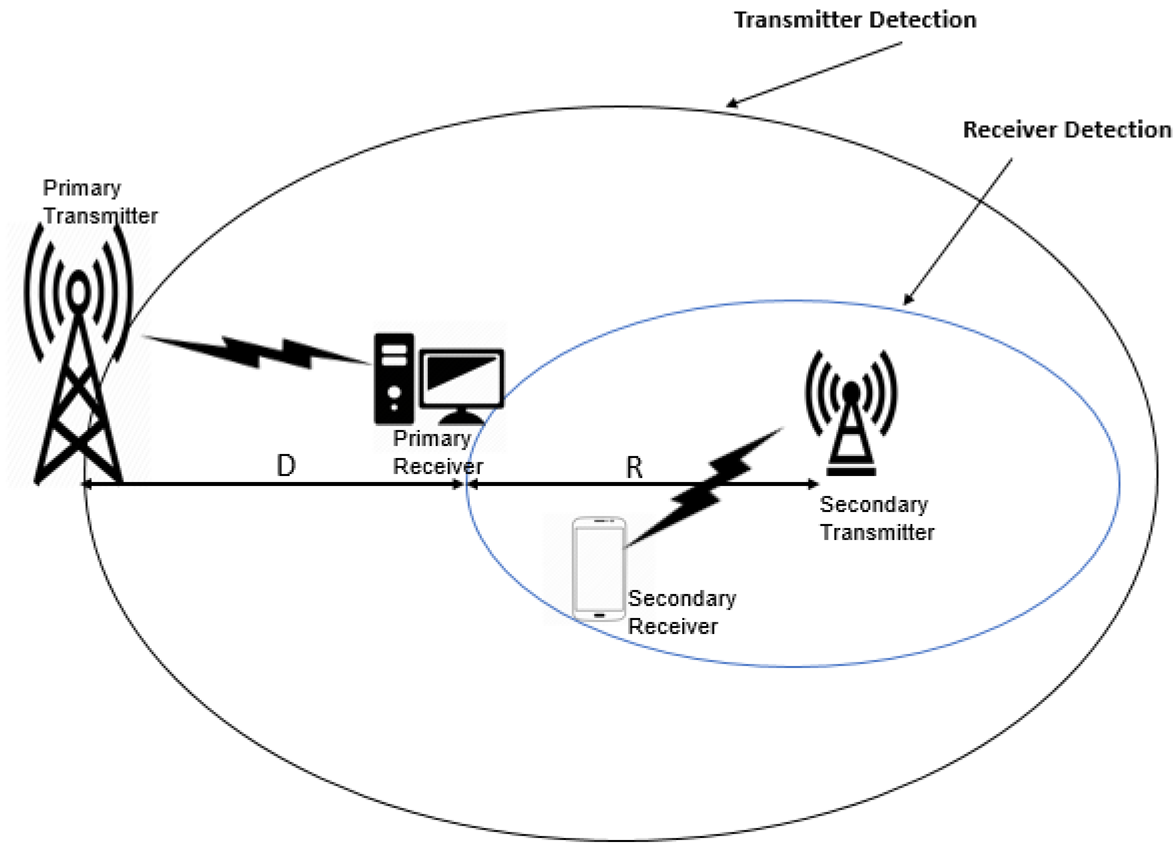

Fig. 1 Spectrum Sensing Principle

Indirect spectrum sensing needs a bigger identification area between R and R + D. Thus, it requires to find much low primary signals also, which becomes a difficult task.

Also, sometimes the primary transmitter signal SNR is much weaker and at the secondary transmitter end which makes it almost impossible to find the primary Transmitter. The receiver detection borderline in the fig. 1 indicates the direct sensing boundary and the transmitter detection borderline indicates the indirect sensing boundary [5].

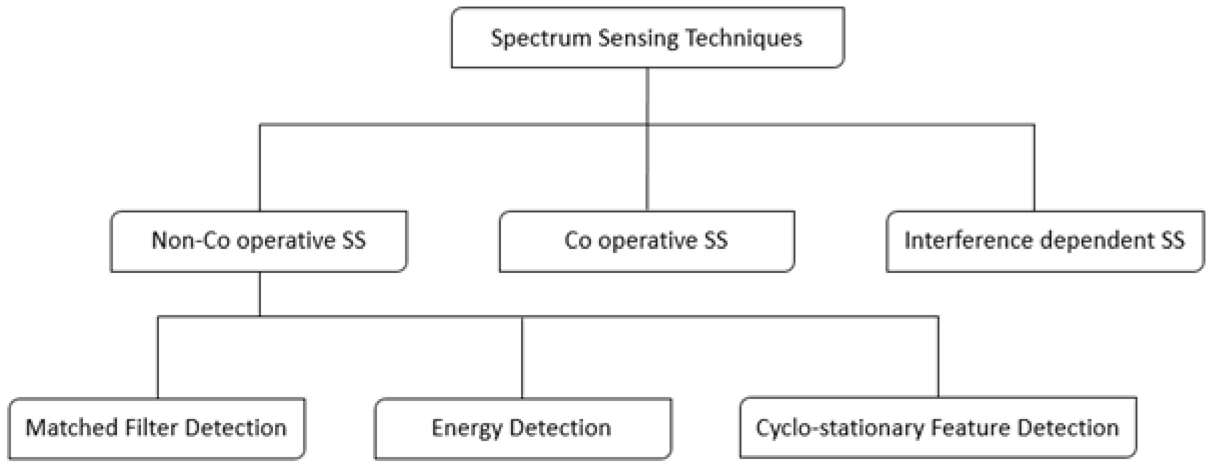

Fig. 2 Spectrum Sensing Techniques Classification

B. Types of spectrum sensing

Spectrum Sensing techniques are diverse: Cooperative, non-cooperative and interference dependent spectrum sensing.

In non-cooperative, white spaces are calculated by checking the presence of a licensed user signal in the frequency band. It is done by 3 methods: 1. Energy Detection, 2. Matched Filter detection and 3. Cyclo-stationary detection [9].
The primary user signal energy analysis is done, and the occurrence of the primary user transmission is estimated in Energy detection method. Waveform of the primary user signal is already known, and this helps in identifying the unused spectrum in Matched filter detection [8]. The info varies in accordance to time and situation in case of Cyclo-stationary detection. Periodic patterns are exhibited by several signals when they are processed by modulation, sampling, multiplexing etc. Secondary users collaborate with each other and measure the network parameters collectively in Cooperative spectrum sensing techniques [3]. CR users individually check the energy levels for a primary user detection and they share the data for better results. Also, there are other methods used in spectrum sensing including the interference levels base.
Energy detection is the most widespread method in spectrum sensing because of its non-complexity. This paper discusses analysis of the energy detection technique. We will also find the scenario with optimum cooperative spectrum sensing.

C. Energy Detection

Energy detection is an easy and popular spectrum sensing scheme due to its ease of implementation and less complicated process. We need not have prior information about the primary user signals. We can use a threshold value and compare the energy of the signal to know whether a primary user signal is present there or not. It is a good technique when we have the good estimation of the surrounding noise. The presence or the non-appearance of the primary user signal is concluded as per the comparison with the threshold value in case of energy detection.

A block diagram is shown here in fig. 3 which shows the various functions involved in the process of Energy Detection. The received signal is first passed through the band pass filter to obtain the desired band of frequencies. Then it is passed through the squaring device where it gets multiplied by itself and the square of the signal is obtained. The received signal is then integrated as per the requirements and finally a comparison is made between the signal and the threshold value.

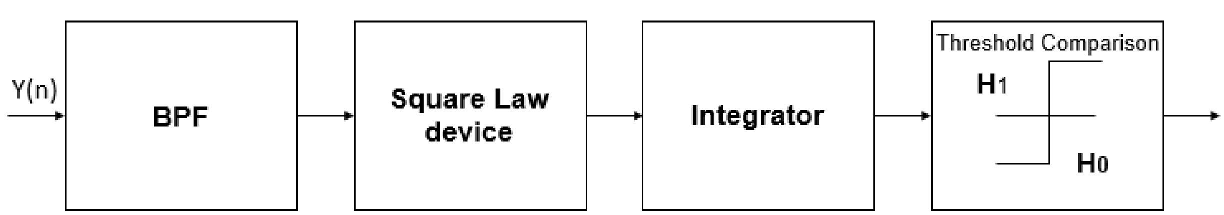

Fig. 3 Block Diagram of Energy Detection

Let the output obtained from the integrator is Y.

$$Y = \sum_{k=-\infty}^{\infty} |y(n)|^2$$

The hypothesis is taken according to presence or absence of the signal after the comparison made between the signal and the threshold λ

$$D = \begin{cases} H_{1,} & if\ Y > \lambda \\ H_{0,} & if\ Y < \lambda \end{cases}$$

Where

H_1 indicates the presence of primary transmitter signal,

H_0 indicates the absence of primary transmitter signal

And

λ is the threshold that depends on receiver noise [6].

III. METHODOLOGY

The analysis and implementation are performed on MATLAB. The following steps express the analysis-

First step:

We write a code for theoretical energy detection.

Second step:

We now take AWGN channel into consideration and do a simulation of Energy Detection with AWGN channel.

Third step:

We vary various parameters including number of samples, signal to noise ratio etc. and will try to find the optimized results for better detection.

Fourth Step:

We will plot the different graphs related to our simulation.

Fifth Step:

We now write a code for Cooperative Spectrum Sensing for Z number of nodes collaborating with each other in MATLAB

Sixth Step:

Now we optimize the threshold by using optimal voting rule by simulating in MATLAB.

Seventh Step:

We plot graph between total error rate and threshold and visualize the best value of threshold.

IV. IMPLEMENTATION AND RESULTS

A. Energy detection technique evaluation

Energy detection technique evaluation can be done by taking probability of detection (P_d) into account. We will also take probability of false alarm (P_f) into consideration. The probability of H_1 outcome when H_1 is true is given here by P_d; The probability of H_1 outcome when H_0 is true is given here by P_f.

Matlab tool is used here for the simulation and finding the results. The evaluation of primary user signal identification is done through variation in the probability of false alarm ranging from 0 to 1 and obtaining the probability of detection by for each case while applying Monte Carlo simulation. SNR used here is -8dB and the sample amount is N=750. The graph corresponding to probability of detection (P_d) and another parameter, probability of false alarm (P_f) is depicted here in fig. 4.

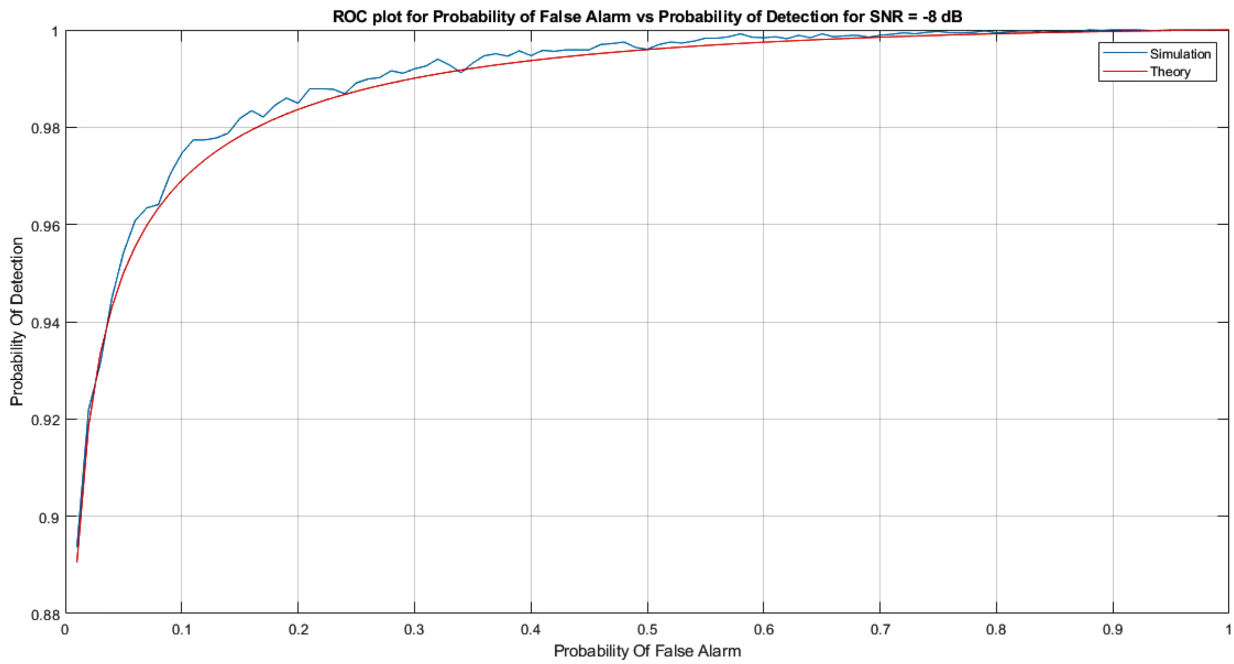

Fig. 4 P_f vs P_d Plot at SNR= -8 dB and N=750

We have plotted another graph in Fig. 5 with X-axis as P_f and Y-axis as P_d. False alarm probability ranging from 0 to 1, number of samples taken are N=750 and varying the values of SNR i.e. -10dB, -12 dB, -16 dB and -20 dB. It is evident that rise in SNR amount gives better detection of the signal in case of energy detection as the graph shows better probability of detection at SNR= -10 dB in the graph which is highest among all the SNR values taken by us.

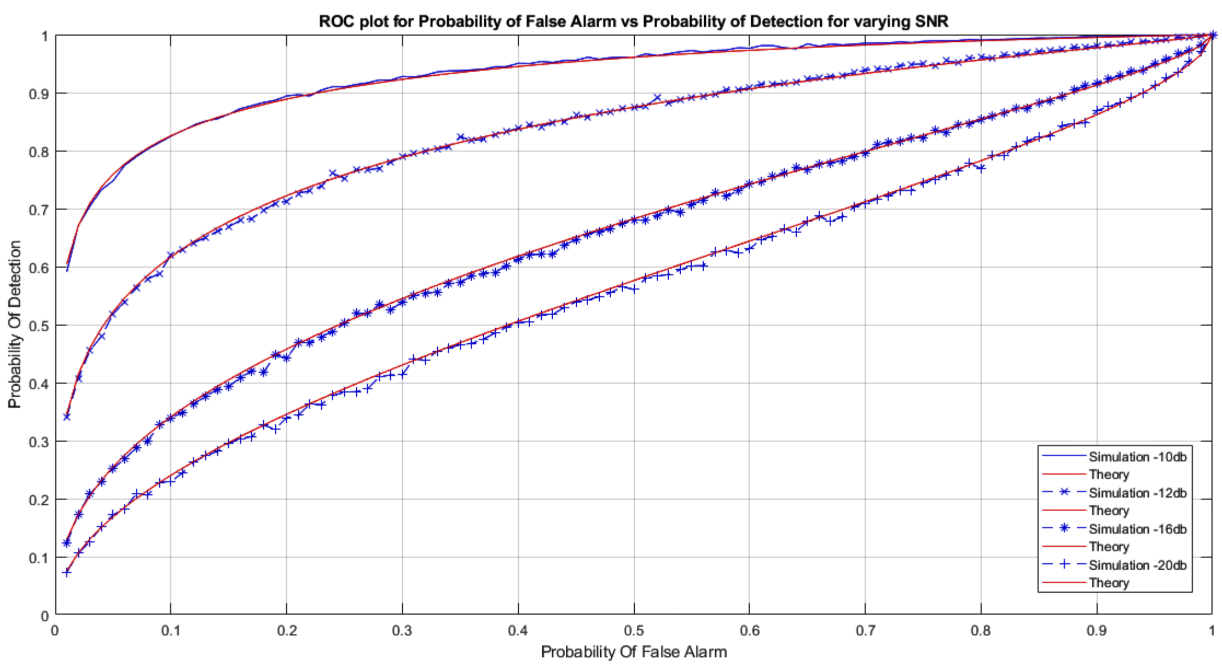

Fig. 5 P_f vs P_d Plot at N=750 and varying values of SNR as -10 dB, -12 dB, -16 dB and -20 dB

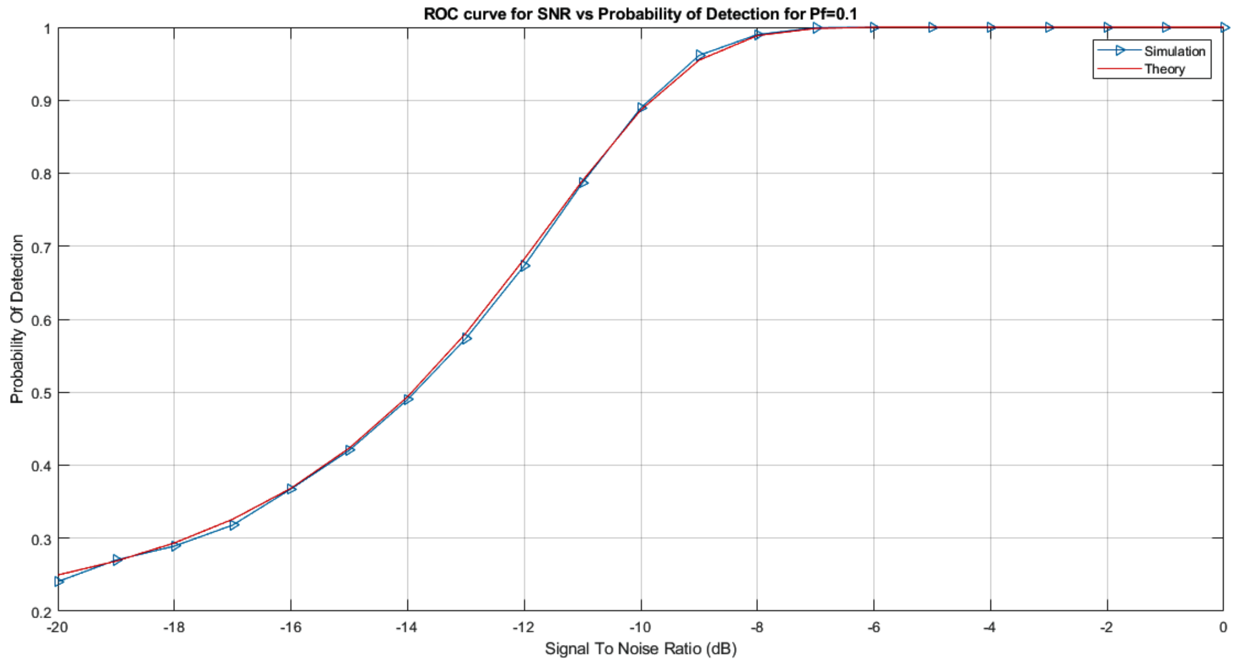

Fig. 6 SNR vs P_d Plot when P_f =0.1

The graph between Signal to Noise Ratio (SNR) and the probability of detection (P_d) is plotted in the fig. 6 when P_f is 0.1.

B. Cooperative Spectrum Sensing Evaluation

The hidden terminal issue is one of the key issues we face in spectrum sensing. Multipath fading is the main cause of this, due to which the CR is unable to detect whether a licensed user is present or not. Mistakenly, the Cognitive Radio user gets the band allocated. When the CR user transmits the signals, the signals create disturbance to the licensed users and the interruption in the primary user communication takes place.

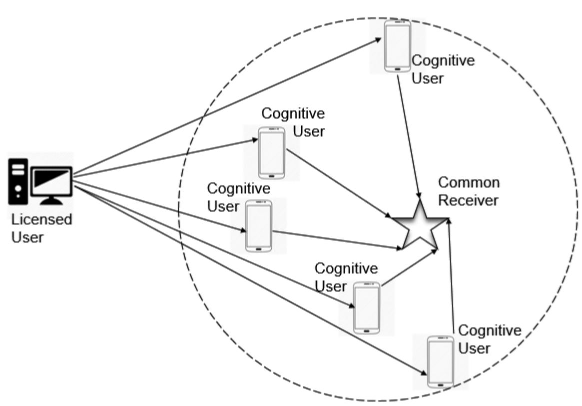

Fig. 7 Cooperative Spectrum sensing

This issue in cognitive radio networks can be handled well by employing several cognitive radio users which perform spectrum sensing as a team. Node detection is better and improved if more cognitive radio users collaborate in spectrum sensing. This technique of detection is known as Cooperative Spectrum Sensing. We will look for the optimum threshold in cooperative spectrum sensing based on simple energy detection so that we can diminish the rate of error.

Let us take a system with Z number of Cognitive users and a common receiver which receives data from all cognitive users. There can be two hypotheses:

H_0: Absence of licensed user

H_1: Presence of licensed user

The hypotheses can be determined by spectrum sensing at i^{th} CR:

$$x_i(t) = \begin{cases} w_i(t)\,, & H_0, \\ h_i(t)s(t) + w_i(t)\,, & H_1, \end{cases}$$

Where $x_i(t)$ is the signal obtained at i^{th} Secondary user node in time-slot t. Primary user signal is denoted by s(t) and AWGN is represented by $w_i(t)$. Complex channel gain is given by $h_i(t)$. We consider the fact that sensing time is lesser than the coherence time of the channel, it may be taken as the time invariant channel h_i [4].

The average probability of detection, false alarm and missed detection is respectively given by

$$P_{d,i} = Q_u\left(\sqrt{2\gamma_i}, \sqrt{\lambda_i}\right),$$

$$P_{f,i} = \frac{\Gamma(u, \frac{\lambda_i}{2})}{\Gamma(u)},$$

and

$$P_{m,i} = 1 - P_{d,i}.$$

Here,

λ_i and γ_i are the threshold of energy detection and instantaneous SNR resp. Energy detector's time and bandwidth product is denoted by u. Γ(a,x) is inadequate gamma function and is shown by

$\Gamma(a, x) = \int t^{a-1} e^{-t} dt$, (integration from x to ∞)

Γ(a) is here for gamma function

Generalized Marcum Q-function is represented as $Q_u(a,x)$ and given by $Q_u(a,x) = \frac{1}{a^{u-1}} \int_x^{\infty} t^u e^{-\frac{t^2+a^2}{2}} I_{u-1}(at)dt,$

where $I_{u-1}(at)$ is revised Bessel function of the first

type and its order is u− 1

Each cooperative partner decides H_0 or H_1 depending on its own local analysis in cooperative spectrum sensing and gives output as one bit of the decision D_i to a central common receiver through a channel without errors. Where 1 represents the existence of licensed user while 0 represents that licensed user is missing. All the 1-bit conclusions are merged together as per the logic at the common receiver end.

$$Y = \sum_{i=1}^{K} D_i \begin{cases} \geq n, & \mathcal{H}_1, \\ < n, & \mathcal{H}_0, \end{cases}$$

The interferences observed at the common receiver tells whether the primary signal is conveyed or not according to the values $\mathcal{H}_0$ and $\mathcal{H}_1$. When we compare the distance between two CR users with the distance between a primary user and CR, we find that the distance is much lower in case of the two CR users. This means that the path loss is almost similar in case of signal received at each CR node. It may be concluded that instantaneous SNR at each node is equal. In Rayleigh channel, we consider that all CR nodes use the same threshold λ. It leads $P_{f,i}$ not to rely on i and thus denoted as P_f. In AWGN channel, $Pd_{,i}$ doesn't rely on i and thus denoted as P_d.

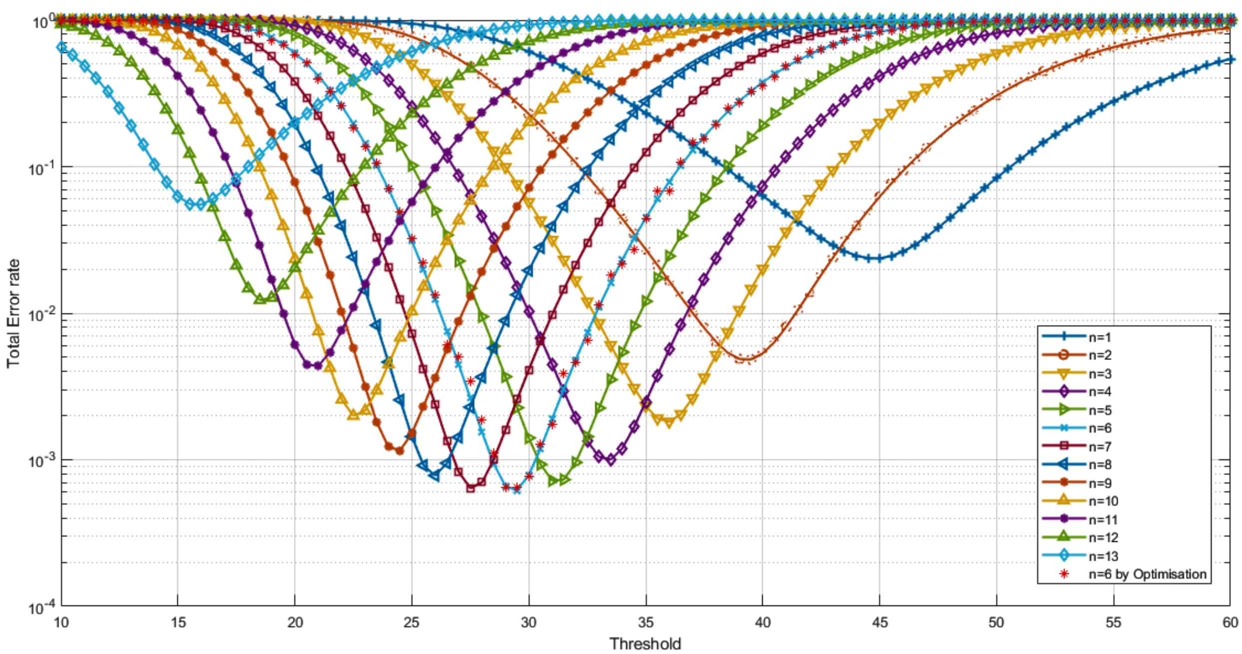

Fig. 8

threshold vs total error rate

Thus, it can be concluded that $P_m=1-P_d$ for Rayleigh and AWGN both.

The false alarm probability in CSS can be represented as

$$Q_f = \mathrm{Prob}\{\mathcal{H}_1|H_0\} = \sum_{l=n}^{Z} \binom{Z}{l} P_f^l (1-P_f)^{Z-l}.$$

The missed detection probability in CSS can be represented as

$$Q_m = \mathrm{Prob}\{\mathcal{H}_0|H_1\} = \sum_{l=n}^{Z} \binom{Z}{l} P_d^l (1-P_d)^{Z-l}.$$

When Z is fixed, the optimal n to obtain the minimum total error rate $Q_f + Q_m$ can be derived. Optimal threshold for minimum error rate can be given as

$$n_{opt} = \min\left(Z, \left\lceil \frac{Z}{1+\alpha} \right\rceil\right),$$

Where,

$$\alpha = \frac{\ln \frac{P_f}{1-P_m}}{\ln \frac{P_m}{1-P_f}}$$

The threshold is denoted by n and characterized by ‘n out of Z’ voting rule where Z is total number of CR nodes involved in Cooperative Spectrum Sensing. The OR rule belongs to n=1 case while AND rule to n=Z case. Here, we illustrate the relation between the total error rate and threshold. Fig. 8 shows the optimal value of threshold. We have taken Z=13 nodes and our best threshold value turns out to be n=6. For fixed very less threshold, the best rule is the AND rule, which indicates n=Z (n=13 in our case). The OR rule is best for fixed very high threshold, which indicates n=1.

V. CONCLUSION

The evaluation and implementation of energy detection and impact of Signal to Noise Ratio on the performance of the methodology has been studied. It is evident from the plots that the detector performance is almost similar to the theoretical value of the energy detection. We also observed that the energy detection performance is directly connected to the SNR value. So higher SNR implies that it is easy to detect the primary signal. We have taken different values of SNR ranging from -20 dB to -8 dB and we found that the best probability of detection lies in higher values of SNR, -8dB in the aforesaid range. In addition to this, we have also observed that the detection is better in case of cooperative spectrum sensing if an optimum threshold value is taken in consideration with optimal voting rule. We have taken 13 nodes and the optimum threshold value turned out to be 6 here. We have observed various factors that can enhance the probability of detection.

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