# PERFORMANCE ANALYSIS OF CO-OPERATIVE SPECTRUM SENSING USING OPTIMIZATION IN COGNITIVE RADIO

By

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*ABSTRACT*

*A cognitive radio system is a mechanism which allows unlicensed (cognitive) user to utilize free bands. Cognitive users detect the presence of such free bands and energy detection which is highly regarded as a prospective technique for this spectrum sensing task. The main aim is to optimize the detection performance in an efficient and implementable way and to reduce the probability of error, which mainly occurs in the wireless channel. The analysis is done under the Rayleigh fading channel. However, there exist two kinds of detection errors (i.e., miss-detection error and false-alarm error), which degrade the sensing performance severely. To overcome the entire problems in the cognitive radio network, the authors need to use an optimization algorithm, which gives the satisfactory result in the given environment. Due to its simplicity and its multi handling capabilities, Genetic Algorithm(GA) is used. The result is compared with Conventional Energy Detector and it is evident from the comparison that, GA finds better solution to the given problem.*

*Keywords: Cognitive Radio, Centralized Spectrum Sensing, Energy Detection, Genetic Algorithm, Probabilities of Total Error.*

## INTRODUCTION

A cognitive radio is known as an intelligent radio that can be programmed and configured dynamically. Cognitive Radio (CR) is regarded as a promising technology to mobile users to provide high bandwidth. A tempting solution to the congestion problem in spectrum gives rise to cognitive radio. CR is a capable technology, which has provided a different way to increase the efficiency of the electromagnetic spectrum utilization. CR allows unlicensed users or Secondary Users (SUs) to use the licensed spectrum through dynamic channel assignment strategies or spectrum access when the Primary Users (PUs) are in a dormant state to improve the spectrum utilization and hence avoid spectrum scarcity. Figure 1 shows the empty or unutilized part of the spectrum results in 'Spectrum holes' or 'White Spaces'. In this figure, red colored arrow indicates the vacant spectrum which can be utilized by cognitive radio user to make RF band more efficient [1].

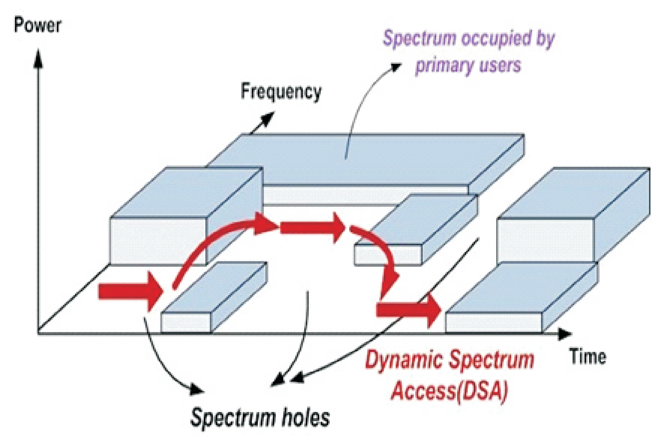


Figure1. Spectrum Hole Concept

For this, intelligent spectrum sensing technique is needed, which can detect the presence of spectrum holes and allocate them to the secondary users without interfering with the activities of the primary users [3] [4]. This paper specifically investigates the energy detector method and their simulation in MATLAB to know the presence of licensed users.

Energy detector is a semi blind spectrum sensing technique, which do not need any prior information about the signal to know the presence of primary users. It is simple and easy to implement, but requires high SNR conditions for optimal performance, which is in accordance with the simulation results. A major impediment to reliable communications over wireless channels is multipath fading. Specifically, when the signal experiences heavy attenuation, the channel reliability is severely affected by a phenomenon known as deep fading. [2] Single node sensing is unreliable and reduces the probability of detection due to fading and hidden terminal (shadowing) effects in the channel (from Primary User to CR User). Because in case of the presence of a single node, present detection probability fails when fading or shadowing occur at the path. [5] Because of this reason, cooperative sensing concept is used in this paper.

The probability of total error is a sum of two kind of detection errors namely probability of miss-detection error and probability of false alarm error. The detection probabilities and false alarm of the ED are derived theoretically under Rayleigh fading channel conditions. In this paper, to minimize the probability of total error in a cognitive radio network, Genetic Algorithm (GA) is used. GA is an adaptive heuristic search algorithm based on the mechanics of natural selection and genetics. Genetic Algorithm is a most popular search algorithm because of it's random nature and flexibility [8].

In this paper, the authors have considered spectrum sensing, which is one of the functions of cognitive radio in which decisions to assign the spectrum is made according to the QoS requirements of the application. The authors consider the optimization of cooperative spectrum sensing with energy detection to minimize the total error rate and compared with Genetic Algorithm, which is an evolutionary computing technique use to solve complex optimization problem. It is shown that, the performance of the proposed GA method not only achieves better performance values, but also exhibits higher convergence rate. The evaluation is done by simulation of this model in MATLAB platform.

## 1. System Model

Figure 2 displays the system model and it is noticed that some of the CR makes detection of the primary signal without any problem, whereas some other CR users cannot detect the presence of the primary signal due to the impact of deep fading and shadowing [15].

In the cooperative spectrum sensing scheme, each cognitive radio user sense the spectrum by performing local sensing and then binary local decision is send to the

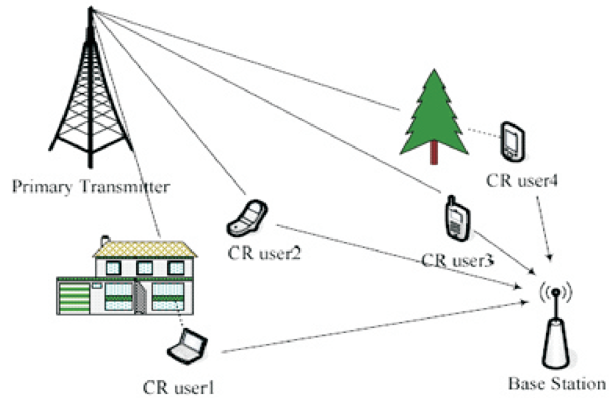


Figure 2. Cooperative Spectrum Sensing Model

fusion center. [7] The fusion center then fuses the local decision and makes the final decision in order to make the primary user to be present or not. Figure 3 shows cooperative centralized sensing. In centralized sensing, a central unit is present which collects sensing information from cognitive devices, identifies the available spectrum, and directly controls the cognitive radio traffic or broadcasts this information to other cognitive radios. The goal is to mitigate the fading effects of the channel and increase the detection performance [14]. The received signal contains two binary hypothesis-testing functions [9]:

- $H_0$: Primary user is absent.
- $H_1$: Primary user in operation.

The probability of correct detection $P_d$, probability of false alarm $P_f$ are the key metric in spectrum sensing, given respectively as:

$P_d$ = Prob. {Decision = $H_1/H_1$}

$P_f$ = Prob. {Decision = $H_0/H_0$}

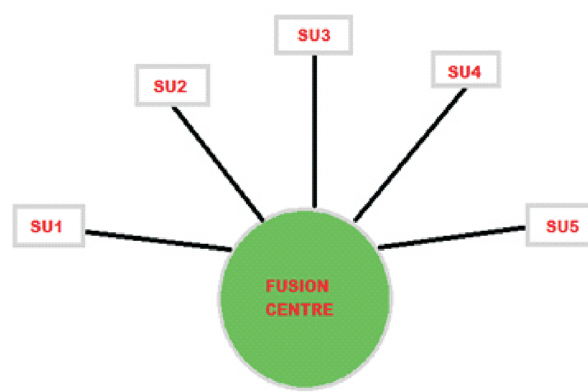


Figure 3. Centralized Cooperative Sensing

*1.1 Energy Detection*

Energy detection is the non-coherent, simple and most popular spectrum sensing method in cognitive radio. Figure 4 shows the block diagram of ED. An Energy Detector (ED) simply treats the primary signal as noise and decides on the presence or absence of the primary signal based on the energy of the observed signal. [13] Since it does not require any prior knowledge of the primary signal, for the variation of the primary signal, the ED performance is robust. The noise pre-filter serves to limit the noise bandwidth; band-limited, flat spectral density noise is given at the input to the squaring device. At any time for the input to the squaring device over the time interval T, the output of the integrator work as energy [6].

Assuming, the received signal is of the form,

$$Y(t) = s(t) + w(t) \quad (1)$$

where s(t) is the signal which is to be detected, w(t) is the AWGN noise sample and n is the sample index, and Y(t) is the signal received by the secondary user [10].

$$H_0: Y(t) = w(t) \quad (2)$$

$$H_1: Y(t) = s(t) + w(t) \quad (3)$$

Calculation of probability of error is done by the following formula:

$$P_d = P_r(\gamma < \lambda | H1) = 1 - Q_u(\sqrt{2\gamma}, \sqrt{\lambda}) \quad (4)$$

$$P_f = P_r(\gamma > \lambda | H0) = \frac{\Gamma(u, \lambda/2)}{\Gamma(u)} \quad (5)$$

where λ is the sensing threshold, γ is the SNR of detecting channel and u is the time-bandwidth product and $Q_u$ (.,.) is generalized Marcum Q-function, $\Gamma$ (.,.) and $\Gamma$(.) are incomplete and complete Gamma functions respectively.

## 2. Proposed Algorithm

There are various optimization techniques available to minimize the total error rate in the CR network. The most reliable one is the genetic algorithm which is adaptable to the radio environment. GA uses Darwin's theory of survival of

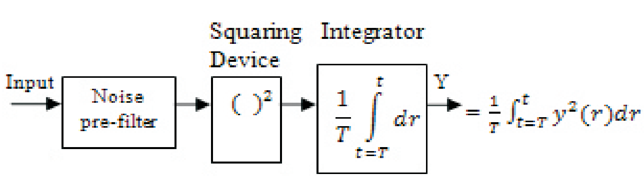


Figure 4. Block Diagram of ED

the fittest. GA is quite flexible to the wireless environment and can be implemented in multi-objective optimization [8] [11].

*2.1 Genetic Algorithm*

*Step 1:* Considering the number of population size as N, initialize the algorithm parameters randomly. For simplicity, the threshold and SNR of population size N are initially assumed.

*Step2:* Evaluate the values of the fitness function corresponding to each chromosome.

$$P_{error} = P(H_0) P_f + P(H_1)(1 - P_d) \quad (6)$$

The values of the probability of detection and probability of false alarm are given in equations 4 and 5.

*Step 3:* Loop (until the maximum generation).

*Step 4:* Select the best chromosome of the population in terms of their fitness and perform Roulette wheel for selection.

For i=1 to population size

Generate random number $S_i$.

If ($S_i$ > crossover probability)

Select $i^{th}$ chromosome for crossover.

End if

End for

*Step 5:* Perform the crossover operation on selected chromosome of the population.

For i=1 to maximum population size

If ($S_i$> mutation probability)

Select $i^{th}$ chromosome for mutation.

End if

End for

*Step 6:* Perform mutation operation on selected chromosome of the population.

*Step 7:* Choose chromosome for next generation and find the optimal solution, if the criteria is achieved, terminate the loop, otherwise move to the step 2 of the algorithm.

*Step 8:* END

## 3. Simulation Result

In this section, the optimization of parameter for both ED and GA optimization is evaluated numerically. The following result mainly focus on analyzing the comprehensive sensing performance and seeking the optimal selections of various parameters. In order to minimize the probability of total detection error occurring during CR spectrum sensing. Figure 5 illustrates the probability of total detection errors with possible values of K conducted in Rayleigh fading environment. In Energy Detection technique, number of parameters (SNR, Threshold, no. of SUs etc.) are assumed first, then the total probability of error is calculated using a formula.

Figure 6 shows the graph between probabilities of total error rate vs. sensing threshold using Genetic Algorithm optimization. From the graph, it is evident that GA gives better result than ED for a fixed population size.

Table 1 shows the parameter specified to calculate probability of detection for Rayleigh fading channel.

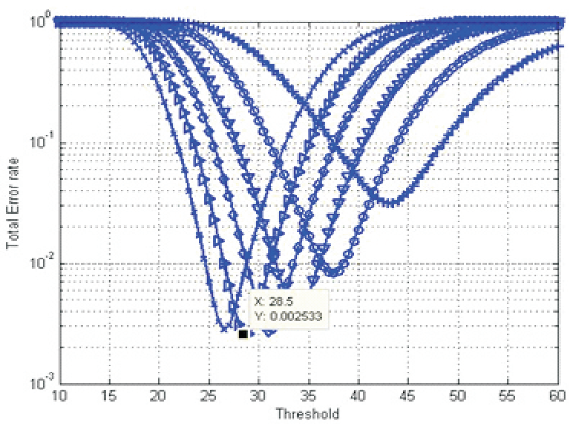


Figure 5. Probability of Total Detection Error vs. Sensing Threshold

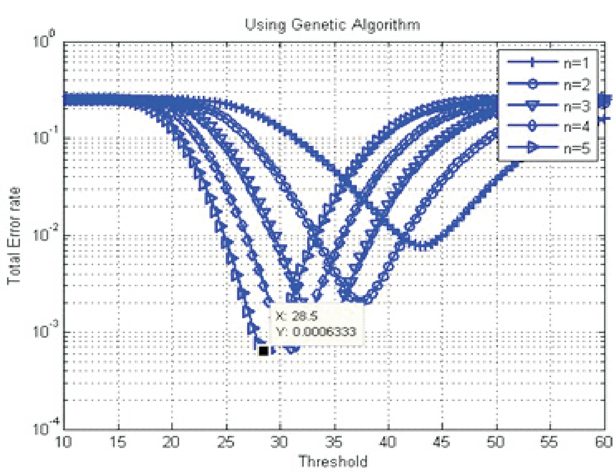


Figure 6. Probability of Total Detection Error vs. Sensing Threshold using GA

Number of SUs considers here are is 20 and modulation is done to avoid the effect of noise using BPSK modulation technique and SNR is taken in the range of -10 to 10 dB and carrier frequency is assumed here 1000 Hz. As we know, Rayleigh fading occurs when there is no direct line of sight between the transmitter and the receiver. Due to scattered signal between transmitter and receiver, fading occur at the channel.

Table 2 shows the parameter specified for GA to calculate the probability of detection for Rayleigh fading channel. Number of SUs consider here is 20. Modulation is done to avoid the effect of noise using BPSK modulation technique and SNR is taken in the range of 10dB. Here, genetic value of genetic operator is assumed such as Crossover Probability (Pc) = 0.8, Mutation Probability (Pm) = 0.05.

Figure 7 depict fitness vs. generation curve, it shows the fitness of the population converge to 18.8% with generation 20. GA finds a better value of the parameter to obtain the required QoS specification for the CR network.

Table 3 shows the comparative analysis of ED and GA performance. It is clear from the result that, GA optimization finds better result than ED. Percentage of trials to find better result is lesser in GA than ED and also Total error rate is much lesser in GA compared to ED.

## Conclusion

Spectrum is a very valuable resource in wireless communication systems and it has been a major research topic from the last several decades. In this paper, the authors have presented an energy detector to solve

| Parameters | Values |
|---|---|
| No. of SUs | 20 |
| Carrier frequency | 1000 Hz |
| SNR | -10 to 10 dB |
| Modulation technique | BPSK |
| Threshold | 10 to 60 |

Table1. System Parameters for ED

| Parameters | Values |
|---|---|
| No. of SUs | 20 |
| SNR | -10 to 10 dB |
| Carrier frequency | 1000 Hz |
| Modulation technique | BPSK |
| No. of generation | 20 |
| Crossover Probability | 0.8 |
| Mutation Probability | 0.05 |

Table 2. Parameters Specification for GA Simulation

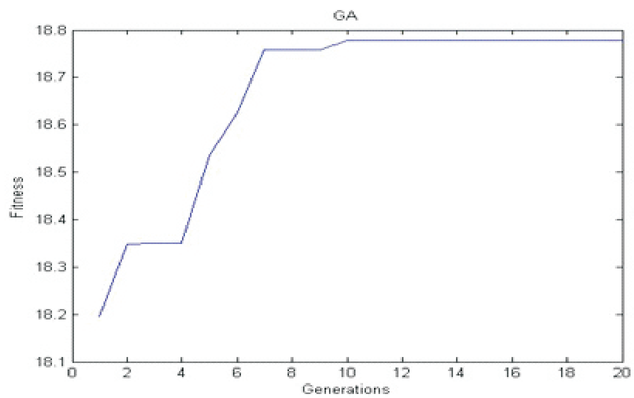


Figure 7. Fitness Vs Generation

| Algorithms | Probability of total | Threshold | No. of Us | SNR |
|---|---|---|---|---|
| ED | 2.553x $10^{-3}$ | 10 to 60 | 20 | -10 to10 dB |
| GA | 6.33x $10^{-4}$ | 10 to 60 | 20 | -10 to10 dB |

Table 3. Comparative Analysis of GA and ED

spectrum sensing problem over Rayleigh fading channel. [12] The overall detector performance is affected by the value of the involved parameters like fading parameters and SNR values and ED has much lower complexity than the other schemes. The use of GA is presented to minimize the total error rate in CR network. The simulation result shows a superior performance of the proposed algorithm and compared to conventional ED. It is clear from the comparison that, GA finds better solution in the given environment.

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