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Genetically Optimized Adaptive Threshold Based Energy Detection Spectrum Sensing Algorithm for Cognitive Radio Networks

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***Abstract*—Cognitive radio is an important technique of dynamic spectrum allocation. By using cognitive radio (CR) spectrum utilization can be improved. Spectrum sensing plays an influential role in detecting white spaces present in the spectrum. So, spectrum sensing algorithm will help secondary user (SU) to detect spectrum holes precisely. Here energy detection (ED) spectrum sensing technique is used. Energy detection spectrum sensing with single threshold has been widely researched in the past. The interference between primary user (PU) and secondary user (SU) was more in energy detection with single threshold therefore the collision rate was much high. So, to minimize collision rate and improve the probability of detection (P_d) this paper proposes a genetically optimized double threshold based energy detection spectrum sensing algorithm to optimize the performance of cognitive radio networks. Simulations based on probability of detection (P_d), probability of miss detection (P_m), and collision rate has been presented in this paper.**

***Keywords*—cognitive radio, spectrum sensing, adaptive threshold, genetic algorithm.**

I. INTRODUCTION

The request for wireless spectrum has been increased due to increase in number of wireless users which led to shortage of the available spectrum. As the demand for spectrum is growing it is difficult for the fixed spectrum allocation policy to serve the growing demand. FCC reported that the main reason behind the spectrum shortage is unskillful utilization [1]. To resolve the issue of inefficient spectrum utilization a technique called cognitive radio is used.

Cognitive radio allows opportunistic use of spectrum to overcome the underutilization problem. The licensed users are known as primary users (PU) and unlicensed users are known as secondary users (SU). The necessary condition for cognitive radio system is to observe the spectrum to find spectrum holes. In cognitive radio, the SU observe the spectrum and access it when it is not occupied by the PU and when PU is absent SU access the spectrum to transmit its own data. So it is important for cognitive user to detect the spectrum changes all the time. Furthermore, if cognitive user senses that the PU is beginning to transmit message, cognitive user leaves that band immediately which it has been using. So this process is known as spectrum sensing.

The basic transmitter detection spectrum sensing techniques are matched filter detection, energy detector and cyclo-stationary feature detection. From these three methods the most commonly used method is energy detector due to its simple execution and it is not necessary to know the previous details of primary users (PU) [8]. The accuracy of spectrum sensing is studied in terms of probability of false alarm (P_f) and probability of detection (P_d) and probability of miss detection (P_m). P_d is the probability that the SU detects that channel is not free it is used by the primary user (PU). P_f is the probability that secondary user (SU) determines that channel is used by the primary user (PU) but in actual the primary user (PU) is absent. P_m is the probability that secondary user (SU) observes the channel and find that the primary user (PU) is absent but in actual primary user (PU) was present. Increase in probability of detection (P_d) leads to improved protection to the PUs. And less probability of false (P_f) alarm means efficient use of spectrum.

A single threshold is used for the detection of PU in conventional energy detection. Due to single threshold there was collision between the primary (PU) user and the secondary user (SU). So this shows that there is interference between the SU and the PU due to unpredictability of the spectrum detection. To improve the detection performance by maximizing P_d and minimizing error rate.

The parameter which is used to find the existence of primary user (PU) is the detection threshold and energy detection performance mainly depends on this threshold and on the received signal SNR level explained in [2]. Adaptive threshold which is adaptive in nature in accordance with the consequence of the power of non-licensed user's transmission has been proposed by Hyun-Ho Choi [3]. In [4], author explains that by using adaptive threshold tradeoff between P_d and P_f can be controlled in a better way. In [5], author explains the energy detection performance calculation in low SNR region using optimal detection threshold to minimize error rate. In [6], double threshold which is algorithm based has advantage over single threshold in terms of detection performance. So adaptive threshold is required to enhance the spectrum efficiency as it senses channel at low SNR region. It is shown that the adaptive threshold system is much better than the system with fixed threshold, [7].

In this paper optimization of adaptive threshold is targeted along with maximization of P_d and minimization of error rate using genetic algorithm (GA). The different values of P_d are calculated at low SNR with and without using genetic algorithm. Motive is to achieve high spectrum accuracy and the spectrum accuracy depends on P_f. A robust CR system is that which gives high detection probability at minimum probability of false alarm (P_f) while SNR is quite low.

The rest of the paper is arranged as follows. Section II discusses the energy detection system model for single and double threshold in detail. Section III gives brief on genetic algorithm implementation. Section IV discusses genetic algorithm used to optimize adaptive threshold. Section V shows result simulation followed by conclusion in Section VI.

II. SYSTEM MODEL

Let us consider a network scenario with single primary user and N-secondary users. This research work modify the energy detection based spectrum sensing algorithm where the received primary user's signal undergoes energy calculation and thereafter received signal's energy is compared with detection threshold to obtain the status of the channel. Let Y_{SU_i} represents the received signal at i^{th} secondary user and $u(i)$ represents the noise content present between primary user and i^{th} secondary user which is assumed to be modeled by Additive White Gaussian Noise (AWGN) with zero mean and σ_n^2 variance. Then the received signal at primary user can be given as:

$$Y_{SU_i} = H_i * X + u(i)\ for\ i = 1,2 \dots N \tag{1}$$

Where X represents primary user's signal modeled by normally distributed random process with zero mean and σ_s^2 variance. And H_i represents channel gain between primary and i^{th} secondary user.

The detection hypothesis can be defined as:

$$Y_{SU_i} = \begin{cases} H_0 \ \ if\ Primary\ user\ is\ abscent \\ H_1\ if\ Primary\ user\ is\ present \end{cases} \tag{2}$$

A. *Single Threshold Based Energy Detection*

The energy detection spectrum sensing works on calculation of primary signal's energy. For detection hypothesis the received signal's energy at i^{th} secondary user (Th_i)can be calculated as:

$$Th_i = \frac{1}{N}\sum_{i=1}^{N}\left|\left(Y_{SU_i}\right)\right|^2 for\ i = 1,2 \dots N \tag{3}$$

Let λ represents detection threshold for hypothesis calculation, then the corresponding probability of detection and probability of false alarm can be given by[7].

$$P_d = Q\left(\frac{\lambda-(\sigma_s^2-\sigma_u^2)}{\frac{\sigma_s^2+\sigma_u^2}{\sqrt{\frac{N}{2}}}}\right) \tag{4}$$

$$P_f = Q\left(\frac{\lambda-\sigma_u^2}{\frac{\sigma_u^2}{\left(\sqrt{N/2}\right)}}\right) \tag{5}$$

Where P_d represents probability of detection and P_f represents probability of false alarm, accordingly the value of detection threshold λ can be given as:

$$\lambda = \frac{\left(Q^{-1}(P_f)\right)}{\sqrt{N}} + 1 \tag{6}$$

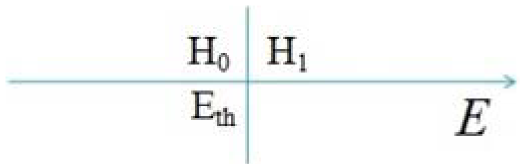

Fig.1. Energy detection based on single threshold

Figure-1 represents hypothesis calculation for single threshold based energy detection technique where E_{th}represents energy threshold for received primary user as given in equation (3). The main issue with single threshold based detection technique is that interference between primary and secondary user is high in case of this technique which results in high collision rate at secondary user. To overcome this issue double threshold based detection technique is proposed.

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B. *Adaptive Double Threshold Based Energy Detection*

In this model there is addition of one more threshold to single threshold, represented as λ_{th1} and λ_{th2}. If E > λ_{th2}, it means that the channel is occupied by the PU. If E < λ_{th1}, it means the channel is available. If λ_{th1}< E < λ_{th2}, spectrum sensing is executed once more.

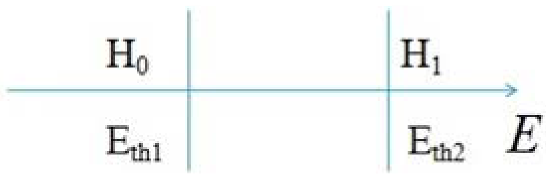

Fig.2. Double threshold model

The detection threshold is given by

$$\lambda_D = \frac{\frac{2}{\mathrm{N}}\ln(\lambda)+\ln(1+\gamma)}{\frac{\gamma}{\sigma_u^2(1+\gamma)}} \tag{7}$$

And the received instantaneous SNR is given by

$$\gamma = \frac{\sigma_s^2}{\sigma_u^2} \tag{8}$$

For double threshold,

$$\lambda_{th1} = m\lambda_D \tag{9}$$

$$\lambda_{th2} = n\lambda_D \tag{10}$$

This method was used to minimize the collision between primary and secondary user. And check probability of detection at low SNR values. At high SNR signal performance is good but at low SNR performance degrades. Using adaptive threshold there is increase in probability of detection and collision rate is minimized. Monte Carlo simulations were carried out taking, N (number of samples=1000), P_f=0.01 and m==1, n=.25.

III. Genetic algorithm

Genetic Algorithm is an approach used to find optimized solution to search problems and it intend to increase the probability of solving the problem. The process of optimization involves selection of the best option from the available set of options to achieve the desired goal. Selection is done such that the spectrum efficiency can be maximized and error can be minimized.

The methodology of genetic algorithm is as follows [9]:

- A random initial population is created.
- Fitness of the initial population is evaluated.
- Reproduction includes selection, crossover and mutation. Selection is done such that the individual with best fitness level from the current population is selected. Now the best individuals reproduce to form new population. Mutation is done at a definite point in the new created individual.
- The process is repeated until a maximum number of generation has evolved or a desired solution is obtained.

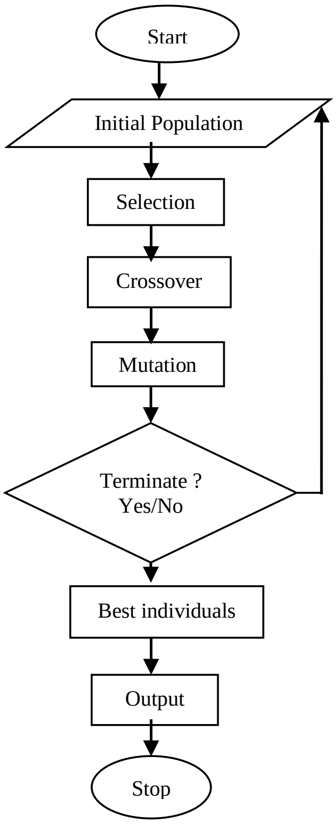

Fig.3. Genetic Algorithm Flow Chart

IV. Threshold optimization

In this paper optimization of double threshold energy detection on the basis of genetic algorithm (GA) is done. So, detection threshold should be set in such a way that maximum spectrum accuracy can be achieved at low SNR. So, to achieve this GA is applied on the adaptive threshold based energy detection. The overall detection threshold λ_D from equation (7) is divided such that some percent of λ_D is λ_{th1} and some percent is λ_{th2}. So, GA gives the values of m and n from equation(9& 10) such that the end outcome P_d will be high on minimum P_f.

In any system there are some input parameters and end outcome. Here in case of CR spectrum sensing the end outcome is detection probability P_d and input parameters are m & n, these are two random values on the basis of which detection probability will vary. And a given range of m & n is specified and an error function is calculated. GA either maximizes or minimizes fitness function in any problem. So, here fitness function is used for minimization of error function.

{

Error = fitness(x)

Error = Target_P_d – Actual_P_d

Where, Target_P_d = 1 and x is a [1x2] matrix i.e. [x1 x2]

Such that, m = x1 & n = x2

}

So, this difference will minimize when P_d is high and on which value this difference will be minimum that value is obtained with the help of GA. The objective function here is error which is to be minimized so, GA starts with selecting initial population at random. Then crossover and mutation operations are performed and then fitness of new population is evaluated. If this generation gives the desired values for m & n then process stops. Otherwise the old population is replaced by new population in the next generation until a solution is reached or maximum number of generations are reached.

V. Simulation results

This research work proposed optimized double threshold based energy detection spectrum sensing algorithm to improve the performance of cognitive radio network. The application of genetic algorithm has been utilized to find the optimal values of lower and upper threshold limit. MATLAB (2014a) based simulation scenario has been developed and simulation results based on variation of probability of detection, collision rate and probability of miss detection has been presented. The simulation parameters are assumed as N = 1000 samples, P_f = 0.01, population size=5, number of generations=10.

Fig.4 shows P_d VS SNR (dB) for single threshold energy detection, double threshold energy detection, and double threshold energy detection with GA. It can be observed that probability of detection is much high at low SNR values in double threshold energy detection with GA than other two algorithms.

At -20db SNR

P_d for single threshold ED = 0.08

P_d for double threshold ED = 0.62

P_d for double threshold ED with GA = 0.982
Probability of detection is increased by 98.2% in case of double threshold energy detection with GA.

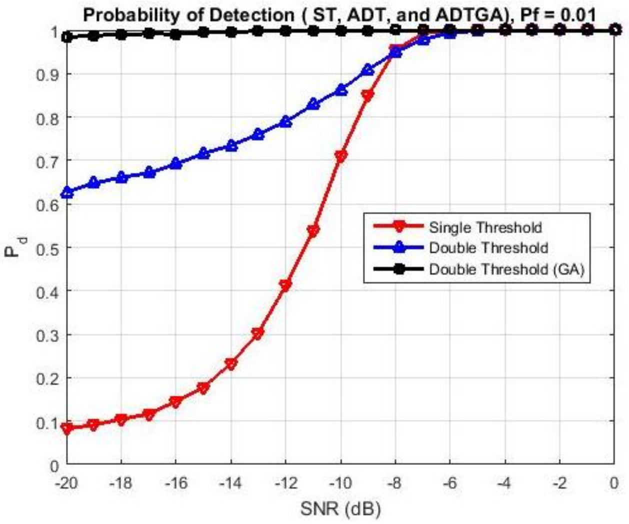

Fig.4. Probability of detection P_d VS SNR for P_f =0.01

Fig.5 shows Collision vs. SNR (dB) for single threshold energy detection, double threshold energy detection, and double threshold energy detection with GA.

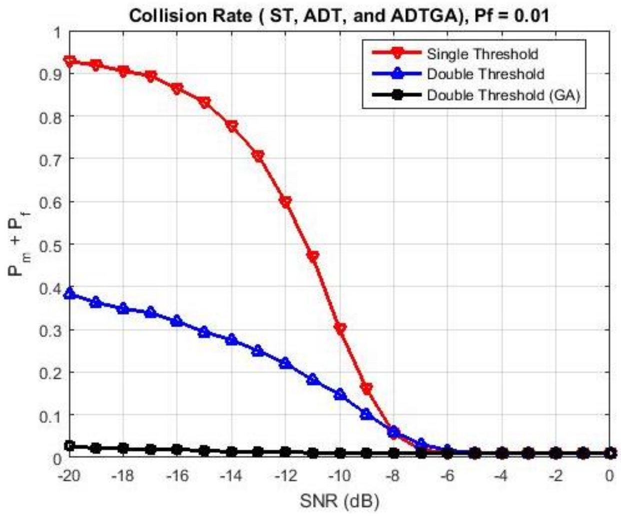

Fig.5. Collision Rate VS SNR for P_f =0.01

The findings are as follows:
At -20dB SNR collision rate for:
Single threshold ED = 0.92
Double threshold ED = 0.38
Double threshold ED with GA = 0.028
Collision rate is reduced to 0.14% in case of double threshold ED with GA.

Fig.6 shows Probability of miss detection vs. SNR (dB) for single threshold energy detection, double threshold energy detection, and double threshold energy detection with GA. The findings are as follows:
At -20dB SNR probability of miss detection (P_m) for:
Single threshold ED = 0.91
Double threshold ED = 0.37
Double threshold ED with GA = 0.018
Probability of miss detection (P_m) is reduced to 0.09% in case of double threshold ED with GA.

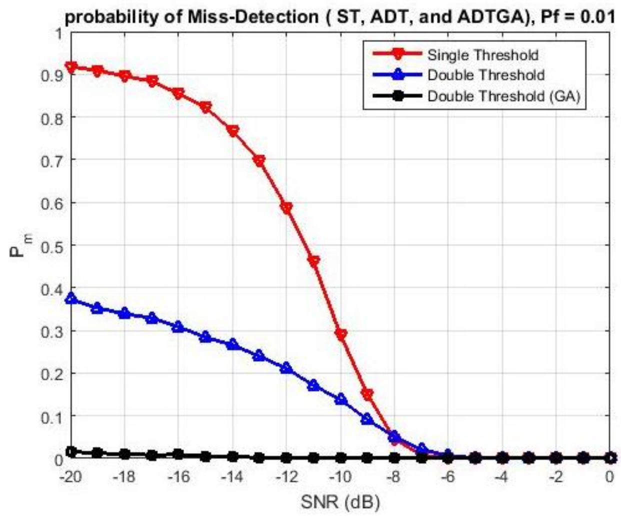

Fig.6. Probability of Miss-detection P_m VS SNR for P_f =0.01

VI. CONCLUSION

This paper presents genetically optimized double threshold based energy detection spectrum sensing for cognitive radio networks. A MATLAB based simulation scenario has been developed and simulation results based on P_d, P_m, and collision rate has been presented. The application genetic algorithm improved the P_d, P_m, and collision rate. P_d increased to 98.2% and P_m and collision rate reduced to 0.09% and 0.14%. This can be concluded that by applying genetic algorithm to double threshold based energy detection sensing improved the overall performance of the system.

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