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Spectrum Sensing Framework in Cognitive Radio using GA and Grey Wolf Optimization

Shruti Sharma
M. Tech. Scholar
Electronics & Communication Engineering
Choukesy Engineering College, Bilaspur, C.G. (India)
shruti0325@gmail.com

Rahul Gedam
Head of Dept.
Electronics & Communication Engineering
Choukesy Engineering College, Bilaspur, C.G. (India)
engg.rahul2801@gmail.com

Abstract – **Spectrum sensing has been identified as a key enabling functionality to ensure that cognitive radios would not interfere with primary users, by reliably detecting primary user signals. The performance of spectrum detection is regularly traded off with multipath fading, shadowing and receiver uncertainty problems. To relieve the effect of these issues, spectrum sensing has been appeared to be a powerful technique to enhance the performance of detection by using spatial diversity. This paper proposes a comparative analysis of Singular Value based Detection (SVD) using Genetic Algorithm (GA) and Grey Wolf Optimization (GWO) for spectrum sensing.**

Keywords –**Cognitive Radio, FCC, Spectrum Sensing.**

I. Introduction

One of the major challenges in design of wireless networks is the use of the frequency spectrum. Recent measurements by Federal Communications Commission (FCC) show that 70% of the allocated spectrum is in fact not utilized. Spectrum utilization can be improved significantly by allowing a secondary user (SU) to utilize a licensed band when the primary user (PU) is absent. Cognitive radio (CR) has been proposed as a promising technique for future wireless communication systems. CR is able to fill in spectrum holes and serve its users (Secondary users) without causing harmful interference to the primary user (PU). To do so, the CR must continuously sense the spectrum it is using in order to detect the reappearance of the PU. Once the PU is found to be active, the SU is required to vacate the channel. Therefore, spectrum sensing is of significant importance in CR networks. Moreover, periodic sensing is essential where the SU has to be aware of the channel status at all times. This is achieved by using a frame structure. In this structure, each frame consists of a sensing period and a transmission period. At the end of each sensing period, the SU transmission starts when the licensed channel is idle. Otherwise, the SU will wait until the next frame to sense the licensed channel again.

The main objective of this research work is to implement a spectrum sensing framework in cognitive radio networks using SVD based detection using Genetic Algorithm and Grey Wolf Optimization for spectrum sensing.

II. Proposed Methodology

The purpose of signal detection is to test the existence of primary user's signal in receiver. For the signal detection, there are two kinds of hypothesis: H_0, which means primary user's signal does not exist; H_1, which means primary user's signal exists. The two hypothesis are given respectively by formula as follows:

$$H_0: x(n) = \eta(n) \quad (1)$$

$$H_1: x(n) = \bar{s}(n) + \eta(n) \quad (2)$$

Where $\bar{s}(n)$ is the received signal samples including the effects of path loss, multipath fading and time dispersion, and $\eta(n)$ is the received white noise assumed to be identically distributed signal, and with mean zero and variance σ_η^2.

The received signal at receiver can be given as:

$$x(n) = \sum_{j=1}^{P} \sum_{k=0}^{N_{ij}} h_j(k) s_j(n-k) + \eta(n) \quad (3)$$

Where, P is the number of source signals i.e. number of transmitters, $h_j(k)$ is channel response and N_{ij} is the order of the channel.

The detection techniques performance can determined through two probabilities: probability of false alarm (P_f) is probability of incorrectly detection of primary user in the frequency band that is case H_0 and probability of detection (P_d) is probability of correctly detection primary user in frequency band that is case H_1.

Singular Value based Detection (SVD)

In linear algebra, the singular value decomposition (SVD) is a factorization of a real or complex matrix, with many useful applications in signal processing and statistics. Formally, the singular value decomposition of a $M \times L$ real or complex matrix R is a factorization of the form:

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$$R = U \sum V^* \quad (4)$$

Where U is a $M \times M$ real or complex unitary matrix, Σ is a $M \times L$ rectangular diagonal matrix with nonnegative real numbers on the diagonal, and V^* (the conjugate transpose of V) is a $L \times L$ real or complex unitary matrix. The diagonal entries $\Sigma_{i,i}$ of Σ are known as the singular values of R. The M columns of U and the L columns of V are called the left-singular vectors and right-singular vectors of R, respectively. Steps to SVD algorithm:

Step 1: Select number of columns of a covariance matrix, L such that $k < L < N - k$, where N is the number of sampling points and k is the number of dominant singular values. here, $k = 2$ and $L = 14$

Step 2: Factorized the covariance matrix.

Step 3: Obtain the maximum and minimum eigenvalue of the covariance matrix which are $\lambda_{\max}$ and $\lambda_{\min}$.

Step 4: Compute threshold value γ.

Step 5: Compare the ratio with the threshold. If $\lambda_{\max}/\lambda_{\min} > \gamma$, the signal is present, otherwise, the signal is not present.

Threshold Determination

Random matrix theory based Eigen values detection provides two parameters namely decision threshold and probability of false alarm. Equation (5) shows ratio of maximum to minimum eigenvalues of the signal received for covariance matrix [1]:

$$T_Y = \lambda_{max}/\lambda_{min} \quad (5)$$

Above equation provides the essential statistics to attain the required probability of false alarm using the estimation of detection threshold (g). It is accomplished using the density of the test statistic (T_Y) [1].

The detection threshold in terms of anticipated probability of false alarm is considered by:

$$\gamma_{mme} = \left((\sqrt{N_s} + \sqrt{L})^2/(\sqrt{N_s} + \sqrt{L})^2\right) \times \left(1 + \frac{(\sqrt{N_s}+\sqrt{L})^{\frac{2}{3}}}{(N_s L)} . F_1^{-1}(1 - P_{fa})\right) \quad (6)$$

Where F_1^{-1} 1 represents the inverse of cumulative distribution function (CDF) of the Tracy-Widom distribution of order 1 [1].

The threshold definition is formulated based on deterministic asymptotic values of the minimum and maximum eigenvalues of the covariance matrix, R, when the number of samples, N_s is very large. As shown in the equation (6), it is defined only in terms of number of samples, N_s, level of covariance matrix, L and the desired probability of false alarm, P_{fa} [1].

Threshold optimization is performed using Genetic Algorithm and Grey Wolf Optimization which are explained as follows.

Genetic Algorithm

Genetic Algorithm of GA is an optimization tool that lies on the platform of Heuristic Approaches. Based on the proposal of Darwin principle of fittest survival, this method was introduced to commence optimization problems in soft computing [2]. The first category of results is termed as initial population and all the individuals are candidate solution. Simultaneous study of the population including all candidates and next phase of solutions are generated following the steps of GA [3].

An iterative application of operators on the selected initial population is the initiative process of GA. Further steps are devised based on valuation of this population. The typical routing of GA is described in following pseudo code:

1. Randomly generate initial population.
2. Employ fitness function for evaluation.
3. Chromosomes with superior fitness are valued as parents.
4. New population generation by parent's crossover with probability function.
5. Chromosome mutation with probability to defend system from early trap.
6. Repeat step 2.
7. Terminate algorithm based on satisfaction criteria.

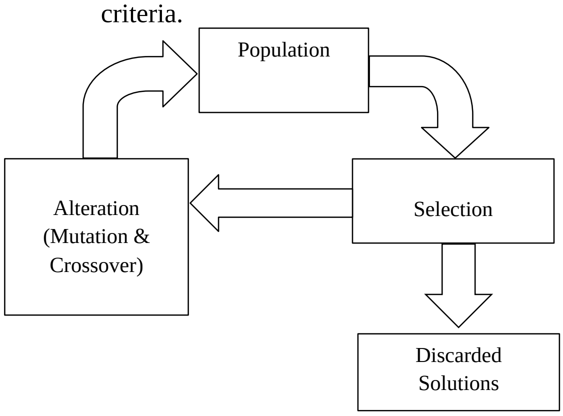

Figure 1: Genetic algorithm evolutionary cycle [3]

Grey Wolf Optimizer

Grey Wolf (Canis Lupus) is a new population based algorithm which is introduced in 2014 by Mirjalili et al. [4]. GWO algorithm inspired by Grey wolves. The method mimicked the social hierarchy and hunting behaviour of Grey wolves. For simulating the leadership hierarchy in GWO algorithm, four groups are defined: alpha, beta, delta, and omega. Furthermore, the three main steps of hunting,

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searching for prey, encircling prey, and attacking prey, are simulated.
This algorithm requires a number of parameters to be set, namely: initialize alpha, beta, and delta, number of search agents, maximum number of iterations, and number of sites selected for neighbourhood search (out of n visited sites) and the stopping criterion.
The main steps of Grey wolf hunting are as follows:

1. Tracking, chasing, and approaching the victim.
2. Pursuing, encircling, and harassing the victim until it stops moving.
3. Attack towards the victim.

For modelling the social hierarchy of wolves until designing GWO, the fittest solution is considered as the alpha (α), accordingly, the second and third best solutions are named beta (β) and delta (δ) respectively. The rest of the candidate solutions are considered to be omega (ω). The x wolves follow these three wolves.
For modelling encircling behaviour, some equations are considered:

$$\vec{D} = |\vec{C}.\vec{X}_p(t) - \vec{X}(t)| \quad (7)$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}.\vec{D} \quad (8)$$

Where t is the current iteration, $\vec{A}$ and $\vec{C}$ are coefficient vectors, $\vec{X}_p(t)$ represents the position vector of the victim. The vectors $\vec{A}$ and $\vec{C}$ can be calculated as below:

$$\vec{X} = 2\vec{a}.\vec{r}_2 - \vec{a} \quad (9)$$

$$\vec{C} = 2.\vec{r}_2 \quad (10)$$

Where $\vec{a}$ include are linearly decreased from 2 to 0 over the course of iterations and $\vec{r}_2$ and $\vec{r}_2$ are random vectors in the range [0, 1].
In GWO, the first three best solutions obtained are saved so far and compel the other search agents (including the omegas) to update their positions due to the position of the best search agents. The following formulas are proposed for this regard.

$$\vec{D}_\alpha = |\vec{C}_1.\vec{X}_\alpha - \vec{X}| \quad (11)$$

$$\vec{D}_\beta = |\vec{C}_2.\vec{X}_\beta - \vec{X}| \quad (12)$$

$$\vec{D}_\delta = |\vec{C}_3.\vec{X}_\delta - \vec{X}| \quad (13)$$

$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1.(\vec{D}_\alpha) \quad (14)$$

$$\vec{X}_2 = \vec{X}_\beta - \vec{A}_2.(\vec{D}_\beta) \quad (15)$$

$$\vec{X}_3 = \vec{X}_\delta - \vec{A}_3.(\vec{D}_\delta) \quad (16)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1(t)+\vec{X}_2(t)+\vec{X}_3(t)}{3} \quad (17)$$

The final position would be in a random position within a circle which is defined by the positions of alpha, beta, and delta in the search space. In other words alpha, beta, and delta estimate the victim position and other wolves update their positions randomly around the victim.

III. Simulation Results

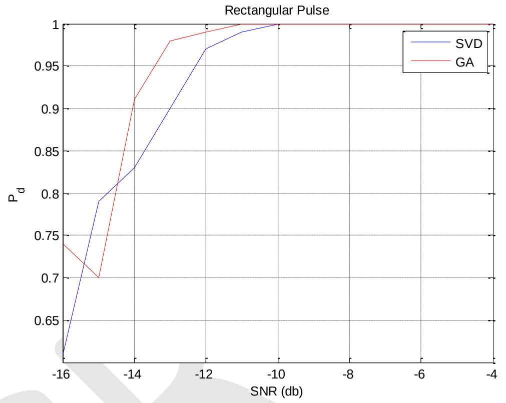

Figure 4: Comparative analysis of SNR vs. P_d graph of rectangular pulse for SVD and GA based methods

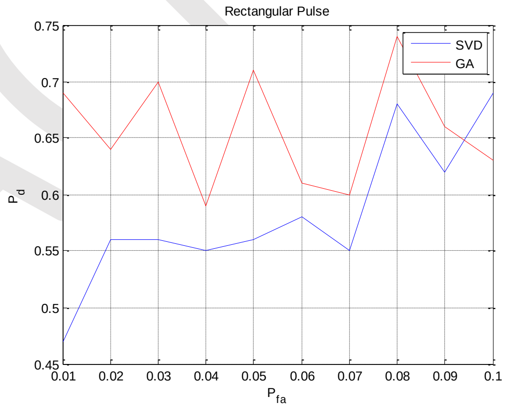

Figure 5: Comparative analysis of P_f vs. P_d graph of rectangular pulse for SVD and GA based methods

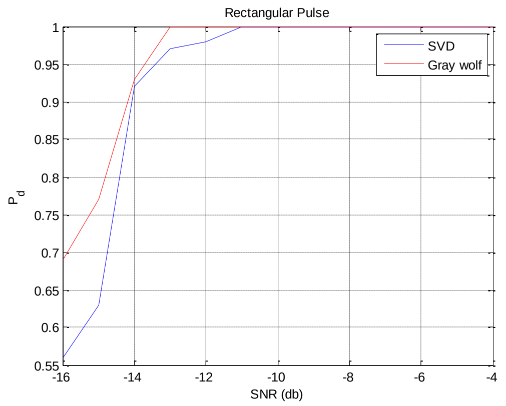

Figure 2: Comparative analysis of SNR vs. P_d graph of rectangular pulse for SVD and GWO based methods

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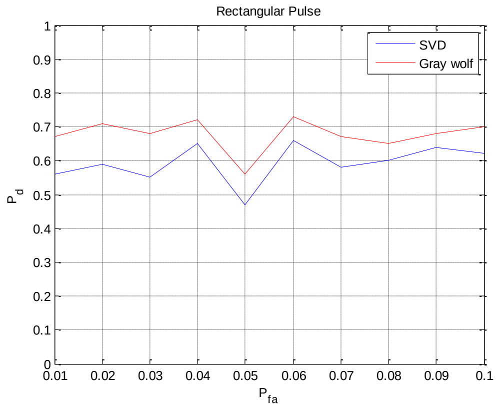

Figure 3: Comparative analysis of P_f vs. P_d graph of rectangular pulse for SVD and GWO based methods

IV. Conclusion

Spectrum is a very valuable resource in wireless communication systems and it has been a major research topic from last several decades. Sensing provides awareness regarding the radio environment so that the spectrum opportunities can be efficiently reused while limiting the interference to the primary user. Simulation results show the performance analysis of Singular Value based Detection (SVD) using Genetic Algorithm (GA) and Grey Wolf Optimization (GWO) for spectrum sensing. On observing the results, it was found that the GWO optimized detection based spectrum sensing outperforms the GA based detection on the basis of probability of detection and SNR.

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