



OPTIMIZATION OF SPECTRUM SENSING IN COGNITIVE RADIO BY DEMAND BASED ADAPTIVE GENETIC ALGORITHM

Subhajit Chatterjee¹ and Jibendu Sekhar Roy²

¹Department of Electronics and Communication Engineering, University of Engineering and Management, Kolkata, West Bengal, India

²School of Electronics Engineering, KIIT University, Bhubaneswar, Odisha, India

E-Mail: chsubhajitch@gmail.com

ABSTRACT

Contemporary wireless communication is administered by spectrum assignment policy and different measurement studies have proved it to be incompetent. In cognitive radio network, to enhance the utilization of radio spectrum, unused spectrum slots of licensed or primary users are sensed and used by secondary users. In Cognitive Radio spectrum sensing performance is more important. The most intelligent aptitude of a cognitive network is to alter the quality of service (QoS) parameters in the tune of the sensed parameters which is varying with time and geographical locations. In this paper, the QoS parameters of cognitive radio, like, bandwidth, signal to noise ratio (SNR), bit error probability (BEP), are optimized using multi-objective genetic algorithm (GA). This is adaptive and demand based optimization of cognitive radio parameters which adapts with the varying nature of available spectrum holes. Probability of detection and probability of false alarm over a set of optimized SNR values are also optimized. The simulation results show that the proposed method gives better real life performance of the cognitive radio network than the generalised genetic algorithm approach.

Keywords: adaptive genetic algorithm, bandwidth, bit error probability, cognitive radio, spectrum sensing.

1. INTRODUCTION

Cognitive radio is used to enhance the spectrum utilization in wireless network [1] is based on the perception spectrum access, mainly dynamic and license holders of a spectrum known as the primary users (PU) allow permission for accessing the spectrum to the non-licensed users i.e. secondary users (SU) as long as interference to PU activity is negligible and limited [2]. The CR transceiver can sense the availability of the communication channels i.e. which are already occupied and which are not and instantly get into the free channels while shunning pre-occupied ones so that the interference to other users is minimized. Spectrum sensing is the most critical task in cognitive radio network where the SU senses a spectrum to sense the whether a PU signal is present or absent and dependent upon the QoS parameters or sensing parameters like bandwidth, signal to noise ratio (SNR), bit error probability, spectral efficiency, throughput etc. Spectrum sensing and estimation is the primary step to implement cognitive radio system [3-4]. Spectrum sensing is performed by the SU to sense a spectrum of interest with the purpose of detecting the presence of any PU signals to avert interference and identify spectrum opportunity for secondary access. Using genetic algorithm, spectrum efficiency can be obtained up to 98.5% with corresponding decrement of sensing time [1, 5-6]. CR is intelligent enough to sense and gather information from the spectrum in the real time environment and can adapt itself to the aura by changing different sensing parameters like signal to noise ratio (SNR), frequency, power etc. The spectrum is utilized more efficiently. Making the necessary changes, a CR senses the spectrum in an enhanced way. It is observed that the sensing methods based on cooperative sensing technique can reduce the probability of false alarm which in turn decrease problems associated with concealed users [7]. To alleviate the impact associated with multipath

fading, shadowing and uncertainty of receiver, it is found that cooperative spectrum sensing is an effective method for the improvement of the detection performance [8]. So, in this paper, cooperative spectrum sensing is considered where secondary users are distributed in nature i.e. distributed spectrum sensing scheme is adopted. After optimization of the sensing parameters, status of probability of detection (P_d) and probability of false alarm (P_f) are also studied with the variation of SNR.

2. RELATED WORK

A generalized GA based approach is proposed [3]. Where P_d and P_f are studied with the variation of few sensing parameters. A throughput-aware routing algorithm for enhancing throughput and decreasing end-to-end delay in industrial cognitive radio sensor networks is proposed [6]. A bandwidth-aware localized routing algorithm is proposed [9] which is suitable for applying to large networks since it is capable of reducing the high computational complexity in such networks. Algorithms, based on the prime principles of GA for optimization of the radio transmission parameters, are also proposed [4, 10]. But, spectrum hole has the time-varying characteristic in cognitive radio network. The activity of the primary user is one of the concerned and prime factors in time-varying characteristic of the radio spectrum i.e. it is observed by the CR user that the available spectrum is heterogeneous in nature which is varying over time and space due to the PU activities [10-12]. Aiming at minimizing the probability of total detection errors, based on the law of total probability a novel target function (which also denotes the so-called comprehensive sensing performance metric) was proposed for optimization of sensing parameters [13]. An adaptive genetic algorithm is proposed to optimize the sensing parameters like bandwidth, throughput and spectral efficiency [14]. In this paper, sensing parameters like bandwidth, signal to noise



ratio (SNR), and bit error probability (BEP) are taken into consideration and optimized using GA. These parameters are optimized on the basis of need and demand i.e. taking the time and location varying characteristic of spectrum hole under consideration. After having these parameters optimized on a real time basis, P_d and P_f are also studied with the variation of optimized values of SNR.

In the proposed work, a performance enhancement of the operation of CR is attempted in the context of time and location varying characteristic of spectrum holes.

3. DEMAND BASED ADAPTIVE GENETIC ALGORITHM

To improve the performance of the algorithm, an adaptive GA is proposed in this paper, where operators and parameters are adaptive as per the changing conditions of the spectrum. This is performed by controlling the operators and parameters in such a way that they will change the values if the population is not producing individuals fit enough. The CR engine is simulated by GA to determine the optimal set of sensing parameters. One multi-objective fitness function is used with weighted sum approach with an intention that each objective can be represented by a level to represent the weight of each objective.

In optimization using GA, the most imperative step is developing a fitness measure to find the total fitness of a chromosome and a proper description of a chromosome is very much required.

In wireless communications, QoS requirements of a user or application have great significance. In this work, each gene of the chromosome is assigned with different analog values depending on the step size and the algorithm runs with these different analog values of sensing parameters, denoted as application requested value. The application requested value will be different in different times and locations for each parameter.

The analog values are encoded into digital levels using binary encoding. i.e. initially each gene in a chromosome is represented by a decimal number. But for the process of mutation, chromosomes are converted into binary and each gene is represented by bit strings. This conversion is used because in mutation an alteration of a single bit will form a new chromosome. The structure of chromosome comprises of the five parameters or genes. The parameters are bandwidth (BW), signal to noise ratio (SNR), and bit error probability (BEP). These parameters or genes are integrated to form a string (chromosome). Table-1 gives the summarized values of the order of the first three genes, the ranges of operation and the binary bits required to encode the corresponding integer values.

Table-1. Summarized values of the chromosome structure.

Gene	Bandwidth (Gene I) (MHz)	SNR (Gene II) (dB)	BEP (Gene III)
Ranges	450 to 3000 MHz	10 to 48dB	0.00059426 to 0.10425177
Step size	10	0.5	0.00000185
Decimal value range	2550	38	0.00047175
Number of bits assigned	8	7	8

Other two genes i.e. P_d and P_f are added to the chromosome structure on later stage and optimized with the variation of optimized values of SNR. Target values of P_d and P_f are assumed as 0.8 and 0.2 respectively. In this work *Roulette wheel* selection is used with Monte-Carlo adaptation along with the incorporation of the time and geographical variance of the radio spectrum as mentioned earlier.

4. FITNESS FUNCTION & CHROMOSOME STRUCTURE

The three parameters specified as genes in chromosome structure need 23 bits for its construction. The composition of this bit string is important because the mutation operation performs at bit level. It is assumed that the parameters be x_1 , x_2 and x_3 corresponding to the bandwidth, SNR and bit error probability, respectively. Fitness functions for each parameter are generated by the formula [4].

$$f_i = \left[\frac{w_i |x_i - x_i^d|}{x_i^d} \right] \text{ if } |x_i - x_i^d| < x_i^d \quad (1)$$

where, x_i^d is the required QoS parameter. w_i is the weight subject to

$$\sum_{i=1}^5 w_i = 1 \quad (2)$$

where, $i=1, 2, 3, 4, 5$.

Overall fitness function f_{total} is the cumulative sum of individual fitness functions of the parameters given as

$$f_{total} = \sum_{i=1}^5 f_i \quad (3)$$

Ideally each w_i should be 25% which signifies each gene will have the same weight. But in practical scenario, the weighting factor w can vary according to QoS specifications. The probability of selection for each individual (chromosome) is given by

$$p_i = \frac{f_i}{\sum_{i=1}^n f_i} \quad (4)$$



p_i is the probability of selection of individual chromosome, f_i is the fitness of the individual gene i and n are the number of chromosome in the population.

Bandwidth is taken as independent variable and as mentioned earlier, sensing parameters like SNR and BEP are optimized over a pre-assumed frequency range on radio spectrum. The pre-assumed range of bandwidth is shown in Table-1.

SNR can be expressed as

$$\text{SNR} = (P \times B) / (N \times R \times m) \quad (5)$$

$$\text{SNR(dB)} = 20 \log_{10}(\text{SNR}) \quad (6)$$

And BEP (P_e) can be expressed as

$$P_e = Q[\sqrt{(2 \times \alpha \times P \times B) / (N \times R)}] \quad (7)$$

Where P is the transmitted power, B is the frequency of operation, N is the noise Power, R is the symbol rate, m is the modulation index and α is a constant. Table-2 shows the summarized structure of simulation parameters.

Table-2. Summary of simulation parameters.

Parameters	Working equation	Constant values
SNR	Expressed by Eq.5 and Eq. 6	$P=250 \mu\text{W}$ $N= 1 \text{ W}$ $R = 270833 \text{ bit/s}$ $m = 0.7$
BEP	Expressed by Eq. 7	$P= 250\mu\text{W}$ $N = 1\text{W}$ $R = 270833\text{bit/s}$ $\alpha= 0.68$

For the adopted distributive co-operative spectrum sensing, two hypotheses are considered.

When primary user is active, signal received by the secondary user [1, 9],

$$y(n) = s(n) + u(n): \text{hypothesis 1, } H_1 \quad (8)$$

When primary user is inactive

$$y(n) = u(n): \text{hypothesis 2, } H_2 \quad (9)$$

Here, $s(n)$ is the primary user's signal.

SNR can also be expressed as [15]

$$\text{Signal-to-noise ratio (SNR)} = \frac{\sigma_s^2}{\sigma_u^2}$$

Here σ_s^2 is the variance of primary signal $s(n)$ and σ_u^2 is the variance of noise $u(n)$.

Probability of detection (P_d) and probability of false alarm (P_f) is formulated by [9,15].

$$P_d(\epsilon, \tau) = Q\left[\left(\frac{\epsilon}{\sigma_u^2} - 1\right)\sqrt{\frac{\tau f_s}{2\gamma+1}}\right] \quad (10)$$

$$P_f(\epsilon, \tau) = Q\left[\left(\frac{\epsilon}{\sigma_u^2} - 1\right)\sqrt{\tau f_s}\right] \quad (11)$$

Here, τ is the sensing time, f_s is the sampling frequency, W is the bandwidth and ϵ is the detection threshold.

Eq. 10 and Eq. 11 can be written as,

$$Q^{-1}P_f = \left[\left(\frac{\epsilon}{\sigma_u^2} - 1\right)\sqrt{\tau f_s}\right] \quad (12)$$

$$Q^{-1}P_d = \left[\left(\frac{\epsilon}{\sigma_u^2} - 1\right)\sqrt{\frac{\tau f_s}{2\gamma+1}}\right] \quad (13)$$

Where Q is the complementary distribution function.

5. TOTAL FITNESS MEASURE (TFM) AND GENE FITNESS MEASURE (GFM)

Firstly initial population is created and each element of the initial population matrix is represented in binary form. To encode the real values of each parameter, corresponding decimal values are used to map them to each binary set of numbers.

To iterate the algorithm, few initial values are pre assumed as shown in Table-3.

Table-3. Pre-assumed initial values.

Input parameters	Values
Initial population size	100
Maximum number of generation iterated	100
Crossover rate	80%
Mutation rate	2%

Each gene is assigned with decimal values and is derived from number of bits assigned to the individual gene and the step size. The individual genes are bandwidth, SNR and bit error probability which is gene1, gene2, gene3 respectively. Each gene has an operating range and the entire operating range has been alienated into few decimal values which is dependent on the step size of individual gene. Each decimal value of a gene is termed as application requested value.

For deriving TFM and GFM with chromosome, the decimal values of genes, configuration of gene and total number of bits in a chromosome are designed. Gene weight of each gene is calculated and the demand & need based adaptability of the GA is taken into account i.e. the application requested value of each gene. Application requested value of bandwidth can be of any value which corresponds to a frequency and this frequency has corresponding application requested values of other genes in the chromosome structure i.e. spectral efficiency and throughput. This application requested values represent the



respective values of the pre-mentioned genes in the chromosome.

The TFM can be expressed as,

$$\text{TFM} = 100 - \sum (\text{gene fitness measure of all genes}) \quad (14)$$

$$\text{i.e. TFM} = 100 - \sum (\text{GFM_G1} + \text{GFM_G2} + \text{GFM_G3}) \quad (15)$$

where, GFM_G1, GFM_G2 and GFM_G3 are the individual gene fitness measures.

Table-4 shows number of bits assigned to each gene and the application requested gene value of each gene. In this work, three cases i.e. three application requested values are studied but the algorithm can be iterated for any application requested values. Fitness points for each gene are also shown in Table-4.

Table-4. Organization of genes, application requested values and fitness point.

Number of bits assigned to each of the genes of the chromosome	Bandwidth (Gene I)		SNR (Gene II)	BEP (Gene III)
	8		7	8
Application requested gene values	i)	83	59	215
	ii)	163	98	248
	iii)	232	121	254
Fitness points of genes (in decimal)	110		50	110

Table-4 does not include P_d and P_f as they are added on later phase and optimized after having optimized values of SNR

6. SIMULATION RESULTS AND DISCUSSIONS

The simulations are done for three application requested values i.e. three cases has been studied. The values are so chosen that it covers almost the entire range of decimal values. The result is shown for four cases i.e. four sets of application requested values. In each case, the plot of total fitness measure, gene fitness measure, variation of each parameter, un-optimized and optimized regions of each parameter are shown.

6.1 Case study 1

Application requested decimal values:

Bandwidth=83, SNR=59, Bit error probability=215, Initial population=100, Max generation=100.

Figure-1 and Figure-2 show the TFM and GFM of the adaptive GA.

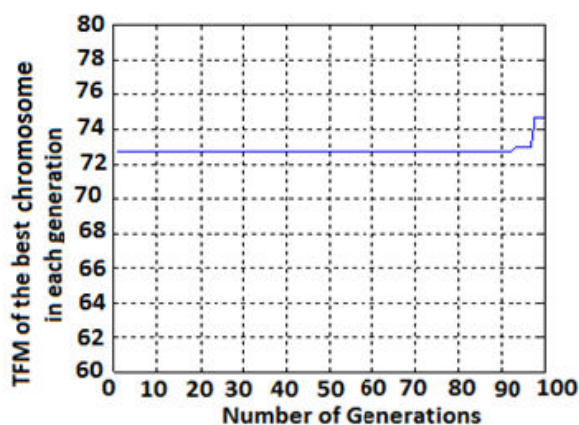


Figure-1. Variation of TFM of the best chromosome with number of generation.

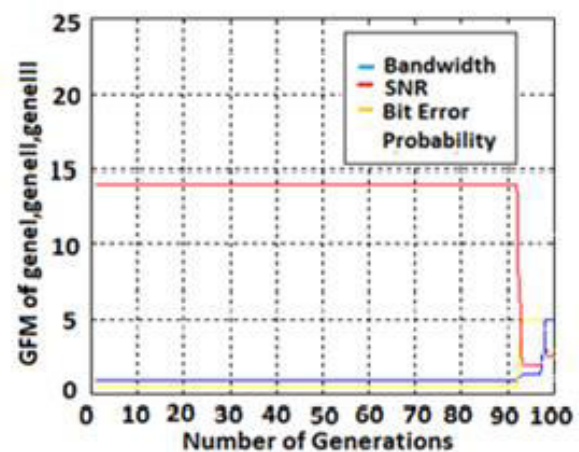


Figure-2. Variation of GFM of gene I, gene II, gene III, with number of generations.

Figure-3 and Figure-4 show the GA optimized plots of SNR and BEP for application requested values.

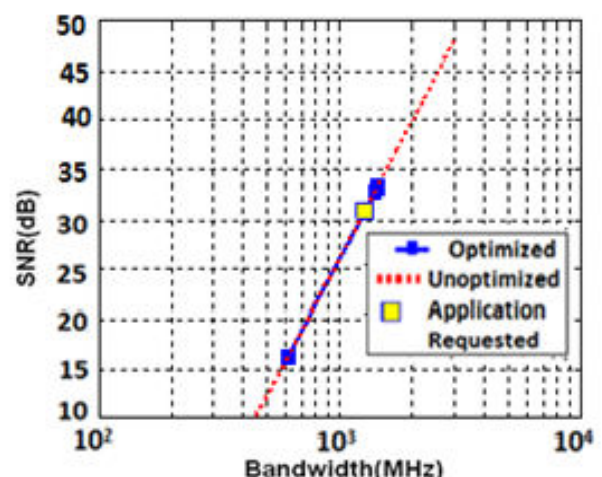


Figure-3. Variation of SNR with bandwidth.

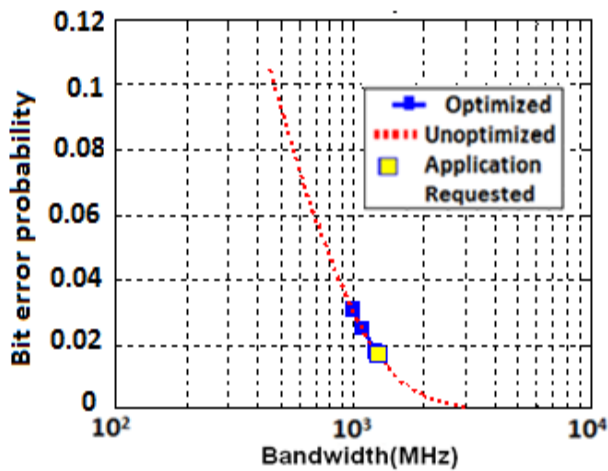


Figure-4. Variation of bit error probability with bandwidth.

The graphs show that using GA, SNR= 31dB where the exact value of the corresponding bandwidth is 1280MHz, corresponds to the application requested value of bandwidth 83 and the corresponding decimal value of received SNR is 59 which is equal to the calculated value 31dB. GA result shows that the BEP=0.0168, corresponds to the application requested value 215 and the exact value of the corresponding bandwidth is 1282 MHz and the actual value corresponding to application requested value 83 is 1280 MHz. There is a deviation of 2MHz.

Figure-5 and Figure-6 show the variation of P_d and P_f with SNR.

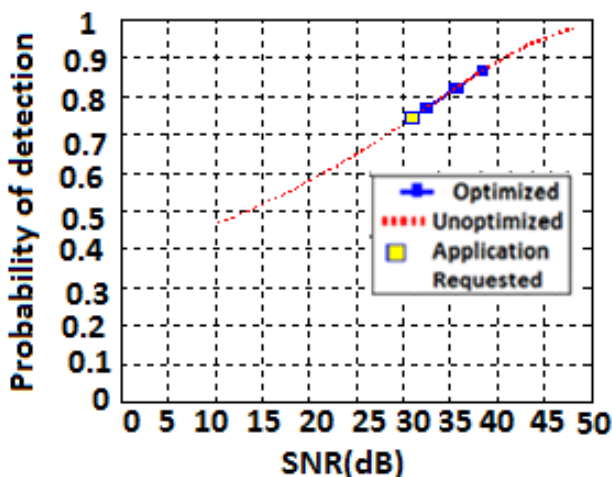


Figure-5. Variation of probability of detection with SNR.

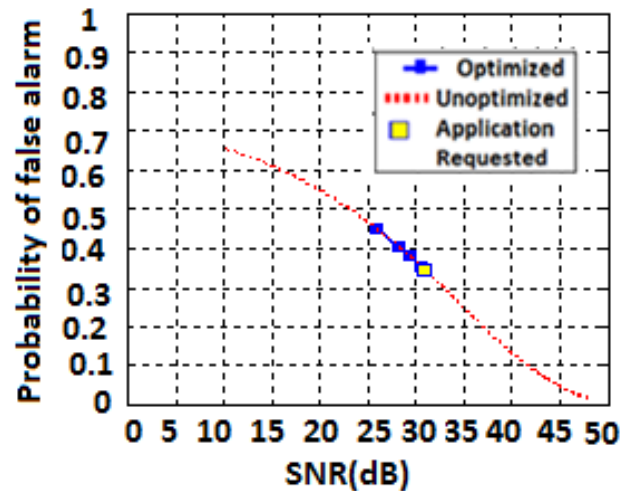


Figure-6. Variation of probability of false alarm with SNR.

It can be seen from Figure-5 and Figure-6 that for the aforesaid application requested values, the P_d is maximized and P_f minimized which is one of the prime requirement for faithful sensing of spectrum. In this case, the values for P_d and P_f are 0.75 and 0.35 respectively, as apparent from the plots whereas the calculated theoretical values for application requested analog value of SNR =59 i.e. 31dB is 0.742 and 0.345 respectively. So, it can be stated that after optimization the values of P_d and P_f has attained almost the calculated value.

6.2. Case study 2

Application requested decimal values:

Bandwidth=163, SNR=98, Bit error probability=248, Initial population=100, Max generation=100.

Figure-7 and Figure-8 show the TFM and GFM of the proposed adaptive GA.

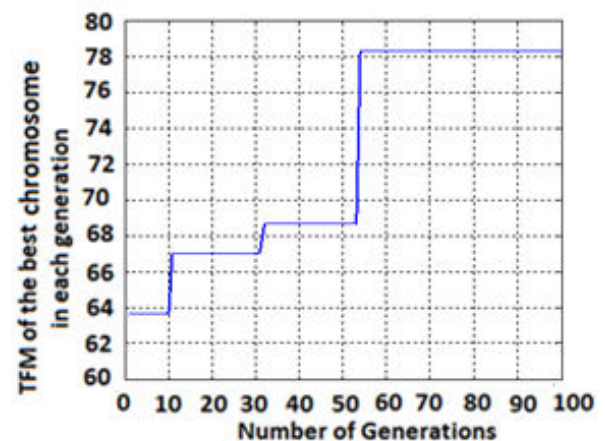


Figure-7. Variation of TFM of the best chromosome with number of generation.

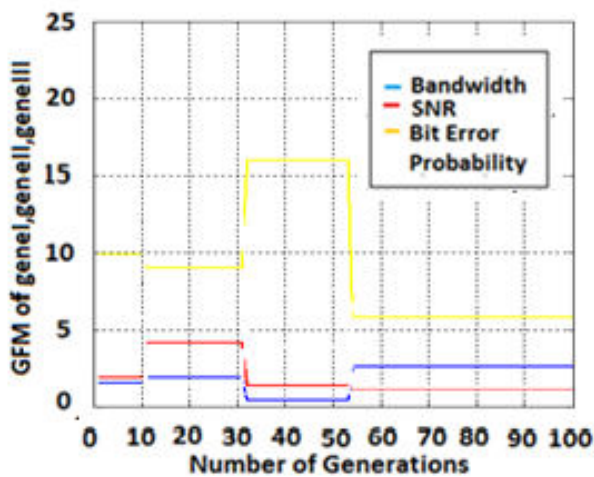


Figure-8. Variation of GFM of gene I, gene II, gene III, with number of generations.

Figure-9 and Figure-10 show the GA optimized plots of SNR and BEP for the mentioned application requested values in case study 3.

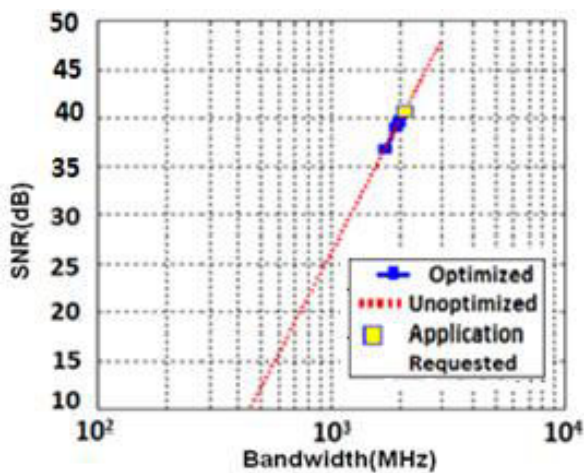


Figure-9. Variation of SNR with bandwidth.

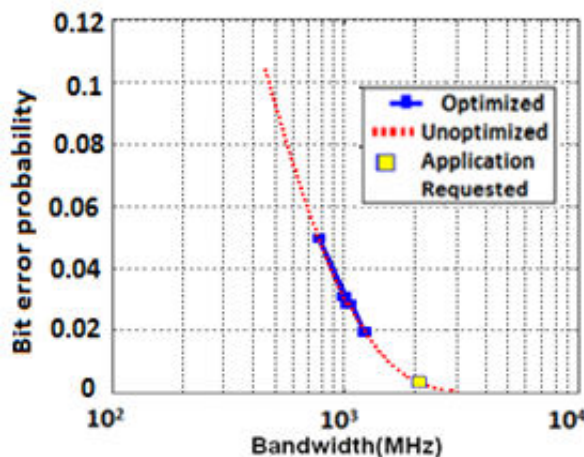


Figure-10. Variation of bit error probability with bandwidth.

It can be seen from the plots that after iteration of the proposed GA, SNR= 40.75dB and the exact value of the corresponding bandwidth is 2018MHz, corresponds to the application requested value of bandwidth 163 and the corresponding decimal value of received SNR is 98 which is equal to the calculated value 40.75dB. GA result shows that the BEP=0.00344, corresponds to the application requested value 248(calculated value is 0.00343) and the exact value of the corresponding bandwidth is 2078 MHz and the actual value corresponding to application requested value 163 is 2078 MHz. There is no deviation in bandwidth but there is a variation of 0.0001, which is negligible.

Figure-11 and Figure-12 show the variation of P_d and P_f with SNR for case study 2.

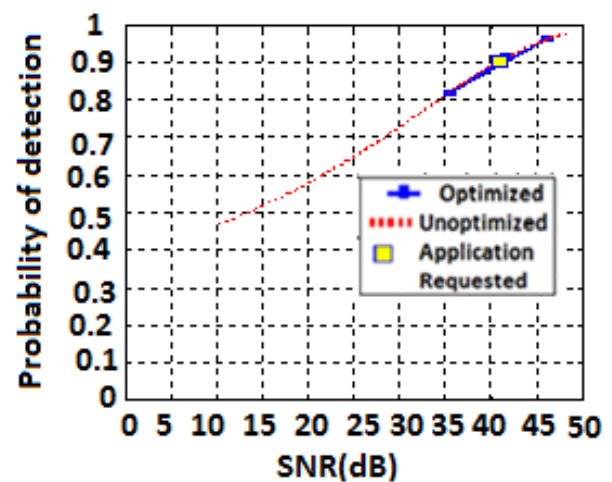


Figure-11. Variation of probability of false detection with SNR.

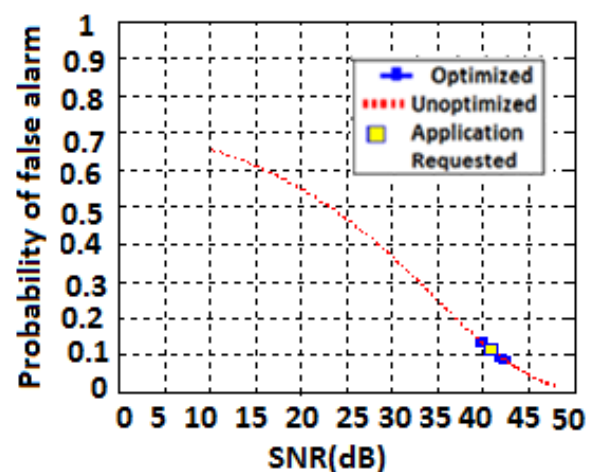


Figure-12. Variation of probability of false alarm with SNR.

Like earlier case, in case study 2, it can be observed from Figure-11 and Figure-12 that for the application requested values as mentioned this case study, the P_d is maximized and P_f minimized. In this case, the



values for P_d and P_f are 0.9 and 0.1 respectively, as derived from the graphs and the calculated theoretical values for application requested value of SNR =98 i.e. 40.75dB are 0.903 and 0.116 respectively. For this case also, it can be said that after the process of optimization the values of P_d and P_f has reached almost the calculated value.

6.3. Case study 3

Application requested decimal values:

Bandwidth=226, SNR=121, Bit error probability=254, Initial population=100, Max generation=100.

Figure-13 and Figure-14 show the TFM and GFM of the adaptive GA for the application requested value mentioned in this case study.

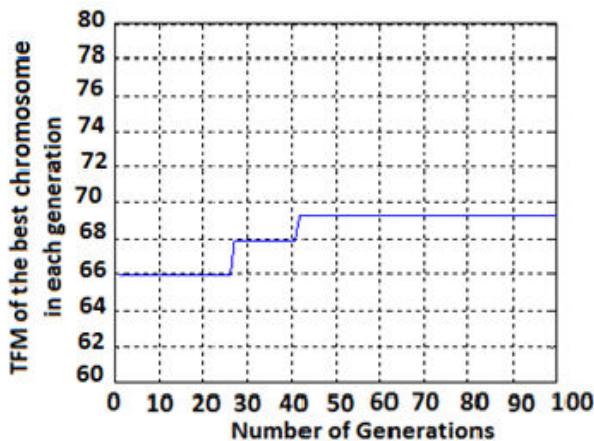


Figure-13. Variation of TFM of the best chromosome with number of generation.

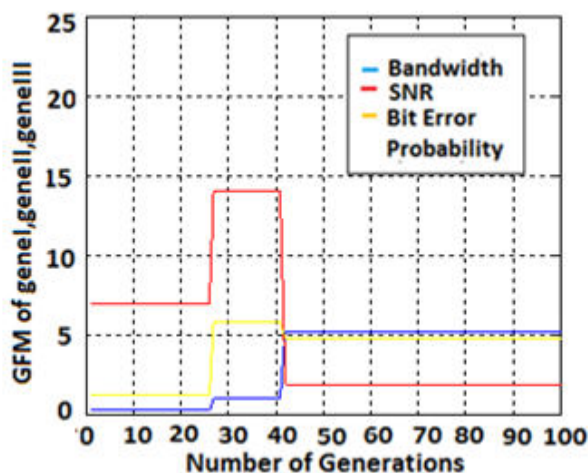


Figure-14. Variation of GFM of gene I, gene II, gene III with number of generations.

Figure-15 and Figure-16 show the GA optimized plots of SNR and BEP for the pre-mentioned application requested values.

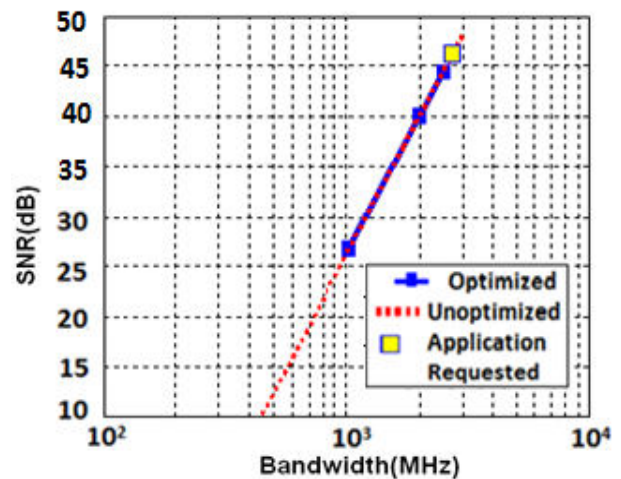


Figure-15. Variation of SNR with bandwidth.

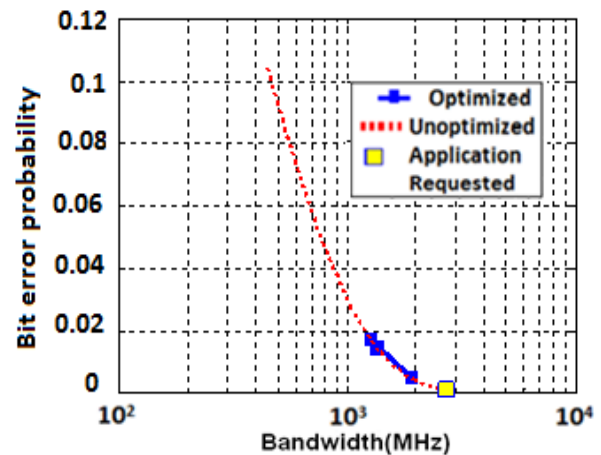


Figure-16. Variation of bit error probability with bandwidth.

The graphs show that after the GA is executed, SNR= 46.5dB where the exact value of the corresponding bandwidth is 2770MHz, corresponds to the application requested value of bandwidth 232 and the corresponding decimal value of received SNR is 121 which is exactly equal to the calculated value 46.5dB. We got the BEP=0.0010006, which is very close to application requested value 254(0.0010007) and the calculated value of the corresponding bandwidth is 2774MHz and the actual value corresponding to application requested value 232 is 2770MHz. Here the deviation is of 4MHz (0.99%). Figure-17 and Figure-18 show the variation of P_d and P_f with SNR for case study 3.

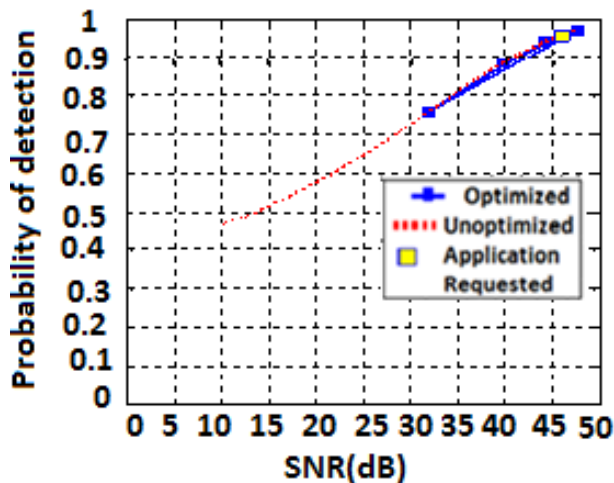


Figure-17. Variation of probability of false alarm with SNR.

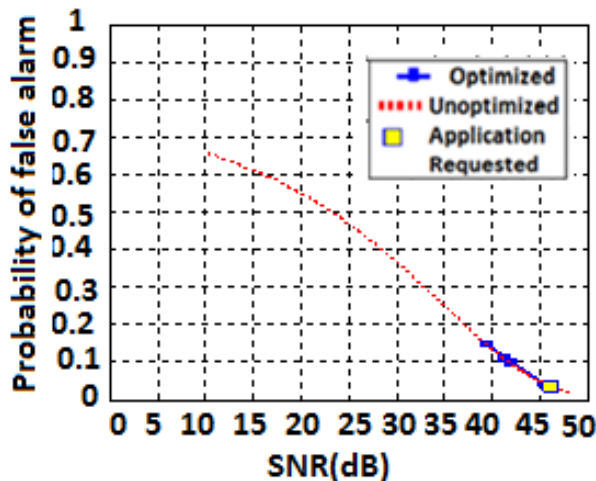


Figure-18. Variation of probability of false alarm with SNR.

In case study3 also, it can be noticed from Figure-17 and Figure-18 that for the application requested values of this case study, the maximization of P_d and minimization of P_f are established. In this case, the values for P_d and P_f are 0.95 and 0.038 respectively, as seen from the graphs and the calculated theoretical values for application requested value of SNR =121 i.e. 46.5dB are 0.964 and 0.030 respectively. It can be stated that after the iteration of optimization algorithm the values of P_d and P_f has reached almost the calculated value.

7. CONCLUSIONS

In this paper, an adaptive genetic algorithm based optimization is proposed which is demand and need based. The parameters chosen are good contributors to cognitive radio system. The parameters were encoded using binary encoded method into chromosomes. Some deviations in the calculated values and the optimized values are observed which are due to the randomness and can be minimized/eliminated by several executions/iterations of

the proposed GA. Any sensing parameters can be optimized by the proposed algorithm. The prime intention of the work is a proposition of an algorithm taking in account the different regions of the spectrum and optimization of the QoS parameters taking in account the time and location varying nature of the spectrum of the radio spectrum. In comparison to the related works discussed earlier, the simulation results shows that the proposed method gives better real life solution to the cognitive system as time varying nature of spectrum hole is considered in every step and the proposed algorithm is having the capability of adoption with the varying nature of spectrum holes.

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