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Cognitive Radio Parameter Optimization and Adaptation using Genetic Algorithm

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***Abstract*—Cognitive radio technology provides operational flexibility and adaptability of communication system according to the RF environment scenario. The main goal is to use the available resources-bandwidth, power, etc optimally in the radio network. In this paper, Genetic Algorithm is used for selection of optimal set of RF parameters for communication over a CR network. The chromosome structure comprises RF genes. Each gene is in the form of binary string, representing RF parameter. Genetic Algorithm is used to select the fittest set of RF parameters for optimal communication in a given RF environment. Fitness Measure parameter is used for evaluating the survival of each individual or chromosome.**

Keywords—RF Parameters; Genetic Algorithm; Cognitive Radio; Fitness Measure; Chromosome.

I. INTRODUCTION

For the past two decades there is a rapid increase in the use of wireless application, which has increased the demand of bandwidth. This increasing demand of bandwidth has resulted in spectrum scarcity. This spectrum scarcity is because of inefficient use of electromagnetic (EM) spectrum which is in fact available in plethora. EM spectrum confines all possible frequency or wavelength of electromagnetic radiation which constitutes visible light. The spectrum is controlled by government authorities like Department Of Telecommunications (DOT). According to the Radio Act of DOT, only licensed users are allowed to use the EM spectrum. At some places this spectrum is fully utilized, at some it's moderately and at some places it's underutilized. Spectrum underutilization results in a decrease in the spectral efficiency of the wireless networks. In order to solve this underutilization problem cognitive radio (CR) has been introduced. This device adapts and changes its behavior according to the radio environment. Cognitive radio which is self organizing system emerges as a promising wireless communication technology in enhancing the utilization of the licensed spectrum band by allowing the secondary user or unlicensed user, to access the spectrum band without intruding the licensed user or primary user. That is, if primary user arrives on a channel then the cognitive radio instantly shifts to another channel or remains silent to avoid the interference with the primary user.

A CR device must have four qualities: first of all the device should be intelligent enough to sense the radio environment it is operating in. Secondly, it should be able to understand the quality of service (QOS) requirement which is an important constraint. Thirdly, it should be aware of the regulatory policies enforced by the licensing authorities. Fourthly the device must have the understanding of the radio parameters. For this reason, the most viable and promising solution is the cognitive radio network.

During process of spectrum allocation there are several issues are to be considered. One such issue is periodic suspensions in the transmission of the Cognitive Radio user which can cause severe deterioration in their quality of Service (QOS). To deal with such troublesome scenarios a new model is introduced in which CR anticipates the future arrival of the primary user on different channels and chooses the best channel for its communication relying upon the list primary user activity. The solution to the problem of CR performance optimization is to apply evolutionary computing and specifically in this work genetic algorithm is used, because of its multi-objective optimization capability. This algorithm can be used to solve the problem which has large search spaces because of the generation of the completely new population for each search space.

GA has the least probability of getting stuck in the local extremes as compared to other techniques. One of the prime advantages of GA over other technique is parallelism, which can really accelerate the simulation results. In this scheme, the objective function converges to the optimal value and then stopping condition is accomplished based on the desired criteria.

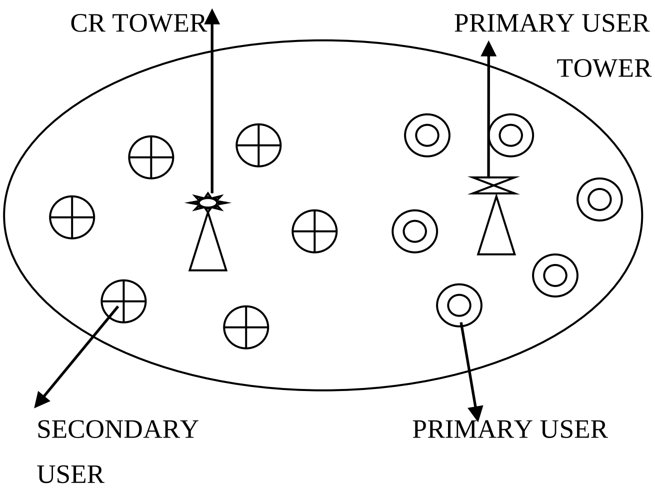

Fig.1. Infrastructure of cognitive radio network

In this work, Genetic Algorithm is used for selection of optimal set of RF parameters for communication over a CR network. The chromosome structure composed of RF genes. Each gene is in the form of binary string, representing RF parameter. Genetic Algorithm is used to select the fittest set of RF parameters for optimal communication in a given RF

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environment. Fitness Measure parameter is used for evaluating the survival of each individual or chromosome. The composition of this work is ordered as follows: Section II explains about the RF operation parameters considered in this work. Genes and chromosome structure is described in Section III. Section IV defines genetic algorithm and its specifics. Fitness measure and its relation with genes is described in Section V. Simulation Results under different situation is shown in Section VI. Finally, conclusion and observations are mentioned in section VII.

II. RF ENVIRONMENT

As the Cognitive Radio works in observe, decide and act cycle so the knowledge acquired from the radio environment should have an adequate representation in the GA to get an optimized solution. The RF parameters that we consider for this work are stated below in the order they are going to be considered in the chromosome.

1. Operating Frequency Band (FB)
2. Modulation technique (MOD)
3. Bit Error Rate (BER)
4. Data Rate (DER)
5. Power Transmitted (PWR)
6. Interference to primary user (ITPU)
7. Transmission to Opportunity Index (TOI)

The above RF parameters act as genes for the chromosomes.

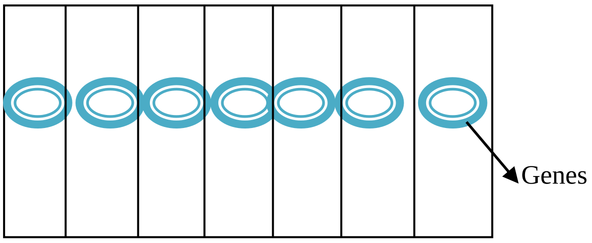

Fig.2. Chromosome structure

In order to get rid of computing complications in our optimization model we have taken the size of chromosome structure as small as possible. Collection of chromosome constitutes population.

III. IMPLEMENTATION OF GENETIC ALGORITHM IN COGNITIVE RADIO NETWORK

In the implementation of cognitive radio network (CRN), the channel selection and parameter adaptation plays an important role. In order to render a better quality of service with respect to data rate, service time and channel switching i.e. minimal interruptions, a new gene which is known as TOI (transmission opportunity index) is added inside the chromosome structure. The TOI gene helps in reducing the number of retransmissions which usually occurs due to collisions with the primary user, thus it helps in saving the transmission power. In this work channel history or activity of primary user has been obtained. From [6] TOI lies between 0.3674~0.9394.

A. GENES AND CHROMOSOME STRUCTURE

Genes are related to chromosome in the same manner as chromosomes are related to GA(genetic Algorithm).A chromosome can consist of several genes but Chromosome should be represented in such a way that it gives out complete information about the solution of the problem. In this work, the chromosome is made up of seven genes such as Opearting Frequency Band(FB), Modulation Technique(MOD) ,Bit Error Rate(BER),Power Transmitted(PWR), Data Rate(DR), Interference To Primary User(ITPU) and Transmission to Opportunity Index(TOI).The union of all these genes form a chromosome which consists of 30 bits.

Encoding of the bits is performed as follows:

I. Operating Frequency Band (FB)

It is the first gene of the chromosome structure. In wireless communication, each transmitter needs a frequency band for its operation. Considering the current communication environment, each technology is associated with fixed spectrum band, on the other hand Cognitive Radio can operate on any convenient band. According to IEEE 802.22 standards, the range of operating frequency band varies from 54MHz to 862 MHz having step size of 8MHz. Therefore for encoding process the total number of bits required by FB gene is 7 bits. Hence the variable of encoding varies from 0000001 to 1100110.

II. Modulation Technique (MOD)

It is the second gene of the chromosome structure. In wireless communication MOD defines the link between two different types of waveforms. According to IEEE 802.22 standards, the modulation schemes considered here are BPSK, QPSK, 8-QAM and 16-QAM. Therefore for encoding process the total number of bits in which all the above modulation schemes can be represented is two bits. Hence the variable of encoding varies from 00 to 11.

III. Bit Error Rate (BER)

The next important RF parameter for wireless communication is Bit error rate. It describes the number of received bits that have been amended due to interference or noisy channel. Each application can endure BER up to a certain value. BER range can be taken from 10^{-1} to 10^{-15} having step size of 10^{-1} [4][5].Therefore for encoding process the total number of bits in which this Bit Error Rate can be represented is 4. Hence the variable of encoding varies from 0001 to 1111.

IV. Data Rate (DR)

The next important RF parameter is data rate. It describes the number of bits transmitted per unit time. The requirement of data rate varies from one application to another. In this work, data rate varies from 50 kbps to 1.55 Mbps having step size of 50 kbps. Therefore for encoding process the total number of bits in which this DR can be represented is 5. Hence the variable of encoding varies from 00001 to 11111.

V. Power Transmitted (PWR)

The fifth RF parameter for the wireless communication system is power. In this work power varies from 3 dbm to 45 dbm having step size of 3 dbm. Therefore for encoding process the total number of bits in which this PWR can be represented is 4. Hence the variable of encoding varies from 0001 to 1111.

VI. Interference to Primary user (ITPU)

ITPU, in the cognitive radio network is one of the important RF parameter. It is taken into consideration such that the performance of primary user is unaffected due to the transmission power of the CR. In this work ITPU varies from 0.0625 to 0.9375 having step size of 0.0625. Therefore for encoding process the total number of bits in which this ITPU can be represented is 4. Hence the variable of encoding varies from 0001 to 1111.

VII. Transmission Opportunity Index (TOI)

TOI is one of the most important parameter for channel selection process. TOI is dependent upon the activity matrix of the primary user. The future use of a channel by the CR is determined with the help of Transmission Opportunity Index (TOI). Greater the value of TOI, lesser the probability of interference by the primary user ,hence the chances of channel usage by the Cognitive user increases. The value of TOI lies between 0.3679 to 0.9394 [6] and the number of time slots taken is 100. Therefore from the equation below, the set of values taken are starting from 0.3697 to 0.9297 with the step size of 0.04, which is within the range and correspondingly finding out the number of time slots utilized by the primary user in each particular channel.

$$H=\begin{bmatrix} \Psi^{1}_{1} & \Psi^{1}_{2} & \Psi^{1}_{3} \ldots\ldots & \Psi^{1}_{s} \\ \Psi^{2}_{1} & \Psi^{2}_{2} & \Psi^{2}_{3} \ldots\ldots & \Psi^{2}_{s} \\ . & . & . & . \\ . & . & . & . \\ \Psi^{k}_{1} & \Psi^{k}_{2} & \Psi^{k}_{3} \ldots\ldots & \Psi^{k}_{s} \end{bmatrix} \quad (1)$$

where H matrix describes about the History patterns of the primary user for k number of channels.

$$\Psi^{k}_{s} = [\Psi^{k}_{1}, \Psi^{k}_{2}, \Psi^{k}_{3} \ldots\ldots \Psi^{k}_{s}] \quad (2)$$

where Ψ^{k}_{s} represents the history vector of a specific channel 'k' for 's' time slots.

$$\eta_s^{k} = \exp\left(-\sum_{s=1}^{Ts} \Psi^{k}_{s} / T_s\right) \quad \text{for } \Psi^{k}_{s} > 0 \quad (3)$$

where η denotes transmission opportunity index (TOI). Ts represent the total number of time slots which is equal to 100. 's' denotes the time slots and 'k' indicates the channel number.

IV GENETIC ALGORITHM AND SPECIFICS

An evolutionary computational technique, Genetic Algorithm, is based on the fact that the measure of success for an optimized problem solution is its fitness, i.e the survival of fittest individual or chromosome.Chromosome structure is developed. Using random generation method initial population is generated. Fitness measure is evaluated using each chromosome. Two selection methods are taken in this work. These are 'Elitism' and 'Tournament selection'. Elitism facilitates in getting the best elite individual/ chromosomes amongst others chromosomes having the best fitness measure in the initially generated population, which is carried forward in the next generation. Tournament Selection is done after Elitism as it recognizes the best optimal solution. A particular size of tournament is defined which helps in selecting the best individual.

Crossover function is applied on two individuals of the respective tournament. If randomly produced value is less than or equals to the cross over rate then the gene of new individual will be taken from the first individual of the tournament selection. Otherwise the gene of the second individual is taken. Pseudo population is thus obtained after cross over application on selected individual of the initial population.

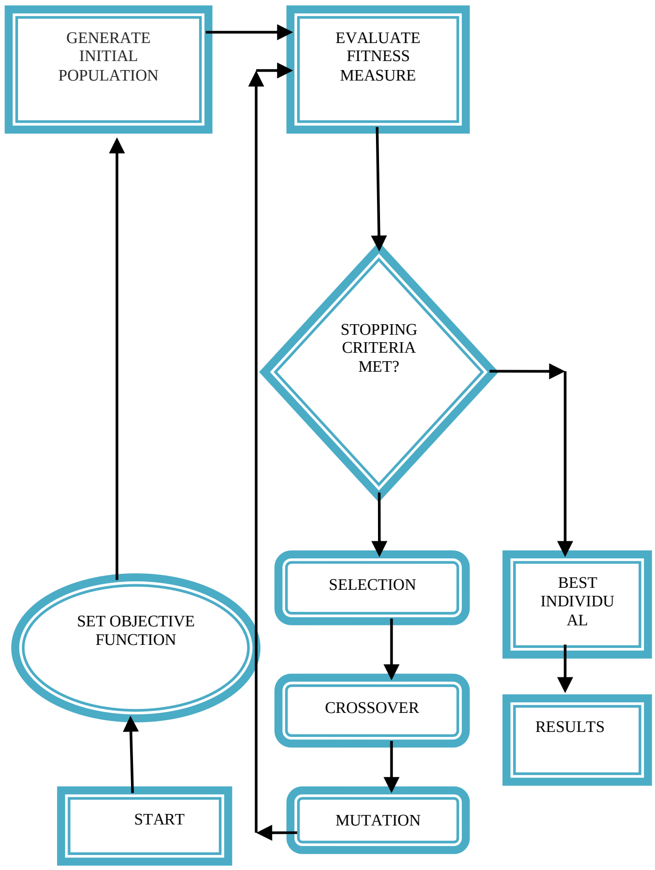

Fig.3. Flowchart of proposed genetic algorithm model

Mutation function is applied over the remaining pseudo population apart from population obtained through elitism. If randomly generated value is less than or equals to the mutation rate, then random gene creation is done which is obtained by the explicit conversion of rounded off randomly generated values by the random generator in the form of bits and the gene is set. Evaluation of fitness measure is obtained at each level of generation and accordingly best individual is obtained.

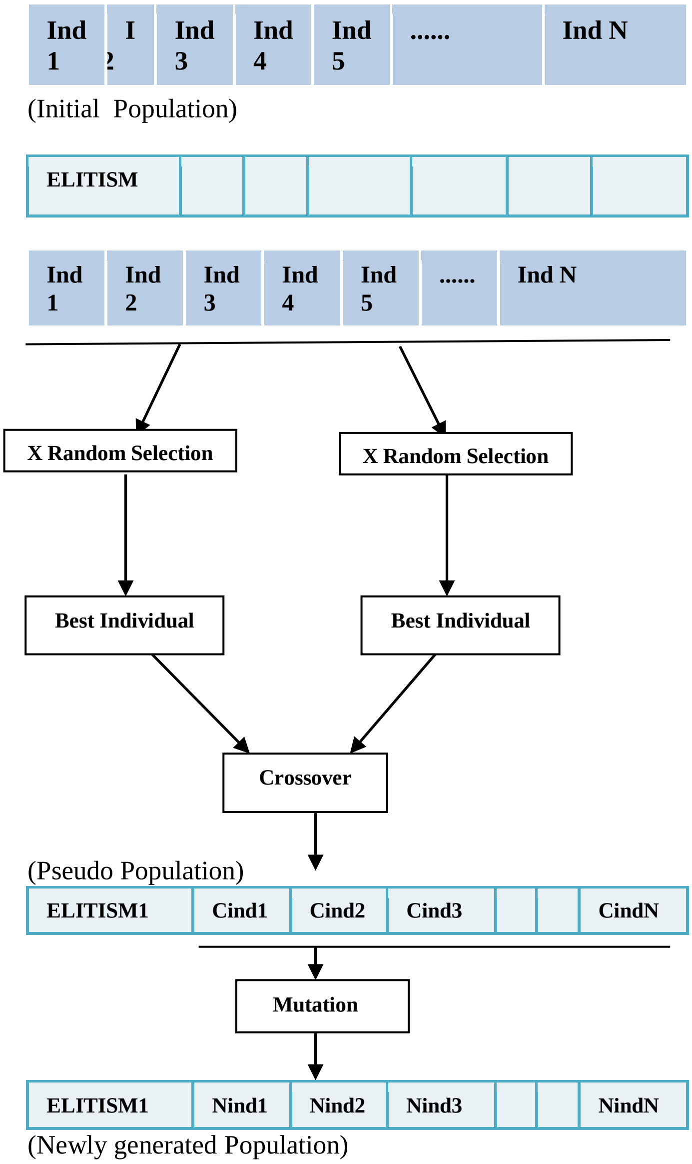

Fig.4.Various stages of fittest candidate selection

Two points cross over is selected in this work as it provides better solution as compared to other techniques [1].In order to get rid of extreme damage which arises due to the probability of getting the same solution set, mutation rate is kept low for the child chromosome, (1- 5%) [2].'Elitism' and 'Tournament Selection' were used for deriving the generation of population depending on the fitness measure.
It is generally observed that GA usually gives an optimal solution at maximum 100 generations [3].

V. RELATION OF GENES TO FITNESS MEASURE

Each individual chromosome structure (individual generated) bit is checked with the corresponding string bits of secondary user (candidate solution) and population generation continues unless each and every bit of individual chromosome resembles with the string bits of the candidate solution and maximum fitness measure is equal to the length of the string bits.

If any individual qualifies the above conditions, then it is the fittest individual which provides the best solution.

$$W = (n \div N) \quad (4)$$

where,
n is the total number of bits used in a particular gene.
N is the total number of genes in a chromosome.
W is the weightage of a particular gene.
The fitness measure is determined by

$$FM = w1*FB + w2*MOD + w3*BER + w4*DR + w5*PWR + w6*ITPU + w7*TOI \quad (5)$$

where w1, w2 ,.....w7 are the respective weights of the genes.

. VI SIMULATION RESULTS

Taking into consideration the RF parameters which are defined above, code was developed in JAVA, simulations were done and results verified.

For Inputs: Operating Frequency band in MHz, Modulation technique, Bit error rate, Data Rate in Kbps, Power Transmitted in dbm, Interference to primary user ,Transmission opportunity Index, Cross Over Rate=80%,Mutation Rate=2%,Tournament Size=5, default gene length=30, Elitism provided, population size provided by the user.

The Outputs displayed were :Firstly, Candidate Solution was generated. Secondly, Individual/Chromosome generation took place at each level.Thirdly, Chromosome/Individual of the population having highest fitness value was obtained. Lastly, Optimum gene solution corresponding to the candidate solution was displayed.

For Example**:-**Inputs provided:Frequency band in MHz= 590, Modulation technique=QPSK, Bit error rate=1.0E-7, Data Rate in Kbps=750, Power Transmitted in dbm=21, Interference to primary user=0.3125, Transmission opportunity Index=0.4079, Population size provided by the user=50.
Results obtained:

Candidate Solution generated:
0011010 01 0111 01111 0111 0101 0010

Generation: 1	Fitness: 21
Generation: 2	Fitness: 23
Generation: 3	Fitness: 24
Generation: 4	Fitness: 26
Generation: 5	Fitness: 27
Generation: 6	Fitness: 28
Generation: 7	Fitness: 29

Solution Found:
Generation: 7th
Fittest individual/Chromosome: 38
Fitness Measure: 30
Genes Component: 001101001011101111011101010010

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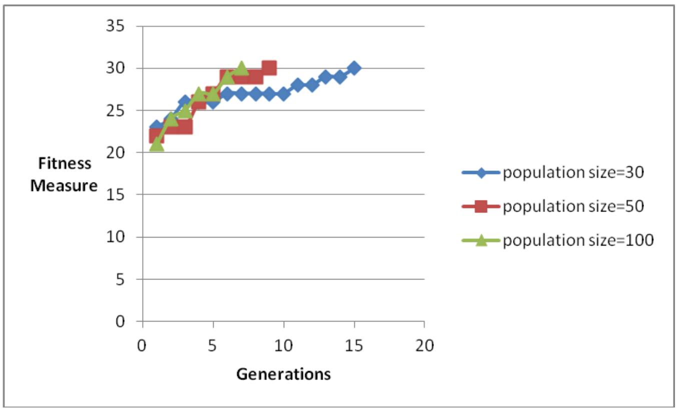

Fig.5. Graphs obtained for Fitness measure versus generation for different population size

From the above graph it can be inferred that as the population size increases due to increase in diversity, the solution set is achieved sooner.

VII CONCLUSION

From the results obtained we conclude that it is not necessary that we get an optimal solution at a fixed number of generations. It may vary since GA is a random process. The probability of finding the most optimal solution might get enhanced as we increase the population size, due to which, diversity of genes increases. The introduction of few more environment parameters such as ITPU and TOI helped in getting more enhanced optimal solution. Weightage of RF environment parameters directly depends upon the number of bits used by each gene. Increase in number of bits helps in diversifying the range of values or sample space for each gene and also minimizing the step size.

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