Performance Evaluation of Qos Parameters in Cognitive Radio Using Genetic Algorithm

Maninder Jeet Kaur, Moin Uddin and Harsh K. Verma

Abstract—The efficient use of available licensed spectrum is becoming more and more critical with increasing demand and usage of the radio spectrum. This paper shows how the use of spectrum as well as dynamic spectrum management can be effectively managed and spectrum allocation schemes in the wireless communication systems be implemented and used, in future. This paper would be an attempt towards better utilization of the spectrum. This research will focus on the decision-making process mainly, with an assumption that the radio environment has already been sensed and the QoS requirements for the application have been specified either by the sensed radio environment or by the secondary user itself. We identify and study the characteristic parameters of Cognitive Radio and use Genetic Algorithm for spectrum allocation. Performance evaluation is done using MATLAB toolboxes.

Keywords—Cognitive Radio, Fitness Functions, Fuzzy Logic, Quality of Service (QoS)

I. INTRODUCTION

RECENT contributions [1] suggested efficient use of licensed spectrum. One of the ways is the use of "Cognitive Radio". A cognitive radio (CR) employs software to measure un-used portions of the existing wireless spectrum (so-called white space) and adapts the radio's operating characteristics to operate in these unused portions in a manner that limits interference with other devices [2]. The already licensed spectrum can be used more efficiently by introducing artificial intelligence, the decision- making to be specific, in the radio. This enables the radio to learn from its environment, considering certain parameters. Based on this knowledge the radio can actively exploit the possible empty frequencies in the licensed band of the spectrum that can then be assigned to other users in such a way that they don't cause any interference to the frequency band that is already in use. This makes the efficient usage of the available licensed spectrum possible. The F.C.C. is reviewing its policies regarding the usage of licensed frequency bands by the unlicensed users [3].

Cognitive Radio not only adapts to the available frequency spectrum around it, but to also the quality of service and the

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channel conditions that could possibly prevent it from effectively communicating in the available bandwidth. This paper presents performance analysis results of a Genetic Algorithm driven Cognitive Radio system that determines the optimal radio transmission parameters. The environment parameters are used as constraints.

This paper will focus on different spectrum allocation techniques for the secondary users, based on Genetic Algorithms and an evaluation of the performance of these techniques with an assumption that the radio environment has already been sensed and the QoS requirements for the application have been specified either by the sensed radio environment or by the secondary user itself.

Cognitive radio is emerging as one of the ways for efficient utilization of the available spectrum. Due to the allocation of the available spectrum to the licensed (primary) users, the spectrum is becoming more and more saturated. Also, the number of the unlicensed (secondary) users trying to access the spectrum is increasing enormously. The ground reality is that the licensed users do not use the whole of the spectrum at all instances of time, so the idea is that sensing the empty frequencies in the licensed frequency bands and thus defining virtually unlicensed frequency bands, within the already licensed frequency bands, can accommodate some other users. This makes the efficient utilization of the available spectrum possible. To achieve this Cognitive Radio can be used, that can allocate these virtually unlicensed frequency bands, dynamically at real time by changing their parameters keeping in view the QoS requested by the secondary user or simply the application, without interfering with the primary users.

II. COGNITIVE RADIO TECHNOLOGY

A. Introduction

The cognitive capability of a cognitive radio enables real time interaction with its environment. This interaction helps to determine the appropriate communication parameters in order adapt to the dynamic radio environment. The radio analyzes the spectrum characteristics and changes the parameters at real time to provide a fair scheduling among the users that share the available spectrum.With the approach to solve the issue of scarcity of available radio spectrum, the Cognitive radio technology is getting a significant attention [4]-[6]. The primary feature of cognitive radio is the capability to optimize the relevant communication parameters given a dynamic wireless channel environment. There have been implementations of GA based

cognitive radio implementations, but the performance of these algorithms has not been thoroughly analyzed and also the fitness functions employed in the algorithms have also not been explored in detail [7]. Specifically, the analysis comes from finding the non-dominated solutions in the solution space, which is known as Pareto front. Genetic algorithms (GA) are used to optimize multi-objective problems, and can produce the Pareto Front. After the Pareto front has been optimized, the final challenge is to make a decision about which waveform on the Pareto front best stands for QoS satisfaction.

B. Cognitive Radio Parameters

The available system parameters should be defined as decision variables for evolutionary algorithms calculating generating fitness functions. The Cognitive Radio system must relate the performance objectives to the transmission parameters and the environmental parameters in order to reach at an optimized solution. While defining the list of parameters we make a compromise between the large time scale, system level parameters and the small time scale, transmission level parameters.

Table I shows the transmission parameters used in this paper to generate a fitness function.

TABLE I
TRANSMISSION PARAMETER LIST

Parameter Name	Symbol	Description
Modulation Type	MT	Type of modulation
Modulation Index	M	Total number of symbols
Transmit Power	P	Transmission Power

Environmental Parameters (Table II) inform the system of the surrounding environmental characteristics.

Genetic Algorithms (GA) are chosen for the allocation algorithm due to their fast convergence and the possibility of obtaining multiple solutions [8].

TABLE II
ENVIRONMENTALLY SENSED PARAMETER LIST

Parameter name	Symbol	Description
Bit-Error Rate	BER	Percentage of bits that have errors relative to the total number of transmitted bits.
Signal-to-Noise Ratio	SNR	Ratio of the signal power to the noise power
Noise Power	N	Magnitude in decibels of the Noise Power

C. Fitness Functions

The system performance indexes are described in terms of fitness functions. The individual with high fitness will have a bigger chance to be selected into the next generation. The actual results should take balance of these fitness functions, which can meet the QoS requirements and improve the performance. Fitness functions are defined individually considering the current user's QoS specifications. These fitness functions are applied on a randomly selected population of chromosomes in a multi-objective decision-making process with the use of stochastic processes. This implies to the existence of a trade-off among the parameters for a particular channel. This is analyzed by the corresponding weights assigned by the user to each of them. This is actually very useful in our decision-making process and provides with a variety of solutions for the best optimization of a problem.

Three performance measures of Power Consumption, Spectral Efficiency and Throughput are considered in this paper and the fitness functions are designed as in Table III:

TABLE III
FITNESS FUNCTIONS

Performance Fitness Functions
Minimize Power Consumption
Maximize Spectral Efficiency
Maximize Throughput

III. GENETIC ALGORITHM

Genetic algorithm (GA) is a technique based on evolutionary computation to find the approximate solutions to the optimization problems. Genetic algorithms are inspired by Darwin's theory of evolution and the best or simply the survivor among the available pool is an evolved solution. The history of evolutionary computation goes back to 1960s when Rechenberg first described it in his work "Evolution strategies". To be particular to the G.A.'s, they were invented and developed by John Holland that lead to his book "Adaption in Natural and Artificial Systems" that was published in 1975. The evolutionary computation may involve techniques like inheritance, mutation, selection and crossover to provide for the best possible optimization. In 1992 John Koza introduced "Genetic Programming" (G.P.).

Since their introduction, the G.A's have been used to solve difficult problems like, Non deterministic problems and machine learning as well as for the evolution of simple programs like evolution of pictures and music. The main advantage of G.A.s over the other methods is their parallelism. G.A.s travels in a search space that uses more individuals for the decision-making and hence are less likely to get stuck in a local extreme like the other available decision-making techniques.

The GA uses a population of chromosomes that represent the search space that determine their fitness by a certain criterion (fitness function). In each generation (iteration of the algorithm), the most fit parents are chosen to create offspring, which are created by crossing over portions of the parent chromosomes and then possibly adding mutation to the offspring. GA is proved to be able to achieve very good

performance in multi-objective optimization problem [9]. The Genetic algorithms approach used for the optimization of the decision- making module in the radio, as they are well suited to the multi-objective functions due to their convergence behavior towards the optimized solution and help the radios in adaptation for the decision-making process. Apart from this, the genetic algorithms also provide the optimization in decision making with multiple advantages. They provide with flexibility in problem analysis, as long as the chromosome and the objective functions are defined properly. Also, the convergence behavior of the genetic algorithm is really helpful in our application, i.e. the Cognitive Radios. The genetic algorithms may have a long convergence time for an optimal solution but normally do not take much time to give very good solutions [10].

Outline for the Genetic Algorithms [11]:

1. Start: Generate a random initial population of n chromosomes that consists of the available solutions for the problem.

2. Fitness: Emulate the fitness of each of the chromosomes in the initial population.

3. New population: Reproduce, according to the following steps until the next generation completes.

4. Selection: Select two chromosomes that have the best fitness level among the current population.

5. Crossover: Crossover the two selected chromosomes considering the crossover probability, to form the off springs for the next generation. If this operation were not performed the offspring would be the exact copy of the parent chromosomes.

6. Mutation: Mutate the new offspring at each defined mutation point, considering the mutation probability and place it in the new population.

7. End Condition: Repeat the above steps until certain condition (maximum no of population or the desired optimum has been reached), has been met. [12]

A representation for the chromosome must provide the information about the solution that it represents. The most popular of all representations is the binary string. Where each bit in the string can represent the chromosome characteristics or the whole string cumulatively can do this. The use of integer or real number representations for the chromosomes can also be useful. This will be explained further as we move towards our decision-making process.

Rieser [7], [13] reported using GA's to determine the optimization of wireless channel models and certain aspects of the wireless communication system. Based on this work it was determined that a Fitness Measure (FM, or Cost Function) needed to be derived. This FM is critical in the success of the GA. The purpose of the FM is to drive the random processes of the GA in the desired direction to optimize the parameters for performance.

IV. PROPOSED MODEL

The Cognitive Radio receives the RF environment at its receiver and involves itself in a decision-making process to accommodate a new user requesting the spectrum allocation. This requires a decision-making considering certain factors, such as the secondary user's requirements as parameters like, its modulation scheme, channel coding, data rate and power consumption etc. The user or the application that needs the spectrum to carry out its communications specifies its QoS requirements to the cognitive radio that also gets the information about the RF environment from a sensing module.

This enables the decision-making process to make a comparison between the user's specifications against the available pool of the solutions received from the RF environment. Thus, this sensed information from the environment serves as the initial population for the genetic algorithm. We shall generate random values that will serve as the initial population information received from the RF environment and then take the decision for allocation as an optimization and come up with the best solution after a comprehensive process

The very first step in the design of a genetic algorithm is the definition of the chromosome structure that is followed by the development of a fitness (or objective) function in order to determine the fitness of a population of chromosomes. The chromosome definition must represent the radio's behavioral traits for the decision-making process to achieve the required optimization. There can be many possible traits that can be considered in this regard but we shall consider only some of the basic traits for the radio in this research. Some of the possible traits that can be considered are the occupied bandwidth, spectral efficiency, power consumption and data rate.

The chromosomes in the genetic algorithms would be represented as simple vectors of data structures with different data types defining their genes. These genes and chromosomes may have different representations. In this research we shall represent the genes and the chromosomes in terms of arrays of bits. We shall use the minimum number of bits for the sake of simplicity. A radio chromosome may have different genes representing its structure, but for the sake of simplicity we shall consider only a few basic ones in this research (four in total), namely frequency, power, bit error rate and the modulation schemes. All these four genes shall be discussed further in the research report in detail, in the coming sections.

We shall just consider a few parameters only, in order to maintain the simplicity in the research. These are the frequency bands, the modulation scheme, power and BER. Some other parameters such as data rate, spectral efficiency, interference; system-to-noise ratio etc can be introduced in the research at the advanced stages.

Before we get started with the definition of the chromosome structure we must have the information and

understanding of the genes of the chromosome that will constitute its structure. The genes in this particular research would be the individual parameters that will be considered for the decision-making process.

The number of bits required to represent a 1000 frequency bands comes out to be 10, as a total of

10 bits can represent up to 1024 frequency bands that fulfills our requirement.

It can be observed that each band is of 10 KHz or .01 MHz and there are a total of 1000 frequency bands and one of these is allocated to each requesting application. In the mutation operation these frequency bands should be converted into the corresponding binary representation. As each of these frequency bands needs 10 bits to represent, the frequency gene therefore will take 10 bits in the initial population of chromosomes, for the frequency part

A. Minimize Power Consumption

Power is a necessary component when considering portable devices i.e. devices whose energy supply is limited.

$$f_{min\_power} = \sum_{i=0}^{N} \; 1 - (P_i/NP_{max}) \tag{1}$$

Where P_i is the transmitting power, N is the number of subcarriers and P_{max} is the maximum value of the power transmitted for any subcarrier.

B. Maximize Spectral Efficiency

It refers to the amount of information that can be transmitted over a given bandwidth.

$$f_{max\_eff} = (m_i R_s B_{min})/(B_i m_{max} Rs_{max}) \tag{2}$$

Where m_i is the number of bits per symbol, R_s is the symbol rate, B_{min} is the minimum value of bandwidth, m_{max} is the maximum modulation index available, Rs_{max} is the maximum symbol rate.

C. Maximize Throughput

This refers to the increase the overall data throughput transmitted by the radio.

$$f_{max\_throughput} = 1 - (\sum log_2 m_i)/ (N \, log_2 m_{max}) \tag{3}$$

Where m_i is the number of bits per symbol, m_{max} is the maximum modulation index and N is the number of sub carriers.

The weighted sum approach

This method is used in cognitive radio scenario [14] because it provides a convenient process for applying weights to the objectives.

$$f(x) = w_1 f_{min\_power} + w_2 f_{max\_eff} + w_3 f_{max\_throughput} \tag{4}$$

The search direction of the Genetic Algorithm can be easily controlled and modified by adjusting the weight vector values.

V. SIMULATION RESULTS

In Genetic Algorithm the population is a class instance, which contains a solution set of parameter values represented as a chromosome. Evolution in GA is done by splitting and

then again combining the chromosomes to form new generation. This process of generation cycle is carried on till we get a solution set.

We simulated a multicarrier system with 64 subcarriers. Simple BPSK modulation is used. Transmit Power is ranged from 0.1mW to 2.56mW. This maximum value of power is selected because it is close to the specified maximum transmit power of 2.5 mW for 1MHz bandwidth allowed in the lower UNII band(5.15GHz-5.25GHz).

TABLE IV
GENETIC ALGORITHM PARAMETERS

Genetic Parameters	Predetermined Value
Population Size	20
Max No. Of Generations	1000
Crossover Distribution Index	30
Mutation Distribution Index	20
Crossover Rate	0.60
Mutation rate	0.001

Population of 20 chromosomes each one represented by 224 bits, and maximum number of generations was set to 1000.

For GA, double point crossover scheme was implemented with probability of 60% and mutation of 0.1 % Crossover rate is a random number uniformly distributed between [0,1] and Mutation rate is another random number distributed between [0, 0.01] (Table IV).

The plot in Fig. 1 shows that despite of the existence of the trade-off and the difference in the range for the individual genes, the total fitness stays over 80% throughout the decision making process to find the optimum. It shows that the fitness values for chromosomes again increase with the increase in number of generations. These fitness values obtained by using a bigger initial population would have greater values than those with a smaller initial population size. So, it can be concluded that increasing the initial population size provides for better fitness values over the number of generations. This may also result in an increase in the computational complexity for the decision-making. So, the trade-off between the computational complexity and the initial population size should always be considered.

Fig. 2 shows that when the number of power levels is low the performance of the system is not good. But as the power level increases the system performance also increases a bit.

Fig. 3 shows typical result for average and maximum fitness measure values for a run through 100 generations. Each generation consisted of 100 chromosomes.
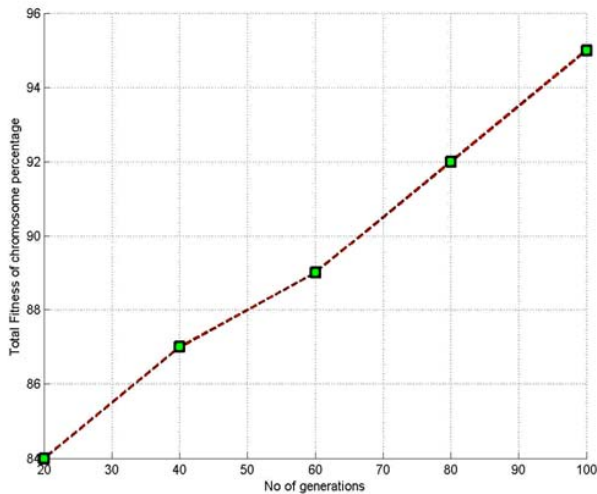
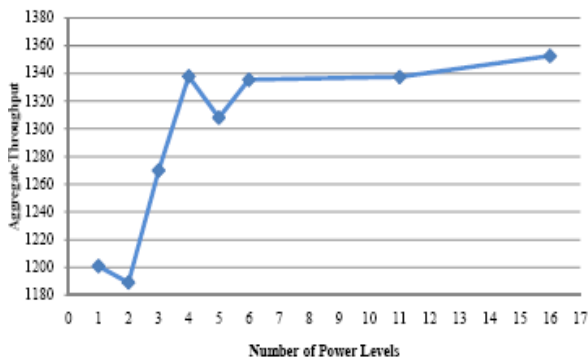Fig. 1: The plot for total fitness for chromosomes versus the number of generations
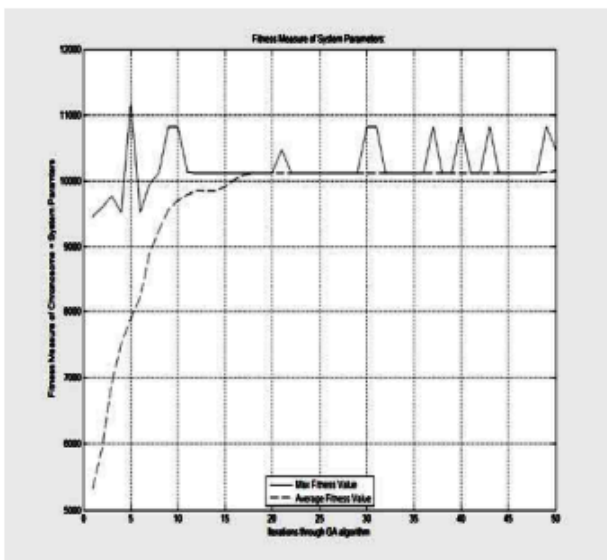

Fig. 2 Throughput Vs Number of Power Levels

Fig. 3 Average and maximum fitness measure

VI. CONCLUSIONS AND FUTURE SCOPE

The G.A.s are very easy to implement and can be reused to solve other problems. Once you have implemented a basic G.A. you just add a new object i.e. just another chromosome and using the same encoding scheme just change the existing fitness function and you can solve another optimization problem. However some problems might find implementation of the encoding scheme and the fitness function to be very difficult. So, summarizing the above discussion, we can simply state that the fitness values for chromosomes increase either by increasing the size of the initial population or by increasing the number of generations, or both of them. We considered only the case of a single user system capable of allocating all the parameters considered i.e. frequency, power, bit error rate and modulation, at a single time instant only, for the research. The allocation of these parameters to multiple users at the same time can be a possible extension of the research in future.

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