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A Comparative Analysis of Optimization Techniques in Cognitive Radio (QoS)

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Abstract: ***Wireless Technology has seen a tremendous advancement in recent times. There has been a huge growth in multimedia applications over the wireless networks. The requirement of significant bandwidth for multimedia services has increased the demand for radio spectrum. The scarcity of radio spectrum has become a challenge for the conventional fixed spectrum assignment policy. Thus, Cognitive Radio (CR) has emerged as a new exclusive choice to address the spectrum underutilization problem by enabling users to opportunistically access unused spectrum bands. It offers a promising solution to meet this demand by fully utilizing available spectrum resources. It improves the utilization of the wireless spectrum by allowing the secondary users to access the primary channels in an opportunistic manner. Efficient utilization of frequency spectrum is possible using dynamic spectrum allocation. Optimization techniques like Genetic Algorithm(GA), Ant Colony Optimization (ACO) and Mutated Ant Colony Optimization (MACO) are discussed here to meet the users QoS needs in the Cognitive Radio. The transmission and environmental parameters along with performance objectives of cognitive radio are studied and compared in the paper using different optimization techniques. In this paper, the results of various optimization techniques in Cognitive Radio System along with CR objectives are analysed to meet users QoS.***

Keywords: Cognitive Radio Genetic Algorithm, Ant Colony Optimization, Mutated Ant Colony Optimization, QoS Provisioning.

I. INTRODUCTION

Radio transmissions in electromagnetic spectrum are with limited frequency band. Due to limited bandwidth and spectrum resource, it is extremely challenging to meet QoS requirements (ie., bandwidth, delay and quality requirements) for transmission over wireless networks [21]. The limited wireless spectrum resource causes major delay problem for efficient multimedia transmission. However, according to an investigation of Federal Communications Commission (FCC) the assigned spectrum is not occupied all the time. FCC has published a report by designing new spectrum strategies to solve the overcrowded bands [4] and allow secondary users to use licensed bands accordingly. The usage of spectrum is concentrated on certain portions of spectrum bands whereas considerable portion of spectrum remains unutilized. Hence, to improve the effective utilization of spectrum in real time and provide efficient communication the concept of Cognitive Radio technology is introduced [1-3].

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1.1. Cognitive Radio

Cognitive radio is a self-organized radio which can be programmed and configured dynamically to use the best wireless channels in its reach. Such a radio automatically detects available channels in the spectrum, then accordingly changes its transmission or reception parameters to allow more efficient wireless communications within a given spectrum band at one location. This process is a form of dynamic spectrum management. It has the capability of achieving large spectrum efficiencies by enabling interactive wireless users to sense and learn the surrounding environment and correspondingly adapt their transmission strategies. Cognitive Radio is a technology for the next generation of wireless communications system. Cognitive techniques have been used in wireless networks to overcome the limitations of conventional Wireless Networks. The CR concept has been proposed with an objective of improving the spectral resources utilization and management. Cognitive devices are allowed to occupy the spectrum that has been left vacant by licensed users. Cognitive Radio has the ability to know the unutilized spectrum in a license and unlicensed spectrum band, and utilize the unused spectrum opportunistically. The primary users (PU)(licensed) have the right to use the spectrum anytime, whereas secondary users (SU)(unlicensed) can utilize the spectrum only when the PU is not using it. Cognitive radio is executed using Software Defined Radios(SDR) [5] it enhances machine learning and optimizing algorithms which can modify radio transmission parameters as per environment parameter conditions. The regular approach used for spectrum allocation for radio communication is fixed spectrum approach. In this approach the secondary users do not have authority to use the spectrum of primary users, this leads to underutilization of radio spectrum. Hence, to overcome this problem a new approach called Dynamic Spectrum Allocation (DSA) [6] is considered. In this approach, secondary users use the frequency band of primary users without causing any problem. Quality of Service (QoS) is important issue for cognitive radio networks. The Cognitive radio decides the best available spectrum bands to meet the Quality of Service. Secondary users access the wireless spectrum opportunistically when the spectrum is idle. While secondary users use an idle channel, the instance that primary user come back it makes SUs to terminate their communications and leave the current channel. Therefore, quality of service is difficult to be ensured for secondary users.

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1.1.1Functions of Cognitive Radio

The functions of Cognitive Radio are as follows,

- Cognitive Radio continuously looks for the unused spectrum which is known as the spectrum hole or white space as shown in the Fig 1. This function of CR is referred as spectrum sensing.
- Once the spectrum holes or white spaces are found, CR selects the available white space or channel. This function of CR is referred as spectrum management.
- It allocates this channel to the secondary user as long as primary user do not need it. This function of CR is referred as spectrum sharing.
- When a primary user is detected, Cognitive radio vacates the channel This function of CR is referred as the spectrum mobility.

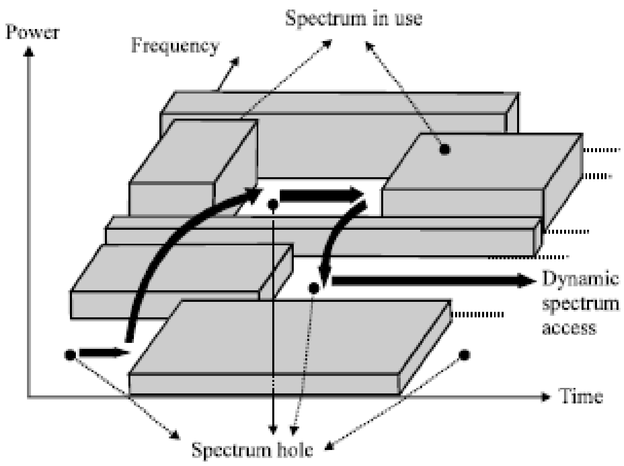

Figure-1: Spectrum Hole Concept

1.1.2Characteristics of Cognitive Radio:

The two main characteristics of CR are:

1) Cognitive Capability: It is the ability of the cognitive radio to sense the environment or channels used for transmission and derive the information about the status of the channel.

2) Reconfigurability: It is a process of programming the radio dynamically without making any changes to its hardware section. Cognitive radio is a software based radio, it has the capability not only to switch between different wireless protocols but also to support number of applications.

Based on the occupancy of the sub bands of radio spectrum can be categorized as:

i) White spaces: These are free from RF interferers, except for noise due to natural and/or artificial sources.

ii) Gray spaces: These are partially occupied by both RF interferers as well as noise.

iii) Black spaces: The contents which are completely full due to the combined presence of communication, possibly RF interfering signals and noise.

1.1.3Types of Cognitive Networks

Depending on transmission and reception parameters, cognitive radios are of two types:

- **Full Cognitive Radio (Mitola Radio):** It considers all possible parameters. Here wireless network or node is able to recognize every possible parameter clear[7].
- Spectrum-Sensing Cognitive Radio: The channels from the available radio-frequency spectrum are detected or considered.

Dependent on parts of the spectrum available for cognitive radio the types are as follows:

- **Licensed-Band Cognitive Radio:** Licensed-Band Cognitive Radio can use bands assigned to licensed users. These users are known as Primary Users (PU). In this type, only licensed users have authority to use the radio frequency spectrum.
- **Unlicensed-Band Cognitive Radio:** They can only utilize unlicensed parts of the radio frequency (RF) spectrum. These users are known as Secondary Users(SU). In this type the users have no licenced authority to use the radio frequency spectrum but they can use it if the spectrum is lying free.

The optimization techniques can be used to optimize the parameters and make them possible as per the required maximum and minimum values. The tricky part is tailoring the traditional wireless services to suit the requirements of the CR concept, which makes us to study the optimization techniques over CR networks.

II. RELATED WORK

Tim R. Newman et al. [2007] [8] introduces a genetic algorithm, here the primary feature of cognitive radios is to provide dynamic wireless channel environment radio parameters. Thus, CR decision engine determines the optimal radio transmission parameters for single and multicarrier systems. In this paper the accurate set of single carrier and multicarrier fitness functions for GA implementation is discussed. Sebastien Herry et al. [2009] [9] authors focused on determination of secondary user parameters using genetic algorithm. In this they investigated a solution to work out parameters of secondary user network that fit into spectrum holes offered by primary user network.

Maninder Jeet Kaur et al. [2010] [10] the author has focused on various optimization techniques on allocation of spectrums to secondary users, GA optimization technique is evaluated and compared here. They have assumed that the secondary users have already specified the requirement of QoS and the sensing of the secondary holes is carried out.

Nan Zhao et al, [2011] [11] In this paper ACO algorithm was applied for the first time in cognitive radio engine design. This problem was usually solved by GA algorithm as per the previous discussions however the GA algorithm converges slowly and its performance can be improved. The author has proposed a Mutated Ant Colony optimization cognitive radio engine. MACO algorithm with excellent performance is applied to the cognitive engine. Kiranjot Kaur et al, [2013][12] has used simulated annealing (SA) technique for optimization of cognitive radio. SA is a stochastic global optimization technique that is separate between different local optimization techniques. The author discusses about how to meet the quality of service (QOS) that is defined by users in terms of cognitive radio objectives.

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In this paper, here SA is compared with GA and it is derived that SA algorithm performs better than GA for the cognitive radio system.

Abdelfatah Elarfaoui et al. [2013] [13] the author has worked on genetic algorithm and proposed crossover method in cognitive radio. In this paper the flexibility of genetic algorithm is shown and it can also be used with other to enhance the quality of solution without effecting the system complexity and time of execution. In this paper the quality of services parameters is considered and appropriate solutions are found to get the output results.

Stephen A. Adubi et al. [2014] [14] This paper presents main variants of the ant colony optimization algorithms by comparing the results of mainly four variants on few selected optimization problems. A review of different ACO algorithms, application and the comparative analysis of some selected variants are presented.

Ismail AlQerm et al. [2014] [15] work on adaptive multi objective optimization scheme is discussed in the paper. Here the transmission parameters to environment conditions using optimization is considered. The author discussed about the reduction of complexity of the system by using adaptive genetic algorithm and the system works on multi objective functions. In this paper, they worked on adaptive genetic algorithm in terms of its parameters.

Seshadri Binaya Behera et al. [2015] [17] the author has worked on particle swarm optimization algorithm to optimize the resource allocation. To maintain the problem of resource allocation the cognitive radio users, require some factors such as signal to interference noise ratio (SINR), spectral efficiency, power efficiency etc. which are improved according to user requirement.

Vibhuti Rana and Dr. P. S. Mundra et al. [2016] [18] The author discusses about the optimization of quality of service parameters of cognitive radio using Genetic algorithm technique. It states that, GA reduces the system computational complexity and it is fast in convergence producing best fitness scores with less number of iterations as compare to other optimization techniques.

III. OPTIMIZATION TECHNIQUES

3.1. Genetic Algorithm (GA)

The genetic algorithm is based on the concept that" the measure of success of an individual is their fitness" (i.e. survival of fittest). The best combination of genes and their resulting chromosomes yields the strongest individual, which will survive the longest.

The computation of the GA starts from the collection of the chromosomes with certain characteristics which are randomly generated and they follow the computation through generation. At generation of chromosomes, fitness is calculated based on stochastic calculation and mutation. The fitness is evaluated on individual basis giving rise to a new population of chromosomes. After this, an iterative algorithm will be used until the most optimum solution is received.

The genetic algorithm has three phases in its process: i) Mutation Cross-over ii) Objective Function and iii) The fitness function [19]. The mutation checks when the state of a node in the network changes. Firstly, node ids are created for all the nodes in the network. If any id is repeated in the sequence, it is changed accordingly, When the data transfer comes into action and if the primary user is not able to take the data load, Genetic algorithm is initiated, based on the energy of the nodes. Therefore, GA is adaptive heuristic search based on evolutionary concepts. Genetic algorithms are specially used as a method of problem optimization and due to its fast convergence, random nature, time and ability to spontaneously generate unique solutions they are an appealing for cognitive radios. Genetic algorithms are used when the search space is too large.

3.2. Ant Colony Optimization (ACO)

ACO is one of the technique that has an approach towards problem solving and learning. It is based on the cooperative foraging (searching widely) strategy of real ants. In this operation ants deposit a substance called pheromone along the path in which they travel during foraging. This substance pheromone influences other ants largely to follow the same path but few ants, due to their random behaviour they choose paths which are not yet explored. Due to this shorter routes are found. The shorter routes have higher concentration of pheromone when compared to longer paths giving rise to the convergence of ants to these routes. This intelligent behaviour or technique was experimentally proved in the double bridge experiment [20] and the results have influenced the author to develop an algorithm based on this phenomenon. In this optimization technique, several artificial ants perform a sequence of operations repeatedly. Within each iteration these ants search in parallel for good solutions in the available solution space. One or more ants are authorized to execute and move iteratively, leaving behind a pheromone trial for others to follow. An ant finds a single path, probabilistically selecting only one element at a time, this processes is repeated until the entire solution vector is obtained. This model of optimization is used by natural ants to get to their destination in the shortest possible time.

3.3. Mutated Ant Colony Optimization (MACO)

Mutated Ant Colony Optimization (MACO) algorithm is proposed by introducing the mutation operator to the ACO algorithm. In this method, an additional operator called mutation operator is used for improving the algorithm with which a new mutation rate is generated by the self-adaptive approach. If ACO algorithm generates the current solution (x) by using mutation operator, random position is changed by new mutation rate in current solution(x). After changing random position, new solution (x^I) is generated. Then the cost of this new solution (x^I) is compared by the current solution (x), if the cost of new solution is less than (or greater than) current solution, then according to combinational problem, new solution is replaced by current solution [21]. This process is repeated until maximum iteration is not reached

The MACO algorithm can increase the searching range and avoid local minima by randomly changing one or more elements of the local best solution. As the mutation operation is simple to implement, the performance of MACO is superior with almost the same computational complexity.

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MACO technique is proposed to solve the multiuser detection problem. The algorithm is formed by only introducing the mutation operation of Genetic Algorithm (GA) to the ACO algorithm. MACO multiuser detector enhances the local searching performance, expands the diversity of solutions, avoids local optima and converges quicker.

IV. COGNITIVE RADIO PARAMETERS

In cognitive radio control system, each cognitive engine should adaptively adjust the transmission parameters according to the environment information. Hence environment and transmission parameters including the key parameters should be defined, Cognitive radio can interact with the environment and this can help to maintain the appropriate communication parameters in order to adjust as per the dynamic radio spectrum. The parameters can be decided in such a way that communication may occur with less interventions and large number of users can accommodate in radio spectrum.

4.1. Environmental Parameters

Environmental parameters include all information about wireless shared environment. The environment parameters should be known to cognitive radio engine. This knowledge on the surrounding environment conditions is given to the cognitive radio system by these environmental parameters. The sensed information through the surrounding helps the cognitive controller in making decisions and to calculate the fitness functions. The three common environmental parameters used are bit error rate (BER), signal to noise ratio (SNR), background noise power (N).

4.2. Transmission Parameters

Transmission parameters include all significant inputs that are controlled by the system and used for making decision. Cognitive radio engine becomes possible, if the transmission parameters within the cognitive engine can be changed adaptively according to the environment. In cognitive radio, the transmission parameters act as decision variables, hence they must be well defined to make the optimal decision before developing the fitness functions to various objectives. The transmission parameters can decide to whom the information can be transmitted and how they are communicated. Table 1 shows the list of transmission parameters used.

Table 1: Transmission Parameters

Parameter	Description
Transmit Power	Transmission power
Modulation Type	Type of Modulation Format: M-QAM, M-PSK.
Modulation Index	Number of symbols for Modulation scheme used
Bandwidth	Bandwidth of transmission
Symbol Rate	Number of symbols per second
Noise power	Noise power
Packet Size	Size of the Packet used for transmission

V. COGNITIVE RADIO OBJECTIVES

There are various objectives that a radio system needs to attain in wireless communications environments. The cognitive radio meets the user requirements and works effectively with these desired objectives. The large number of users can use the frequency spectrum efficiently after fulfilment the following objectives criteria. Table 2 describes the cognitive radio objectives. The search space is created by combining the transmission and environmental parameters along with the defined objective functions.

Table 2: Cognitive Radio Objectives

Cognitive Radio Objectives	Description
Minimize Bit Error Rate	Improve the overall BER of the transmission environment and utilize spectrum with minimum errors.
Maximization of Throughput	Increase the overall data throughput transmitted by the radio and maximize the user's data transmission
Minimization of Power Consumption	Decrease the amount of power consumed by the system and maximize efficiency by consuming less power.
Minimization of Interference	Reduce the number of Interferences
Maximization of Spectral Efficiency	Frequency spectrum is utilized more efficiently

VI. PERFORMANCE OBJECTIVES & FITNESS FUNCTIONS

There are several desirable objectives that the radio system wants to achieve in a wireless communications environment. Five objectives have been defined for the fitness function in order to guide the system to an optimal state.

i). Minimization of Bit Error Rate (B.E.R):

This objective represents minimizing the amount of errors, relative to the number of bits being sent. It is used to find the quality of each link in terms of number of bit errors per unit time. The complexity of the system is reduced while minimizing errors. Thus, the fitness function is decided to minimize the BER.
The fitness function of BER minimization is given as:

$$F_{min-ber} = \frac{\log_{10} 0.5}{\log_{10} P_{ber}} \quad (1)$$

Here, P_{ber} represents the BER of modulation type being used.

ii) Maximization of Throughput:

Maximizing the throughput trades with the data throughput rate of the system. This objective improves system throughput. It is important optimization objective in certain areas like multimedia and computer applications. Thus, throughput is total rate at which something can be produced.

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Maximizing throughput produces large amount of information. Thus, fitness function is obtained to optimize the maximization of throughput.

$$F_{max-throughput} = \frac{log_2(M)}{log_2(M_{max})} \quad (2)$$

Here, M is modulation index of a single carrier and Mmax is the maximum modulation index.

iii) Minimization of Power Consumption:

Minimize power consumption is self-explanatory and is used to direct the system to a state of minimal power consumption. The usage of battery and power consumed are important factors for reducing power consumptions. The fitness function is obtained to optimize the minimization of power consumption.

$$F_{min-power} = \frac{P}{P_{max}} \quad (3)$$

Here, P is average transmit power, Pmax is maximum available transmit power.

iii) Minimization of Interference:

Minimizing interference deals with the areas of the spectrum with a high noise floor, or areas with high possibility of interference. Interference is main problem in CR due to the shared spectrum environments. Interference occurs mainly when secondary and primary users use in the system simultaneously. The fitness function is obtained to optimize the minimization of interference.

$$F_{min-interference} = \frac{\{(P+B+TDD)-Pmin+Bmin+1)\}}{(Pmax+Bmax+RSmax)} \quad (4)$$

Here B= bandwidth required for single carrier,

B_{min} and B_{max} is minimum and maximum bandwidth,

TDD is Time Division Duplexing,

RSmax = Maximum Symbol Rate.

v) Maximization of Spectral Efficiency:

The emphasis on the maximizing spectral efficiency objective would reduce the spectral space used by the transmitted signal. Spectral efficiency is the total amount of information that is transmitted over a given bandwidth. The fitness function to maximize spectral efficiency is expressed as:

$$F_{max-spectraleff} = \frac{1-(M*B_{min}*Rs)}{(B*M_{max}*RS_{max})}$$

(5)

To derive the objective function for this optimization in cognitive radio, the weighted sum approach is used, because it provides a suitable process for applying weights to the objective. The weight vector is applied to fitness function since all the parameters run simultaneously and get their values, hence to reduce the system complexity the weight vectors are applied.

$$F_{Sum} = W1*(F_{min-ber})+W2*(F_{max-throughput})+W3*(F_{min-power})+W4*(F_{min-interference})+W5*(F_{max-spectraleff}) \quad (6)$$

The above equation (6) shows the overall fitness function with weighted vectors. These weights evaluate the fitness function given in the equation.

Therefore, optimization techniques like GA, ACO, and MACO are applied with number of iterations to optimize these performance objectives.

VII. COMPARISION OF OPTIMIZATION TECHNIQUES

The performance of GA, ACO and MACO cognitive engines is compared. The number of iterations in GA, ACO and MACO cognitive engines is 500[11]. In order to ensure almost the same computational complexity, the parameters in these engines are set as follows. The number of ants are ACO is 20, the number of ants in MACO are 19, and the number of chromosomes in GA are 20. The total number of mutation times, traveling times by the ants, and calculating the value of the multiple-objective fitness function (MOFF) in GA, ACO, and MACO engines are listed in Table 3[11]. From Table 3 we can see that MOFF calculation times of these engines is all equal to 10,000, hence, the computational complexity of these engines is almost the same.

Table 3: Computational Complexity Comparison

Engine Type	Traveling times by ants	Mutation times by ants	MOFF Calculation times
GA	0	0	500×20=10,000
ACO	500× 20=10,000	0	500×20=10,000
MACO	500× 19=9,500	500	9,500+500=10,000

The GA, ACO and MACO engines with their optimal parameters are used to solve the cognitive engine problem and the average fitness scores obtained by these engines after 500 iterations over 20 simulations are shown in Table 4.

Table 4: Comparison of Fitness Scores

Scenario	GA	ACO	MACO
Low power mode	0.9383	0.9107	0.9482
Emergency mode	0.8422	0.8485	0.8523
Multimedia mode	0.9395	0.9416	0.9422
Balanced mode	0.8305	0.8336	0.8460

In Table 4[11], it is shown that, the fitness scores obtained by MACO cognitive engine in all the scenarios are larger than GA engine, while the fitness scores obtained by GA engine are better than ACO engine.

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VIII. CONCLUSION

In this paper the basic concepts of cognitive radio along with the environment and transmission parameters are discussed. Different transmission parameters of the CR system which have been optimized to satisfy various performance objectives under the environmental constraints are compared. Simulated results are compared after implementation of GA, ACO & MACO optimization techniques and the optimal set of solutions are found to be efficient. These results show that the fitness scores gained by the MACO engine in different scenarios are larger than the ACO engine as well as the conventional GA engine, and the MACO engine also converges quickly.

Hence, compared with the GA, ACO, the MACO multiuser detector can lead to quicker convergence and avoid local optima with almost the same computational complexity

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