ADAPTATION OF TRANSMISSION PARAMETERS IN COGNITIVE RADIO USING GWO TECHNIQUE

A Dissertation Submitted in Partial fulfillment of the Requirement for the Award of the Degree of

MASTER OF ENGINEERING

In

Electronics and Communication Engineering

Submitted By

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JULY, 2018

DECLARATION

I, NishaYadav hereby declare that the work presented in this thesis entitled "**Adaptation ofTransmission Parameters in cognitiveradio using GWO technique"** in fulfillment of the requirement for the award of degree of Master of Engineering (ECE) submitted at Department of Electronics and Communication, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala is an authentic record of work carried out under supervision of Dr. Amit Mishra (Assistant Professor, Department of Electronics and Communication, Thapar Institute of Engineering & Technology (Deemed to be University) from July 2016 to July 2018. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

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It is certified that the above statement made by the candidate is correct to the best of my knowledge and belief.

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ACKNOWLEDGEMENT

I would like to convey my deep sense of gratitude to my project guide, **Dr. Amit Mishra, Assistant Professor, ECED** who is a constant source of motivation and firm support in carrying out this project. The support and supervision that he gave has helped me to progress in the project. His co-operation is highly appreciated and I highly oblige to him for his valuable comments and moral support during this research period. I value his concern and support at all times, good and bad. He has always emphasis on self-motivation during rough or bad periods and appreciated in good days. The words are not enough to thank him.

I am also thankful to Thapar University for the facilities and healthy environment for study. I also express my sincere thanks to my Head of the Department, **Dr. Alpana Agarwal** for providing me adequate environment in carrying the work.

A big thanks to my friends for their support in accomplishment of my course work. They always taught me the patience and never to give up attitude in the research work. I would like to thanks my parents for raising me, believing in me, allowing me to do things in my way and to agree with me even if they don't want. The presence of my brother and sisters is always supporting and loving in every aspect of my life.

Finally, I would like to extend my gratitude to all those persons who directly or indirectly helped me in the process and contributed towards this work.

Above all I thank the Almighty God who is being with me and showers his blessings and his grace towards me in all walks of my life.

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ABSTRACT

Cognitive radio works on important area of wireless communication system. Cognitive radio has two main functions that are sensing unutilized spectrum and adaptation of transmission parameters in wireless system. For real time scenario, the cognitive radio commonly can sum up with some artificial intelligence related techniques so that an intelligent and adaptive radio system get generated in terms of parameter adaptation and spectrum sensing. The work has done on parameter adaptation function. For parameters adaptation, different optimization techniques has applied and observed their advantages and challenges. This thesis initially, represents the cognitive radio, its functions, its characteristics, environmental and transmission parameters. Then, it introduces nature inspired artificial intelligence techniques and highlights the part of knowledge in cognitive radio. The new proposed technique has applied i.e., GWO for adaptation of transmission parameters. The result for this algorithm has analyzed and compares its result to the existing algorithm such as Genetic algorithm, stimulated annealing, Spider monkey optimization. The literature survey of mentioned optimization techniques has been done with their pros and cons. Then present the simulation results for given algorithms. The literature survey is planned that depends upon various artificial intelligence techniques like GA, PSO, ABC, CSO, CBR, Cuckoo search, SMO and SA.

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LIST OF ABBREVIATIONS

FCC	Federal Communication Commission
DDI	Department of Defense Institute
SDR	Software Defined Radio
CR	Cognitive Radio
TX	Transmission
AWGN	Additive White Gaussian Noise
AI	Artificial Intelligence
ML	Machine Learning
BER	Bit Error Rate
PDA	Personal digital assistant
CRN	Cognitive Radio network
QoS	Quality of Service
DSA	Dynamic Spectrum Allocation
FER	Frame Error Rate
SNR	Signal to Noise Ratio
GA	Genetic Algorithm
PSO	Particle Swarm Optimization
ABC	Artificial Bee Colony
SA	Stimulated Annealing
SMO	Spider monkey optimization
NSGA	Non- dominated sorting genetic algorithm
MOGA	Multi objective genetic algorithm
CGA	Conventional Genetic Algorithm
AGA	Adaptive Genetic Algorithm
CSI	Channel side Information
AMOS	Atomic metaphor optimization strategy
FD	Full duplex
N/W	Network
BPSO	Binary particle swarm optimization
BBO	Biography based optimization
CBR	Case Based Reasoning
PER	Packet Error Rate
QGA	Quadratic Genetic Algorithm
CS	Cuckoo Search
ANN	Artificial Neural Network
SVM	Support Vector Machine
PU	Primary Unit
RL	Reinforcement Learning
FPGA	Field Programmable Array
TDD	Time Division Duplex

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CHAPTER 1

INTRODUCTION

1.1 RESEARCH MOTIVATION

Cognitive radio is a latest technology which improves the Federal Communication Commission (FCC) identified problem of spectrum scarcity for available radio spectrum. Cognitive radio uses conventional software defined radio SDR which has reconfigurable features. Software defined radio called "intelligent" radio because it has smart control method to spontaneously adapt the operating parameters that depends on the current and previous inputs to the system[1-4]. Significant research work has been done to remove the spectrum scarcity problem therefore Department of Defense Institute (DDI) Department approaches a software that are flexible in nature and can be used in Defense like war, industries [1] etc. The subsequent link of cognitive radio resolution range from CR components and its radio network components to broad system set [2] and [5]. But still there is a question how to implement a cognitive radio? There is no best way to use as the "intelligent" control. The examination [1], provides two methods for control and also defines the systematic relationship between radio environment and the radio transmission parameters that offers the controlling technique of a solution. By this systematic relationship, the sensitivity can be analyzed that operates on the communication parameters basically used in wireless communication to define the performance effect on each parameter.

The primary motivation of this thesis is to search the technology which could be used to make a cognitive radio engine with decision making criteria. There are still so many questions about cognitive radio that are to be examined, so that an efficient solution can be achieved. Basically, cognitive radio gathers the information about environment and decides which transmission parameter has the best possible set to use the given set of performance objectives. To make a cognitive radio decision, environmental parameters have been defined as input to make exact and accurate decision. The measurements depend on the decisions that are to be taken in the system. The transmission parameters that are defined in system are managed by the cognitive radio and it radically affects the radio efficiency. Various references have been referred in the wireless communication field and to search the application of cognitive decision system, a list of five transmission parameters is proposed with six environmental parameters.

For the selection of optimum set of transmission parameters, cognitive radio engine uses the interaction between measurement input and transmission parameters. This provides information about the relationship between environmental and transmission parameters. For example, every parameter are interlinked to each other, if transmission parameter A is modified then environmental parameters B, C, and D shall also affected in different ways. Therefore, there must be a systematical relation that includes

both input and output parameters. The solution for this problem is to design a systematic environmental model, originate relationship between transmission and environmental parameters and allow a function that adapts the engine for cognitive radio application. After implementation of CR model, a function is derived and suitable transmission parameters are determined to optimize the problem.

The research aim of this thesis is to find the appropriate algorithm to solve the optimization problem. Due to the wireless environment nature, the optimization problem is categorized in non-linear way. Depending on the current scenario of the wireless environment, few variables like path loss, received power signal, or noise power are varied. In an AWGN channel, for designing the fading characteristics, we approached non-linear models [7]. There are various methods to solve the optimization problems but non-linear models increases the complexity and vigorously change the wireless environment therefore we used traditional non-linear programming optimization methods pertaining to the convergence to a local optimal solution but it does not find reasonable solution in some cases. In a traditional non-linear optimization schemes, gradient search method is used to find suitable solution, in these schemes, we move along the curve until reached the maximum spot. It is shown in figure 1.1. The traditional method offers large computational complexity therefore we move forward to the artificial intelligence (AI) technique which solves the optimization problems efficiently. Some AI techniques like genetic algorithms and stimulated annealing removes the local optimum problems.

Artificial techniques can be classified into two classes: Traditional/Conventional AI and Non-traditional/ Computational AI.

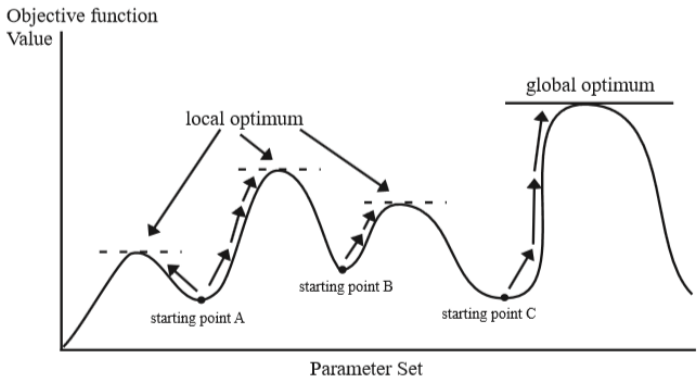

Figure 1.1 Gradient search techniques [2]

Conventional artificial intelligence stated as machine learning, it includes various functionalities [8, 9]. The machine learning process has shown in figure 1.2. The Machine learning system uses objectives as input of the system, and ML sense the data and choose appropriate actions to solve optimization problem.

During simulation action, a feedback fed to the machine learning element, allows a measurement that show the efficiency of the action.

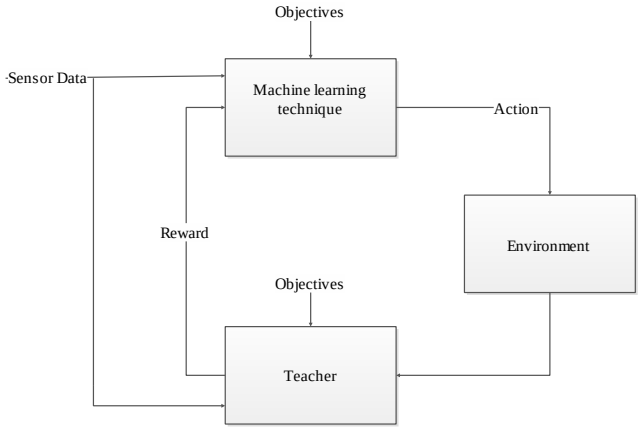

Figure 1.2 Machine Learning Flow [1]

Through machine learning techniques we estimate, the output and verify the suitability of achieved goal. This estimation stage is called the selection stage. After the selection stage, we continuously receive the knowledge about the action and proceed to get better solutions, through applying the output of present solution to the system. Function is generated which defines the optimality of the output, called the fitness function [10]. The input of the fitness function contains objective sets for the system.

In this work, we worked on optimization of transmission parameters and taken five transmission parameters such as minimum power consumption, BER, Interference and maximum throughput and power spectral efficiency. A lot of work has been done in this area by using different optimization techniques. We summarized the existing research work and compare other techniques to the proposed techniques algorithm. Each algorithm offers its own pros and cons which suits to a particular domain problems. In our work an effort has been made to use an efficient metaheuristic approach i.e. Grey wolf optimization (GWO) in the field of cognitive radio. The simulation results show that the GWO provides much better parameter optimization when compared with other existing scheme.

1.2 RESEARCH OBJECTIVES

The first research a very of this thesis is: What is the Best optimization technique for Parameter optimization of cognitive radio? To answer this question firstly, we have to define the characteristics of cognitive radio to make a model of CR for simulation. For the decision making in CR we have explore the requirement of common parameters. These defined parameters are transmission level control parameters and environmental sensed parameters. It is really in need that the defined parameters must contain the common parameters so that work can be connected to most of the radios that developed.

Radio operating areas must also be explained while defining a list of parameters. These defined areas required to control the system to a particular output, and it changes according to the wireless environment, hardware situations of radio etc.

The cognitive radio modifies the transmission parameters after observing the wireless environment that depends on observations and areas of radio operation. With this explanation, the operation of cognitive engine can be improved using an optimization technique. We still focus on the primary research question that ask in this thesis earlier that the best optimization or adaptation techniques for the cognitive engine. We considered various techniques to answer this question. We analyzed our problem and identified the main characteristics that prepare for optimization techniques. The second question is how much will be the effect of these parameters on the performance of communication of CR. The study is completed using the relationship of fitness function already derived with the help of output of fitness function, we also explained the effectiveness of CR communication system. If we do not consider the effects of specific parameters channel performance, cognitive radio not using SNR will not give an exact decision. For effective decision making, huge quantity of processing is needed for some parameters; still for same parameters have not so much effect on communication system so that this analysis can save time and cost of cognitive system developers.

We discussed various optimization techniques. First we have to find the logical relationship that relates all parameters. This tells the second research answer for this thesis, that how transmission and environmental parameters can be in relation. After finding the appropriate optimization techniques, we make the relationship formation and use this relationship in our optimization techniques.

1.3 COGNITIVE RADIO OVERVIEW

The cognitive radio, the concept is not so latest in this modern era, because it is a concoction of manual radio resource management technique that has been invented and proved earlier for improving the performance of wireless communication system, now imbruted by the computer. Commonly, Cognitive radio is the combination of radio trans-receiver with computerized intelligence to the mechanized co-ordination of devices, networks and services for refined functionality, interoperation, and spectrum utilization. The first approach of cognitive radio is contemplated by Joseph Mitola at some workshop in 1988 and the article written by him published in 1999. It was a distinctive approach of wireless communication system, which Mitola designated as: Cognitive radio is the idea in which wireless devices such as PDA and the equivalent networks are computationally intelligent about their radio resources and correlated each other to discover users' requirements in communication and it provides services which is necessary for the user [11]. Basically, they specified cognitive radio referred as the combination of different models with software radio technologies [12]. Cognitive radio is commonly remarked as one of

the most upcoming technologies for future in wireless communications. We have required many efforts from many research communities to make radio and networks properly cognitive; it includes communication theory, signal processing, reconfigurable antenna and various frequency designs [13]. As shown in Figure 1.3, Cognitive radio is generally a radio or system track the surrounding according to users requirement, analyzes the parameters for transmission, and then decide for allocation of time-frequency space resource to choose the best allocation and managing to increase the application for the electromagnetic spectrum of radio. It uses white spaces (not presently used frequency) present in the spectrum for electromagnetic. Usually, Radio resource management improves the radio system to optimize the application of various radio resources. For illustration, the author cleared CRNs optimum resource allocation, particularly in the system of spectrum identification, and also considering the limits of temperature interference [14]. The optimization provides optimum solutions for resource allocation and disadvantage for convergence in global system, complexity and computational time. Cognitive radio required to be implemented to ease the complexity and for attaining real time resource allocation.

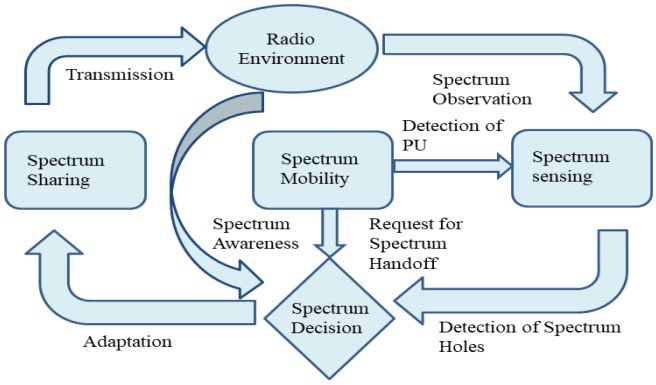

Figure 1.3 Conceptual view of Cognitive Radio

Cognitive radio correlates with cognitive engine by combining the use of artificial intelligence techniques. Simon Haykin illustrated Cognitive Radio as, “cognitive radio is an intelligent wireless communication system that is aware of its environment and uses the methodology of understanding by-building to learn from the environment and adapt to statistical variations in the input stimuli” [15]. Hence, A Cognitive radio act as intelligent and it learn from their own experience by collaborating with their behavior and environment. Consequently, learning is a necessary process for cognitive radio that supports Artificial intelligence (AI) and machine learning (ML) technique. In this paper, we primarily describe the cognitive radio system principle, its transmission parameters, its environmental resources, its objectives and approach for solving optimization problem. After that we discuss a literature survey of all optimization techniques applied to cognitive radio. Various surveys were planned to study the application of AI techniques in CR and have some challenges in their techniques.

Cognitive radio is a self-standardized radio system which is computed and composed vigorously for the use of best wireless channels in its capacity. This type of radio significantly recognizes existing channels in the spectrum, and then subsequently it changes its transmission parameters to recognize more accomplished wireless communication within an available spectrum band in one region. This method creates management of dynamic spectrum. It has the efficiency of accomplishing extensive spectrum capabilities by increasing the wireless users to adapt the behavior of surrounding environment and their adapting strategies. Cognitive Radio is a next generation wireless communication system technology. To reduce the drawback of conventional Wireless Networks cognitive techniques is used. Cognitive radio method has been proposed with an objective of spectrum utilization and spectrum management. CR occupied that spectrum which has been left vacant by the primary or licensed users. It gets to know which spectrum is in unutilized spectrum in license and unlicensed band and it utilizes the unused spectrum. Primary users have the ability to use spectrum anytime but secondary user uses opportunistically when spectrum is available.

Cognitive radio is executed using Software Defined Radios [12] it enhances machine learning and optimizing algorithms which can modify radio transmission parameters as per environment parameter conditions. Basically, spectrum allocation for radio communication is fixed. For this allocation secondary users are not allowed to use the spectrum provided for primary users. This creates empty radio spectrum. Hence to remove the mentioned problem, a new technique is proposed called DSA [16] is considered. By this method, secondary users use the unutilized spectrum band of primary users without any interference. Main issue for CR is quality of service (QoS) in CR networks. To meet the Quality of Service CR decides the best vacant spectrum bands. When the spectrum is not in use the secondary users uses the available spectrum opportunistically. While secondary users use an idle spectrum, that occurrence the primary user comes back it makes SUs to exit their communications and leave the current spectrum. Therefore, quality of service is difficult to be ensured for secondary users.

1.4 COGNITIVE RADIO ARCHITECTURE

Cognitive radio network has been classified into two groups' networks that are primary network (licensed n/w) and secondary network (unlicensed n/w). The primary network users already allocated a spectrum band. The preference will give to primary users, when operation will be done and secondary users' interference will not effect on the primary users. Secondary users do not have permanent spectrum band allocation. So some functions are added for the secondary users to use the licensed spectrum band [17]. Spectrum management should be flexible for the secondary users so that they can operate on band, the licensed or unlicensed spectrum band, or both bands. So, the functions that are needed for secondary networks vary according the spectrum whether it will be licensed or unlicensed.

- **Primary user /licensed band operation:** Secondary users try to use the unused spectrum holes of licensed spectrum band. Though the preference is given to the primary users, therefore secondary users must have the capability to detect the existence of primary users and must empty the spectrum band instantly if a primary user comes in the spectrum band occupied by secondary users.
- **Secondary user /unlicensed band operation:** If the spectrum is not used by the primary users, then secondary users uses that empty spectrum undoubtedly. This case represents the coordination between the secondary users using appropriate spectrum sharing method to increase the spectrum efficiency and for giving best Quality of Services.

Primary network have some challenges with existing of Secondary network that are (i) Secondary users must not interfere with the primary users. (ii) Secondary network must take care of Quality of services in spectrum environment. (iii) Secondary users must provide seamless communication [18]. There are four abilities of Cognitive radio that are achieved for optimum spectrum utilization these are: knowing QoS Requirements, Spectrum sensing, knowing regulatory policies for the regulator, knowing the CR abilities [19]. Cognitive radio takes benefits of Software Defined Radio (SDR). Cognitive Radio has the ability of sensing and responding according to the change in the environment. This radio has some past memory of transmitted and received data accompanied by transmission parameters and it has capability to sense the existing spectral environment. The cognitive radio takes suitable decisions to optimize the objectives. In CR primary and secondary users have different goals from their point of view such as SINR, Throughput, Battery life, Medium access and Data rate must be maximized. BER, Power Consumption, must be minimized. CR have other operations from the network standpoint that spectrum utilization efficiently, coverage must be appropriate, optimal capacity network should be optimum. The main focus of CR is its ability to optimize of communication parameters and it increases the ability to adapt environment changes.

1.5 COGNITIVE RADIO FUNCTIONS

The Cognitive Radio functions are as following.

- **Spectrum Sensing**: In this, CR continuously approach for unused spectrum that is called white spaces/ spectrum holes as shown in Figure 1.4.
- **Spectrum Management**: When white spaces get found then CR, chooses the existing empty white space.

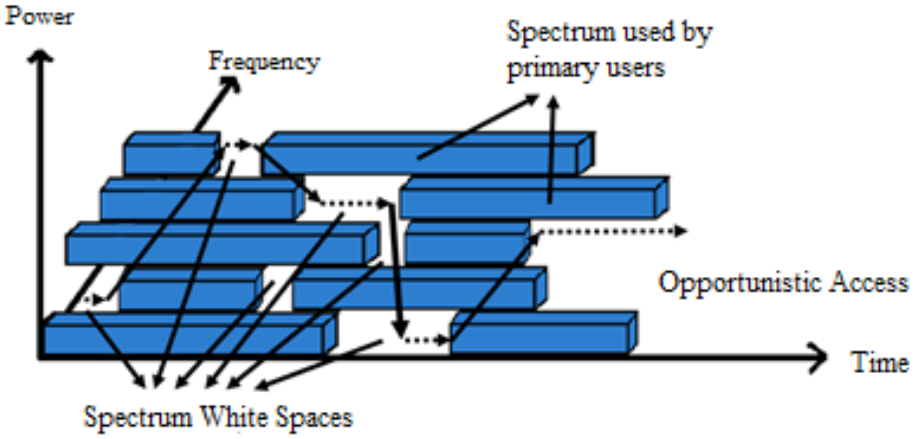

Figure 1.4 Concept diagram of White space

- **Spectrum Sharing**: In this, Secondary users use the primary users' spectrum when they are absent.
- **Spectrum Mobility**: Secondary user empty the channel instantly after detect the primary user.

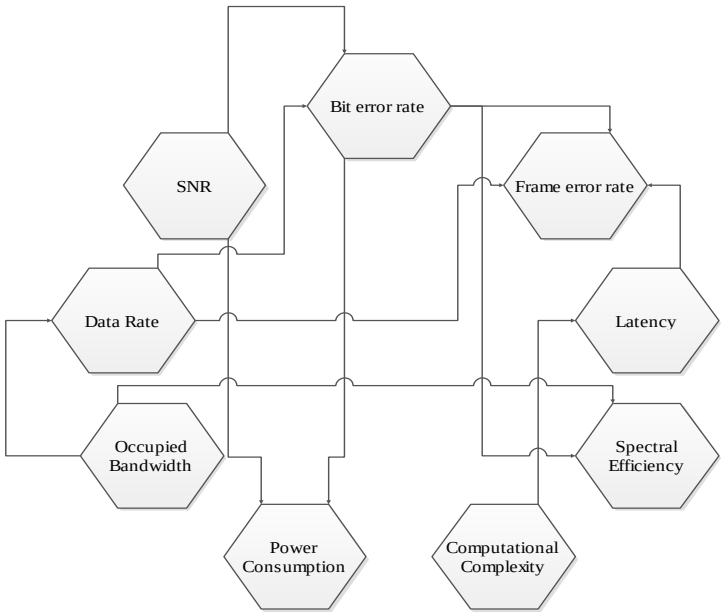

Figure 1.5 Directed graph indicating how one objective affects another objective.

1.6 CHARACTERISTICS OF COGNITIVE RADIO

The two main characteristics of CR are:

- **Cognitive Capability:** It has the ability to sense the environment for transmission and arise the data from the channel.
- **Reconfigurability**: It is a radio programming process, which does not, changes its hardware dynamically. CR is basically software dependent radio. It can be change between one protocol to the other and have various applications. The occupancy of sub band is divided into three that are a).White spaces: These spaces are free from RF interferers, but not from noise. b).Gray spaces. These are moderately employed by both RF interferers and noise. c) Black spaces: The spaces are totally occupied because of the shared occurrence of communication, RF interference and noise. Cognitive radios vitally setup the wireless communication system, that uses exists RF environment

All parameters are non-linearly linked for the particular network configuration and geographic configuration. The parameters are inter-dependent to each other so parameters are considered carefully while designing a radio link. Like BER linked to SNR and FER as figure 1.5. Some parameters have non-linear and linear linked relationships and they are dependent on interference levels, fading in multipath and their network topology.

In Figure 1.5, due to demand in real time optimal solution for these parameters they become more complicated. Most of the parameters objective overlaps and varies among each other so one objective affect another objective and complexity increases as more number of parameters increases in on objective so multi-parameter is difficult task. The quality and amount of input to the system all depends on the decision accuracy applied on Artificial Intelligence techniques. So more number of input that make radio more knowledgeable, that's why allows the decision making process to obtain the decisions which are more accurate. The optimization problem becomes more complex because the dependency between all parameters and performance objectives. The aspect of optimization solutions will depend on the type of optimization algorithm is used, population size, its execution time and solution optimality.

1.7 ADAPTIVE PARAMETERS

Cognitive radio achieved a specific or desired goal by adapting the available transmission parameters. This is done to develop a decision making engine by joining different adaptation techniques. Adaptation in wireless systems is not so latest topic. We combine different techniques for getting efficient communication; these techniques are dynamic spectrum allocation, adaptation in modulation, dynamically adjustment in power and adaptation in frame length. The problem for these techniques comes when a system efforts to optimize and usage of all these techniques that contributes the objective parameters.

Like modulation adaptation is very mutual in wireless networks. This technique applied in the Physical layer of h/w monitor of the SNR of communication signal and it gets best throughput by maintaining the power and modulation consequently and simultaneously retaining BER. In order to get best value of throughput in low environment of signal to noise ratio environments, Adaptation frame length is used to change the frame length value.

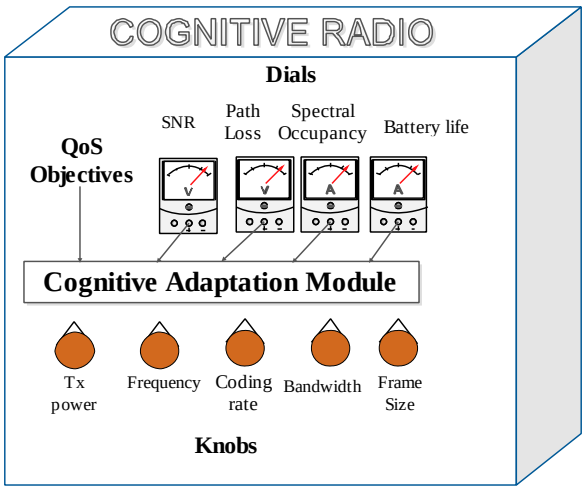

Figure 1.6 Visual representations of cognitive radio knobs and dials [2]

We use these techniques individually to optimize the result to reach at particular goal. A trade-off is made while using various techniques at same time and even single parameters have great impact on various techniques in different ways. Cognitive engine joints these adaptive techniques which has input environmental criteria and output the adaptation criteria depends upon particular objectives of system. Figure 2.4 shows how parameters relate to each other that are used in cognitive radio.

1.8 COGNITIVE RADIO OPERATING PARAMETERS

While emerging a control system of cognitive radio, various input parameters must be selected. The superiority and extent of inputs can be obtained by the accurateness of the decisions created by an Artificial intelligence technique. A radio system can be Informative radio when it has more inputs, so that's why we permitting decision making process for obtaining more correct decisions. It comes to the system's first input set. There are two parameters for the inputs of cognitive radio system. First one is environmental parameters that give details regarding existing wireless environment that must be molded inside and CR engine create decision regarding output. CR engine created to sense the data from environment by an exterior sensor. For sensing there are various devices, that sense the environment characteristics, hardware such as DARPA next generation used for this, it includes utilization of spectrum [20]. If we need CR spectral efficiency to be maximized, then this above information would be used. Several sensors are exists and have their own characteristics like, BER determination for the existing

formation, SNR, Existing Noise floor. In this section, we approached a set of list of environmental parameters. It will helps in the CR decision making process. Discussed section tells variables for environmental sensed parameters. There is one more variable that are significant for the input to AI techniques that is Decision variables. These variables show the transmission parameters in CR case, measured by system.

After the creation of simulated environment in wireless communication, decision variables set generated and provides it to the fitness function and get to know the estimation of achievement of objective goals that depends on the simulated environment. By this at the end we get the approximated results for attaining setup goals of transmission parameters sample set. To obtain optimum set of transmission parameters set Artificial intelligence procedures used. These transmission parameters and objective functions must be specified to explain the operation of the system and the environmental parameters used to structure the wireless channel. The system performance all depends on the system's objective. These objectives are the regulator to pilot the system at the particular rate. We have taken five objectives; each objective has their own criteria, like Interference minimization for the system. We can achieve the basic criteria of our objectives by operating the transmission parameters in such a way that they give required possibilities for the given environment. In this section, we have covered the area of objective parameters.

1.8.1 Transmission Parameters

Software defines radio gives benefits to the Cognitive radio for controlling parameters. These controlling parameters are driven as input to the fitness function alongside environmental parameters and objectives. We get fitness score by the operation of fitness function and by this fitness score explains the approximated achievement of objective goals. In cognitive system, transmission parameters list is required to creating fitness functions. As said earlier that transmission parameters are same as controlling parameters that generated by the components of software radio. In this thesis, transmission parameters are taken as a reference for the parameters list that will be used for controlling the single components of radio. It is very complex and challenging to explain full transmission parameter list and creating a fitness function for all radios. Radio has many different features and according to the requirement for the application, it generates a specific parameters list. The transmissions parameters are used in this thesis are the parameters that automatically adapt the surrounding environment according to requirement. For our research work we have taken eight parameters. We have taken these transmission parameters that could be used by CR to control the characteristics of communication system [21-25]. The complete list of parameters used in this dissertation to generate a fitness function is shown in Table 1.1.

The transmissions parameters are used in this thesis are the parameters that automatically adapt the surrounding environment according to requirement.

1.8.2 Environment parameters

Environmental parameters defines the characteristics of external or surrounding and the data present in these characteristics are operation state of radio information that are located internally, and information about environment of wireless channel that present externally. This kind of information is used in decision making process for helping the manager in CR. There are two types of classification of environmental variables:

- Primary environmental parameters
- Secondary environmental parameters

Environmental parameters are the parameters in which fitness function directly uses the objective parameters. Likewise an example, objective function BER used by the channel's noise power. This straightly affects the particular objective's fitness score. The second groups of these parameters are active parameters. The system examined these parameters simultaneously and values are to be selected for the decision making process regarding objective function. An example of battery's life parameter, system continuously examines this parameter while it reduces below to the threshold level. By the weighted sum approach, objective functions weight can be changed for upper the weight on Power consumption objective minimization by the system.

Table 1.1 Parameters of Transmission list

Parameter Name	**Description**
Transmitted Power	Tangible extent of power
Type of modulation	Modulation format type
Modulation Index	Number of symbols that are given for modulation format
Coding rate of Channel	Particular rate of coding system
Frame Size	Transmission frame size
Symbol rate	Number of symbols per second
Time division duplex	Transmission time percentage

Table 1.2 Environmental parameter list

Environmental Parameters	**Description**
Bit-Error-Rate (BER)	Number of error present in existing bit.
Signal-to-noise ratio (SNR)	Amount of noise in a desired signal.
Noise power (N)	Power produced by random EM process, Noise power Magnitude in dB
Battery Status	Predictable energy left in batteries
Power Utilization	Power utilization of present configuration

Path loss: It is decreasing the signal strength and density of power in the space. There are many causes due to path loss occurs.

- Loss in free-space.
- Diffraction
- Shadowing
- Refraction
- Reflection
- Absorption

The clutter around the environment and the terrain creates effects on the environment and the cause of path loss. There are many parameters of environment. As an example, Noise power, Power consumption, Battery life. These are the internal parameter and define the system gives importance to the power minimization factor. The utilization of spectrum details is the first external parameters. This parameter defines the occupancy of spectrum band after sensing [26, 27]. This desertion work defines that both parameters how can be summed into CR system by weights of objective for adjusting the aim of communication system.

1.9 PERFORMANCE OBJECTIVES

There are various appropriate objectives that taken by radio system to attain at their goals in wireless communication. We have explained five objective parameters for attaining the optimum solution.

These five objectives are:

- Minimizing BER
- Minimizing Power consumption
- Maximizing Throughput
- Maximizing spectral efficiency
- Minimizing Interference.

1.9.1 BER Minimization

Minimization of BER is the common requirement in wireless communication. This objective defines to reducing the extent of errors in complete set of bits. The main purpose of these objective parameters is to improve the communication signal for the radio system. BER is the amount of error present in the total number of bits. Communication system for single carrier, BER is expressed as

$$f_{min\_ber} = 1 - \frac{log_{10}0.5}{log_{10}P_{be}} \quad (1.1)$$

where P_{be} is bit error rate probability. BER should be minimized. Communication systems for multicarrier, the complementary fitness function $f_{multicarrier\_\min\_ber}$ are attained by interchanging P_{be} to $\overline{P_{be}}$.

1.9.2 Throughput Maximization

Maximize throughput objective means the maximum amount of information gathering. Throughput defines as the maximum amount of data can be transferred from one place to another in a given amount of time. It should be maximized in communication system.

$$f_{\text{maximum}\_throughput} = \frac{log_2(M)}{log_2 M_{max}} \tag{1.2}$$

where M represents modulation index and M_{max} represents maximum modulation index. For the multicarrier communication systems, its complementary fitness function for is represented as $f_{muticarrier\_maximum\_throughput}$ .For real time scenario, there are different restrictions factors which decide the performance of primary and secondary user networks like power dissipation, rate of change of environment and interference etc.

1.9.3 Minimization of Power Consumption

Minimization of power consumption is defined itself. This objective parameter is to guide a system to a minimum power consumption state. Power consumption should be minimized. Fitness function for power consumption is indicates as:

$$f_{minimum\_power} = 1 - \frac{P}{P_{max}} \tag{1.3}$$

where P represents transmission power, $P_{maximum}$ represents maximum transmission power. The complementary fitness function $f_{multicarrier\_\min\_power}$ is attained by interchanging P from $\sum_{i=1}^{N} \frac{P_i`0}{N}$ where P_i is the transmitted power on the i_{th} sub-carrier for multicarrier communication systems.

1.9.4 Minimization Of Interference

Minimization of interference, it removes the large noise floor regions in the spectrum of wireless communication. Communication system has main problem of interference because of spectrum sharing environments. The fitness function is generated to minimized optimization of interference. When using cognitive radio system, the secondary user can't intermediate with primary user is the first priority.

$$f_{\min\_interference} = \frac{\{(P+D+TDD)(P_{min}+D_{min}+1)\}}{(P_{max}+D_{max}+R_{smax})} \tag{1.4}$$

where D= single carrier bandwidth, D_{min} = min bandwidth and D_{max} = max bandwidth, TDD = Time division duplexing and R_{smax} = max symbol rate.

1.9.5 Maximization Of Spectral Efficiency

The complete information that is transmitted above a give bandwidth is defined as Spectral Efficiency and it can be expressed as:

$$f_{\max\_spetral\_eff} = 1 - \frac{B*M_{max}*R_{smax}}{M*B_{min}*R_s} \quad (1.5)$$

Spectral efficiency should be maximized for the optimization problem so that more information can be transmitted with the limited amount of bandwidth where M_{max} is the maximum modulation index, B is bandwidth and R_s is the spectral rate.

1.10 GLOBAL OPTIMIZATION SOLVING APPROACH:

Multi objective fitness function optimization gives a collection set of local solutions rather than an individual global solution. For multi objective fitness function optimization each communication function has importance of it. The literature [28-33] represents various multi-objective fitness functions optimizations by different optimization techniques.

For single carrier communication system the Cognitive radio engine can be expressed as:

$$Maxf_{single} = w_1 * f_{minimum\_ber} + w_2 * f_{minimum\_power} + w_3 * f_{maximum\_throuhput} + w_4 * f_{maximum\_spectral\_eff} + w_5 * f_{minimum\_interfernce}. \quad (1.6)$$

The weights choose randomly and all this based upon the need of QoS for application. We initially use the resultant fitness function for every parameter [34]. The weight w_1, w_2, w_3, w_4 and w_5 represents the way for the optimization algorithm. The weight shows for every objective function in a particular mode suggests the optimization algorithm in changing on the way to a global solution regarding that mode. These given weights assistance the algorithm to change from one mode to other mode too. It is difficult to maintain set of solutions because all objective parameters are inter-linked to each other. If for system guiding, we have to attain a particular solution, so for the creation of objective we have to sum up with some inclination. If this does not happen BER minimization and power minimization would give set of solution in place of individual solution. So, that's why both objective parameters give different solutions. Each objective has its own priority. By this fitness function distinguish each objective by giving position to objective in order of priority. Various methods presents for defining the priority in creation of objective parameter set [35]. The solution is this problem is to create weighted sum approach, where importance given to each objective by giving a weight. This method operation is simple in nature used by various techniques like genetic algorithm.

1.11 ADAPTIVE COGNITIVE RADIO ENGINE TECHNIQUES

There are various methods that are applied to the cognitive engine in cognitive radio and different global optimization techniques called Artificial intelligence techniques such as neural networks, fuzzy logic system, genetic algorithms, expert systems and all. In wireless communication, these existing techniques can be used as control for the transmission parameters. Traditional optimization is made of resultant algorithms that find out the proper optimum parameters. Various optimization techniques consist of both linear and nonlinear problems. For nonlinear optimization we have to deal with dynamically and constantly changing environment. Cognitive radio sense the environment periodically, and dynamically changing the set of inputs. For compensate the large changes in the environment, the real system changes occasionally. When any changes to the system component then problem constraints also changes like transforming from one modulation to other, it needs change in coding type and available maximum transmit power. So this method of changing constraints makes traditional optimization method more complex and not appropriate for using in this problem. For dynamic parameters we have to update optimization algorithm regularly. A flexible optimization algorithm is requires for adapting the dynamic environment. So, we deals with AI based techniques.

We have applied two methods for cognitive radio that could be used as adaptive engines. A system is designed that tells the rules of system designing operation that called Expert system. Each environment have data base rule with optimum decision. For this, we require an appropriate rule set and we need hand written analyses of the problem as a solution. The benefit of this technique is the speed at which our solution is generated. However, the speed of the result depends upon the big data base requires to symbolizes the rules. We have to find out the relationship between the extents of rule base, the accuracy of the output and time needs finding out the solution. This technique becomes standard technique besides of machine learning techniques that not uses complete data base for all possible cases. By this research we came to know that this technique is more efficient than machine learning technique. We require machine learning technique to determine the optimum solution for adaptive cognitive engine and requires following characteristics.

- Reduces the local minima problem in non-linear system.
- In large search space, efficient searching.
- Gives flexibility in system.
- Memory storage usage is less.
- For operation only small setup is needed.

There are various surveys on machine learning [36,37,38, 59]. Different techniques of machine learning are neural networks, genetic algorithms, CBR etc. Each method has their own pros and cons but we have to search the technique that would be adjusted with our requirements. The overcoming of local minimum problem is the main aim of all machine learning techniques. This problem is firstly present in simple techniques like hill climbing. We mainly focus on the capability to work in large search space and flexibility techniques for distinguishing between different techniques. We have to focus on the technique that uses the amount of memory is achievable else a full search space will be adjusted according to our demands. Basically solution will be generated on radios which have incomplete processing and memory resources.

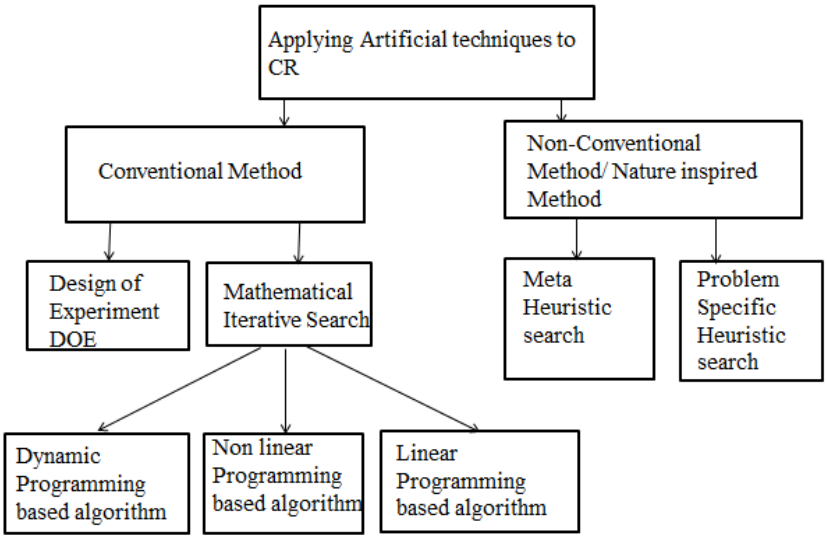

Figure 1.7 (a) Basic AI techniques

Artificial intelligence main purpose is to make machines to do tasks in such a way that resembles to the expert. Machine increases their own advantages by adapting surrounding environment [39]. The major steps of artificial intelligence in machine learning in cognitive radio can be represented as following: (1) Sensing: Sense the spectrum frequency, (2) Observing: Observes the surrounding situation and evaluating the response such as Acknowledgment reactions, (3) learning, (4) Track: preserve and tracks observations and updating decisions for the modal and to obtain the well precision for decision making process in future, and (5) Decision: Resource management decision and adjustment of transmission errors [34, 59]. Zhao et al. proposed the idea of CRs from the outlooks of machine learning (ML) and Artificial intelligence (AI). Different authors represented the probable important ideas and applications that are used for Cognitive radio technology. Artificial intelligence has vast scope in various fields and may be signified but it is not restricted to the following evolutionary techniques: Genetic algorithms, Particle

swarm optimization, cat swarm optimization, artificial bee colony algorithm, Spider monkey optimization, Case-based reasoning and Cuckoo search optimization algorithm. These algorithms can be applied to CR networks.

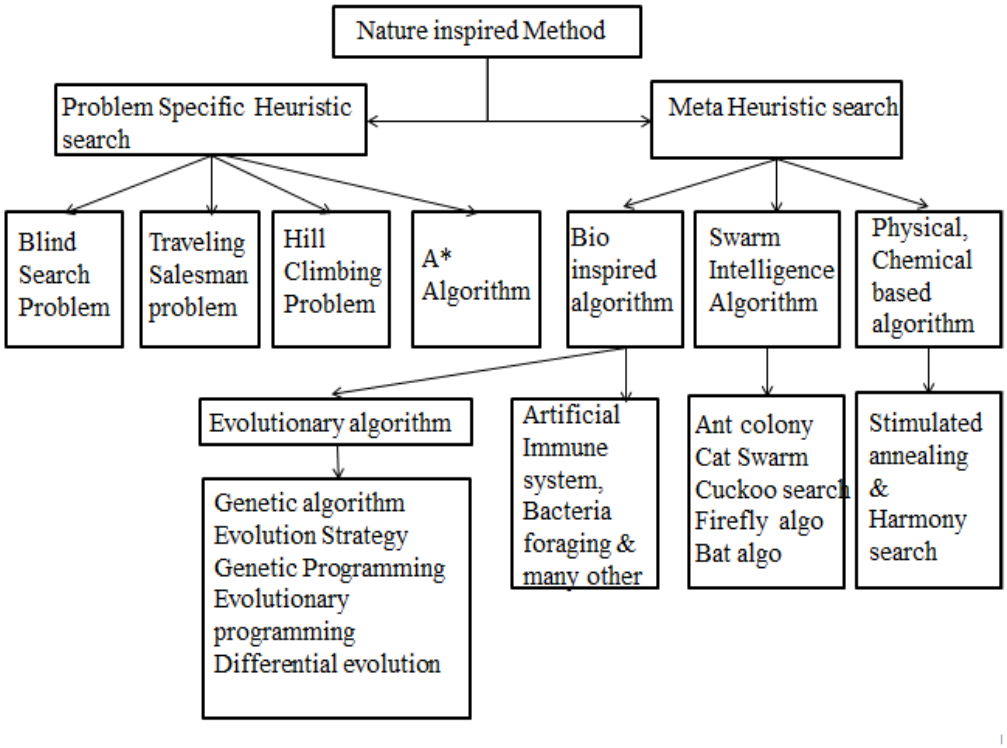

Figure 1.7(b). Nature inspired AI techniques

Figure 1.7(a) and 1.7(b) Tree classification of various nature inspired optimization algorithms grouped by the area of inspiration

1.11 Applying AI Techniques

- Genetic Algorithm

The concept idea behind of Genetic algorithm is “Survival of the fittest”. A GA is approached by Charles Darwin’s theory. This theory tells about the selection of fittest element by natural mixture and that mixture further goes to another reproduction process and generate offspring for future generation. This GA process starts with selection of fittest individuals from a huge population.

GA algorithm

Begin

Step 1: Generate the population.

Step 2: Define the fitness of population.

Step 3: Repeat

Step 3.1 Choice Parents from population

Step 3.2 Implement Crossover on the chosen parents and generating the poulation .

Step 3.3 implement mutuation of population

Step 3.4 Define fitness of population at next state.

Step 4: till the best individual is not good enough

Stop

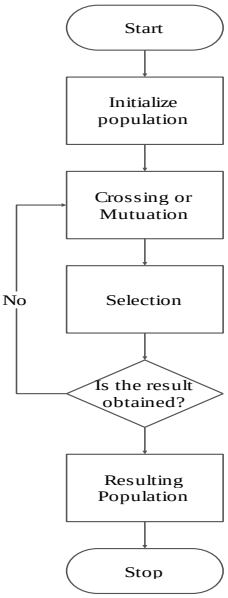

Figure 1.8 GA flowchart

They generate offspring which adapt the behavior of the parents and they will contribute to the next generation. If parents' fitness is better, then their offspring would be better than their parents and have good opportunity to survive. This process keeps on iterating until end, till the fittest generation does not get. This procedure is applied for a searching problem. There are a number of set of solution and select the best one out of them. There are following five processes in a genetic algorithm. (i) Initial population: This is generated by fixed set of elements or individuals called population. Each individual meant to a solution for the problem we want to solve. (ii) Fitness function: This function determines individual fitness. This determines the fitness score to each individual. The probability of selection for reproduction depends on its fitness score (iii) Selection: The idea of selection is to select the fittest individuals and passes genes to the further generation (iii) Crossover: This is the crucial process for every duo of parents that are to be coupled. e).Mutation. Definite new offspring generated, some of their genes are exposed to a mutation with a less random probability.

- PSO (Particle Swarm Optimization)

For decision making process, each swarm works on two types of information. Primarily they learn from their own experience and know which experience is better till now and they know how it can be better. Second one is, from other's experience that they know how other has performed around them and according to their and other experience they select the best decision. Initially PSO has a set of population

of the random solutions. In this, each solution is considered as the particle, it has random velocities that are present in problem space. Each individual has retention and they keep follow its former best position P_{best} and its equivalent fitness. Each particle has its own P_{best} and the particle which has greatest fitness from all, consider as the G_{best} (global best) of the Swarm particle. In N- dimensional parametric space every present particles is measured. Global best is between all the particles and it is determined by P_g= (p_{g1}, p_{g2} ,..., p_{gn}). Velocity of ith particle is indicated as L_i = (v_{11}, v_{12} ,..., v_{12}) and it define as the rate of change of position. Here are the equations that define the velocity and position. The Previous best position of the i_{th} particle is P_{besti} that is indicated by P_i= (p_{11}, p_{12} ,..., p_{1n}) and it contributes the value of best fitness.

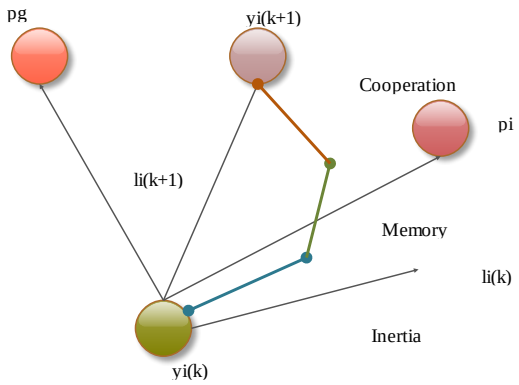

Figure.1.9. Velocity and Position update in PSO.

For updating of velocity:

$$l_i(n+1) = \text{w}\times l_i(n) + c_1 \times r_1 \times (l_i(n) - y_i(n)) + c_2 \times r_2 \times ((p_g) - x_i(n)), \quad (1.7)$$

For updating of position:

$$y_i(n+1) = y_i(n) + l_i(n+1) \quad (1.8)$$

Where $i = 1,2,\ldots,N$, and N represents the population size; w is weight of inertia; c1 and c2 represents positive constants number ; r1 and r2 indicates randomly generated numbers that are arranged in the range 0 to 1. Eq. (7) shows the particle's new velocity $l_i(n+1)$, for every repetition, and Equation. (8) Determines position of the new ith particle $y_i(n+1)$, sum of updated velocity $l_i(n+1)$ and its current position. Figure 4.3 updating of velocity and position for a particle of 2-Dimensional space [40].

PSO algorithm

Start

Step 1: Initialize positions and velocities of each particle.

Step 2: Set P_{best} andG_{best}.

Step 3: Calculate particle velocity of each swarm as equation (6)

Step 4: Update particle position of each swarm as equation (7)

Step 5: Calculate the objective function.

Step 6: Until a suitable solution is found.

Stop

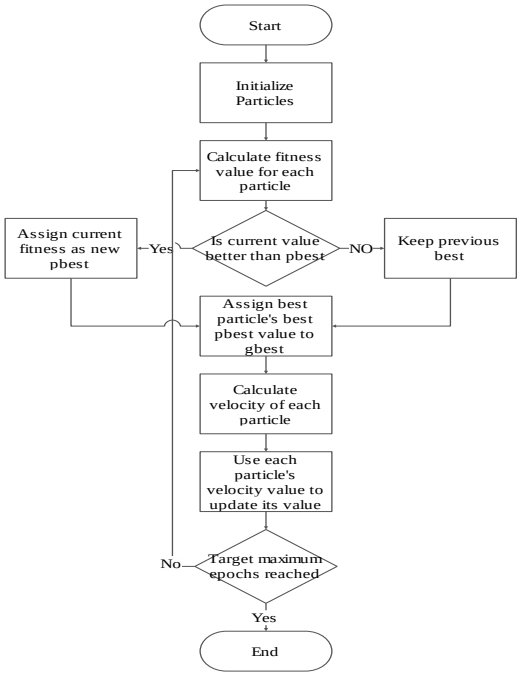

Figure 1.10 PSO flowchart

- Artificial Bee Colony Algorithm:

In Artificial Bee Colony (ABC) algorithm method, it made up of group of three colonies of the bee these are: active bee, it specifies the food sources, viewer bees sees the dance of the active bee in the hive and finds a food source and last one is detective bees searching for food sources randomly where it get food source. Both onlookers and detectives bees are considered as idle bees.

Firstly, the detective bee discovered all near position of food sources. After that the active bees and viewer bees achieved the fluid of food sources and frequently exploitation of food source will cause that food source come to vanish. The active bees become detective bee in searching for source of food again afterwards the fluid of the source of food achieved with both detective and active bees. In given algorithm, food source location indicates a probable result for a problem and the quality of the related solution is meant as fluid of food source. All active bees are connected with only food source, when the active bee's generation becomes equal to the generated food sources.

ABC algorithm

Step 1: initialization of population.

Step 2: Determine the fitness f_i for poulation

Cycle initialse to one.

Step 3:Replication

Step 4: For every active bee.

Step 4.1: New solution generation.

Step 4.2:Calculate the fitness function value f_i.

Step 4.3: Apply desirous processof selection.

Step 5: Find the probablity values g_i for the solutions y_i

Step 6: For each viewer bee.

Step 6.1: Choose a solution x_i subjected on p_i.

Step 6.2: Generate new solution.

Step 6.3: Calculate the fitness function value f_i

Step 6.4: Apply desirous process of selection.

Step 7: If an uninhibited solution for the detective exists,

Step 8: Switch it with a newly generated solution.

Step 9: Memorize the finest solution till now.Increase by 1;

Step 10:Until cycle=machine cycle

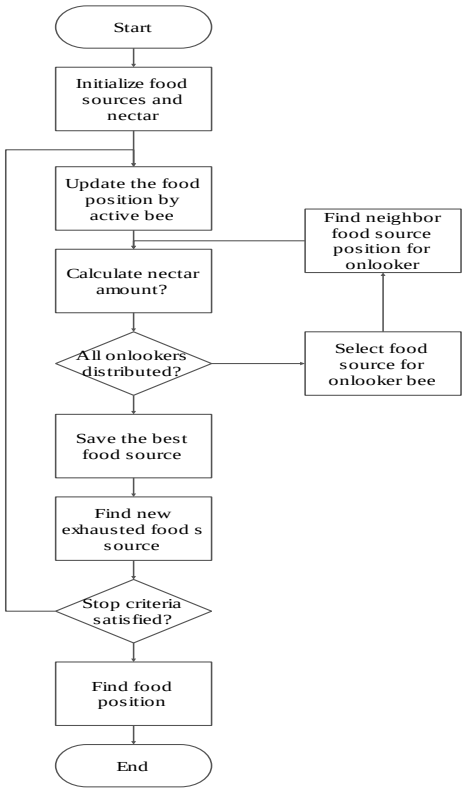

Figure 1.11 ABC algorithm flowchart

- Stimulated Annealing (SA)

Stimulated Annealing is an optimization algorithm which is used in very common purpose for optimization and it can combines with many optimization problems [41-46].The key concept of SA is the similarity that how liquid freeze and crystallize. Their molecules moves liberally and independent in associated to each other when the melted temperature becomes high. When the liquid temperature become lower, the movement of liquid is vanished and the liquid starts to become solid. If the liquid cools gradually, the molecules organized in the way of crystallize structure. The molecule carry minimum energy state if molecule making up the crystalline structure but if molecules does not cools quickly crystallize structure will not make and that energy state of molecules will not reach at the minimum state of energy. The necessary concept of SA is that which action is taken by this algorithm are same as the displacement of the molecules of a liquid substance that created when it becomes cool. The cost function

is attached to the liquid's energy elements and this cost function has to optimize by stimulated algorithm. So, the SA targets to attain a optimum solution globally by slow convergence that tells a finish solution that creates changes downward side with infrequent changes in upward side, so expectantly ends with a global optimum. The SA solution experiences a limited change at iteration at every level of solution.

There will be small deviation in energy ΔE when little change happens. If this deviation gets negative, the newly generated solution will exchange to previous solution. Otherwise it exchange with earlier generated solution on the bases of Metropolis–Hasting algorithm:

SA algorithm

Step 1: **input:** $iteration_{max}$

Step 2: **output:** S_{best}

Step 3: $S_{present} \leftarrow Create\_initial\_solution( )$

Step 4: $S_{best} \leftarrow S_{current}$

$\boldsymbol{For}\ (i = 1\ \boldsymbol{to}\ iteration_{max})$

Step5: $S\_initial \leftarrow create\_neighbor\_solution\ (S_{Current})$

Step 6: $temp_{current} \leftarrow calculate\ temperature\ (i)$

$\boldsymbol{If}\ \boldsymbol{f}\ (S_{initial}) > \boldsymbol{f}\ (S_{current})$

Step 7: $S_{present} \leftarrow S_{initial}$

$\boldsymbol{If}\ \ \boldsymbol{f}\ (S_{initial}) \geq \boldsymbol{f}(S_{best})$

Step 8: $S\_best \leftarrow S\_initial$

End

$\boldsymbol{Else\ if}\quad exp\ (\frac{f(S_{present})-f(S_{initial})}{temp_{present}}) > rand\ ( )$

Step 9: $S_{present} \leftarrow S_{initial}$

End

End

Return (S_{best})

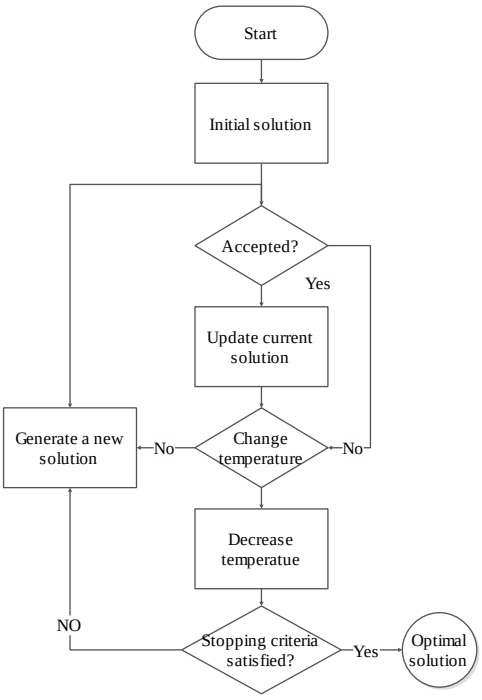

Figure 1.12 Flow Chart of SA

$$X\ (\Delta E) = e^{-\Delta E/T} \tag{1.9}$$

The value of all constraints with probability *X*, changes with limited variation. The requirement of probability is small to make solution of neighbor but not the other solution. For the dynamics of the system, temperature is the controlling constraints. In this scenario, at all iteration the parameter develops this law:

$$T_{N+1} = T_N \times (1 - \frac{10}{N}) \quad (1.10)$$

where N is the iteration number. We have to keep solution X_n=0 with initialization of probability by the initial temperature.

- Spider Monkey Optimization (SMO)

SMO technique is suggested by Bansal, JC and he classified SMO by swarm intelligence techniques in 2014[47]. As PSO, SMO is also based upon the food searching criteria and also based upon fusion-fission social system of spider monkey behavior. SMO have many advantages but there are some possibilities for further improvements. The population of spider monkey is headed by a female, they get segmented into sub-groups for searching food and in one group there are 40 to 50 individuals, which again governed by a female. If female flops to reach the sustenance then they again go for searching the food and also governed by female and they search food until they get food [48]. SMO algorithm mechanism is depends on the behavior of spider monkeys. The value of local maxima and minima obtained with its optimized value. That why usage of this algorithm is used to get optimized and perfect values in various cases.

Method of SMO is depending upon population iterative approach. It has seven levels. Each step level is mentioned as follows: Initialization of Population: Here are N Population of spider monkeys in D-dimensional space N_i where $i = 1,2,\dots K$. Each spider monkey represents a solution towards problem. Each M_i is initiated below:

$$N\_ij = N\_minj + R(0,1) \times (N\_maxj - N\_minj) \quad (1.11)$$

here N_{minj} and N_{maxj} are limits of N_i in jth vector and R have range (0,1) and it is random number.

Local Leader Phase (LLP)

LLP represents the connection of local leader and group mates, N Population get fitness value by the renovation of its current position. If the previous location for the measurement of fitness is smaller than the current location, then population N adjusts the location from the current location.

$$N\_newij = N\_ij + R(0,1) \times (LL\_nj - N\_ij) + R(-1,1) \times (N\_lj - N\_ij) \quad (1.12)$$

here N_{ij} define i^{th} N in dimension j^{th}, LL_{nj} correlate to the n^{th} leader of local assembly position dimension in j^{th} . N_{lj} Defines lth N that is randomly picked from n[th] troop like $l \neq i$ in dimension for j^{th}.

Global Leader Phase (GLP)

This level exists next to the LLP. Population N, changes its position that based on the global leader and local troop mates observation. GLP level location modification equation is following:

$$N\_newij = N\_ij + R(0,1) \times (GL\_j - N\_ij)R(-1,1) \times (N\_lj - N\_ij) \quad (1.13)$$

where GL_j poises for global leader's location in dimension jth and j is randomly selected number like $j = 1,2,3,\ldots,D$.by taking probabilitiesP_{ri}'s, N_i adjusts its position. For calculating the probability of particular solution fitness is considered by different techniques like:

$$P\_ri = (0.1 + (\frac{fitness_i}{fitness_{max}}) \quad (1.14)$$

Global Leader Learning Phase (GLLP)

It is the next level just after global leader phase and its position gets updated by finding all solutions. The spider monkey which has highest fitness function that position will be the global leader position and refer time to time that its position is changing or remains same. Global limit count will be increase by one if it not changing.

Local Leader Learning Phase (LLLP)

This is level of desirous search will be carried by the sub-groups. Now the spider monkey who has great function of fitness will be consider as local leader position and refer time to time that its position is changing or not. Local Limit Count will be increase by one if it is not changing.

Local Leader Decision Phase (GLDP)

In this phase, local leader have to be updated if it is not then local leader limit the position of the member of that particular group. In order to remove inactivity of the solution, the new position has set for the monkeys such that monkeys are attracts towards the global leader position and avoid by the local leader.

$$M\_newij = N_{ij} + R(0,1) \times (GL_j - N_{ij}) + R(0,1) \times (N_{ij} - LL_{kj} \quad (1.15)$$

In this equation, the modified dimension N is captivated towards global reader and avoids local leader. So that modified N has found out.

SMO algorithm

Step 1: Begins with Population,

Step 2: Set Local Leader Limit, Global Leader Limit.

Step 3: Determine fitness for each individual or monkey.

Step 4: Use desirous choice to select global leaders and local leaders. Till Execution state does not meet.

Step 4.1: New location for group is generated with their self-experience and their local and group populace experience to track the target.

Step 4.2: Depends upon greedy selection technique and group members fitness value

Step 4.3: Find the probability of all confidantes using eq(4)

Step 4.4: For every group confidants, generate new locations selected by experience of its own, global leader experience and Global Leader Phase (GLP) experience.

Step 4.5: Greedy selection technique is applied for the modifications of locations of global and local leaders for entire groups.

Step 4.6: If any group of local leader fails to modify the location within LLL then change the specific group confidantes using LLD phase.

Step 4.7: If any group of global leader flops to adjust the position in GLL then change the specific group into smaller group confidantes using GLD phase less group size of threshold

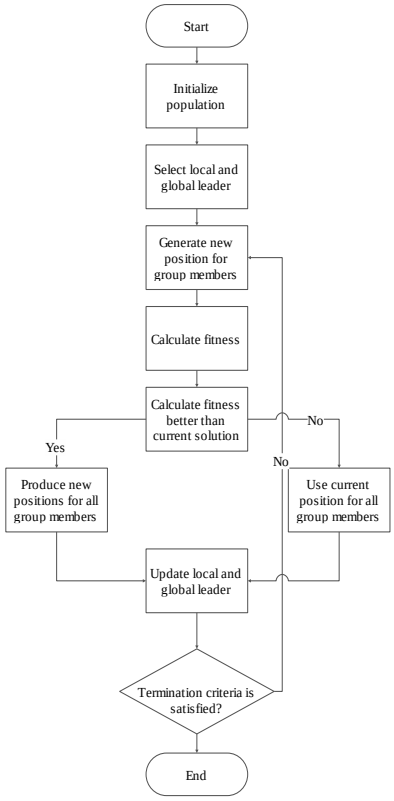

Figure 1.13 SMO flowchart

Global Leader Decision Phase (GLDP)

In this level, if the global leader did not change their position up to predefined iterations limit then divisions of population into sub groups will be occurs by the global leader that is caused by local leader. Two classes population division will be occur and later division continues till the maximum group count is reached. After this, LLL has taken place for formation of new classes.

1.12 DISSERTATION ORGANIZATION:

Chapter 1 This chapter presents the Motivation of research and the objective of research and reason for utilizing the cognitive radio, concept of cognitive radio, it signifies the architecture of cognitive radio, its

characteristics, and covers all the functions in details. This chapter summarizes the impact of the transmission and environment parameter in wireless communication. It covers various parameters that are used in cognitive radio model during simulation. It represents the various techniques for parameter optimization. This chapter also covers their introduction with algorithms and flowchart.

Chapter 2 covers the literature review of various research papers about cognitive radio with their challenges or gaps.

Chapter 3 presents the proposed methodology that is used in this dissertation. This chapter signifies the introduction of proposed GWO algorithm. It also covers parameters which used in this dissertation.

Chapter 4 This chapter discusses the solution of optimization problem. It also presents the comparative analysis of existing and proposed algorithm.

Chapter 5 presents the summary and conclusion arrived and future scope.

CHAPTER 2

LITERATURE SURVEY:

This chapter involces the work done by the various reasearchers in the field of cognitive radio for the adaptation of transmission parameters. This literature survey has been categorized as follows:

2.1 GENETIC ALGORITHM

Tim R. Newman *et al*. [49**],** introduces a genetic algorithm, the main work of CR is to avail dynamic wireless channel environment radio parameters.so, The optimum radio's parameter of transmission for single transmission system and multicarrier systems are rectify by the CR decision engine. This paper describes the exact set of particular transmission system and fitness functions of multicarrier for GA application but convergence rate is so slow.

Sebastien Herry *et al.* [50]**,** authors aims to find a secondary user parameters using genetic algorithm. For secondary user network they find a solution for objective parameters that fit into primary user network holes.

Maninder Jeet Kaur *et al.* [51], the author focused on various optimization techniques on allocation of spectrums for secondary users; the Genetic algorithm technique is applied and compared. They have predicted that the secondary users already specified the requirement of QoS and the sensing of the secondary holes is carried out but complexity is present.

Deepak K. Tosh *et al.* [52], they proposed a method, multi-evolutionary algorithm based Genetic Algorithm (NSGA-II) to define the required transmission parameters for multicarrier system like Non-dominated Sorting criteria. Fitness function is shown for all criterions and for composite function. All this is done for radio parameters. In this scenario, the adaptation of parameters is done for unconstrained optimization for multi-objective parameters and approached an algorithm centered on NSGA-II for the optimization of CR transmission parameters and we analyzing the fitness score by taking iterations with respect to time till optimum result does not get. They get best individual fitness value considering two objectives for multi-objective optimization. The convergence time is low for NSGA-II.

Abdelfatah Elarfaoui *et al* [53], they proposed crossover method and it has methodology of weighted sum for different parameters. It is also called Combined Single-Heuristic Crossover by GA. Parameters to be taken are: min BER, min power consumption, spectral efficiency, min interference and maximizing throughput. This work represents the flexibility in implementation and adapting behavior of transmission

parameters. This technique can be used with other meta-heuristic to increase the solution's quality without increasing complexity and time execution but more quality of service can get after using more performance objectives so future work can be motivated on proposing new metaheuristic optimization technique which decide spectrum management problem.

Timothy R. Newman *et al.* [54], they represents various approaches to increase the convergence time and improve the performance results by multi-objective GA. They come to know GA-based approaches have the benefit to be capable of discover huge parameter spaces by treating multiple solutions in parallel. Compared to other techniques for optimization, genetic algorithms allow easier implementations for multi-objective optimizations, where NSGA-II [55] is one of many implementations. They get to know GA method using weighted sum has fastest approach but slightly worse than NSGA-II. Weighted sum method gives higher result on throughput but not MOGA.

N.Ali Saoucha *et al.* [56], this paper signifies an algorithm which is based on real-coded GA. Various trials can be initiated on different parameters of the algorithm. Standard GA (De Jong setting) with binary coding has been compared to get the suitable results. From the result analyses we get to know that proposed algorithm have best convergence speed according to other standard Gain [34] which is created on a binary coding and setting of GA parameter standard but the analyses shows them, De Jong setting is not best optimum for the QoS optimization problem in CR.

ZHAO Jun-hui1*et al*. [57], They proposed a method for fitness of individual chromosome by scale of linear transformation, for decreasing, the effect of unusual individuals escaping from the premature iterations for evolution, and trying to compete with individuals afterwards progress iterations and also specifies for parameter adjustment, an adaptive crossover, with algorithm of mutation probability this certify that the population have variety and convergence. This method improves given algorithm and converges fast to the global optimum solution and removes premature convergence problem of GA.

Ismail AlQerm *et al.* [58], they proposed adaptive optimization scheme of multi-objective genetic algorithm and measured that transmission parameters changes according to the conditions of environment. They worked on transmission parameters of adaptive genetic optimization algorithm. In this the system, works on the functions of multi-objective and complexity overcomes by applying proposed algorithm.

Maninder Jeet Kaur *et al.* [59], they proposed modified GA that is Adaptive genetic algorithm (AGA). This approached method is compared with conventional genetic algorithm. This has achieved by the same set of circumstances and parameters. Primarily the CGA is simulated. The GA pseudo code is created for

gradually implementation of GA or the same set of conditions and environments are applied to the proposed AGA in which the crossover and mutation rates are preset. They get to know the proposed AGA have better results than CGA. AGA adaptive capabilities are more as compared to CGA and AGA converges faster than CGA. AGA has higher fitness value and also has the proficiency to achieve the balance between multiple objectives more efficiently. In adaptive genetic algorithm the convergence stability reaches at 95% which is the best convergence fitness value. By this proposed method, premature convergence related problem get solved because it regulates to the suitable Crossover and mutation rates to decrease, exertion of searching for both rates, since the presentation is not linear so that balance among these parameters have to be maintained.

2.2 PARTICLE SWARM OPTIMIZATION

ISeshadri Binaya Behera *et al.* [60], they applied particle swarm optimization algorithm for the problem of allocation of source in spectrum to optimized this problem. They get to know that, they need some features like spectrum efficiency, SNR, efficiency for power etc. to balance the resource allocation complexity. These required factors advanced according the necessity of users. This paper solves the problem of spectrum utilization and PSO is used to optimizing the parameters. The author also did comparison of PSO and GA so that result comes to obtain less computational complexity.

Gozde Ozcan, *et al.* [61] they defines the spectrum sharing method which are depends on sensing in CR system and did survey on schemes of energy capability power allocation for secondary users . This method defines the secondary user for sensing the channel with inaccuracies. Based on decision of sensing, the data are transmitted with initialization and various power levels. By this method, they take limit to avg. transmission power and avg. interference for energy efficiency maximization (EE) for problem of optimization. To overcome the problem, Dinkelbach's technique is approached, in this the problem of maximization in EE, this exchanged into the structure of problem of concave. In the existence of CSI various optimum power get indicated at the transmitter concerning of link of interference and transmission, for perfect single transmitter link CSI, both perfect link of CSI at transmitter and interference link, Imperfect link of CSI of interference etc. The result analysis, have influence of presentation of sensing, occupancy of CSI of various kinds and limits of power of interference and transmit on energy efficiency for the secondary user.

Loredana Arienzo *et al*. [62], they approached a mixed optimization techniques. In multi-hop secondary n/w, this techniques permits the spectrum sensing for minimum power consumption parameter and this network limits the performance of detection, find the missed detection and false alarm's probability and the power consumption. This technique's optimum quality is obtained by two methods: a) case when solution is nastiest b) stochastic method. These both methods explain that approached method permits

the power consumption. But the optimum solution beats the present method in the way of computational complexity. This approached method has verified that it provides fewer signals to noise ratio in wireless communication.

Saeed Motiian, *et al*. [63], they study that interference limits are explained for the guard of Quality of service parameters for primary and secondary users, this problem they studied in CR. For matching the axioms of Nash for every secondary user, some values are explained as function of SNR. Non convex area is the area of values that encounters the constraints. In convex area, make simplifications are convincible, and for obtaining the solution simple convex optimization is proposed. But the PSO requirement for this simplification is no use and that why the result analysis of PSO is better than method of convex optimization. PSO algorithm based on social behavior of birds, that behavior used in various problem of optimization. And this algorithm not need the objective function to be differentiable but other algorithm needs differentiation of objective function.

Ankur dixit *et al*. [64], they proposed Particle Swarm optimization algorithm to optimize transmission and environmental parameters with objective (Bit error rate, spectral efficiency, throughput, power consumption). The objective function fitness value in various types and networks are inspected in MATLAB. They get to know that the PSO has 70% better convergence time than Genetic algorithm. PSO technique is fast, reliable and efficient for primary user in cognitive radios but complexity increases.

W.F.Abd-El-Waheda *et al*. [65], their approach is combining of two exploratory optimization techniques that are PSO with GA. Their methodology is, combine the advantages of both techniques and it obtains two characteristics advantage. First, the algorithm is generated with fixed arbitrary elements which passes over the search space while this scenario of the travelling an advancement of these elements is achieved by adding PSO and GA together. Another one is, to control velocity of the particles, they presented improved compression factor. The result shows that the proposed methodology is better in terms of capacity to find the optimum solution globally. They get optimum solution in large convergence time.

Ali H. Mahdi [66], due to problems occurs in Conventional GA as its convergence speed is low and overcome the GA problem, Conventional PSO has introduced and it reduced the computational cost of GA. But PSO has problem of local optimum so they introduced ADPSO (Adaptive Discrete PSO) algorithm to overcome this problem. Algorithm of ADPSO has taken for the optimization of transmission and environmental parameters and completion of requirements of QoS parameters for cognitive radio by multi-objective optimization. The results after simulation shows, best and less converges time generated by ADPSO. In accumulation, it also reduces the problem of local optimum in PSO so discrete concept takes and optimizes the given parameters with better fitness value than the other optimization algorithms.

Ismail Al Qerm *et al*. [67], they introduced an AMOS scheme to increase spectrum process and network performance that is Optimization Scheme of Adaptive Multi-Objective. This is basically adapting the radio transmission parameters using controlled modeling define as fitness functions. The fitness functions take account of power consumption minimization, bit error rate (BER), delay and interference and throughput maximization and maximization of spectral efficiency. They show that AMOS gives better result than other optimizing scheme for multi carrier environment. They are interested in most general studies have large-scale networks then examine problems for global network capacity checks.

2.3 ARTIFICIAL BEE COLONY

Pyari Mohan Pradhan [68], in the wireless environment, optimization of already defined fitness function used by evolutionary algorithm. They took three evolutionary algorithms these are GA, PSO and ABC and analyzed their behavior in different mode in the existence of spectrum interference. Their results are associated by the convergence characteristics and geometric metrics of two. The result shows that for cognitive engine ABC technique has better design as compared to compared techniques.

Kuldeep singh kaswan [69], this paper represents the application area where Artificial intelligence technique has applied. This works on real time parameter optimization problem. They simulated that ABC is well worked for various applications like general assignment problem, cluster analysis, constrained problem optimization, structural optimization, and advisory system. It has also been applied to software engineering for software testing and parameter estimation in software reliability growth models. ABC also plays an important role in medical, as used in MR brain image classification, face pose estimation, bioinformatics etc. We can find more applications regarding ABC techniques.

Deepika.S [70], this paper represented throughput maximization for secondary user in full duplex(FD) cognitive radio n/w by ABC techniques. They show how throughput maximization occurs by ABC by optimizing the detection threshold including restraints on the probability of missed detection by the fusion center. Their results shows that the Artificial Bee Colony optimization technique has less computational complexity, high convergence speed and more flexible than Particle Swarm optimization technique. Thus the throughput of secondary user in full-duplex (FD) cognitive radio network is maximized by optimizing the detection threshold.

K Sultan *et al*. [71]**,** they proposed ABCO method, for the problem of allocation and spread selection. Their aim is to maximized the ratio of signal at the secondary level instantaneously balance the interference level high to low. The author explained that in ABC method, we can represent fitness function by SNR and the main constraint is interference threshold level. In CR, they find the problem of selection of relay and allocation problem in power transmitting and they use ABCO to overcome this

problem. Their goal is Signal to ratio maximization at the secondary level instantaneously maintain the low level of interference. The model of ABC defined by the author, it tells that by SNR, fitness function can be symbolized, and the important constraint for this is level of interference threshold. Author compares the food source of neighbor with that bee, which are updating their memory and position with the best solution to explain the active bee work scenario. It recovers the fitness function and improves the given limits.

J wang *et al*. [72], in cognitive radio cooperative relay network, the author utilizes the ABC method for choosing of multiple relay. The author main goal is to calculate the optimum SNR and the good spread to cooperate, first of this meant to a fitness value and second one meant to a good source of food.

AGhasemi *et al.* [73], this paper represents the solution quality. It suggests the food source position and shows the best solution for problem of optimization. It shows that the quantity of food source represents the solution quality. It balances the equality.

XCheng *et al*. [74], this paper represents the function maximization of parameters. It also shows the equality between devices. They define the allocation of channel scenario. The function utility takes interference limits, and without error assignment of channels.

2.4 STIMULATED ANNEALING

Kiranjot Kaur *et al.* [75], they proposed Stimulated annealing algorithm (SA) for optimization of CR.SA is deliberate as global optimization technique. SA is similar technique where minimum energy crystalline structure state is attained between the metal cooling and freezing state. SA achieved the quality of service (QoS) in the way of five parameters that are minimum transmit power (P), minimum bit error rate (BER), interference (I), and power consumption and maximum throughput (T), and spectral efficiency (S). The analyses after simulation represents, Stimulated annealing method is outdoes GA in CR but the challenge come regarding time required and finite iteration's number needed by SA to attain the solution of optimization are large compared to the Genetic algorithm.

2.5 CAT SWARM OPTIMIZATION

Yousef Sharafi *et al*. [76], they introduced an algorithm named binary discrete optimization of Cat Swarm Optimization. This CSO represents in binary form. CSO founded on the behaviors of cats. The working behaviors of both techniques are same. As CSO, BPSO have two working mode that are tracing mode and seeking mode. BPSO simulation result has been compared to different approaches of binary particle swarm optimization and Genetic algorithm. They get to know that proposed methodology have better results than any other binary discrete optimization techniques. The achieved results have been compared

to the different optimization techniques like Binary PSO, New BPSO and GA. The analyses signify the approached manner outpaces the stated algorithms in the way of accuracy and convergence speed. It creates premature convergence.

2.6 BIOGRAPHY BASED OPTIMIZATION

Pei-Han Qi *et al*. [77], they resolve the problem for minimization of power consumption in the cognitive adaptation. To solve the optimization problem BBO is proposed. A different approach is introduced that is habitat suitability index (HSI) mechanism, they worked on two parameters and quality of service (QoS) has meant into consideration in this approach The results represents that BBO maintains the minimum power consumption with various QoS requirement equivalent to various techniques, and also sustaining the requirements of quality of service. Comparison of particle swarm optimization (PSO) and cat swarm optimization (CSO) shows that analyses of BBO is good, for real-time applications BBO is best selection. In the way of convergence rate BBO completes better with PSO and CSO But the exploiting the solution is worse. From complete population, it is difficult to find the best solution.

2.7 CASE BASED REASONING AND DECISION TREE

Ismail AlQerm *et al.* [78], for achieving radio adapting in multi-carrier wireless networks, they planned a hybrid technique of cognitive engine. Hybrids of two methods are CBR and DT (Decision tree). The complication of this amalgam technique can be compact by using decision trees that improves the index methodologies and CBR retrieval cases. By Software defined radio and simulation in multicarrier environment the performance of hybrid cognitive engine has maintained Environmental and transmission parameters like throughput, SNR and ratio of interference, and PER are acquired. Then compare with other techniques in various cases. The simulation results shows that CBR based engine gives maximum throughput, maximum Signal to noise ratio and minimum PER has various possessions of interference associated to other existing techniques. Make to add, result analyses represents speed of convergence higher than existing techniques and better throughput in comparison of various techniques with hybrid concept. It can generate good quality solution in fragile concept, here it is difficult to maintain features affecting value. When any best system obtain it will gives quality for solution.

L.D.Xu *et al.* [79], they proposed the CBR method that based upon the problems of past and same conditions for present solution. CBR method it creates a data set regarding problems of past conditions and generate the solutions. Latest problem calculated by the searching the same conditions and cases present in memory and takes the present condition.

Ken-Shin Huan *et al*. [80], they proposed CBR technique of multi-objective function. This method requires more capacity of storage but traditional method need less than the approached method. For creating the proposed model, to be accurate, the author takes all likely situations or cases This proposed method based on divide and conquer approach and gives equality of functions.

Reddyin *et al*. [81], they describes the, how can design better spectrum allocation techniques by using CBR. They also defines the approach of collaborative filter. By this method they able to describe that CBR are the method to find the channel favored by secondary users.

Dali *et al*. [82], this paper describes the system efficiency, network management and balancing of traffic in network by using CBR. They study each situation and find out the problem, generate the solution of corresponding problem with their results and it given to the cognitive radio system. The solution is better in utilization information to the input, by its past selections and their drawbacks. The main goal of this paper is to reduce the time. This is done by searching the resemblances between cases.

Z.J.Zhao *et al*. [83], they proposed CBR quantum genetic algorithm for optimizing and adjusting the cognitive parameters. The environment changing factor, used for measuring the resemblance of present and past data set. For increasing the speed of optimization of QGA, and for avoiding the carelessness of initial population search, they initialize the Quantum bits.

2.8 CUCKOO SEARCH OPTIMIZATION

Kiranjot kaur *et al.*[84], in this paper, Cuckoo search based new meta heuristic algorithm is proposed in which new multi user cognitive radio and optimization of transmission parameters are used. The optimization result of this algorithm is compared by other optimization techniques like Biogeography based optimization (BBO) and traditional stimulated annealing (SA). By comparing all three optimization techniques, they get to know Stimulated annealing slow down the convergence problem and BBO uses migration and mutation operators and focuses more on exploitation. The result after simulations and comparisons of Cuckoo Search with BBO and SA it signifies that Cuckoo search has suitable balance between exploitation and mutations. At fixed number of evaluations CS gives best solution but not SA so that's why Cuckoo search is the simple and best optimization technique so far and it gives best results and it finds best solution for little number of function evaluations. CS is optimum to detect the good solution for a specific problem it is not necessary for always. It stuck into local states and achieving the premature convergence and it creates the problem in precision of models.

2.9 DECISION TREE

H. Han *et al*. [85], this paper describes the decision learning techniques that detects the sensing order of wideband spectrum optimally. Starting node is called the root node and at the each stage selection of channel is done by the leaf node. For generating the equivalent child node and making branch node, one technique is chosen that depends on specific rules at each node. Sensing order followed start to root at the ending of leaves of tree.

S. Soltani *et al*. [86], they proposed a technique of decision tree in CR. By this, the nodes understand their environment and adapt the behavior of the parameters according to the environmental change. For choosing the correct and consistent future hop neighbor, a source uses the decision tree.

S. Soltani *et al*. [87], the author goal is to advance the SNR of received signal of video by taking condition of channel, equivalent service of frame, availability of spectrum and occupancy of bandwidth for this they taken decision tree method for video signals that routs in Cognitive radio networks.

M. Gandetto *et al*. [88], they described about spectrum sensing with cooperative manner by theory of detection. Decision tree method is used, to generate the division's procedure simple.

2.10 ARTIFICIAL NEURAL NETWORK

X. Tan *et al*. [89], they study a problem of spectrum utilization deficiency in present scenario for wireless communication system. They approached a new method using artificial neural networks to exchange the allocation system of existing frequency. They did experiment about two cases: single user case and multiuser case. They took review of theory of back propagation theory, in this the data transmission is in forward and errors transmission in backward.

T. Zhang *et al*. [90], the author proposed new method of artificial neural network to advances the performance of spectrum sensing in cognitive radio. At each secondary user, ANN installation will occur to calculate the probability of sensing. They generate a technique by which they associate secondary user with existence of ANN abilities to the new spectrum sensing techniques. Global less false alarm probability of CR network is produced as the result.

Yang *et al*. [91], they generate a cognitive radio engine that are depends upon the function of radial basis and genetic algorithm. This is done for the parameters adjustment for the system and any changes in

parameters it automatically adapts that. For the training of the radio basis function model, they produce a table by the genetic algorithm to adapts the transmission parameters of neural network of radio basis function like date rate, transmission power etc.

J. JPopoola *et al*. [92], in this paper, the author first survey the methods of spectrum sensing and after that they approached a new technique for detection of primary user. The important idea of this paper is depends upon the circumstances of secondary user have not proper knowledge about the primary user and also it don't know the hidden node of primary user so the author generate the digital classifier by artificial neural network that permits all user to track signals and detects the primary signal if its weak, broken or unknown.

2.11 BAYESIAN METHOD

Yuqing Huang *et al*. [93], they approached a decision making engine that depends upon the Bayesian networks. By this proposed method, the author uses the tree algorithm to make a model of interference by approximated model that generate by the bayesian network. This technique also used for the adaptation of quality of service parameters for the user.

C. Jiang *et a*l, [94**],** they defined the sensing of multi-channel and admittance in distributed networks and they not take consideration of secondary user channel number. By this the secondary users detect the signal and access properly. They took a baysian approach for solving multichannel detection problem and cooperative method for knowing the status of channel estimation.

S. Zheng *et al*. [95], they proposed a method for spectrum utilization maximization in cognitive radio network by Bayesian method. By Bayesian rule they focused to sense the multi-phase shift keying primary signal modulation over additive white Gaussian channel.

Zhou *et al*. [96], they approached a method based on Bayesian approach that are cooperative spectrum sensing in which secondary user occurs. They tell that to increase the quality of service, use of SUs reputation degree. This technique tells the spectrum sensing of secondary user that are malicious. They track the behavior of secondary user by the Bayesian approach.

Fli *et al*. [97**],** this paper represented the spectrum scarcity problem. The spectrum scarcity in cooperative spectrum sensing tells that primary user has less space to occupy in the spectrum and user population is

very less in small fraction of area. By this paper, they approached a Bayesian model to overcome the spectrum scarcity problem.

2.12 SUPPORT VECTOR MACHINE

Y.Huang *et al*. [98], this paper defines new method for cognitive radio design that are Support Vector Machine modal design. SVM depends upon Signal to noise ratio, bit error rate, data rate and mode of modulation. In this they took various channels modal that are flat, deep and no fading modals for trained the data. Data tests after the modal generation by the inputs bit error rate, signal to noise ratio and data rate.

Z. Dandan *et al*. [99], the author approached support vector machine modal. This is done for spectrum sensing and detection in real time. The data for sampling would not divide through training and analysis of support vector machine but as primary user. They discuss the method of SVM that how division of class occurs if received signal, primary user detection will be shown in class, if the detected signal is composed of additive white Gaussian noise and the signal. And the primary user will not be shown in class when detected signal only have additive white Gaussian noise.

S. Hu *et al*. [100], in this paper MAC detection is created by the support vector machine. They approached this method that enables users of cognitive radio so that they sense and detect the protocol of MAC for the current transmission parameters and they adapt these parameters when any change occurs in the environment. They utilize basis functions that are linear, radial and polynomial.

O. PAwe *et al*. [101], they applied support vector machine technique to the multi-antenna cognitive radio. The SVM is used by the spectrum sensing that are based on eigen value. Their work is to create a train modal by analyzing the N samples and eigen value -covariance matrix is creating after that. Data points divides that depends on the SVM modal so that they get to know the existence or absence of primary user.

MinLin *et al*. [102], the author simplifies the beam forming design in CR. CR base station shares spectrum with PU. CR has many abilities and it supports the transmission of primary data. The main goal is minimization of total power of transmission while balancing the quality of service parameters and the interference created commonly are permitted.

2.13 REINFORCEMENT LEARNING

K. LAYau *et al.* [103], author combined Reinforcement Learning to accomplish the cognitive cycle in compacted and stationary mobile networks. The concept regarding RL applied to the secondary users, where they flourishing the channels vigorously consistent with the primary user's utilization and PER while transmission of data for increasing the throughput of secondary users and quality of services levels during decreasing delays.

S. Barve *et al*. [104], in this paper author took concept of routing in CRN's. They approached a new Reinforcement Learning system that works on choosing channel and multi-hop routing in CRN's in combination. The RL is the combination of system and each decision's compensation hence, each element increases its compensation. To increase the performance of spectrum utilization cognitive radio users of Reinforcement Learning would spread at optimum state, afterward of trial and error. The author displayed the problem using Markov decision procedure and it utilizes the environment's feedback. Author selects the channel by transmission time and link-cost. By this technique, the author selects the best routing availability by future-hop efficient determination.

P. Zhou *et al.* [105], the author signifies the problem of high power consumption created by the slide communication among various cognitive radio users. Author approached a latest method of power controlling system that depends upon the Reinforcement Learning to overcome the problem of interference while sharing and reduces the requirement of power policies of every elements of CR. Cognitive users increases their iterations to maximize their objectives and in this interference limits are predefined by the CR network.

S. Arunthavanathan *et al*.[106], author explained how spectrum sensing for SU, signal detection for primary users and Decision of transmission in CRNs by Reinforcement Learning. Secondary users adapt the behavior of primary user to fill the holes spectrum.

N. Zhao *et al.* [107], author applied a new technique called entropy detection that gives best detection through reduced computational and this technique depends on the spectrum power density. Author used this technique on minimization of signal to noise ratio. Two stage entropy detection advances the enactment of entropy detection. Basically entropy detection method is act as spectrum sensing utilization.

W Ejaz *et al*. [108], author explained the application of entropy detection. Entropy detection is used in naval surroundings where the distance between the land and ship is large enough. To communicate one ship to other ship, ship to land and ship to ad-hoc network it is used.

Srinu *et al.* [109], the author goal is to increase the performance of spectrum sensing and consistency in accommodating wide band sensing surrounding. The entropy detection method is applied to every channel by various multi CR user elimination methods. Weight gain combination (WGC) and Equal gain combination (EGC) methods are applied to improve the consistency of accommodating spectrum sensing.

Srinu *et al.* [110], signal. They applied entropy detection at FPGA. The consistency wide band spectrum sensing depends upon entropy detection and elimination of CR user with GEST test and test of signal constraints.

2.14 SPIDER MONKEY OPTIMIZATION

Vibhuti Rana *et al.* [111], in this paper they approached a new algorithm called SMO and it represents the optimum value of the transmission and environmental parameters as discussed later. They compare with two existing algorithm that are stimulated annealing and Genetic algorithm. SMO is based on swarm category techniques that carried by behavior of spider monkey. SMO has iterative process. It has fusion fission social structure subdivided group that depends on the criteria of monkey hunting behavior. For searching of food they create divisions in various subgroups. Author took five Qos parameters for optimization that are BER, interference, throughput, spectral efficiency and power consumption according their needs it minimize or maximize. With the same parameter of GA and SA compared with SMO. The result analyses represent that SMO have better optimized values than given algorithm. The problem of low convergence rate comes in SMO.

CHAPTER 3

PROPOSED METHODOLOGY

3.1 INTRODUCTION

In 2014,Grey wolf optimization was first introduced by Mirjalili et al. It is one of the latest meta-heuristic nature inspired algorithm. It is motivated by grey wolves (canis lupus). The knowledge of this algorithm comes by the grey wolves behavior that lives in a pack. As shown in fig [3.1] they always live in a group and creates firm social dominant hierarchy. This hierarchy is created as alpha, beta, delta and omega [114,115].

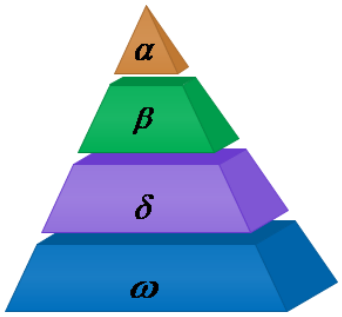

Figure 3.1. Grey wolf hierarchy (ascendency falls from top down)

Alpha (α) are the leaders that are liable for decision making process like sleeping time, hunting time, wake up time etc. for the pack but there are any kind of independent behavior has also viewed, where alpha monitors the further wolf in the pack.t It has both members male and female. In mean, alpha wolf called as leading wolf because their decision must be monitored by the pack [114]. The α wolf gives entry to mate in the pack and it is not important to be strong member from the pack members but it manages the pack. This represents that the discipline and organization is very important from the power strength.

The second phase in given hierarchy for them is Beta (β). The β's are the secondary wolves or second helping hand for alpha wolves. Beta wolves obey the orders of alpha wolves but when alpha wolves become weak and passes away the beta wolves takes the responsibility. Beta command on other low level wolves but respect the order of alpha. It gives suggestions to the alpha along with maintains discipline

among the pack. The beta supports the judgment of alpha all over the pack and contributes response to alpha.

The third phase in hierarchy considered as Delta (δ). Providing details to alpha and beta is the work of delta. Sentinels Hunters, Elders, Caretakers and Scouts comes in this type of group. Scouts has gaze on the boundaries and warns the pack for the threat. Sentinels work as guard; they shield and assure pack protection. Hunter hunts the prey and help alphas and betas to provide food for the pack. Experienced wolves are the elders and considered as alpha and beta. Lastly, ill, injured and weak wolves in the pack are taken care by the Caretakers wolves.

Omega (ω) is final hierarchy of grey wolf. They are last that are permitted to eat. Omega is general wolves that have not so much work in the pack, but after losing them, whole pack struggles internal fighting and dispersion. Omega wolves maintain the decorum in the group. They also work as babysitters for the group.

GWO is implemented by observing the behavior of grey wolves where specific grey wolves search for prey in a multi-dimensional search space. The position variables are the grey wolves particular location and the objective function and its fitness value can be obtained by the distance measurement from grey wolf to prey. To get best position, wolf changes their position from one to other. The main aim of this algorithm is to get the best and shortest path to reach to the prey. According to C.Muro et al. [115] there are four processes for each individual movement.

(a) Tracking, Searching, Chasing and Approaching to prey.

(b) Enclosing, Pursuing and Harassing prey.

(c) Hunting.

(d) Attacking of Prey.

3.1.1 Tracking, Searching, Chasing and Approaching for prey

To represent in mathematical order, as shown in figure3.2, the wolves in social hierarchy during GWO process, we select fittest solution as alpha. Subsequently, other best solution called as beta and delta individually. Least solution called as omega. In GWO process of optimization is directed by $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$. Omega wolves follow these wolves. The grey wolves divide their position for searching a prey. Take a $B\vec{M}$ with arbitrary values to make the hunt executor divides to prey. $W\vec{M}$ are random weights in search

space for finding the prey. $W\vec{M}$ vector also represents the problems to approaching the prey. So, the searching through $B\vec{M}$ and $W\vec{M}$ allows this algorithm to search the space globally.

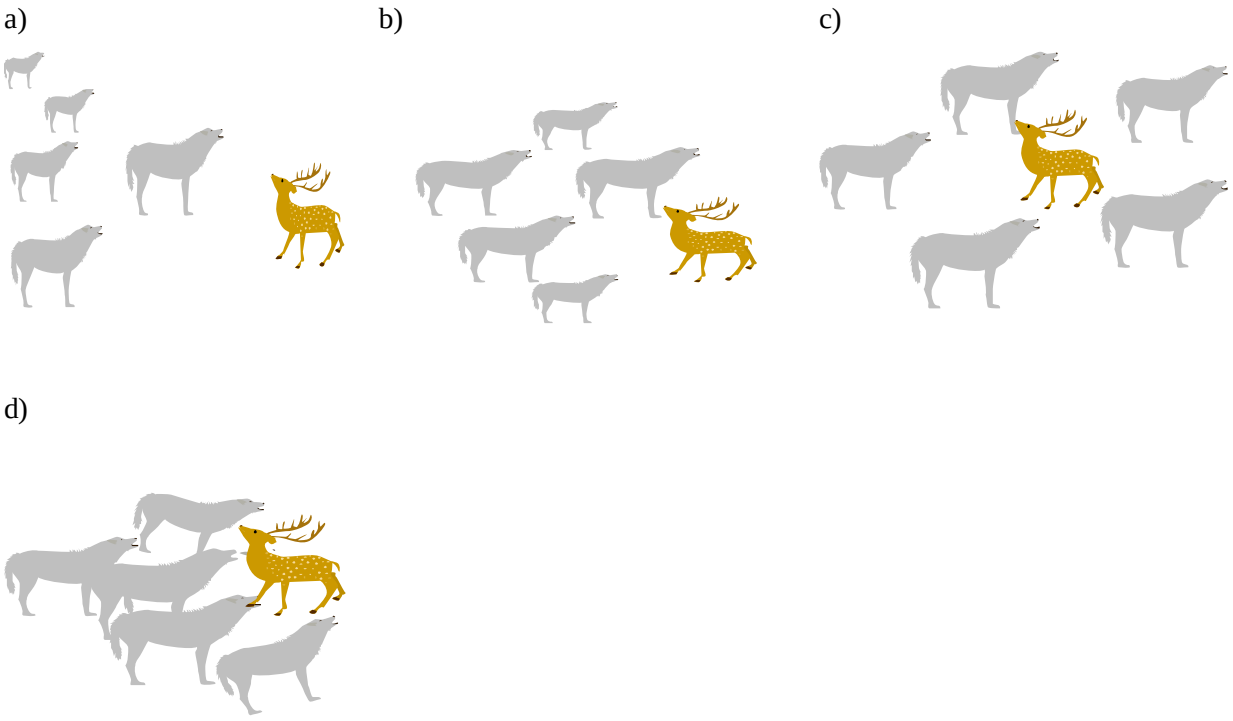

Figure 3.2 Behavior of grey wolves while hunting: (a) searching, tracking, impending, and chasing victim (b) following and harassing of victim (c) enclosing prey (d) static state and attack.

a) Enclosing prey:

The $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$ wolves have best location and omega updates their position according to the rest wolf position. Grey wolves encircle victim while hunting. Encircling behavior can be shown by $C\vec{M}$. Below equations has been proposed for the mathematical model of encircling behavior.

$$C\vec{M} = \left|W\vec{M}.Y\vec{L}(t) - \vec{Y}(t)\right| \quad (3.1)$$

$$\vec{Y}(t+1) = X\vec{L}(t) - B\vec{M}.C\vec{M} \quad (3.2)$$

Where t represents existing iteration, $B\vec{M}$ and $C\vec{M}$ are the vector constants, $Y\vec{L}(t)$ indicates location vector for victim, $Y(t)$ shows location vector for grey wolves

$$B\vec{M} = 2\times \vec{a} \times \overrightarrow{v1} - \vec{a} \tag{3.3}$$

$$W\vec{M} = 2\times \overrightarrow{v2} \tag{3.4}$$

Where $\overrightarrow{v1}$ and $\overrightarrow{v2}$ are arbitrary vectors. $\vec{a}$ Component is linearly decreased from 2 to 0.

b) Hunting:

After encircling, Identification of the location of prey carried by grey wolves. Alpha monitors for hunting to all of them. Beta and Delta also takes contribution in hunting. The optimum location of prey is difficult to interpret. We mathematically visualize the grey wolves behavior while hunting, and let that alpha has the finest solution. To search the position of the prey, Beta and Delta are capable. After that save the best obtained solution and help other agents to inform its location with reference of the location of best search agent. The below equation are follows regarding the hunting behavior of alpha, beta, delta can be represented as:

$$\overrightarrow{CM}_{\alpha} = \left| C\vec{M}_{\alpha}.\ Y\vec{L}_{\alpha}(t) + \vec{Y} \right| \tag{3.5}$$

$$\overrightarrow{CM}_{\beta} = \left| C\vec{M}_{\beta}.\ Y\vec{L}_{\beta}(t) + \vec{Y} \right| \tag{3.6}$$

$$\overrightarrow{CM}_{\delta} = \left| C\vec{M}_{\delta}.\ Y\vec{L}_{\delta}(t) + \vec{Y} \right| \tag{3.7}$$

Lastly, the various category wolves' position is improved as follows:

$$\vec{Y}_{\alpha 1} = \vec{Y}_{\alpha} - B\vec{M}_{1}.\overrightarrow{CM}_{\alpha} \tag{3.8}$$

$$\vec{Y}_{\beta 1} = \vec{Y}_{\beta} - B\vec{M}_{2}.\overrightarrow{CM}_{\beta} \tag{3.9}$$

$$\vec{Y}_{\delta 1} = \vec{Y}_{\delta} - B\vec{M}_{3}.\overrightarrow{CM}_{\delta} \tag{3.10}$$

$$\overrightarrow{Y(t+1)} = \frac{\vec{Y}_{\alpha 1} + \vec{Y}_{\beta 1} + \vec{Y}_{\delta 1}}{3} \tag{3.11}$$

c) Attacking prey (exploitation)

When the prey becomes still then grey wolves stop its hunt. We arithmetically simulate model, decrease the value of $\vec{a}$ for approaching the prey and deviation range of $\overrightarrow{L(t)}$ is also decreases by $\vec{a}$. $\overrightarrow{L(t)}$ Is

arbitrary value in interval of [-a,a] and $\vec{a}$ is lessen to 2 to 0. When $\overrightarrow{L(t)}$ lie in interval [-1, 1] that means the following location of examine manager in middle of its present location and position of prey. Figure.4 (a) indicates if $|L(t)| < 1$ the wolves attack the prey. In GWO, the alpha, beta and delta update their position and attack to victim

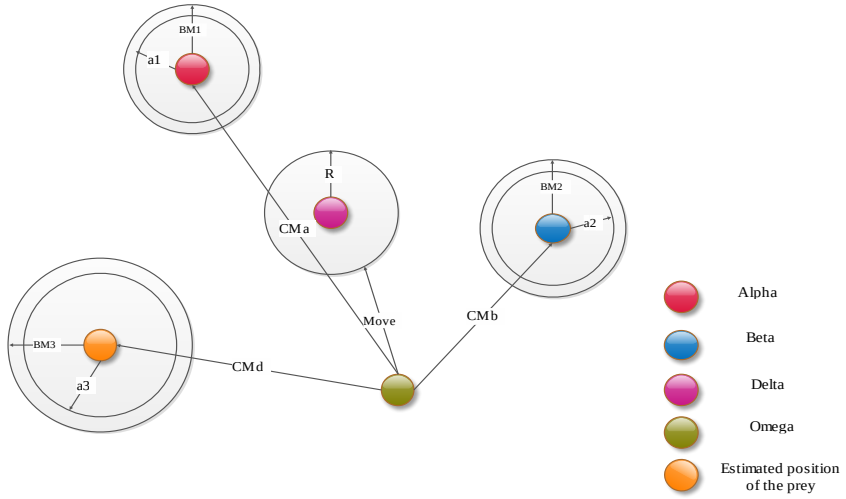

Figure 3.3: GWO Position updating

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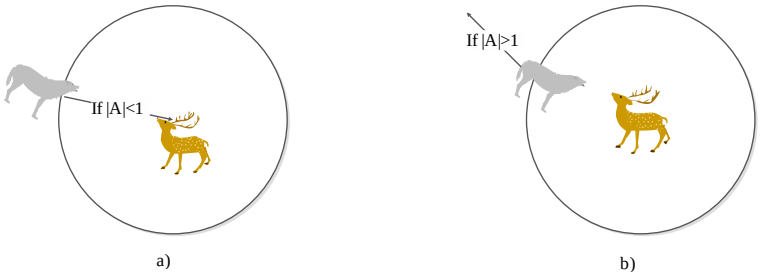

Figure 3.4 Prey attacks versus Search prey.

We have to update$\bar{a}$. The $\bar{a}$ parameter adjusts between exploration and exploitation.

$$a = 2 - t\frac{2}{max.iter} \tag{3.12}$$

where t is the number of iteration and max.iter is the total number of iteration.

GWO algorithm

Initialize the population of grey wolf

Initialize a, C$\overline{M}$ and B$\overline{M}$.

Find out the examine manager fitness of individual

$\vec{Y}_\alpha$, $\vec{Y}_\beta$, $\vec{Y}_\delta$ is the best examining manger priority wise.

While (t< no. of max. iterations)

For individual examine manager

Current examine manager gets changed by equation (11).

Change a, C$\overline{M}$ and B$\overline{M}$

Find out the examine manager fitness for all

Change $\vec{Y}_\alpha$, $\vec{Y}_\beta$ *and* $\vec{Y}_\delta$

t incremented by 1

End while

Return Y_α

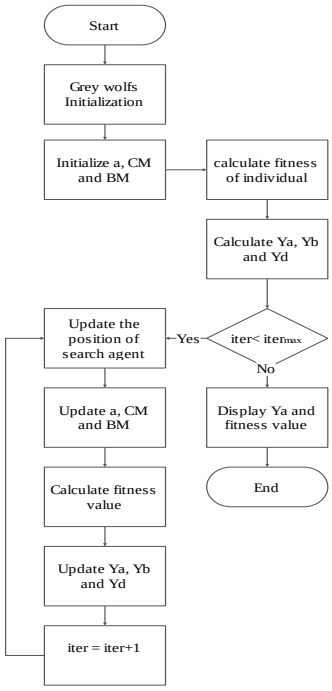

Figure 3.5 Flow chart of GWO

3.2 COGNITIVE RADIO PARAMETERS

Cognitive radio have real time interface with the environment and it supports the communication in CR system. Cognitive radio has QOS parameter which tells system utilization by the users. CR has transmission and environmental parameters that are utilized with performance objective parameters. These parameters has discussed in Chapter 3 in detail

3.2.1 Cognitive Radio Transmission and Environmental Parameters

- **Environmental Parameters:** These are used as input to the Cognitive Radio system that is mention in our paper i.e. path loss, Noise power etc.
- **Transmission Parameters:** These Parameters are tuned in system of Cognitive Radio. It tunes its equivalent values from the optimum parameters. These parameters are bit error rate (BER), channel loss, modulation index, signal-to-noise ratio (SNR), time division duplex in percentage (TDD), bandwidth (B), and symbol rate (Rs). For the simulation analysis of CR system the performance range of transmission parameters that are used by the Grey wolf optimization, Spider monkey optimization, Stimulated annealing and Genetic algorithm has given in table 6.2.

3.3 FITNESS FUNCTIONS/PERFORMANCE OBJECTIVES FOR GWO:

Fitness function determines the solution fitness (how solution is close to desired or optimum solution).In wireless environment, we have to optimize the multi-fitness functions and its objectives. A set of Pareto optimum solution get after the optimization of multi objective functions. From the defined set, user has to choose a solution that depends on the requirement of quality of services. Therefore, basic optimization requires the sum of optimization of all fitness functions. In this paper, we have taken five performance objectives or fitness functions that are: power consumption, interference, BER, throughput and spectral efficiency. The fitness function and performance objectives are given in Chapter 1.

CHAPTER 4

EXPERIMENTS AND RESULTS

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4.1 RESULTS AND DISCUSSION

The simulation has been done on MATLAB software 2015 version. In this analysis we have compared result of three algorithms with proposed algorithm.

4.1.1 Result Analysis:

In this thesis, we proposed GWO algorithm and simulated the fitness function for objective parameters. We have carried out result analysis for GWO for the simulation of cognitive radio parameters. The simulation has done on different objective parameters such as bit error rate, power consumption, throughput, spectral efficiency and interference. Now, we have multi-objectives to operate. So, the weighted sum approach will be used in GWO technique based cognitive system. It permits us to combine one objective function into one summative multiple objective functions.

$$Max f_{single} = w_1 * f_{minimum\_ber} + w_2 * f_{minimum\_power} + w_3 * f_{maximum\_throuhput} + w_4 * f_{maximum\_spectral\_eff} + w_5 * f_{minimum\_interfernce} \quad (4.1)$$

This equation [28] represents that every objective is multiplied by a weight and added with them to provide optimized parameter set. Weights are given that values find the search direction to get the optimized results. Table 4.1 shows the weights of given mode.

4.1.2 Simulation and Comparisons

Grey wolf optimization has been applied to CR system with single carrier that achieves different objectives by MATLAB. We compared four techniques for this purpose. We have taken six simulation parameters in our work such as Bit Error Rate, Spectral efficiency, Throughput, Power consumption, Interference which is explained in the Chapter 1 in detail.

Table 4.1 Weighting mode for five objectives

Modes	Weight vectors [w1, w2, w3, w4, w5]
Power Minimization mode	[0.45 0.10 0.20 0.15 0.10]
BER minimization mode	[0.10 0.50 0.10 0.10 0.20]
Throughput Maximization mode	[1.10 0.15 0.50 0.15 0.10]
Interference Minimization mode	[0.10 0.10 0.20 0.50 0.10]
Spectral efficiency minimization mode	[0.10 0.15 0.15 0.10 0.50]

.

Table 4.2 Parameters for Simulation

PARAMETERS	**VALUES**
Bandwidth	2 to 32 MHz
Transmission power (P)	0.158 to 251 mW
Modulation index	2 to 256
Time division duplexing	25 to 100%
Modulation type	QAM
Symbol rate (Rs)	125 kbps to 1Mbps

We have taken five objectives in this paper. These parameters are discussed in Chapter 1 in details. The objectives are minimum power consumption, maximum throughput, minimum Bit error rate, maximum spectral efficiency and minimum interference. These objectives are directed by simulation parameter as shown in table 4.2. The table 4.3 shows the final optimized or best value for different modes in GWO.

Table 4.3 Result achieved by GA, SA, SMO and GWO algorithm for given objective modes

Objective modes	Algorithm	Transmitted power(mW)	Modulation index(M)	Bandwidth (MHz)	Time division duplexing (in%)	Symbol Rate(Rs) (in kbps)	Fitness Score
Power Consumption Minimization mode	GA	04.39	256	02.04	31.40	698.01	0.071512
	SA	3.64	256	21.86	56.24	915.72	0.036618
	SMO	2.69	256	18.36	60.02	900.01	0.22876
	GWO	0.258	256	02.02	70.15	928.12	0.01992
BER Minimization mode	GA	16.83	256	02.01	65.60	839.98	0.090974
	SA	25.83	256	02.40	85.60	901.88	0.070041
	SMO	28.67	256	02.01	72.41	910.54	0.031325
	GWO	32.68	256	02.01	92.05	905.28	0.0247
Throughput Maximization mode	GA	04.41	256	02.00	43.40	812.18	0.039174
	SA	15.27	256	02.00	33.80	923.85	0.02380
	SMO	20.42	256	02.00	35.03	954.18	0.0161123
	GWO	36.17	256	02.00	50.18	973.02	0.011639
Interference Minimization mode	GA	07.66	256	02.00	65.80	353.48	0.030121
	SA	15.23	256	02.00	47.30	636.24	0.049242
	SMO	18.12	256	02.00	38.26	800.14	0.0127736
	GWO	25.41	256	02.00	34.61	875.43	0.011837
Spectral efficiency Minimization mode	GA	12.37	256	02.01	29.40	962.49	0.065183
	SA	34.57	256	02.00	59.60	999.18	0.019472
	SMO	38.24	256	02.00	71.57	922.81	0.0161197
	GWO	40.26	256	02.00	78.42	998.03	0.015825

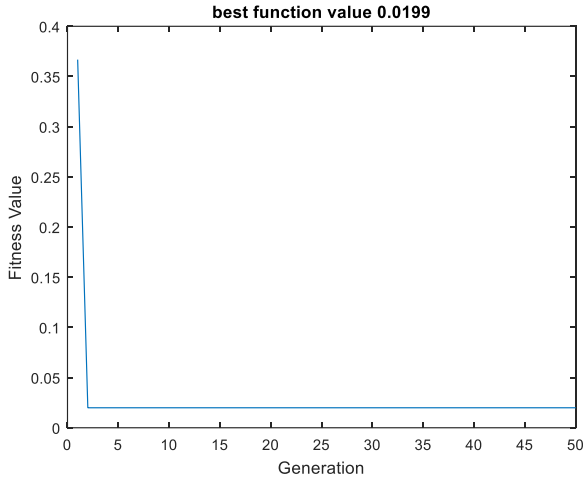

Figure 4.1(a). Convergence Characteristics of minimum power consumption

While GWO simulation in power minimization mode, the number of generation is taken as 50. In this simulation, as number of generation increases, the fitness value get reduced and arrived at minimum value. The fitness value reduced to the best of minimum value. Therefore, the mode of power consumption works more correctly, when we get fitness value less or minimum as we required. Figure 4.1 (a) represents the optimized or best value of minimum power consumption in GWO algorithm.

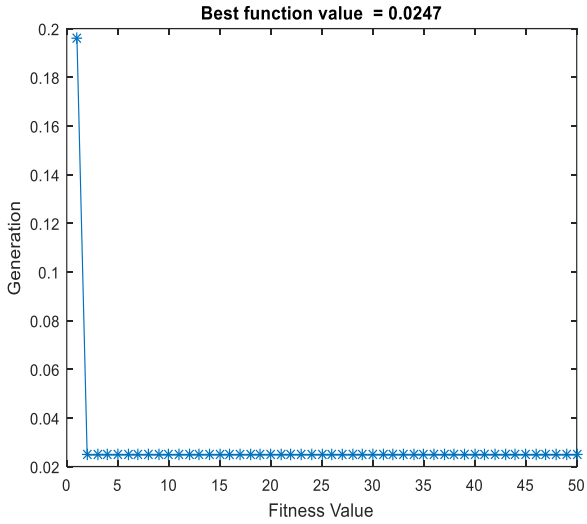

Figure 4.1(b). Convergence Characteristics of minimum BER

In the simulation of BER minimization mode, the desired result is to get minimum error. The figure 4.1(b) shows that as the number of generation increases, the fitness value gets reduced and we get the best optimized value at that point. This value is the best optimized value so that system can work efficiently.

Figure 4.1(b) shows its best fitness value for BER by GWO. Throughput is defined as the transfer of amount of information successfully through communication channel. The aim of this objective is to consume throughput is that the transmission rate of information is increases, when time reduces. Therefore, this is the reason for fitness function generated by the approached method i.e. GWO is less than the other method of optimization. It suggests that less amount of fitness function conclude to large amount of data transmission through the CR system. Figure 4.1(c) represents its best fitness value applied on GWO.

The simulation of minimum interference mode is desired to get the result with minimum value. Figure 4.1(b) shows its best fitness value for BER by GWO. Throughput is defined as the transfer of amount of information successfully through communication channel. The aim of this objective is to consume throughput is that the transmission rate of information is increases, when time reduces The figure 4.1(b) shows that as the number of generation increases, the fitness value gets reduced and we get the best optimized value at that point.

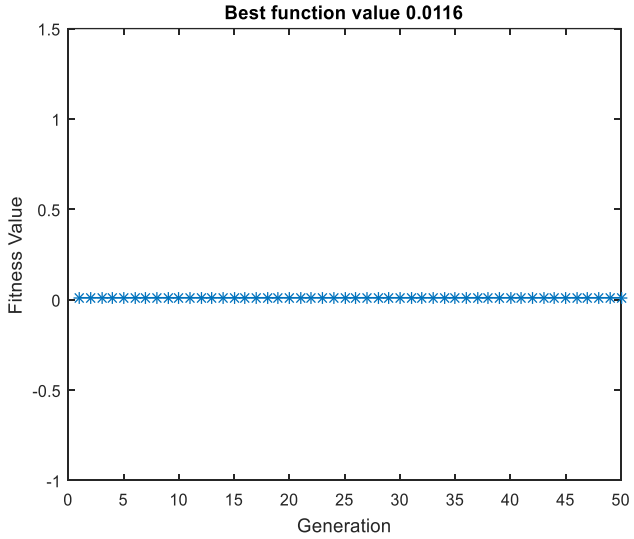

Figure 4.1 (c) Convergence Characteristics in mode of maximum throughput

The figure 4.1(c) shows that as the number of generation increases, the fitness value gets reduced and we get the best optimized value at that point. This value is the best optimized value so that system can work efficiently. Figure 4.1(d) shows its best fitness value for interference minimization by GWO.

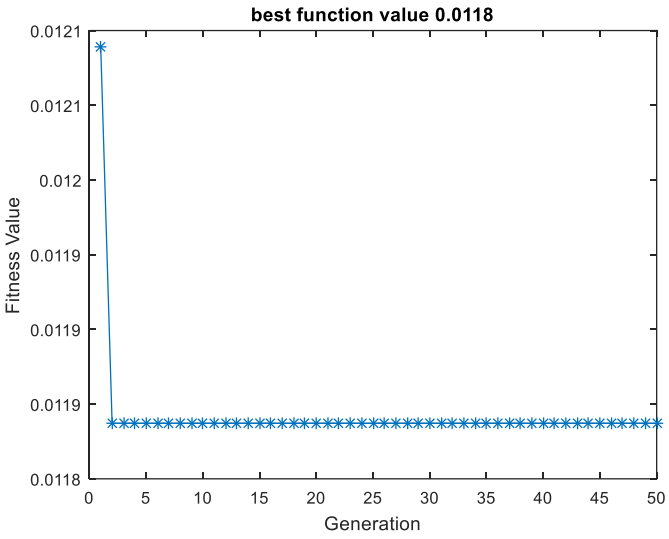

Figure 4.1(d). Convergence characteristics in mode of minimum interference

The objective of the simulation in Spectral efficiency mode is to maximize the efficiency of spectrum at the maximum rate but the frequency requirement is less. At minimum fitness, the spectral efficiency is high so that at less frequency rate we can send maximum amount of information. Figure 4.1(e) shows the fitness value of maximum spectral efficiency.

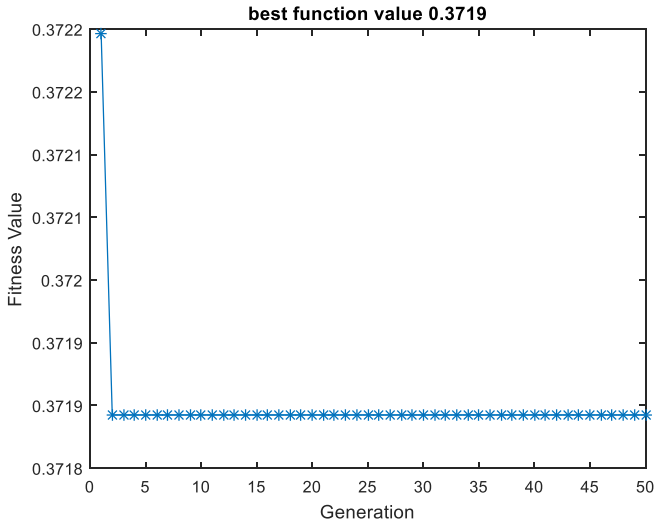

Figure 4.1(e). Convergence Characteristics in mode of maximum spectral efficiency

4.2 COMPARISON ANALYSIS

Grey wolf optimization has been applied to CR system with single carrier that achieves different objectives by MATLAB. We compared four techniques for this purpose. The simulation parameters are shown in table 4.2. The fitness function convergence characteristics for various objective parameters are simulated by approached method GWO for specific Quality if service parameters and these identical parameters are also applied to the SA, GA and SMO. The approached GWO algorithm calculate fitness functions of performance objective and compare the results of same objective parameters by existing algorithm like Genetic algorithm, stimulated annealing and spider monkey algorithm [116][111]. We have simulated different objective parameters such as bit error rate, throughput, power consumption, spectral efficiency and interference. These parameters results are analyzed for different algorithms. The results are shown in simulation table 4.3 for GA. This table shows the simulation parameter result that has been compared to the GWO simulation table. The fitness score of GWO is better than GA. The results are shown in simulation table 4.3 for SA. This table shows the simulation parameter result that has been compared to the GWO simulation table 4.3. The comparison shows that the fitness score of GWO is better than SA. The GWO simulation parameter which shows that GWO algorithm has better result than SMO. We get best optimized value for the GWO.

4.2.1 Comparisons of Fitness Score of GA, SA, SMO and GWO algorithms

In figure 4.2, Minimum power consumption fitness values have shown. In this Genetic algorithm represents maximum value as compared to other. So GA is not suitable for this optimization. We require minimum power consumption and GWO signifies the minimum fitness value.

Throughput is defined as the transfer of amount of information successfully through communication channel. The aim of this objective is to consume throughput is that the transmission rate of information is increases, when time reduces. Therefore, this is the reason for fitness function generated by the approached method i.e. GWO is less than the other method of optimization. Maximum Throughput values have shown for given algorithms. Throughput must be high. Minimum interference fitness values have represented for given algorithms. Interference must be reduced. the number of generation increases, the fitness value gets reduced and gets the best optimized value at that point. This value is the best optimized value so that system can work efficiently. Fig 4.2 shows its best fitness value for interference minimization by GWO. The objective of the simulation in Spectral efficiency mode is to maximize the efficiency of spectrum at the maximum rate but the frequency requirement is less.

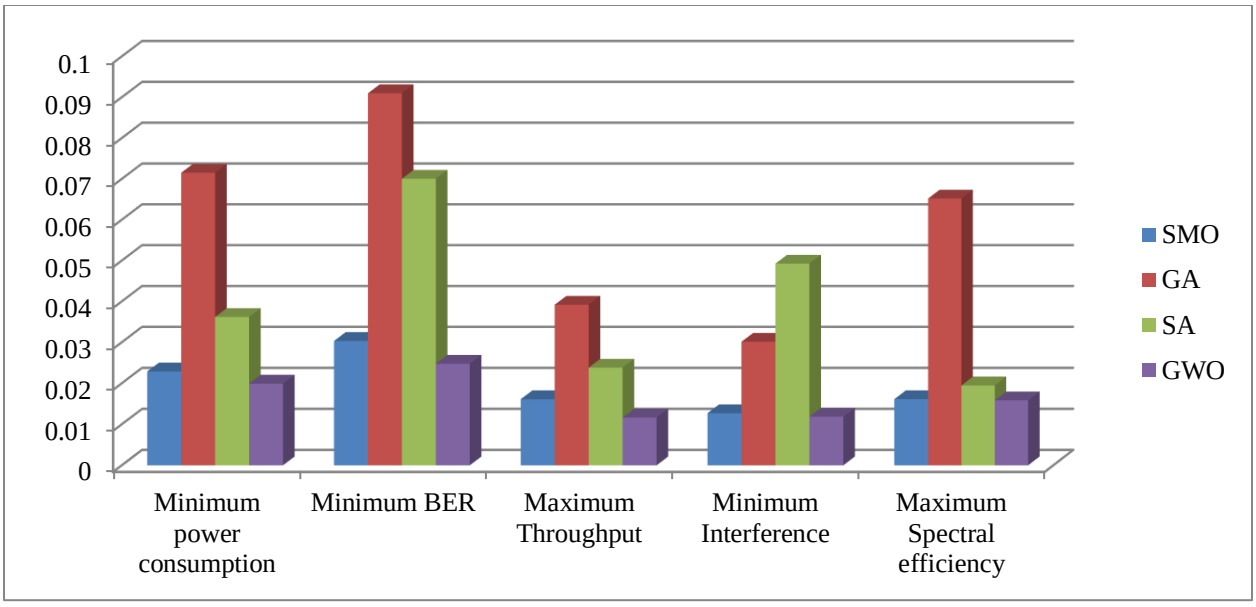

Figure 4.2 Comparative fitness value for respective algorithms

Table 4.4 Comparative fitness values for respective algorithms [111]

Objective parameters	Genetic algorithm	Stimulated Annealing	Spider monkey optimization	Grey wolf optimization
Minimum power consumption	0.071512	0.036184	0.022876	0.01992
Minimum bit error rate	0.090974	0.0700412	0.031325	0.024742
Maximum throughput	0.039174	0.0233801	0.0161123	0.011639
Minimum interference	0.030121	0.049248	0.0127736	0.011837
Maximum spectral efficiency	0.065183	0.0194727	0.0161197	0.015825

At minimum fitness, the spectral efficiency is high so that at less frequency rate we can send maximum amount of information. It shows the fitness value of maximum spectral efficiency.

Fitness value for spectral efficiency has shown for respective algorithms. The efficiency should be high. Table 4.7 shows the convergence fitness value for the existing algorithms and proposed algorithm.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 SUMMARY AND CONCLUSION

We planned new algorithm called GWO to optimize the difficulty in CR system in this paper. We have compare GWO from three existing algorithms called GA, SA and SMO and analyses each objective parameters. The primary goal of algorithm for optimization in cognitive radio structure is to adaptation or optimization of preferred objective and attains to minima and maxima locally. We get simulation result after applying GWO to the objective parameters of cognitive radio system. We compare four different algorithms in different operating mode and compare their results and these algorithms are also applying to the same objective parameters for comparing the results. In the power consumption mode, BER mode, maximum throughput mode and maximum spectral efficiency mode, GWO performs better than other with less fitness score. In wireless communication, the noise interference must be very less and GWO signifies the least interference than existing algorithms. So we prefer GWO over the SMO, GA and SA.

5.2 FUTURE SCOPE

There is various numbers of issues resultant from this area of work that can be persistent further.

- Numerous other probable nature inspired machine learning techniques present that can be applied to the CR system for further achievement and exploration of this working area.
- We can propose our new algorithm to get better results.
- There are various exploration exists if we change the weighting combination that will affects the performance of the system.
- The fitness function generated by the hypothetical equations that are not appropriate and occasionally cannot estimate the environmental parameters accurately.

REFERENCES

[1] Sabri Murat Bicer, "Software communications architecture specification," M.S. dissertation, Northeastern University Boston, Massachusetts, November 2002.

[2] C. J. Rieser, "Biologically inspired cognitive radio engine model utilizing distributed genetic algorithms for secure and robust wireless communications and networking," Ph.D. dissertation, Virginia Polytechnic Institute and State University, April 2004.

[3] Etkin, R., Parekh, A., & Tse, D. (2007). Spectrum sharing for unlicensed bands. *IEEE Journal on selected areas in communications*, 25(3).

[4] Spectrum Policy Task Force, "Report of the spectrum policy workgroup," Available at http://www.fcc.gov/sptf/files/SEWGFinalReport 1.pdf' (Accessed on January 2018).

[5] Mishra, S. M., Cabric, D., Chang, C., Willkomm, D., Van Schewick, B., Wolisz, A., & Brodersen, R. W. (2005, November). A real time cognitive radio testbed for physical and link layer experiments. In *New Frontiers in Dynamic Spectrum Access Networks, 2005. DySPAN 2005. 2005 First IEEE International Symposium on* (pp. 562-567). IEEE.

[6] Chapin, J., & Bose, V. (2002, November). The vanu software radio system. In *2002 Software Defined Radio Technical Conference, San Diego*.

[7] J. G. Proakis, *Digital Communications*, 4th ed. McGraw-Hill, 2000.

[8] J. P. Ignizio, *Introduction to Expert Systems: The Development and Implementation of Rule-Based Expert Systems.* McGraw-Hill, 1991.

[9] B. G. Buchanan and E. H. Shortliffe, *Rule-Based Expert Systems: The MYCIN Experiments of the Stanford Heuristic Programming Project*. Addison-Wesley, 1985.

[10] D. E. Goldberg, *Genetic Algorithms in Search, Optimization, and Machine Learning*. Addison Wesley, 1989.

[11] Mitola, J., & Maguire, G. Q. (1999). Cognitive radio: making software radios more personal. *IEEE personal communications*, *6*(4), 13-18.

[12] Mitola, J. (2009). Cognitive radio architecture evolution. *Proceedings of the IEEE*, *97*(4), 626-641

[13] Liang, Y. C., Chen, K. C., Li, G. Y., & Mahonen, P. (2011). Cognitive radio networking and communications: An overview. *IEEE transactions on vehicular technology*, *60*(7), 3386-3407

[14] [14]. Abbas, N., Nasser, Y. and El Ahmad, K., 2015. Recent advances on artificial intelligence and learning techniques in cognitive radio networks. *EURASIP Journal on Wireless Communications and Networking*, *2015*(1), p.174.

[15] Haykin, S. (2005). Cognitive radio: brain-empowered wireless communications. *IEEE journal on selected areas in communications*, *23*(2), 201-220.

[16] Mitola, J. (1993). Software radios: Survey, critical evaluation and future directions. *IEEE Aerospace and Electronic Systems Magazine*, *8*(4), 25-36.

[17] Chen, K. C. *et al.* (2008, January). Cognitive radio network architecture: part I--general structure. In *Proceedings of the 2nd international conference on Ubiquitous information management and communication* (pp. 114-119). ACM.

[18] Khalid, L., & Anpalagan, A. (2010). Emerging cognitive radio technology: Principles, challenges and opportunities. *Computers & electrical engineering*, *36*(2), 358-366.

[19] Newman *et al.* (2007). Cognitive engine implementation for wireless multicarrier transceivers. *Wireless communications and mobile computing*, *7*(9), 1129-1142.

[20] "DARPA XG program web site." Available at http://www.darpa.mil/ato/programs/XG/ (Accessed on May 2018).

[21] Rieser, C. J. *et al .(*2004, October). Cognitive radio testbed: further details and testing of a distributed genetic algorithm based cognitive engine for programmable radios. In *Military Communications Conference, 2004. MILCOM 2004. 2004 IEEE* (Vol. 3, pp. 1437-1443). IEEE.

[22] Yarkan, S., & Arslan, H. (2008). Exploiting location awareness toward improved wireless system design in cognitive radio. *IEEE Communications Magazine*, *46*(1).

[23] Weingart, T., Sicker, D. C., & Grunwald, D. (2007). A statistical method for reconfiguration of cognitive radios. *IEEE Wireless Communications*, *14*(4).

[24] Pursley, M. B., & Royster, T. C. (2008). Low-complexity adaptive transmission for cognitive radios in dynamic spectrum access networks. *IEEE Journal on selected areas in Communications*, *26*(1).

[25] Arslan, H., & Yarkan, S. (2007). Enabling Cognitive Radio via Sensing, Awareness, and Measurements. In *Cognitive Radio, Software Defined Radio, and Adaptive Wireless Systems* (pp. 235-261). Springer, Dordrecht.

[26] Rajbanshi, R., Wyglinski, A. M., & Minden, G. J. (2006, June). An efficient implementation of NC-OFDM transceivers for cognitive radios. In *Cognitive Radio Oriented Wireless Networks and Communications, 2006. 1st International Conference on* (pp. 1-5). IEEE.

[27] Rajbanshi *et al*. (2006, August). Comparative study of frequency agile data transmission schemes for cognitive radio transceivers. In *Proceedings of the first international workshop on Technology and policy for accessing spectrum* (p. 15). ACM.

[28] Zadeh, L. (1963). Optimality and non-scalar-valued performance criteria. *IEEE transactions on Automatic Control*, *8*(1), 59-60.

[29] Ignizio, J.P., *Goal programming and extensions*. Lexington Books, 1976.

[30] . Goicoechea, A., Hansen, D. R., & Duckstein, L. (1982). Multiobjective decision analysis with engineering and business applications.

[31] Hans, A. E. (1988). Multicriteria optimization for highly accurate systems. *Multicriteria Optimization in Engineering and Sciences*, *19*, 309-352.

[32] Schniederjans, M.J., Goal Programming Solution Methodology. In *Goal Programming: Methodology and Applications* (pp. 45-72). Springer, Boston, MA, 1995.

[33] Newman, T.R., 2008. "Multiple objective fitness functions for cognitive radio adaptation" Ph.D. dissertation, University of Kansas, 2008.

[34] Newman, T. R. et al. (2008). Population adaptation for genetic algorithm-based cognitive radios. *Mobile networks and applications*, *13*(5), 442-451.

[35] Kaur, M. J., Uddin, M., & Verma, H. K. (2012). Optimization of QoS parameters in cognitive radio using adaptive genetic algorithm. *International Journal of Next-Generation Networks*, *4*(2), 1.

[36] . Chen, H. (1995). Machine learning for information retrieval: neural networks, symbolic learning, and genetic algorithms. *Journal of the Association for Information Science and Technology*, *46*(3), 194-216.

[37] . Lippmann, R. (1987). An introduction to computing with neural nets. *IEEE Assp magazine*, *4*(2), 4-22.

[38] J. Carbonell, R. Michalski, and T. Mitchell, "An overview of machine lerning." Available at http://www.citeseer.ist.psu.edu/527935 (Accessed on April 2018).

[39] .Woods, W. A. (1986). Important issues in knowledge representation. *Proceedings of the IEEE*, *74*(10), 1322-1334.

[40] Abd-El-Wahed, W. F., Mousa, A. A., & El-Shorbagy, M. A. (2011). Integrating particle swarm optimization with genetic algorithms for solving nonlinear optimization problems. *Journal of Computational and Applied Mathematics*, *235*(5), 1446-1453.

[41] Saloman, P., Sibani, P., & Frost, R. (2002). Facts, conjectures and improvements for SA. *Society for Industrial and Applied Mathematics, Philadelphia.*

[42] Kirkpatrick, S., Gelatt, C. D., & Vecchi, M. P. (1983). Optimization by simulated annealing. science, 220(4598), 671-680.

[43] Youssef, H., Sait, S. M., & Adiche, H. (2001). Evolutionary algorithms, simulated annealing and tabu search: a comparative study. *Engineering Applications of Artificial Intelligence*, *14*(2), 167-181.

[44] Jonathan, D., Bruno, D., & Hamid, B. A. (2010, June). Simulated annealing and genetic algorithms in topology optimization tools: a comparison through the design of a switched reluctance machine. In *Power Electronics Electrical Drives Automation and Motion (SPEEDAM), 2010 International Symposium on* (pp. 1247-1252). IEEE.

[45] Mahmoud, T. M. (2007). A genetic and simulated annealing based algorithms for solving the flow assignment problem in computer networks. *World academy of science, engineering and technology*, *27*, 360-366.

[46] Liu, L., & Feng, G. (2007). Simulated annealing based multi-constrained QoS routing in mobile ad hoc networks. *Wireless Personal Communications*, *41*(3), 393-405.

[47] Dorigo, M., & Di Caro, G. (1999). Ant colony optimization: a new meta-heuristic. In *Evolutionary Computation, 1999. CEC 99. Proceedings of the 1999 Congress on* (Vol. 2, pp. 1470-1477). IEEE.

[48] Kumar, S., & Kumari, R. (2014). Modified position update in spider monkey optimization algorithm. In *International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS*.

[49] Newman *et al*. (2007). Cognitive engine implementation for wireless multicarrier transceivers. *Wireless communications and mobile computing*, *7*(9), 1129-1142.

[50] Herry, S., & Le Martret, C. J. (2009, August). Parameter determination of secondary user cognitive radio network using genetic algorithm. In *Communications, Computers and Signal Processing, 2009. PacRim 2009. IEEE Pacific Rim Conference on* (pp. 395-400). IEEE.

[51] Kaur, M. J., Uddin, M., & Verma, H. K. (2010). Performance evaluation of qos parameters in cognitive radio using genetic algorithm. *World Academy of Science, Engineering and Technology*, (46).

[52] Tosh, D. K., Udgata, S. K., & Sabat, S. L. (2012). Cognitive radio parameter adaptation using multi-objective evolutionary algorithm. In *Proceedings of the International Conference on Soft Computing for Problem Solving (SocProS 2011) December 20-22, 2011* (pp. 737-748). Springer, India.

[53] Elarfaoui, A., & Elalami, N. (2013). Optimization of QoS parameters in cognitive radio using combination of two crossover methods in genetic algorithm. *International Journal of Communications, Network and System Sciences*, *6*(11), 478.

[54] Kalaichelvi *et al.* (2013, July). GA based dynamic spectrum allocation in UHF-ISM band of 902–928MHz with RADAR as primary user for cognitive radio. In *Recent Trends in Information Technology (ICRTIT), 2013 International Conference on* (pp. 182-188). IEEE.

[55] Deb, K. *et al.* (2002). A fast and elitist multiobjective genetic algorithm: NSGA-II. *IEEE transactions on evolutionary computation*, *6*(2), 182-197.

[56] Saoucha, N. A., Lammari, A. C., & Benatchba, K. (2013, June). Real-coded genetic algorithm parameter setting for cognitive radio adaptation. In *Smart Communications in Network Technologies (SaCoNeT), 2013 International Conference on* (Vol. 1, pp. 1-5). IEEE.

[57] ZHAO, J. H., Fei, L., & ZHANG, X. X. (2012). Parameter adjustment based on improved genetic algorithm for cognitive radio networks. *The journal of china universities of posts and telecommunications*, *19*(3), 22-26.

[58] AlQerm, I., & Shihada, B. (2014, December). Adaptive multi-objective Optimization scheme for cognitive radio resource management. In *Global Communications Conference (GLOBECOM), 2014 IEEE* (pp. 857-863). IEEE.

[59] Kaur, M. J., Uddin, M., & Verma, H. K. (2012). Optimization of QoS parameters in cognitive radio using adaptive genetic algorithm. *International Journal of Next-Generation Networks*, *4*(2), 1.

[60] Behera, S. B., & Seth, D. D. (2015, February). Resource allocation for cognitive radio network using particle swarm optimization. In *Electronics and Communication Systems (ICECS), 2015 2nd International Conference on* (pp. 665-667). IEEE.

[61] Ozcan, G., Gursoy, M. C., Tran, N., & Tang, J. (2016). Energy-efficient power allocation in cognitive radio systems with imperfect spectrum sensing. *IEEE Journal on Selected Areas in Communications*, *34*(12), 3466-3481.

[62] Arienzo, L., & Tarchi, D. (2017). Stochastic Optimization of Cognitive Networks. *IEEE Transactions on Green Communications and Networking*, *1*(1), 40-58.

[63] Motiian, S., Aghababaie, M., & Soltanian-Zadeh, H. (2011, October). Particle Swarm Optimization (PSO) of power allocation in cognitive radio systems with interference constraints. In *Broadband Network and Multimedia Technology (IC-BNMT), 2011 4th IEEE International Conference on* (pp. 558-562). IEEE.

[64] Dixit, A. (2014). PSO based Cross Layer Optimization for Primary User selection in Cognitive Radios.

[65] Abd-El-Wahed, W. F., Mousa, A. A., & El-Shorbagy, M. A. (2011). Integrating particle swarm optimization with genetic algorithms for solving nonlinear optimization problems. *Journal of Computational and Applied Mathematics*, *235*(5), 1446-1453.

[66] Mahdi, A. H., Kalil, M. A., & Mitschele-Thiel, A. (2013, September). Dynamic packet length control for cognitive radio networks. In *Vehicular Technology Conference (VTC Fall), 2013 IEEE 78th* (pp. 1-5). IEEE.

[67] AlQerm, I., & Shihada, B. (2014, December). Adaptive multi-objective Optimization scheme for cognitive radio resource management. In *Global Communications Conference (GLOBECOM), 2014 IEEE* (pp. 857-863). IEEE.

[68] Pradhan, P. M. (2011, December). Design of cognitive radio engine using artificial bee colony algorithm. In *Energy, Automation, and Signal (ICEAS), 2011 International Conference on* (pp. 1-4). IEEE.

[69] Kaswan, K. S., Choudhary, S., & Sharma, K. (2015, March). Applications of artificial bee colony optimization technique: Survey. In *Computing for Sustainable Global Development (INDIACom), 2015 2nd International Conference on* (pp. 1660-1664). IEEE.

[70] S,Deepika., G.Padmavathi, (April, 2017). Throughput Maximization for Full-Duplex Cognitive Radio Networks using Artificial Bee Colony (ABC) Optimization Technique. Vol. 5, Special Issue 3, IJIRCCE.

[71] Sultan, K., Qureshi, I. M., & Zubair, M. (2013). SNR maximization through relay selection in cognitive radio networks. *Res. J. Appl. Sci. Eng. Technol*, *5*(8), 2616-2620.

[72] Wang, J., Li, X., & Ma, K. (2013, September). Multiple Relay Selection Scheme Based On Artificial Bee Colony Algorithm. In *Instrumentation, Measurement, Computer, Communication and Control (IMCCC), 2013 Third International Conference on*(pp. 1055-1059). IEEE.

[73] Ghasemi, A., Jahromi, A. F., Masnadi-Shirazi, M. A., Biguesh, M., & Ghasemi, F. (2012, November). Spectrum allocation based on artificial bee colony in cognitive radio networks. In *Telecommunications (IST), 2012 Sixth International Symposium on* (pp. 182-187). IEEE.

[74] . Cheng, X., & Jiang, M. (2011, September). Cognitive radio spectrum assignment based on artificial bee colony algorithm. In *Communication Technology (ICCT), 2011 IEEE 13th International Conference on* (pp. 161-164). IEEE.

[75] Kaur, K., Rattan, M., & Patterh, M. S. (2013). Optimization of cognitive radio system using simulated annealing. *Wireless personal communications*, *71*(2), 1283-1296.

[76] Sharafi, Y., Khanesar, M. A., & Teshnehlab, M. (2013, September). Discrete binary cat swarm optimization algorithm. In *Computer, Control & Communication (IC4), 2013 3rd International Conference on* (pp. 1-6). IEEE.

[77] Pei-Han, Q., Shi-Lian, Z., Xiao-Niu, Y., & Zhi-Jin, Z. Cognitive radio adaptation for power consumption minimization using biogeography-based optimization.

[78] AlQerm, I., & Shihada, B. (2017, January). Hybrid cognitive engine for radio systems adaptation. In *Consumer Communications & Networking Conference (CCNC), 2017 14th IEEE Annual* (pp. 778-783). IEEE.

[79] LD Xu (1994). Case based reasoning. *IEEE Potentials*. 13(5),10–13. IEEE.

[80] Huang, K. S., Lin, C. H., & Hsiung, P. A. (2010). A space-efficient and multi-objective case-based reasoning in cognitive radio.

[81] Reddy, Y. B. (2010, July). Efficient spectrum allocation using case-based reasoning and collaborative filtering approaches. In *Sensor Technologies and Applications (SENSORCOMM), 2010 Fourth International Conference on* (pp. 375-380). IEEE.

[82] .Ali, D., Park, J. M. J., & Amanna, A. (2013, July). A feature partitioning approach to casebased reasoning in cognitive radios. In *Cognitive Radio Oriented Wireless Networks (CROWNCOM), 2013 8th International Conference on* (pp. 288-293). IEEE.

[83] .Zhao, Z. J., & Lai, H. C. (2012, November). A cognitive engine based on case-based reasoning quantum genetic algorithm. In *Communication Technology (ICCT), 2012 IEEE 14th International Conference on* (pp. 224-228). IEEE.

[84] .Kaur, K., Rattan, M., & Patterh, M. S. (2018). Cuckoo Search Based Optimization of Multiuser Cognitive Radio System Under the Effect of Shadowing. *Wireless Personal Communications*, 1-14.

[85] .Han, H., Wang, J. L., Wu, Q. H., & Huang, Y. Z. (2010, October). Optimal wideband spectrum sensing order based on decision-making tree in cognitive radio. In *Wireless Communications and Signal Processing (WCSP), 2010 International Conference on* (pp. 1-5). IEEE.

[86] .Soltani, S., & Mutka, M. W. (2015). A decision tree cognitive routing scheme for cognitive radio mesh networks. *Wireless Communications and Mobile Computing*, *15*(10), 1405-1417.

[87] .Soltani, S., & Mutka, M. W. (2013, June). Decision tree modeling for video routing in cognitive radio mesh networks. In *World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2013 IEEE 14th International Symposium and Workshops on a* (pp. 1-9). IEEE.

[88] Gandetto, M., & Regazzoni, C. (2007). Spectrum sensing: A distributed approach for cognitive terminals. *IEEE Journal on selected areas in communications*, *25*(3).

[89] Tan, X., Huang, H., & Ma, L. (2013, April). Frequency allocation with artificial neural networks in cognitive radio system. In *TENCON Spring Conference, 2013 IEEE* (pp. 366-370). IEEE.

[90] Zhang, T., Wu, M., & Liu, C. (2012, September). Cooperative spectrum sensing based on artificial neural network for cognitive radio systems. In *Wireless Communications, Networking and Mobile Computing (WiCOM), 2012 8th International Conference on* (pp. 1-5). IEEE.

[91] Yang, Y., Jiang, H., Liu, C., & Lan, Z. (2012, May). Research on cognitive radio engine based on genetic algorithm and radial basis function neural network. In *Engineering and Technology (S-CET), 2012 Spring Congress on* (pp. 1-5). IEEE.

[92] Popoola, J. J., & van Olst, R. (2011, September). Application of neural network for sensing primary radio signals in a cognitive radio environment. In *AFRICON, 2011* (pp. 1-6). IEEE.

[93] Huang, Y., Wang, J., & Jiang, H. (2010, April). Modeling of learning inference and decision-making engine in cognitive radio. In *Networks Security Wireless Communications and Trusted Computing (NSWCTC), 2010 Second International Conference on* (Vol. 2, pp. 258-261). IEEE.

[94] Jiang, C., Chen, Y., & Liu, K. R. (2014). Multi-channel sensing and access game: Bayesian social learning with negative network externality. *IEEE Transactions on Wireless Communications*, *13*(4), 2176-2188.

[95] Zheng, S., Kam, P. Y., Liang, Y. C., & Zeng, Y. (2013). Spectrum sensing for digital primary signals in cognitive radio: a Bayesian approach for maximizing spectrum utilization. *IEEE Transactions on Wireless Communications*, *12*(4), 1774-1782.

[96] Zhou, M., Shen, J., Chen, H., & Xie, L. (2013, April). A cooperative spectrum sensing scheme based on the Bayesian reputation model in cognitive radio networks. In *Wireless Communications and Networking Conference (WCNC), 2013 IEEE* (pp. 614-619). IEEE.

[97] .Li, F., & Xu, Z. (2014). Sparse Bayesian hierarchical prior modeling based cooperative spectrum sensing in wideband cognitive radio networks. *IEEE Signal Processing Letters*, *21*(5), 586-590.

[98] Huang, Y., Jiang, H., Hu, H., & Yao, Y. (2009, December). Design of learning engine based on support vector machine in cognitive radio. In *Computational Intelligence and Software Engineering, 2009. CiSE 2009. International Conference on*(pp. 1-4). IEEE.

[99] Z. Dandan and Z. Xuping, (2011). SVM - based Spectrum Sensing in Cognitive radio, *Proc. IEEE 7th International Conference on Wireless Communi- cations, Networking and Mobile Computing (WiCOM),* Wuhan, China, pp.1-4, Sept. 23-25, 2011

[100] Hu, S., Yao, Y. D., & Yang, Z. (2014). MAC protocol identification using support vector machines for cognitive radio networks. *IEEE Wireless Communications*, *21*(1), 52-60.

[101] Awe, O. P., Zhu, Z., & Lambotharan, S. (2013, December). Eigenvalue and support vector machine techniques for spectrum sensing in cognitive radio networks. In *Technologies and Applications of Artificial Intelligence (TAAI), 2013 Conference on* (pp. 223-227). IEEE.

[102] Lin, M., Ouyang, J., & Zhu, W. P. (2013, December). BF design in cognitive relay networks via sup2ort vector machines. In *Global Communications Conference (GLOBECOM), 2013 IEEE* (pp. 3247-3252). IEEE.

[103] Yau, K. L. (2012). Reinforcement learning approach for centralized cognitive radio systems.

[104] Barve, S. S., & Kulkarni, P. (2012, December). Dynamic channel selection and routing through reinforcement learning in cognitive radio networks. In *Computational Intelligence & Computing Research (ICCIC), 2012 IEEE International Conference on* (pp. 1-7). IEEE.

[105] Zhou, P., Chang, Y., & Copeland, J. A. (2012). Reinforcement learning for repeated power control game in cognitive radio networks. *IEEE Journal on Selected Areas in Communications*, *30*(1), 54-69.

[106] Arunthavanathan, S., Kandeepan, S., & Evans, R. J. (2013, December). Reinforcement learning based secondary user transmissions in cognitive radio networks. In *Globecom Workshops (GC Wkshps), 2013 IEEE* (pp. 374-379). IEEE.

[107] Zhao, N. (2012, November). A novel two-stage entropy-based spectrum sensing scheme in cognitive radio. In *Communication Technology (ICCT), 2012 IEEE 14th International Conference on* (pp. 22-25). IEEE.

[108] Ejaz, W., Atiq, M. K., Kim, H. S., & Shah, G. A. (2013, July). Optimal entropy-based spectrum sensing for cognitive radio networks under severe path loss conditions. In *Cognitive Radio Oriented Wireless Networks (CROWNCOM), 2013 8th International Conference on* (pp. 93-98). IEEE.

[109] Srinu, S., Sabat, S. L., & Udgata, S. K. (2012, December). Reliable cooperative wideband spectrum sensing based on entropy estimation. In *Signal Processing and Communication Systems (ICSPCS), 2012 6th International Conference on* (pp. 1-5). IEEE.

[110] Srinu, S., & Sabat, S. L. (2013). Cooperative wideband spectrum sensing in suspicious cognitive radio network. *IET Wireless Sensor Systems*, *3*(2), 153-161.

[111] Rana, V., & Mundra, P. S. (2017, March). Simulation of QoS parameters in cognitive radio system using SMO algorithm. In *Inventive Communication and Computational Technologies (ICICCT), 2017 International Conference on* (pp. 292-297). IEEE.

[112] Mitola, J. (2009). Cognitive radio architecture evolution. *Proceedings of the IEEE*, *97*(4), 626-641.

[113] Rieser, C. J. (2004). *Biologically inspired cognitive radio engine model utilizing distributed genetic algorithms for secure and robust wireless communications and networking* (Doctoral dissertation, Virginia Tech).

[114] Muro, C., Escobedo, R., Spector, L., & Coppinger, R. P. (2011). Wolf-pack (Canis lupus) hunting strategies emerge from simple rules in computational simulations. *Behavioural processes*, *88*(3), 192-197.

[115] Mirjalili, S., Mirjalili, S. M., & Lewis, A. (2014). Grey wolf optimizer. *Advances in engineering software*, *69*, 46-61.

[116] Kaur, K., Rattan, M., & Patterh, M. S. (2013). Optimization of cognitive radio system using simulated annealing. *Wireless personal communications*, *71*(2), 1283-1296.

LIST OF PUBLICATIONS

[1] Nisha Y., Amit M.,(2018)," Optimization of Transmission Parameters in Cognitive Radio using Grey wolf Optimization", *Journal of Systems Engineering and Electronics*, (Communicated- Science Citation Indexed).

[2] Yadav. N and Mishra A, "Parameters adaptation in wireless system by different nature inspired algorithms: A Survey", *International journal on electrical engineering and informatics*, (Communicated- Scopus Indexed).