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A SURVEY ON OPTIMIZATION OF TRANSMIT POWER IN COGNITIVE RADIO NETWORKS THROUGH NATURE INSPIRED COMPUTATIONAL INTELLIGENCE TECHNIQUES

Paurav Goel[1], Avtar Singh[2] and Ashok Goel[3]
[1,2]Department of Electronics and Communication Engineering, I.K Gujral Punjab Technical University, India
[3]Department of Computer Science, Maharaja Ranjit Singh Punjab Technical University, India

Abstract
Cognitive radio (CR) is a field which is gaining a lot of interest of researchers in around the whole world. It is also termed as nextgen technology as it aims to solve the problem of unutilized electromagnetic spectrum assigned to licensed users. With increasing wireless devices there is a demand of more spectrum resources and cognitive radio can help in making available the unused or underused spectrum for real time communication. When number of cognitive users communicate together at the same time there exists the problem of interference due to transmit power of all the devices to the licensed users. So there is a need of controlling power of transmission for cognitive users so that they may not interfere with Primary licensed users and maintain Quality of Service (QoS) with other cognitive users. The power control of a large number of devices together can be done by the application of computational intelligence techniques. In this paper three nature inspired computational intelligence techniques like Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Ant Colony Optimization (ABC) for optimization of transmit power in cognitive radio networks are discussed.

Keywords:
Cognitive Radio, Secondary User, Primary User, Efficient Utilization of Spectrum, Power Allocation Strategy, Dynamic Spectrum Access

1. INTRODUCTION

The electromagnetic radio spectrum utilized by the transmitters and receivers is licensed by govt. Fixed spectrum allocation wastes resources. Various radio frequency spectrums are inefficiently utilized. Cognitive Radio (CR) improves performance by enabling unlicensed users to use the spectrum allocated to licensed users without creating any interference with licensed users. The utilization of spectrum strongly depends on time and place.

The logic of CR was introduced Joseph Mitola III and Gerald Q. Maguire, Jr in 1999 and described CR [1]. According to them cognitive Radio is an intelligent system that has the knowledge of environment in which it is functioning. It learns from the environment and then adapts its internal states according to the incoming stimuli and then reconfigures its transmission parameters to operate in real time. The two main objectives of CR are efficient usage of the radio spectrum and reliable communication.CR is a capable technology for addressing the spectrum underuse issue presented by the present strategy of inflexible spectrum allocation. In a cognitive radio network (CRN), a secondary user (SU) is permitted to use the spectrum that was initially reserved to primary users (PUs) in the secondary communication network (SCN) if the spectrum is not used by any PU. This secondary spectrum utilized strategy is termed as opportunistic spectrum access [2]. The performance of using the spectrum can be significantly increased throughout this manner. It is not a straightforward job to precisely find a vacant spectrum [3]. Additionally, CRN may also be designed to allow simultaneous PU and SU transmission. At the point of view of PU, SU is permitted to operate so long as SU's interference does not affect the PU's quality of service (QoS) to an inappropriate degree. From the SU point of view it must properly monitor its transmission ability to achieve a relatively high transmission rate without causing too much interference with PU, and the secondary link SINR must also not fall below a certain level of QoS of secondary communication network (SCN.) Such mechanism of transmission is known as spectrum sharing [4]. In Cognitive Radio system there are number of SU’s and PU’s, and each SU selfishly tries to raise its transmission power to increase its own utility, due to which an inevitable increase in the interference at other SU’s takes place, therefore resulting in mutual interference between SU’s [5]. A balance point should be found when SU’s transmit their data on some channel. So the major concern for cognitive radio is to establish a balance between transmits power and interference. The following operational constraints in CRNs should be taken care of the interference at PUs must not exceed a predefined threshold due to total amount of interference power caused by SUs and at every SU, the received SINR must be higher than a predefined threshold to guarantee its QoS. The other constraints imposed are transmission power constraints for SU’s, mutual interference constraints among SU’s, outage probability constraint for SU’s and minimum Bit Error Rate (BER).

In a real time cognitive radio there are number of primary users and secondary users operating simultaneously and to control the transmission power of all secondary users in accordance to primary users is a tedious task. Researchers have applied various nature based computational intelligence techniques to optimize the power of transmission in all secondary users simultaneously. In [6], genetic algorithm (GA) is consumed for optimization purpose of transmit power using two fitness functions. The first is used to mitigate the total power of transmission intake of the secondary network and second is a multi-goal function and is orientated to the combining optimization of total capacity including consumed power of transmission in the secondary network. In a particle swarm optimization (PSO) method [7] is used to optimize the transmit power taking co-channel interference into view. A weighted fitness function is used to control the transmit power, target signal-to interference noise ratio (SINR) in desired limits. In artificial bee colony group optimization method [8] is utilized into optimize the power of transmission to lower down the interference. Here the weights forming by beam is helpful in decreasing interference are calculated. Weights depend upon the number of secondary users and number of antennas. In a cluster based PSO(C-PSO) optimization method [9] is used to tradeoff between outage probability at PU and total aggregated throughput of all SU's at heterogeneous fading channels by optimizing transmit power, sensing duration and frame duration and at different distances between PU and SU.

The rest organization of this is provided as: section 2 describes general model of cognitive radio for transmit power control. In section 3, optimization techniques for transmit power and their result analysis is described. Finally, section 4 discusses the result and section 5 discusses the conclusion of paper.

2. GENERAL MODEL OF COGNITIVE RADIO FOR TRANSMIT POWER CONTROL

In [10-15]] different system models and mathematical models for power allocation in CRNs are discussed. Summary of all the methods is discussed below.

2.1 SYSTEM MODEL

System model of Cognitive radio network that shares the spectrum resource with licensed primary network [8] is shown in Fig.1 for better understanding. The primary base station and a single PU forms the Primary network. The *N* SU's connected to cognitive radio base station (CBS) forms the secondary network.

Here, h_1, h_2, h_3,…., h_n is the channel gain of SU_1, SU_2, SU_3… SU_n users respectively. h_0 denotes the channel gain between *PU* and *CBS*. g_1, g_2, g_3……… g_N denotes channel gain between the SU_1, SU_2, SU_3,…,SU_n and the *PU*.

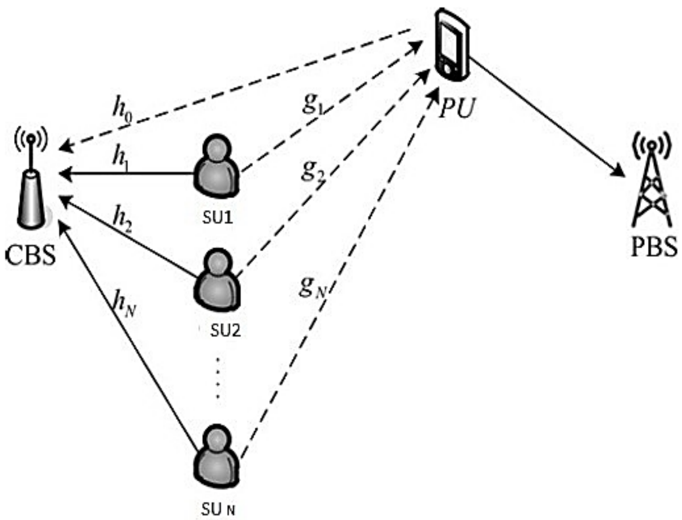

Fig.1. CR System and Channel Model [15]

2.1 CHANNEL MODEL

The received power *P′* is linked with transmitted power *P* as [17]-[18]:

$$P'=Pd^{-n}\,\Omega\alpha^2 \tag{1}$$

The channel model consists of concatenation of the three effects: path loss (*n*) that depends on the distance, large scale signal shadowing (Ω), the channel fading (*α*), the distance between a pair of transmitter and receiver (*d*).

2.2 MATHEMATICAL MODEL

The SINR of the i^{th} SU is calculated by [13]:

$$\gamma_i = \frac{p_i h_i}{\sum_{j=1, j\neq i}^{N} p_i h_i + p_o h_o + \sigma^2} \tag{2}$$

where p_i and p_0 is corresponding to the transmission power of the i^{th} CU and PU respectively. AWGN is considered as background noise with zero mean and variance σ^2.

To avoid any interference with PU, the interference should not exceed a threshold value I_{th} at the PU [13].

$$\sum_{i=1}^{N} p_i g_i \leq I_{th} \tag{3}$$

The maximum secondary power should not exceed secondary transmit power constraint [13]

$$p_i \leq p_i^{th} \tag{4}$$

For reliable communication in CR network the SINR at the receiver must be greater than a threshold [13]

$$\gamma_i > \gamma_i^{th} \tag{5}$$

The distance of secondary *Tx* from primary user is also very relevant

$$dis_{\min} = \left(\frac{Ac_i p_i^{th}}{I^{th}} \right)^{\frac{1}{\alpha}} \tag{6}$$

where *A* is attenuation and c_i is correlation coefficient.

If distance is less than r_{min}, SUs don't have authorization to introduce unacceptable interference to PU Rx so that QoS of PU is guaranteed, if distance is more than r_{min}, SUs can use spectrum in underlay way without the knowledge of PU.

2.2 OBJECTIVES OF TRANSMIT POWER CONTROL

- **To Maximize Ergodic Capacity**: The maximum achievable rate also termed as ergodic capacity in an n^{th} channel and i^{th} SU is given by [20]

$$r_{i,n} = \max W \log_2(1+\gamma_i) \tag{7}$$

where γ_i is same as in Eq.(2).

- **To Enhance Channel Capacity**: The sum capacity of the i^{th} secondary user is [20]

$$R_i = \sum_{n=1}^{N} \rho_{i,n} r_{i,n} \tag{8}$$

- **To Minimize Probability of Outage**: For attaining higher transmission rates probability of outage should be minimum and is given by [10].

$$\min P_r \{\log_2(1+\gamma_i)<r_o\} \tag{9}$$

where r_o is the given transmission rate.

3. OPTIMIZATION OF TRANSMIT POWER

In CR system having number of SU's and PU's, the SU cannot selfishly increase its transmission power. By doing so it will increase mutual interference amongst SU's. Therefore a balance in transmit power of all SU's transmitters must be maintained [21]. There are different nature inspired computational intelligence techniques that had already been employed for transmit power control: Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Artificial Bee Colony Optimization (ABC).

3.1 GENETIC ALGORITHM

In genetic algorithm [22] individual fitness is analyzed. The fittest survives and other are replaced. The fittest genes and their resulting chromosomes produces strong humans that will survive till last. The calculation of the GA begins with the set of the chromosomes with certain randomly generated properties and follows the calculation by generation. Fitness is determined based on stochastic estimation and mutation when producing chromosomes. The health is measured on an individual basis, giving rise to a new chromosome population. Following this, an iterative algorithm is used before it receives the desired solution.

There are three steps to the genetic algorithm: i) Mutation Cross-over ii) Objective Function and iii) The fitness function. Genetic algorithms are suited for cognitive radio because they converge at fast rate, their arbitrary nature and the ability to produce specific solutions spontaneously and they are appealing for cognitive radios. To optimize the results using a nature inspired computational intelligence technique the parameters of proposed technique should be mapped with that of natured inspired computational intelligence technique.

Table.1. Mapping of Parameters of Genetic Algorithm

Genetic Algorithm	**Transmit Power Control Technique**
Population (Chromosomes)	Secondary User's Transmit Power
Selection (selects best values of objective function to form parents)	Calculating Objective Function - Network Capacity
Mutation and cross over	Generating a new population from old one to improve the objective function using sum operations.

Table.2. Result Analysis of Optimization of Transmit Power in Cognitive Radio using Genetic Algorithm

Number of Users	**Total Secondary Network Power (mW)**	**Total Secondary Network Capacity (bps/Hz)**	**Secondary Links Outage Probability**
1	3	9	0.025
2	5	15	0.045
3	7	20	0.05
4	10	24	0.06
5	12	28	0.063
6	15	31	0.08
7	17	34	0.093
8	20	36	0.098
9	23	38	0.118
10	25	40	0.128

Mapping of parameters of Genetic Algorithm (GA) [6] with transmit power control problem is given in Table.1. In the GA for the optimization of transmit power in cognitive radio is discussed. Two fitness functions are proposed. The first is used to reduce the secondary network's overall transmit power consumption. The second is a multi-purpose function and aims to jointly optimize the total capacity and the secondary network power consumption. The findings reveal a fact that the rules for genetic selection are nearly better than the power control scheme based on the multifunctional fitness function as shown in Table.2.

3.2 PARTICLE SWARM OPTIMIZATION (PSO)

There are various application areas of PSO to overcome enormous problems. PSO's algorithm observes animal societies activities that have no leader in their party or swarm, including herds of birds and fish guidance. A herd of animals that do not have bird watchers will typically find food randomly, following one of the group members that have the closest position with a food source (possible solution). At the same time the flocks reach their optimum conditions through communication between members who already have a better situation. Animals with a better condition will inform to its herd, and at the same time the others will follow the one. This will happen again and again before the best circumstances or a food source discovered that PSO achieves efficiency by iteratively targeting the particles to the best use of social and cognitive components. In which $x_{i,j}$ represents the particle position, which is affected by the velocity particles moved in the n dimensional dear space. Here, particle velocity is represented by $v_{i,j}$, where, i, j represents the index of particle and dimension in the defined search space.

In PSO there are different parameter like Vmax that denote maximum velocity with which particles fly in virtual space, the best position $p(i,j)$ that denotes maximum output and g_i known as global best that stores best positions achieved so far. In general, the local_best of each particle can be seen for the position in which the enhanced performance of the particle is achieved; whereas the best in the world of each particle can be seen as the best local position accomplished through neighboring particles. To optimize the results using a nature inspired computational intelligence technique the parameters of proposed technique should be mapped with that of natured inspired computational intelligence technique. Mapping of parameters of PSO as provided in Table.3.

In PSO, method is used to optimize the transmit power taking co-channel interference into view. A framework of multiple secondary users (SU) along with primary users (PU) in pair in spectrum underlay fashion is considered. A weighted fitness function is used to control the transmit power, target signal-to interference noise ratio (SINR) in desired limits. By choosing the weight parameters W_1 and W_2, the performance of fitness function is enhanced. The success of optimization technique is determined by the ratio of W_1 and W_2 and will drive the optimization to a particular direction as shown in Table.4.

In a cluster based PSO (C-PSO) optimization method [9] is discussed to tradeoff between secondary's total aggregate power and primary outage property. Various parameters like sensing duration, frame duration, secondary total aggregate power and primary user outage probability are optimized as a function of distance between PU and center of secondary user's (*m*). The result analysis is shown in Table.5.

Table.3. Mapping of Parameters of PSO

PSO	Transmit power Control technique
Search space (*n* dimensional)	Secondary user's transmit power of n secondary users
Range of search space	SU's Transmit Power (P_{min}, P_{max})
Objective function	Average transmitted power of secondary network and network capacity.

Table.4. Result Analysis of Optimization of Transmit Power in Cognitive Radio using PSO [7]

W_1/W_2	Number of Iterations	Average power per node (W)	Network capacity (Hz)
$W_1/W_2 < 3$	5000	0.078	1.9
	10000	0.081	2.1
	15000	0.082	2.2
$3 < W_1/W_2 < 7$	5000	0.06	1.5
	10000	0.058	1.5
	15000	0.057	1.5
$W_1/W_2 > 7$	5000	0.01	0.3
	10000	0	0
	15000	0	0

Table.5. Result Analysis of S-PSO [9]

Distance between PU and Centre of SU's (m)	Optimal frame duration (μs)	Optimal sensing duration (μs)	Maximum SUs' Aggregated Throughput (Mbps)	Interference Probability to PU
500	900	120	3.6	0.1
600	1070	175	3.25	0.1
700	1240	210	2.95	0.1
800	1300	250	2.75	0.1
900	1200	210	2.5	0.1
1000	900	160	2.35	0.1

3.3 ARTIFICIAL BEE COLONY OPTIMIZATION (ABC)

ABC is an optimization algorithm which approximates honeybee feeding behavior and has been applied successfully to various practical problems. ABC is comes under the part of the Swarm Intelligence algorithms. The collection of honey bees operates via social cooperation.

There are three types of bees in the ABC algorithm: Employed bees, onlooker bees and scout bees. Searching for food around the food source from their memory is performed by employed bees while they share the knowledge of these food sources to the onlooker bees. The better sources of food is selected by onlooker bees among those that gathered by employed bees.

The sources of food with greater quality (fitness) whose possibility of selection is higher by the onlooker bees as compare to lower fitness value. The scout bees are converted from some employed bees that can abandon their sources of food to get newer ones.

To optimize the results using a nature inspired computational intelligence technique the parameters of proposed technique should be mapped as shown in Table.6. In artificial bee colony optimization method [8] to optimize the power of transmission to lower down the interference plus with the aim to obtain the substitute beam forming weights which is helpful into decreasing interference is described. Weights depend upon the number of users *M* and number of antennas *K*. The results Power v/s Iterations is shown in Table.7.

Table.6. Mapping of Parameters of ABC

ABC	Transmit Power Control Technique
Scout bees	Secondary transmitters
Employed bees	Secondary receivers
Onlooker bees	Secondary network controller
Food source	Average transmitted power of secondary network and network capacity.
Waggle dance	Channel state information

Table.7. Result Analysis of Optimization of Transmit Power in Cognitive Radio using ABC [8]

Number of Iterations	Total Power (mW)		
	M=K=15	M= 20, K=15	M=10, K=20
5	75.9	75.9	113
10	74.1	74.1	102
15	73.8	73.8	92
20	71.9	71.9	82
25	68.9	68.9	70
30	68.9	68.9	57

4. RESULTS

The Table.5 gives the result analysis of optimization of transmit power in cognitive radio using Genetic algorithm. Total Secondary Network Power, Total Secondary Network Capacity and Secondary Links Outage Probability are discussed as a function of number of secondary users. The results shows the increasing number of users total secondary network power increased.

Total Secondary Network Capacity increased but probability of outage at Primary users also increased. The Table.4 gives the result analysis for PSO where average power per node and network capacity was plotted against number of iterations for different ranges of weighted fitness functions. Results shows that PSO for transmit power optimization performs best for weighted fitness function $W_1/W_2 < 3$.

The Table.6 discusses the cluster based PSO(C-PSO).The results shows that Secondary users aggregate throughput is a high value when distance between PU and secondary users center is around 500m but it decreases as the distance from PU reaches to 1000m. The Table.7 gives the result analysis of optimization of transmits power using artificial bee colony optimization. The results show a relation between total secondary power and number of iterations for various beam forming weights. This technique shows a decrease in total secondary power with increasing number of iterations.

5. CONCLUSION

From the result discussion it is clear that Particle Swarm optimization method is more suitable for optimization of transmit power in cognitive radio networks. The PSO in [7] optimizes average transmit power up to 52.43 mW while maintaining the Network Capacity to an almost constant value of 1.5×107 Hz. Whereas C-PSO method gives maximum SUs' aggregated throughput of 3.5285Mbps. There is always a scope of improvement and results can be further enhanced. There are other natures inspired computational intelligence techniques which are still unexplored for CRN like grey wolf optimization, bat algorithm, neural network etc. Also the convergence time of the computational intelligence approaches has to be controlled. Further research may be carried out to improve the results.

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