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Underlay and Overlay Subcarrier Power Optimization of OFDMA Based Cognitive Radio Network Using Different EvolutionaryAlgorithm

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Article Info
Volume 83
Page Number: 2595 - 2601
Publication Issue:
May - June 2020

Article History
***Article Received**: 11August 2019*
***Revised**: 18November 2019*
***Accepted**: 23January 2020*
***Publication**:10May2020*

Abstract:

The higher transmitted power is always beneficiary to the wireless communication system to combat noises and for providing a higher data rate. The power is restricted due to cost implications and limits of radiation level. In the case of cognitive radio, it is further restricted for minimization of interference introduced to the primary users. Hence, a power level optimization is required for the cognitive radio network (CRN). The total power is distributed to the sub-channels according to the channel behaviour. In this paper, power allocation to underlay and overlay subcarrier (sub-channel) has been done based on channel capacity. Due to a large number of the subcarrier, evolutionary algorithms like Genetic Algorithm, Particle Swarm Optimization, Moth Flame Optimization have been applied for the CRN system. The comparative results have been presented for different power budget.
Keywords:GA, PSO, MFO, Wireless communication system, CRN etc.

I. Introduction

The wireless communication system becomes the most important system to provide the basic facility of various data communication services like voice communication, video communication, internet facilities. The numbers of users availing these services have increased rapidly in the last few years. Hence the demand regarding the data rate and the number of channels has increased drastically. Due to the limitation of the frequency spectrum, the number of channels is limited and this makes difficult to satisfy the increasing demand of the user. It was observed that many of the beam spectrums are not utilized regularly. This unutilized or underutilized frequency band is used for data communication using cognitive radio. Cognitive radio is a system that can sense the environment, adaptively change the transmission system, and dynamically change the protocols [1]. The utilization of the unused spectrum in the CR system is explained in figure 1 [2].

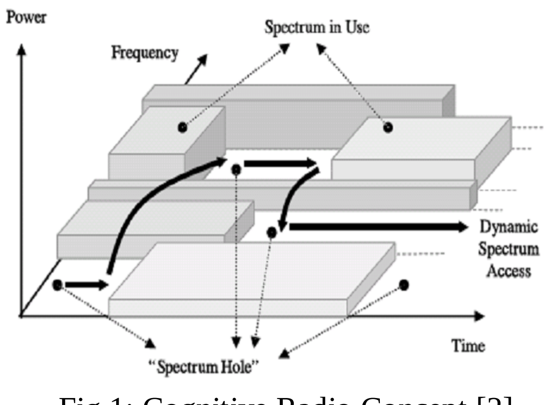

Fig.1: Cognitive Radio Concept [2]

CR system senses the spectrum holes in every time slot by analyzing the spectrum of the primary users (Licensed users). The CR users transmit the data through the spectrum holes. Reconfigurable orthogonal frequency division multiple access

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(OFDMA) is a good choice for cognitive radio. The data is transmitted by using different subcarriers. The subcarrier placed in the spectrum hole called overlay subcarrier produces a negligible interface to the primary users. Another concept of sharing the spectrum is in the presence of primary users with a low level of RF power. These subcarriers are known as underlay subcarrier.

A comparative analysis of GA, PSO, and MFO is described in this paper. A genetic algorithm is a common approach for many scientific optimization problems. Several scholars and investigators have implemented genetic algorithm in order to evaluate the performance of CRN [7-9]. With the advances in optimization technique, it is observed in many problems, the particle swarm optimization (PSO) shows better results, especially for a single objective problem. The PSO technique has also been used for the optimization of the CRN system [10-12]. The MFO, based on the navigation method of moths in nature called transverse orientation, has faster convergence than the GA and PSO. Hence in the present work, MFO has been applied for the optimization of subcarrier power and convergence performance is compared with GA and PSO.

At the beginning periods of software process it is hard to characterize a total software specification. Hence, in spite of the fact that product may adjust to its specification, clients don't live up to their quality desires.

1. Genetic Algorithm

Genetic Algorithms (GAs) are adaptive techniques that might be utilized to obtain solution and optimise problems. These are basically based on the process of genetics among the biological based organisms. With time, multiple generations, population evolve as per the protocols of nature and selection "survival of fittest" which was initially mentioned by Charles Darwin. By replicating this process the method of genetic algorithm provides the solution to any given problem. [13]

A solution generated by GA is termed as chromosome and the collection of such chromosomes is termed as population. A chromosome comprises of genes and the value might be in the form of numbers or binary codes, symbols as well as characters depending on the type of solution that needs to be obtained. These further, encounters the process of fitness function to calibrate and measure the solution produced by the GA. Few of the chromosomes mate by the means of crossover process and hence generating newer chromosome known as the off springs which have gene combination as per the parent chromosome [14]

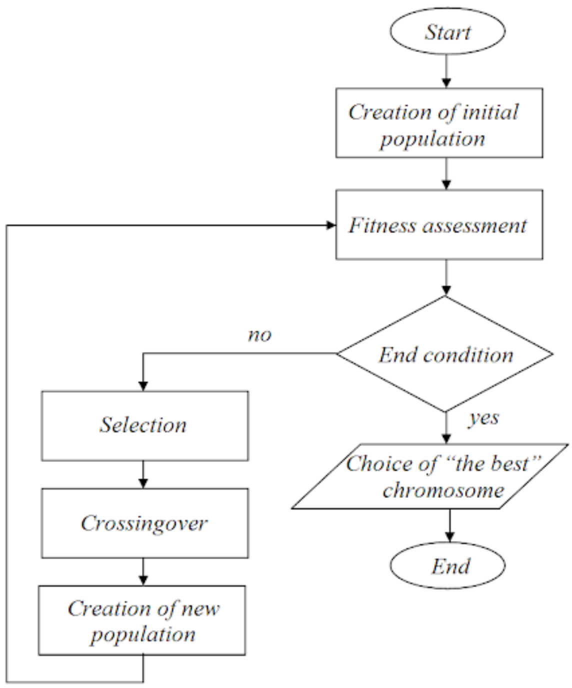

Fig.2: GA flow process

Basic structure of a genetic algorithm is given here under:

"Algorithm
t: = 0;
Compute initial population B0;
WHILE stopping condition not fulfilled DO
BEGIN
Select individuals for reproduction;
Create offspring's by crossing individuals;

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Eventually mutate some individuals;
Compute new generation
END

2. Particle Swarm Optimization

Particle swarm optimizations (PSO) are inspired from the nature based on population algorithms which was actually credited to Eberhart, Kennedy, and Shi. These codings replicate the social aspect behaviors of a swarm of birds or fish. Beginning with a randomly dispersed set of particles known as probable solutions; the coding attempt to enhance the solution as per the measure of the quality known as the fitness function. The improvisation is performed through moving the particles around the search space by means of a set of simple mathematical expressions which model some inter-particle communications. These mathematical expressions, in their simplest and most basic form, suggest the movement of each particle toward its own best experienced position and the swarm's best position so far, along with some random perturbations. [15].

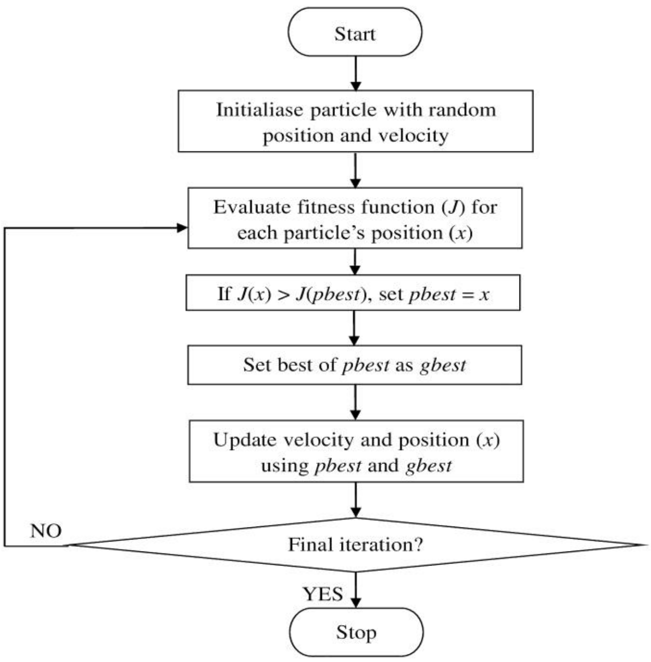

Fig.3: PSO flow process

The particle swarm optimization algorithm

Initialize the parameters such as number of particles "*N*, dimension *d*, and lower (*L*) and upper (*U*) boundaries of the search space.
Generate random solutions (*X*).
Generate a random velocity for each solution (*vi*).
While (termination criterion doesn't meet)
For each particle in *X*
Compute the objective function value.
Update the best personal position (*x p I*).
Update the global best position (*xg*).
Update a new velocity
Update the position of current particle
End For
Return the global best solution" (*xg*).

3. Moth Flame Optimization

Moth flame optimization algorithm (MFOA) is inspired from the nature of flying moths around a flame of fire or light. Moths follow a distinctive pattern in their process of covering long straight distances. It is observed that they fly in straight path but also they move in spiral formations around any light source. The moths behaviour around any flame is enhanced as moth flame optimization algorithm.[16]

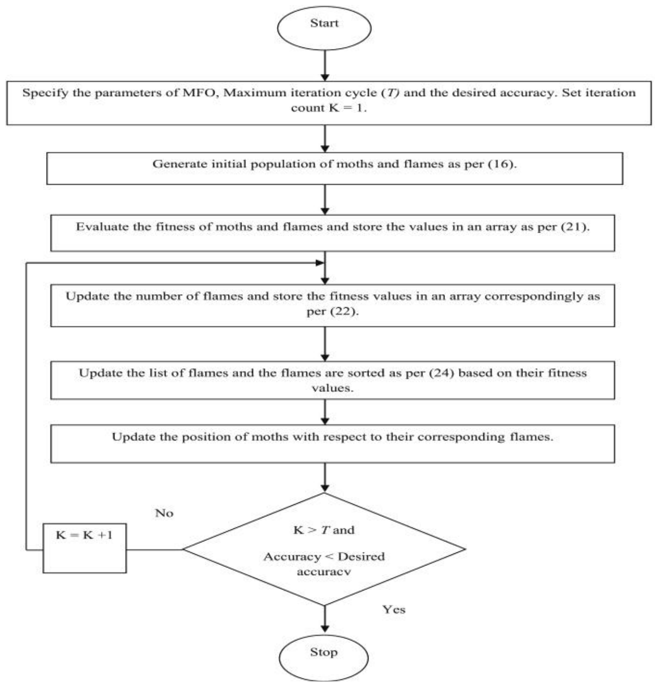

Fig.4: MFO Flow process

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Algorithm for MFO
"Update the number of flames (Flame Number)
Initialise the population of moths
Calculate the objective values
for all moths
for all paramters
update r and t
Calculate D with respect to the corresponding moth
Update the matrix M with respect to the corresponding moth
end
calculate the objective values
Update flames
End"

II. System Model

The objective function for optimization depends on the system parameters and configuration of the system. The typical CRN with primary user configuration is shown in figure 5.

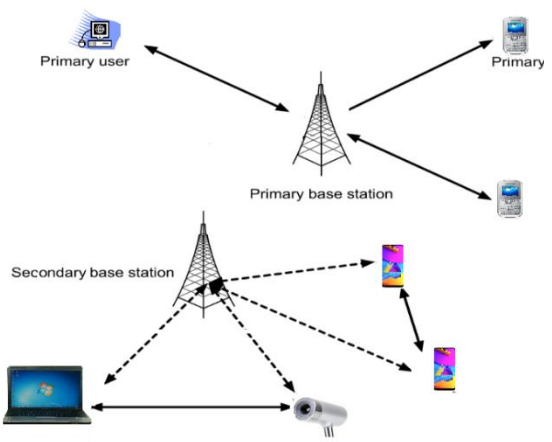

Fig.5: CRN with primary and secondary users

The CRN system used in this model assumed to be stationary during optimization, hence a fixed number of underlay and overlay subcarrier are considered. A Total of 16 channels have been used for overlay and underlay subcarriers (The 8 underlay and 8 overlay subcarriers) in a fixed pattern (red for overlay, blue for underlay as well as black for primary users) as depicted in figure 6.

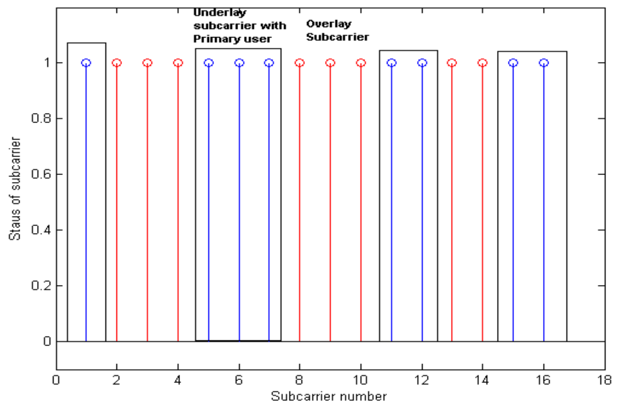

Fig.6. Subcarrier pattern

The Rayleigh fading channel has been considered with fixed fading and a single path as shown in figure 7

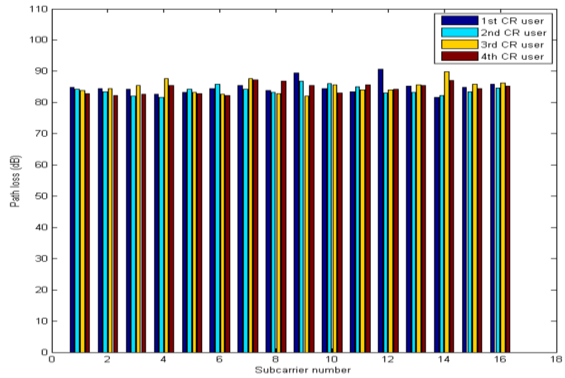

Fig.7. The path loss for each subcarrier and each CR user

III. Problem Formulation and Objective Function

Let's assume, for a given geometrical area, total W bandwidth is allotted to primary users. Total bandwidth is divided into M parts for different primary user groups.

$$W = \sum_{m=1}^{M} W_m \qquad (1)$$

Where, Wm is the bandwidth of the mth primary user group. Consider K CR users are also using the bandwidth W. For Z subcarriers of CR users, the spectral distance between subcarrier can be given as

Published by: The Mattingley Publishing Co., Inc.

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$$\Delta f = \frac{W}{Z} \qquad (2)$$

Both overlay and underlay subcarriers are contained in Z subcarriers (i.e. Z=N+L). The power spectral density φk(f) is given as [3]

$$\phi_k(f) = p_k T_S \operatorname{Sinc}^2(\pi f T_s) \qquad (3)$$

Where Ts and p_k are symbol for duration and the power allocated in the kth subcarrier respectively. Spectral distance factor F (d,k, l) is defined as[4].

$$F(d_{k,l}) = T_s \int_{dk,l-\Delta f/2}^{dk,l+\Delta f/2} \operatorname{Sinc}^2(\pi f T_s)\, df \qquad (4)$$

Let h_l^{SP} be fading coefficient of the channel between CR transmitter and *u*th PU subcarrier. The interference created by the CR subcarrier to an *l*th primary user group can be given as [4][5].

$$i_l^{SP} = |h_l^{SP}|^2 \sum_{u=1}^{K} \sum_{k=1}^{Z} \rho_{u,k}\, p_{u,k}\, F(d_{k,l}) \qquad (5)$$

Where, $\rho_{u,k}$ denotes the status (0 or 1) that uth CR user is allotted kth subcarrier

Let $h_{u,k}^{SS}$ be the fading channel coefficient between uth CR user in kth subcarrier and CR transmitter of all CR hence, the transmission rate for secondary users is given as [5]

$$C = \Delta f \sum_{u=1}^{K} \sum_{k=1}^{Z} \rho_{u,k} \log\left(1 + \frac{|h_{u,k}^{SS}|^2 P_{u,k}}{\sigma^2 + j_{u,k}}\right) P_{u,k}\, F(d_{k,l}) \qquad (6)$$

where, $|h_{u,k}^{SS}|^2$ is the magnitude of complex channel fading coefficient between the CR transmitter and the *u*th CR user in the *k*th subcarrier, σ^2 denotes the Additive White Gaussian Noise (AWGN) variance, $j_{u,k}$ and denotes the interference introduced to the *k*th subcarrier of the *u*th CR user due to the transmission of all PUs.

To enhance the total transmission rate C in addition with minimizing the interference regarding all primary users, different spectrum access techniques are applied to a CR systems and while doing so, the Probability (Pr) for interference should remain below a certain value to the *l*th underlay subcarrier. Therefore, the objective function for a given power budget (P_T) is given as [6]

$$\max_{p_{u,k},\, \rho_{u,k}} = \Delta f \sum_{u=1}^{K} \sum_{k=1}^{Z} \rho_{u,k} \log_2\left(1 + \frac{|h_{u,k}^{SS}|^2 \rho_{u,k}}{\sigma^2 + j_{u,k}}\right) \qquad (7)$$

Conditions

$$P_r\,(i_l^{SP} < I_{th}^{l}) > a. \qquad (8)$$

$$\sum_{u=1}^{K} \sum_{k=1}^{Z} \rho_{u,k}\, p_{u,k} \leq P_T \qquad (9)$$

$$\sum_{u=1}^{K} \rho_{u,k} = 1 \ \& \rho_{u,k} = \{0,1\}$$

for all u and k (10)

1. Subcarrier allocation

To achieve the goal defined by equation 7, subcarrier allocation to a CR user should be done satisfying the following conditions [6]

$$\rho_{u,k} = \begin{cases} 1 & \text{when } u = u^* \\ 0 & \text{otherwise} \end{cases} \qquad (11)$$

Where

$$u^* = \underset{u}{\arg\max} \frac{|h_{u,k}^{SS}|^2}{\sigma^2 + j_{u,k}},$$

$$\text{for } k = 1,2 \ldots\ldots z \qquad (12)$$

After subcarrier allocation according to (12), the equation (7) can be written as

$$\sum_{u=1}^{K} \sum_{k \in \Omega_u} \log_2\left(1 + \frac{|h_{u,k}^{SS}|^2 p_{u,k}}{\sigma^2 + j_{u,k}}\right) \qquad (13)$$

From equation 13, it is clear that power needs to be optimized without exceeding total power budget to enhance total capacity and according to the channel condition.

IV. Results

The system model given in figure 6 is used for the simulation and channel allocation has been carried out as per the equations 11 and 12. The optimization algorithms are GA, PSO, and MFO. The parameters of optimization are given in table 1

Table 1: Parameters for Simulations

Parameter	Value
No. of variable	8
Population size	20

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No. of iteration	50
Variable range	0.001 mW to 4 mW
Interference threshold	10^{-12} W
Bandwidth	5 MHz
Probability P_r	0.4
Power budget	0.1 mW to 9 mW

The simulation has been performed and the optimization convergence with different methods has been achieved. The optimization method is used to minimize the fitness value which is reciprocal to the transmission rate. Figure 5 shows the convergence of optimization for GA, PSO and MFO methods.

From figure 6, it is clear that the convergence performance of PSO is better than GA and MFO. Nevertheless, it stuck in local minima for this problem, which has performed better in finding minima. The assigned powers to subcarriers are shown in figure 8.

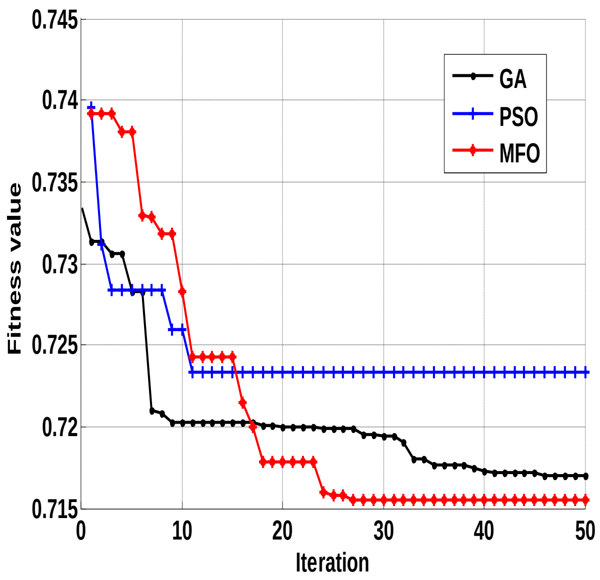

Fig.8. Convergence curve for different evolutionary algorithm

From figure 9, the power allocation is nearly the same for GA and MFO, however it is different when compared to PSO. The transmission rates for different power budgets are shown in figure10

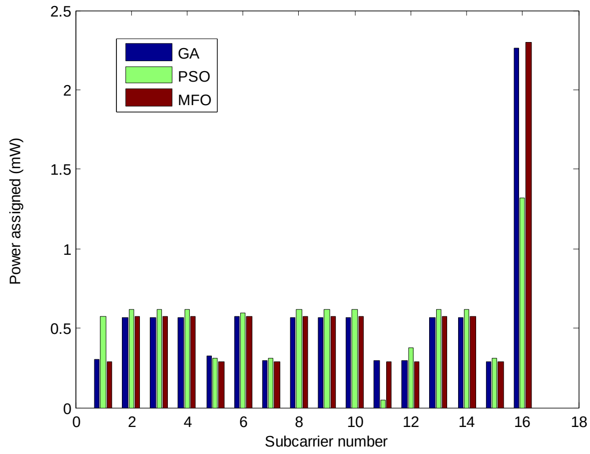

Fig.9. Power assigned to subcarriers using different evolutionary algorithm

From figure 10, it is clear that the result of GA and MFO are almost identical. There is a small betterment for MFO when compared to GA. The result of PSO is poor in comparison to GA and MFO.

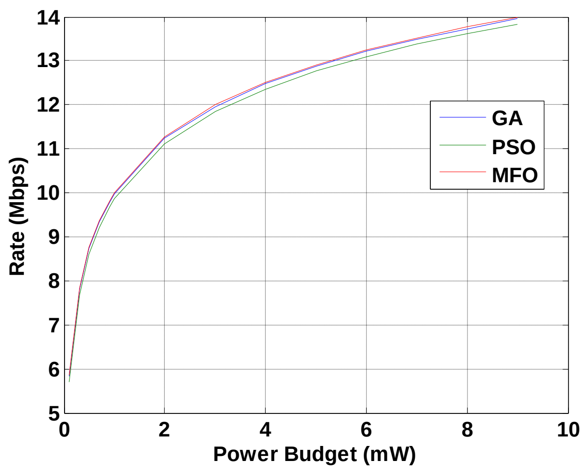

Fig.10: Data rate for different power budgets

V. Conclusions

The present work includes the description of optimization techniques such as GA, PSO and MFO. The general algorithms used to implement these techniques are also discussed. The power allocation to underlay and overlay subcarrier (sub-channel) has been incorporated for maximizing the channel capacity for a given power budget. The comparative results show that the MFO algorithm performed better than GA and PSO in terms of speed of optimization as well as the capacity of the CRN in this research work. There is further scope to include the time-variant nature of CRN in order to choose an optimum or near optimum solution to meet the time deadline for online optimization.

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