

## PSO based Cross Layer Optimization for Primary User selection in Cognitive Radios

Ankur Dixit<sup>1</sup> and Rajender Kumar, Member IEEE ('2010)<sup>2</sup>

*Department of Electronics and Communication Engineering,  
National Institute of Technology, Kurukshetra, Haryana, India*  
<sup>1</sup>*ankur.dixit003@gmail.com,* <sup>2</sup>*rkumar.kkr@gmail.com*

### **Abstract**

*In Cognitive Radio Networks, selection of primary users (PUs) is an important process for achieving optimal performance during a session. The selection process of PU is limited due to the strict boundaries between layers that are enforced in Open System Interconnection (OSI) model which prevent the coordination, interaction and data transfer between the layers. To overcome such limitations, cross layer optimization is proposed where different operating parameters such as transmission power, packet length, bandwidth etc. across the OSI layers of a device are optimized. In this paper Particle Swarm Optimization (PSO) algorithm is proposed to optimize different operating parameters with the objective to optimize throughput, power consumption, interference, Bit Error Rate and spectral efficiency for a set of PUs across the physical, network and Media Access Control (MAC) layer in OSI model. The fitness values of these objective functions in different modes and channels are investigated using MATLAB and the results shows that PSO is 70% faster than the Genetic Algorithm in terms of convergence rate. Finally paper proposes that PSO based algorithm is an efficient, reliable and fast technique for primary user selection in cognitive radios.*

**Keywords:** *Cognitive Radio Network; Cross Layer; iteration; Optimization*

### **1. Introduction**

Cognitive Radio Network (CRN) is a smart wireless network which senses the surrounding radio environment and adapt its operating parameters for efficient utilization of available radio spectrum. CRNs are used for improving the quality of wireless applications and achieving better radio bandwidth utilization. Well-designed multi-hop CRN provides high bandwidth efficiency by using Dynamic Spectrum Access (DSA) technologies as well as it provides extended coverage and ubiquitous connectivity for the wireless end users [1]. CR automatically detects available channels in a wireless spectrum and the transmission parameters are changed to allow more simultaneous communications.

Cognitive Radios (CRs) have been presented as the new communication paradigm for wireless systems utilizing the existing spectrum opportunistically [2, 3]. CR senses the surrounding radio spectrum to find the free spectrum and this free spectrum is simply used by CR without causing interference to the licensed users. The challenge of the CR is that a large portion of data is manipulated when it is changing the various parameters to adapt the environment [4]. The licensed user is known as Primary user (PU) who can access the spectrum at any time. The spectrum can be used by the secondary user (SU) when it is idle and it is not used by PU. When PU wants to access the channel, SU must vacate that channel and the process requires large set of overheads. However, CRN imposes increasing complexity of network architecture, high cost of configuring and managing large-scale

networks, fluctuating nature of the available spectrum, diverse QoS requirements of various applications, and the intensifying difficulties of centralized control [5]. These challenges are generated when there is lack of interaction between the layers due to strict boundaries between the layers in Open System Interconnection (OSI) model of a system. Hence to overcome these problems cross layer optimization is explored in which main motive is to optimize different objective functions of the cross layer viz. maximizing throughput, minimizing Bit Error Rate (BER), minimizing power consumption, maximizing spectral efficiency and minimizing the interference. In this paper cross layer optimization (CLO) is considered as an evolutionary process where after every iteration the process is yielding a better PU.

Several optimization algorithms are referred in literature for deploying optimization techniques such as Artificial Immune Algorithm (AIA)[6], Evolution Strategy (ES)[7], Differential Evolution (DE)[9], Genetic Algorithm (GA)[8], Evolution Programming (EP)[10], Bacteria Foraging Optimization (BFO)[11], etc. Among all, GA works on the principle of the Darwinian theory of evolution of the living organisms [8]. ES is based on the hypothesis that during the biological evolution the laws of heredity have been developed for fastest phylogenetic adaptation [7]. ES imitates in contrast to the GA, the effects of genetic procedures on the phenotype. EP also simulates the phenomenon of natural evolution at phenotype level [10]. DE is similar to GA with specialized crossover and selection method [9]. BFO is inspired by the social foraging behavior of Escherichia coli [11]. AIA works on the immune system of the human being [6]. Ant Colony Optimization (ACO)[12] works on the principle of foraging behavior of an ant for the food and Artificial Bee Colony (ABC) algorithm works on the principle of foraging behavior of a honey bee (Karaboga, 2005; Basturk & Karaboga, 2006; Karaboga & Basturk, 2008).

All the evolutionary based algorithms are probabilistic algorithms and require common controlling parameters like population size, number of generations, elite size, etc. For example, GA uses crossover rate and mutation rate. The improper tuning of algorithm-specific parameters either increases the computational efforts or yields the local optimal solutions [13]. In 1995, Kennedy and Eberhart introduced an idea of evolutionary computation technique inspired by swarm intelligence such as fish schooling, bird flocking and even human social behavior known as Particle Swarm Optimization (PSO). PSO is a Nature inspired population based algorithm which simulates different natural phenomena to solve a wide range of problems. In the swarm optimization technique the random solutions of the fitness functions are known as population. The individual objective functions in the population are known as particles. The new velocity is based on the previous velocity (its personal best position and the global best position) and the position of each particle is updated by a new velocity. The PSO has a memory which is based on the updated value of the velocity of each particle in every iteration so that the information of good solutions is reserved by all individuals [14]. Furthermore, the PSO has constructive cooperation between individuals so that individuals in the population share information between them [15]. In proposed approach PSO is utilized to represent the following multiple design variables of CLO shown in Table 1.

**Table 1. Nomenclature of PSO and CLO Design Variables**

PSO variables	CLO design variables
Particles	Objective functions ( $f_{min\_ber}$ , $f_{max\_thr}$ , $f_{min\_pow}$ etc.)
Random solutions	Randomly selected values of design parameters
Population	Set of fitness values of objective functions

Velocity vector	Fitness value
-----------------	---------------

A set of Multiple Objective Decision (MOD) functions is used to generate the set of PUs which denotes the population size in PSO. The best fitness value (F.V.) of the MOD function corresponds to the best PU selected by the SU.

The rest of the paper is organized as follows: Section 2 presents an analytical framework for CLO. Section 3 proposes PSO based decision algorithm based on the MOD function. Important modelling and simulation parameters are discussed in section 4 followed by results and performance analysis. Finally conclusion is presented followed by future scope of work and references.

## 2. Cross Layer Optimization

OSI model is a standard description for data transmission between the nodes in the network. The core idea in OSI model is that the communication process between two nodes is divided into layers, where each layer has its own set of special and related functions. These functions are executed by exchanging data with the adjacent layers only. These strict boundaries increase the Round Trip Time (RTT), overheads and overall system delay which degrade the QOS (Quality of Service) of the wireless system. Therefore to overcome this performance degradation, CLO is used which reduces the effect of strict boundaries between the layers and enable the transmission and exchange of the data between the non-adjacent layers also. In CLO approach different objective functions (such as maximizing throughput, minimizing transmission power, minimizing BER etc.) of different layers (physical layer, MAC layer, network layer) are optimized with the help of operating parameters such as code rate, symbol rate, packet length, modulation scheme, bandwidth etc. Here, Table 2 is showing the relationship of different operating parameters to the different layers of an OSI model.

**Table 2. Decision Variables**

OSI Layers	Operating parameters
Network Layer	Packet Length $L$ , Bandwidth, Time Division Duplexing ( $T_{dd}$ ).
Data Link Layer	Code Rate $R_c$ , Bit rate $R_b$ , Symbol Rate $R_s$ .
Physical Layer	Transmit power $P_t$ , Modulation scheme.

These are the transmission parameters used in the proposed approach. One important thing of this algorithm is that the ratio of bit rate to code rate ( $R_b/R_c$ ) must not exceed its maximum channel capacity, according to Shannon's theorem [16] as shown in equation (1)

$$\frac{R_b}{R_c} \leq B_{ch} \log_2(1 + SNR) \quad (1)$$

Where ' $R_b$ ' is the bit rate, ' $R_c$ ' is the code rate, SNR is the signal to noise ratio and ' $B_{ch}$ ' is the bandwidth of the channel. The MOD function ( $f_{modf}$ ) based on PSO in CLO for the selection of PU is defined as follows

$$f_{modf} = f(f_{min\_ber}, f_{max\_thr}, f_{min\_pow}, f_{min\_interference}, f_{max\_speceff}) \quad (2)$$

Where objective function  $f_{min\_ber}$  is representing minimization of Bit Error Rate,  $f_{max\_thr}$  is maximization of throughput,  $f_{min\_pow}$  is representing minimization of power consumption,

$f_{min\_interference}$  is the minimum interference and  $f_{max\_speceff}$  is the maximization of spectral efficiency used by the primary user. In weighted sum approach the Multi Objective Decision (MOD) function is written as equation (3)

$$f_{modf} = \sum_{i=1}^5 w_i * f_i \quad (3)$$

Where ' $w_i$ ' is presenting different weights assigned for different objective functions and  $\sum_i w_i = 1$ . And these different objective functions are used for optimizing the cross layer of an OSI model which are described as follows:

#### 4.1 Minimizing Bit Error Rate

To obtain an error free signal or minimization of BER [17] is the one of the most common goals of the communication system. BER depends on several parameters such as transmission power, modulation type, modulation index, bandwidth, noise power and signal power. The channel type and the modulation index are also important factors on which BER depends. Other important factors for the calculation of BER are energy per bit ( $E_b$ ) and noise spectral density ( $N_0$ ). If ' $S$ ' is the signal power, ' $R_s$ ' is the symbol rate and ' $m$ ' is the modulation index (number of bits in each symbol) then energy per bit is calculated as in equation (4)

$$E_b = \frac{S}{R_s * m} \quad (W/b) \quad (4)$$

The noise spectral density is the noise per hertz and it is calculated by using Boltzmann's constant as in equation (5)

$$N_0 = K_b * T \quad (J) \quad (5)$$

$$N = N_0 * B \quad (WHz) \quad (6)$$

Where ' $K_b$ ' is the Boltzmann's constant ( $1.38 \times 10^{-23}$  J/K), ' $T$ ' is the noise temperature of the system, ' $B$ ' is the bandwidth of the channel and ' $N$ ' is the total noise power.

For measuring the BER it is required to calculate the ratio of  $E_b/N_0$  which is calculated by using equation (7)

$$\frac{E_b}{N_0} = \mu = 10 \log_{10} \left[ \frac{S}{R_s * m * N_0} \right] \quad (7)$$

The probability of bit error ( $P_{ber}$ ) for M-ary QAM is calculated as follows [17]

$$P_{ber} = \frac{4}{\log_2(m)} \left( 1 - \frac{1}{\sqrt{m}} \right) Q \left( \sqrt{\frac{3 * \log_2(m)}{m-1}} \mu \right) \quad (8)$$

Now the objective function which is used to calculate the minimum BER, is defined as in equation (9)

$$f_{min\_ber} = 1 - \frac{\log_{10}(0.5) - \log_{10}(P_{ber})}{\log_{10}(0.5) - \log_{10}(10^{-6})} \quad (9)$$

## 4.2 Maximum Throughput

Average rate of successful message delivery over a communication channel is known as maximum throughput. Throughput is the good output or the useful information received at the receiver. Maximum throughput is very useful in variety of applications such as data and video streaming. For this objective it is required to calculate fitness score of ideal transmission environment. The operating parameters on which throughput depends are: coding rate, modulation index, percent of transmission time, bandwidth in use and frame size. For determining the throughput, calculation of the probability of packet success rate is important. The probability of packet success rate is defined in equation (10)

$$P_{psr} = 1 - (1 - P_{BER})^{(L+O)} \quad (10)$$

Where ‘ $L$ ’ is the frame length size in bytes. Equation (11) shows the derived equation that gives the relationship among framesize,  $P_{psr}$  and objective function throughput ( $f_{thr}$ ) [18]

$$f_{max\_thr} = m * R_s * \frac{L}{L+O+H} * P_{psr} = R_b * \frac{L}{L+O+H} * P_{psr} \quad (11)$$

Where ‘ $R_b$ ’ is the bit rate of the system in bits per second, ‘ $H$ ’ is the Internet Protocol (IP) and MAC layer overhead and ‘ $O$ ’ is representing the physical layer overhead. The throughput function can be also calculated by using block coding and time division duplex ( $T_{dd}$ ) parameters which is shown by equation (12)

$$f_{max\_thr} = R_c * T_{dd} * \frac{L}{L+O+H} * P_{psr} \quad (12)$$

## 4.3 Minimum Power Consumption

Transmission power control is an important factor to improve the energy efficiency in CRNs. There are several factors which are responsible for power consumption in CRNs such as bandwidth ( $B$ ), modulation type ( $m$ ), time division duplexing ( $T_{dd}$ ), and the most common factor is transmission power. The first objective function which is required for minimization of power consumption, depends on bandwidth and the transmission power. This first objective function ‘ $f_x$ ’ is defined as follows

$$f_x = \frac{(P_{max}+B_{max})-(P+B)}{(P_{max}+B_{max})} \quad (13)$$

The power consumption also depends on complexity of the system and complexity depends on the modulation index or the number of bits per symbol. So the second objective function for minimization of power consumption is given as equation (14)

$$f_y = \frac{\log_2(m_{max})-\log_2(m)}{\log_2(m_{max})} \quad (14)$$

By increasing the symbol rate the sampling rate can be also increased which increases the processing required in a linear way. The third objective function related to symbol rate is given as equation (15)

$$f_z = \frac{R_s \max - R_s}{R_s} \quad (15)$$

The total objective function for power consumption which depends on the values of  $f_x$ ,  $f_y$  and  $f_z$  is given as equation (16)

$$f_{min\_pow} = 1 - [a_1 * f_x + a_2 * f_y + a_3 * f_z] \quad (16)$$

Here,  $\sum_j a_j = 1$

Where  $a_1$ ,  $a_2$  and  $a_3$  are the weighting factors for different conditions. The selection of these parameters for simulation is presented in 'results and discussion' section. The values of  $a_1$ ,  $a_2$  and  $a_3$  for different modes are described according to the Table 3:

**Table 3. Values of  $a_1$ ,  $a_2$  and  $a_3$  for Different Modes**

Modes	$a_1$	$a_2$	$a_3$
Low power mode	Low	Medium	Low
Emergency mode	Medium	Medium	Low
DSA mode	Medium	High	Low
Multimedia mode	High	Low	Low

#### 4.4 Minimum Spectral Interference

Interference hinders capacity and coverage of the communication systems and limits the effectiveness and the performance of both the new and existing systems together [19]. In CRNs number one enemy of the system designers and the service provider is the spectral interference. In the frequency bands used in CRNs the interference should be minimum. The spectral interference depends on the transmission power, bandwidth and time division multiplexing [20]. Ideally for calculating total interference it is required to integrate over total bandwidth on which the signal is transmitted for calculating the total power of overlapping transmission. In this paper uniform power transmission is assumed over the transmission bandwidth and the interference is calculated according to equation (17)

$$f_{interference} = P * B \quad (17)$$

Objective of this paper is to decrease the interference produced in the spectrum for a given bandwidth. The normalized value of the interference in addition to  $T_{dd}$  parameter is calculated by equation (18):

$$f_{min\_interference} = 1 - \frac{(P*B*T_{dd}) - (P*B)}{P_{max}*B_{max}*100} \quad (18)$$

#### 4.5 Maximum Spectral Efficiency

Spectral Efficiency tells about how efficiently the spectrum or band of allotted frequency is being utilized by the physical layer protocol or the MAC layer protocol. Spectral efficiency is the rate of maximum information that can be transmitted over a given bandwidth in a specific communication system. Objective of this paper is directly related with the bandwidth and the information being transmitted. Total amount of information being transmitted also depends on the symbol rate and modulation index. The normalized objective function for calculating the spectral efficiency is given as equation (19)

$$f_{max\_spceff} = \frac{m * R_s * B_{min}}{B * m_{max} * R_{s\ max}} \quad (19)$$

In proposed algorithm the weighted sum approach is used. One aggregate multiple objective function is obtained from the number of single objective functions by using weighted sum approach. Equation (20) shows the relationship between MOD function to the single objective functions by using weighted sum approach as follows

$$f_{modf} = w_1 * f_{min\_ber} + w_2 * f_{max\_thr} + w_3 * f_{min\_pow} + w_4 * f_{min\_interference} + w_5 * f_{max\_spceff} \quad (20)$$

The MOD function depends on the values of weights. The values of weights for different modes has been defined in the results and discussion section.

### 3. Proposed Modified PSO Algorithm

Optimization involves mathematical technique which is used to make a system or design as effective and functional as possible. In this paper PSO algorithm is used to optimize the different objective functions with respect to their fitness values. PSO is an evolutionary optimization technique proposed by Kennedy and Eberhart [21]. Its development is based on observations of the social behavior of animals such as bird flocking, fish schooling, and swarm theory [21, 22]. The initialization of PSO is done with the population of random solutions of the fitness function. The individuals  $y_k$  ( $k = 1, 2, \dots, m$ ) in the population are known as particles. The PSO is an iterative method based on the search behavior of a swarm of 'm' particles in a multidimensional search space [22]. The velocity  $u_k$  ( $k = 1, 2, \dots, m$ ) and the position  $y_k$  ( $k = 1, 2, \dots, m$ ) of each particle are updated in every iteration.  $y_{k\ pbest}$  and  $y_{gbest}$  are the personal best position and global best position of particles among all particles respectively which are updated according to the fitness values of the updated individuals. The PSO searches its global optimum solution by modifying the path of each particle in the direction of its personal best position and the global best position. Based on the above theory, the procedure of the PSO algorithm is described as follows:

**Step 1.** Start the PSO and set values of constant.

Set the number of iterations (*iter*), individuals (*m*) and the constants for the PSO ( $c_1$ ,  $c_2$  and  $w$ ), where 'm' is the total number of design parameters used in optimization of objective function,  $c_1$  and  $c_2$  are set to constant values and  $w$  is inertia weight which controls the updated value of new velocity from previous velocity.

**Step 2.** Generate initial positions of particles ' $y_k$ ' randomly where  $k = 1, 2, \dots, m$  in the population. In CLO initial positions of particles are indicating the initial values of objective functions calculating by using different design parameters and the population

is indicating the set of values of different objective functions defined for optimization of cross layer.

**Step 3.** Generate initial velocity vectors  $u_k, k = 1, 2, \dots, m$  of the particles randomly, these velocity vectors are uniformly generated random numbers.

**Step 4.** Compute the F.V. of particles and set initial  $y_{k\ pbest}$  and  $y_{gbest}$  for the initial population where  $y_{k\ pbest}$  and  $y_{gbest}$  are the local best value and the global best values of the objective functions respectively in each iteration.

(i) Set  $y_{k\ pbest} = y_k, k = 1, 2, \dots, m$ .

(ii) The index  $d$  of the particle with the best fitness value is calculated by

$$d = \arg \operatorname{opt}_{k=1}^m f(y_{k\ pbest}), \quad (21)$$

Where  $f(y_{k\ pbest})$  represents the F.V. of  $y_{k\ pbest}$ . Then, set  $y_{gbest} = y_{d\ pbest}$

**Step 5.** Set  $g = 1$  and  $ind = d$ , where  $g$  is showing the iteration number and  $ind$  is showing the index.

**Step 6.** Update  $y_{k\ pbest}$  and  $y_{gbest}$ .  $y_{k\ pbest}$  and  $y_{gbest}$  values are updated by doing the comparison of local best values with the previous local best values and the previous global best values of the objective functions.

(i) Update  $y_{k\ pbest}$ :

If  $f(y_k) > f(y_{k\ pbest}), k \in \{1, 2, 3, \dots, m\}$ , then set  $y_{k\ pbest} = y_k$ .

(ii) Update  $y_{gbest}$  as follows

If  $f(y_{k\ pbest}) > f(y_{gbest}), k \in \{1, 2, 3, \dots, m\}$ , then set  $y_{gbest} = y_{k\ pbest}$ .

**Step 7.** Find the index of  $f(y_k)$  by using equation (21) and if  $f(y_k) > f(y_{gbest})$ , update the index.

**Step 8.** In this step the velocity vector  $u_k$  and the position vector  $y_k$  of each particle are updated.

(i) Update the velocity vector:

$$u_k = u_k + c_1 * \operatorname{rand}() * (y_{k\ pbest} - y_k) + c_2 * \operatorname{rand}() * (y_{gbest} - y_k),$$

Where  $k = 1, 2, \dots, m$  and  $\operatorname{rand}()$  is a uniformly distributed random number between 0 and 1.

(ii) Update the position vectors:

$$y_k = y_k + u_k, k = 1, 2, \dots, m.$$

**Step 9.** Decrease the velocity vector:

$$u_k = u_k * w, k = 1, 2, \dots, m,$$

Where  $w$  is the value of inertia weight in between 0 and 1.

**Step 10.** Update the value of  $g$ .

$g = g + 1$ , if  $g < iter$  then go to Step 6.

**Step 11.** Now the global best position  $y_{gbest}$  having the best F.V.  $f(y_{gbest})$  is obtained with

selection of best PU.

#### 4. Results and Discussion

The proposed Cross layer optimization for the selection of primary users based on PSO algorithm is modelled and different design variables for aforesaid objective functions are



simulated. For simulation MATLAB 2012 tool is used with processor speed of 2.30 GHz. The different objective functions are confined as per following design constraints:

#### 4.1 Modelling Parameters

With reference to PSO based CLO algorithm for PU selection following are the modelling parameters:

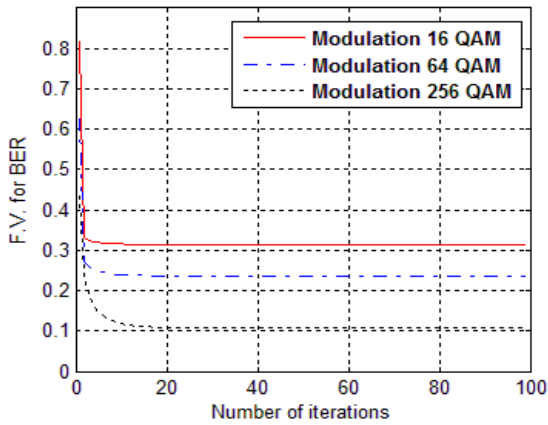
- 1) In this paper PU could be any wireless node in the vicinity of SU *i.e.*, it may be base station of GSM (Global System for Mobile)/CDMA (Code Division Multiple Access), access point of WLAN (Wireless Local Area Network), mobile node of MANET (Mobile Ad hoc Network) etc. Hence number of PU for simulation is taken 100.
- 2) The objective functions of 100 users are considered as the particles for PSO algorithm and the optimized fitness values are calculated for 100 iterations for every objective functions.
- 3) Range of transmission power  $P$  is considered from -8 dBm to 26 dBm with step size 1 dBm. The range of this power is selected because it is in the specified range of transmitted power in the middle UNII (Unlicensed National Information Infrastructure) band for a given 1 MHz bandwidth.
- 4) In CLO  $m$ -ary QAM type modulation is considered and the limit of modulation index  $m$  is 2 to 256.
- 5) The environmental parameters are: The noise floor is -85 dBm, Path Loss is 85 dB and the channel attenuation is between 0 and 1 and simulated channels type is AWGN [17].
- 6) Bandwidth  $B$  of each channel is considered between 2 MHz to 32 MHz with step size of 1 MHz [23].
- 7) Packet length  $L$  is taken from 94 bytes to 1504 bytes with channel code rate  $R_c = [1/2, 2/3, 3/4, 4/5, 5/6, 6/7, 7/8]$ [24].
- 8) The symbol rate  $R_s$  in this simulation varies from 125 Ksps to 1 Msps with step size of 125 Ksps.
- 9) The weighting factors  $w_1, w_2, w_3, w_4$  and  $w_5$  are obtained from Table 4 [25-28].

**Table 4. Selection of Weighting Factors for Different Modes**

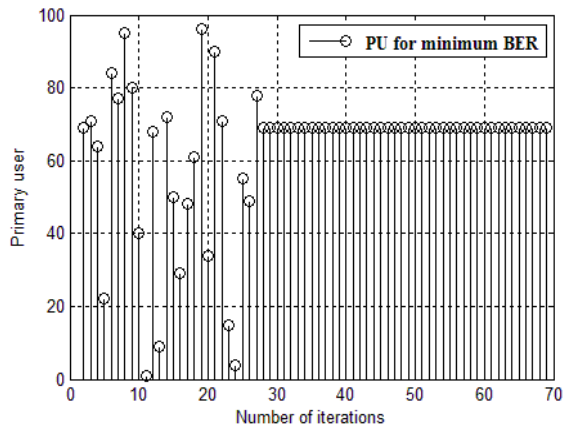
Modes	$w_1$	$w_2$	$w_3$	$w_4$	$w_5$
Low Power mode	0.10	0.20	0.45	0.15	0.10
Emergency mode	0.50	0.10	0.10	0.10	0.20
DSA mode	0.10	0.20	0.10	0.50	0.10
Multimedia mode	0.15	0.50	0.10	0.15	0.10

#### 4.2 Performance Analysis

Initially objective functions are optimized separately and later weighted sum of the objective functions is modelled as MOD function. Figure 1 is showing various forms of QAM (Quadrature Amplitude Modulation) viz. 16 QAM, 64 QAM, and 256 QAM.

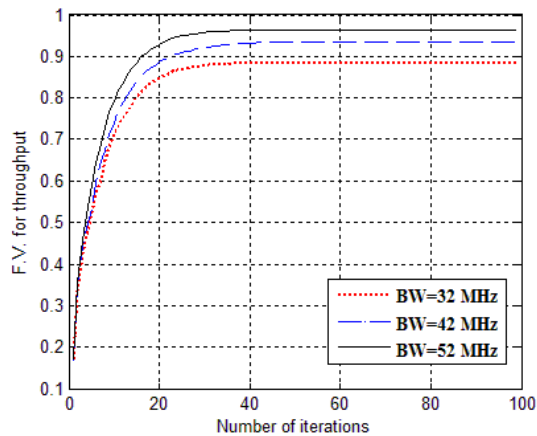


**Figure 1. Optimization of BER**

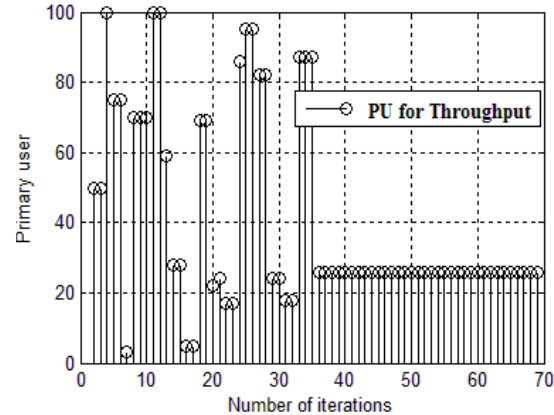


**Figure 2. Selection of PU for Minimum BER**

It shows that as the modulation order of QAM increases the BER of PU decreases. When the modulation order is increased from 16 to 64, the F.V. for BER is reduced by 54% and when modulation order of QAM is increased from 64 to 256, the F.V. for BER is reduced by 50%. The Figure 2 shows the selection of PU when the priority is given to BER. This figure shows that 69<sup>th</sup> user is giving the optimum value of BER for 256 QAM after 27<sup>th</sup> iteration. If SU wants to select the PU on the basis of BER it can select 69<sup>th</sup> user as PU at 28<sup>th</sup> iteration. In Figure 2 from iteration 1 to 27 different PUs are giving optimized values of BER at different iterations hence it shows non-reliability from iteration 1 to 27 but reliability after 27<sup>th</sup> iteration.



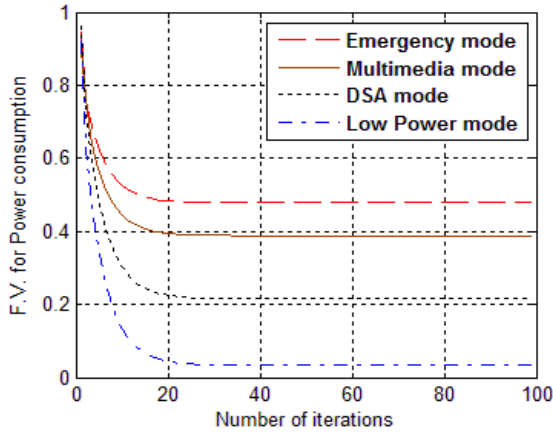
**Figure 3. Optimization of Throughput Maximum**



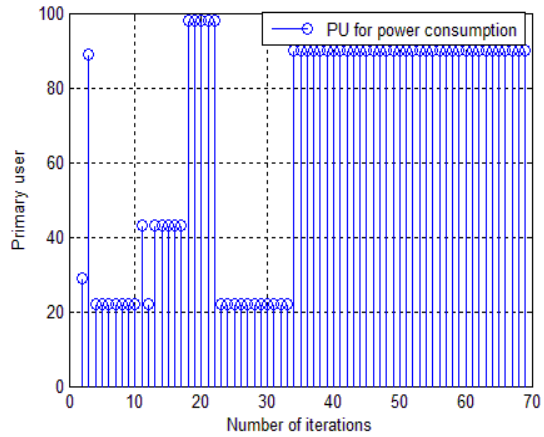
**Figure 4. Selection of PU for Throughput**

Figure 3 shows optimized throughput for different number of channels. Figure 3 is showing that higher F.V. of throughput is obtained for higher number of channels and by using PSO the optimized value of throughput is obtained within the 40 iterations. The figure also shows that for 50 channels the Optimized value of the throughput is 0.64 and on increasing channels, the F.V. of throughput is increased by 6%. And for 150 channels the F.V. of the throughput is increased by 13%. This shows that for higher number of channels the throughput of the PU is

higher. On the basis of throughput the SU will select that PU which has the highest throughput among all PUs. The selection of PU is shown in Figure 4. In this figure the 26<sup>th</sup> PU is selected by SU after 37<sup>th</sup> iteration for 52 MHz bandwidth. The 26<sup>th</sup> PU is continuously giving optimized value for throughput after 36<sup>th</sup> iteration as shown in Figure 4.

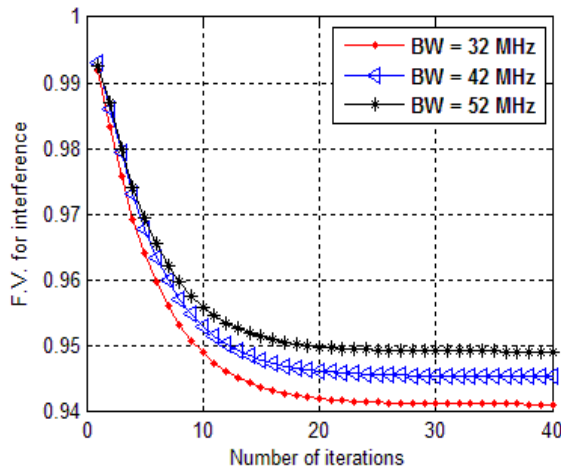


**Figure 5. Optimization of Power Consumption**

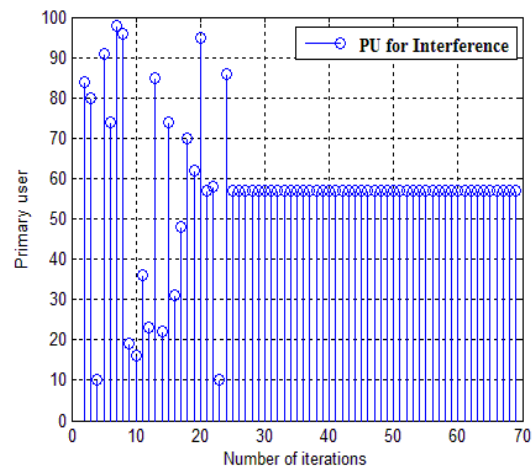


**Figure 6. Selection of PU for Minimum Power Consumption**

Figure 5 shows optimization of power consumption in CR in 4 different modes viz. emergency mode, DSA mode, multimedia mode and low power mode. The F.V. for emergency mode is highest among all modes. The F.V. for multimedia mode is obtained 6% lower than the emergency mode and higher than the DSA mode and low power mode. And the F.V. of low power mode is lowest among all modes. The optimized values are dependent on  $a_1, a_2$  and  $a_3$  described in equation (16) and in Table 3. On the basis of these optimized values, PU is selected. Figure 6 is showing 90<sup>th</sup> PU is selected for minimum power consumption in multimedia mode after 37<sup>st</sup> iteration.

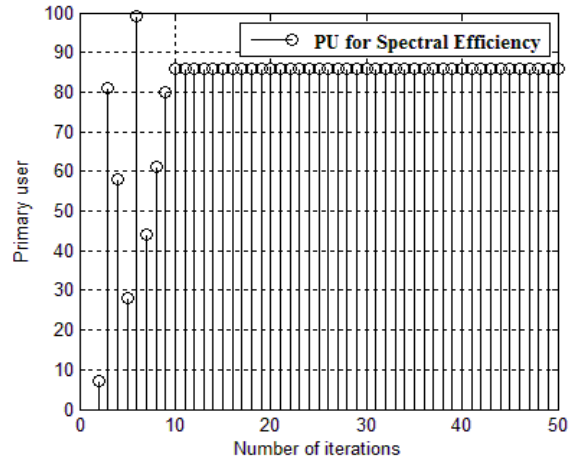
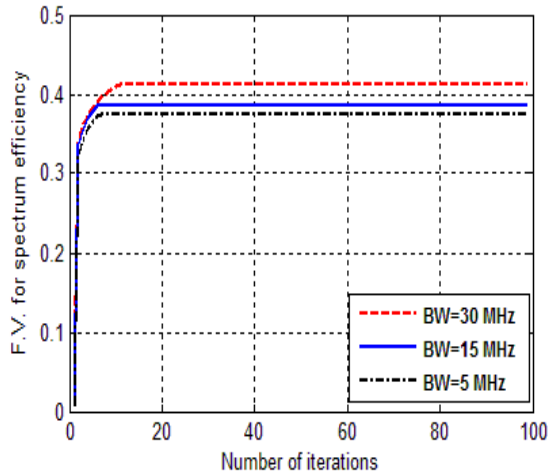


**Figure 7. Optimization of Interference**



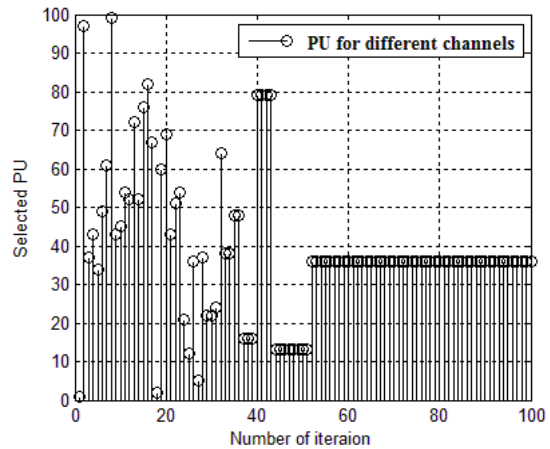
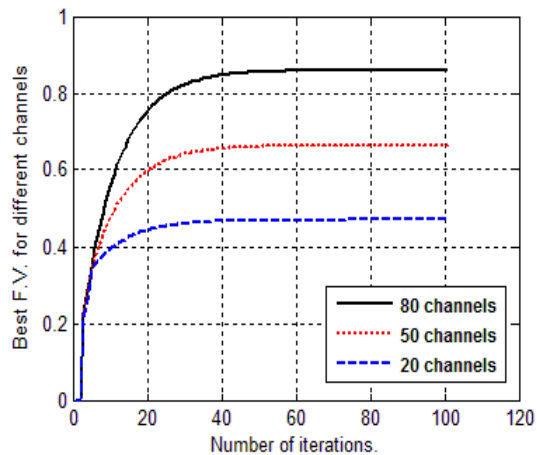
**Figure 8. Selection of PU for Minimum Interference**

The relationship between the maximum value of power and the interference is shown in equation (18) where maximizing signal power reduces interference (inversely proportional). The interference is optimized for different values of signal power *e.g.*, at 24 dBm the F.V. is 0.996 which further decreases when signal power is increased. Here, SU selects that PU which has minimum F.V. of interference for 52 MHz bandwidth. Figure 8 shows that 57<sup>th</sup> PU is selected by SU at 25<sup>th</sup> iteration. 57<sup>th</sup> PU is giving optimized value of interference after 24<sup>th</sup> iteration.



**Figure 9. Optimization of Spectrum Efficiency**      **Figure 10. Selection of PU for Maximum Spectrum Efficiency**

Figure 9 is shows the F.V. of spectral efficiency for different values of bandwidth. The Spectral efficiency defines the rate of information that can be transmitted over a given bandwidth. The maximum and minimum F.V. of spectrum efficiency is obtained at 30 MHz and 5 MHz bandwidth respectively. The Figure b10 is showing that 86<sup>th</sup> user is giving optimized value of spectral efficiency at 10<sup>th</sup> iteration. The optimized value of spectral efficacy has been calculated for 30 MHz bandwidth.



**Figure 11. Cross Layer Optimization for Different Number of Channels**      **Figure 12. Selection of PU for Multimedia Multimedia Mode when 80 Channels are Used**

Total F.V. of cross layer (20) is obtained for proposed PSO algorithm. Figure 11 is showing F.V. of CLO for different numbers of channels. The optimized value is obtained after 52<sup>nd</sup> iteration irrespective of number of channels. Figure 12 presents PU selection when 80 channels are used. The objective functions are considered for multimedia mode. The weights are assigned to the objective functions according to the Table 4. Figure 12 is showing that 36<sup>th</sup> PU is selected after 52<sup>nd</sup> iteration i.e. if SU wants to select PU for multimedia mode then it selects 36<sup>th</sup> PU at 53<sup>rd</sup> iteration which is giving optimal value consistently.

Like any other optimization problem, the challenge of the proposed algorithm is to get a global optimal solution. The proposed algorithm is consistently giving a unique 'PU-ID' (optimal solution), which is claimed as nearly global optimal solution. Further the algorithm gives global optima much earlier as compared to other evolutionary technique like GA [8, 29]. The convergence rate to global optimal solution is 70% higher as compared to GA algorithm. Subsequently there is a proportionate reduction in overhead bits.

## 5. Future Scope of Work

The proposed algorithm in this paper may be extended to other advanced evolutionary optimization technique like Teaching Learning Based Optimization (TLBO) algorithm. PU/SU selection can be further explored for optimal resource allocation in emerging CRN.

## 6. Conclusions

In this paper different objective functions of cross layer (throughput, BER, power consumption, spectrum efficiency and interference) are optimized with the help of PSO algorithm. Which helps in optimization of cross layer in different modes as well as for different numbers of channels. By using the results in CRN the SU selects that PU which gives the best fitness value of objective functions and optimized value of cross layer and hence it optimizes the overall selection process.

## References

- [1] S. Sengupta, "Open Research Issues in Multi-Hop Cognitive Radio Networks", IEEE Communications Magazine, (2013) April, pp.169-177.
- [2] Mitola III, Ph.D. dissertation, "Cognitive Radio: An Integrated Agent Architecture for Software Defined Radio", Royal Institute of Technology (KTH) Stockholm, (2000) May.
- [3] I. Akyildiz, W. Lee, M. Vuran and S. Mohanty, "Next Generation Dynamic Spectrum Access/Cognitive Radio Wireless Networks: A Survey, Computer Networks, vol. 50, no. 13, (2006), pp. 2127–2159.
- [4] N. Shribala, Dr. P. Srihari and Dr. B. C. Jinaga, "Performance Analysis of Data Negation Codes for Cognitive Radio", International Journal of Scientific Engineering and Technology, vol. no.2, no.4, (2013) April, pp. 233-238.
- [5] Z. Zhang and K. Long, "Self-organization Paradigms and Optimization Approaches for Cognitive Radio Technologies: A Survey", IEEE Wireless Communications, (2013) April, pp. 36-42.
- [6] S. A. Taher and A. Afsari, "Optimal Location and Sizing of DSTATCOM in Distribution Systems by Immune Algorithm", International Journal of Electrical Power & Energy Systems, vol. 60, (2014), pp. 34-44.
- [7] H. G. Beyer and H. P. Schwefel, "Evolution Strategies: A Comprehensive Introduction", Journal Natural Computing, vol. 1, no.1, (2002), pp. 3–52.
- [8] C. S. Hyuk and C. T. Tappert, "A Genetic Algorithm for Constructing Compact Binary Decision Trees", Journal of Pattern Recognition Research, vol. 4, no.1, (2009), pp. 1–13.
- [9] K. Price, R. M. Storn and J. A. Lampinen, "Differential Evolution: A Practical Approach to Global Optimization", Springer, (2005).
- [10] A. E. Eiben and J. E. Smith, "Introduction to Evolutionary Computing", Springer, (2003).
- [11] S. Das, A. Biswas, S. Dasgupta and A. Abraham, "Bacterial Foraging Optimization Algorithm: Theoretical Foundation, Analysis and Applications", Foundations of Computational Intelligence, vol. 3, (2009), pp. 23–55.

- [12] M. Dorigo, V. Maniezzo and A. Coloni, "Ant System: Optimization by a Colony of Cooperating Agents", IEEE Transactions on Systems, Man and Cybernetics–Part B, vol. 26, no.1, (2009), pp. 29–41.
- [13] R.V. Rao, V. J. Savsani and D. P.Vakharia, "Teaching Learning-based Optimization: A Novel Method for Constrained Mechanical Design Optimization Problems", Computer-Aided Design, vol. 43 no. 3, (2011), pp. 303–315.
- [14] Z. H. Zhan, J. Zhang, Y. Li and Y. H. Shi, "Orthogonal Learning Particle Swarm Optimization", IEEE Transactions on Evolutionary Computation, vol. 15, no. 6, (2011), pp. 832–847.
- [15] C.-C. Chen, "Two-layer Particle Swarm Optimization for Unconstrained Optimization Problems", Applied Soft Computing, (2011), pp.295-304.
- [16] B.P. Lathi and Z. Ding, "Modern Digital and Analog Communication Systems", Oxford University Press (1998).
- [17] J. G. Proakis, Digital Communications, 4th ed. McGraw-Hill (2000).
- [18] P. Lettieri and M. B. Srivastava, "Adaptive Frame Length Control for Improving Wireless Link Throughput, Range and Energy Efficiency", in INFOCOM, vol. 2, (1998), pp. 564–571.
- [19] K. Hojoong, K. Soomin, S. Hanbyul and L. Byeong Gi, "Inter-cell Interference Management for Next-generation Wireless Communication Systems", IEEE Transaction on Wireless Communication, vol. 10, no.3, (2008), pp. 258-267.
- [20] H. Lu, P. Hong and K. Xue, "High-Throughput Cooperative Communication with Interference Cancellation for Two-Path Relay in Multi-Source System", IEEE Transaction on Wireless Communication, vol. 12, no. 10, (2013), pp. 4840-4851.
- [21] J. Kennedy and R. Eberhart, "Particle Swarm Optimization", Proceedings of IEEE International Conference on Neural Networks; (1995), pp. 1942–1948.
- [22] M.E.H Pedersen and A. J. Chipperfield, "Simplifying Particle Swarm Optimization", Applied Soft Computing, vol. 10, no. 2, (2010), pp. 618–628.
- [23] G. J. Minden, J. B. Evans, L. S. Searl, D. DePardo, R. Rajbanshi, J. Guffey, Q. Chen, T. R. Newman, V. R. Petty, F. Weidling, M. Peck, B. Cordill, D. Datla, B. Barker and A. Agah, "Cognitive Radios for Dynamic Spectrum Access - An Agile Radio for Wireless Innovation", Communications Magazine, IEEE, vol. 45, no. 5, (2007), pp. 113–121.
- [24] A. S. Tanenbaum and D. J. Wetherall, "Computer Networks, 5<sup>th</sup> ed", Pearson Publication (2011).
- [25] L. Zadeh, "Optimality and Non-scalar-Valued Performance Criteria", IEEE Transactions on Automatic Control, vol. 8, (1963), pp. 59–60.
- [26] A. Goicoechea, D. Hansen and L. Duckstein, "Multiobjective Decision Analysis with Engineering and Business Applications", John Wiley and Sons (1982).
- [27] R. Steuer, "Multiple Criteria Optimization: Theory, Computation and Application", Robert E. Krieger Publishing (1989).
- [28] K. Yoon and C. Hwang, "Multiple Attribute Decision Making, and Introduction", Sage Publications (1995).
- [29] M. A. C. Lima, A. F. R. Araujo and A. C. Cesar, "Adaptive Genetic Algorithms for Dynamic Channel Assignment in Mobile Cellular Communication Systems", IEEE Transactions on vehicular technology, vol. 56, (2007), pp. 2685-2696.

## Authors



**Ankur Dixit** is a student of Master of Technology program in Electronics and Communication Engineering at National Institute of Technology Kurukshetra, Haryana, India. He did B.Tech. (Honors) from Dr. Ambedkar Institute of Technology, Kanpur, Uttar Pradesh, India in 2011. His area of research is optimization in Cognitive radios.



**Rajender Kumar** is working as Assistant Professor and in Electronics and Communication Engineering Department at National Institute of Technology (NIT), Kurukshetra (India). He is pursuing Ph.D. in Vertical Handovers (Heterogeneous Wireless Networks). He did B.Tech in Electronics and Communication Engineering (ECE) from Institute of Engineering Technology, Kanpur in 2001 (India). He received M.Tech (Honors) in ECE from NIT Kurukshetra in 2004. He teaches Telecommunication networks, Wireless communication, Statistical modeling and Mathematical models for internet. He has 23 research paper publications in National and International Conferences and Journal. His field of Interest includes Vertical Handovers, Cognitive radio, NGWN challenges & Cross layer design issues. He is Member of IEEE society ('10) and lifetime member of IETE ('06). Rajender Kumar received 'All India Young Scientist Award' for novel research contribution in Information Technology at Bhopal (India) in November, 2007.

