A Hybrid PSO–SA Algorithm for Maximizing the Data Rate for the Cognitive OFDM System

Sami abuishaiba, Mohammed .I.Youssef, ibrahim F. Tarrad, Mohammed .I.Youssef and ibrahim F. Tarrad

Abstract-. Due to the rapid demand for wireless applications and the increased number of the wireless devices, there is absence of available spectrum bands. Therefore, Cognitive Radio (CR) has been nominated as a promising technique because of its ability to enhance the spectrum utilization. Orthogonal Frequency Division Multiplexing (OFDM) is used for the CR networks due to its flexibility of allocate the available spectrum in dynamic environment. This paper proposes an efficient power allocation framework based on a Hybrid Particle Swarm Optimization and Simulated Annealing (PSO-SA) algorithm for downlink OFDM-Based CRN will be applied. This algorithm solves the random initial solution drawback compared with SA algorithm. it gives a good performance by allocating the optimal power for each subcarrier needed to maximize the total SUs data rate. Moreover, the proposed algorithm will be compared with PSO algorithm and SA algorithm. Simulation results showed that the proposed algorithm gives a better data rate compared with the other methods. The parameters which are considered for comparison are maximum transmitted power, number of SUs, number of Primary Users (PUs) and the number of subcarriers.

Keywords- CR; OFDM; Particle Swarm Optimization (PSO); Data rate; Simulated Annealing (SA).

1. Introduction

Over the past few years, CR network has attracted a lot of research attentions. Due to the rapid increase of the modern wireless communication devices, the radio spectrum band became more crowSami abuishaiba, Mohammed .I.Youssef, ibrahim F. Tarradded. It is heavily utilized by the licensed systems at different times and locations [1]. Therefore, CR is proposed as a hopeful approach for solving the scarcity problem of the spectrum band. It used to enhance the spectrum utilization. CR has a dynamically mechanism to management the spectrum and efficiently exploit the vacant portions of the spectrum [2].

Actually, CR networks is based on the spectrum sharing techniques that classified the access technology into:

- Underlay spectrum sharing: SUs share the same spectrum band of the PUs. But their transmission is controlled by interference threshold to assure the QoS for the PUs. Underlay modes can utilize greater bandwidth at the cost of complexity.
- Overlay spectrum sharing: CR users allocate only the vacant available portions. of the spectrum that has not. been assigned by licensed PUs.

This can limits the interference to the licensed network [3]. We consider the underlay mode n this paper,

Orthogonal Frequency Division Multiplexing (OFDM) technique [4] has been considered as an appropriate multicarrier modulation candidate for CR network. In OFDM system, the total spectrum band is divided into a large number of small bands called subcarriers that are completely orthogonal to each other using specific frequencies. Because of different users in this structure use adjacent subcarriers, issues of total capacity improvement and interference suppression become important. OFDM technique outperform FDM technique by reducing the mutual interference between the subcarriers that can save more bandwidth. It also improve the spectral efficiency [5].

A fundamental issue in CR network is to maximize the total data rate for the SUs taking into account the interference constraint and assuring the QoS requirements. Using the Shannon's theorem, capacity. of wireless. channels. can be estimated by transmit power. and channel. gain, as well as noise level and bandwidth. With the constraints: maximum transmit power at the SU Access Point (AP), and Interference threshold at the PU receiver. Power. allocation. strategy. is a critical. functionality.to estimate the total data rate for SU. It can do that by allocating an optimal value of transmit. power to each. sub-carrier, such that the total data rate of the SU can be maximized.

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Recently, a lot of research has been directed towards the power allocation techniques in the CR networks. Where the authors in Ref. [6] used an efficient power allocation strategy by running the classical Water- Filling (WF) method only once, then directly uses a binary algorithm to calculate the final power vector to allocate a certain power level for each OFDM sub-carrier of the signal transmission, that can maximize the SU's overall throughput.

The authors in Ref. [7] focused on the multiple-input multiple-output (MIMO) system for maximizing the SU's throughput. Double antennas were used at all the nodes of the cognitive relay network (CRN). Because of using multiple antennas introduce a space diversity that overcome the multi-path fading problem and hence, maximize the overall throughput and improve the detection capability. the throughput can be maximized by obtaining an optimum value for the relay amplification factor under power constraints.

The authors in Ref. [8] presented a subcarrier and power allocation technique in underlay femto-cell network under some constraints like the total interference to macro-cell users under acceptable threshold. The aggregate throughput of the multiple femto-cell users is maximized by jointly allocating subcarriers to users within a femto-cell.

The authors in Ref. [9] proposed an approach based on PS Algorithm as an optimization method for GFDM-Based underlay CR network. It is used PS algorithm to find the optimal power value needed to maximize the overall throughput for SUs under power and interference constraints. Also, the effect of varying some parameters like the number of PUs, SUs and subcarriers have been studied.

The authors in Ref. [10] proposed power allocation method based on PSO algorithm to maximize the minimal throughput of the SUs under some constraints like the deduced interference from each SU is limited by threshold level and guaranteeing the QoS for all PUs and SUs. Also, they used the capacity pound of SUs under co-channel interference to measure the throughput of the SUs. The minimal throughput among SUs is used to quantify system performance.

In this paper, we focus on an efficient power allocation technique that based on a novel hybrid PSO-SA algorithm to efficiently allocate a certain amount of transmit power to each sub-carrier for OFDM system. It is used to maximize the total data rate for the SUs under some constraints such as: the maximum transmit power at the SU Access Point (AP), and the interference at the PU receiver does not exceed a predetermined threshold level. This algorithm is based on a combination of PSO and SA algorithms that has overcome an important drawback of the SA algorithm that is the need to supply a suitable starting point. Also, the effect of varying some parameters like the number of SUs, the number of the PUs and the number of subcarriers were studied. Numerical results show that the proposed algorithm outperforms SA and PSO algorithms as it gives the maximum data rate of SUs but with more complexity.

The remaining of this paper is organized as follows. The System model is described in Sect. 2. 1. Optimal Scheme is discussed in Sect. 3. Hybrid PSO-SA algorithm presented is in Sect. 4. The simulation results were demonstrated in Sect. 5. Finally, in Sect. 6, conclusion of the obtained results was done.

2. System Model

We have considered a co-existence scenario of SUs radio and PUs radio in geographical location in the underlay CR mode as shown in the Fig. 1. Where the Secondary users (M) are served by the unlicensed Access Point (AP). The primary users (L) are served by the licensed Base Station (BS). Both PUs and SUs are coexisting in the same area. Basically, it is assumed that the available bandwidth for CR transmission W in MHz. this bandwidth has been licensed by the PU(s) 1, 2, ...L, are sensed by the SU(s) 1, 2, ...M system and known to it. The SUs system sense and share all the bandwidth for possible transmission but under some constraints such as:

The interference on the PUs is limited by a predetermined threshold level, to assuring the QoS for the PUs.

The SUs transmit power is limited by the maximum power of their Access Point (AP)

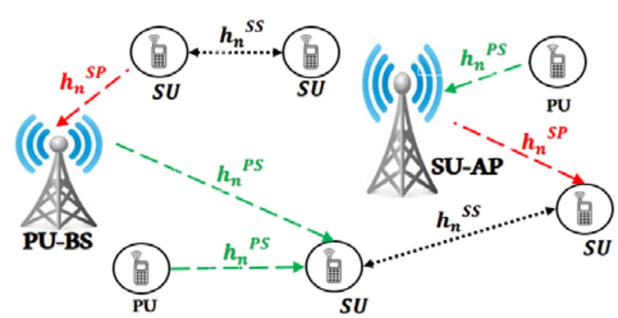

Fig. 1 System model

The accessible bandwidth for SUs transmission is divided into N orthogonal subcarrier based OFDM system. It is assumed that the bandwidth for each SU subcarrier is Ws MHz.

As shown in the Fig. 1, in downlink transmission scenario, there are three instantaneous fading gains: the index h_n^{PS} is the channel power gain from PU to SU receiver. The index h_n^{SP} is the channel power gain from SU to PU, and the index $h_n{}^{SS}$ represents the channel gain of SUs pairs. All these channels fading gain are perfectly known at SU's transmitter.

Due to the coexistence of PU and SU users in side by side sharing the same bands. There are three types of interference in the system. One is introduced by the SUs into the PUs, and the second is introduced by the PUs into the SUs. The third is introduced by the SUs on each other. In what follows, we introduce brief description for the three types of the interference that can be stated as the following:

Interference by SU on PU

Assuming that the transmitted signal s(t) on each single carrier is represented as a rectangular NRZ signal. So, the power density spectrum (PDS) of the n^{th} subcarrier can be written as [11], [12]

$$\emptyset_n(f) = p_n T_s \left(\frac{\sin \pi f T_s}{\pi f T_s}\right)^2 \quad (1)$$

where p_n denotes the amplitude of the total transmit power and T_s is the symbol duration. Let us denote the interference caused by the n^{th} subcarrier of SU to the l^{th} PU's band as $I_n^l(d_n.p_n)$. This interference can be stated by the integration of the power density spectrum of the n^{th} subcarrier across the l^{th} PU band, and can be written as [12]

$$I_n^l(d_n.p_n) = \int_{d_n-W_s/2}^{d_n+W_s/2} |h_n{}^{sp}|^2 \emptyset_n(f)\,df \quad (2)$$

Where d_n represents the frequency distance between the n^{th} subcarrier of the SU band and the l^{th} PU band, and W_s represents the bandwidth occupied by l^{th} PU.

Interference by PU on SU

The PU signal is processed through an M-fast Fourier transform (FFT) function. Hence, the power density spectrum can be expressed by the expected value of the periodogram as [12]:

$$E\{I_n(\omega)\} = \frac{1}{2\pi\bar{N}} \int_{-\pi}^{\pi} \emptyset_{pu}\,(e^{j\omega}) \left(\frac{\sin(\omega-\varphi)N/2}{\sin(\omega-\varphi)/2}\right) d\varphi \quad (3)$$

where $\emptyset_{pu}(e^{j\omega})$ is the PDS of the PU signal and ω denotes the frequency normalized to the sampling frequency. The PU signal has an amplitude P_{pu} [11].

The interference introduced by the l^{th} PU signal to the n^{th} subcarrier is denoted as $J_n(d_n, p_{pu})$, can be results by the integration of the PDS of the PU signal across the n^{th} subcarrier, and can be expressed as [12]:

$$J_n(d_n, p_{pu}) = \int_{d_n-W_s/2}^{d_n+W_s/2} |h_n{}^{ps}|^2 E\{I_n(\omega)\}\,d\omega \quad (4)$$

Interference by SU on another SU

From (1), that stated the power density spectrum (PDS) of the n^{th} subcarrier. The interference introduced by the n^{th} SU signal to another SU is denoted as $INT_n(p_n)$, and can be expressed as [12]:

$$INT_n(d_n, p_n) = \int_{d_n-W_s/2}^{d_n+W_s/2} |h_n{}^{ss}|^2 \emptyset_n(f)\,df \quad (5)$$

Where $h_n{}^{SS}$ is the channel power gain between the SUs terminals.

3. Optimal Scheme

In this paper, our objective is to maximize the total data rate for the Secondary users in the downlink underlay mode. While keeping the interference under some constraints as the SU transmit power does not exceeds the maximum power of the AP, and the introduced interference to PU is limited by threshold for QoS requirements. This maximization problem can be expressed mathematically as:

$$\begin{aligned} &\text{Maximize} && \textstyle\sum_{n=1}^{N}\sum_{i=1}^{M} R_T \\ &\text{Subject to} && \textstyle\sum_{n=1}^{N} p_n \le P_{max} \\ &&& \textstyle\sum_{n=1}^{N} I_n(p_n) \le I_{th} \\ &&& 1 \le n \le N \end{aligned} \quad (6)$$

Where R_T is the total data rate for all SUs, P_{max} is the maximum power of the AP, and I_{th} is the maximum interference threshold. Starting from the Shannon Capacity equation, the data rate can be calculated for the i^{th} CR user over n^{th} subcarrier can be expressed as:

$$R_i(p) = (1 - SEL) W_s \log_2 \left[1 + \left(\frac{|h_n{}^{ss}|^2}{\Gamma\{\sum_{M\neq i} I_n + \sum_{l=1}^{L} J_n + N_0 W_s\}}\right)\right]$$

$$1 \le n \le N \quad (7)$$

where the parameter SEL represents the Spectral Efficiency Loss caused by the addition of CP and can be expressed as:

$$SEL = \frac{T_S + T_{CP}}{T_S} \quad (7)$$

T_S represents the symbol duration and T_{CP} is the symbol duration plus CP. Г is a Bit Error Rate (BER) factor based on the mapper type. It can be stated as [13]:

$$\Gamma = -\ln(5BER/1.6) \quad (8)$$

The total data rate that can be achieved by i^{th}SU that utilizes all the subcarrier N can be denoted as:

$$R_N(p) = \sum_{n=1}^{N} (1 - SEL) W_s \log_2 \left[1 + \left(\frac{|h_n{}^{ss}|^2}{\Gamma\{\sum_{M\neq i} I_n + \sum_{l=1}^{L} J_n + N_0 W_s\}}\right)\right] \quad (8)$$

N_0 referred to the noise power and W_s is the bandwidth of the n^{th} subcarrier.

Finally, the total data rate that can be achieved when all SUs M use all subcarriers N, is formulated as:

$$R_T(p) = \sum_{i=1}^{M}\sum_{n=1}^{N} (1 - SEL) W_s \log_2 \left[1 + \left(\frac{|h_n{}^{ss}|^2}{\Gamma\{\sum_{M\neq i} I_n + \sum_{l=1}^{L} J_n + N_0 W_s\}}\right)\right] \quad (9)$$

4. Hybrid PSO-SA algorithm

The Hybrid proposed algorithm is a combination between the population based stochastic Particle Swarm Optimization (PSO) algorithm and a heuristic evolutionary probabilistic SA algorithm, this hybrid algorithm is called PSO-SA algorithm.

This section presents a brief description about the three algorithms: PSO, SA and the hybrid PSO-SA algorithm as the following:

5. PSO Algorithm

PSO is presented by Kennedy and Eberhart in 1995. It is inspired on social manners of fish schooling or bird flocking. The algorithm use the shared information to examines for the optimum value among a set or swarm shaped by conceivable solutions of the problem, which are so-called particles. It outperforms the traditional optimization methods, as it doesn't involve any gradient information about the problem to be optimized. The PSO method starts by setting randomly each. particle with random velocity and position in the search space. Each particle velocity is updated as stated in [14], [13]:

$$V_{i.j}^{t} = \left[w.V_{i.j}^{t-1} + c_1.rand_1.\left(Pbest_{i.j} - P_{i.j}^{t-1}\right) + c_2.rand_2.\left(Gbest_i - P_{i.j}^{t-1}\right)\right]F_c \qquad (10)$$

and the particle position is updated through the search space according to the following equation:

$$P_{i.j}^{t} = P_{i.j}^{t-1} + V_{i.j}^{t} \qquad (11)$$

Where F_c represents the contraction coefficient that can be calculated as the following:

$$F_c = \frac{2}{\left|2-\emptyset-\sqrt{\emptyset^2-4\emptyset}\right|} \qquad (12)$$

With $\emptyset = C_1 + C_2 \geq 4$

c_1 and c_2 are the acceleration constants, and the dimension of search space problem is represented by j, $rand_1$ and $rand_2$ are random numbers uniformly distributed over the range [0, 1]. Parameter w denotes the inertia weight factor, specifies the contribution of the previous velocity with the new one, it is updated at each iteration t by the following [15] :

$$w = w_{max} - \frac{w_{max}-w_{min}}{I_{max}}t \qquad (13)$$

where I_{max} is the maximum number of iterations, w_{max} and w_{min} are maximum and minimum values of inertia respectively.

Each particle of the swarm is analysed by evaluating the fitness function/system's data rate and the one that produces the best position fitness value through the iterations, i.e. best local solution, and is called Pbest (Personal best). The best position in the swarm is defined as Gbest (Global best). The Pbest of all of the particles are compared. If the new Gbest value is better than the old Gbest, value, then set the Gbest as the current global best position.

6. SA Algorithm

In fact, SA was proposed by Kirkpatrick, S., Gelatt, C.D., and Vecchi, M.P. it is a heuristic evolutionary probabilistic method based on the fundamentals of thermodynamic systems. It can evolve a single solution without retaining recent or past information about the process [16]. Initially SA algorithm is used to find the local minimum and to solve complex and large combinatorial problems. SA has the ability to locate a quasi-optimal solution in high dimensional and non-linear search spaces, so it has been successfully used in a great variety of technical and scientific areas.

Basically, the SA algorithm is inspired on the annealing process of a metal. The annealing process is a thermal process to obtain the low energy states of substance in heat bath. This process happens in two steps. Firstly, the solid material is heated until it melts. Secondly, it slowly cooled down with a control mechanism until it solids back. The algorithm starts with choosing an initial random solution. A suitable mechanism is done to generate a new solution neighbor to the initial solution. The cost function f of the two solutions is estimated. If the cost function of the new solution is lower than the initial solution. It is replaced by the new solution. But, if the cost function of the new is more, the new solution is replaces the current solution with an acceptance probability function:

$$\rho = exp\left(\frac{-(f[j]-f[i])}{T}\right) \qquad (14)$$

Where $f[i]$ is the cost function of the current state and $f[j]$ is the cost function of the generated state. T is a control pareameter. It represents the temperature value in the annealing process. It is noted that, the acceptance function reveals that the small increases in cost function f are better than large increases. In the SA algorithm, the initial temperature T_0 is kept high, where the algorithm does not get trapped in a local minimum. But, when T is high, the generated neighbors are mostly accepted. The algorithm goes on by producing a certain number of neighbors at each temperature. The search process of SA algorithm is controlled by the cooling schedule. By drooping the temperature parameter gradually through a colling schedule, the algorithm leads to a near optimal solution.

7. Hybrid PSO-SA Algorithm

In this algorithm, the hybridization of PSO algorithm and SA algorithm are combined in an optimization technique in order to search for the local optimal solution that is the optimal power value needed for each subcarrier to maximize the fitness function/system's data rate. The SA algorithm starts by using a random initial solution that may be not the suitable solution. The hybrid PSO-SA algorithm will overcome an important drawback of the random initial value for the SA algorithm. The hybrid algorithm applied by firstly running the PSO algorithm to generate a suitable initial solution as a starting point for a SA algorithm.

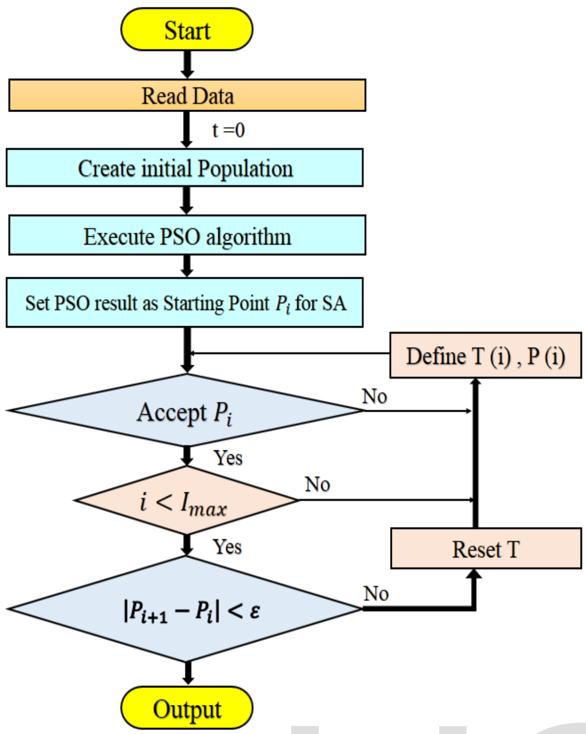

Fig. 2 Flow chart of Hybrid PSO-SA algorithm

The proposed hybrid PSO–PA algorithm is applied to allocate the optimal power value for each subcarrier that can maximizes the total data rate for all SUs. As shown in Fig. 2, the hybrid PSO–SA steps can be summarized as the following steps [17]:

Step 1: Define the input data such as the swarm size, the weight factor, the acceleration constants, the maximum number of iterations (Imax), specify the cooling schedule, a stopping criteria and set t = 0.

Step 2: Initialization: Run PSO algorithm, Set the output of PSO as the initial power value P_i for the SA algorithm.

Step 3: Set the iteration counter to be t = 0. SA algorithm starts using the initial solution P_i generated from PSO algorithm.

Step 4: Evaluate the objective function $E(P_i)$ using simulation model.

Step 5: Perturb P_i to evaluate a neighbouring power vector P_{i+1}.

Step 6: Evaluate the objective function of the neighbouring solution $E(P_{i+1})$ using a simulation model.

Step 7: If $E(P_{i+1}) < E(P_i)$, set P_{i+1} as the new current solution and set t = t+1.

Step 8: Else if $E(P_{i+1}) > E(P_i)$, create a random number r in the range (0, 1), then accept P_{i+1} as the new current solution with a Probability $e^{\left(\frac{-\Delta}{P}\right)} \geq r$ Where $\Delta = E(P_{i+1}) - E(P_i)$, and set t = t+1. Else, go to step (5).

Step 9: If $|P_{i+1} - P_i| < \varepsilon$, and P is small. Satisfying the constraints STOP. Else, go to step (10).

Step 10: Reduce the system power according to the cooling schedule.

Step 11: Terminate the algorithm if the iteration time reaches the maximum value. Display the best objective function value (system's transmission data rate).

Simulation Results

In this Section, the performance evaluations of hybrid PSO-PS as the proposed algorithm are introduced using the system parameters indicated in Table.1. All channel power gains are assumed to be Rayleigh distribution with PSD of AWGN of zero mean and variance σ^2 equal 10^{-6}. Each PU has a power assumed to be equal 0.01W. The parameters of PSO algorithm will set as swarm size equal 50. The acceleration factors c1 and c2 and inertia weight factor are equals to 2, 2 and 0.8 respectively. Also, the SA algorithm parameters are the initial temperature equals 100 k, the exponential annealing scheduling equals to $P * 0.95^t$, the initial solution, i.e. P_i will be generated from output of the PSO algorithm. As for the stopping criteria, all tolerances set to be = 10^{-6} .

TABLE 1. SIMULATION PARAMETERS, [13].

parameter	Index	OFDM system
PUs Number	L	2
SUs Number	M	8
Modulation Type		16 QAM
subcarriers Number	N	32
Length of cyclic prefix	Ncp	16 samples
Number of sub-symbols	V	9
Threshold interference	I_{th}	1mW
System band width	W	12.8 MHz
Subcarrier band width	Ws	0.4 MHz
Symbol duration	Ts	1/ Ws

Fig. 3 studies the total data rate for the SUs with the maximum transmitted power of the AP for OFDM system using a hybrid PSO-SA algorithm as the proposed scheme compared with PSO and SA Algorithms. Where this Figure shows that when increasing the value of Max. transmitted power of the SU base station (AB), the total data rate is increases until it reaches to the saturation level.

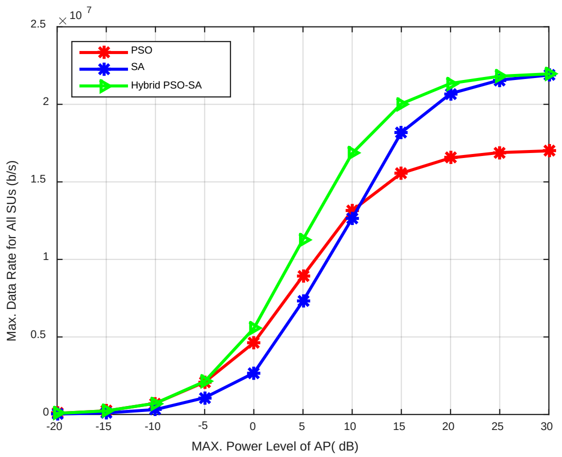

Fig. 3 Max. Data Rate for all SUs ver SUs Max. Power Level of AP for OFDM systems using PSO, SA and PSO-SA algorithms.

Form Fig. 3, it is observed that the proposed Hybrid PSO-PS algorithm outperforms the PSO and SA algorithm. Where the Hybrid algorithm combined the advantages of the two algorithms PSO and SA, and overcame the drawback of using a random initial solution. It is used efficiently to locate the optimal power value that maximizes the total data rate for all SUs. It is observed that, at the maximum transmitted power of the AP equals 5 dB. The Hybrid PSO- PS algorithm outperforms the PSO algorithm by about 20 % increasing in the total data rate. Also, when it compared by the SA algorithm. It is observed the Hybrid algorithm outperforms the SA algorithm by about 35 % increasing in the total data rate.

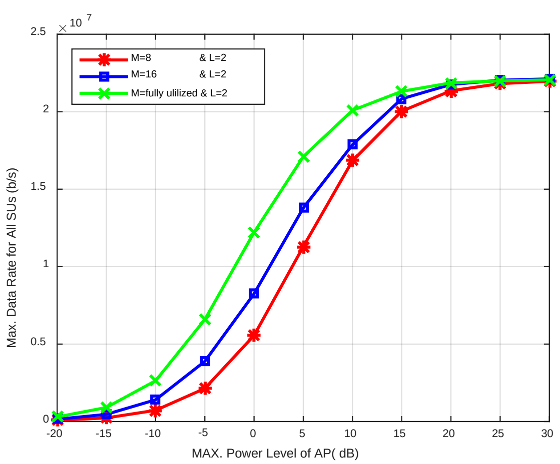

Fig. 4 The effect of varying the number of the SUs (M) with constant number of the PUs (L = 2 users).

Fig. 4 investigates the effect of varying number of the SUs on the total data rate for all SUs. As shown in this Figure, at the maximum transmitted power of the AP equals 5 dB. It is observed that the total data rate for all SUs is increased by about 18 % when we changed the number of he SUs from 8 to 16 users. Also, when doubling the number of the SUs from 16 to 30 users, the total data rate is increased by about 19.4% at this point.

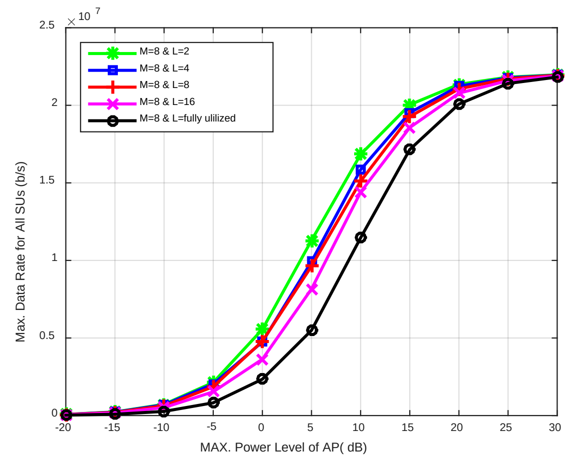

Fig. 5 The effect of varying the number of the PUs (L) with constant number of the SUs (M = 8 users).

Fig. 5 shows the effect of varying the number of PUs on the total data rate for all SUs. As shown in this Figure, at the maximum transmitted power of the AP equals 5 dB. And increasing the number of PUs from 2 to 4 users, the total data rate decreased by a value reached about 12%. Also, when the number of PUs changed from 4 to 8 users, the data rate will be decreased by about 3%. until the system reached to the fully utilized by the 32 PUs, the total data rate is decreased by about 32% at the same 5 dB.

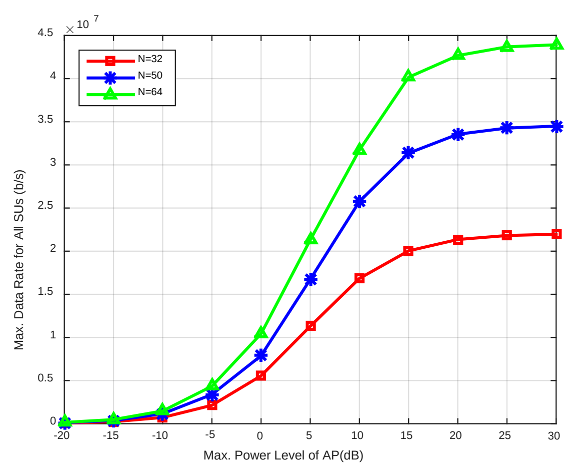

Fig. 6 The effect of varying the number of the subcarriers (N) at L=2 PUs & M= 8 SUs.

Fig. 6 presents the effect of varying the number of subcarriers on the total data rate for all SUs. From this figure, it is observed that increasing the number of subcarriers leads to increase the total data rate for all SUs. In fact, at the maximum transmitted power of the AP equals 5 dB, and when we increase the number of subcarriers from 32 to 50 subcarriers, the total data rate is increased by about 32.4 %. Also, when the number of subcarriers is changed from 50 to 64 subcarriers, the total data rate is increased by about 21.5 % at the same power value 5 dB.

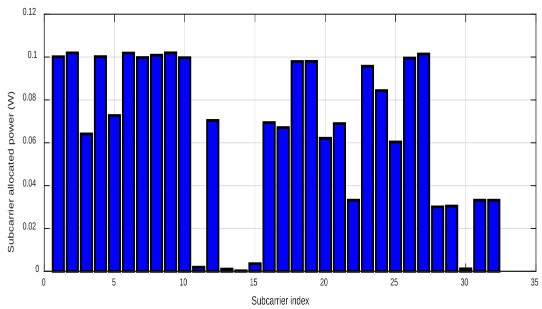

Fig. 7 Subcarrier allocated power at Max. Power Level of AP equal 5 dB.

Fig. 7 investigates the power allocated to each subcarrier at P_{max} = 5dB. Where the PSO-SA algorithm tries to allocate an optimal power value for each subcarrier for maximizing the total data rate for the SUs. The power allocated to some subcarriers is very small as two of them are assigned for two PU and so limited allocated power on them to assure the QoS requirements.

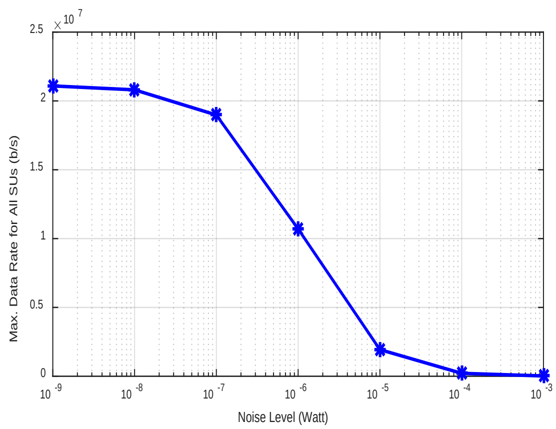

Fig. 8 Max. Data Rate for all SUs verSUs Noise level at P_{max} = 5dB.

Fig. 8 presents the maximum data rate for the SUs under varying the noise level at P_{max} = 5dB. Where the data rate at low noise level will be high and by increasing the noise level, the total data rate will be reduced until the noise level will be high and the total data rate will be destroyed

8. Conclusion

Orthogonal Frequency Division Multiplexing (OFDM) is used for the CR networks due to its flexibility of allocate the available spectrum in dynamic environment. This paper proposed an efficient power allocation technique based on a Hybrid Particle Swarm Optimization and Simulated Annealing (PSO-SA) algorithm for downlink OFDM-Based CRN. This algorithm solved the random initial solution drawback compared with SA algorithm. it helped to find the optimal power for each subcarrier needed to maximize the total SUs data rate. Moreover, the proposed algorithm was compared with PSO algorithm and SA algorithm. Simulation results showed that the proposed algorithm gives a better data rate compared with the other methods. Moreover, the system performance under varying the SUs number, the PUs number and the subcarriers number had been studied for increasing the total data rate for SUs. Furthermore, the performance of the proposed hybrid algorithm improves with the increase of complexity and size of the system.

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