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ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 10 (5): 955-964, 2011
ISSN 1812-5638 / DOI: 10.3923/itj.2011.955.964
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Modified Particle Swarm Optimization and Genetic Algorithm Based Adaptive Resources Allocation Algorithm for Multiuser Orthogonal Frequency Division Multiplexing System

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Abstract: In this study, we divided adaptive resources allocation for multiuser OFDM system into two continuous parts: (1) subcarrier allocation and (2) power allocation and proposed a modified particle swarm optimization (PSO and GA) to deal with this adaptive resources allocation for multiuser OFDM system in three main scenarios: (1) multiuser unicast services; (2) multiuser multicast services at low and constant rate and (3) multiuser multicast services at high rate. Simulation results show that adaptive resources allocation for multiuser OFDM system can be done by normal PSO and modified PSO in these three scenarios. Comparing the allocation scheme of both algorithms, this modified PSO (PSO and GA) can greatly improve performance of adaptive resources allocations.

Key words: Particle swarm optimization, genetic algorithm, multiuser, orthogonal frequency division multiplexing, adaptive resources allocation, fairness, convergence rate

INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is considered as one of the most promising transmission techniques in wideband wireless systems because of its bandwidths efficient performance in combating multipath fading as well as Inter Symbol Interference (ISI) (Van Nee and Prasad, 2000).

To meet the increasing users demand for high data rate, allocation of appropriate frequency spectrum as well as efficient usage of channel frequencies have became a very vital issue. OFDM, like other wireless systems requires the proper allocation of the limited resources for specified scenarios like: multiuser unicast services; multiuser multicast services at low and constant rate; multiuser multicast services at high rate and so on. There have been a lot of studies on resource allocation in OFDM systems. It was proved by Zhang and Letaief (2002) that the system spectral efficiency can be enhanced significantly by adjusting the allocation of subcarriers, bit rate and power in accordance with the user's channel state. Wong *et al*. (2004) and Jianwei Huang *et al*. (2009), there are some algorithms proposed to resolve the resource allocation problem in OFDM systems. Because the solution space of this allocation problem is too large and conventional deterministic algorithm cannot solve it well, evolutionary algorithm is attracting increasing attention especially GA and PSO. The Genetic Algorithm (GA) is based on the nature of survival of the fittest. It randomly generates the population, using crossover and mutation methods and evaluates chromosomes by a well-defined fitness function. GA performs well for finding an optimal solution but constrained by its own shortage: low convergence rate. The Particle Swarm Optimization (PSO) algorithm was first introduced by Kennedy and Eberhart (1995) as an alternate tool to Genetic Algorithms (GA) and gained a lot of attention in various optimal control system applications. Comparisons between PSO and the GA were done analytically (Hassan *et al*., 2005). Some studies of OFDM resource allocation have been done basing on GA and PSO. Liu *et al*. (2009) has proved GA method outperform conventional method in resource allocation of OFDM system. Then, Ahmed and Majumder (2008) introduced Particle Swarm Optimization (PSO) which is a better algorithm than Genetic Algorithm (GA). Considering PSO's advantages, performances of adaptive resource allocation of OFDM can be improved but constrained by its own shortage: PSO has a more global searching ability at the beginning of the run and a local search near the end of the run (Kennedy and Eberhart, 1995). Therefore, while solving problems with more local optima, there are more possibilities for the PSO to explore local optima at the end of the run. In this study, considering the complementary between advantages and disadvantages of GA and PSO, we proposed a modified PSO which is a kind of combination of PSO and GA in updating period in order to make the algorithm get out of the local optima and

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considered as a better one. We use this modified PSO as a global search algorithm to find near optimal solution of adaptive OFDM resource allocation and get a better performance in simulation results.

SYSTEM MODEL

A multiuser OFDM system is shown in Fig. 1. All channel information, subcarrier gain according to each user and all user information are sent to resource allocation algorithm in the PSO optimizer. The PSO optimizer contains two resource allocation optimizations: subcarrier allocation and power allocation. The result of the optimization is this OFDM resource allocation scheme and this resource allocation scheme is updated as fast as the channel information is collected. In this study, perfect instantaneous channel information is assumed to be available at the base station and the subcarrier and power allocation information is sent to each user by a separate channel.

In this study, let we consider an OFDM system having K users want to be served simultaneously and N subcarriers. The system allocates a subset of N subcarrier to a particular user and determines the transition power per each assigned subcarrier on downlink transmission (Fig. 1).

As Fig. 1 illustrates, there is a PSO optimizer module in this OFDM system model. This module is the core of resource allocation and the job of it is find an optimization combination (resource allocation solution) base on the input information (Users, subcarriers and matrix h) and optimization algorithm of resource allocation.

The result of resource allocation is to meet a specific system requirement by how each subcarrier mapped to a particular user and determined how much the transmission power per each assign subcarrier has. The system requirement is not the same in different scenarios. In this study, we consider three scenarios: (1) multiuser unicast services; (2) multiuser multicast services at low and constant rate; (3) multiuser multicast services at high rate. Mathematically, the optimization problem in these three scenarios is formulated as follows:

The capacity of each client after allocation is:

$$R_i = \sum_j \log_2\left(1 + \frac{P_{i,j} \times (h_{i,j} H_{i,j})^2}{N_0 \times B \times Q^{-1}(Pe_{i,j})}\right) \tag{1}$$

where,

$$Q(x) = 2/\sqrt{\pi}\int_x^{\infty} e^{-\frac{t^2}{2}} dt$$

and here Q^{-1} is the inverse Q function, the matrix h is a matrix mapping users impulse responses to subcarriers, B is the band width, P_i is transition power of client i, N_0 is the power spectral density of noise, P_e is BER for each client and H is a matrix shows each subcarriers occupied by which users as:

$$H_{i,j} = \begin{cases} 1, & \text{if channel j is occupid by user i} \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

Fairness of clients is:

$$F = \frac{\left(\sum_i R_i\right)^2}{\sum_i (R_i^2)} \tag{3}$$

- System requirement of multiuser unicast services (MCSPF) is maximizing the total capacity:

$$\max\left(\sum_i \sum_j \log_2\left(1 + \frac{P_{i,j} \times (h_{i,j} H_{i,j})^2}{N_0 \times B \times Q^{-1}(Pe_{i,j})}\right)\right) \tag{4}$$

- System requirement of multiuser multicast services at low and constant rate (MPF) is making users allocated fairly in capacity as much as possible:

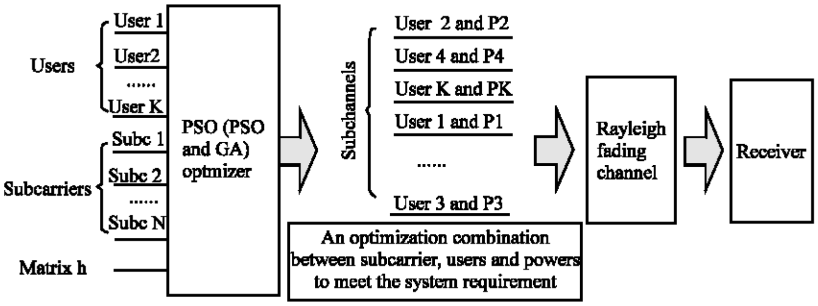

Fig. 1: OFDM system resource allocation model

$$\max\left(\frac{\left(\sum_i\sum_j \log_2\left(1+\frac{P_{i,j}\times\left(h_{i,j}H_{i,j}\right)^2}{N_0\times B\times Q^{-1}\left(Pe_{i,j}\right)}\right)\right)^2}{\sum_i\left(\sum_j \log_2\left(1+\frac{P_{i,j}\times\left(h_{i,j}H_{i,j}\right)^2}{N_0\times B\times Q^{-1}\left(Pe_{i,j}\right)}\right)\right)^2}\right) \quad (5)$$

- System requirement of multiuser multicast services at high rate (MMC) is enhancing the capacity of the lowest capacity user in all users:

$$\max\left(\min\left(\sum_j \log_2\left(1+\frac{P_{i,j}\times\left(h_{i,j}H_{i,j}\right)^2}{N_0\times B\times Q^{-1}\left(Pe_{i,j}\right)}\right)\right)\right) \quad (6)$$

All of these system requirements:

$$\begin{aligned}
\text{subject to: } & C1: \sum_{i=1}^{K} H_{i,j}p_{i,j} = P_{total}/N \\
& C2: p_{i,j} \geq 0 \text{ for all } i,j \\
& C3: H_{i,j} = \{0,1\} \text{ for all } i,j \\
& C4: \sum_{i=1}^{K} H_{i,j} = 1 \text{ for all } j \\
& C5: BER_i <= BER_i^{lim} \text{ for all } i
\end{aligned} \quad (7)$$

where, N is the number of available subcarrier in this system; represents the lowest bit error rate of user i. There are six constraints C1-C6, the meanings of these are: C1: transition power in each subcarrier is allocated equally; C2: transition power is positive; C3 and C4: each subcarrier can only be allocated to one specific user in one allocation; C5: BER of each user isn't over the lowest BER requirement.

PSO AND GA-BASED MULTIUSER POWER AND BIT ALLOCATION

The purpose of resource allocation at the base station is to allocate intelligently the limited resources, e.g., total transmit power and available frequency bandwidth, among users to meet users' service requirements. Adaptive resources allocation has been shown to achieve higher system performance than static resource allocation and is becoming more critical in current and future wireless communication systems as the user data rate requirements increase. Furthermore, the subcarrier allocation problem of multiple users has many different permutations, thereby making the solution space very large. Unlike other algorithms, the evolutionary approaches can handle large solution space without any performance degradation. In this study, we creatively divide this resource allocation into two continuous part and module this OFDM system in PSO framework. Basing on this module we optimize OFDM resource allocation by PSO and modified PSO in three scenarios constrained by a total transmit power or fairness of clients and the subcarriers are allocated to different users according to the dynamic channel state information. Each user is allocated one or more subcarrier provided that only one user can use one subcarrier.

A modeling method of multiuser OFDM system basing on framework of PSO: In an OFDM system, there are three elements we care: (1) user, (2) subcarrier and (3) power. Before the power allocation we must known the map between users and sub carriers i.e., the matrix h. Using only one step allocation process for these elements, it must be complex and become an multi-objective optimization, so in order to make this question simple and clear we creatively divide the whole allocation process into two parts: In the first part, we want to get suboptimal solution of the mapping between subcarriers and users. This part is an integer optimization problem. When this mapping is settled, according to matrix h we can get each user's impulse response in each subcarrier. Then the second part allocation begins: The purpose of the second part is to get the suboptimal solution of power for each user basing on the first part's subcarrier mapping. The second part is a continuous optimization problem. Because two part of allocation have to solve different kind of optimization problem, the particle structure must be modeled respectively as follows:

- The particle structure in the first part of allocation (Fig. 2).
- The particle structure in the second part of allocation (Fig. 3).

Fitness function and constraint function of the three scenarios in PSO: Each service has one ultimate goal but there always are constraint conditions must be considered. The capacity of client i is as formula (1)

- **Service 1:** Multiuser unicast services. In this scenario, the system requirement is that make sure we have the maximum of total capacity, i.e. the system requirement in Fig. 4 flowchart is the maximum of total capacity. Fitness function in the scenario is as follows:

$$\text{fitness} = \sum_i R_i - c_3 \times \left|\min\left(0, P_{total} - \sum_i P_i\right)\right| - c_4 \left|\max\left(0, 1 - \left(\left(\sum_i R_i\right)^2 \Big/ \sum_i (R_i^2)\right)\right)\right| \tag{8}$$

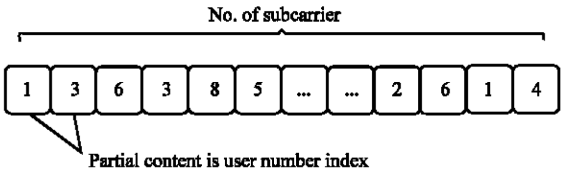

Fig. 2: Particle structure of subcarrier allocation

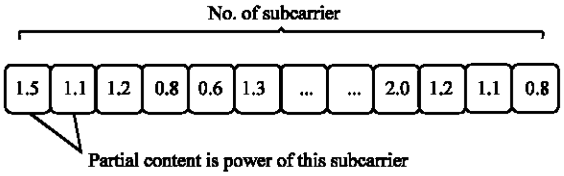

Fig. 3: Particle structure of power allocation

- **Service 2:** Multiuser multicast services at low and constant rate. In this service, the system requirement is that make sure we have the best fairness of clients, i.e., the system requirement in Fig. 4, flowchart is the best fairness of clients. Fitness function in this scenario is as follows:

$$\text{fitness} = \left(\left(\sum_i R_i\right)^2 \Big/ \sum_i (R_i^2)\right) - c_5 \times \left|\min\left(0, P_{total} - \sum_i P_i\right)\right| \tag{9}$$

- **Service 3:** Multiuser multicast services at high rate. In this service, the system requirement is that make sure we have the maximum of the minimum capacity client i.e., the system requirement in Fig. 4 flowchart is the maximum of the minimum capacity client. Fitness function in this scenario is as follows:

$$\text{fitness} = \min(R_i) - c_6 \times \left|\min(0, P_{total} - \sum_i P_i)\right| \tag{10}$$

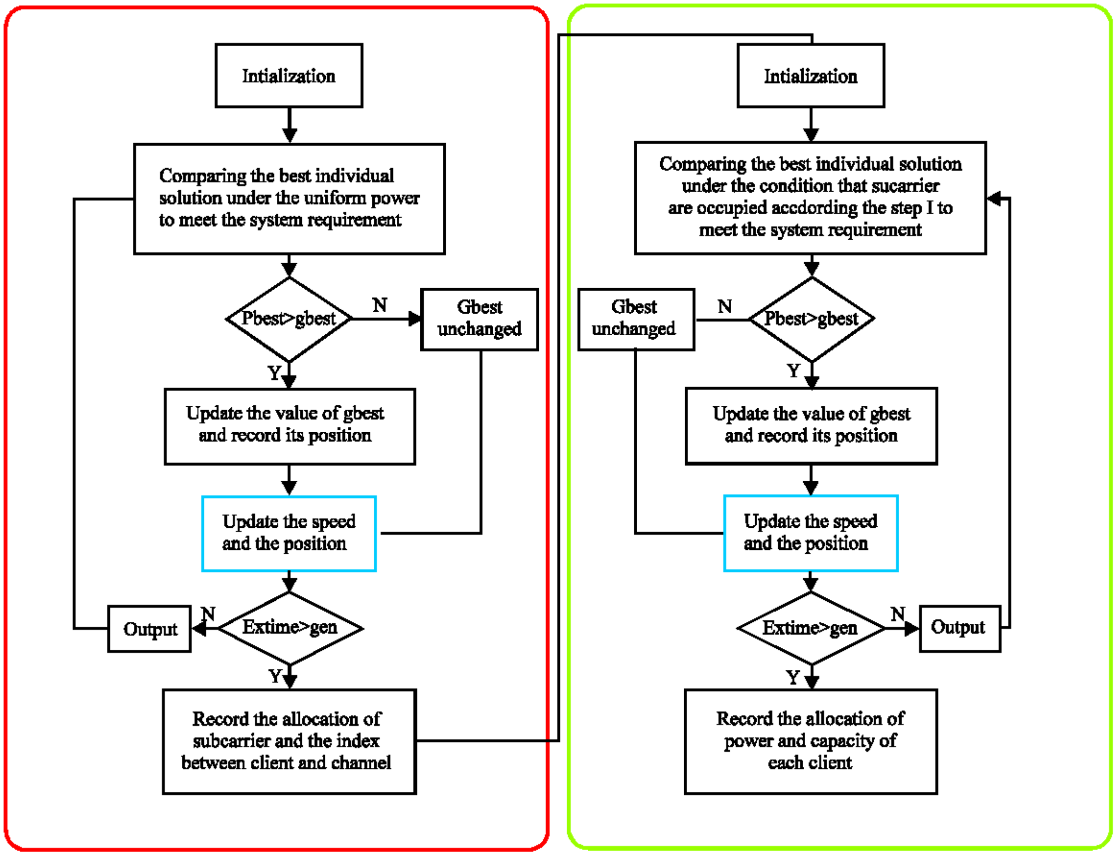

Fig. 4: Flowchart of allocation process

Table 1: Fitness and constraint function of three services

Fitness function		Constraint function	
Scenario 1 (MCSPF)	Total capacity	Scenario 1 (MCSPF)	Fairness, power
Scenario 2 (MPF)	Fairness	Scenario 2 (MPF)	Total power
Scenario 3 (MMC)	Minimum capacity	Scenario 3 (MMC)	Total power

Table 1 shows you goal functions and constrains function in each service. And c_3-c_6 coefficients are constraint coefficients.

Allocation for this model of multiuser OFDM system: We use modified PSO to find the optimum arrangement of the users as well as subcarriers. The flowchart of this allocation has shown in Fig. 4.

The process of this allocation has two parts: one is subcarrier allocation (the red part); the other one is power allocation (the green part). In the first part, we don't use water-filling method because of the fairness among clients. We want to make sure all the clients can use the channel at a relatively even level, so, $P_i = P_{total}/k$, P_{total} is the total power constraint.

- **Initialization:** Matrix h, particles initialization
- Comparing with the best individual solutions to find a best subcarrier allocation particle to meet the system requirement. (Uniform power is an assumption and power allocation is in the second part; System requirement: it is different in different scenarios)
- If pbest>gbest
  gbest←pbest
- Else
  gbest unchanged
- Particles update
- Output

Basing on the first allocation's result, the second part power allocation begins. In the second part, as the mapping between users and subcarrier is settled we try to optimize transmission power.

- **Initialization:** Load the result of first optimization, matrix h, particles initialization
- Comparing with the best individual solutions to find a best power allocation particle to meet the system requirement. (Subcarriers have already been allocated to each client according the solution of subcarrier allocation part. System requirement: it is different in different scenarios)
- If pbest>gbest
  gbest←pbest
  Else
  gbest unchanged
- Particles update
- Output

Through these two parts of resource allocation, we can get our OFDM resource allocation scheme as a sub-optimal solution. In the whole allocation, the PSO updating process of particles is modified by GA updating (Fig. 5).

The blue part in the middle of the allocation flow chart we call it updating part, in this part we made a combination of PSO and GA. In order to get out of the local optima, we use GA algorithm to enhance the diversity of this particle group as follows:

- First of all we pick two of those particles for special updating (GA updating)
- Produce a random value between 0-1 named $rand_1$
- If $rand_1$>0.8 (we can also change this threshold value for particular scenarios), particles updating use GA algorithm update step 1 (crossover)
  Else
  Particles update as the normal PSO algorithm. Then next loop begins

- Produce a random value between 0-1 named $rand_2$
- If $rand_2$>0.9 (we can also change this threshold value for particular scenarios), particles updating use GA algorithm update step 2 (mutation). Then next loop begins
  Else

Next loop begins without mutation.

More detail about this PSO and GA algorithm updating I will describe in particles. Figure 6 represents a generation of particles is going to update.

These are particles concluding information for specified scenarios. Updating processes as follows:

- **Selection:** Select two of those particles for crossover randomly
- **Crossover:** these two particles crossover with the probability p_1, then two new particles produced. In this study, particles crossover by half
- **Mutation:** Each digit of new particle mutates with the probability p_2 and another two new particles produced. The method of Mutation: turn decimal data into binary data. Each digit place of the binary data may turn into its opposite side (0-1, 1-0) according to a given probability. Then turn this mutated data back into decimal data. This process called mutation in this study

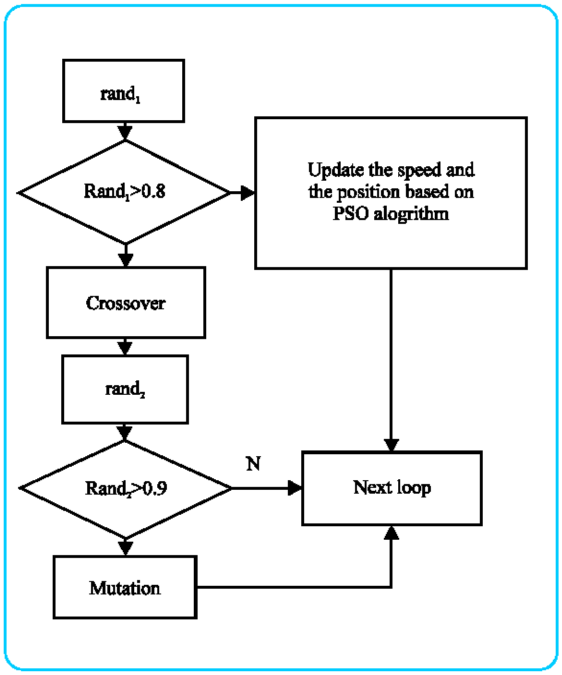

Fig. 5: Updating process

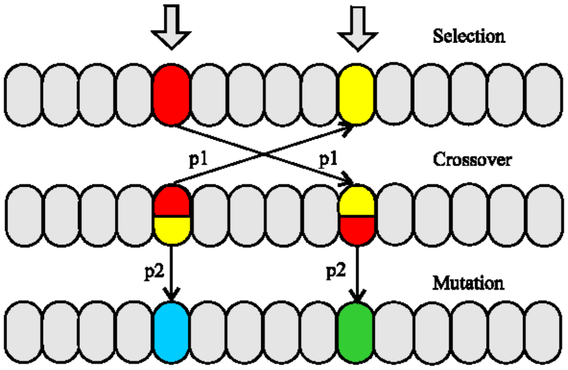

Fig. 6: Crossover and mutation

SIMULATION RESULTS

Simulations in the three scenarios: In this section, particle swarm optimization as well as the proposed algorithm-modified PSO have been applied to OFDM resources allocate along with some relative comparative [illegible]res. The channel has been assumed here as the quasi static. Total transmit power constraint P_{total} is known. In this simulation, 128 subcarriers have been prepared for 16 users. Using the subcarrier allocation the subcarriers have been allocated as needed and we use the power allocation to finish the whole allocation. We assume the modulation type in this OFDM system is continuous modulation. According to these specifications, the simulations have been performed by PSO and modified PSO. The parameters of the used algorithms are shown in Table 2.

Table 2: Parameters setting of PSO and modified PSO

PSO and Modified PSO			
Subcarrier allocation	Values	Power allocation	Values
Population size	100	population size	200
Generations	100 (200)	Generations	200 (500)
C_1	2	C_1	2
C_2	2	C_2	2
Crossover	0.6	Crossover	0.6
Mutation	0.6	Mutation	0.6
Total power	100	Total power	100
Max velocity	1	Max velocity	0.5

Figure 7 represents the convergence curves after normalization of 16 users in different scenarios with different specified fitness function. MPF scenario has the fastest rate of convergence; MCSPF scenario has the second; MMC scenario has the lowest.

This simulation shows that the more complicated system requirement the lower convergence rate it has. MPF system's requirement is fairness. The only thing we consider is how to balance each client's capacity. MCSPF system's requirement is total capacity with fairness and total power constraint. That is more complicated than MPF because we cannot only consider the total capacity but also fairness does not cross a certain threshold value and the total power is not over the constraint. MMC system's requirement is to maximize the minimum capacity with the total power constraint. In this system we must consider which client has minimum capacity and re-allocated the capacity of each client to raise the minimum capacity and the total power cannot cross the boundary line that is the most complicated in three systems and lowest convergence rate. And the convergence rate is according to the complexity of each scenario: MPF is the simplest one and the fastest one; MCSPF is in the middle of these three; MMC is the most complicated and lowest one.

Figure 8 illustrates each client's capacity in these three scenarios. We can see every feature of these scenarios clearly and these simulation features just fit the real scenario features. Scenario 1: we have the max totally capacity. As Fig. 8 illustrated, some well-conditioned client has a very high capacity to maximize the total capacity and some bad-conditioned client has a really low capacity as well; Scenario 2: we have the best fairness. As it showed, all the capacities of clients are at the same level; Scenario 3: we have the max minimum client's capacity. In this scenario, we can see the minimum capacity of client is almost 4.7 bit/s/Hz and it is the highest in these three scenarios. Through this simulation, particle swarm optimization can be used

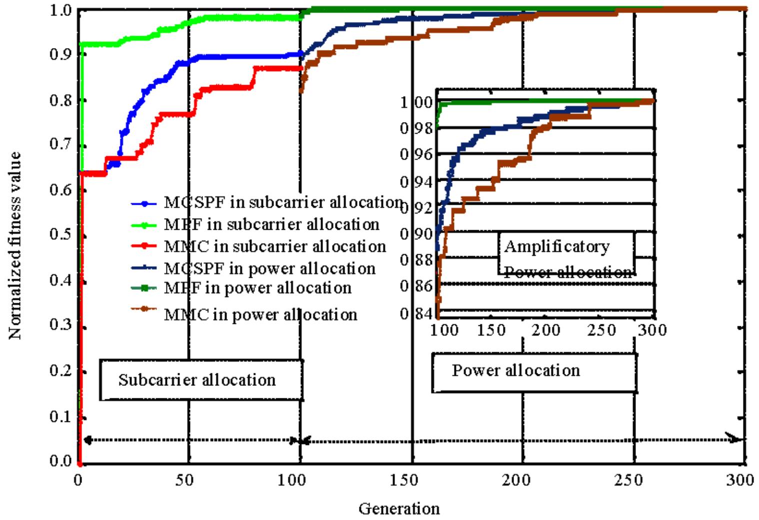

Fig. 7: Three services simulation

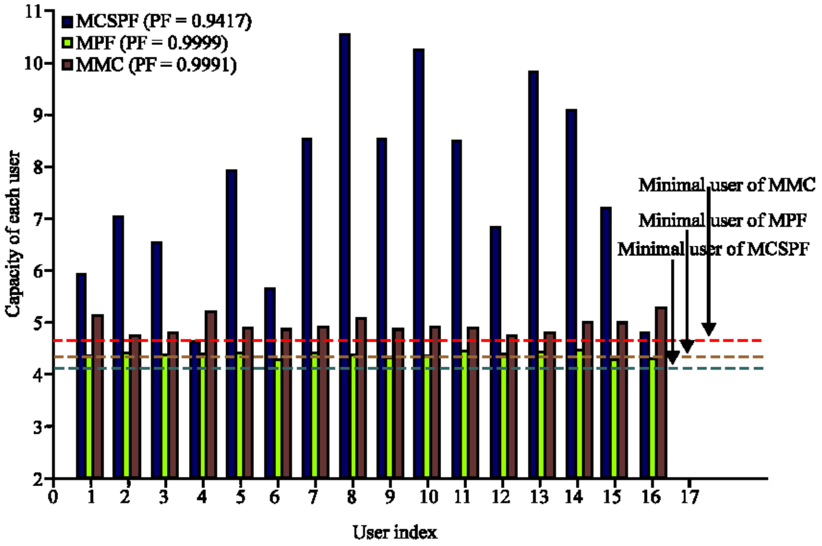

Fig. 8: Clients capacity in three scenarios

perfectly to deal with the adaptive resource allocation of multiuser OFDM system. In different scenarios, the only thing to do is switching the fitness function as the specific scenario needs.

Advantages of modified PSO in adaptive resource allocation: In this section, we will show the advantages of this modified PSO we proposed by comparison with normal PSO in adaptive resources allocation algorithm for multiuser OFDM system. All the simulations in this part are in the MCSPF scenario, for instance. And all the comparisons base on the same condition. Comparisons between normal PSO and modified PSO are divided into two parts to describe clearly.

First part: Comparison between modified PSO and normal PSO in single test under same situation: In this part, how the proposed updating process improves the performance of this resource allocation is shown in simulations.

Figure 9 represents the differences between normal PSO and modified PSO in performance of subcarrier allocation. When using normal PSO, the allocation solution has not changed since almost generation 30.

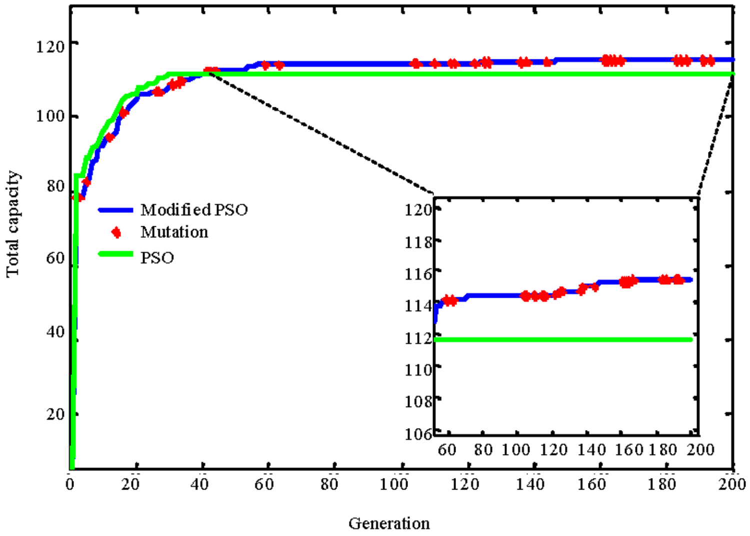

Fig. 9: Performance in subcarrier allocation

But when using the modified one, the allocation solution is still getting better in nearly generation 145. (Those red stars are generations which mutation happened).

As Fig. 9 illustrated, we can clearly see that when the mutation happened there was a chance by which this algorithm get out of the local optima but not a 100% chance. And the solution got better without mutation, because there is a crossover mechanism here too. Both crossover and mutation can improve the diversity of PSO and the diversity is the insurance of exploring the global optima.

By and large, normal PSO has a faster convergence rate but its allocation solution cannot be global optima in subcarrier allocation. Using modified PSO we can get a more optimized allocation when normal PSO has already converged. This modified PSO method can help us get a solution closer to global optima or global optima in this adaptive resource allocation. And the convergence rate in subcarrier allocation is also acceptable.

Figure 10 represents the different performance between PSO and modified PSO algorithm in the whole resource allocation (Red and green stars represent mutated generations).

In Fig. 10, we can see the difference in allocation performance between modified PSO and normal PSO became bigger as the allocation process continued. In the first part of allocation we can see the difference and the second part allocation undertaken basing on the first step's solution, so the difference must be much clearer. Modified PSO algorithm can allocate the resource of this OFDM system better. Its solution is much closer to the real global solution.

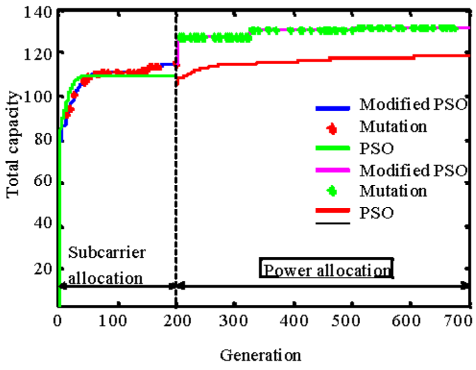

Fig. 10: Performance in the whole allocation

Second part: Comparison of the allocation performance between modified PSO and normal PSO basing on several tests: Evaluation of an optimization algorithm's performance in this resource allocation has two important parameters: (1) quality of solution: the purpose of optimization algorithm is to allocate resource optimally, so the quality of solution is the quality of resource allocation and this is why we need resource allocation; (2) convergence rate: This parameter is about the feasibility of this optimization algorithm in this resource allocation. Because the resource allocation couldn't take too long to calculate, convergence rate is the faster the better.

Quality of solution: On the basis of several tests, the advantages of modified PSO and characteristics of

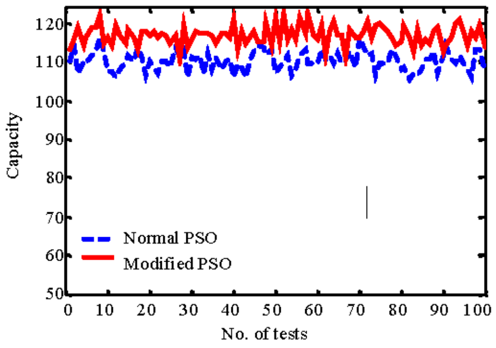

Fig. 11: Optimization solution in subcarrier allocation

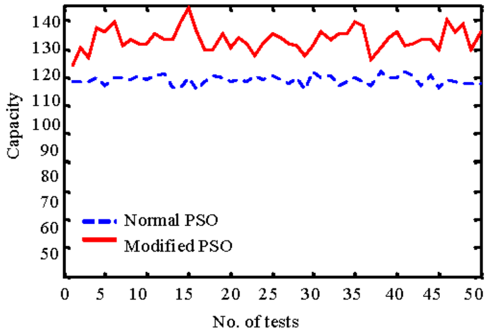

Fig. 12: Optimization solution in whole allocation

both modified PSO and PSO in this resource allocation are shown much more clearly.

Figure 11 represents the suboptimal allocation solutions of the subcarrier allocation after 100 times test and it shows that modified PSO always get a better allocation result than the normal PSO on the basis of 100 times tests.

Figure 12 illustrates the suboptimal solutions of the whole allocation after 50 times test. On the basis of 50 times tests, modified PSO optimized the resource allocation much better than only after the subcarrier allocation. The average total capacity of all clients allocated by modified PSO is about 115 bit/sec/Hz and that allocated by normal PSO is 110 bit/sec/Hz.

Comparing with Fig. 11 and 12, we can get the average quality of solution became much better in the whole allocation than in the first subcarrier allocation by using modified PSO. So modified PSO has a better quality of solution in OFDM resource allocation than normal PSO. The average total capacity of all clients allocated by modified PSO is about 132 bit/sec/Hz and that allocated by normal PSO is 119 bit/sec/Hz.

Convergence rate: Figure 13 represents the convergence rate of the subcarrier allocation after 100 times. Normal PSO has a high convergence rate. As we known, subcarrier allocation is an integer optimization process. Normal PSO has a greater chance to converge to local optima in integer optimization process than continuous optimization (Kennedy and Eberhart, 1995). Normal PSO's average convergence rate is nearly 40 generation, that's because it converges to the local optima and cannot get out of it. Modified PSO has a mechanism to get out of local optima and this mechanism sacrifices convergence time to get a better solution.

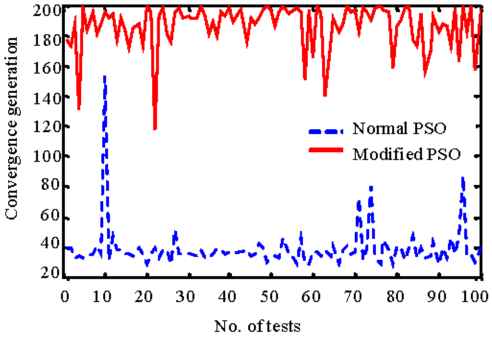

Fig. 13: Convergence rate in subcarrier allocation

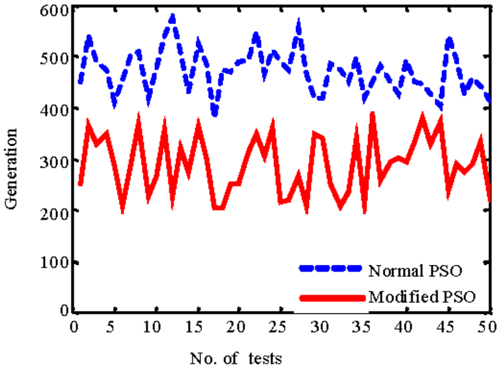

Fig. 14: Convergence rate in whole allocation

Figure 14 represents the convergence rate of the whole allocation after 50 times test. Normal PSO's convergence rate is lower than modified PSO on the basis of 50 times test. The second part of allocation is power allocation. In power allocation, optimization is continuous optimization. Normal PSO has a very large convergence rate in the early period but when in the late optimization period, i.e., near or in the global optimization solution zone the convergence rate become really low (Kennedy and Eberhart, 1995) but the modified PSO doesn't have this characteristic. Because of the diversity of the particles in modified PSO, at the end of the allocation the particles still have enough diversity to insure the algorithm could find a much better solution.

The average convergence rate of modified PSO in this allocation is at 290th generation and the average convergence rate of normal PSO use in this allocation is at 440th generation.

Comparing with Fig. 13 and 14, though modified PSO has a low convergence rate in the subcarrier allocation but this convergence rate is relatively constant in the whole allocation. And normal PSO has a very high convergence rate in the early period but low one in the late period as simulated. On the whole, modified PSO has a better convergence rate.

CONCLUSION

In this study, we proposed a modified particle swarm optimization with a mechanism which can increase diversity of particles notably and make algorithm get out of the local optima to deal with adaptive resource allocation problem. This mechanism is a combination between PSO and GA in updating period, because of this mechanism, the algorithm outperforms normal particle swarm optimization both in solution and convergence rate of adaptive OFDM resource allocation problem. In solving OFDM resource allocation problem, we divide this allocation into subcarrier and power allocation creatively to make this allocation simpler and clearer. In subcarrier allocation, modified PSO has a better quality of solution but a lower convergence rate. In power allocation, modified PSO improves the algorithm performance both in quality of solution and convergence rate. On the whole, modified PSO outperforms normal PSO. And we present simulations of three main scenarios of OFDM system have been optimized by proposed algorithm. In each scenario resources can be allocated much better to meet the system requirement. Resource of multiuser OFDM system can be allocated better with the modified PSO.

ACKNOWLEDGMENTS

This study was supported by Major Project of Chinese National Program s for Fundamental Research and Development (973 Program) with grant number 2009CB320402. The author would like to thank Mr. Zhang Qin Yu and Mr. Wang Ye for their assistance and instruction in this study.

REFERENCES

Ahmed, I. and S.P. Majumder, 2008. Adaptive resource allocation based on modified genetic algorithm and particle swarm optimization for multiuser OFDM systems. Proceedings of the International Conference on Electrical and Computer Engineering, Dec. 20-22, Dhaka, pp: 211-216.

Hassan, R., B. Cohanim, O.L. de Weck and G. Venter, 2005. A comparison of particle swarm optimization and the genetic algorithm. Proceedings of the 1st AIAA Multidisciplinary Design Optimization Specialist Conference, AIAA-2005-1897, April 18-21, Austin, Texas, pp: 1-13.

Huang, J., V.G. Subramanian, R. Agrawal and R.A. Berry, 2009. Downlink scheduling and resource allocation for OFDM systems. Wireless Communi. IEEE Trans., 8: 288-296.

Kennedy, J. and R. Eberhart, 1995. Particle swarm optimization. Proc. IEEE Int. Conf. Neural Networks, 4: 1942-1948.

Liu, B., M. Jiang and D. Yuan, 2009. Adaptive resource allocation in multiuser OFDM system based on genetic algorithm. WRI Int. Conf. Commun. Mobile Comput., 1: 270-273.

Van Nee, R. and R. Prasad, 2000. OFDM for Wireless Multimedia Communications. 1st Edn., Artech House Inc., Norwood, MA, USA., ISBN: 0890065306, pp: 280.

Wong, I.C., Z. Shen, B.L. Evans and J.G. Andrews, 2004. A low complexity algorithm for proportional resource allocation in OFDMA systems. Proceedings of the 18th IEEE Workshop on Signal Processing Systems, Oct. 13-15, Austin, Texas, USA., pp: 1-6.

Zhang, Y. and K.B. Letaief, 2002. Multiuser subcarrier and bit allocation along with adaptive cell selection for OFDM transmission. IEEE Int. Conf. Commun., 2: 861-865.