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Fairness Aware Resource Allocation in Downlink MIMO-OFDMA System using NSGA-II

K.Sumathi[1], R.Udaiyakumar[2]

[1] currently working in ECE Department of Sri Krishna College of Technology, Coimbatore, Anna University, India, *k.sumathi@skct.edu.in*

[2] currently working in ECE Department of Sri Krishna College of Technology, Coimbatore, Anna University, India, *r.udaiyakumar@skct.edu.in*

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Abstract:
Resource allocation is a very important factor in wireless communication systems due the limited radio resources like subchannels and power. Resource allocation is carried out with MIMO and OFDMA combination to combine the benefits of both the schemes. Multiple Input and Multiple Output (MIMO) scheme is used to increase the data rate and spectral efficiency in wireless communication system. Singular Value Decomposition (SVD) converts MIMO channels to many Single Input Single Output channels. Subchannels and bits can be allocated jointly in MIMO-OFDMA systems. Subchannel and bits allocation is handled by Non-dominated Sorting Genetic Algorithm (NSGA)-II in downlink of MIMO-OFDMA system. Capacity maximization and overall transmit power reduction and considering fairness among users are the main objectives in this work. Performance analysis is done with and without considering fairness for SNR values 4.6 dB and 24.6 dB respectively. Simulation results reveal that fairness is achieved at the cost of reduction in capacity.

Keywords: *Orthogonal Frequency Division Multiple Access, Multiple Input and Multiple Output, Resource Allocation, Non-dominated Sorting Genetic Algorithm, Fairness.*

I INTRODUCTION

In Multiple Input Multiple Output (MIMO) system, multiple transmit and receive antennas are used to enhance the spectral efficiency and throughput of wireless communication systems. MIMO-OFDM is used by the IEEE 802.16e and IEEE 802.11n standards. High data rate is needed for many real time applications. The advantages of both methods are achieved by combining MIMO with OFDMA. Many research works have been carried out to increase the data rate in wireless communication systems. In resource allocation several optimal and suboptimal algorithms were developed. Also many optimization algorithms along with their possible combinations were used in the allocation of resources like subchannels, power and bit.

Adaptive modulation is used in [1] along with subchannel allocation to reduce the overall transmit power. In [2], the author proposed the use of multi objective Non-dominated Sorting Genetic Algorithm (NSGA) to solve complex optimization problems with less computational complexity. An effective algorithm for subchannel and power allocation to maximize the total system capacity along with proportional rate constraints for MIMO-OFDMA in considered in [3]. In another novel approach [4], for subchannel and bit allocation in MIMO-OFDM system used zero forcing beam forming technique to reduce the transmit power and interference among the users. In [5], the performance of two different methods of OFDM namely MIMO-MC-CDMA and MIMO-OFDMA is discussed and analyzed with and without fairness in a single cell multiuser environment with CSIT.

Orthogonal GA for adaptive resource allocation to maximize the minimum user capacity in MIMO-OFDM system is suggested in [6]. The total capacity improvement with fairness is addressed [7] for MIMO-OFDMA systems. The algorithm considers fairness as the main factor and it involves subchannel rearrangement.

A Tradeoff-Factor (TF) is introduced for subchannel exchange to have a fair resource allocation. The non-convex optimization complexity is converted from exponential to linear by Lagrangian dual composition method [8]. The linear beam forming is included at both the transmitter and receiver to reduce the complexity. In [9], the author focused on optimizing multi antenna diversity (MAD) problem by convex method for MIMO-OFDMA system under two cases namely, perfect CSI at the transmitter and statistical CSIT considering power control by distributed convergence. The use of multi objective Non-dominated Sorting Genetic Algorithm for MIMO-OFDMA systems is proposed in [10], where capacity maximization and power minimization are considered for analysis. Resource allocation in MIMO-OFDMA with and without adaptive modulation for co-ordinate multipoint is dealt in [11]. To reduce inter user interference, linear pre and post processing techniques are used.

Novel GA that combines the characteristic of both deterministic and GA is suggested in [12] to maximize the throughput and maintain the proportionality among the users in MIMO-OFDMA system. Multi objective PSO is used to tackle the problems in the multiuser OFDM system for the resource allocation [13]. In [14] dynamic RA and scheduling for MIMO-OFDMA system with full duplex and hybrid relaying as a non-convex and combinational optimization problem is considered. Joint allocation of power, subchannel and phase duration for the user equipment in bidirectional MIMO-OFDM network with the aim of minimizing the energy consumption with multiple decode and forward relay stations [15]. Transient stability problem is modeled as objective function and NSGA-II is used to provide the better solution [16]. The reactive power flow based optimization problems are provided with the best possible solution by gravitational search algorithm (GSA)[17]. The energy of the individual node is being minimized by using queue threshold concept which helps in improving the life time of a node [18]. Fuzzy logic optimization algorithm was used in clustering based routing protocol to nominate cluster heads [19].

The work concentrates on improving fairness among users in multiuser wireless system for MIMO-OFDMA with perfect Channel State Information (CSI) known at the transmitter using NSGA-II. This is achieved by introducing fairness as an additional objective along with capacity maximization ad power minimization using NSGA-II. There should be a tradeoff between sum capacity and fairness. Here fairness is achieved at the cost of sum capacity.

The paper is organized as follows: Section 2 provides the system model and optimization problem. The steps involved in NSGA-II are described in Section 3. In Section 4 performance metrics are provided. Simulation parameters are mentioned in Section 5. The results and discussions are given in Section 6. In Section 7 the conclusions are drawn.

II SYSTEM MODEL

The downlink system model of MIMO-OFDMA system consists of ‘N’ subchannels shared among ‘K’ users. The following assumptions are considered during the analysis,

- No subchannel is shared by different users.
- Perfect CSI is assumed at both the receiver and the transmitter.
- Each subchannel has to be used by only one user at a time.

The resource allocation scheme[20] is updated and the subchannel and bit allocation information is sent to each user for detection through a separate channel.

The system consists of 'K' users, sharing 'N' subchannels with the total transmit power of . The objective is to maximize the total system capacity, minimize the total power and care about fairness between the users within the power budget. The bandwidth 'B' is divided into several subchannels each with its own Mt transmitter antennas and Mr receiver antennas. For user K on subchannel N the channel state matrix is with dimension of Mr X Mt. After SVD, MIMO channel of each subchannel is converted to parallel independent Single Input Single Output subchannels.

$H_{k,n}$ can be decomposed through SVD as,

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$$H_{k,n} = U_{k,n} \sum_{k,n} V_{k,n}^{H} = \sum_{i=1}^{M} u_{k,n}^{(i)} \sigma_{k,n}^{(i)} \left(v_{k,n}^{(i)}\right)^{H}$$

(1)

$\sigma_{k,n}^{(i)}\ \forall i = 1\ to\ M$ is the singular value of $H_{k,n}$ in descending order, $u_{k,n}^{(i)}\ \forall i = 1\ to\ M$ and $v_{k,n}^{(i)}\ \forall i = 1\ to\ M$ are the corresponding left and right singular vectors, respectively.

The channel gain for the kth user of nth subchannel as,

$$\sqrt{\sigma_{k,n,m}}\ (\sigma_{k,n,I} \geq \cdots \geq \sigma_{k,n,M} \geq 0)$$

(2)

The rate power function $f_k(c)$ depends on QoS and the modulation type used. The transmit power of the mth eigen mode on nth subchannel of kth user is,

$$P_{k,n,m} = \frac{f_k(c_{k,n,m})}{\sigma_{k,n,m}}$$

(3)

$c_{k,n,m}$ is the bits allocated for unit channel gain.

The total transmit power P_T is given by,

$$P_T = \sum_{k=1}^{K} \sum_{n=1}^{N} \rho_{k,n} \sum_{m=1}^{M} \frac{f_k(c_{k,n,m})}{\sigma_{k,n,m}}$$

(4)

where $\rho_{k,n}$ subchannel allocation indicator. If subchannel is allocated $\rho_{k,n}$ takes a value of 1, else takes 0 as value. For square M-QAM $f_k(c)$ can be expressed as,

$$f_k(c) = \frac{N_o}{3}\left[Q^{-1}\left(\frac{p_e(k)}{4}\right)\right]^2 (2^c - 1)$$

(5)

$N_0 / 2$ is the variance of the Additive White Gaussian Noise (AWGN), Q (x) is the Q function and $p_e(k)$ is the minimum required bit error rate for kth user.

The multi-objective optimization problem considered is concentrating on three aspects.

- Maximization of the minimum user capacity
- Minimization of the total transmit power
- Consideration of fairness among the users.

$$\max_{c_{k,n,m}\ \rho_{k,n}} \min_{k} R_k = \max_{c_{k,n,m}\ \rho_{k,n}} \min_{k} \sum_{n=1}^{N} \sum_{m=1}^{M} c_{k,n,m}\, \rho_{k,n}$$

(6)

$$\min_{c_{k,n,m}\ \rho_{k,n}} \left| P_T - \sum_{k=1}^{K} \sum_{n=1}^{N} \rho_{k,n} \sum_{m=1}^{M} \frac{f_k(c_{k,n,m})}{\sigma_{k,n,m}} \right|$$

(7)

$$\max\ F = \frac{\left(\sum_{k=1}^{K} R_k / \alpha_k\right)^2}{K \sum_{k=1}^{K} (R_k / \alpha_k)^2}$$

(8)

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Subject to constraints,

$$C_1 : \sum_{k=1}^{K} R_k \le N\, M\, D_{max} \quad (9)$$

$$C_2 : \sum_{k=1}^{K} \rho_{k,n} = 1,\ and\ \rho_{k,n} = \{0,1\} \quad (10)$$

If D value is less than D_{max}, the constraint C_1 is satisfied. Constraint C_2 denotes one subchannel is assigned to one user only. Fairness is introduced to maximize the allocation of the resources in a fair manner. It is unable to satisfy few users who demand more resources than their allotted fair allocation, leading to reduction in system capacity. Fairness index 'F' can have values in the range from 0 to 1. The maximum value of fairness index is 1. If all the users are assigned with the same resources, it is considered as the fairest case. As the number of users increase, it is hard to maintain fair allocation among the users. Reduction of capacity occurs due to the fair allocation of resources between the users. A tradeoff has to be maintained between fairness and the system capacity.

III NSGA-II

The NSGA-II is a Multiple Objective Optimization algorithm and is an extended form of basic Genetic Algorithm. In [2] multi objective Non-dominated Sorting Genetic Algorithm (NSGA) is used to solve complex optimization problems. In NSGA, multiple conflicting objectives are optimized by non-domination sorting mechanism.

NSGA-II procedure has three important features, namely,

- Utilizes elitism concept.
- Works on non-dominated solutions
- Employs diversity preserving concept

The steps involved in NSGA-II are as follows.

- Initialize variables and generate a population of 'N' chromosomes.
- Evaluate the fitness of multiple objective functions for each individual.
- Population is graded in two ways.
    - By sorting the individuals by non-domination sorting algorithm
    - Calculating the crowding distance to each individual
- Pick two chromosomes from the population based on binary tournament selection, which involves crowded comparison operator to compare two dissimilar solutions within the same front.
- Choose two parents from the current generation to create children for the next generation and perform crossover operation.
- Perform mutation over the new generation with a probability of P_{mu}.
- Repeat steps 4, 5 and 6 until the maximum generation limit N_{gen} is reached and the chromosome with the highest fitness value is selected for resource allocation.

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The detailed steps of NSGA-II for MIMO-OFDMA system is as follows.

a) Population Initialization and Objective Function Evaluation

The number of individuals in the population 'N' and the number of generations N_{gen} are initialized. For each individual the fitness values of the objective functions are calculated based on Equation (6) - Equation (8).

b) Non-Dominated Sorting Algorithm and Crowding Distance

The initial population is sorted into fronts. Non domination sort is performed over the fronts to assign rank to each individual. First front being completely a non-dominant set in the current population and the second front being dominated by the individuals only in the first front and the front goes so on. Each individual in each front is assigned with rank values. All the individuals in the first front are assigned a rank of 1 and the individuals in second are assigned with 2 and so on. For each individual, the crowding distance is calculated to find the closeness of an individual to its neighbors.

c) Crossover and Mutation

The selected parents generate children from crossover and mutation operations. The current population and current children are arranged again based on non-domination and only the best N individuals are selected. Three point crossover is performed and bit wise mutation with probability p_m.

Chromosome Structure

The structure of the chromosome is shown in Figure 1. Each chromosome is mapped into an array of N (Subch 1,…,Subch N) elements, where N is the number of subchannels. The elements are binary coded with ($\log_2 K + \log_2 D$) bits where K represents the number of users and D represents number of bits allocated. The size of the chromosome is obtained from N x ($\log_2 K + \log_2 D$).

Subch 1	**Subch 2**	**-- ---**	**Subch N**
K-1 C-1	K-2 C-2	-- ---	K-N C-N
001 01	011 11	-- ---	101 10
101	1111	-- ---	10110

Figure 1. Structure of chromosome

IV PERFORMANCE METRICS

The following are the performance metrics considered for simulation.

Sum capacity: It is the overall capacity of the system, i.e Sum of capacities per channel for all subchannels for that user.

Convergence*:* It is a means of modeling the tendency for genetic characteristics of populations to stabilize over time.

Fairness: The fairness index is defined by,

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$$FI = \frac{\left(\sum_{k=1}^{K} R_k / \alpha_k\right)^2}{K\sum_{k=1}^{K} (R_k / \alpha_k)^2}$$

Minimum user capacity: Sum of capacities per channel which is minimum for that particular user. (minimum utilization)

Average user capacity: Mean value of the sum of capacities per channel for all subchannels for that user.

Normalized capacity: Sum capacity of a user to the sum all the users sum capacity.

SIMULATION PARAMETERS

The proposed multi-objective algorithm for MIMO-OFDMA system using NSGA-II algorithm with capacity, transmit power and fairness as the objectives to be improved [*f* (sc, tp, f)] is designed using MATLAB 7.1 on a PC with Core 2 Duo processor operating with a clock 2.53 GHz , where sc, tp, and f refers to sum capacity, transmit power and fairness respectively. The experimental evaluation of the proposed multi objective algorithm for MIMO-OFDMA system is carried out using simulations with parameters specified in Table 1.

Table 1 Simulation parameters

PARAMETER	VALUE
K	2~16
N	64
B	1 MHz
P_{tot}	1W
BER	10^{-3}
Doppler shift	30 Hz
Delay spread	5µs
N_o	-80 dBW/Hz
Channel model	Frequency selective Rayleigh channel with six multipath
$M_r = M_t$	2
α_k	1:1:1:4
N_{pop}	30
N_{gen}	100
P_{mu} , P_c	0.01,0.8
D max	8 bits for low SNR (4.6 dB) 16 bits for high SNR (24.6 dB)

V RESULTS AND DISCUSSION

The performance of the proposed multi objective algorithm for MIMO-OFDMA system using NSGA-II algorithm viz., [*f* (sc, tp, f)], is compared with existing multi objective algorithm viz., [*f* (sc, tp)]. The algorithm used for comparison is also implemented for MIMO-OFDMA system using MATLAB 7.1 on a PC with Core 2 Duo processor operating with a clock 2.53 GHz.

The bandwidth 'B' is set to 1 MHz and the wireless channel is modeled as a frequency selective channel with six independent multipath Rayleigh channels. The performance metrics viz., sum capacity and fairness are analyzed for two different SNR values. Experimental evaluation is carried out with low SNR (4.6 dB) with D_{set} = 8 and high SNR (24.6 dB) with D_{set} = 16.Sum capacity for SNR = 4.6dB using NSGA II for [*f* (sc, tp)] and [*f* (sc, tp, f)] for different user index are graphically represented in Figure 2 for the values of K=16 and N = 64 subchannels. Number of users is varied from 2 to 16. The sum capacity is calculated for each user and compared for [*f* (sc, tp, f)] and [*f* (sc, tp)]. Sum capacity is more in the case of [*f* (sc, tp)] than when fairness is included. The capacity is fairly distributed to the user in [*f* (sc, tp, f)]. The capacity is lesser [*f* (sc, tp, f)] compared to [*f* (sc, tp)].

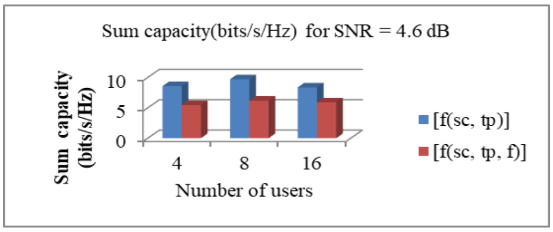

Figure 2. Sum capacity for SNR=4.6 dB

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Experimental evaluation using simulations revealed that there is 8.48% reduction in capacity when fairness is considered. Fairness index using NSGA II with and without considering fairness is tabulated in Table 2 for the values of K = 16 and N = 64.

Table 2 Fairness vs number of users for SNR=4.6 dB

Fairness index for SNR =4.6 dB		
K	[*f*(sc, tp)]	[*f*(sc, tp, f)]
4	0.7497	0.8929
8	0.7066	0.9048
16	0.4181	0.6585

The fairness scheme ensures the minimum number of subchannels required for all users. Sum of the user's data rates are fairly allocated between the users for different data rate constraints. Different proportional data rates can be achieved among the users. There is 28% fairness improvement achieved for [*f* (sc, tp, f)] over without fairness. Average user capacity to number of users using NSGA II with and without considering fairness is compared and graphically represented in Figure 3. For all the users, the average user capacity is comparatively better with "without fairness".

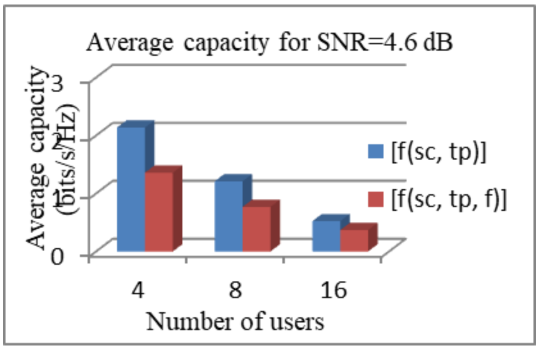

Figure 3. Average capacity vs number of users for SNR=4.6 dB

Minimum user capacity to number of users using NSGA II with and without considering fairness is tabulated in Table 3 for K = 16 and N = 64 subchannels. For all the users, the minimum user capacity with fairness is comparatively better without considering fairness.

Table 3 Minimum user capacity vs number of users for SNR=4.6 dB

Minimum User Capacity(bits/s/Hz) for SNR = 4.6 dB		
K	[*f*(sc, tp)]	[*f*(sc, tp, f)]
4	0.8561	0.9449
8	0.1776	0.3552
16	0.0024	0.0972

Normalized capacity to number of users using NSGA-II with and without considering fairness is graphically represented in Figure 4 for the values of K = 16 and N = 64. The number of users taken is 8. For without fairness case, it is unable to satisfy the minimum rate requirement of the users based on the predefined proportional rate constraints. The predefined rate constraints considered in this work is 1:1:1:4. For with fairness case, it satisfies the user rate requirements based on the proportional rate constraints.

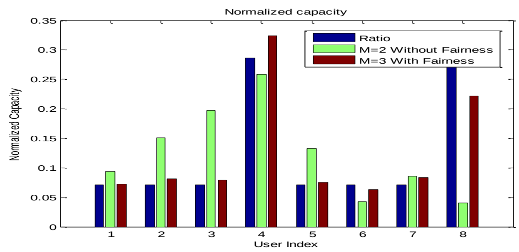

Figure 4. Normalized capacity vs number of users for SNR=4.6 dB

The following graphs are with respect to high SNR (24.6 dB). Sum capacity using NSGA-II [*f* (sc, tp, f)] and without considering fairness performances are graphically represented in Figure 5. The sum capacity is calculated for each user and compared for [*f* (sc, tp, f)] and without fairness. Sum capacity is more in the case of [*f* (sc, tp)] than fairness being considered. There is 6.03% reduction in capacity when fairness is considered. The capacity is less for the sum capacity [*f* (sc, tp, f)] compared to without fairness.

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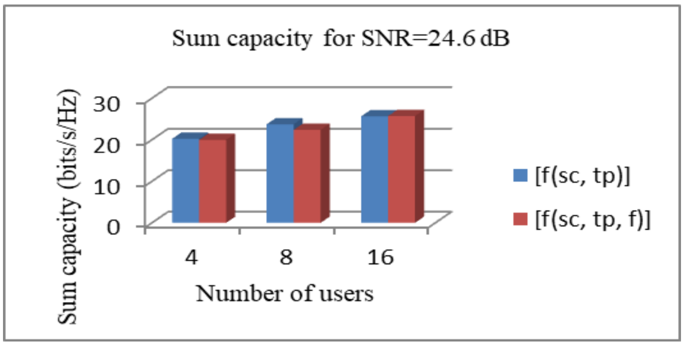

Fig. 5. Sum capacity for SNR=24.6 dB

Farness index using NSGA-II with and without considering fairness performances are tabulated in Table 4 for K = 16 and N = 64. The fairness scheme ensures the minimum number of sub channels required for all the users. Sum of the user's data rates are fairly allocated between the users for different data rate constraints. Different proportional data rates can be achieved among users. There is 28 % fairness improvement achieved for [*f* (sc, tp, f)] over without considering fairness.

Table 4 Fairness vs number of users for SNR=24.6 dB

Fairness Index for SNR =24.6 dB		
K	[*f*(sc, tp)]	[*f*(sc, tp, f)]
4	0.7073	0.8475
8	0.6637	0.7336
16	0.5963	0.7652

Average user capacity to the number of users using NSGA-II with and without considering fairness is graphically represented in Figure 6. For all the users, the minimum user capacity is comparatively better with [*f* (sc, tp)] case.

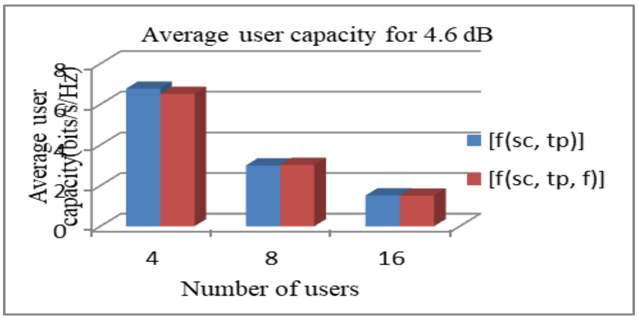

Fig. 6. Average user capacity vs number of users for SNR=24.6 dB

For all the users, the average user capacity when M=2 without considering fairness is better than with fairness. Minimum user capacity to the number of users using NSGA-II with and without considering fairness is compared and tabulated in Table 5. For all the users, the minimum user capacity [*f* (sc, tp, f)] is better for [*f* (sc, tp)] case.

Table 5 Minimum user capacity vs number of users for SNR=24.6 dB

Minimum user capacity(bits/s/Hz) for SNR =24.6 dB		
K	[*f*(sc, tp)]	[*f*(sc, tp, f)]
4	2.1066	2.8750
8	0.8541	1.1841
16	0.2582	0.3746

Normalized capacity to the number of users using NSGA-II with and without considering fairness is compared and graphically represented in Figure 7 for the values of K = 16 and N = 64.The number of users taken is 8. In the case of without fairness, it is unable to satisfy the minimum requirement of the users based on the predefined proportional rate constraints. The predefined rate constraints considered in the present work is (1:1:1:4). For without fairness case it satisfies the rate requirements based on the proportional rate constraints.

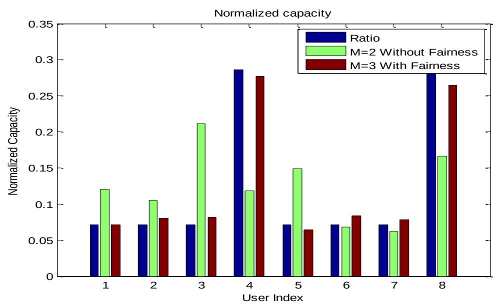

Fig. 7. Normalized capacity vs number of users for SNR=24.6 dB

Total power convergence with respect to the number of iterations using NSGA - II with and without considering fairness is graphically represented in Figure 8 for the values of K = 16 and

N = 64.

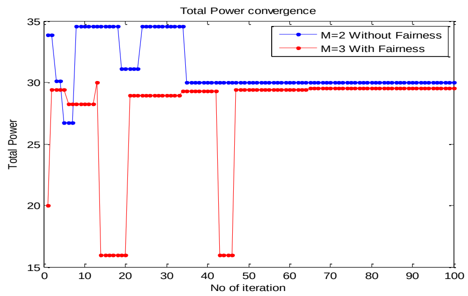

Fig. 8. Total power convergence vs iterations for SNR=24.6 dB

The power is converged within 35 iterations for [*f* (sc, tp)]case using NSGA-II. However, fairness case using NSGA-II takes more iteration (nearly 55 iterations) to reach a stable point and consumes more time to converge.

VI CONCLUSION

The combined subchannel and bit allocation in multiuser MIMO-OFDM system with for [*f* (sc, tp, f)] and [*f* (sc, tp)] among users is implemented using NSGA-II for low SNR (4.6 dB) and high SNR (24.6 dB) values. The subchannel and bit allocation in multiuser MIMO-OFDM system are jointly handled with and without considering fairness among users is proposed using NSGA-II for low SNR (4.6 dB) and high SNR (24.6 dB) values. The sum capacity achieved by [*f* (sc, tp, f)] is comparatively less with [*f* (sc, tp)]. There is 8.48% and 6.03% reduction in capacity for [*f* (sc, tp, f)] compared to [*f* (sc, tp)] for SNR=4.6 dB and 24.6 dB respectively. However, there is a 28% and 10.6% improvement in fairness for [*f* (sc, tp, f)] compared to [*f* (sc, tp)] for SNR = 4.6 dB and 24.6 dB respectively.

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