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MIMO Broadcast Scheduling for Weighted Sum-rate Maximization

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***Abstract*—**Multiple-Input-Multiple-Output (MIMO) is one of the most important communication techniques that allow wireless systems to achieve higher data rate. To overcome the practical difficulties in implementing Dirty Paper Coding (DPC), various sub-optimal MIMO Broadcast (MIMO-BC) scheduling algorithms are employed which choose the best set of users among all the users. In this paper we discuss such a sub-optimal MIMO-BC scheduling algorithm which employs antenna selection at the receiver side. The channels for the users considered here are not Identical and Independent Distributed (IID) so that users at the receiver side do not get equal opportunity for communication. So we introduce a method of applying weights to channels of the users which are not IID in such a way that each of the users gets equal opportunity for communication. The effect of weights on overall sum-rate achieved by the system has been investigated and presented.

***Keywords*—**Antenna selection, Identical and Independent Distributed (IID), Sum-rate capacity, Weighted sum rate.

I. INTRODUCTION

MULTIPLE-Input Multiple-Output (MIMO) is one of the important communication techniques that allow wireless systems to achieve higher data rate[1]-[3]. Earlier studies have shown that wireless systems can achieve data rate close to fundamental capacity limit using Dirty Paper Coding (DPC) at the base station [4]. However, DPC can be implemented on the ideal assumption of perfect channel state information at the transmitter and it is very complex to implement. There are various scheduling schemes which achieve performance close to fundamental capacity limit for MIMO Broadcast (MIMO-BC) under more practical assumption.

The scheduling scheme discussed in [5]-[6] employs simple zero-forcing beam-forming at the transmitter side and an algorithm named as Semi-orthogonal User Selection (SUS) algorithm. Although this algorithm achieves near optimal sum-rate but the amount of feedback required for this scheme is very large. In multiuser MIMO systems which have many users at the receiver side, it is advantageous to have full Channel State Information (CSI) at the base station. But providing full CSI to the base station requires huge amount of resources on the uplink channel. Therefore, scheduling schemes based on partial CSI are of great interest. The scheduling scheme discussed in [7] requires partial CSI. However this scheduling scheme results in loss of system throughput. The feedback reduction scheme is described in [8]. In this scheme a threshold is applied on the channel information to reduce the feedback and it is shown that there is not much of reduction of the sum-rate of the system. Opportunity beam-forming is another scheme that is used by systems having partial CSI. In this scheme the transmitter sends random beams to the users and the user which has the highest Signal-to-Noise Ratio (SNR) for each beam is selected [9]. However, none of the receiver processing are considered in the proposed scheme. The amount of feedback is reduced in [10]. The algorithm uses limited feedback. Each of the users at the receiver side selects a pair of transmit and receive antenna which provide the maximum Signal-to-Interference plus Noise Ratio (SINR). For large number of users it is shown that this scheme achieves near optimal sum-rate. It is also shown that by maintaining a threshold on the SINR value, the amount of feedback can significantly be reduced without much loss in the system throughput.

The MIMO downlink channels for the users are in general considered as Independent and Identical distributed (IID) Gaussian random channels for ease of computation. But in practical applications many times the channels encountered are not IID. In this paper such a MIMO downlink system is considered in which the downlink channels are not IID. A practical method of generating non-IID users is considered first. The Antenna Selection (AS) algorithm [10] is used for user selection and scheduling. Since the channels for the users are not IID, they behave differently to the transmit signal. Hence each user will not get equal opportunity by the base station for communication. A scheme of applying weights to the channels is considered so that each of the users gets nearly equal opportunity by the base station. Then the effect of applying weights to the channels on the sum-rate of the system is investigated. The weighted sum-rate is compared with the sum-rate achieved by the system without any weights.

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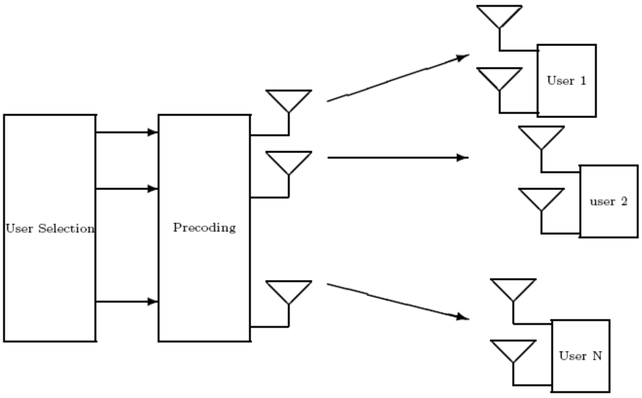

Fig. 1. MIMO Broadcast Downlink Channel

II. ANTENNA SELECTION ALGORITHM

This is a multiuser downlink scheduling algorithm which is based on limited feedback of partial channel state information in MIMO Broadcast channel. It uses spatial multiplexing at the transmitter side and Antenna Selection (AS) at the receiver side. The transmitter with M number of transmitting antennas chooses M favorable users with the highest Signal-to-Interference plus Noise Ratio (SINR) and allocates independent or same messages to the users.

A. System Model

The wireless system considered here has *M* number of transmit antennas at the base station and *N* number of users with each users having *K* number of receive antennas as shown in Fig. 1. So there are *K* x *N* number of receive antennas from which the base station selects *M* for communication. The received signal by the n_{th} user at any time slot is

$$\mathbf{y}_n=\mathbf{H}_n\,\mathbf{x}+\mathbf{w}_n \qquad (1)$$

where $\mathbf{H}_n$ is *K* X *M* complex Gaussian channel matrix from the transmitter to the n_{th} user, **x** is the transmit signal and $\mathbf{w}_n$ is the noise vector ~ $\mathcal{CN}(0,\mathbf{I}_k)$. It is assumed that the transmitter has a power constraint *P*, i.e. $\mathbb{E}\{\mathrm{Tr}\,(xx^*)\} \leq P$. The total power is distributed equally among all the antennas. Hence the average transmit power per antenna is *P*/*M*. The power constraint is assumed to be per frame. The received signal at the k_{th} antenna of user *n* can be derived from as

$$y_n(k)=\sum_{m=1}^{M} h_n(k,m)x(m)+w_n(m) \qquad (2)$$

Assuming *x(m)* to be the desired signal for user *n*, the signals x(m′), m′≠ m are considered as interference for the user *n*. Hence the SINR of *y(n)* is given as

$$SINR_{m,n}^{(k)}=\frac{|h_k(n,m)|^2}{\frac{M}{P}+\sum_{m'\neq m}|h_k(n,m')|^2} \qquad (3)$$

where M/P is the average SNR of user *n*.

Each user finds out a set of SINR values for each of its antennas. It also finds out the index of transmit and receive antenna (m and n) which achieve the highest SINR. The maximum SINR values along with the index *m* are fed back to the Base station. The base station then selects *M* users with the highest SINR and transmits messages to them. The messages can be same or independent.

B. Scheduling Algorithm

The Antenna Selection algorithm that is considered here is given as below:

1. Let B_n be the maximum SINR for a user, T_{xn} and R_{xn} are the transmit and receive antenna respectively which provides the maximum SINR. B_n, T_{xn} and R_{xn} are initialized to zero.
2. Each user selects a pair of receive and transmit antenna with maximum SINR. The SINR of each user is found out by using (3). The values of the maximum SINR, i.e.B_n and the index of the transmit antenna, i.e. T_{xn} are feedback by each user to the base station.
3. At the base station, after all the information are received, each of the transmit antenna selects a receive antenna with maximum SINR.

C. Throughput Analysis

The sum-rate capacity achieved by the system using the Antenna Selection algorithm can be given as

$$R=\sum_{m=1}^{M}R_m=\sum_{m=1}^{M}\left(1+SINR_{m,Rx_{n_m^*}}^{n_m^*}\right) \qquad (4)$$

where $SINR_{m,Rx_{n_m^*}}^{n_m^*}$ is the SINR of user n_m^* scheduled by the m_{th} transmit antenna, and R is the receive antenna selected by user n_m^* .

The simulation for the sum-rate achieved by the AS algorithm is carried out and the achieved throughput versus number of users is shown in Fig. 2, where the plots for different SINR values are shown. Channels of unity noise variances are considered here. All the simulation are performed for M=2 and K=2. The simulations are performed over 10000 iterations. The plot in Fig. 3 shows the same relationship between throughput and number of users for large number of users.

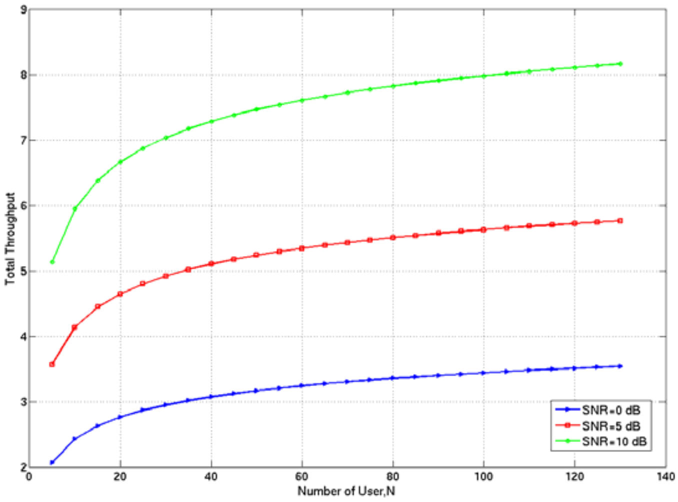

Fig.2. Total throughput in bps/Hz versus number of users for M=2, K=2 (no. of users up to 130).

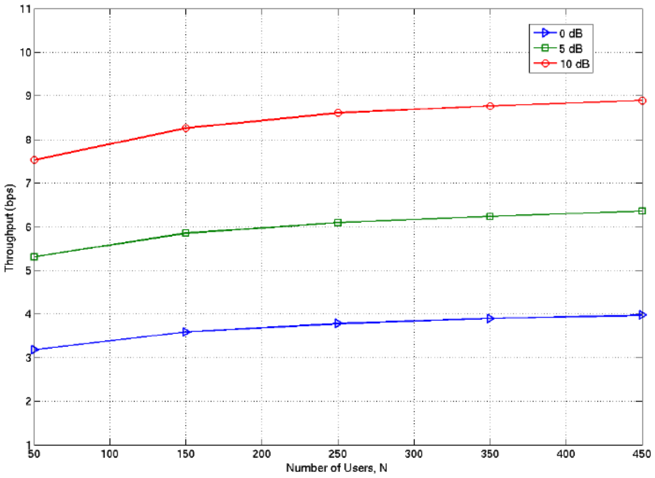

Fig.3 Total throughput in bps/Hz versus number of users for M=2, K=2 (no. of users up to 450).

III. WEIGHTED SUM-RATE

Till now the sum-rate capacity for the MIMO broadcast downlink channels using different scheduling algorithms have been discussed. The base station chooses the best set of users under different conditions and transmits signals to them on priority basis. Different scheduling algorithms use different practical methods to choose the best set of users at any given time slot. All through the previous discussion the channels are assumed to be Identical and Independent Distributed (IID) Gaussian random channels. Since the channels for the users are identical, over a long period of time on an average each of the users get nearly equal opportunities and therefore have nearly equal average individual-rate. But in many cases the channels for the users may not be independent and identically distributed random channels. Since the channels are not identical in those cases it is observed that not all the users get equal opportunities and therefore does not have equal average rate. And also it may so happen that some of the users may not even get any chance of communication from the transmitter over a long period of time.

To study the behavior of the users whose channels are not IID, firstly a practical method is found out by which we can generate groups of users whose channels are not IID and then devise a method of applying weights to the users so that all the users get nearly equal opportunities over a longer time. In other words the average rate of each of the users becomes nearly equal.

In the previous discussion it is assumed that the channels for the users are identical and have unit noise variances. Here the users are differentiated into different groups on the basis of different noise variances i.e. each group of users have different noise variances. Then the individual rates of the users and the average group rate are found out over a long period of time. The antenna selection algorithm [10] is used for the user selection and scheduling. It is shown that the group of users having lesser noise variance achieves higher individual rates as well as higher average group rate. Since they have lesser noise variances, their SINR will be comparatively higher than users in the group having higher noise variances and hence they will be preferred more by the transmitter.

Next different weights are applied to different group of users. The weights are determined in such a way that the group of user having less average group rate in an iteration is given more weights in the next iteration. The weights are applied to (3) to improve the SINR values of the users of group having less average group rate, i.e. users in Group 2.

The algorithm of proposed approach is presented below:

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Let $\epsilon = 0.001$,  $\delta = 0.001$,  $\lambda = 0.2$
1.  Initialize i=1;
2.  Divide the users into two groups with noise variance for users in Group 1 are set to unity and for users in Group are set to 1.2.
3.  Assign weight of $\mathcal{W}_1 = 1$ for users in Group 1 and weight of $\mathcal{W}_2 = 1$ for users in Group 2.
4.  Multiply the weights to the SINR values of the corresponding users in each Group. Then calculate the average rate for each user in each Group as well as the average group rate $\mathcal{R}_1$ and $\mathcal{R}_2$ of both the users. Obviously $\mathcal{R}_1 > \mathcal{R}_2$.
5.  If $\mathcal{R}_1 - \mathcal{R}_2 \geq \epsilon$ then
        $\mathcal{W}_2 = \mathcal{W}_2 + \delta$ and go to step 4.
    Else
        $\mathcal{W}(i) = \mathcal{W}_2$
    End If
6.  i=i+1 and $N_{0_2} = N_{0_2} + \lambda$, where $N_{0_2}$ is the noise variances of users in Group 2.
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In this paper we apply noise variance of unity to one set of users (i.e. Group 1) and noise variance of 1.2 to the second set of users (i.e. Group 2). The noise variances applied to the users in Group 2 are increased by 0.2 stepwise keeping the noise variances for users in Group 1 as unity. The procedure followed can be best explained by the following algorithm.

IV. SIMULATIONS AND RESULTS

The plots in the following figures explain the scheme. Figs. 4 and 5 show the average individual rate versus number of users when unity noise variance is used for users in Group 1 and noise variance of 1.2 is used for users in Group 2. Fig. 4 depicts the case when no weights are applied to users in both groups whereas Fig.5 shows the case after weights are applied to the users. The solid lines represent the average individual rate whereas the dotted lines represent the average group rate.

Similarly Figs. 6 and 7 represent the case when we assign the noise variance to users in Group 1 as 1 and users in group 2 as 1.4.

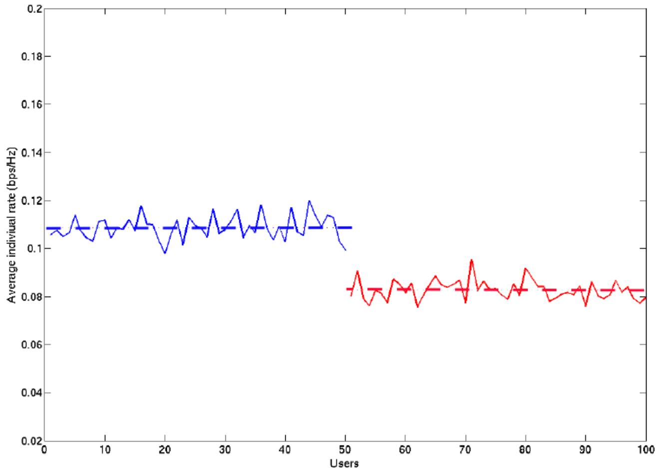

Fig. 4 Average individual rate versus number of user without any weights (noise variance of users in Group 1= 1 and noise variance of users in Group 2= 1.2)

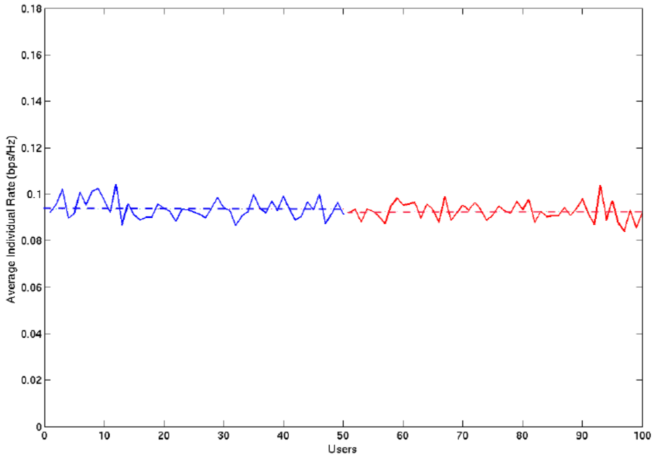

Fig. 5 Average individual rate versus number of user with weights. .(noise variance of users in Group 1= 1 and noise variance of users in Group 2= 1.2)

It can be observed from Fig. 4 and Fig. 6 that when the noise variances of users in a particular Group are more than noise variances of users of another Group, then the average individual rates of users having higher noise variances are lower. This is due to fact that users with high noise variances have low SINR values. As the Antenna selection algorithm chooses the users with the highest SINR values, users with lower SINR values have less chance of being selected by the base station.

When weights are applied it is observed from Fig. 5 and Fig. 6 that the average individual rates of users of both the groups become the same. It is also observed that there is a decrease in the average individual rates of the users with less noise variances (i.e. good users). This is because of the fact that after weights are applied to the SINR values of poor users (i.e. users with higher noise variances), the SINR values are comparable with the SINR values of good users. Hence poor users are also getting nearly equal opportunities as that of good users. Since some users with high noise variances are selected by the algorithm after the weights are applied, the weighted sum-rates of good users go down whereas the weighted sum-rates of poor users go up.

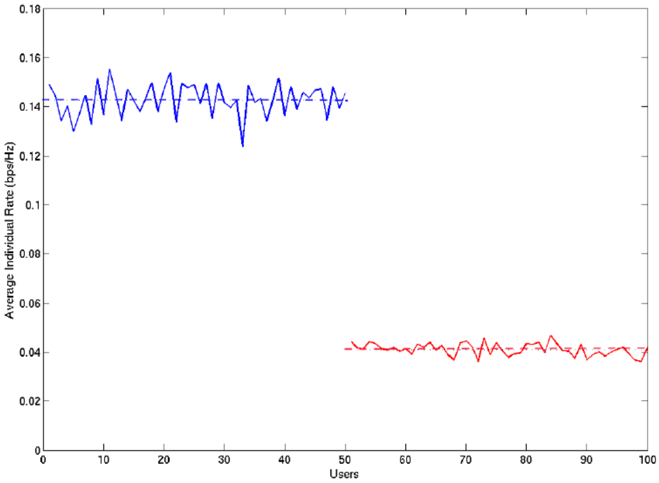

Fig. 6 Average individual rate versus number of user without any Weights (noise variance of users in Group 1= 2 and noise variance of users in Group 2= 2.2).

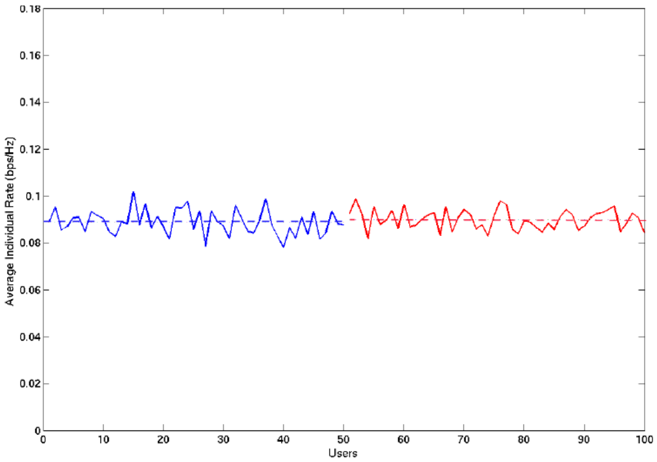

Fig. 7 Average individual rate versus number of user with weights (noise variance of users in Group 1= 2 and noise variance of users in Group 2= 2.2).

Next the noise variances of users in Group 2 are increased in a step of 0.2, keeping the noise variances of users in Group 1 fixed at 1.0. Weights are applied to poor users, i.e. users with higher noise variances until users in both the groups attain nearly equal average group rate. Fig. 8 shows the plot between the noise variances to users in Group 2 and weights applied to the users in Group 2 to attain equal average group rate between Group 1 and Group 2.

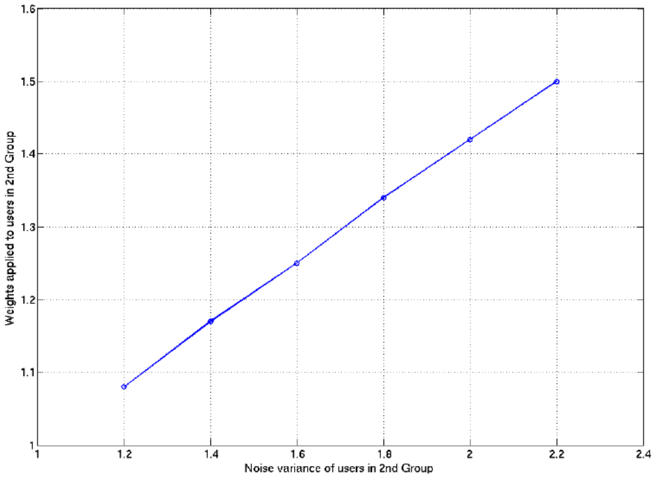

Fig. 8 Weights versus Noise variances (noise variance of users in Group 1=1)

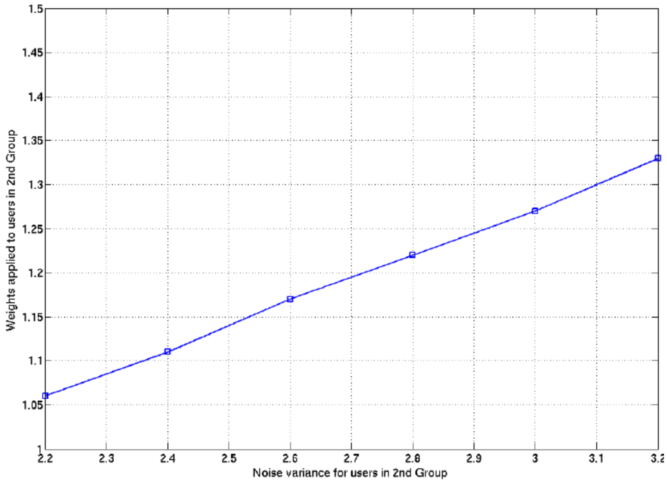

Fig. 9 Weights versus Noise variances (noise variance of users in Group 1=2)

In the next situation, noise variance of 2.0 is applied to users in group 1 whereas for users in Group 2 the noise variance is increased in a step of 0.2. The corresponding weights needed to be applied to users with higher noise variances are found out. The plot in Fig. 9 shows the relationship between the weights applied to the noise variances to users in group 2

It is observed that more and more weights are needed to be applied to users of Group 2 as the noise variances of users in Group 2 are increased. The weights & noise variances have a linear relationship.

V. SUM-RATE AND WEIGHTED SUM-RATE COMPARISON

The sum-rate capacity for the system is find out using antenna selection (AS) algorithm. Weights are found out for users for different groups of users whose channels are not identical. After the weights are applied to the poor users, the same antenna selection (AS) algorithm is used to find out the weighted sum-rate of the system. The sum-rate of the system without weights being applied and the weighted sum-rate are plotted versus the number of users and the plots are shown in Fig. 10. It is observed that the weighted sum-rate achieved after applying weights is lower than the sum-rate achieved by the system without applying any weights in the Antenna Selection algorithm. Although lower throughput results, equal average rate for each users is achieved by applying weights to the users. By applying weights the SINR of users having lower SNR has been enhanced. At any time slot the system while selecting the best users also chooses some of the poor users whose SINR have been increased by the application of weights. Hence there is a reduction in weighted sum-rate of the system.

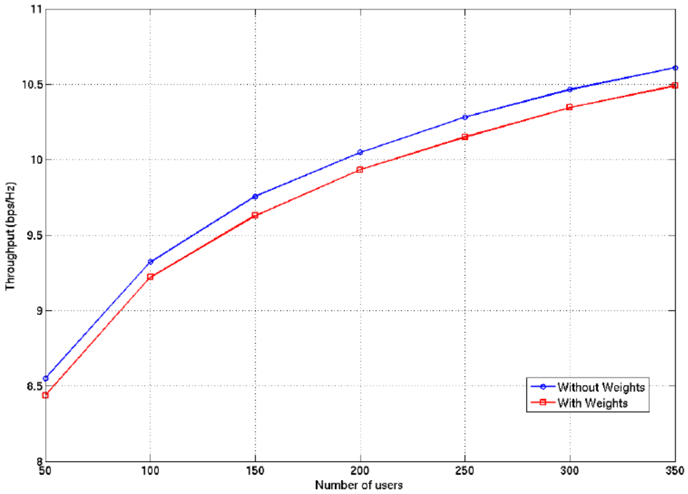

Fig. 10 Total throughput with and without weights versus number of users

VI. CONCLUSION

A limited feedback MIMO broadcast scheduling scheme was discussed assuming the channels to be identical. The same scheduling scheme is also applied to a MIMO system in which downlink channels are not identical. When the channels are not IID then each of the users achieves nearly equal average individual rate by application of appropriate weights. The weighted sum-rate is somewhat lower than the sum-rate achieved by the system. The reduction is sum-rate when weights are applied can be compensated by the fact that all the users get equal opportunities by the transmitter, thereby achieving nearly equal average individual rates. The same analysis can be performed when the users are divided into more number of non-identical groups. Further studies can find out a more realistic relationship between the weights being applied and the noise variances of users in different groups.

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