PARTIAL FEEDBACK MULTI-USER SCHEDULING IN MULTI-ANTENNA SYSTEMS

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Abstract: In this paper we consider the greedy scheduling algorithm that routes transmission of users' packets based on their reported CSI in the uplink channel to the user with the best instantaneous channel conditions. We propose a scheduling scheme that relies on reporting partial feedback of the CSI. We compare the proposed scheme to the one that uses perfect channel information at the base station, we will see that the proposed scheme has significantly less complexity at the expense of a loss in the system's capacity.

1 INTRODUCTION

In order to support services requiring high data rates such as the Internet while ensuring the quality of service (QoS), the spectral efficiencies of the next generation of wireless networks has to be greatly enhanced. The concept of multiple-input multiple-output (MIMO) systems introduced in the mid 1990s demonstrated that using multiple antenna elements at both the receiver and the transmitter can result in enormous capacity gains. Since then, various MIMO architectures have been proposed such as space-time block coding and smart antenna beamforming.

In multiuser environments, independence of fading among users, called multiuser diversity, can be exploited to increase the system capacity. Two critical targets of packet scheduling are to maximize the system capacity (throughput) and to offer fairness among users. This is accomplished by tracking the instantaneous channel quality of the users in the system and schedule transmissions to the user who has the best channel quality at any given time. In this case the system is 'riding the peaks' of channel qualities of all the users at all times.

In the case of greedy scheduling, the scheduling scheme maximizes the system capacity through the use of multiuser diversity. Specifically, each spatial channel is allocated to a user with the best channel condition for each time slot. Therefore, some users in adverse channel conditions may not be served, causing unfairness among users. While in the round robin scheduling (RRS) scheme was studied for MIMO cellular systems operated in a cyclic fashion regardless of the channel conditions, and thus achieves fairness among users.

Much of the work on multi-user MIMO channels has assumed that the transmitter and receivers all know the channel exactly. Accurate CSI may be easy to obtain when the channel is changing slowly (e.g., as in indoor scenarios), but it is much more difficult in situations where the channel is changing rapidly. An analysis of the penalty for using imperfect or outdated feedback of channel information would be of significant benefit to system designers.

In this paper we propose a scheduling algorithm that would require the users to report part of their CSI back to the transmitter, where it then will decide to route the transmission to the user with the best effective SNR The key reason for this idea is to reduce the traffic in the feedback path, so then it can be used for other purposes, but the question is does this sacrifice worth it, and what are the effects of using such scheme on the capacity of the system, and is it tolerable or not, such questions and other more will be further discussed in this paper.

2 SYSTEM MODEL

The model we consider applies to the downlink of a multiuser MISO wireless packet data system as illustrated in Figure 1, where we assumed having a single BTS of multi transmit antennas that provides data services to M users, each of which is equipped

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with a single antenna. Each user reports his channel state information (CSI), using it and harnessing the unequal latency property of the service to serve multiple users with disparate SNRs.

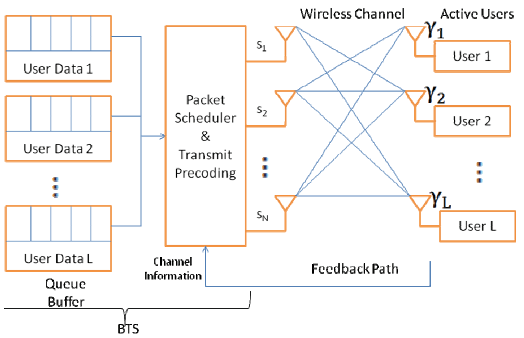

Figure 1: Multiuser MISO model.

In the proposed partial feedback multiuser scheduling each user will feedback only the minimum and the maximum of his paths' gains, along with the number of the antenna that corresponds to the maximum path gain of each.

For simplification purposes, we assume that the M users experience the same average SNR and that each link exhibits quasi-static frequency non-selective (flat) fading so that the channel gains remain constant throughout the transmission of one data packet. According to the proposed scheduling scheme each user will report the minimum and the maximum of his paths' gains, namely (for the ith user):

$h_{\min}^{(i)} = \min\limits_{j=1,2,\ldots,N} \left|h_j^{(i)}\right|^2$, and $h_{\max}^{(i)} = \max\limits_{j=1,2,\ldots,N} \left|h_j^{(i)}\right|^2$

Where $h_j^{(i)}$ is the complex fade coefficient for the path from transmit antenna (j) to the receive antenna of the ith user.

Each user also reports the antenna number that corresponds to his maximum path gain, now each user has chosen the most favourable antenna for him, but more than one user could compete to get the same antenna, here the antenna will select his user by applying the following maximization rule:

Choose user i such that

$$\max_{i=1,2,\ldots,M} \left[\gamma_B^{(i)} - \gamma_W^{(i)}\right] \tag{1}$$

where $\gamma_B^{(i)}$ is the best SINR of the ith user defined as

$$\gamma_B^{(i)} = \frac{\left|h_{\max}^{(i)}\right|^2}{1+(N-1)\left|h_{\min}^{(i)}\right|^2} \tag{2}$$

, and $\gamma_W^{(i)}$ is the worst SINR of the ith user defined as

$$\gamma_W^{(i)} = \frac{\left|h_{\max}^{(i)}\right|^2}{1+\left|h_{\min}^{(i)}\right|^2+(N-2)\left|h_{\max}^{(i)}\right|^2} \tag{3}$$

The best case of the SINR occurs when there is one path with maximum gain $h_{\max}^{(i)}$, and (N-1) paths with minimum gain $h_{\min}^{(i)}$.While the worst case for SINR occurs when there are (N-1) paths with maximum gain $h_{\max}^{(i)}$, and one path with minimum gain $h_{\min}^{(i)}$. And in both cases the noise power is normalized to unity.

Also we use the following maximization rules:

$$\max_{i=1,2,\ldots,M} \left[\frac{\gamma_B^{(i)} - \gamma_W^{(i)}}{\gamma_B^{(i)}}\right] \tag{4}$$

$$\max_{i=1,2,\ldots,M} \left[\gamma_B^{(i)}(\gamma_B^{(i)} - \gamma_W^{(i)})\right] \tag{5}$$

A special case in this context is if one antenna was not selected by any user, then he would choose the best user among those who weren't chosen by the other antennas.

Let's start with the complete fading coefficients matrix (h), defined as:

$$h = \begin{bmatrix} h_1^{(1)} & \cdots & h_1^{(M)} \\ \vdots & \ddots & \vdots \\ h_N^{(1)} & \cdots & h_N^{(M)} \end{bmatrix} \tag{6}$$

But here we're only interested in the magnitude of those fading coefficients, so we define the magnitudes matrix ($\tilde{h}$) as:

$$\tilde{h} = \begin{bmatrix} \left|h_1^{(1)}\right|^2 & \cdots & \left|h_1^{(M)}\right|^2 \\ \vdots & \ddots & \vdots \\ \left|h_N^{(1)}\right|^2 & \cdots & \left|h_N^{(M)}\right|^2 \end{bmatrix} \tag{7}$$

Now, and because we're only gone use the maxima and minima of the fading coefficients of the users, the receiver of each user will feedback to the BTS only the maximum and minimum of his fading coefficients, so now we form two matrices on for the maximum of the gains of each user for, and the other for minimum of the gains of each user for, defined by:

$$\begin{aligned} \tilde{h}_{\max} &= \left[\max_{j=1,2,\ldots,N}\left(h_j^{(1)}\right) \;\cdots\; \max_{j=1,2,\ldots,N}\left(h_j^{(M)}\right)\right] \\ \tilde{h}_{\min} &= \left[\min_{j=1,2,\ldots,N}\left(h_j^{(1)}\right) \;\cdots\; \min_{j=1,2,\ldots,N}\left(h_j^{(M)}\right)\right] \end{aligned} \tag{8}$$

And consequently we can find the best and worst

SINR matrices:

$$\gamma_B = \left[\gamma_B^{(1)} \quad \cdots \quad \gamma_B^{(M)} \right] \tag{9}$$

$$\gamma_W = \left[\gamma_W^{(1)} \quad \cdots \quad \gamma_W^{(M)} \right] \tag{10}$$

Now, each antenna will select his best user from those who were competing on it (i.e. who had their maximum path gains with that antenna) by using the maximization rule.

If we select the maximization by Eq(1) then define:

$$\begin{aligned} \gamma_D &= \gamma_B - \gamma_W \\ &= \left[\gamma_B^{(1)} - \gamma_W^{(1)} \quad \cdots \quad \gamma_B^{(M)} - \gamma_W^{(M)} \right] \end{aligned} \tag{11}$$

With keeping the terms corresponding to the users who selected the specified antenna and dropping the others.

To calculate the capacity of the system, we simply sum the capacities of the active links, for each link the capacity in bits per second per Hertz can be calculated using Shannon's theorem:

$$C = \log_2 \left[1 + SINR \right] \tag{12}$$

Where the SINR in Eq(12) corresponds to the user that has been chosen by the antenna, and it can be calculated as follows:

$$SINR_j^i = \frac{\left| h_j^{(i)} \right|^2}{1 + \sum_{\substack{k=1 \\ k \neq j}}^{N} \left| h_k^{(i)} \right|^2} \tag{13}$$

3 RESULTS AND DISCUSSION

Some computer analysis were conducted using Matlab to quantify and qualify our analysis, these analysis carried out comparative analysis between systems employing different feedback schemes, namely, the full feedback, and the partial feedback. In the code that we implemented, many sample functions were generated for the capacity, and then they were averaged for each value of the Mean SNR.

In Figure 2, the capacity is plotted versus the mean SNR for various values for the number of active users (M), with setting the number of transmit antennas (N) to 4. From the Figure , it is observed that the proposed scheme provides higher capacity when the number of users is larger. This is expected since as the number of users increases, it is more likely that the base station schedules the users experiencing little interference from the other users. In addition, it is observed that the rate of increase of the capacity for larger number of users is greater since that's because we're assuming multichannel MUD in which the scheduling scheme exploits degrees of freedom in the channel.

In Figure 3, the capacity of the greedy scheduling with partial feedback is compared to that of the full feedback when the number of active users (M) is 10, with setting the number of transmit antennas (N) to 4, where it appears that the capacity is in the case of partial feedback is less than that in the case of full feedback, and we also note that the difference between the two curves grows larger with increasing the average signal to noise ratio.

It is also observed that for a given number of users, as the SNR increase, the capacity becomes limited since the system is interference limited at high SNR.

In Figure 4, the capacity of the greedy scheduling with partial feedback is compared to that of the full feedback when the number of active users (M) is 100, with setting the number of transmit antennas (N) to 4. It is noted that the capacity in the case of partial feedback is much less than that in the case of full feedback, that's because in the case of full feedback we have full knowledge of the channel and so the scheduler will make correct decisions almost all the time , while in the case of partial feedback, as some of the CSI is not reported then the scheduler will tend to choose users who are not actually the best users, and then assign them to be the best users and route the transmission for them, and this will lead to a loss in the advantage that we gained from having the transmission routed to users with better channel conditions much often than the others.

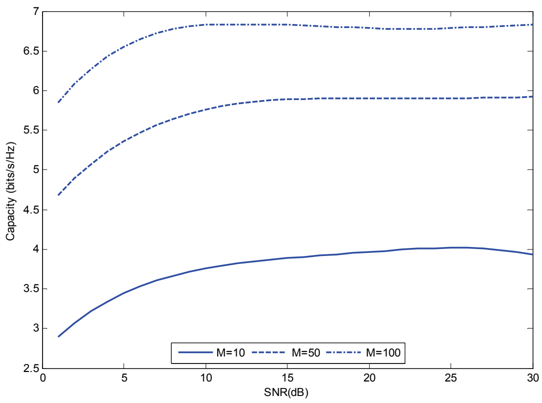

Figure 2: Capacity of the partial feedback scheme versus the mean SNR for various numbers of active users, M=10, M=50, and M=100.

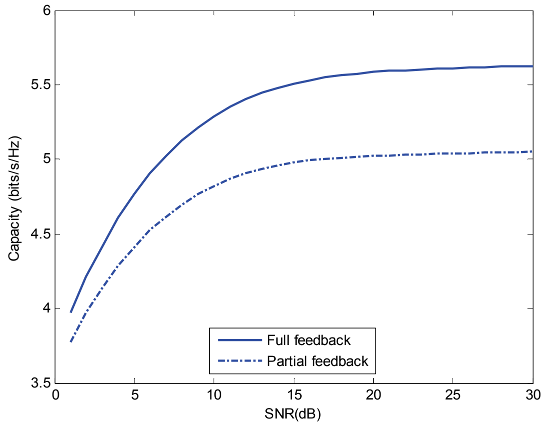

Figure 3: Capacity versus the mean SNR for full and partial feedback multiuser scheduling when the number of active users M=10.

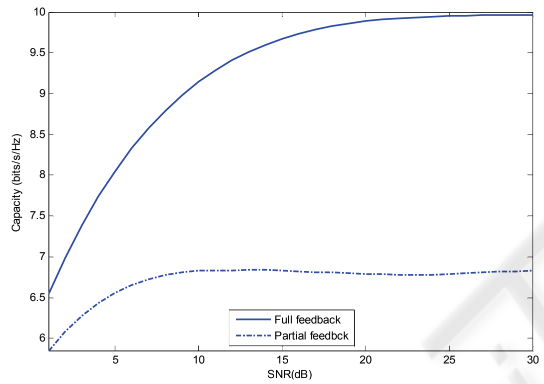

Figure 4: Capacity versus the mean SNR for full and partial feedback multiuser scheduling when the number of active users M=100.

When the number of antennas is set to 4 and the number of active users is 10, the three maximization rules were tested and they provided similar results in terms of the mean squared error, which was found to be about 0.246, which is surely dependent upon the parameters set in the Matlab code, and the MSE would change if they were changed.

To judge whether this loss in the capacity is tolerable or not, we need to look closer at the application in hand, where some applications will tolerate it, and others won't, but in general the loss in the capacity seems to be acceptable when the number of active users is small, while it is unacceptable when the number of active users is large. A significant advantage of this method, is that whatever the number of the transmit antennas, the user will still send only two of his paths' fading coefficients, which is much less than sending N fading coefficients by each user in the case of full feedback, and this would be extremely useful in the forthcoming generations of MIMO systems, where systems using large number of transmit antennas will be used much often.

Another advantage that is a sequence of the latter is saving the power and increasing the battery life for the user equipment, Also, the uplink path can now handle more traffic for other applications.

According to that we can propose a dynamic greedy scheduling that would give us the advantages of both full feedback and partial feedback in the same time. This could be done by setting the system such that if there is high traffic on the downlink channel, the BTS would prompt the users to report full CSI, while if there's high traffic on the uplink channel, the BTS would prompt the users to report partial CSI.

4 CONCLUSIONS

The capacity of the system when using partial feedback was compared to that when perfect CSI is used, the results proved that there is a small reduction in the capacity when the number of active users is small, this reduction increases when the number of active users becomes larger, i.e. regarding the capacity, partial feedback is inferior to full feedback when the number of active users is large.

At the end, we state that the proposed scheme can significantly reduce the complexity at the expense of a small loss in the system's capacity.

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