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EFFECT OF PER-USER THRESHOLD SCHEDULING OVER DIFFERENT FADING CHANNELS

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ABSTRACT

In this paper, we investigate scheduling algorithm for the downlink of a multiple input multiple output (MIMO) multiuser wireless system. A scheduling scheme is proposed that exploits multiuser diversities available in the channel. A scheduling scheme with per-user threshold in MIMO systems is proposed and then analyzed for various fading channels. The conventional scheduling scheme uses a common feedback threshold for all the users and analyzed for Single-Input and Single-Output systems. The proposed scheme constructs a sequence of feedback threshold, such that, each user compares its instantaneous Signal-to-Noise Ratio (SNR) with their corresponding threshold in the sequence. The threshold is a function of long-term average SNR of the users as well as the number of users involved in the process. Numerical and simulation results show that, due to the flexibility of the per-user feedback threshold, fairness is obtained. Also, the system capacity of the proposed scheme is better than the conventional scheme. Finally, the performances of different fading channels are evaluated and compared.

Keywords: per-user threshold, signal-to-noise ratio, SISO, MIMO.

INTRODUCTION

In wireless communication systems, as the spectrum became more and more precious resources, researchers investigated ways of improving the capacity of the wireless systems without actually increasing the required spectrum. Multi-antenna systems offer such a possibility [1].Multiple antennas can be used to enhance capacity via different scenarios: (a) *Diversity*, increases the quality of the received signal, which can be exploited to increase capacity. (b) *MIMO* increases the capacity of each link.

In [2], Knopp and Humblet pointed out another form of diversity inherent in a wireless system with multiple users, referred to as *multiuser diversity* that can be exploited to increase the system capacity. They demonstrated that, the system throughput can be enhanced through a scheduling scheme where the system resources are allocated to the user experiencing the most favorable channel. However, the scheduling algorithm presented in [3] is limited to single antenna systems. The general belief is that fading effects of wireless channels does not have a non- negative impact on the performance of the systems. But, actually fading channels can be used to obtain multiuser diversity and thus help to enhance the overall system performance in a multiuser environment when used with a proper scheduler [4].

Know fact that schedulers often become much more complicated as the number of users in the system increases, so we have to choose a low complexity scheduling algorithm with a reasonable system performance. The scheduler has to make a proper user selection, based on the users' channel quality information. Since the resources for a feedback channel from users to the base station (BS) are typically very limited, collecting channel quality information from potentially hundreds of users is expensive. So, in order to make the user selection process in a simpler manner and decrease the number of feedbacks, each user must trigger a feedback only when the channel quality is greater than the pre-determined threshold, which is termed the feedback threshold [5]. The notion behind this scheme is that the scheduler selects only the users with good enough channel quality. When multiple users send feedbacks, then collisions occur and this is the case of distributed feedback. Hence, a collision resolution needs to follow such that the whole procedure iterates until a single user is found. The other one is, a centralized feedback method which organizes the users to be orthogonal when they send feedbacks, such as time division multiplexing (TDM) where users are separated over time [6]. In order to find a single user, typically the best user, the feedback threshold needs to be adjusted such that the distributed feedback schemes may suffer from user fairness problems whereas the time division feedback access can re-arrange the user sequence for every scheduling process so that every user can have the same chance of taking the first place in user sequence over an extended period of time.

The basic principle of this scheme is to find any acceptable user instead of the best user. Here, the base station probes the users one by one, so only one user has an opportunity to send a feedback at one time. This scheme uses a common feedback threshold for all the users. But the proposed scheme allows different threshold for every user. Because of the threshold flexibility, the proposed scheme offers higher capacity than the conventional scheme.

The rest of the paper is organized as follows. Section II introduces the system of interest and reviews

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multiuser diversity concepts. The conventional scheme is revisited in Section III. The new scheduling scheme is developed in Section IV and Section explains some numerical results demonstrating the gains offered by the proposed scheme. Concluding remarks are offered in Section VI.

PRELIMINARIES

System Model

We consider the downlink of a cellular system for a data application with *M* users. We assume that the base station is equipped with N*t* antennas and the users have N*r* antennas. The base station has to deliver to each user independent information. We assume that each user has perfect information about the channel between the base station and its antennas. We consider a time slotted system where the base station allocates the system resources to different users at each slot based on the feedback information from the users [7]. A time slot consists of a short guard period followed by data burst. Selection of user is performed during the guard period and during the data burst, the selected user performs data transmission or reception. Time-slot duration is assumed to be in the order of channel coherence time such that channel quality stays roughly stationary over several time-slots.

Assume the scheduler builds a user sequence based on users long term average channel SNRs, not based on instantaneous SNRs. Therefore, when there is any change in some of the users channel statistics then the feedback threshold(s) have to be updated.

Fading Environment

Our analysis applies to many fading scenarios of interest. In Table-1, we summarize the PDF, $f_s(x)$, CDF, $F_s(x)$ of the faded signal power without diversity transmission for the three fading models under consideration, namely Rayleigh, Rice and Nakagami- m [8]. In Table-1, Ω is the average fading power, Γ (.)-- gamma function, $I_0(.)$ -- modified Bessel function of the first kind with zero order, $\Gamma(.,.)$ is the incomplete gamma function and Q_1 (.,.) is the first-order Marcum Q-function.

CONVENTIONAL SCHEME WITH COMMON THRESHOLD

The switched multiuser access scheme [9] is an extension of the multi-branch switch-and-examine diversity combining (SEC) scheme [8] to multiuser scenarios. In the time slotted system, the scheduler performs a sequential search over users during the guard period. Each user compares its channel quality with the pre-determined feedback threshold, denoted by γ^*.The pre-determined feedback threshold is the common feedback threshold for all users. If the users' channel quality is greater than the threshold then it sends a feedback containing its UID. This process continues until a user channel quality exceeds the threshold. If no user exceeds the feedback threshold, then the scheduler selects the last examined user for the subsequent data transmission. This case is called a scheduling outage. The optimal feedback threshold, denoted by $\gamma^*$is a function of the total number of users involved in the user selection process and the average channel SNRs of those users.

The capacity of the conventional scheme is written as [13].

$$C_c = B \int_0^\infty \log(1+x) f_\gamma(x) dx \quad [\text{bps/Hz}] \tag{1}$$

where B is the system bandwidth, log (·) is the logarithm function with base 2, and $f_\gamma(x)$ is the probability density function (PDF) of output SNR given by[3]

$$f_\gamma(x) = \begin{Bmatrix} \sum_{i=0}^{M-1} \prod_{k=1}^{i} F_k(\gamma_s) f_{i+1}(x) & , x \geq \gamma_s \\ \prod_{k=1}^{M-1} F_k(\gamma_s) f_M(x) & , x < \gamma_s \end{Bmatrix} \tag{2}$$

where f_k (.) and F_k (·) are the PDF and the cumulative distribution function (CDF) of the k^{th} user, respectively. The optimal feedback threshold can be calculated as

$$\gamma_s^* = \arg\max_{\gamma_s} C_c$$
(3)

where C_c is the capacity of the conventional switched multiuser access scheme.

PROPOSED SCHEME WITH PER-USER THRESHOLD SCHEDULING

The method uses a sequence of feedback thresholds, where the k^{th} user compares its channel quality with its own feedback threshold in the sequence, which is denoted by γ_{sk}^*.

Mode of Operation

The first user compares its channel quality with its own threshold γ_{s1}^*. If the channel quality exceeds the threshold of its own, then the user sends a feedback. Otherwise, the second (next) user compares its channel quality against its own feedback threshold γ_{s2}^*. Again, if the second users' channel quality exceeds γ_{s2}^* , the second user sends a feedback, and otherwise the next user will be examined. This process continues until either a user with greater channel quality than its corresponding feedback threshold is found or all the users are examined.

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Table-1. Statistics of faded signal power S for the three fading models under consideration.

Model	Rayleigh	Rician	Nakagami-m
Parameter		$K=n^2 \geq 0$	$m \geq 0.5$
PDF($f_s(x)$)	$e^{\frac{-x}{\Omega}} \frac{1}{\Omega}$	$\frac{1+n^2}{\Omega} e^{-n^2-\frac{(1+n^2)x}{\Omega}} I_0\left(2n\sqrt{\frac{1+n^2}{\Omega}x}\right)$	$\frac{x^{m-1}}{\Gamma(m)} e^{\frac{-mx}{\Omega}} \left(\frac{m}{\Omega}\right)^m$
CDF($F_s(x)$)	$1-e^{\frac{-x}{\Omega}}$	$1-Q_1\left(n\sqrt{2}, \sqrt{\frac{2(1+n^2)}{\Omega}x}\right)$	$1-\frac{\Gamma(m,\frac{m}{\Omega}x)}{\Gamma(m)}$

The whole user selection process ends, as soon as the scheduler detects a feedback from any user. If all the users fail to exceed their feedback thresholds, then the last examined user is selected for simplicity [8], [9]. Therefore, the threshold for the last user is not required. If the feedback threshold remains constant for all the users then the proposed scheme becomes similar to the conventional scheme. The proposed scheme, therefore, is a generalized form of switched multiuser access schemes. The main idea in the proposed scheme lies in the introduction of per-user threshold such that each user uses its own threshold rather than the common threshold existing in the conventional scheme.

USER SEQUENCE

The scheduler builds a user sequence based on users' long term average channel SNRs ($\gamma_{sk}^{*}$for the k^{th} user). In this strategy, the users are sorted in a descending order of their long-term average SNRs. Such that the user sequence is known as Capacity maximizing sequence

OPTIMAL THRESHOLD

Our goal is to construct the sequence of optimal feedback thresholds $\{\gamma_k^*\}_{k=1}^{M-1}$ that maximize the system capacity. C_p is the capacity of the proposed scheme, which can be written based on the mode of operation as

$$C_p = B\left\{\begin{array}{c}\sum_{i=1}^{M-1}\prod_{k=1}^{i-1} F_k(\gamma_k^*) \int_{\gamma_i^*}^{\infty} \log(1+x) f_i(x)dx \\ + \\ \prod_{k=1}^{M-1} F_k(\gamma_k^*) \int_0^{\infty} \log(1+x) f_M(x)\,dx\end{array}\right\} \quad (4)$$

Considering a different threshold for each user, we equate as

$$\{\gamma_1^* \dots\dots \gamma_{M-1}^*\} = arg\max_{\{\gamma_1^* \dots\dots \gamma_{M-1}^*\}} C_p$$
(5)

Taking a derivative of C_p with respect to the thresholds and then solving it is easy to see that

$$\frac{\partial Cp}{\partial \gamma_1^* \dots \gamma_{M-1}^*} = -\log(1+\gamma_{M-1}^*) + \int_0^{\infty} \log(1+x)\, f_M(x)dx \quad (6)$$

On equating the above equation to zero, we get

$$\gamma_{M-1}^* = \exp[\int_0^{\infty} \ln(1+x) f_M(x)dx] - 1 \quad (7)$$

In the same way, $\{\gamma_{M-2}^* \dots\dots \gamma_1^*\}$ can be found one after another using the following recursion:

$$\gamma_n^* = \exp\left[\begin{array}{c}-\sum_{k=n+1}^{M-1} e^{1/\bar{\gamma}_k} \quad Ei\left(-\frac{1+\gamma_k^*}{\bar{\gamma}_k}\right) \\ -e^{1/\bar{\gamma}_M} Ei\left(-\frac{1}{\bar{\gamma}_M}\right)\end{array}\right] - 1 \quad (8)$$

where n = 1 …M-1 and Ei (.) is the exponential integral function [6] defined as

$$Ei(x) = -\int_{-x}^{\infty} \frac{e^{-t}}{t} dt \quad (9)$$

The intuition behind the above recursion is given as follows. In this paper, thresholds have a unidirectional relation. The thresholds in the threshold sequence are not mutually correlated, since the users are evaluated in a sequential manner. Here a threshold depends only on the later thresholds in the sequence but not on the previous thresholds, i.e., γ^*_n is only a function of $\{\gamma^*_{n+1}, \cdot\cdot\cdot, \gamma^*_{M-1}\}$, but not a function of $\{\gamma^*_1, \cdot\cdot\cdot, \gamma^* n-1\}$, where n = 1, · · ·, M −1. Thus, γ^*_{M-1} does not have a correlation with any others and therefore can be first obtained. Once γ^*_{M-1} is determined, γ^*_{M-2} can subsequently be obtained. Similarly, the rest of the thresholds can be obtained backwards one after another.

NUMERICAL RESULTS

Figure-1 compares the capacity of the conventional scheme and that of the proposed scheme when both are used with the optimal feedback threshold(s) in case of independent and identical Rayleigh channel statistics over all the users.

As shown in the figure, the proposed scheme offers some capacity gain over the conventional scheme. The intuition behind the capacity gain achieved by the proposed scheme is provided based on per-user threshold. The proposed scheme allows the first users in the user sequence to start with high thresholds in order to increase the good put, whereas the later users in the user sequence use low thresholds, which eventually results in the maximum capacity. Therefore, the optimal thresholds for the proposed scheme are monotonically decreasing, as shown in Figure-4.

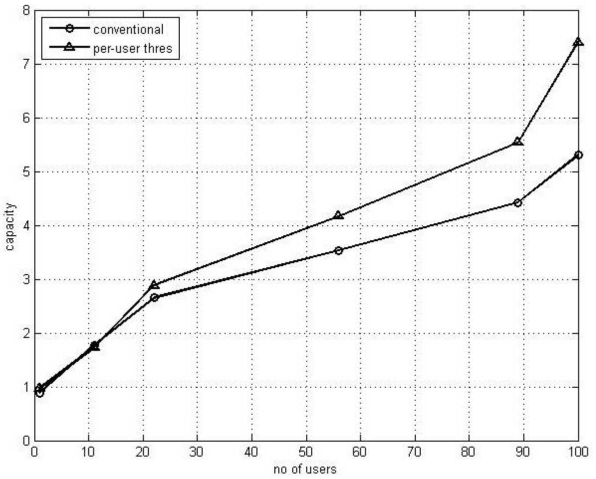

Figure-1. Capacity comparison between the common threshold for all users (conventional scheme) and the per-user threshold for all users (proposed scheme) as a function of the number of users over Rayleigh fading channels when the average user channel SNR is 12 dB.

Figure-2 shows that when the number of antenna increases in either in the transmitter or/ and receiver then the capacity of such systems gives increased capacity over the single-input single- output system [10], [11].

Figure-3 shows that the Rayleigh fading environment is the least one when the capacity of all other channels (Rician, Nagakami, AWGN) considered. Therefore the Rayleigh channel is used to model small-scale fading in wireless communication [12].

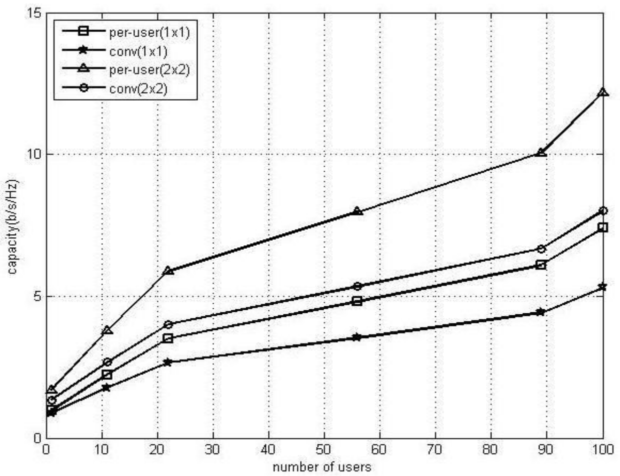

Figure-2. Capacity comparison between SISO and MIMO using the per-user threshold for all users over Rayleigh fading channel.

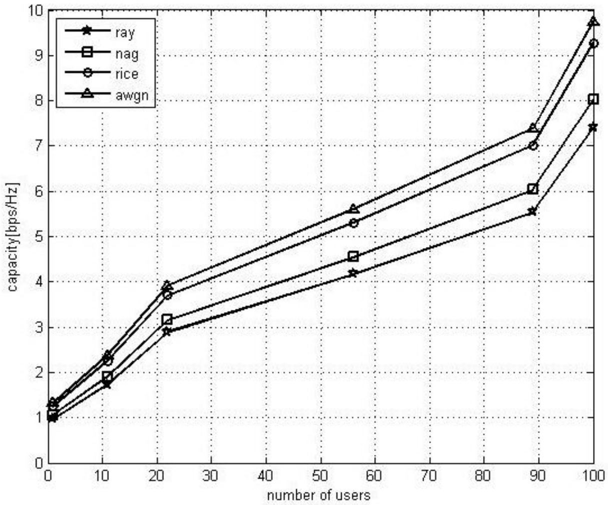

Figure-3. Capacity comparison between different fading channels using per-user threshold scheduling.

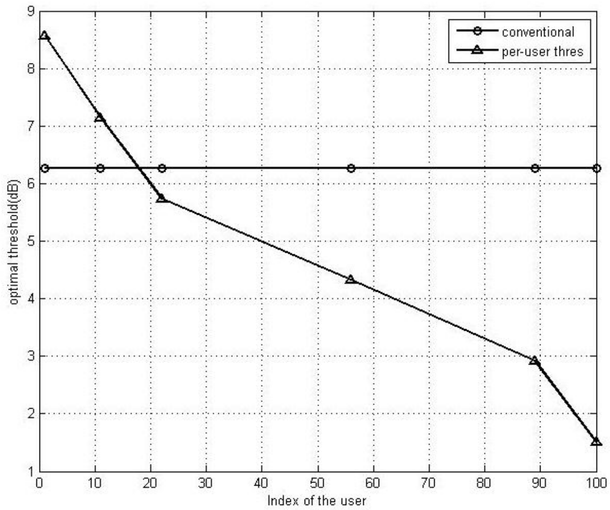

Figure-4. Sequence of optimal feedback thresholds for the proposed scheme for 52 users.

CONCLUSIONS

A switched multiuser access scheme with per-user threshold is introduced in the concept of MIMO and compared over different fading channels is proposed in this paper. Interestingly, having a different feedback threshold for each user instead of a single threshold allows each optimal feedback threshold in the sequence to be computed one after another based on a simple recursive equation. More importantly, the proposed scheme provides a higher capacity than the conventional scheme when both are used with the optimal threshold(s) due to the flexibility of threshold selection.

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