Exploiting Multiuser Diversity in Scheduling MIMO Cellular Systems

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Abstract— In this paper we consider a scheme of packet scheduling for the forward link of a MIMO cellular system, to increase system capacity by exploiting multiuser diversity based on spatial multiplexing (SM). The proposed scheme exhibits considerable increases in system capacity compared to commonly used schemes, while, at the same time, giving a fair chance of channel access to all users regardless of their channel fading status.

Index Terms— Antenna selection , MIMO systems, spatial multiplexing (SM), Wireless channels.

I. Introduction

Multiple-input-multiple-output (MIMO) cellular systems are communication systems in which the base station (BS) and the mobile stations (MS) are equipped with multiple transmit/receive antennas. These cellular systems, unlike SISO (single-input-single-output) cellular systems, are able to exploit the fading nature of the wireless channel [1]. A multiplexing scheme that is suitable for such systems is spatial multiplexing (SM). In SM, the downlink input packet stream is divided into different packet substreams, destined to different mobile stations, and each one of these substreams is sent out through a different transmit antenna [2]. Therefore, SM may exploit multiuser diversity, that is, the varying fading and interference characteristics of each user in a MIMO system, in order to increase system throughput.

Antenna selection based on multiuser diversity has been addressed in various schemes to minimize the symbol error rate as in [3]-[7], and to increase system capacity as in [1], [2], [8],[9], [10], [11]. The work in [3]-[7] show that, given perfect channel status information available at the receiver side, a variety of methods including linear, successive, and maximum likelihood (ML) decoding can be used to remove the effect of the channel and reassemble the transmitted substreams. In particular, the authors in [7] proposed a criteria for selecting a subset of transmit antennas in spatial multiplexing systems that employ different types of receivers in order to minimize the symbol error rate. While, in [8], users compete independently for each transmit antenna, and the base station assigns each transmit antenna to the user who has the best associated channel, i.e., the highest signal-to-interference-plus-noise ratio to increase the system capacity. According to this scheme, a user may employ more than one antenna, depending on channel conditions. Therefore, this scheduling scheme does not give fair channel access to all users, as users with severe fading conditions may not have any chance to receive data from the base station.

In [11], the authors investigate the problem of *receive* antenna subset selection in MIMO spatial multiplexing systems,

where they developed selection algorithm for maximizing the system capacity.

In [10], the authors propose a transmit antenna selection scheme that gives fair access to all users while still achieving higher system capacity than the simple round-robin scheme (RRS). The scheme in [10], called antenna-assisted round-robin-scheme (AA-RRS), initially segments active users into groups in a round-robin fashion, with the number of users in each group equal to the number of transmit antennas in the base station. Then, at symbol time t, the transmit antennas will be assigned to mobile users in a greedy way, i.e., in the way that maximizes system capacity.

In this paper, we propose a scheduling scheme that guarantees channel access to all users and exhibits significant increases in system capacity as compared to AA-RRS. We use the word *cycle* to refer to the symbol time interval in which the base station is serving a set of users. Our approach is to allow the users to compete independently for the transmit antennas in one scheme with two different views in the last cycle in around. In the first view (V1), each user is allowed to use only one antenna per cycle (with the exception that users are allowed to use more than one antenna if the total number of active users in the cell are less than the number of transmit antennas in the BS), unlike the scheme in [8]. In the second view (V2), some users may use more than one antenna in the last cycle of a round depending on their channel status even if the number of total active users are more than the number of transmit antennas in the BS.

The remaining of this paper is organized as follows: In Section II, we introduce the system setup under investigation. Demonstration of our proposed transmit antenna selection is given in Section III. Simulation results of the proposed scheme and of AA-RRS scheme [10] are discussed in Section IV. Finally, we conclude our results in Section V.

II. System Setup

The system model we investigate in this paper is shown in Fig. 1 [10], described as follows: we consider the forward link (downlink) of a single cell MIMO cellular system with the base station equipped with N_t transmit antennas, and each mobile station equipped with $N_r \geq N_t$ receive antennas. K active users are distributed uniformly over the cell area with radius R and served by the base station in a time-division manner. At the base station, each transmit antenna is loaded with different data, and the N_t transmit antennas share the available transmit power. The receiver at each mobile station is assumed to be a linear minimum mean square error (MMSE)
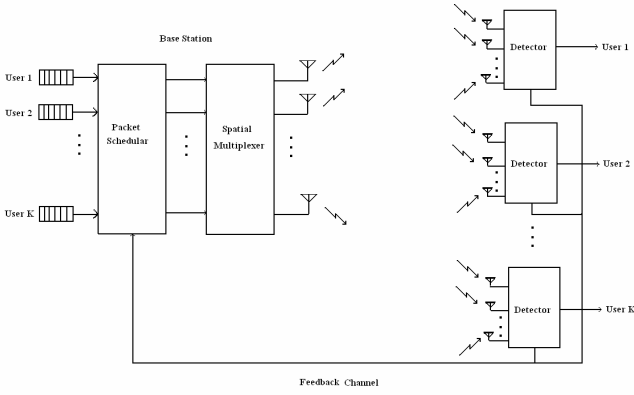
Fig. 1.   Down-link MIMO cellular system.

detector to estimate its symbol from the received signal as in [9]. Using pilot signals, the receiver at each mobile station estimates the post-detection signal-to-interference-plus-noise-ratio (PD-SINR) received from each transmit antenna and sends this information to the base station via a robust feedback channel. Then the base station builds a matrix of all these estimates of PD-SINRs and assigns each transmit antenna (spatial channel) to the user who has the best associated channel, i.e.,the highest PD-SINR.

The transmitted signal undergoes log-normal shadow fading, path attenuation and multipath flat fading. The channel is assumed to be varying independently from cycle (symbol time interval) to cycle. The background thermal noise is assumed to be additive white Gaussian noise (AWGN) with variance σ^2 per receive antenna. Let SNR_0 represent the median signal-to-noise ratio at the cell boundary, r_k be the distance of the k'th mobile station from the base station, and α denote the path loss exponent. The channel matrix $H_k(t)$ has elements that characterize the signal attenuation between the base station and the k'th mobile station at symbol time slot t [10], as given by

$$H_k(t) = \sqrt{SNR_0 \left(\frac{r_k}{R}\right)^{-\alpha} 10^{S_k(t)/10}} \, G_k(t), \qquad (1)$$

where $S_k(t)$ is a zero mean real Gaussian process with variance σ_S^2 to capture the log-normal shadow fading effect. $G_k(t)$ is a $N_r \times N_t$ matrix with each entry modelled as an independent and identically distributed (iid) zero-mean complex Gaussian process with variance 1 in each dimension and uniform phase. Thus, the multipath fading coefficients between the transmit antennas of the base station and the receive antennas of kth mobile station are modelled as Rayleigh random processes.

III. PACKET SCHEDULING SCHEME

In this Section we propose a scheme for packet scheduling with two different views in the last cycle, namely, view 1 (V1) and view 2 (V2), to simultaneously address fairness of channel assignment and maximization of system capacity. In both views of the proposed scheme, each user competes independently with the other active users in the cell, for the assignment of a transmit antenna. An efficient and fair method

of assignment of the N_t transmit antennas to N_t users (out of K active users) at each cycle of transmissions is the desired algorithm to be employed at the base station. Unlike AA-RRS, *all* active users estimate the values of PD-SINRs received from each transmit antenna and send these values back to the base station via a robust feedback channel. For each cycle, the base station transmits N_t different symbols of N_t different users through the N_t transmit antennas, with one transmit antenna for each mobile station. The base station uses the highest estimated PD-SINRs corresponding to yet unserved receivers to match transmit antennas to mobile stations. In the next cycle, a different group of N_t users are served. The N_t users who are served in a given cycle are not allowed to compete again until all users have had access to a transmit antenna. Another difference between the proposed scheme and the AA-RRS scheme is that the users served at the first cycle (first symbol time interval) are random, and the randomness level decreases from cycle to cycle in a round, as less users compete for transmission.

The distinction between the two different views of the proposed scheduling scheme is related to the last cycle in a round (last symbol interval before all users can compete again). It occurs when the number of remaining users in the last cycle of the round is less than N_t. In V1, each user in the remaining set of users will be assigned to one transmit antenna, while the other users, who have been already served in previous cycles, will compete independently for the remaining transmit antennas. In the alternative scheme, V2, After assigning the remaining users to their corresponding transmit antennas, *all* users including the left over users will compete for the remaining antennas.

Transmit antenna (spatial channel) assignments to users in the proposed scheme under both views take place as follows. User k ($1 \leq k \leq K$) sends to the base station an estimate of its PD-SINR $\gamma_{k,n}(t)$ for the reception of the signal sent over the nth ($1 \leq n \leq N_t$) transmit antenna at symbol time slot t. The values of $\gamma_{k,n}(t)$ after MMSE filtering may be expressed as [9]:

$$\gamma_{k,n}(t) = \frac{|[W_k(t)H_k(t)]_{nn}|^2}{(\sigma^2/P_r') \sum_{m=1}^{N_t} |[W_k(t)]_{nm}|^2 + \sum_{m \neq n}^{N_t} |[W_k(t)H_k(t)]_{nm}|^2} \qquad (2)$$

where $P_r' = P_r/N_t$, and P_r is the total received signal power (for N_t symbols), and $W_k(t)$ is the $N_t \times N_r$ MMSE processing matrix, given by [9]:

$$W_k(t) = H_k(t)^* \left(H_k(t) H_k^*(t) + \frac{\sigma^2}{P_r'} I_{N_r}\right)^{-1} \qquad (3)$$

where $*$ denotes the Hermitian matrix, and I_{N_r} is the $N_r \times N_r$ identity matrix. The base station uses all these received values of PD-SINRs $\gamma_{k,n}(t)$ to construct a $K \times N_t$ channel-state matrix $\Gamma(t)$. Then, the base station uses a max-delete search (MDS) as in [10] (modified to fit our proposed scheme with V1 and V2) to determine the ordered subset of $\{k_n\}_{n=1}^{N_t}$ users that maximizes the system capacity at symbol time slot

t, given by [10]:

$$C_{V1,V2}(t) = \sum_{n=1}^{N_t} \log_2(1 + \gamma_{k_n,n}(t)), \qquad (4)$$

where k_n represents the index of the user assigned to receive data from transmit antenna n. The MDS algorithm for users independently competing for the transmit antennas at time slot t works as follows: The base station searches for the maximum PD-SINR in $\Gamma(t)$. Suppose the maximum is the (j,n)th entry. Then the nth antenna will be assigned to the jth user. Then the nth antenna and jth user are excluded, for the remaining of the round, by zeroing the nth column and the jth row of $\Gamma(t)$. Next, another maximization of PD-SINR in the modified $\Gamma(t)$ is performed to assign another antenna to another user, and so on until all N_t transmit antennas are assigned to N_t users.

The MDS algorithm is used for both views of the proposed scheme as long as the number of antennas for assignment is not less than the number of pending users. In case the number of remaining users in the last cycle is less than N_t, the views in the last cycle differ as follows: Under V1, assume that the number of remaining users (which equals the number of nonzero rows of $\Gamma(t)$) is $K_1 < N_t$. The MDS algorithm is applied to assign K_1 transmit antennas to the K_1 leftover users. Then the original channel-state matrix $\Gamma(t)$ is modified by zeroing the K_1 rows that correspond to the users already served in the last cycle and the K_1 columns that correspond to the assigned transmit antennas. All the $K - K_1$ users who were served in earlier cycles compete to use the $N_t - K_1$ unassigned antennas by applying the MDS algorithm to the newly modified $\Gamma(t)$ matrix. Alternatively, under V2, the MDS algorithm is initially applied to matrix $\Gamma(t)$ to assign K_1 transmit antennas to the $K_1 < N_t$ leftover users (exactly as in V1). Then, the K_1 columns that correspond to the assigned antennas are zeroed, but *all* rows of the original $\Gamma(t)$ are retained for completing the antenna assignments. The motivation is to allow all users (including those K_1 just considered) to compete for the remaining $N_t - K_1$ transmit antennas.

IV. SIMULATION RESULTS

Since the system capacity in (4) is a random variable, in this Section, we evaluate the performance of our proposed scheme with V1 and V2 in terms of the expected system capacity, the 10%-outage capacity and the 1%-outage capacity, and compare them with the results of AA-RRS [10]. The expected system capacity is estimated as the system capacity in (4) averaged over 2×10^4 channel realizations of (1). The 10%-outage capacity is the value of the system capacity that is exceeded 90% of the time. Similarly, the 1%-outage capacity is the value of the system capacity that is exceeded 99% of the time. In this paper we consider as an example the same system as in [10], adopting parameters $N_t = N_r = 4$, and $SNR_0 = 10$ dB. The path loss exponent is assumed to be 3.7, and the log standard deviation of shadow fading, denoted by σ_S, is 8 dB. Also, r_k and $S_k(t)$ in (1) are assumed to vary on the same time-scale as $G_k(t)$, to simplify the simulation.

By examining Figs. 2 to 4, a significant increase in system capacity is noticed for the proposed scheme as compared to AA-RRS. The reason is that the proposed scheme takes more advantage of multiuser diversity than AA-RRS, by independently allowing all users to compete for the transmit antennas. Additionally, the proposed scheme is fair in the sense that it maintains a uniform access of system slots given to all users in each round of cycles. Results of the proposed scheme under V1 and V2 are identical when the number of users K is a multiple of N_t (since the number of pending users in the last cycle equals N_t). Otherwise, V2 exhibits higher system capacities than V1. The reason is that V2 allows more users to compete for the remaining antennas in the last cycle compared to V1.

Note, proposed scheme (under V1 and V2) and AA-RRS have essentially the same values of expected system capacities when $K \leq N_t$. The differences may be more accentuated for some choices of K and N_t. Consider, for example, the case when $K = 3$ and $N_t = 4$. Here, AA-RRS assigns users periodically in the following groups: $\{1,2,3,1\}$, $\{1,2,3,2\}$, and $\{1,2,3,3\}$, where the numbers denote the user indices corresponding to each antenna in three consecutive cycles. Thus, the expected system capacity is the average of the system capacities of these groups. On the other hand, for the proposed scheme with both views, V1 and V2, if fading conditions are varying slowly, there will be only one type of assignment, with the "best" user getting access to an additional antenna, so the system capacity is the largest system capacity of the groups listed above.

One observation on the results depicted in Figs. 2 to 4 is that the system capacity achieved under the proposed scheme with both views V1 and V2 decreases as we go from number of users $K = 3$ to $K = 4$. This may be the due to the approach of assigning the last antenna, in case of $K = 3$, 3 users will compete for the last antenna, while for $K = 4$ only one user is competing for the last antenna.

Moreover, When the number of active users is such that higher number of users are competing for yet unassigned antennas in the last cycle, higher system capacity will be attained as we can see from the figures. This explains the drop in the system capacity as we go from $K = 7$ to $K = 8$.

V. CONCLUSIONS

In this paper we propose a scheme with two different views in the last cycle for scheduling packets in the forward (direct) link of a MIMO cellular system. Users served at each cycle (symbol time period) are random, and the randomness level decreases progressively from cycle to cycle, until all users are served. Simulation results suggest that the proposed scheme with the two different views in the last cycle, (V1 and V2) yield a noticeable increase in system capacity when compared to AA-RRS [10]. Moreover, a uniform access of system slots given to all users in each round of cycles, by allowing all users to access the channel, regardless of channel conditions.

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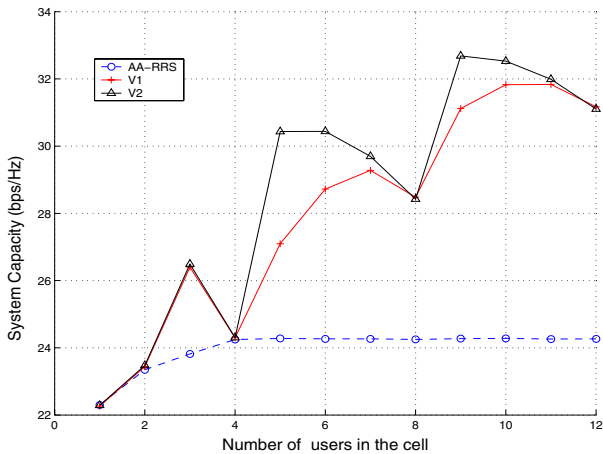
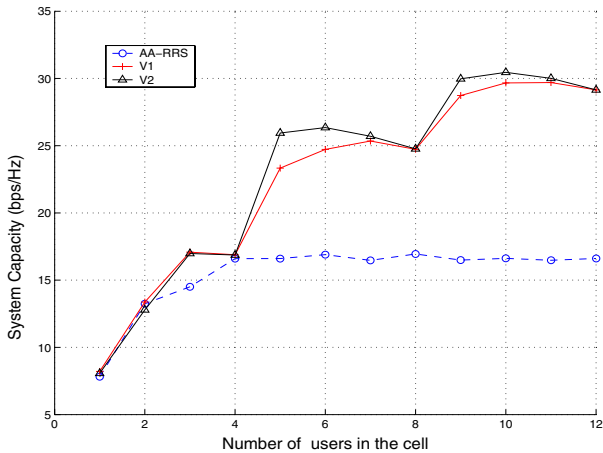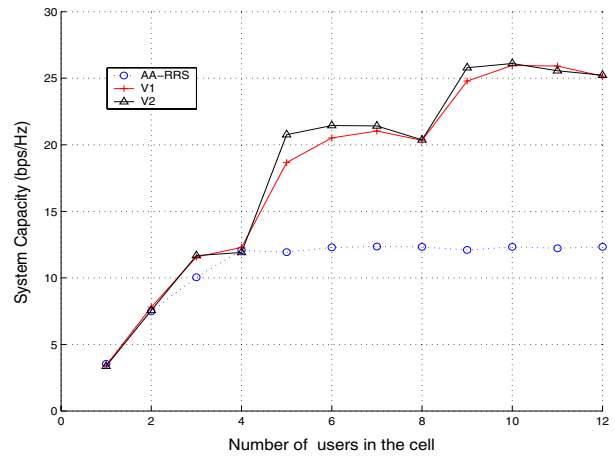Fig. 2.   Expected capacity versus the number of users in the cell.

Fig. 4.   1% outage capacity versus the number of users in the cell.

Fig. 3.   10% outage capacity versus the number of users in the cell.