

Uplink Scheduling Criteria Comparison for V-BLAST Users

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Abstract: We study in this paper uplink scheduling for V-BLAST users. Each user spatially multiplexes his data over multiple transmit antennas. This spatial multiplexing (SM) scheme provides high data rates while multi-user diversity obtained from scheduling improves the performance of the uplink system. The scheduler selects one user at a time based on a criterion that minimizes aggregate BER. The main results of this study show that the scheduler that maximizes the optimal MIMO capacity doesn't work well for a V-BLAST system. Instead, a scheduler that maximizes the V-BLAST capacity is derived specifically from the V-BLAST detection algorithm. Furthermore, we propose and compare suboptimal schedulers that are based on the received MIMO channels before processing.

I. INTRODUCTION

Until recently, most of the studies on MIMO techniques were focused on optimizing the physical layer. However, in a multiuser environment, optimizing the physical layer for each user doesn't necessary optimize the system performance nor does it take advantage of the statistical independence of the fading channels among the users in a typical mobile environment. Furthermore, different users have different needs in terms of data rates, power limits and Quality of Service (QoS). These requirements make scheduling an important technique for optimizing the performance of a communication system and utilizing the system resources efficiently. Scheduling transmission to the best user leads to a form of selection diversity known as multiuser diversity [1].

In single-input single-output (SISO) systems, where each mobile and the base station have one antenna, it was shown that selecting the user that has the maximum signal to noise ratio (MaxSNR) maximizes the total information capacity of the uplink system [2]. This scheduler is known as MaxSNR scheduling. Over MIMO channels, most of the studies are based on theoretical information capacity [3-5] and on the downlink, which is the broadcast channel from the base station to the mobile unit. It has been shown in [6] that space time block coding (STBC) and scheduling aren't a good match. In fact, scheduling to a user with a single antenna can outperform scheduling using STBC. The reason is that STBC averages the fades while the scheduler tends to benefit from high peaks in the fading channel. In addition, the multiuser diversity obtained from scheduling is much higher than the spatial diversity of STBC, so STBC diversity doesn't add much benefit. On the other hand, spatial multiplexing (SM) schemes are more synergistic with scheduling. This is because they

provide high data rates while the scheduler provides multiuser selection diversity.

In a MIMO system, scheduling can be done to a single user or multiple users. Scheduling to multiple users, i.e allowing more than one user to transmit or receive at the same time, is shown to be optimal in terms of maximizing system capacity and throughput. In [3], downlink scheduling to multiple users improved the average throughput compared to single user scheduling. Furthermore, the optimal uplink MIMO scheduling based on an information theoretical approach was considered in [7]. They showed that the scheduler should allocate all the power to at most M_R users, where M_R is the number of receive antennas at the base station. Also, they found that the optimal power resource allocation is water-filling in space and time. In [4], the authors found that multiuser scheduling reduces the average delay experienced by the users compared to single-user scheduling.

In this paper, we investigate scheduling for uplink V-BLAST [8] users. V-BLAST is a practical spatial multiplexing (SM) MIMO system. We focus on single-user scheduling. Although it is not optimal, it is more practical and easily implemented. The search space for best transmission is much less than the multiuser case and a multiuser diversity of order K , where K is the number of users, can be achieved. The scheduler selects one user at a time based on a criterion that minimizes the aggregate error rate of the uplink MIMO system. Each user spatially multiplexes their data over the transmit antennas to provide high data rates while the multiuser diversity obtained from scheduling improves the performance of the uplink system. Our main contribution in this work is finding the capacity maximization scheduling criteria for V-BLAST uplink users. Also, the results show that the scheduler that maximizes optimal MIMO capacity doesn't work well for V-BLAST. The V-BLAST maximum capacity scheduler is derived specifically from its detection algorithm. Furthermore, we investigate the performance of suboptimal scheduling criteria that are based on the MIMO channel matrix directly.

II. SYSTEM MODEL

We consider scheduling a single user at a time. The average SNR is assumed to be the same for all users; they are either at a similar distance or they use loose power control. There are K users and each user transmits through M_T transmit antennas and the receiver has M_R receive antennas. A block diagram of the uplink system is shown in Figure 1. The MIMO

channel is assumed to be an independent Rayleigh flat fading MIMO channel where each coefficient is an i.i.d complex Gaussian random variable with zero mean and unit variance. The received signal from user k is:

$$\mathbf{y}_k = \mathbf{H}_k \mathbf{x}_k + \boldsymbol{\eta}_k \quad (1)$$

where \mathbf{y}_k is an $M_R \times 1$ received vector, \mathbf{H}_k is an $M_R \times M_T$ MIMO channel matrix for the k^{th} user, \mathbf{x}_k is an $M_T \times 1$ transmitted symbols from user k , and $\boldsymbol{\eta}_k$ is an $M_R \times 1$ i.i.d complex AWGN vector of zero mean and variance $N_0/2$ per dimension.

III. SCHEDULING CRITERIA

Assuming that an optimal MIMO encoder and decoder are available, the scheduler that maximizes the optimal MIMO capacity selects a user k such that:

$$k = \arg \max_{n=1,2,\dots,K} \{C_n\}; \text{ where}$$

$$C_n = \log_2 \left(\det \left(\mathbf{I}_{M_R} + \frac{SNR}{M_T} \mathbf{H}_n \mathbf{H}_n^H \right) \right) \quad (2)$$

where \mathbf{I}_{M_R} is the identity matrix and \mathbf{A}^H is the conjugate-transpose (Hermitian) of \mathbf{A} .

For V-BLAST users, selecting the user that has the maximum SNR (MaxSNR), as in [2], is not optimal and scheduling based on maximization of MIMO channel capacity as in (2) is also not optimal for V-BLAST since its detection algorithm is suboptimal.

Since V-BLAST is an open loop system and all layers have the same rate, an outage in capacity will occur if an outage happens in at least one layer. Therefore, the V-BLAST capacity is dominated by the weakest layer and it is given by [9]:

$$C_{VBLAST}^{ZF} = M_T \cdot \min_{i=1,2,\dots,M_T} \left\{ \log_2 \left(1 + \frac{SNR}{M_T \|W_{ZF,i}\|^2} \right) \right\} \quad (3)$$

where $W_{ZF,i}$ is the ZF projection row for the i^{th} layer and M_T is the number of layers (transmit antennas).

V-BLAST detector performs a series of interference nulling and cancellation operations. At the n^{th} stage, the ZF nulling matrix is:

$$\mathbf{W}_{ZF} = \left(\mathcal{H}_n^H \mathcal{H}_n \right)^{-1} \mathcal{H}_n^H \quad (4)$$

where \mathcal{H}_n is the MIMO channel matrix after canceling the $n-1$ detected layers.

The detected layer at this stage, assume it is the i^{th} layer, is the strongest layer which has:

$$\|W_{ZF,i}\|^2 = \min \left(\text{diag} \left(\left[\mathcal{H}_n^H \mathcal{H}_n \right]^{-1} \right) \right) \quad (5)$$

and its post-processing SNR is:

$$SNR_i^{ZF} = \frac{SNR}{M_T \|W_{ZF,i}\|^2} \quad (6)$$

After detecting all layers, the capacity of V-BLAST is determined by the weakest layer as in (3). The norm of the ZF projection row of the weakest layer for user k is:

$$w_k = \max_{i=1,2,\dots,M_T} \left\{ \|W_{ZF,i}^k\|^2 \right\} \quad (7)$$

where $W_{ZF,i}^k$ is the ZF projection row for the i^{th} layer of user k .

Then, the scheduler that maximizes V-BLAST capacity selects user k such that:

$$k = \arg \min_{k=1,2,\dots,K} \{w_k\} \quad (8)$$

To reduce the computations needed to perform the above scheduler, we examine suboptimal schedulers that are based on the received MIMO channels before V-BLAST processing. The first one chooses the user with the largest MIMO channel power ($\text{trace}(\mathbf{H}_k \mathbf{H}_k^H)$) and we refer to it as MaxSNR scheduler, which mimics the optimal scheduler for single antenna systems. The other scheduler measures the eigenspread of $\mathbf{H}_k \mathbf{H}_k^H$ and selects the user with the minimum eigenspread (MinES). The eigenspread is defined as $s = \lambda_{\max} / \lambda_{\min}$ where λ_{\max} and λ_{\min} are the largest and smallest eigenvalues of $\mathbf{H}_k \mathbf{H}_k^H$. The eigenspread gives insight into the orthogonality of the channels. The smaller the value of s , the closer the matrix is to be orthogonal. The minimum value of s is one, and it occurs when the channel matrix is orthogonal.

Let ρ_{\max} and ρ_{\min} be the largest and smallest singular values of \mathbf{H}_k , then we have the following relation:

$$\rho_{\min} = \frac{\rho_{\max}}{\sqrt{s}} \quad (9)$$

Thus, selecting the user that has the largest minimum singular value of \mathbf{H}_k takes into account both the channel power and the eigenspread of \mathbf{H}_k . We refer to this scheduler as MaxMinSV.

The performance of these algorithms are compared to round-robin (RR) scheduling which is a passive algorithm that cycles equally through all users irrespective of their channel status and it doesn't obtain any multiuser diversity.

IV. SIMULATION RESULTS

The aggregate BER performance of the wireless uplink system with scheduling is shown in Figure 2 for 10 users at 8bps/Hz and over 4×4 MIMO channels. The MaxSNR scheduler captures very little multiuser diversity and it gains around 1dB compared to the RR algorithm. On the other hand, the best scheduler is the one that maximizes V-BLAST capacity (MaxVBLASTCap) by selecting the user who has the strongest weakest layer as described earlier. The MinES and the MaxMinSV schedulers capture most of the multiuser diversity but MaxMinSV provides more gain since it takes into account the power of the MIMO channel. They perform very close to MaxVBLASTCap which has more diversity at high SNR (sharper slope). The results in this figure also show that using maximum MIMO capacity as the scheduling criterion doesn't perform very well for V-BLAST. The reason is the suboptimality of the V-BLAST detection algorithm.

The complementary cumulative distribution function (CCDF) of the capacity of V-BLAST uplink scheduling is shown in Figure 3. The results show that the MaxMinSV and MinES schedulers perform very close to the MaxVBLASTCap scheduler.

Figure 4 shows the capacity gains of uplink V-BLAST scheduling at 10% outage versus the number of users. Optimal MIMO capacity scheduling, as defined in (2), is estimated by assuming the availability of optimal MIMO modems. Therefore, it provides an upper bound for the V-BLAST scheduling algorithms. However, when using RR scheduling with optimal MIMO modems, the rates provided by V-BLAST with scheduling are higher when the number of users is greater than five. The reason is that V-BLAST with scheduling captures K -fold diversity, where K is the number of users, in addition to being a full spatial multiplexing scheme while the optimal MIMO system with RR scheduling has only spatial diversity. Furthermore, the MaxVBLASTCapc scheduler approaches optimal MIMO scheduling at a large number of users. Thus, scheduling greatly improves the information capacity of the uplink system even with suboptimal detectors. The results in this figure also illustrate the poor performance of MaxSNR scheduling. It has very little gains even at high number of users.

V. CONCLUSION

This paper proposed and compared several scheduling algorithms for V-BLAST uplink scheduling. The scheduler selects one user at a time and each user spatially multiplexes his data over the transmit antennas. V-BLAST capacity maximizing scheduler that minimizes the aggregate BER of the uplink system is proposed in this paper. It selects the user that has the maximum post-processing SNR of the weakest layer. A suboptimal scheduler that performs very close to the optimal is to schedule to the user that has the maximum minimum singular value of the MIMO channel. Furthermore, the results showed that scheduling based on maximum MIMO capacity is not optimal for V-BLAST. This is due to the suboptimality of the V-BLAST detection algorithm while the MIMO capacity criterion assumes optimal encoding and decoding. In addition, scheduling for V-BLAST users outperformed optimal MIMO users with round-robin scheduling. This emphasizes the capacity gains that scheduling offers to wireless uplink systems.

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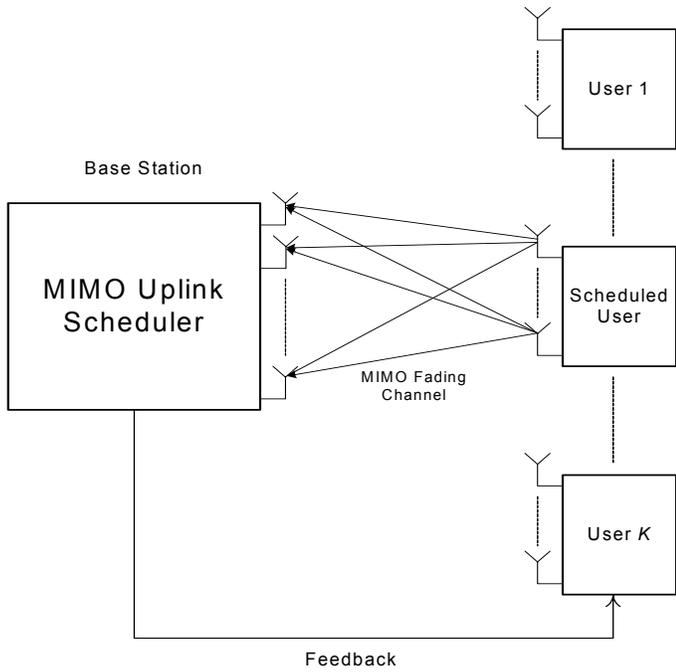


Figure 1: Block Diagram of Uplink MIMO Scheduling

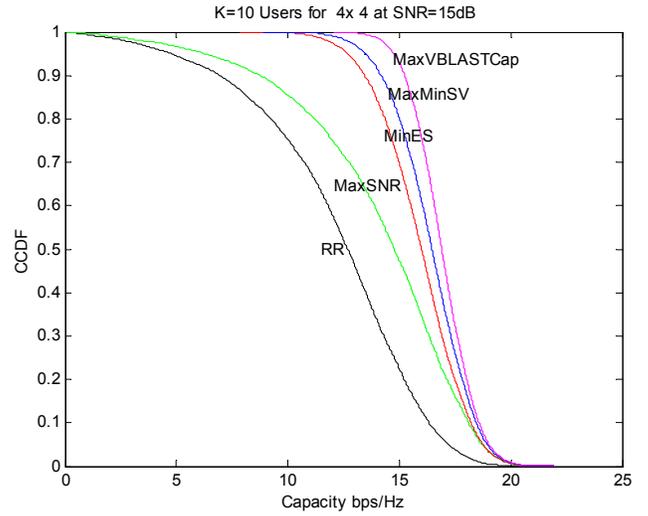


Figure 3: Capacity CCDF of 4x4 QPSK V-BLAST with uplink scheduling

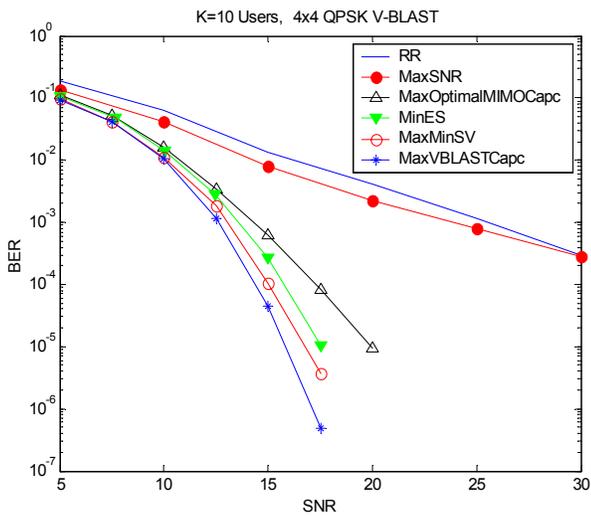


Figure 2: Aggregate BER of 4x4 QPSK V-BLAST users with uplink scheduling

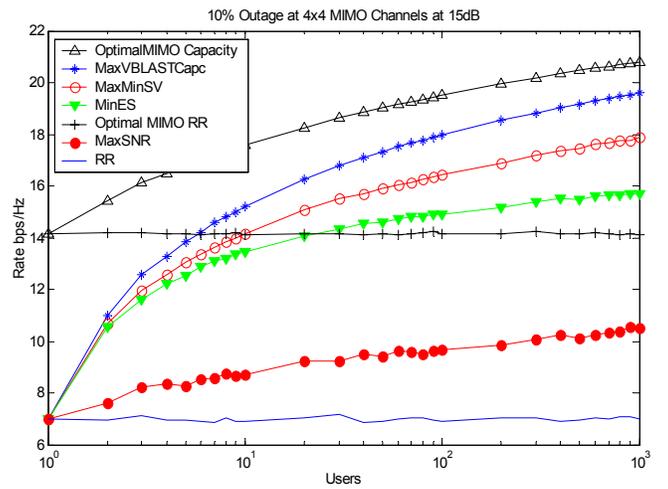


Figure 4: Capacity versus number of users at 4x4 MIMO channels and at 10% outage probability