VARIABLE-RATE ADAPTIVE MODULATION IN MIMO SYSTEMS EXPLOITING MULTIUSER DIVERSITY

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ABSTRACT

An adaptive modulation technique for multiuser MIMO systems with multiuser diversity is proposed. This technique maximizes the sum of the instantaneous bit rate under a target BER constraint by feeding back sub-channel SNRs only. By generating a random transmit beamforming matrix with water-filling configuration, each user estimates and feeds back the effective SNRs for its sub-channels. With each user's sub-channel SNRs, the transmitter then schedules the transmission to one particular selected with proportional fair scheduling algorithm. Finally, adaptive modulation is applied to each sub-channel of the selected user based on the BER constraint. The simulation results show that the throughput of proposed method will converges to that of eigen-beamforming when the number of users in a cell is large.

1. INTRODUCTION

The limited bandwidth available and time-varying multipath fading inherent to the wireless link are the main hindrances in wireless communications. Some popular technologies to improve bandwidth efficiency include smart antennas, mimo technology, coded muticarrier modulation, adaptive modulation and coding technology.

Adaptive transmission uses feedback knowledge to optimize the transmitted signal, which maintain target BER by varying the transmitted power level, symbol rate, constellation size, or coding scheme. Adaptive modulation has also been studied in [1][2] and the reference therein, all in SISO systems. In [3], the adaptive modulation is employed in MIMO system. In [4], an adaptive modulation scheme for multi-antenna transmission based on partial CSI is designed and the transmitter adapt the basis beams, the power allocation between two beams and the signal constellation to maximize the transmission rate, while maintaining the target BER.

The schemes mentioned above are designed for point-to-point communications, and are not applicable for multiuser scenario. In this paper, we combine adaptive MIMO technique with multiuser diversity in multiuser MIMO environment. Multiuer diversity originates from the fact that there is one user whose SNR is at its peak when a sufficient number of users are given and the fading channels of users are independent in a cell [5], which is expanded to MIMO system in [6][7]. Multiuser diversity can maximize the system capacity[5]. By random beamforming at the transmitter and singular value decomposition, the MIMO channel is decoupled into several independent subchannels. No perfect channel state information (CSI) is needed at the transmitter side. According to subchannel SNRs fed back to transmitter, desired user is chosen according to proportional fair scheduling [5]. To maximize the transmission rate, subchannel modulation is used in terms of received SNR in maintaining the target BER. Uncorrelated channel and correlated channel are considered respectively. Numerical results show that WF and AM is more noticeable in correlated channel.

2. SYSTEM MODEL

We consider the transmission system with one base station (BS) and multiple mobile stations (MSs), and both BS and MSs are assumed, for simplicity, to be equipped with equal number of antennas. We consider downlink multiuser diversity, and assume that the MIMO channels are quasi-static, and are independent among different users. With these assumptions, the received signal at the kth user can be written as:

$$Y_k(n) = H_k X(n) + W_k(n) \qquad (1)$$

where a subscript k denotes user index, b denote a BS, the $N \times 1$ vector $Y_k(n)$ denotes a received signal. H_k is a $N \times N$ matrix with complex entries which account for the random fluctuations and random phase shifts of the channel transfer characteristics. $W_k(n)$ is the N × 1 complex noise vector. $X(n)$ is transmit data, and $E(X^T X) = P$. P is total transmit power.

2.1 Spatially uncorrelated channel

An uncorrelated channel matrix can be used to describe an indoor environment where no LOS component exists or many scatters are located around the transmitter and receivers. The channel coefficient has an independent complex gaussion distribution with variance 1 and zero mean:

$$H \in N_C^{N\times N}(0,1) \quad (2)$$

2.2 Spatially correlated channel

In most cases, the mobile is surrounded by many local scatters and therefore the received signals at the antenna are approximately uncorrelated. At the base station, the situation is different. There are few dominant scatters around the BS, therefore a spatially correlated channel is obtained.

To model a spatially correlated channel we make use of the channel model introduced in [8] with

$$H = GA^T \sqrt{\frac{N}{tr(A^* A^T)}} \quad (3)$$

where G is an uncorrelated random matrix with $G \in N_C^{N\times K}(0,1)$,K denotes the number of impinging waves, *tr* denotes the trace of a matrix and A is a steering matrix and consist of K weighted steering vectors of length N. By choosing a specific Angular power spectrum (APS), many uniformly distributed angles are chosen randomly and the corresponding steering matrix A is built.

3. RANDOM BEAMFORMING AND ADAPTIVE MODULATION

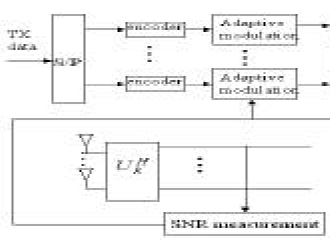

Fig.1. Block diagram of the adaptive modulation in the multiuser diversity method

3.1 random beamforming

Denote the singular value decomposition (SVD) of the kth user's channel matrix as: $H_k = U_k \Lambda_k V_k^H$, where U_k and V_k are unitary matrices and Λ_k is the (diagonal) singular value matrix of H_k. At the transmitter side, a training sequence X_b is first multiplied by a random matrix *R*, then transmitted out through the multiple transmit antennas. The random matrix *R* is selected from a water-filling configuration: $R = V_b \Gamma^{1/2}$, where V_b is the right unitary matrix of a random matrix H_b ($H_b = U_b \Lambda_b V_b^H$); and Γ is a diagonal matrix whose elements are calculated through the 'waterfilling' algorithm

$$\gamma_b = (\mu - \lambda_b^{-1})^+ \quad (4)$$

for $b = 1,..., N$, where λ_b 's are the eigenvalues of $H_b H_b^H$, μ is the water level constant with which the equality power constraint is satisfied, and $(x)^+$ denotes max(0,x).

The received signal at the kth user is given by

$$Y_k = H_k R X_b + W_k \quad (5)$$

As the training sequence, X_b, is known to all users, the composite channel $H_k R$ can be estimated accordingly. However, the purpose of sending this training sequence is for all users to sense the channel condition, and feed back this information to the transmitter so that one user can be selected for transmission. Thus the performance of the signal estimator at each user is of great interest.

Consider the following linear receiver:

$$\hat{X}_b = B_k^H Y_k \quad (6)$$

where B_k is chosen to be the left unitary matrix of the composite channel $H_k R = B_k F_k D_k^H$, where B_k and D_k are unitary matrices, and F_k is the singular value matrix of $H_k R$. If the transmit beamformer V_b is happened to be V_k , then $V_k^H V_b = I$, and $H_k R = U_k \Lambda_k \Gamma^{1/2}$, thus $B_k = U_k$, and

$$\hat{X}_b = \Lambda_k \Gamma^{1/2} X_b + B_k W_k \quad (7)$$

However, when $V_b \neq V_k$, $B_k^H H_k R$ is not a diagonal matrix, thus the data streams will interfere with each other. Define $\Omega_k = F_k D_k^H$, then the effective SNR for the qth sub-channel is given by

$$SNR_k^q = \frac{\psi_{qq}^2 \frac{P}{N}}{\sum_{\substack{j=1\\ j\neq q}}^{N} \psi_{qj}^2 \frac{P}{N} + \sigma_k^2} \quad (8)$$

where ψ_{ij} denotes the (i,j)th element of Ω_k. At the kth receiver, we get N effective SNRs ($SNR_k^1 \sim SNR_k^N$) and feed them back to the transmitter side. At the transmitter, we calculate the capacity according to the SNRs and select one user according to a proportional fair scheduling algorithm [5].

To summarize, the steps for achieving multiuser diversity using random beamforming are as follows:

(1) The transmitter chooses a random matrix H_b according to the PDF knowledge of all channels, and performs SVD on H_b : $H_b = U_b \Lambda_b V_b^H$, and construct the random beamformer: $R = V_b \Gamma^{1/2}$, where the elements of Γ is calculated from (4);

(2) The transmitter sends training sequence X_b through the beamformer R ;

(3) Each user estimates its composite channel $H_k R$, and the associated receive beamforming matrix B_k ; and calculates and feeds back the effective SNR for the sub-channels.

(4) The transmitter calculates the sum rate for each user and selects one user for transmission according to the proportional fair scheduling algorithm.

3.2 adaptive modulation

The information rate for each sub-channel can be achieved through continuous rate modulation and infinity-length coodbooks. In this subsection, we study the adaptive modulation scheme considering discrete rate and practical BER constraint.

A set of modulation formats from 2PSK to QPSK and from 8QAM to 256QAM is employed to implement adaptive modulation. Denote the constellation size $M = 2^k$, where k is the number of bits per symbol. The BERs for an AWGN channel with ideal coherent detection are given by the following expressions [9].

$$BER_{MPSK} \approx \frac{1}{k} erfc(\sqrt{SNR} \sin(\frac{\pi}{2^k})) \quad (9)$$

$$BER_{MQAM} \approx \frac{2}{k}(1 - \frac{1}{\sqrt{2^k}}) \times erfc(\sqrt{\frac{1.5SNR}{2^k - 1}}) \quad (10)$$

For uncoded PSK or M-QAM, the attainable normalized throughput for the qth sub-channel can be given in terms of the BER for block length L as [3]

$$T_k^q = [1 - BER_k^q]^L \log_2 M_q \quad (11)$$

where BER_k^q is not larger than the target BER requirement. On each of these sub-channels, the modulation format is chosen

$$M_q = \arg\max T_k^q \quad (12)$$

Obviously, a sub-channel with high instantaneous SNR will be assigned with a high order M-QAM and a sub-channel with low instantaneous SNR with a low order M-QAM or M-PSK. Through adaptive modulation for each sub-channel, we can maximize the instantaneous bit rate while maintaining the target BER.

4. PERFORMANCE EVALUATION

In this section, we evaluate the system performance in two different channel types: slow fading uncorrelated channel and slow fading correlated channel. Slow fading means that the channel matrix of each user will remain constant for all values of t. Although channel keeps constant, random beamforming can cause channel fluctuation to realize multiuser diversity.

To make the $H_k R$ be in the 'waterfilling configuration', We generate random transmission matrix R from a specfic distribution, which based on a random realization of channel matrix H (2) or (3). The channel capacity of the user k is at a maximum when the beamforming matrix V_b is the same as V_k and Γ is in the 'waterfilling' configuration. In this case, the channel capacity is equal to that of transmitter knowing perfect CSI. Figure.2 shows achived information rate by adaptive modulation . The target BER is 10^{-3} . Block length L=100. N=4. When mean SNR is kept constant (mean SNR is 13dB), the information rate grows with increasing the user number. However, when the user number is large enough, the information rate will keep constant. Subchannel number one corresponds to the subchannel with the largest SNR, subchannel number two corresponds to the subchannel with the next largest SNR and so on. The larger the subchannel's SNR is, the larger the subchannel throughput is. Compared with figure.2, whose results come from spatially uncorrelated channel, the results of figure.3 are presented for spatially correlated channel. Obviously, the throughput of correlated channel is smaller than that of the uncorrelated channel. Moreover, there are only two subchanenls left to provide the throughput, which means the difference between the highest eigenvalue and the smallest eigenvalue increases. Because of the dominance of the subchannel number one, most information is carried over subchannel one. This is why the rate decreases.

In figure.4, we compare the throughput of the correlated channels with different AS. The smaller the AS is, the stronger the correlated is. So, as we can see, the capacity decreases as decreasing AS. Meanwhile, we observe that the effect of waterfilling and adaptive modulation is more noticeable in the presence of correlation among the channels.

In figure5, we present the modulation format for four subchannel with increasing mean SNR. The subchannel four has the lowest SNR, so it transmits no data or transmits data using low modulation format. While the subchannel one transmit data using high modulation format frequently. When the SNR increases, each subchannel will use higher modulation format than what it use in low SNR.

The figure 6 shows the capacity bound, capacity and data rate of given user. The capacity bound is obtained by perfect eigen beamforming. When the user number in a cell increases, the capacity of the given user will converges to the that of eigen beamforming and the rate will reach maximum. The smaller the meam SNR, the faster the capacity converges. This is because the influence of beamforming mismatch is negligible compared to the effect of noise when SNR is low.

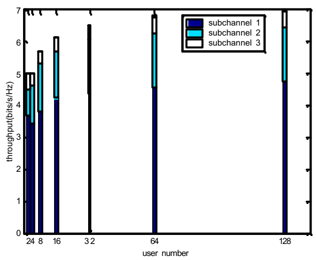

Figure 2. information bit rate on each subchannel versus the user number; spatially uncorrelated channel

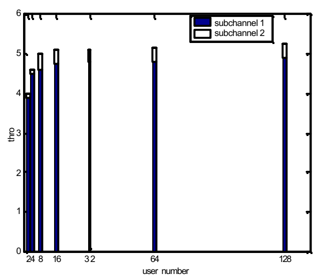

Figure 3. information bit rate on each subchannel versus the user number; spatially correlated channel

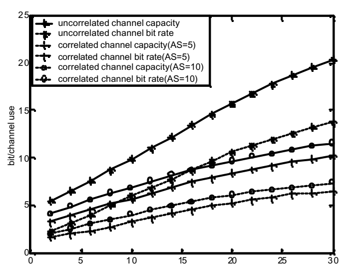

Figure 4. the capacity and bit rate versus mean SNR for different correlated channel; the user number is 50

5. CONCLUSION

In this paper, a random transmission and adaptive modulation scheme in multiuser environment is presented. Random beamforming is adopted to realize the multiuser diversity. In uncorrelated channel, this scheme can be used to maximize the rate information. In correlated channel, correlated characteristic between channels decrease the usable subchannel number and degrade the system performance. However, random power allocation and adaptive modulation have better effect on correlated channel to improve the rate information.

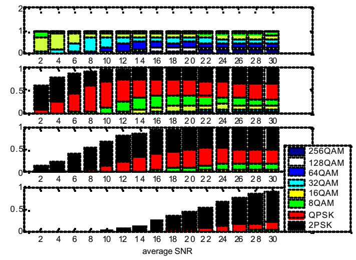

Figure 5. the frequency of modulation format used in each subchannel versus mean SNR; the user number is 50

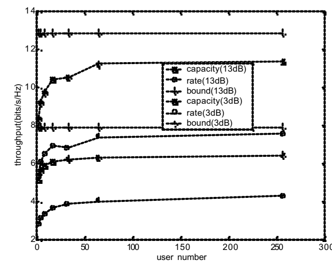

Figure 6. throughput for user 1 versus user number with different mean SNR

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