Comparing Antenna and Beam Selection for Different Selection Strategies over Measured Indoor MIMO-OFDM Channels at 6 GHz

Lu Dong and Mary Ann Ingram
School of Electrical and Computer Engineering
Georgia Institute of Technology Atlanta, Georgia 30332–0250
Email: ludong@ece.gatech.edu; mai@ece.gatech.edu

***Abstract*— Selection of a subset of receiver antennas for a multiple-input-multiple-output (MIMO) wireless link has been studied by many as a way to reduce cost and complexity in a spatial multiplexing MIMO system, while providing diversity gain. However, most of these studies have been over simulated channels. In this paper, we use measured indoor channels. We compare three selection criteria to be implemented at the access point in an indoor wireless LAN: minimum symbol error rate (SER), maximum capacity, and the maximum of the minimum singular value of the MIMO channel. The comparison is based on SER which is computed for 802.11a OFDM waveforms, where the same selection is made for every subcarrier. The dual-user scenario is considered, and the access point comprises two RF beamformers that are separated by at least 5 m, such that the beam selection is done jointly for the two beamformers.**

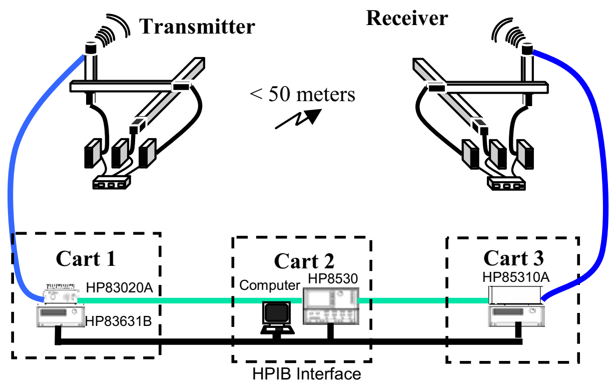

Fig. 1. MIMO channel measurement system

I. INTRODUCTION

Multiple input and multiple output (MIMO) links are known to provide extremely high spectral efficiencies in rich multipath environments [1], such as indoor wireless environments. Antenna selection offers a good trade off between complexity and performance of the MIMO system [2], [3]. Several selection criteria have been proposed [2], [4], however to the authors' knowledge, all performance comparisons for these selection criteria have assumed ideal or simulated channels. This paper presents a comparison of selection criteria for measured channels at 6 GHz in terms of symbol error rate (SER). The modulation method is 802.11a orthogonal frequency division multiplexing (OFDM) [5]. Channel estimation with a high performance 4×4 long preamble structure [6] is used for SER calculation.

The maximum channel capacity (MCC) and the maximum minimum singular value of channel matrix (MMSV) are two popular selection metrics [2]. In [2] and [4], these metrics are compared in terms of their SER performance over i.i.d. circular complex Gaussian simulated channels. [4] compares these same selection criteria with the minimum SER (MSER) criterion over simulated channels and finds very little difference between them in terms of SNR required for a specified SER for 6-select-2 receiver selection. [7] considers the MCC and MMSV criteria for theoretical and simulated correlated channels as a function of angular spread. They find that for a wide range of spreads, these two criteria produce approximately the same SER. They do not compare to the MSER criterion. In this paper, we compare all three criteria and find that the measured channel produces a significant performance difference between the MSER and the other selection criteria, even for the 6-select-2 case.

This paper also considers beam selection. While it is known that beam selection can offer significant advantages over antenna selection in terms of channel capacity in correlated channels [12], these advantages have not been demonstrated on measured indoor channels. The work reported in this paper was motivated by previous work by the author's group. An eight-element array is considered here because it performed better in simulation than the two-element array in [9]. In [8], beam selection was compared to antenna selection for measured indoor channels, using beamwidths that were consistent with a 4-element array. That paper found beam selection offered a 10 dB improvement relative to antenna selection in the overloaded case (i.e. when there are more data streams than selected receiver beams or antennas) but less than a 2 dB improvement for the non-overloaded case. In [9], diversity combining with beams suffered because, while both beams exhibited frequency selective fading, either one beam had a much higher average power than the other or the selected beams were adjacent and had correlated fading. This last observation is what motivated the two-beamformer access point architecture that we consider in this paper. If the access point can select beams from two significantly separated beamformers, then it should be

The authors gratefully acknowledge the support of this research by the Georgia Tech Broadband Institute (GTBI) and by the National Science Foundation under Grant No. CCR-0121565.

Fig. 2. Layout of Old Civil Engineering Building

possible to select two uncorrelated beams with similar average power.

II. MIMO CHANNEL MEASUREMENT SYSTEM AND THE MEASURED INDOOR CHANNEL

The 3D MIMO channel measurement system is the same as [8]. As illustrated in Figure 1, the MIMO-channel measurement system is composed of two parts: (1) the HP 85301B stepped-frequency antenna pattern measurement system, which, because of its coherent reference signal, can measure the channel frequency response directly, and (2) the actuator positioning system, which creates the virtual array by moving the antenna to arbitrary pre-programmed locations.

The measurements were conducted in Old Civil Engineering Building at the Georgia Institute of Technology. Figure 2 shows the locations of the three transmit arrays (Tx) and five receive arrays (Rx). The line on each position represents the arrangement of the linear array.

The Tx and Rx antennas were both at the height of 1.35m. At each node, a virtual 10-element uniform linear array (ULA) was formed using a biconical antenna, which was omnidirectional in azimuth. All 10 elements were used for normalization, however, only eight- and four- element ULAs are considered for the beamformers in this paper. The antenna spacing is 0.5λ where λ is the wavelength of the 6.0 GHz signal. 51 frequency samples within 6.0-6.5 GHz were chosen so that the separation between adjacent samples (10 MHz) is large enough to have a low correlation realization of the flat fading channels. As a consequence, for each Tx-Rx link, there are $8 \times 8 \times 51 = 3264$ realizations of flat fading. With three Tx and five Rx, there are 15 MIMO links.

III. DUAL-USER AND DISTRIBUTED DUAL-RECEIVER JOINT SELECTION SYSTEM MODEL

The system model is shown in Figure 3. A simple 4-node network with any 2 Tx and 2 Rx chosen from Figure 2 is considered. Each Tx node (Tx1, Tx2) uses the first two antennas of its 8-element linear array, while each Rx node (Rx1, Rx2) chooses two antennas or beams from a total of either four (4-2) or six (6-2) antennas or beams. The selection for Rx1 and Rx2 is done jointly. In this case, Rx1 and Rx2 represent a kind of distributed access point.

With the choice of 2 Tx and 2 Rx, we have 4 links totally (Tx1-Rx1, Tx1-Rx2, Tx2-Rx1, Tx2-Rx2). For each frequency sample k, each link Txi-Rxj's raw channel data is a 10×10 matrix $\hat{H}_{ij}^k$, where $i, j = 1, 2$ and $k = 1...51$. We assume the combined channel for all the four links is $\hat{H}^k$; it is easy to see $\hat{H}^k$ is a 20×20 matrix. So the normalized channel matrix H_{ij}^k is calculated as

$$H_{ij}^k = \frac{\sqrt{51 \times 20 \times 20} \times \hat{H}_{ij}^k}{\sqrt{\sum_{k=1}^{51} \parallel \hat{H}^k \parallel_F^2}} \tag{1}$$

where $\| \cdot \|_F$ means Frobenius norm. The normalization makes the average magnitude square value of each element approximately 1.

We choose the 4×4 long preamble structure which increases the channel estimation performance [6]. Each OFDM symbol has 64 subcarriers, 52 of them are used to transmit data. Although 20 to 40 user data symbols can be included for each OFDM frame, one user data symbol per frame is enough for SER calculation here. For each subcarrier of the OFDM symbol, 64-QAM was used. The lengths of each long preamble is 64 with guard samples G=16. Zero forcing linear detection of V-BLAST is used for the receive data vectors on each subcarrier. SER is calculated over all the 51 frequency samples within 6.0-6.5 GHz.

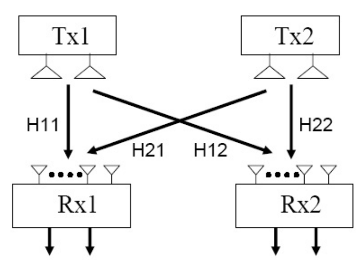

Fig. 3. Dual-user and distributed dual-receiver jointly selected 4×4 MIMO system

IV. DESCRIPTION OF ANTENNA (BEAM) SELECTION AND SOME DIFFERENT SELECTION METRICS

The mathematical expressions for antenna and beam selection are the same as [8]. N_T and N_R denote the numbers of transmit and receive antennas, respectively. n_T and n_R denote the numbers of selected transmit and receive antennas, respectively. The measured normalized channel matrix for link Txi-Rxj, denoted as H_{ij}, is an $N_R \times N_T$ matrix. For the considered network,

$N_T = n_T = 2$ for each transmit antenna (Tx1, Tx2). To form the 4×4 MIMO channel, two antennas or beams are selected at each receiver (Rx1, Rx2) which means $n_R = 2$. The $n_R \times n_T$ MIMO channel matrices for link Txi-Rxj after antenna selection and beam selection are given by

$$H_{ij}^{ant} = J_R H_{ij} \tag{2}$$

$$H_{ij}^{beam} = J_R B_R H_{ij} \tag{3}$$

respectively, where $J_R \in \boldsymbol{R}_{n_R \times N_R}$ is the lossless receive selection matrix, $B_R = [B_R^1 \; B_R^2 \cdots B_R^{N_R}] \in \boldsymbol{C}_{N_R \times N_R}$ is the lossless receive Butler matrix [13]. The m^{th} column of B_R is

$$B_R^m(n) = \frac{1}{\sqrt{N_R}} e^{\frac{j\pi(m-1)[-(N_R-1)+2(n-1)]}{N_R}}, n = 1 \cdots N_R \tag{4}$$

The network topology with beam selection is implemented as follows. For 4-2 beam selection, the first four elements of each receive array are connected to the 4×4 receiver Butler matrix B_R to form the four receive beams, which can cover about 110^o on each side of the array. For 6-2 beam selection, the first eight elements of each receive array are connected to the 8×8 receiver Butler matrix B_R to form the eight receive beams. The two outside beams are abandoned; the remaining six middle beams can cover 90^o on each side of the array. Two beams are selected from those remaining six.

The 4×4 MIMO channel matrix for the 4-node Tx-Rx links after antenna selection and beam selection are given by

$$H^{ant} = \begin{bmatrix} H_{11}^{ant} & H_{12}^{ant} \\ H_{21}^{ant} & H_{22}^{ant} \end{bmatrix}, \; H^{beam} = \begin{bmatrix} H_{11}^{beam} & H_{12}^{beam} \\ H_{21}^{beam} & H_{22}^{beam} \end{bmatrix} \tag{5}$$

The optimal selection metric is the minimum SER (MSER). However, MSER is not a practical metric because its calculation is time-consuming. Its SER performance in our simulation is a lower bound for the other two practical selection metrics.

The first practical selection metric is the maximum channel capacity (MCC), which is calculated according to the following equation [1].

$$C = log_2 \mid I + \frac{\rho}{n_T} H H^H \mid \tag{6}$$

where ρ is the signal to noise ratio per antenna at the receiver. The antenna or beam selection should let the channel matrix H^{ant} or H^{beam} have the maximum channel capacity.

The second practical selection metric is the maximum minimum singular value (MMSV) of the channel matrix. From [2], with the ZF linear receiver, the minimum post-processing SNR_{min} is lower-bounded by λ_{min}^2. Therefore, the antenna or beam selection can choose the channel matrix H^{ant} or H^{beam} with the MMSV to increase the SER performance.

V. Experimental results

We consider two dual-user and distributed dual-receiver scenarios, which are (T2, R3, T3, R5) and (T1, R1, T2, R2) respectively. We call the first Scenario I and the second Scenario II.

Figure 4 shows the correlation coefficients at the receiver for every link of the two scenarios. We can see Scenario I has higher

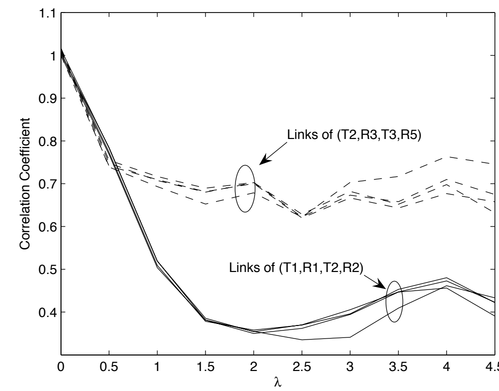

Fig. 4. Receiver correlation for scenario (T2, R3, T3, R5): (dashed curves) and scenario (T1, R1, T2, R2): (solid curves).

correlation than Scenario II. After looking at Figure 2 carefully, we can easily observe that Scenario I has some LOS channels or narrow angle of arrival links. For example, the Rice factor $K = 1.7622$ for link T2-R3, while $K = 1.2762 \times 10^{-7}$ for link T1-R2. So it is reasonable to observe large correlation difference between the two scenarios [11].

Before analyzing the SER performance over the measured channel, we first take a look at the i.i.d channel results. From Figure 5, we can see beam selection has no obvious difference from antenna selection. This is easy to understand because beamformer is only a normalized phase shift matrix; it will not change the statistics properties of the i.i.d channel.

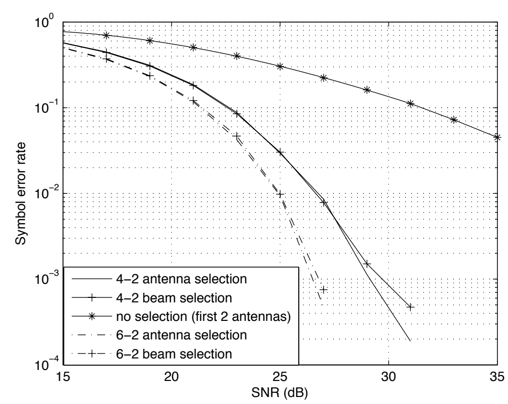

Fig. 5. SER over iid channel

Figures 6 and 7 show the same curves as in Figure 5, but for the measured channels of Scenarios I and II, Respectively. From Figure 4, we already know Scenario I has higher correlation. So, we observe that in Figure 6, beam selection offers larger improvement over antenna selection, while in Figure 7, beam selection is only a little better than antenna selection. This result matches [12] very well. However, [12] considered a geometric outdoor channel model [14] which is not suitable for the indoor application like the 802.11a MIMO-OFDM system we study here. It also did not consider the SER performance. We also find, even in Scenario I with higher correlation, 6-2 antenna selection

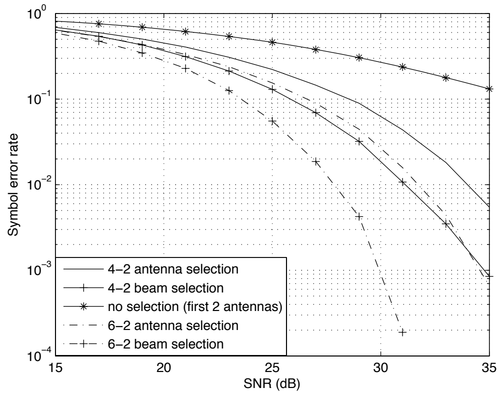

Fig. 6. SER over (T2, R3, T3, R5) channel

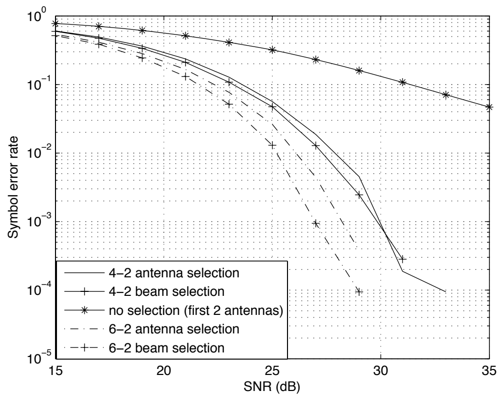

Fig. 7. SER over (T1, R1, T2, R2) channel

is almost as good as 4-2 beam selection. While in Scenario II, 6-2 antenna selection is better than 4-2 beam selection. This is because in the low correlation scenario, antenna selection has more diversity gain. So for the indoor channel, we should not use 4-2 beam selection method, because a 4×4 beamformer is more complex than an additional 2 antennas.

Figure 8 shows the SER performance over (T2, R3, T3, R5) channel with MSER, MCC and MMSV selection metrics for 6-2 selection. This figure shows us that the two practical metrics have at least a 5dB SNR disadvantage compared with the optimum one, at SER=10^{-2}. We can also observe that the optimum MSER metric gives beam selection more of an improvement over antenna selection than the other two metrics. In this measured channel, MCC metric is a little bit better than MMSV metric. But this is not the rule. When we draw the same curves in (T1, R1, T2, R2) channel, there are no obvious difference between this two metrics.

VI. Conclusion

This paper introduced a set of measured indoor wireless channels. We analyzed the SER performance improvement caused by joint selection with some popular selection metrics in 802.11a MIMO-OFDM system. There is a significant SER gap between the optimal selection criterion and both the maximum capacity

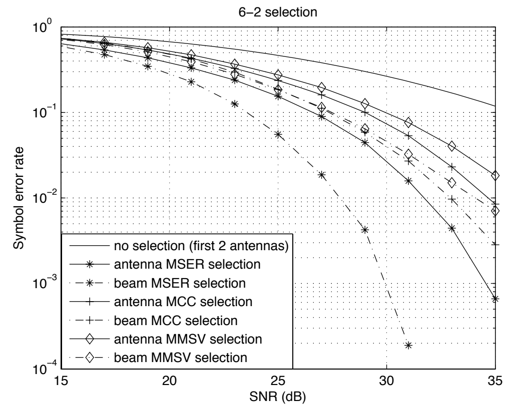

Fig. 8. SER over (T2, R3, T3, R5) channel with three different selection metrics

and the maximum of the minimum singular value selection criteria. Beam selection gives different gains over antenna selection in different indoor environment. Correlation level is the main reason for this difference.

References

[1] G. J. Foschini and M. J. Gans, "On Limits of Wireless Communications in a Fading Environment when using Multiple Antennas," *Wireless Personal Communications*, pp. 311–335, 1998.

[2] R. W. Heath and A. J. Paulraj, "Antenna Selection for Spatial Multiplexing Systems Based on Minimum Error Rate," *IEEE International Conference on Communications*, vol. 7, no. 11-14, pp. 2276 – 2280, June 2001.

[3] D. A. Gore and A. J. Paulraj, "MIMO Antenna Subset Selection With Space-time Coding," *IEEE Transactions on Signal Processing*, vol. 50, no. 10, pp. 2580 – 2588, Oct 2002.

[4] I. Berenguer and Xiaodong Wang, "MIMO Antenna Selection with Lattice-reduction-aided Linear Receivers," *IEEE Transactions on Vehicular Technology*, vol. 53, no. 5, pp. 1289 – 1302, Sep 2004.

[5] IEEE 802.11a, *Part 11: wireless LAN Medium Access Contol (MAC) and Physical Layer PHY Specifications*, LAN/MAN Standards Committee, 1999.

[6] A. N. Mody and G. L. Stuber, "Receiver Implementation for a MIMO OFDM System," *IEEE Global Telecommunications Conference*, vol. 1, no. 17-21, pp. 716–720, Nov 2002.

[7] Lin Dai, S. Sfar, and K. B. Letaief, "Receive Antenna Selection for MIMO Systems in Correlated Channels," *IEEE International Conference on Communications*, vol. 5, pp. 2944 – 2948, Jun 2004.

[8] J.-S. Jiang and M. A. Ingram, "Comparison of Beam Selection and Antenna Selection Techniques in Indoor MIMO Systems at 5.8 GHz," *IEEE Radio and Wireless Conference*, vol. 1, no. 10-13, pp. 179 – 182, Aug 2003.

[9] K.-H. Li and M. A. Ingram, "Space-time Block-coded OFDM Systems with RF Beamformers for High-speed Indoor Wireless Communications," *IEEE Transactions on Communications*, vol. 50, no. 12, pp. 1899 –1901, Dec 2002.

[10] M. F. Demirkol and M. A. Ingram, "Stream Control in Networks with Interfering MIMO Links," *IEEE Wireless Communications and Networking*, vol. 1, pp. 343 – 348, Mar 2003.

[11] J. Salzand and J. H. Winters, "Effect of Fading Correlation on Adaptive Arrays in Digital Mobile Radio," *IEEE Transactions on Vehicular Technology*, vol. 43, no. 4, pp. 1049 – 1057, Nov 1994.

[12] A. F. Molisch and Xinying Zhang, "FFT-Based Hybrid Antenna Selection Schemes for Spatially Correlated MIMO Channels," *IEEE Communications Letters*, vol. 8, no. 1, pp. 36 – 38, Jan 2004.

[13] Bruno Pattan, *Robust Modulation Methods and Smart Antennas in Wireless Communication*, Prentice Hall PTR, 2000.

[14] Da-Shan Shiu, G. J. Foschini, M. J. Gans, and J. M. Kahn, "Fading Correlation and Its Effect on the Capacity of Multielement Antenna Systems," *IEEE Transactions on Communications*, vol. 48, no. 3, pp. 502 – 513, Mar 2000.