A comparison of measured 8$\times$8 MIMO systems with a popular stochastic channel model at 5.2GHz

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Abstract

We compared the average capacities of measured 8×8 MIMO systems with the capacities calculated from a popular stochastic MIMO model. This model separates the influence of fading from the correlation at transmit (TX) and receive (RX) arrays. By using directional RX antennas and a virtual 20×10 TX array with omni antennas we measured the MIMO channel at different RX positions in an indoor office scenario at 5.2GHz.

For low correlation at the receiver and transmitter the model fits very well. But for high correlation at both receive and transmit side considerable discrepancy arose. In these cases we found that the entries in the fading matrices are not independent identically distributed with mean power of unity, as assumed in the model.

1 Introduction

Multiple-input multiple-output (MIMO) systems promise large information-theoretic capacities, enabling high data rate transmission, especially in rich multipath indoor scenarios. They are candidates for very broadband wireless local area networks. However, to develop such systems, it is essential to have an accurate description of the underlying radio channel. There exists already a manifold of different stochastic or geometrically-based stochastic MIMO models ([1], [2], [3], [4]).

In this paper we will investigate whether a popular stochastic MIMO model, based on TX and RX correlation, is a good fit to describe measured capacities. This model decomposes the MIMO channel matrix into the receive and transmit correlation matrices, respectively, and an i.i.d. Rayleigh-fading matrix. I.e., this model separates the influence

of fading from the correlation at RX and TX sides.

Particularly we will compare average capacities of measured 8×8 MIMO channels with the predicted capacities from this stochastic MIMO channel model. Also the statistical properties of the extracted fading matrix will be analyzed.

Additionally we analyze whether the assumptions of this channel model are fulfilled or not.

2 Measurement

2.1 Measurement Setup

For the measurements, we used the wideband vector channel sounder RUSK ATM [5] with a measurement bandwidth of 120MHz at a center frequency of 5.2GHz. At the receive side a $\lambda/2$ spaced 8-element uniform linear patch array (ULA) with two additional dummy elements was used. Each single patch antenna had a 3dB beamwidth of 120° and was consecutively multiplexed to a single receiver chain. At the transmit side, a monopole antenna was mounted on a 2D positioning table where the position was controlled by the channel sounder by means of two stepping motors. The monopole TX antenna was moved to 20 possible x-coordinates and 10 possible y-coordinates on a rectangular grid with $\lambda/2$ spacing, forming a virtual TX matrix *without* mutual coupling.

For each TX position the channel sounder measured 128 temporal snapshots of the frequency dependent transfer function between the TX monopole and all RX antennas. Within the measurement bandwidth of 120 MHz 193 equidistant frequency samples of the channel coefficients were taken Altogether, this resulted in a (128×193×8×200) 4-dimensional complex channel transfer matrix containing the channel coefficients for each snapshot, frequency, RX and TX position. Since the measurement of the whole 4-dimensional channel transfer matrix took about 10 minutes, we took the measurements at night to ensure stationarity.

2.2 Scenario

The measurements were carried out in the offices of the Institute of Communications and Radio Frequency Engineering at the Vienna University of Technology. A number of different office rooms were measured, always with the TX antenna positioned in the same place in the corridor. For our evaluation we took only the measurements of a single room with the RX antenna placed on 8 different positions. This room was amply furnished with wooden and metal furniture and plants, without line of sight to the TX. At each position we rotated the Rx antenna to three different broadside directions D1,D2 and D3 (see Figure 1). These directions were angularly spaced by $120°$. The door to this room was open.

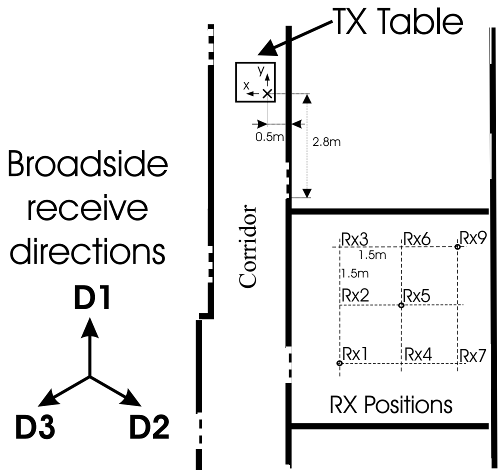

Figure 1: Floor plan of the corridor and office rooms

3 Data Evaluation

3.1 Generating Different Channel Realizations

Before we generated the MIMO channel realizations for these systems, we averaged over all 128 snapshots to increase the SNR leading to an 8×200 MIMO matrix for each frequency bin. The 200 TX positions were used to create different spatial realizations of the 8×8 MIMO system. We used all RX antennas and selected 8 adjacent TX positions in the x-direction out of the 20×10 TX matrix. This virtual 8-element TX ULA was moved over all possible TX antenna positions resulting in $13 \cdot 10 = 130$ spatial realizations of the 8×8 MIMO channel matrix.

Since we have measured the MIMO channel matrix at 193 different frequencies, this gives us in total $130 \cdot 193 = 25.090$ different realizations of the channel matrix to average over.

3.2 Capacity, Normalization and Correlation

The MIMO capacity for each spatial and frequency realization was calculated by [6]

$$C = \log_2 \det \left(\mathbf{I_8} + \frac{\rho}{\mathrm{n}} \mathbf{H}\mathbf{H}^{\mathrm{H}} \right) \tag{1}$$

where $\mathbf{I}_8$ denotes the 8x8 identity matrix, $n = 8$ the number of transmit antennas, $\mathbf{H}$ the MIMO channel matrix and ρ the average receive SNR (for a normalized channel matrix). The superscript *H* denotes Hermitian transposition. This gives the capacity when the channel is not known at the transmitter.

Since the measured MIMO matrices include the pathloss we had to do a proper normalization. For each system and each RX position, this was done by setting the equivalent SISO pathloss, defined by

$$\frac{1}{n^2} \sum_{i=1}^{n} \sum_{j=1}^{n} |h_{ij}|^2, \tag{2}$$

on average over all spatial and frequency realizations to zero dB. Here h_{ij} is the corresponding MIMO channel matrix element.

Using the normalized MIMO channel realizations, we calculated the average MIMO capacity for each RX position and direction.

In addition to capacity, we also considered the *correlation* at both the transmit and receive side. To estimate the transmit and receive correlation matrix we used

$$\tilde{\mathbf{R}}_{\mathrm{tt}} = \frac{1}{\mathrm{N}} \sum_{\mathrm{r}=1}^{\mathrm{N}} \mathbf{H}(\mathrm{r})^{\mathrm{H}} \mathbf{H}(\mathrm{r}) \tag{3}$$

$$\tilde{\mathbf{R}}_{\mathrm{rr}} = \frac{1}{\mathrm{N}} \sum_{\mathrm{r}=1}^{\mathrm{N}} \mathbf{H}(\mathrm{r}) \mathbf{H}(\mathrm{r})^{\mathrm{H}} \tag{4}$$

where N is the number of channel realizations, in our case 25.090, and $\mathbf{H}(r)$ the r*th* channel realization.

3.3 Stochastic MIMO Correlation Model

To determine whether if the correlation is sufficient to describe the measured MIMO capacity in our scenario, we considered a popular stochastic MIMO model based on the transmitter and receiver correlation [7]:

$$\tilde{\mathbf{H}} = \mathbf{R}_{\mathrm{rr}}^{1/2} \mathbf{G} \mathbf{R}_{\mathrm{tt}}^{1/2}. \tag{5}$$

Here $\mathbf{R}_{\mathrm{rr}}$ and $\mathbf{R}_{\mathrm{tt}}$ are the receiver and transmitter correlation matrices and $\mathbf{G}$ is a matrix with independent identically complex Gaussian distributed (i.i.d.) elements with mean power of unity.

To evaluate whether this model is able to give an accurate prediction of the measured MIMO capacity, we synthesized a set of 1000 different $\mathbf{H}$ matrices using the estimated correlation matrices. We normalized them the same way as the measured channel matrices and compared the resulting capacities for both measured and synthesized channel matrices.

4 Results

In figure 2 the average MIMO capacity versus the SNR for receive position Rx6 direction D1 is plotted. The solid line shows the measured capacity, the dashed line the synthesized capacity calculated from the stochastic channel model and the dotted line the case of an i.i.d. Rayleigh fading channel, as a reference. As can be seen, the stochastic MIMO model fits very well for this position and direction.

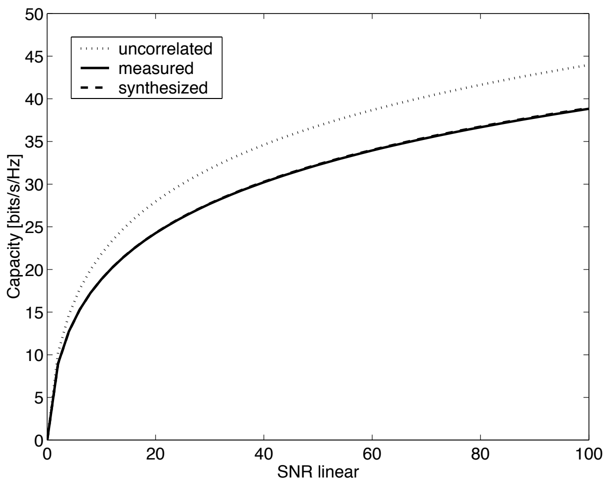

Figure 2: Average MIMO capacity vs SNR for receive position Rx6, direction D1

Figure 3 depicts the transmitter and receiver correlation. Note that the main diagonal elements of both matrices are the average power of the corresponding antenna elements, therefore they are not unity. The transmit array is nearly totally uncorrelated and there is also low correlation at the receive side. As a consequence the capacity loss of the measured MIMO channel compared to the i.i.d. Rayleigh fading case is small.

However, at position Rx5 and direction D1 this changes totally (see Figure 4). The synthesized capacity is below the measured capacity, i.e. at an SNR level of 20 dB the measured capacity equals 27 bits/s/Hz, whereas 23.5 bits/s/Hz was predicted. A difference of -13% occurs. Considering the transmit and receive correlation (see Figure 5), we can see that the transmit and particularly the receive side is highly correlated. This explains the large gap to the i.i.d. Rayleigh case but not the discrepancy between the measurement and the channel model.

To check whether the assumptions of the channel model are fulfilled, we extracted the realizations of the fading matrix $\mathbf{G}$ from the measured 8×8 MIMO channel matrices $\mathbf{H}(\mathrm{r})$:

$$\tilde{\mathbf{G}}(\mathrm{r}) = \tilde{\mathbf{R}}_{\mathrm{rr}}^{-1/2}\mathbf{H}(\mathrm{r})\tilde{\mathbf{R}}_{\mathrm{tt}}^{-1/2}, \tag{6}$$

using the estimated receive ($\tilde{\mathbf{R}}_{\mathrm{rr}}$) respectively transmit ($\tilde{\mathbf{R}}_{\mathrm{tt}}$) correlation matrices. Further, to verify whether these extracted fading matrices are i.i.d. or not, we calculated the correlation along any row

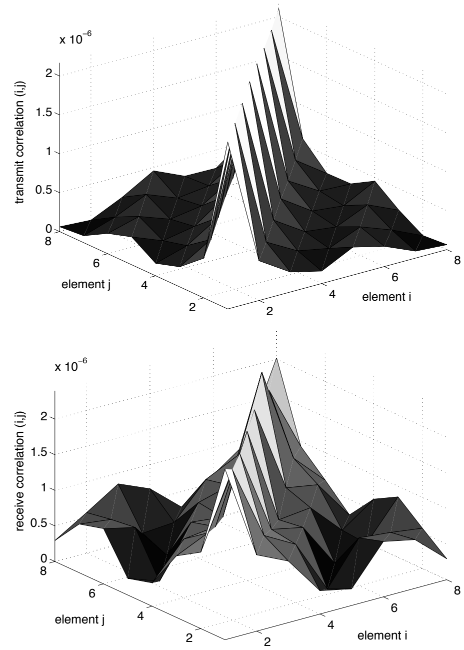

Figure 3: Transmitter (top) and receiver (bottom) correlation matrix for receive position Rx6, direction D1

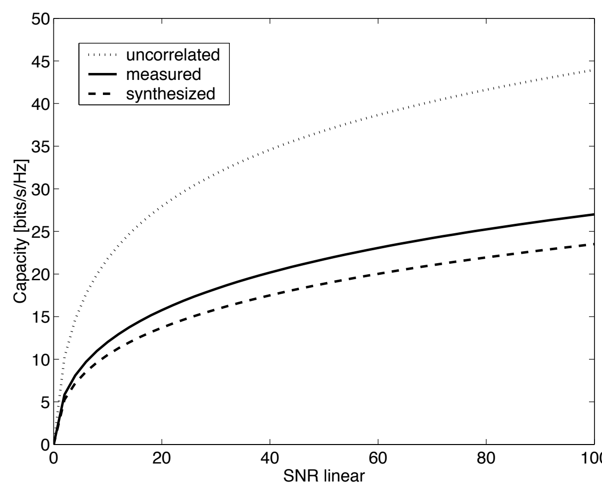

Figure 4: Average MIMO capacity vs SNR for receive position Rx5, direction D1

$$\mathbf{R}_{GG,row} = \frac{1}{N}\sum_{r=1}^{N} \tilde{\mathbf{G}}(\mathrm{r})\tilde{\mathbf{G}}(\mathrm{r})^{\mathrm{H}} \tag{7}$$

and any column

$$\mathbf{R}_{GG,col} = \frac{1}{N}\sum_{r=1}^{N} \tilde{\mathbf{G}}(\mathrm{r})^{\mathrm{H}}\tilde{\mathbf{G}}(\mathrm{r}), \tag{8}$$

where again $N = 25090$ is the number of channel realizations. For receive position Rx6 we observe that there is no correlation in the entries of $\tilde{\mathbf{G}}$ along any

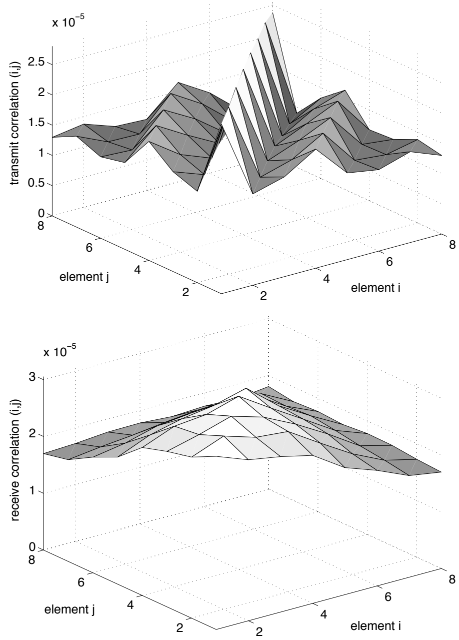

Figure 5: Transmitter (top) and receiver (bottom) correlation matrix for receive position Rx5, direction D1

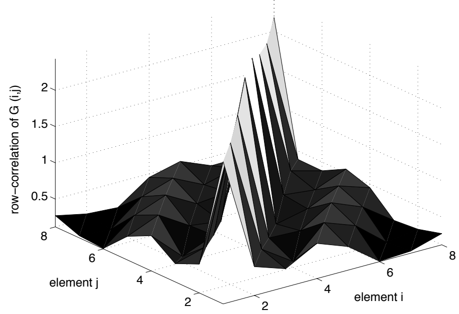

Figure 6: Correlation of the fading matrix G for receive position Rx5, direction D1

row (see fig. 7) or any column. The entries of the fading matrix seem to be i.i.d., as assumed in the model. They also do have mean power of unity.

The row correlation for receive position Rx5 is shown in Figure 6.

Here we have both significant correlation between the entries of $\mathbf{G}$ and an average power which is not unity but about 2.5. This means that the assumptions of the channel model are not fulfilled, and therefore the channel model cannot give an accurate description of the measurement.

Also at other Rx positions and directions we observe that the MIMO capacity calculated from the stochastic MIMO model is an underestimate for the measured capacity. This is the case when high correlation at the transmitter and receiver occurs.

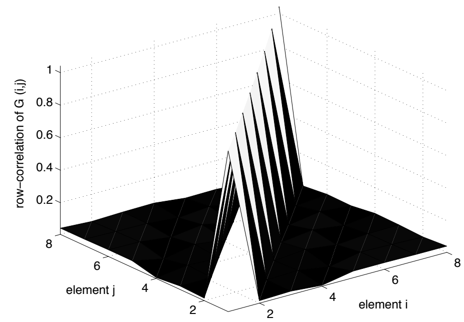

Figure 7: Correlation of the fading matrix G for receive position Rx6, direction D1

5 Conclusion

We investigated how good the average capacity calculated from a stochastic MIMO model []fits our measurements in an indoor scenario. This model separates the influence of fading from the correlation at transmit and receive arrays. We calculated estimates of the transmit and receive correlation matrices, respectively, and extracted the fading matrix from the measured 8×8 MIMO channel matrices.

We found that at RX positions and directions, where the correlation at the transmitter and receiver is low, the model fits very well. The entries of the extracted fading matrix are uncorrelated with mean power of unity.

However, when there exists considerable correlation at both the transmit and receive side quite some discrepancy arose. The entries of the fading matrix are not independent

identically distributed with mean power of unity any more, as assumed in the model. The predicted capacity was up to 13% below the one expected by theory. We note that this result is in contrast to findings in [8].

6 Acknowledgment

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