Variation of the Measured Indoor MIMO Capacity with Receive Direction and Position at 5.2GHz

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Abstract:

Using a directional receive (RX) antenna array we measured the channel capacity of an 8×8 multiple-input multiple-output (MIMO) system in an office scenario at 5.2GHz for different RX directions and positions. The average MIMO capacity can be related to dominant-wave propagation. However, when path-loss is normalised out, MIMO capacity is nearly independent of RX direction and position.

Introduction: MIMO systems are promising candidates for future broadband wireless local area networks. The MIMO capacity sets an upper bound for the achievable throughput. Since the capacity is strongly dependent on the prevailing radio channel [3,4], it is important to investigate the influence of different transmit (TX) and receive (RX) positions on the actual capacity. When directional antenna arrays are envisaged, eg on the back of a laptop computer display, RX direction enters as a further parameter.

Measurement set-up and scenario: For the measurements we used the RUSK ATM channel-sounder operating at 5.2GHz carrier frequency [1]. An 8-element uniform linear patch array (ULA) with 120° 3dB beamwidth and $\lambda/2$ spacing served as an RX antenna. The monopole TX antenna was moved to 20×10 positions on a rectangular grid of $\lambda/2$ spacing, forming a virtual TX matrix without mutual coupling. The measurements took place in the offices of the Institute of Communications and Radio Frequency Engineering at the Vienna University of Technology. The TX antenna was located in the corridor, the RX antenna at 8 different positions within a single office, amply furnished with wooden and metal furniture and plants, without line of sight to the TX. The door to this room was open. Using three different broadside directions of the RX array (D1, D2, D3), angularly spaced by 120° (Figure 2), we measured the channel transfer matrix for each RX position at 193 orthogonal frequency bins within a bandwidth of 120 MHz [1].

Capacity Computation: We considered different realisations of the capacity (in bit/s/Hz), and calculated both the average and the 10% outage capacity. The capacity when the channel is not known at the TX was calculated by [2]

$$C = \log_2 \det\left(\mathbf{I}_8 + \frac{\rho}{n_T}\mathbf{H}\mathbf{H}^H\right) \qquad (1)$$

where $\mathbf{I}_8$ denotes the 8×8 unity matrix, ρ the mean receive SNR, n_T (=8) the number of TX antennas and $\mathbf{H}$ the 8×8 MIMO channel matrix. The superscript H denotes hermitian transposition. To get different 8×8 MIMO channel realisations we took 8 adjacent TX positions out of the 20×10 TX matrix and moved this virtual 8-element ULA in x and y directions over all possible TX array positions, which resulted in 13×10=130 *spatial* realisations of the MIMO channel matrix. Taking the 193 frequency bins, the total set of channel samples is formed by 130×193=25.090 different spatial and frequency realisations. The complementary cumulative distribution functions (ccdf) of the channel capacity at RX position 1 are shown in Figure 1.

We considered two different cases: The capacity with and without path-loss effects. In both cases we had to normalise the measured MIMO matrices. In the first case we multiplied all MIMO matrices by a constant normalisation factor, which was determined such that at the bottom left RX position into direction D3 in average over all frequencies and spatial realisations

$$\sum_{i=1}^{n_R} \sum_{j=1}^{n_T} \left| h_{ij} \right|^2 = n_R n_T \qquad (2)$$

is fulfilled. By setting ρ to 10dB we now have an average receive SNR of 10dB at the bottom left RX position into direction D3. Of course, the average receive SNR is different for other RX positions and directions due to a different path-loss. In the second case we calculated, for each RX position and direction, a different normalisation factor such that, in average over all frequencies and spatial realisations, equation (2) is fulfilled at each RX position and direction. By setting ρ again to 10dB, the average receive SNR for each RX position and direction is now 10dB, ie we normalised the different path-losses out. By this normalisation method we ensure that in both cases the resulting channel capacity is the same for the bottom left RX position into direction D3.

Results: Figure 2 shows the capacity values *with path-loss* for each RX direction and position. The length of each arrow represents the *average* capacity for this direction and position of the RX antenna. The average and the 10% outage capacities are plotted next to the arrows, the latter in parentheses. It can be seen that both capacity values vary strongly with receive direction. Direction D3 always leads to the largest, and D2 mostly to the lowest capacity. The capacity is largest for the bottom left RX position and decreases with increasing distance from this point.

Figure 3 depicts the capacity with *path-loss normalised out*. The variations in the capacity values are much lower and we observe only a slight increase of the capacities from the lower left towards the upper right corner. Figure 4 shows the mean path-loss in dB, so the length of the arrows represent the signal strength. Corresponding to Figure 2 the path-loss is lowest for direction D3 in the bottom left corner. Additionally direction D3 gives always the lowest, and D2 mostly the highest path-loss for a specific RX position. This leads to the conjecture that both the propagation through the opened door and the obstructed line of sight component are dominating the wave propagation. Nevertheless, the average capacity for *constant average receive SNR* (Figure 3) is about the same for all RX direction. From a system point of view, capacity with path-loss relates to the case of constant TX power and capacity with path-loss normalised out to the case with constant average receive SNR, ie TX power control.

Conclusion: Our measurement with a directional receive array demonstrates that the average MIMO capacity *with path-loss* can be related to basic wave propagation mechanisms, eg open doors or quasi-line-of-sight dominating the scenario. Still, the average MIMO capacity with *path-loss normalised out* depends mainly on the average receive SNR and not significantly on the RX direction nor the RX position in the cluttered scenario measured. This means that even in directions with high receive SNR where dominating multipath components are expected, we still observe rich multipath scattering.

References:

[1] R. Thomä et al., “Identification of time-variant directional mobile radio channels”, IEEE Trans. on Instrumentation and Measurement, vol. 49, April 2000, pp. 357-364.

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[3] J. Wallace and M. Jensen, "Measured Characteristics of the MIMO Wireless Channel", IEEE VTC Fall 2001, Atlantic City, N.J., USA, Oct. 2001

[4] D.P. McNamara, M.A. Beach, P.N. Fletcher and P. Karlsson, "Capacity variation of indoor multiple-input multiple-output channels", Electronics Lett., vol. 36, No. 24, 23. Nov. 2000

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Figure captions:

Fig. 1 Complementary cumulative capacity distribution at RX position 1

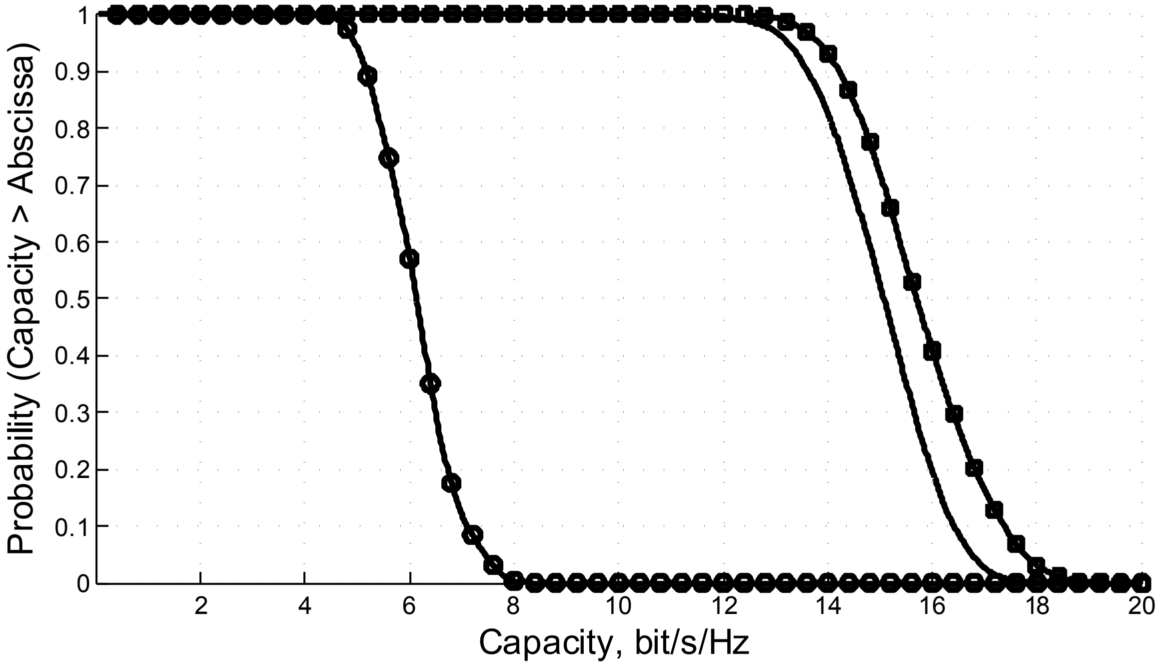
——— Direction D1
—o— Direction D2
— — Direction D3

Fig. 2 Average and 10% outage (in parentheses) channel capacities in bit/s/Hz *including* path-loss as a function of broadside direction and position of the RX array

Fig. 3 Average and 10% outage (in parentheses) channel capacities in bit/s/Hz with *path-loss normalised out* as a function of broadside direction and position of the RX array

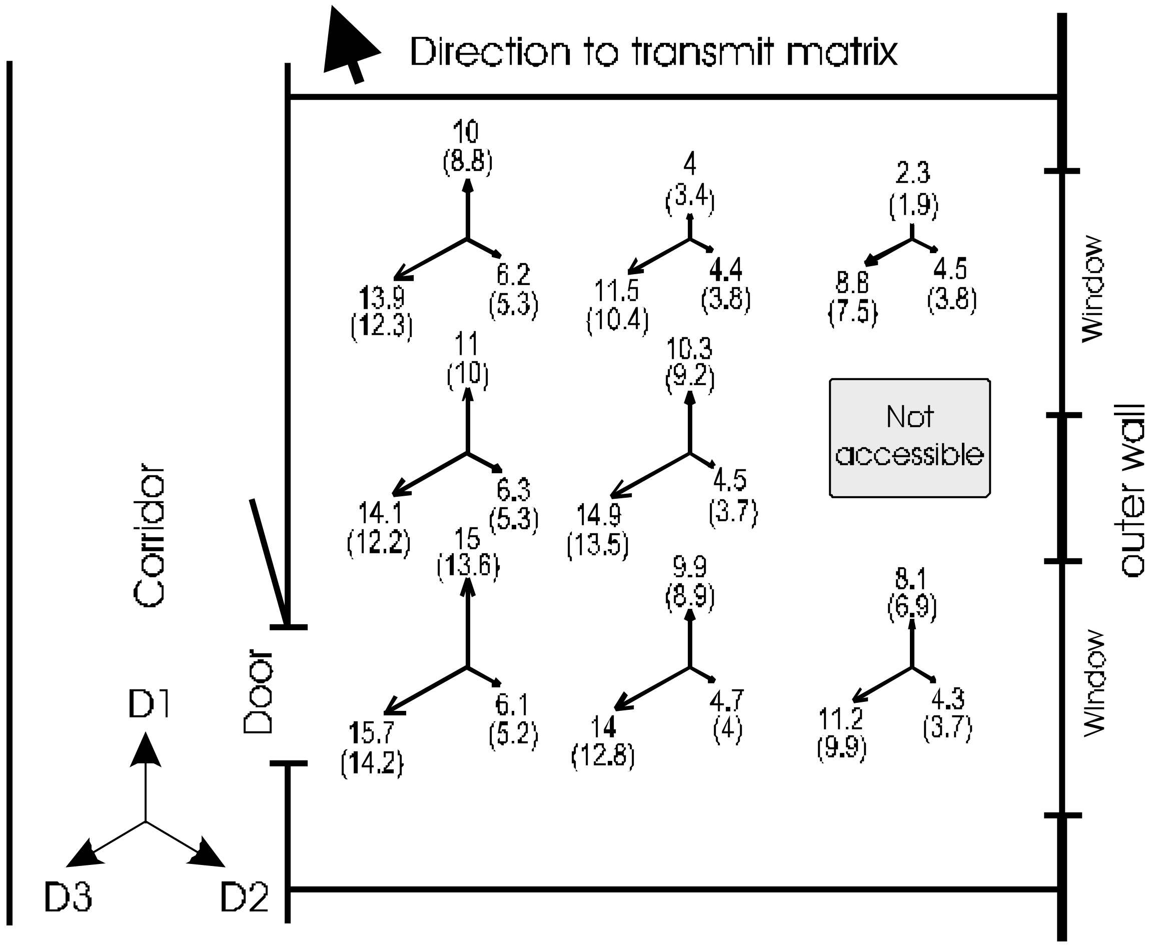
Fig. 4 Average path-loss in dB from the transmit antenna to the receive antenna as a function of broadside direction and position of the RX array

Figure 1



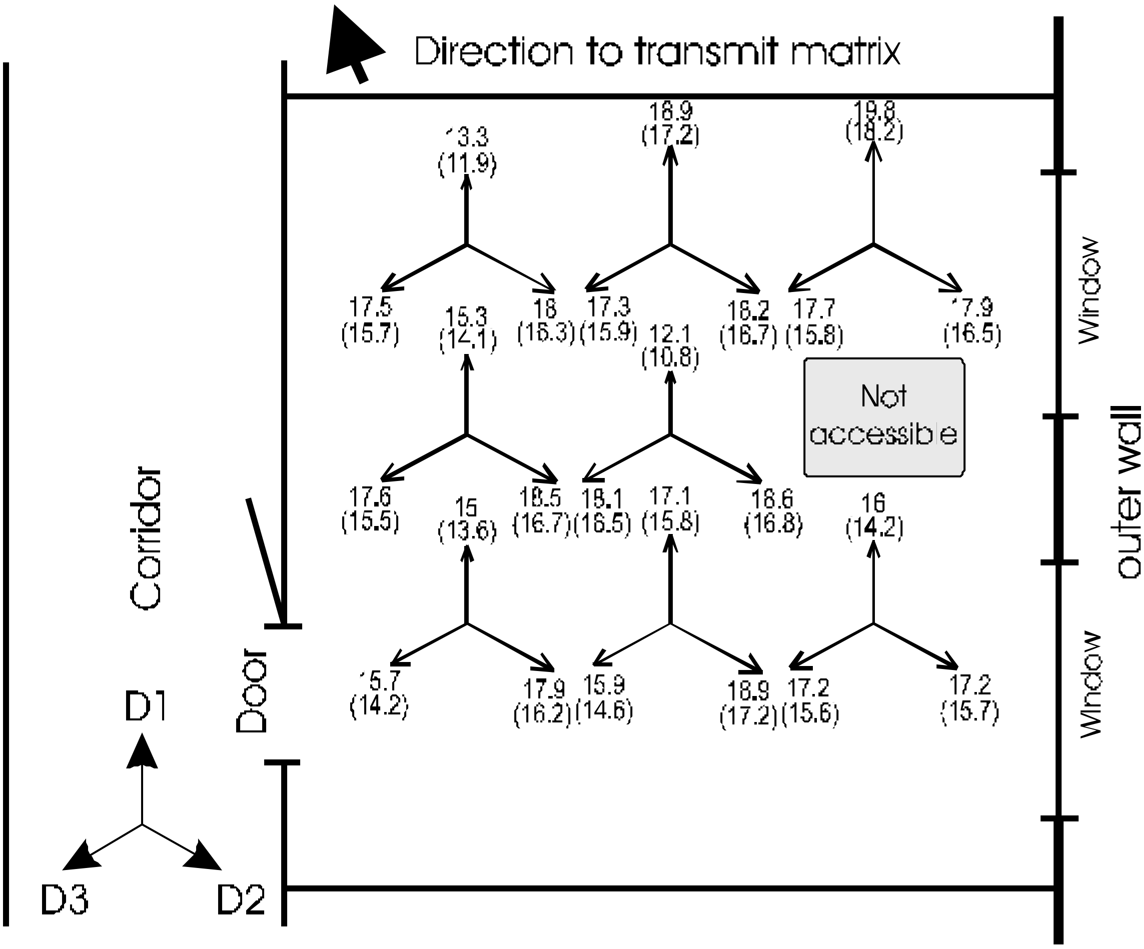
Probability (Capacity > Abscissa)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
4
6
8
10
12
14
16
18
20
Capacity, bit/s/Hz

Figure 2



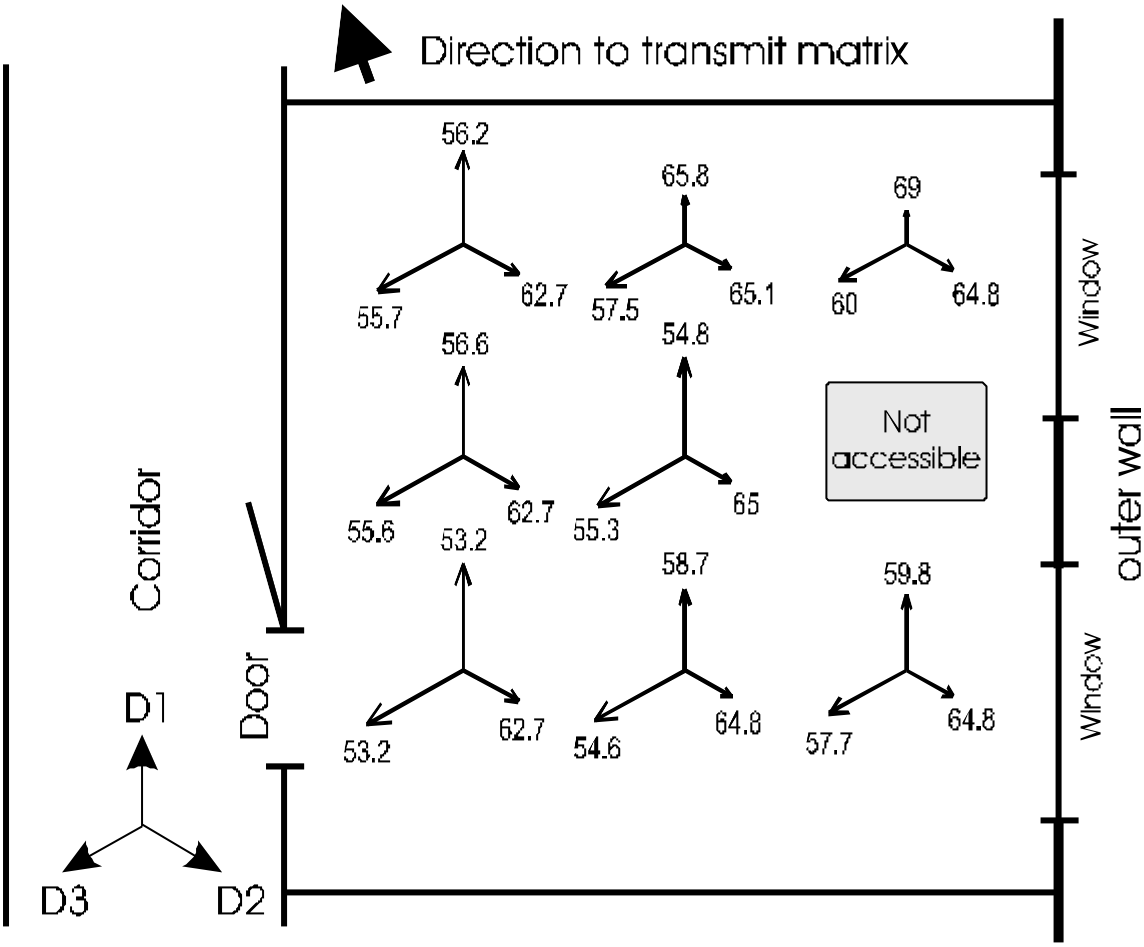
Direction to transmit matrix
10
(8.8)
13.9
(12.3)
6.2
(5.3)
4
(3.4)
11.5
(10.4)
4.4
(3.8)
2.3
(1.9)
8.8
(7.5)
4.5
(3.8)
Window
11
(10)
14.1
(12.2)
6.3
(5.3)
10.3
(9.2)
14.9
(13.5)
4.5
(3.7)
Not accessible
outer wall
Corridor
15
(13.6)
15.7
(14.2)
6.1
(5.2)
9.9
(8.9)
14
(12.8)
4.7
(4)
8.1
(6.9)
11.2
(9.9)
4.3
(3.7)
Window
Door
D1
D3
D2

Figure 3



Direction to transmit matrix
Corridor
Door
D1
D2
D3
Window
outer wall
Window
Not accessible
13.3 (11.9)
18.9 (17.2)
19.8 (18.2)
17.5 (15.7)
15.3 (14.1)
18 (16.3)
17.3 (15.9)
12.1 (10.8)
18.2 (16.7)
17.7 (15.8)
17.9 (16.5)
17.6 (15.5)
15 (13.6)
18.5 (16.7)
18.1 (16.5)
17.1 (15.8)
18.6 (16.8)
16 (14.2)
15.7 (14.2)
17.9 (16.2)
15.9 (14.6)
18.9 (17.2)
17.2 (15.6)
17.2 (15.7)

Figure 4



Direction to transmit matrix
56.2
55.7
62.7
65.8
57.5
65.1
69
60
64.8
56.6
55.6
62.7
54.8
55.3
65
Not accessible
53.2
53.2
62.7
58.7
54.6
64.8
59.8
57.7
64.8
Window
Window
outer wall
Corridor
Door
D1
D2
D3