Impact of transmit antenna spacing on 2 × 1 Alamouti radio transmission

S. Caban and M. Rupp

It is a common belief that multiple transmit antennas have to be placed far apart in order to avoid undesired effects such as mutual coupling, changing beampatterns, antenna mismatching losses, and correlation. The following radio communication setup is considered: two $\lambda/4$-monopole ground-plane transmit antennas, a single receive antenna, 4QAM modulation, Alamouti space-time coding, uncoded single carrier transmission at 2.4 GHz, indoor scenario. By measurements, the impact of very low transmit antenna spacing on the average uncoded BER over transmit-power performance of such a radio link, therefore accounting for all losses in the transmission chain, is examined. The common belief that multiple transmit antennas have to be placed far apart cannot be confirmed.

Introduction: Transmit diversity has emerged as an effective means of achieving higher throughput in wireless communication systems. The so-called Alamouti space-time block coding [1] is one quite robust way to exploit the presence of – in the optimum – independent multipath fading to improve the reliability of a transmission. It is well agreed that correlation between the propagation paths lowers the achievable link capacity. Traditional analysis, however, typically ignores other important effects (e.g. antenna coupling [2]). The lower the spacing, the worse the radio link performance, but the smaller the device can be. The question is: What minimum antenna distance is feasible without significant loss of performance?

Measurement setup: To investigate the BER over SNR (over transmit power) performance of an Alamouti link in real-time, we utilise our MIMO testbed described in [3] and [4]. At a data rate of 500 ksymbols/s, we transmit a 4QAM modulated and root raised cosine filtered signal from two transmit antennas to a single receive antenna (see Fig. 1). First, we transmit 100 SISO symbols plus sufficient training on the left transmit antenna, next 100 Alamouti coded symbols plus sufficient training on both transmit antennas, and lastly, 100 SISO symbols plus training on the right transmit antenna. Each of the three transmissions is separately decoded at the receiver, leading to an estimated SNR and BER. We then repeat the whole transmission for six different SNRs (six different transmit powers), 50 different antenna spacings (we mounted the left of the two transmit antennas on a linear guide), 17 times 17 different xy-positions of the transmit antenna (this is achieved using an xy-positioning table), and 17 times 17 different xy-positions of the receive antenna (this is achieved using a second xy-positioning table). The resulting $3 \times 6 \times 50 \times 17^2 \times 17^2 \simeq 75$ million blocks are then subject to averaging over all $17^2 \times 17^2$ transmit and receive table positions.

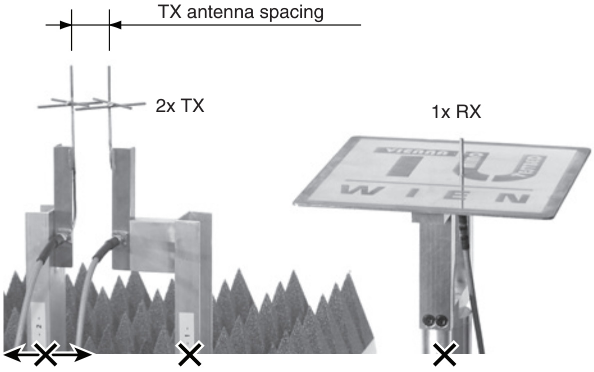

Fig. 1 *Transmit antenna (spacing = 0.02λ to 1.8λ) and receive antenna*

Measurement results: We placed the transmit and receive antennas about 30 m apart in an indoor scenario. For each of the 50 different transmit antenna spacings and a target BER of 0.01, the above described measurement procedure leads to a ‘SISO1’, an ‘Alamouti’, and a ‘SISO2’ SNR over distance curve (see Fig. 2). The dashed lines are drawn for transmit power (measured at the power-amplifiers’ outputs before the transmit antennas) over distance in order to account for all losses in the transmission chain.

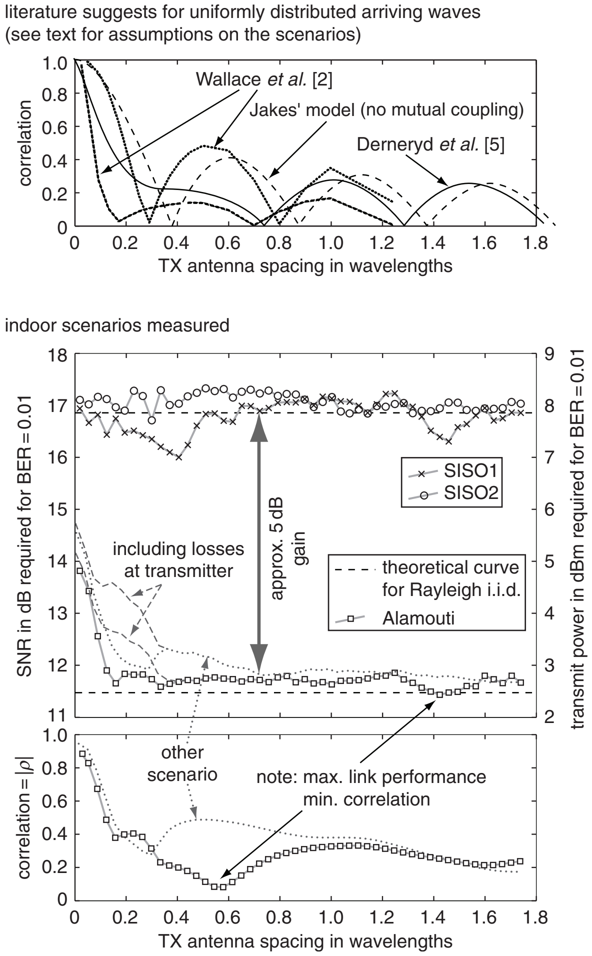

Fig. 2 *Measurement results*

As expected, we observed that the performance of the SISO links stay, apart from fluctuations in the scenario, nearly equal over all measured antenna spacings at Rayleigh-like conditions. Down to very low spacings, the Alamouti link also achieves approximately the performance of an Rayleigh i.i.d. channel. The same behaviour could be observed for different scenarios measured, with the Alamouti link loosing performance somewhere between 0.1 and 0.3λ. In none of the measured scenarios, the Alamouti link performance showed a periodic behaviour. We confirmed our measurements using a $\lambda/4$-monopole common-ground-plane antenna (similar to the receive antenna shown in Fig. 1) with a fixed antenna spacing of 0.2λ. We also used a rotation-unit to check if the results stay similar for different orientations (broadside, etc.) of the transmit antenna array.

Antenna correlation ρ is obtained as defined in (1) (see also Fig. 2):

$$\rho \overset{\text{def}}{=} \frac{\sum_i h_{1i} h_{2i}^*}{\sqrt{\sum_i |h_1|^2 \sum_i |h_2|^2}} \tag{1}$$

Compared to the literature (e.g. [2, Fig. 6] assuming ‘azimuthal arrival angles uniformly distributed on [0, 2 π]’, and [5, Fig. 3], assuming ‘incident waves in the horizontal plane within an angle region of 120°’), we do not observe pronounced correlation minima at constant antenna distances for different scenarios (see e.g. the dotted line in Fig. 2).

Conclusion: We carried out many different measurements in indoor scenarios where transmitter and receiver are placed far enough apart to show Rayleigh-like fading. In scenarios satisfying the conditions outlined in the Abstract of this Letter, we observed the following. Antenna distances as low as 0.3λ, and even lower, are feasible for dipole antennas without loosing on link performance. Even at antenna distances of 0.05λ, the Alamouti link still shows considerably better performance than the SISO link. Plotting correlation against antenna distance did not show any pronounced minima and periodicity when comparing different scenarios. In fact, measurements with other antennas demonstrated that they cannot be placed closely enough (due to mechanical limitations) to significantly worsen an Alamouti link performance. For a target BER of 1%, the application of two transmit antennas lowered the average transmit-power required by about 5 dB.

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