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Description	

The Dependency of Turbo MIMO Equalizer Performance on the Spatial and Temporal Multipath Channel Structure – A Measurement Based Evaluation

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***Abstract*— In this paper a performance analysis of the turbo MIMO equalizer concept for broadband MIMO channels is presented. The channel modeling in the link-level simulations is based on MIMO measurements in different scenarios. The results reveal the strong relationships between the propagation conditions in terms of the available spatial and temporal multipath diversity, the antenna configurations, and the achievable bit error rates. It is shown that the consideration of a simple transmit diversity concept and the application of antenna subset selection leads to remarkable performance improvements.**

Keywords— Turbo MIMO equalization, measurement data, single carrier, performance evaluation, subset selection, transmit diversity

I. INTRODUCTION

Multiple-input multiple-output (MIMO) air interfaces based on antenna arrays at both the transmitter as well as the receiver side are considered to be the ultimate means to increase the available capacity for high bit rate wireless links. Commonly known MIMO signal processing concepts like BLAST [1] aim to exploit the spatial diversity of the propagation channel. A straightforward extension of such narrowband algorithms to broadband single carrier systems would mostly result in an unacceptable numerical complexity. The turbo MIMO equalizer (TME) concept has shown the potential for a low-complexity signal separation method which exploits the spatial as well as the temporal structure of frequency selective MIMO channels [2], [6].

The performance evaluation regarding efficiency, usability and deployment of MIMO systems in various different propagation scenarios – combined with the optimization and enhancement of such systems is still a white spot. Adaptive space-time signal processing concepts, e.g., antenna subset selection [7], seem to be steps towards reasonable and robust MIMO communication.

Channel sounding techniques provide the possibility to evaluate the performance of radio multiple access and signal processing schemes under realistic propagation conditions. Complex channel impulse responses (CIR) gathered through MIMO measurements in different real field scenarios have been used in link-level simulations. The characterization of the multipath channel by means of high resolution parameter estimation is essential for investigating the influence of the spatial and temporal structure on the performance of the TME. Therefore this paper employs the results of double-directional channel sounding experiments for MIMO link-level simulations [3].

First, in section II a brief overview of the considered turbo MIMO detector is presented. This is followed by a description and notes to the measurement scenarios and the data used for realistic link-level simulations. Section IV shows bit error rate (BER) curves as performance results. The TME's performance is investigated under different propagation conditions. Furthermore, the impact of a transmit antenna subset selection test and a simple transmit diversity concept is highlighted.

II. MIMO SYSTEM

A. Turbo MIMO Detection

The considered MIMO transmission system based on an iterative receiver concept was inspired through [2] and is shown in Fig. 1. The receiver consists of two main parts: the MIMO SC/MMSE equalizer producing soft outputs and the soft input soft output channel decoder. Both are linked in order to exchange reliability information for the coded bits and together they perform the turbo MIMO detection. The reliability information is used within the MIMO equalizer block in order to perform a soft interference cancellation (SC) step of the interference components, which arise from inter-symbol interference (ISI) and multiple access interference (MAI). In the multiuser (MU) MIMO case the MAI are caused by different users (e.g., equipped with one antenna) transmitting signals at the same time and frequency slot. In a high data rate point-to-point (P2P) MIMO setup the MAI comes up from the multiple antennas of one transmitter. A spatial-temporal minimum mean square error (MMSE)

Figure 1. MIMO transmission system with turbo MIMO detection

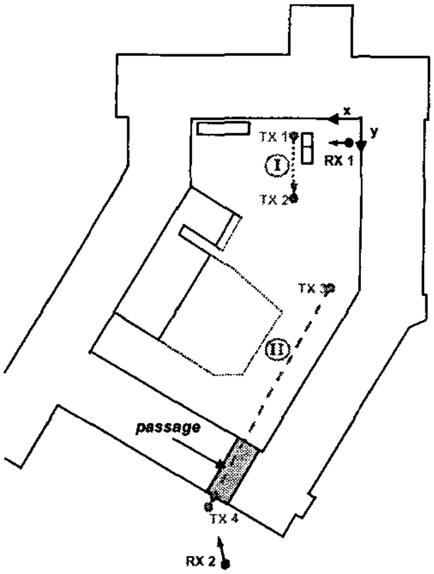

Figure 3. Measurement scenario with 2 different tracks

equalizer subsequently follows the SC step to minimize remaining ISI and MAI components at the filter output. For each transmitted data stream one filter output exists and consequently one decoder embedded together with de-interleaver and interleaver in an iterative feedback loop. In the first iteration no SC step can be applied due to the fact that no reliability information of the coded bits is available at this point. Therefore, the MMSE filter alone plays the role to suppress all interferences.

B. Transmit Schemes

The MIMO system concept illustrated in Fig. 1 was primarily designed for MU-MIMO applications [2]. In this transmit concept, each user is equipped with one antenna and generates a transmit data stream with independent convolutional encoding, interleaving and modulation. For the P2P-MIMO system the same principle can be used. A demultiplexer block in front of the encoders divides the total data stream into sub streams according to the number of transmit antennas. Again, each data stream is independently encoded, interleaved, modulated and transmitted over a fixed allocated antenna. As an alternative, a simple modified transmit scheme arises if the convolutional error correction encoding is shifted before the demultiplexer as depicted in Fig. 2. Considering an encoder with a code rate of 0.5 and a P2P-MIMO system with 2 transmit antennas, the 2 coded bits representing 1 information bit are split over two sub streams and transmitted by both antennas. This can be seen as coding over the transmit antennas, thus yielding a transmit diversity scheme. The 2 decoders embedded in the iterative turbo MIMO detection receiver can potentially obtain a diversity gain from this modification.

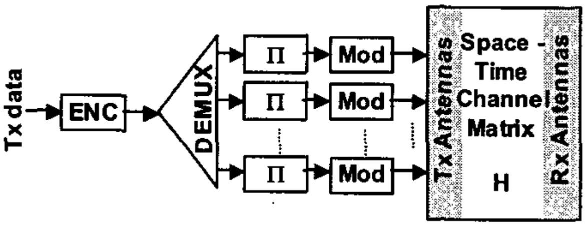

Figure 2. P2P-MIMO transmit concept using transmit diversity

III. REALISTIC LINK-LEVEL SIMULATION USING MEASUREMENT DATA

A. Importance of Measurement Data

Link-level or system-level simulation methods have the aim to evaluate and compare the performance of different air interface concepts as well as system concepts under realistic considerations. In contrast to the development of prototypes, multi-dimensional channel sounding techniques provide efficient possibilities to perform such simulations with a manifold of variations. Furthermore, these techniques open the way to high resolution path parameter estimation results, and hence, face simulation performances with the physical nature of propagation. Realistic conclusions and understandings of the system or algorithm under test can be drawn and consequently used to enhance and optimize the considered concept. The broadband real-time channel sounder RUSK MIMO from MEDAV [4] supports multiple antennas at both sides and was used for the measurement campaign treated in this paper. Important aspects for performing MIMO measurements and using the measurement data in transmission system simulations are discussed in [6].

B. Selected Scenario and Measurement Setups

Two measurements were performed within a large courtyard at the campus of the Technische Universität Ilmenau. This place is completely enclosed by a building of about 15 m height, whereby several different metal objects (container, mesh fence and tubes) were located within the courtyard. Measurement track "I", see Fig. 3, is characterized by a non line of sight (NLOS) part for approx. 3 m from position TX1 and line of sight (LOS) conditions for the rest of the track. The transmit antenna, an omnidirectional 16 element uniform circular array (UCA), fastened at a height of 2.10 m, was moved at walking speed. For the receive antenna, an 8 element uniform linear patch array with separate ports for horizontal and vertical polarization was considered, whereby the antenna was mounted at a height of 1.67 m and only the vertical polarization was measured. During measurement track "II," the same antenna configuration, but with different heights (transmitter at 1.10 m and receiver at 1.13 m) was applied. Most parts of the track had NLOS. The emphasis of this selected run laid on the passage (tunnel) between transmitter and receiver[1]. The passage has a length of 13.10 m, a height and width of 4.15 m and 4.47 m, respectively. All measurements have been performed at 5.2 GHz carrier frequency and with a bandwidth of 120 MHz.

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[1] Data from this scenario can be downloaded free of charge from [4].

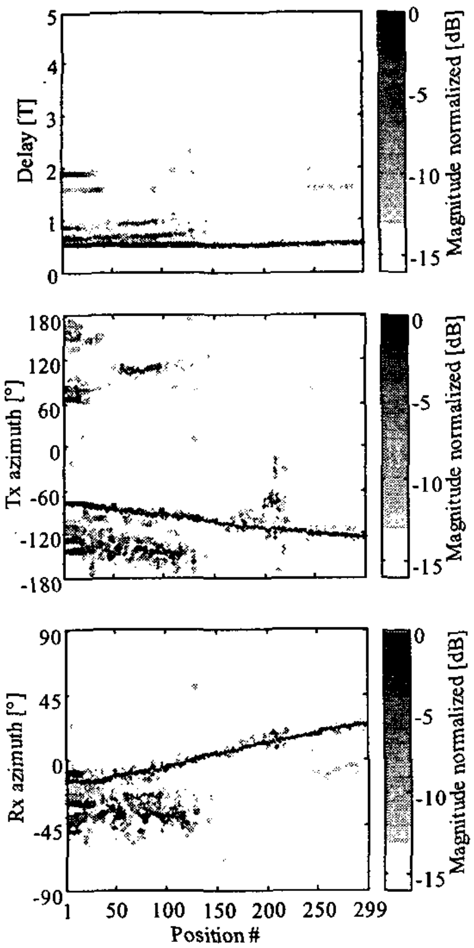

Figure 4. Results of propagation parameter estimation for measurement track "I" (delay normalized to 1/T = 12 Msym/s, magnitudes smaller than –15 dB are plotted with –15 dB)

IV. Link Level Simulation Results

A. Simulation setup

In this paper all simulation results have been produced for TME based systems operating at 12 Msymbols/s per Tx antenna. The transmit space-time signal processing uses a convolutional encoder with code rate 0.5 and constraint length 3, random interleaver and BPSK modulation for each sub stream. The channel impulse responses for both selected tracks are modeled, according to the delay components observed within the measurement data, using 17 delay taps. For complexity reasons the receiver itself is only equipped with L = 5 temporal taps. This is sufficient to capture the significant part of the received energy within the channel impulse responses. The signal to noise ratio (SNR) at the receiver is held constant and identical for each transmit signal by an adaptive power control. The total transmitted power is independent of the numbers of transmit antennas.

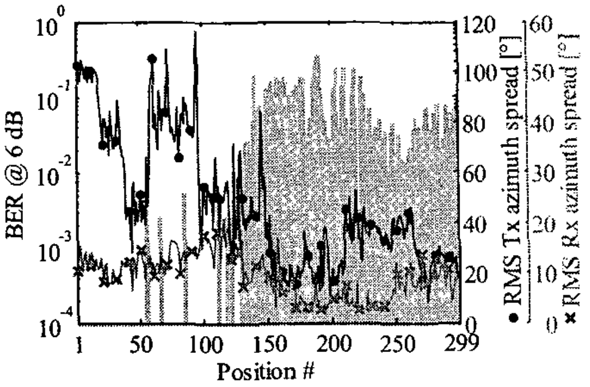

Figure 5. BER of a 3/3 TME (gray bars) vs. Rx and Tx azimuth spread along measurement track "I"

B. NLOS – LOS propagation

Using the high resolution path parameter estimation approach [3], two different propagation conditions for track "I" can be identified. In Fig. 4 the estimation results for the multipath components over the whole measurement run are shown in terms of direction of arrival (Rx azimuth), direction of departure (Tx azimuth) and path delay time. From the beginning until position #125 strong multipath components between 0° and –45° Rx azimuth and for the Tx azimuth ranges of –60°…–170° and respective 60°…120° characterize the NLOS part. The different multipath components can also be separated within the delay time plot. Obviously, for a small number of positions (#1-#20) only very minor changes in the estimated parameters and additional strong multipath components for 2 T in delay time as well as for the Tx azimuth around +70° can be found. Here, the Tx antenna did not move. After this section the paths disappear. As expected from Fig. 3, LOS condition can be observed for the rest of the track (#126–#299). Multipath contributions are attenuated by 15 dB and more relative to the strongest path. The displayed BER results (after 4 iterations and at 6 dB SNR) for a TME system using 3 Tx antennas and 3 Rx antennas (denoted by 3/3) in Fig. 5 reflect very well the dependency of the considered MIMO system on the spatial and temporal

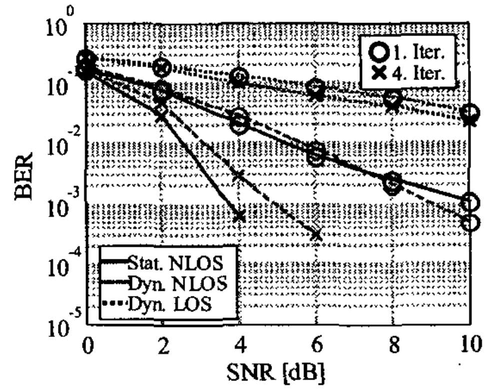

Figure 6. BER curves for a 3/3 TME under NLOS and LOS condition

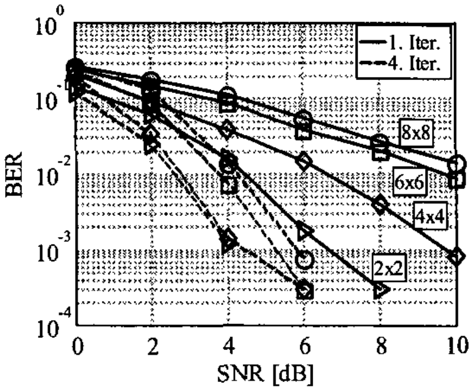

Figure 7. BER curves for 2/2, 4/4, 6/6 and 8/8 TME, under stationary NLOS

multipath diversity for different propagation conditions. Here, the NLOS parts are indicated by Tx azimuth spreads between 50° and 100°, whereas the LOS parts show values between 20° and 40°. Due to the limited view of the uniform linear patch array (Rx antenna), the spread for the Rx azimuth is significantly lower as for the Tx azimuth, but still a small dependency on the different propagation condition (NLOS-LOS) can be found. The TME performance strongly depends on the NLOS and LOS propagation. This relation can be more distinctly seen in Fig. 6. After 4 iterations the 3/3 TME shows reasonable performance for the dynamic NLOS part (position #21-#125) and slightly better curves for the stationary NLOS part (#1-#20), but for the LOS part the transmission completely fails. Fig. 7 compares BER curves after the 1st and 4th iteration of a 2/2, 4/4, 6/6, and 8/8 TME, respectively, within the stationary NLOS part. For the 1st iteration, the performance decreases with an increasing number of considered streams, due to the increased MAI. After the 4th iteration, 2/2 and the 4/4 systems reach the same performance. For the 6/6 and 8/8 TME a good iteration gain can be observed, but the BER performance of a 4/4 system can not be achieved. The TME is capable to exploit multipath diversity by performing iterations.

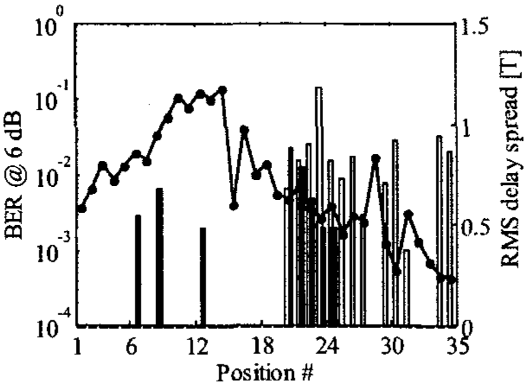

Figure 8. BER of 2/2 TME's considering 2 different transmit antenna subsets (dark and light bars) vs delay spread along track "II"

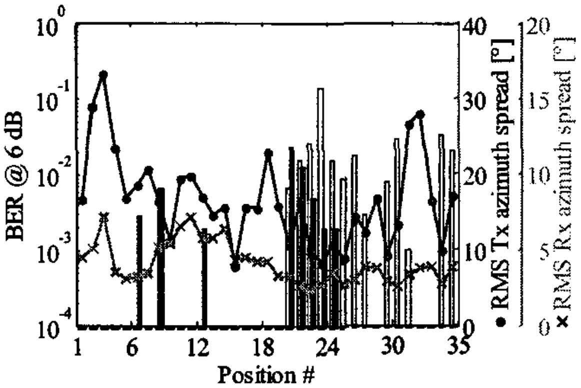

Figure 9. BER of 2/2 TME's considering 2 different transmit antenna subsets (dark and light bars) vs Rx and Tx azimuth spread along track "II"

C. *MIMO Antenna Subset Selection and Transmit Diversity*

Measurement track "II" in particular was selected due to the passage between transmitter and receiver. For this scenario lower azimuth spreads for Tx and Rx compared to track "I" were expected. For the following performance evaluations only the middle part of track "2", consisting of 35 positions, were considered. In Fig. 8 and Fig. 9 the results of the high resolution parameter estimation are displayed together with position variant BER (after 4 iterations and at 6 dB SNR) for a 2/2 TME, in which 2 different Tx element subsets out of 16 elements were used. The interesting observation is that for different Tx element combinations significant performance differences occur without an obvious interpretation regarding the path parameter estimations. That means even small changes in the antenna positions could cause large performance variations. Furthermore, this fact was also found for simulation trials with 3/3 and 4/4 TME systems. Only the positions with significantly high azimuth and delay spreads seem to be independent to antenna subset selection.

Motivated by the aforementioned observation a dynamic subset selection test was carried out to investigate the influence on the mean BER performance over the selected snapshots. One fixed Tx antenna subset for all 35 position leads to a high BER, see Fig. 10. The selection test follows no specific measure or key parameter. The BER for 2/2 and 3/3 TME systems for 5 different Tx antenna subsets were simulated. Afterwards the antenna subset with the minimum BER for one specific snapshot was selected to compute the mean BER over all positions. This simple test shows impressively the significance of the MIMO antenna subset selection. Performance gains of 6 dB at a BER of 10^{-3} (see Fig. 10) can be expected, if an effective subset selection algorithm for frequency-selective MIMO channels can be applied.

As shown above a possible Tx antenna subset selection can be useful to reach reasonable and robust mean BER for TME even in channels with low azimuth and delay spreads. This approach can only be used if the transmitter has channel knowledge or a feedback channel from the receiver and at least the transmitter has several selectable transmit antennas.

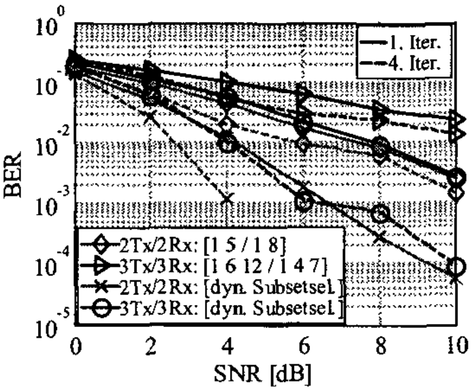

Figure 10. BER curves for 2/2, 3/3 TME, comparison between fixed transmit antenna and dynamic antenna subset selection

A simple change in the transmit signal processing for the P2P-MIMO setup, as described in section II, introduces transmit diversity without increasing complexity and loss of throughput. In Fig. 11 the significant performance gain is illuminated. The link-level simulations have been performed in the same middle part of track "II" as before. Without the transmit diversity concept the typical iteration gain for the 2/2 TME and the 4/4 TME is not observable – the mean performance is rather poor, due to the potential lack of multipath diversity. Using the simple change in the transmit concept leads to impressive gains for the 4th iteration in both systems. For the 2/2 TME an improvement of around 4 dB at a BER of 10^{-3} can be remarked. The first iteration shows no difference between systems with and without the transmit diversity approach. It seems that the iterative turbo MIMO equalization can significantly benefit with higher iteration numbers from additional diversity. The lack of spatial-temporal multipath diversity, which is essential for broadband MIMO communications, can be partially compensated through introducing another form of diversity – the transmit diversity.

V. CONCLUSIONS

The potential performance of broadband MIMO communication systems strongly depends on the offered spatial as well as the temporal radio channel diversity. MIMO measurement trials combined with high-resolution channel characterization provide detailed insights into the physical propagation conditions in different real world scenarios. Using these methods the performance of the P2P-TME concept can be realistically evaluated and interpreted.

Reasonable and robust results can be gained for the P2P-TME in NLOS scenarios with a high degree of spatial and temporal diversity – indicated by azimuth and delay spreads. In contrast to that, LOS or even NLOS channels with a low degree of multipath diversity show poor MIMO system performances. A simple extension of the P2P-TME concept towards introducing a form of transmit diversity leads to remarkable performance gains for 2/2 and even for 4/4 TME's. Furthermore, a MIMO antenna subset selection test illuminates an enormous influence on the simulation results.

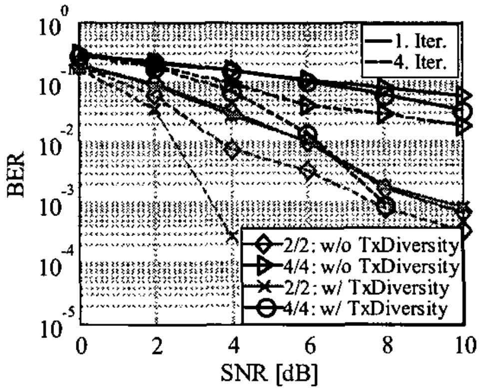

Figure 11. BER curves for 2/2, 4/4 TME, w/ and w/o transmit diversity

Adaptive space-time algorithms for the transmitter as well as for the receiver seem to be essential. The optimization and enhancement of MIMO algorithms with respect to application and deployment issues will play an important role for future research work.

ACKNOWLEDGMENT

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