Correlation between MIMO Link Performance Evaluation Results and Characteristic Channel Parameters

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ABSTRACT

This paper investigates the comparison between the link performance and the characteristic channel parameters (e.g. delay spread, spatial correlation). The link performance is described by the bit error rate and the channel capacity. It is shown that there exists strong relation between the performance of the link and properly chosen characteristic channel parameters. The investigations presented within the article are based on measurements performed by a real-time MIMO channel sounder.

I. INTRODUCTION

The use of multiple antennas at both ends of the transmission system can increase the link capacity. Therefore a lot of articles were dedicated to investigate the capacity of the multiple input multiple output (MIMO) channel [1], [2]. Recent research activities have shown that narrowband as well as broadband spatial multiplexing systems are sensitive to the instantaneous multipath channel behaviour [3], [4]. The channel behaviour can be described by various channel parameters. The characteristic channel parameters provide information necessary e.g. for the channel classification, or the channel modelling. The goal of this article is to highlight if characteristic channel parameters can predict the performance of the wireless transmission system. The information carried by channel parameters that are strongly related to the link performance could be in future advantageously used for the adaptive control of transmitter and receiver in space multiplexed MIMO systems. This seems to be essential to ensure reliable quality of the communication in these systems.

To quantify the relationship between the characteristic channel parameters and the link performance expressed in terms of bit error rate (BER) and channel capacity the correlation coefficient among these measures is computed. In order to gain realistic BER characteristics of a MIMO communication system the performance of the broadband Turbo MIMO Equalizer (TME) [5] was analysed under real-world propagation condition. Firstly, the link performance characteristics are discussed in more details. The article follows with a short overview of characteristic channel parameters. The correlation between link performance and characteristic channel parameters is illustrated on an example using data measured by a broadband real-time MIMO channel sounder [6].

II. LINK PERFORMANCE

Within this article, link performance of the simulated MIMO communication system is described in terms of channel capacity and BER. Basically, channel capacity can be defined for two different cases:

- full or partial information about channel is available in the transmitter,
- there is no knowledge about the channel in transmitter.

This article focuses on the channel capacity related to the later case when the transmitter has no knowledge about the channel. In this case the optimum transmit strategy is to assign power independently among the transmitters. The equal power channel capacity $C$ for the narrowband channel is defined as

$$C = \log_2 \det \left( I_{M_R} + \frac{P}{M_T \sigma_N^2} H H^H \right)$$  (1)

where $H$ is the channel matrix with the size $M_R \times M_T$ ($M_R$ is number of receivers and $M_T$ is number of transmitters), $P$ stands for the signal power, $\sigma_N$ defines the noise power and $I_{M_R}$ is the identity matrix. The ergodic channel capacity is obtained by averaging in frequency domain (assuming stationary behaviour of the channel in this domain).

Apart from the channel capacity the link performance can also be described by BER, whereby this is specific to a certain transmit and receiver algorithm configuration for the MIMO system. As mentioned above, here, a broadband MIMO system based on the TME is considered [5]. The system design considered within this article is shown in Fig.1. It is based on a spatial multiplexing scheme with an iterative receiver concept. The receiver consists of two main parts: the MIMO soft interference cancellation (SC) and minimum mean square error (MMSE) equalizer and the soft input soft output channel decoder. Both are linked in a feedback loop 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 SC step of the interference components, which arise from inter-symbol interference (ISI) and multiple access interference (MAI). A spatial-temporal MMSE equalizer subsequently follows the SC step to minimize remaining ISI and MAI components at the filter output. There exists
one filter output for each transmitted data stream and consequently one decoder embedded together with de-interleaver and interleaver in an iterative feedback loop. More detailed information about the system concept can be found in [4].

A MIMO system with 3 transmit and 3 receive antennas (3x3 TME) was considered. The signals were transmitted at binary phase shift keying (BPSK) modulation independently from each transmit antenna after convolutional encoding (7;5) and random block interleaving. The frame within which the channel was locally stationary contained 1024 symbols. The symbol rate of 12 MSymbol/s was selected. For the receiver perfect channel knowledge was assumed.

The relation between selected channel parameters and the communication transmission systems.

Moreover, if channel characteristics should be used e.g. for adaptive control of the receiver it is desired that the extent of raw measured data is usually large and therefore it is quite challenging to observe certain channel characteristic directly from measured data. However, the extent of raw measured data is usually large and therefore it is quite challenging to observe certain channel characteristic directly from measured data. The obtain information about the channel can be used for channel classification, channel modelling and also it allows to roughly assess the achievable link performance of communication transmission systems.

The relation between selected channel parameters and the performance of communication system will be shown further in the next section. For that purpose, following channel parameters were chosen:

- delay spread – period within which substantial reflections arrive,
- MCC power (multipath component cumulated power) – number of reflections that are necessary to achieve 95% of the total power carried by all detected multipath components,
- path loss – parameter describing the channel attenuation,
- LRS length (local region of stationarity) - length of region within which is the channel locally stationary,
- spatial correlation at the receiver side – correlation among parallel subchannels of the MIMO communication system.

More information about these channel parameters can be found in the appendix or in [7], [8].

IV. MEASUREMENT EXAMPLE

The simulation of the communication system, computation of the channel capacity and characteristic channel parameters is based on the measured data.

The measurement was performed by a real-time MIMO channel sounder [6] within a large courtyard at the campus of the Technische Universität Ilmenau. This place was 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 (TX1 to TX2 in Fig.2) was 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 omni-directional 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 (ULA) 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. The measurement was performed at 5.2 GHz carrier frequency with a bandwidth of 120 MHz. A detailed description on pre-processing of the measurement data for realistic performance evaluations can be found in [3],[4].

V. RESULTS

The obtained BERs for the 3x3 TME MIMO communication system (3 elements from the ULA array and 3 elements from the UCA array) are illustrated in Fig.3. Here, it is possible to see 3 different BERs
corresponding to 3 independent data streams of the described communication system. Presented BERs were obtained after 4 iterations in the receiver at 4dB signal to noise ratio (SNR). The SNR at the receiver was held constant and identical for each transmit signal by an adaptive power control. It is possible to observe two different BER regions. The system performance in the first region (0s – 6s) is distinctly better then in the second one (7s – 15s). This is caused by the NLOS transmission conditions where the MIMO system can excellently separate parallel data streams due to the high spatial diversity, which is fundamental for the spatially multiplexed MIMO communication systems. In the second part of the transmission (LOS), there is too little spatial diversity. This part is dominated by one path and hence it is almost impossible to separate parallel data streams. This causes poor system performance.

The comparison between the achieved BER, channel capacity and the characteristic channel parameters was done by means of the envelope correlation coefficient defined as

$$ \rho_{uv}(c,d) = \frac{E[cd] - E[c]E[d]}{\sqrt{E[c^2] - E[c]^2} \sqrt{E[d^2] - E[d]^2}} $$

(2)

where $u$ is BER, or capacity (or derived function, e.g. log) and $v$ represents channel parameter (or its function, e.g. inverse, or log) that is to be compared with the link performance measures. The correlation among these characteristics was investigated using their time-smoothed forms with the variable smoothing window length.

Fig.4 and Fig.5 illustrate an example of the instantaneous (not time-smoothed – the smoothing window length is 0) characteristics that were compared. On the one side stands link performance described by the logarithm of the mean BER computed from the 3 BERs related to 3 independent data streams of the 3x3 TME system (Fig.4) and on the other side is the characteristic channel parameter e.g. spatial correlation (Fig.5). Fig.5 illustrates time dependence of the one element of the modified spatial correlation matrix ($Corr_m^{2,1}$) computed at the receiver side.

Each element of the spatial matrix provides information about the correlation between two signals at the receiver side (averaged over all transmitters). It means that e.g. assuming 3x3 TME system, matrix element $Corr_m^{2,1}$ represents the correlation between signals received by the second and the first element of the receiver antenna array and the correlation is averaged over all 3 transmitters.

Fig.6 and Fig.7 illustrate the same comparison as Fig.4 and Fig.5, however, for the time-smoothed versions of these characteristics.
The relation between these characteristics was quantified by the correlation coefficient defined by the equation (2). The dependence of the correlation coefficient on the length of smoothing window is depicted in Fig. 8. The same dependence, however, between channel parameters and channel capacity is displayed in Fig. 9.

In Fig. 8, it is possible to observe that in case of the unsmoothed (smoothing window length is 0) characteristics there exist clear differences in correlation between BER and selected characteristic channel parameters. The best results are gained by the spatial correlation. It means that by this parameter it is possible to predict instantaneous link performance expressed in terms of BER. Other characteristic channel parameters except LRS length parameter (only small correlation) approach the spatial correlation performance with the increasing smoothing window length. Thus, almost all selected characteristic channel parameters show the trend of the system link performance described by the BER, however, only spatial correlation provides information about the instantaneous behaviour of the whole system.

Different results were obtained comparing channel capacity defined by (1) with characteristic channel parameters. Analysing Fig. 9, it is obvious that there is not such a distinct difference in correlation between instantaneous and smoothed channel parameters. If the selected instantaneous channel parameter provides only small correlation with the channel capacity then the correlation is only slightly improved by the time smoothing. The best results were obtained again by the spatial correlation. Thus, it seems that this parameter is a good candidate for the adaptive control of transmitter and receiver in MIMO systems.

**VI. CONCLUSIONS**

The article has compared the link performance evaluation results with the selected characteristic channel parameters that were directly computed from data measured by the real-time MIMO channel sounder. It was shown that almost all selected channel parameters provided information about the basic trend of the link performance behaviour. The best results were achieved by spatial correlation at the receiver side, especially if the instantaneous BER and channel capacity characteristics were of interest.

The presented results are related to one specific measurement scenario and cannot be generalised. For that purpose a further work is necessary. However, it seems to be possible to predict the link performance of the complex MIMO communication system and advantageously use information carried by characteristic channel parameters.
for adaptive control of transmitter and receiver in space multiplexed MIMO systems.

REFERENCES


APPENDIX - SELECTED CHARACTERISTIC CHANNEL PARAMETERS

Path loss
Path loss describes effects of the channel attenuation. There are different possibilities for the path loss definitions. The wideband and minimum path losses are defined by following equations

\[ L_{WB}(t,s) = \frac{1}{\int_{\tau} [d_{ANT} h(t,\tau,s)]^2 d\tau} \] (3)

and

\[ L_{MIN}(t,s) = \frac{1}{\int_{\tau} [d_{ANT} h(t,\tau,s)]^2 d\tau}, \] (4)

where \( d_{ANT} \) stands for distance between transmit and receive antennas, \( h(t,\tau,s) \) is the measured time, delay and space dependant CIR.

Delay spread
Delay spread describes period within which the substantial reflections arrive. It is defined as the standard deviation of reflection delays that are weighted proportionally to the energy contained in the reflected waves.

MCC power
Another parameter that describes multipath environment is parameter MCC power, which represents the number of reflections that are necessary to achieve 95% (or other threshold value) of the total power carried by all detected multipath components (reflections).

LRS length
LRS is a region in which the channel statistics are approximately constant and so the propagation environment remains unchanged. The appropriate measure for the description of such a channel behaviour is the correlation coefficient defined as

\[ c(t_1,\Delta t) = \frac{\int_{\tau} P_h(t,\tau,s) \cdot P_h(t,\tau,s)_{t_1+\Delta t} d\tau}{\max \left[ \int_{\tau} P_h(t,\tau,s)^2 d\tau, \int_{\tau} P_h(t,\tau,s)_{t_1+\Delta t}^2 d\tau \right]}, \] (5)

where \( P_h(t,\tau,s) \) is a delay spectrum averaged in a reference window positioned at time \( t_1 \) and \( P_h(t,\tau,s)_{t_1+\Delta t} \) is a delay spectrum averaged in a window with variable position \( t_1+\Delta t \).

Spatial correlation
Spatial correlation is important measure especially for the MIMO communications systems. It provides information about the correlation among parallel subchannels of the MIMO systems. The lower is the correlation among the subchannels the higher is the capacity of the MIMO system. If we assume time and frequency dependant channel matrix \( H(t,f) \) with the size \( M_R \times M_T \) (\( M_R \) is number of receivers and \( M_T \) is number of transmitters) spatial correlation at the receiver side is defined as

\[ \text{Corr}(t) = E[H(t,f)H(t,f)^*]. \] (6)

The spatial correlation at the receiver side \( \text{Corr}(t) \) is time-dependent matrix with the size \( M_R \times M_T \).

If we assume that channel matrix is the result of a measurement, than we have to take into account the measurement noise that can make to appear the spatial correlation lower than it is in reality. That is why it is reasonable to modify the correlation definition in the following way

\[ \text{Corr}_m(t) = \frac{E[H(t,f)H(t,f)^* - \sigma_{\text{meas}} I_{M_T}]}{\text{trace}\left[ E[H(t,f)H(t,f)^* - \sigma_{\text{meas}} I_{M_T}]\right]}, \] (7)

where \( \sigma_{\text{meas}} \) stands for the measurement noise variance and \( I_{M_T} \) is the identity matrix with the size \( M_T \times M_T \). It can be seen that the modification was achieved by the subtraction of the estimated noise power from the correlation matrix and by the correlation matrix normalisation.