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CORRELATION BETWEEN MIMO LINK PERFORMANCE EVALUATION RESULTS AND CHARACTERISTIC CHANNEL PARAMETERS

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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. The link performance is described by the bit error rate and the channel capacity. It is shown that there exists strong relation between the link performance and chosen characteristic channel parameters. The link performance and channel parameters presented within the article are based on measurements performed by a real-time MIMO channel sounder.*

Introduction

The use of multiple antennas at both ends of the transmission system can increase the channel capacity. Therefore a lot of articles were dedicated to investigate channel capacity of the multiple input multiple output (MIMO) channel.

Resent research activities have shown that narrowband as well as broadband spatial multiplexing systems are sensitive to the instantaneous multipath channel characteristic. The adaptive control of transmitter and receiver in such MIMO systems seems to be essential to ensure reliable quality of the communication. To allow adaptive control on transmit side full or partial channel feedback is required. The goal is to highlight if characteristic parameters can predict the link performance in terms of channel capacity and bit error rate (BER) and hence can be used for adaptive control.

In order to gain realistic BER characteristics of a MIMO communication system the performance of the broadband Turbo MIMO Equalizer (TME) was analysed [1] under real-world propagation condition. Therefore the results of MIMO channel sounding trials were directly used for the link level simulations [2].

To quantify the relationship between link performance (BER and capacity) and the characteristic channel parameters the correlation coefficient among these measures is computed. The results show a strong relation between them and are promising to use characteristic parameters for adaptive link control.

Firstly, the link performance characteristics are discussed in more details. The article follows with a short overview of characteristic channel parameters that can be used not only for the adaptive control as indicated above, however, also for the channel classification, channel modelling and assessment of the achievable link performance. 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 [3].

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:

- 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

$$C = \log_2 \det\left(\mathbf{I}_{M_R} + \frac{P}{M_T \sigma_N^2} \mathbf{H}\mathbf{H}^H \right), \tag{1}$$

where H is the channel matrix with the size M_R x M_T (M_R is number of receivers and M_T is number of transmitters), P stands for the signal power, σ_N defines the noise power and I_{MR} is the identity matrix. The broadband channel capacity can be 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 restricted 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 [1].

The MIMO communication system 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 SC/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. 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 BPSK modulation independently from each transmit antenna after convolutional encoding (7;5) and random block interleaving. The frames contained 1024 symbols and the symbol rate was to be selected at 12 MSymbol/s. For the receiver perfect channel knowledge was assumed.

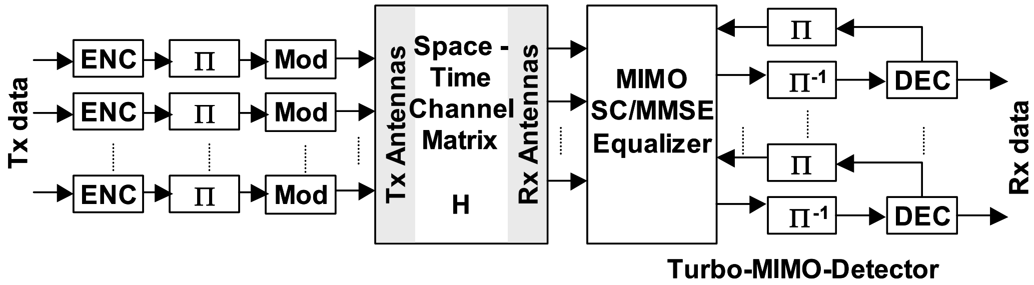

Fig.1 MIMO transmission based on Turbo MIMO Equalizion

Channel parameters and functions

In order to describe mobile radio channel in a realistic way, the description must be based on measured data. However, the extent of raw measured data is too large and therefore it is quite challenging to observe channel characteristics directly from measured data.

Channel parameters and functions are used to overcome this obstacle and to compress raw measured data. Although there is a certain loss of information the relevant information is brought to front. Obtained 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 by shown further in the next section. For that purpose following channel parameters were chosen:

- delay spread,
- MCC power (multipath component cumulated power)
- path loss,

- LRS length (local region of stationarity length) length of region within which is the channel locally stationary, whereas the channel stationarity is described by the correlation coefficient,
- spatial correlation at the receiver side.

These channel parameters are described in more details within the appendix.

Measurement example

The simulation of the communication system described above, channel capacity and the characteristic channel parameters are based on the measured data.

The measurement was performed by a real-time MIMO channel sounder [3] 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 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. 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 [2].

The obtained BERs for the 3Rx (3 elements from the ULA array) and 3Tx (3 elements from the UCA array) MIMO communication system (3x3 TME) are illustrated in Fig. 3. Here, it is possible to observe 3 different BERs corresponding to 3 independent data streams of the described communication system.

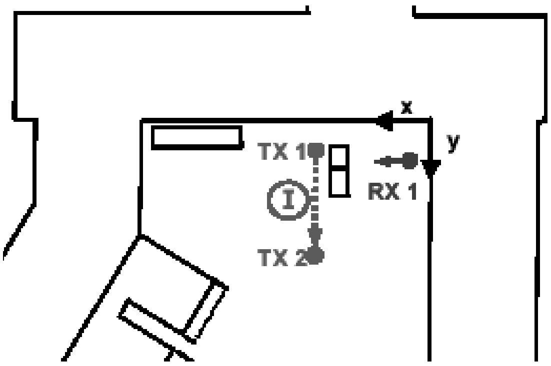

Fig. 2 Measurement constellation

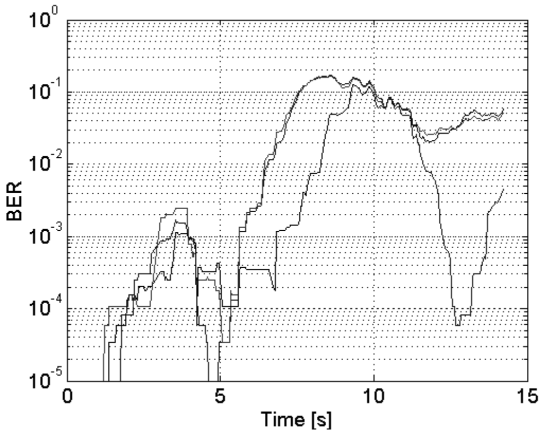

Fig.3 BER for 3x3 TME obtained by measurement based simulation

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

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

$$c=\left|u-\min(u)\right| \quad d=\left|v-\min(v)\right|$$

where *u* is BER, 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 lengt is 0) characteristics that were compared. On the left 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 characteristic channel parameter e.g. spatial correlation. Fig. 5 illustrates time dependence of the one element of the modified spatial correlation matrix ($Corr_{m\ 2,1}$) computed at the receiver side (see Appendix). 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 $\mathrm{Corr}_{\mathrm{m}\ 2,1}$ 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.

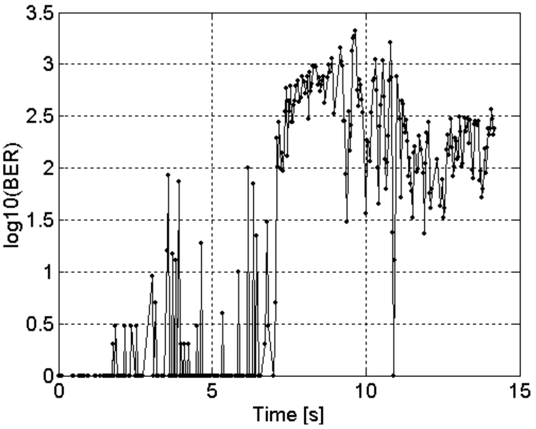

Fig.4 log10(BER) (without time smoothing)

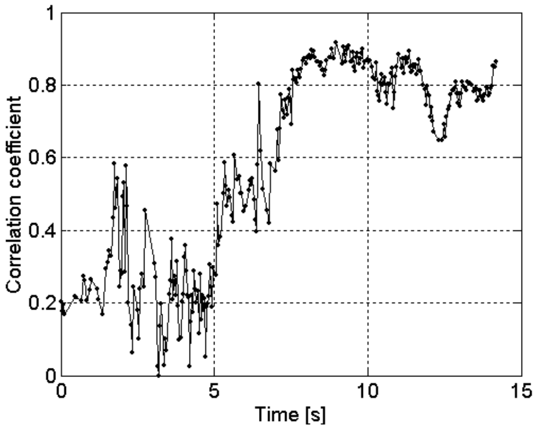

Fig.5 Spatial correlation coefficient (without time smoothing)

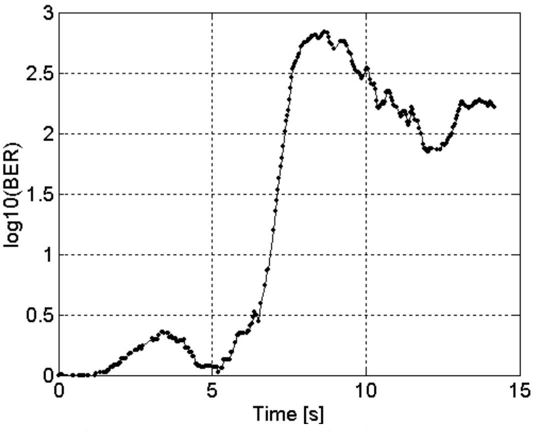

Fig. 6 log10(BER) smoothed with 1.1s long window

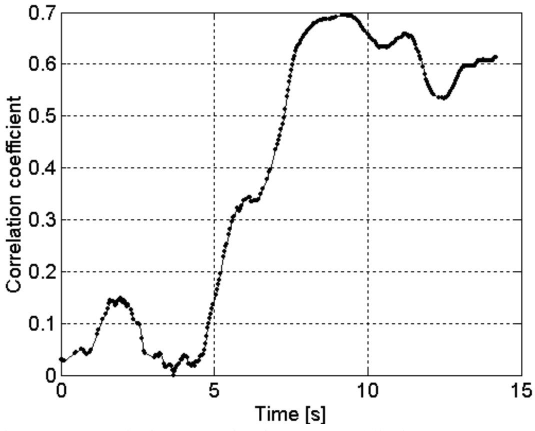

Fig. 7 Spatial correlation coefficient smoothed with 1.1s long window

The correlation 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.

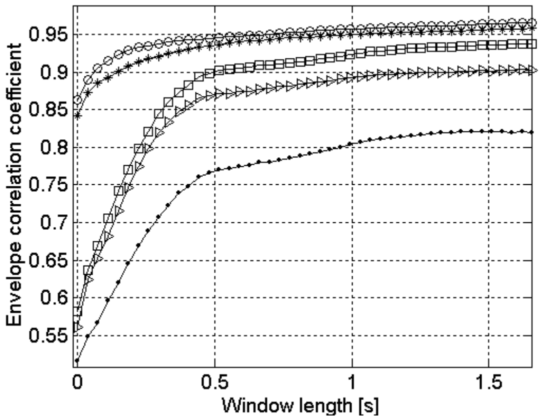

Fig. 8 Envelope correlation coefficient between BER and channel parameters as a function of smoothing window length

o – Spatial correlation *Corr*$_{m\ 2,1}$ vs log(BER)
* – Tx spatial correlation *Corr*$_{m\ 3,1}$ vs log(BER)
□ – inverse delay spread vs. BER
Δ – inverse MCC power vs. BER
. – inverse path loss vs. BER

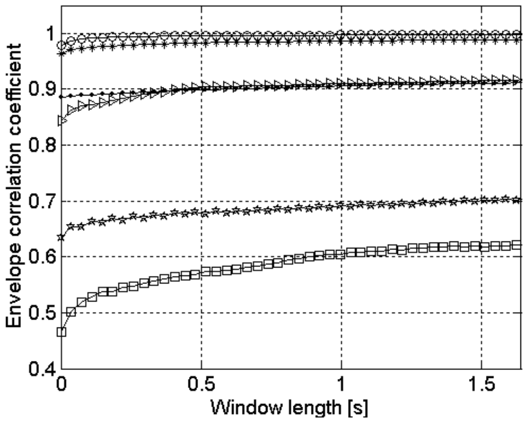

Fig 9 Envelope correlation coefficient between capacity and channel parameters as a function of smoothing window length

o – log(1- *Corr*$_{m\ 2,1}$) vs capacity
* – log(1- *Corr*$_{m\ 3,1}$) vs capacity
□ – delay spread vs. capacity
Δ – MCC power vs. capacity
. – path loss vs. capacity
⋆ – inverse LRS length

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 than the correlation is only slightly improved by the smoothing. The best results were obtained again in case of spatial correlation. Thus, it seems that this parameter is a good candidate for the adaptive control of transmitter and receiver in MIMO systems

Conclusion

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 progress. However, the best results were achieved by spatial correlation at the receiver side, especially if the instantaneous BER and channel capacity characteristics are of interest. Thus, 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 such MIMO systems.

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Appendix

Selected characteristic channel parameters

Delay spread

Because of multipath reflections, the channel impulse response (CIR) of a wireless channel looks likes a series of pulses. Delay spread describes period within which the substantial reflections arrive. It is defined as the standard deviation (or root-mean-square) value of the delay of reflections, weighted proportional to the energy in the reflected waves. This can be expressed by the following equation

$$DS(t,s)=\sqrt{\frac{\int\left|h(t,\tau,s)\right|^{2}(\tau-\bar{\tau})^{2}\,d\tau}{\int\left|h(t,\tau,s)\right|^{2}\,d\tau}}\qquad \bar{\tau}(t,s)=\frac{\int\left|h(t,\tau,s)\right|^{2}\tau\,d\tau}{\int\left|h(t,\tau,s)\right|^{2}\,d\tau}$$

where *h(t,* τ*,s)* is the measured time, delay and space dependant CIR.

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). Multipath components can be determined e.g. as a local maxima of the measured CIR *h(t,* τ*,s)* that exceed a power threshold.

Path loss

Path loss is one of the fundamental quantities characterizing mobile radio channel. 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

$$L_{WB}(t,s)=\frac{1}{\int_{\tau}\left|d_{ANT}h(t,\tau,s)\right|^{2}d\tau}\ \text{and}\ L_{MIN}(t,s)=\frac{1}{\left(\int_{\tau}\left|d_{ANT}h(t,\tau,s)\right|d\tau\right)^{2}},$$

where d_{ANT} stands for distance between transmit and receive antennas, *h(t,* τ*,s)* is the measured time, delay and space dependant CIR. The CIR h(t,τ,s) is firstly multiplied by the antenna distance since the signal power of the measured CIR depends on the distance between transmit and receive antennas and if this measure should be used to compare different measurements it should be independent from the transmitter-receiver distance.

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

$$c(t_i, \Delta t) = \frac{\int\limits_{\tau} \overline{P_h(t,\tau,s)}_{t_i} \, \overline{P_h(t,\tau,s)}_{t_i+\Delta t} \, d\tau}{\max\left[\int\limits_{\tau} \overline{P_h(t,\tau,s)}_{t_i}^{\,2} \, d\tau, \int\limits_{\tau} \overline{P_h(t,\tau,s)}_{t_i+\Delta t}^{\,2} \, d\tau \right]},$$

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

The LRS length is computed following way. Firstly, the window with variable position is set to be equal to the reference window. Then, the position delay Δt is increased successively in the time direction. If the correlation coefficient c is above a predefined level, then the window with variable position is assumed to be from the same LRS as the reference window. If the correlation coefficient c is smaller than the predefined level, then a new LRS is determined and the window with variable position is set to be the reference window and the window position delay is again increased successively till the end of the measured data (in time direction).

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 x M_T (M_R is number of receivers and M_T is number of transmitters) than spatial correlation at the receiver side can be defined as

$$Corr(t) = E\left[H(t,f) H(t,f)^{*} \right].$$

The spatial correlation at the receiver side $Corr(t)$ is time-dependent matrix with the size M_R x M_R.

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

$$Corr_m(t) = \frac{M_R \left(E\left[H(t,f) H(t,f)^{*} \right] - \sigma_{meas} I_{M_T} \right)}{trace\left\{ E\left[H(t,f) H(t,f)^{*} \right] - \sigma_{meas} I_{M_T} \right\}},$$

where σ_{meas} stands for the measurement noise variance and I_{MR} is the identity matrix with the size M_RxM_R. 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.

More information about channel parameters can be found in [5] and [6].