MACROCELL MIMO CHANNEL MEASUREMENT AND MODELING*

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ABSTRACT

By use of multiple antennas at the transmitter as well as at the receiver end of a wireless communication link enormous overall channel capacity increase in terms of bps/Hz can be achieved theoretically if proper coding is applied, [2]. To investigate the potential in a realistic manner measurement based simulation models are necessary. Only few measurements are done up to now and most of these measurements are for indoor channels and/or for carrier frequencies above 1 GHz, e.g. [1]. On the other hand there is an increasing interest in carrier frequencies below 1 GHz for mobile multimedia applications for subscribers in high speed trains or vehicles and only enhanced air interface techniques can deliver the requested data rates in conjunction with optimized spectral efficiency, see e.g. [4]. In this paper we present measurements with multiple element antennas for transmitter and receiver. A stochastic wideband channel model based on the WSSUS assumption enhanced by introduction of correlations between transmitter signals as well as correlations between receiver signals is developed and parameterized by deriving parameters from a comprehensive measurement campaign with 2 TX and 8 RX antenna elements. As an application of the simulator results on overall channel capacity are given.

INTRODUCTION

New multimedia services are demanding high downlink data rates. Due to limited frequency resources only enhanced air interface concepts can deliver these high data rates in a frequency economic sense. Especially multiple input multiple output systems are promising. Channel models and measurements to parameterize these models are of general interest to investigate spatio-temporal signal processing and coding techniques on a realistic basis. Only few measurements below 1 GHz are existing up to now.

1. CHANNEL SOUNDER MEASUREMENTS

The basis for the following MIMO investigations was a comprehensive measurement campaign performed in the southern Rhein-Main area near Frankfurt/Germany. The measurement bandwidth was 8 MHz at a center frequency of 920 MHz. The total measurement run length was about 200 km. Every 100 m a block of 256 impulse responses for each of the $n_R \times n_T = 16$ with $n_R = 8$ receiver antenna elements and $n_T = 2$ transmitter antenna elements was measured and stored. Sampling of the impulse response was chosen so that the sampling theorem in space was fullfilled. Thus Doppler evaluation of the measurement is possible. For moderate vehicle speeds (≈ 50 km/h) the run length for one block of 256 impulse responses corresponds to about 5..10 m. With the carrier wavelength of $\lambda_0 = 33$ cm it is reasonable to assume a stationary channel per block. At the receiver the channel sounder uses a fast multiplexer to allow multielement measurements. To allow also multiple transmitter elements some signal processing was applied. The same transmitter baseband test sequence was mixed with different LO frequencies which were $+/-f_1 = 80$ Hz shifted to the receiver LO frequency, see Figure 1. That frequency shift can be viewed as a constant virtual Doppler shift of $+/-80$ Hz which adds to the real one. By filtering in the Doppler domain the received signal can be separated into the different transmitter signal parts, see also [3].
The RX antenna elements were monopoles over a ground plane arranged as a uniform circular array on top of a measurement van with a distance between two neighbouring antenna elements of approx. $\lambda_0/2$. The TX antenna elements were 8 m horizontally spaced vertical polarized sector antennas and about 35 m above ground level.

2. MIMO CHANNEL MODEL BASED ON WSSUS ASSUMPTION

Based on the wide sense stationary uncorrelated scattering (WSSUS) assumption for each individual radio channel of the MIMO system a model was implemented as a tapped delay line including proper correlation effects. Especially we have to consider

- correlation between transmitted signals from different TX antennas which cannot be resolved in time by the receiver due to small distances between transmitter antennas.
- correlation of the received signals from different RX antennas but from the same TX antenna. We also

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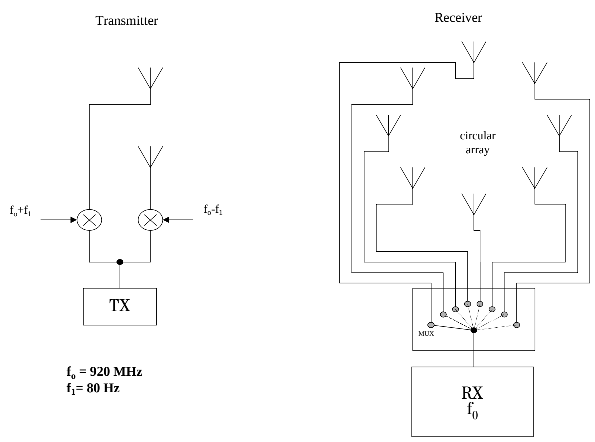

Figure 1: MIMO channel sounder measurement setup with 2 TX and 8 RX antenna elements

assume small distances between the receiver antennas.

To consider TX correlations the involved scattering processes $a_{\nu,j}, \nu \in [1,p], j \in [1,n_T]$ with p the number of multipaths are correlated. They can be obtained by linear combining of uncorrelated scattering sequences by means of multiplication with a triangular matrix $\mathbf{L}_\nu$ calculated from the correlation matrix $\mathbf{C}_\nu$, e.g. for the first multipath $\nu = 1$ with delay τ_1

$$\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n_T} \end{pmatrix}^T = \mathbf{L_1} \cdot \begin{pmatrix} a'_{11} & a'_{12} & \cdots & a'_{1n_T} \end{pmatrix}^{\mathbf{T}} \quad (1)$$

, where

$$\mathbf{C}_\nu = \begin{pmatrix} 1 & r_{12\nu} & \cdots & r_{1n_T\nu} \\ r^*_{12\nu} & 1 & & \\ \vdots & & \ddots & \vdots \\ r^*_{1n_T\nu} & & \cdots & 1 \end{pmatrix} = \mathbf{L}_\nu \cdot \mathbf{L}_\nu{}^{\mathbf{H}} \quad (2)$$

and the elements of the correlation matrix $\mathbf{C}_\nu$ are defined by

$$r_{(l,m)_\nu} = \frac{E\left([l_\nu - E(l_\nu)]\,[m^*_\nu - E(m^*_\nu)]\right)}{\sqrt{E\left(|l_\nu - E(l_\nu)|^2\right) E\left(|m_\nu - E(m_\nu)|^2\right)}} \quad (3)$$

with $E(\cdot)$ expectation and $(l,m)_\nu \in (1, n_T)$ are the sequences of received signals from TX antenna $1, 2, ..., n_T$ for multipath number ν.

Correlation between different RX antenna elements is taken into account by linear combining of n_R simulator structures for each RX antenna element where the individual scattering processes of the n_R simulators are uncorrelated. If $\mathbf{Z}$ is the correlation matrix between RX antenna elements it can be decomposed into a triangular $n_R \times n_R$ matrix $\mathbf{K}$ for which $\mathbf{Z} = \mathbf{K} \cdot \mathbf{K^H}$ holds. The desired n_R-dimensional correlated output signal of the simulator is then given by $\mathbf{Y} = \mathbf{K} \cdot \mathbf{Y}'$. In Figure 2 the complete simulator structure is depicted. This simulator can be parameterized completely from measurements.

The vector of the n_R time variant impulse responses between TX antenna $j \in [1, n_T]$ and RX antenna $i \in [1, n_R]$ is thus given by

$$\begin{pmatrix} h_1(t,\tau) \\ h_2(t,\tau) \\ \vdots \\ h_{n_R}(t,\tau) \end{pmatrix}_j = \mathbf{K} \cdot \begin{pmatrix} \sum_{\nu=1}^{p} \mathbf{L}_\nu \mathbf{a}_\nu^{(\mathbf{1})}(\mathbf{t}) \cdot \delta(\tau - \tau_\nu) \\ \sum_{\nu=1}^{p} \mathbf{L}_\nu \mathbf{a}_\nu^{(\mathbf{2})}(\mathbf{t}) \cdot \delta(\tau - \tau_\nu) \\ \vdots \\ \sum_{\nu=1}^{p} \mathbf{L}_\nu \mathbf{a}_\nu^{(\mathbf{n_R})}(\mathbf{t}) \cdot \delta(\tau - \tau_\nu) \end{pmatrix}_j \quad (4)$$

where each $\mathbf{a}_\nu^{(\mathbf{i})}$ is a $n_T \times 1$ scatterer vector.

3. CHANNEL INFORMATION THEORETIC CAPACITY

The Shannon information theoretic channel capacity C is a measure of the maximum bit rate over a channel with arbitrarily low bit error probability. For a single AWGN channel C is given by $C = \log_2(1 + \frac{S}{N})$ in

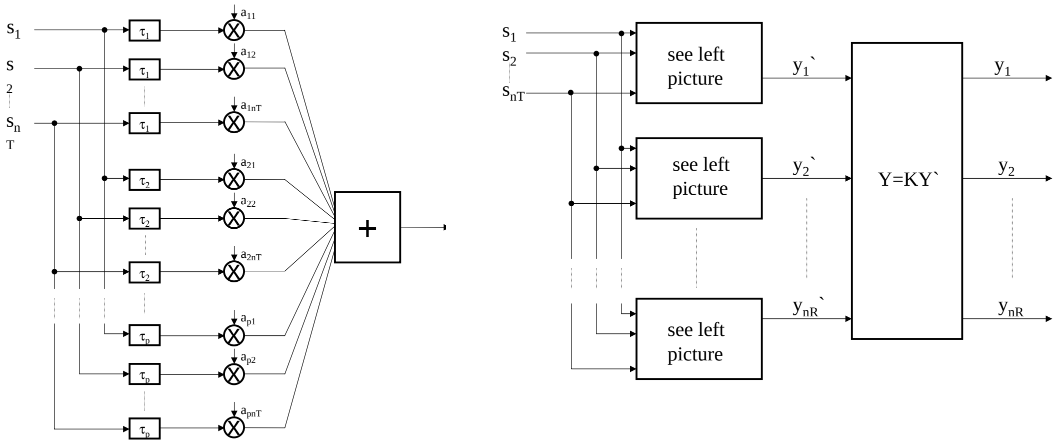

Figure 2: stochastic simulator schematic considering TX correlation (left) and RX correlation (right)

bps/Hz with S the signal power and N the noise power.
In the following we restrict ourselves to the uniform input power channel where we assume that the transmitter has no knowledge about the channel transfer function. In this case it holds for the capacity for a smallband MIMO channel, see [1] or [2],

$$C_\mu = \log_2(\det(\mathbf{I}_{n_R} + \frac{\rho}{n_T}\mathbf{H}_\mu\mathbf{H}_\mu^*)) \tag{5}$$

where $\mathbf{H}_\mu$ is a $n_R \times n_T$ matrix of sampled channel transfer functions and ρ is the signal to noise ratio. For a wideband MIMO channel the overall channel capacity is given by

$$C = \frac{1}{N}\sum_{\mu=1}^{N}\log_2(\det(\mathbf{I}_{n_R} + \frac{\rho}{n_T}\mathbf{H}_\mu\mathbf{H}_\mu^*)) \tag{6}$$

with N frequency-flat channels in parallel.

4. RESULTS

For all 1594 blocks of 256 impulse responses of the measurement campaign described in section 2 WSSUS models were derived as described in section 3. Also correlation of TX signals as well as correlation of RX signals was calculated for each block to calculate the matrices $\mathbf{L}_\nu$ and $\mathbf{K}$.
Following the simulator structure in Figure 2 we simulated realizations of IRs with a simulator bandwidth of $B = 8$ MHz corresponding to the measurement bandwidth and with different correlation matrices as calculated from the measurements for n_R =2, 4, 8 and n_T =2 antenna elements. Evaluation of the simulated IRs by applying (6) was done and a comparison with the capacity calculated out of the measurement data was performed. In Figure 3 (left) C as a function of signal to noise ratio SNR is given for three different typical channel models. For 'open area' it holds $|r|_{TX} = 0.83$, $|r_{12}|_{RX} = 0.84$ and $K = +6.75$ dB the Rice factor. 'Forest' is characterized by $|r|_{TX} = 0.6$, $|r_{12}|_{RX} = 0.64$ and $K = -4.1$ dB whereas for 'urban area' $|r|_{TX} = 0.65$, $|r_{12}|_{RX} = 0.67$ and $K = -3.2$ dB was calculated. For comparison also the capacity for the uncorrelated Rayleigh channel ($|r_{ij}|_{RX} = |r|_{TX} = 0, i \neq j$) as well as for the correlated one ($|r_{ij}|_{RX} = |r|_{TX} = 1$) is given. Simulation agrees very well with measurement in terms of channel capacity. For the three typical channel models derived from our measurement campaign a significant improvement in overall channel capacity can be expected. The additional application of RX diversity provides only little further improvement for high SNR values as can be seen from Figure 3 (right). On the other hand it is worth to think about diversity reception in low SNR regions. Again simulation agrees very well with measurement. Figure 4 (left) shows the distribution of capacity with fixed SNR = 20 dB for simulation and measurement. The steeper curves for measurement are due to the fact that the corresponding 256 IRs were measured over a short time interval whereas the 256 simulated IRs were taken out of a longer real time interval and thus have higher variance. One can see that the capacity for 10% outage probability decreases from approx. 10 bps/Hz for measurement to approx. 8.5 bps/Hz in simulation. In Figure 4 (right) the simulated capacity distribution for SNR = 20dB in open area environment is shown for two arbitrary smallband channels with $B = 19$ kHz out of a wideband channel with $B = 8$ MHz is depicted. The steeper curve for the wideband channel distribution indicates some frequency diversity effects.

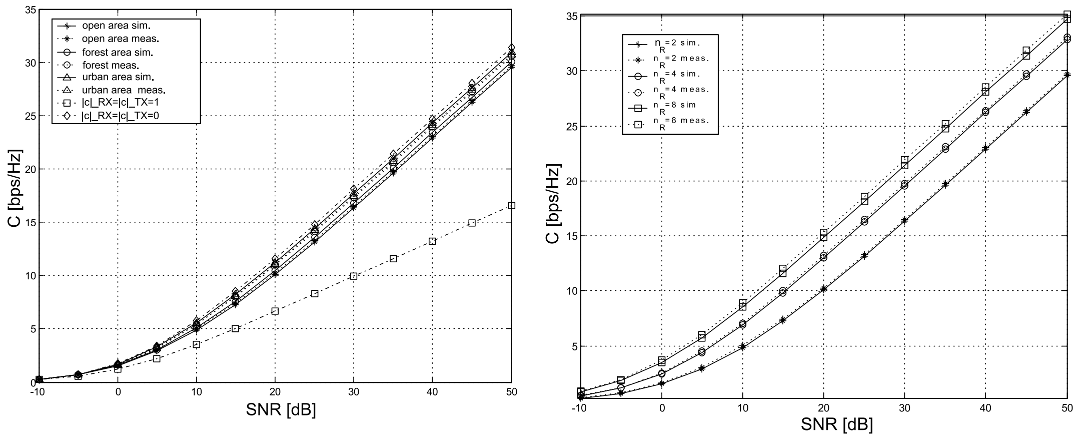

Figure 3: Capacity for different land usage classes measured/simulated for $n_R = n_T = 2$ (left), capacity measured/simulated for open area with $n_T = 2$, $n_R = 2$, 4 and 8 (right)

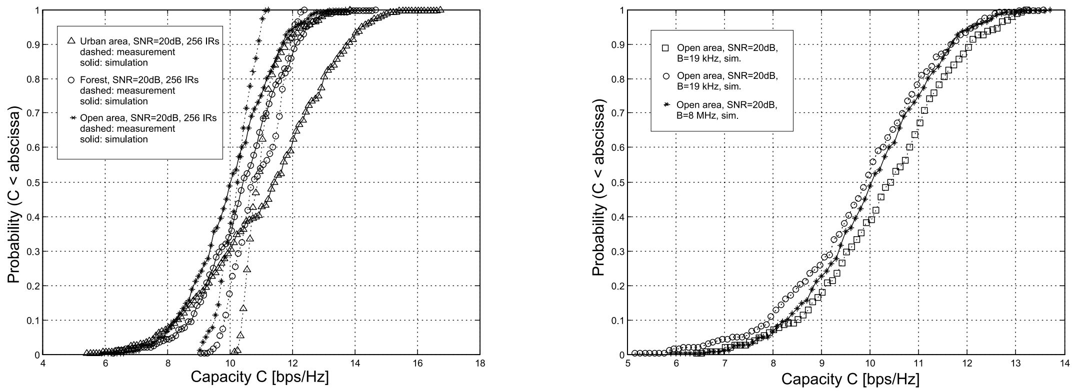

Figure 4: Capacity distribution for different land use classes measured/simulated for $n_R = n_T = 2$ and SNR = 20 dB (left), simulated capacity distribution for open area with $n_R = n_T = 2$ and B = 19 kHz and B = 8MHz (right)

5. CONCLUSION

In this paper a stochastic WSSUS based MIMO channel simulator was introduced and its parameterization from wideband channel sounder measurements was shown. From a comprehensive measurement campaign with 2 TX and 8 RX antennas in a macrocell environment at 920 MHz carrier frequency this simulator was parameterized and evaluated. It turns out that even in an open area environment an enormous capacity increase should be possible by use of multiple element antennas. From these results we conclude that space-time coding will not only be of interest for rich scattering indoor channels but will also be beneficial for radio communication in outdoor macrocells with carrier frequencies < 1 GHz.

6. REFERENCES

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