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Experimental Verification of Vector Channel Models for Simulation and Design of Adaptive Antenna Array Receivers

Marcus Bronzel(1), Jens Jelitto(1), Nadja Lohse(1), Gerhard Fettweis(1), Reiner Thomä(2), Gerd Sommerkorn(2), Dirk Hampicke(2), Uwe Trautwein(2), Andreas Richter(2)
(1)Dresden University of Technology, (2)Ilmenau University of Technology

Abstract: *In this paper a new spatial model for the mobile radio channel is introduced, which allows performance analysis of smart antenna receivers. In order to validate this model real-time measurements in the Hiperlan frequency range have been carried out using a recently developed vector channel sounder. The main features of this device and first measurement results are presented. These results reveal a promising match between the measurements and the channel parameters derived from the model.*

1 Introduction

Future mobile communication systems are facing an increased demand for heterogeneous broadband services and applications. It is generally expected that the deployment of smart antennas will increase the overall system capacity and performance [Nos]. Smart antennas will not only increase the antenna gain, but also reduce interference and delay spread by means of spatial filtering and thus enhance the properties of the mobile radio channel. In the Integrated Broadband Mobile System (IBMS) [Bro], smart antennas are used in the micro-cellular environment to effectively improve the radio channel properties and enable more bandwidth-efficient higher modulation techniques. Therefore, reliable channel models are needed to obtain realistic estimates of the increased system capacity and performance. Several vector channel models have been worked out to demonstrate these effects. A vector channel model provides a time-varying vector impulse response that consists of the set of impulse responses between the transmitter and each of the antenna array outputs. The choice of a statistical modeling approach seems to be most promising. These statistical models can be divided into models based on simple geometric assumptions for a typical scattering-scenario [Lib] and directional tapped delay line models that rely on some clustering of scattered waves [Mar].

The RUSK ATM vector channel sounder [Tra] has been developed to carry out broadband measurements for micro-cellular scenarios in the 5 GHz band within the German ATMmobil framework [Fet]. This paper presents a new geometrically based stochastic vector channel model and first results obtained from measurements carried out in the Hiperlan domain to verify this model.

2 Vector channel sounder

A new vector channel sounder - called RUSK ATM - has been developed jointly by MEDAV and Ilmenau University of Technology, permitting real-time measurements of time-varying mobile radio channels. This device operates in the frequency band between 5...6 GHz and offers a measurement bandwidth of 120 MHz. The impulse response identification is based on periodic multi-frequency excitation signals and correlation signal processing. For vector channel reception a uniform linear array composed of 8 planar antenna elements is used, combined with fast array signal multiplexing to ensure quasi-simultaneous measurements. Thus, up to 1000 vector impulse responses per second can be measured in the standard Doppler mode, which are called snapshots, and up to 20000 snapshots per second in the fast Doppler mode. Besides these time triggered measurement modes, there exists a distance triggered mode additionally. The high repetition rate is a major advantage compared to other direction of arrival (DOA)-estimating channel sounders which use rotating directional antennas or which are based on synthetic aperture procedures. In spite of the small array dimensions a large number of distinct echo paths can be resolved in the joint delay-time and angular domain, due to the large measurement bandwidth.

The hardware effort is kept moderately because only a single RF-to-digital downconverter channel is necessary (see Figure 1). Synchronization between a mobile transmitter with the (usually) fixed receiver (inclusively antenna array) is established by means of two rubidium reference elements or by an optical fiber connection. The influence of the directional characteristics of the used antennas on the measurement results is taken into account. In order to avoid ambiguities, the distance between the individual antennas is 0.4λ (λ...wavelength). Consequently, coupling effects between the antennas cannot be neglected. In addition, considerable phase differences between the individual multiplexer paths may occur. Therefore, a calibration method has been developed, which is based on a reference measurement with a known signal source from different directions, allowing determination of a correction matrix to eliminate phase and coupling errors [Pen].

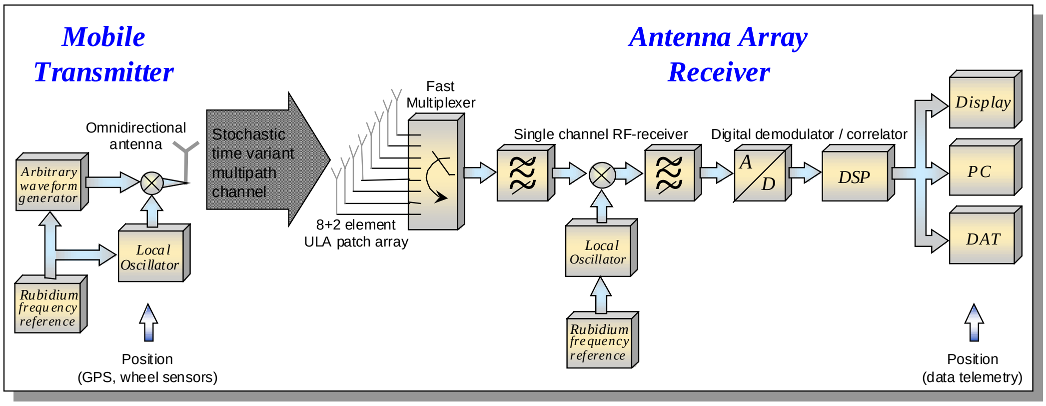

Figure 1: Principle of the RUSK ATM vector channel sounder

In order to gain superresolution in the delay-angular domain a two-dimensional unitary ESPRIT procedure [Haa] is used for joint delay-DOA estimation. With the uniform linear patch array employed which provides a horizontal angle of view of 120 degrees, only an estimation of the azimuthal direction of arrival is possible. Using other types of antennas it is possible to consider the elevation or different polarizations as well.

3 Spatial Channel Modeling

For estimating the channel improvement when utilizing smart antennas a new channel model is introduced. It assumes a certain scatterer distribution around the mobile, based on a joint scatterer density function in polar coordinates R and φ with uniformly distributed scatterers of finite dimension:

$$p_{R,\varphi} = \frac{\lambda_e}{2\pi} e^{-\lambda_e R} \qquad (1)$$

v	speed of the mobile
α	angle between mobile direction and LOS
R	distance scatterer - mobile station
φ	angle between R and LOS
s_0	distance LOS
ψ	angle of arrival
s_{rel}	ratio indirect to direct path
λ_e	parameter of exponential distribution

The model uses the single bounce approach; which has also been used by Liberti [Lib]; whereby scatteres corresponding to equal time delays are distributed on ellipses with the focal points base station

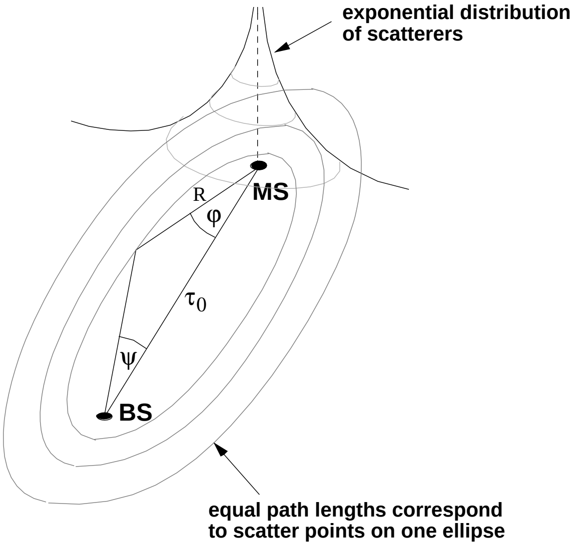

Figure 2: Geometrically based stochastic channel model

(BS) and mobile station (MS). Through the geometrical superposition of the scatter circle and path length ellipse as shown in Figure 2, it is possible to assign to every scatterer - defined by polar coordinates radius R and angle φ - a path length s and an angle of arrival ψ:

$$R(s_{rel},\psi)=\frac{s_0}{2}\left(s_{rel}-\frac{s_{rel}\cos\psi-1}{s_{rel}-\cos\psi}\right) \tag{2}$$

$$\varphi(s_{rel},\psi)=a\cos\left(\frac{2s_{rel}-\cos\psi-s_{rel}^2\cos\psi}{1-2s_{rel}\cos\psi+s_{rel}^2}\right) \tag{3}$$

For the estimation of radio channel parameters using adaptive antennas the time-variant joint pdf of the signal path length and the angle of arrival is necessary. The transformation of probability variables

$$p_{s_{rel},\psi}=p_{R,\varphi}\left|J\begin{pmatrix}R & \varphi\\ s_{rel} & \psi\end{pmatrix}\right|\Bigg|_{\substack{R=f(s_{rel},\psi)\\ \varphi=f(s_{rel},\psi)}} \tag{4}$$

and the time-variant distance between base station and mobile station

$$s_0(t)=s_0(t_0)+vt\cos\alpha \tag{5}$$

results in the desired time-variant joint pdf of relative signal path length and angle of arrival:

$$p_{s_{rel},\psi}(t)=\frac{\lambda_e}{2\pi}e^{-\lambda_e\frac{s_0(t)}{2}\left(s_{rel}-\frac{s_{rel}\cos\psi-1}{s_{rel}-\cos\psi}\right)}\frac{\left(2s_{rel}{}^2-s_{rel}{}^4-1\right)s_0(t)}{\sqrt{1-\cos\psi^2}\left(1+s_{rel}{}^2-2s_{rel}\cos\psi\right)^2}\left(1-\frac{\cos\psi^2-1}{\left(s_{rel}-\cos\psi\right)^2}\right) \tag{6}$$

Using (6) the time-variant and angle-variant path-length marginal density can be determined. Furthermore, from this marginal density the time-variant angle-variant time of arrival pdf can be derived. Figure 3 (solid line) shows the effect of the antenna beamwidth on the rms delay spread (relative to its maximum value), which correspond to our measurements described in the next section (depicted as stars) for the angle of view (120^o). The respective Doppler spread is shown in Figure 4.

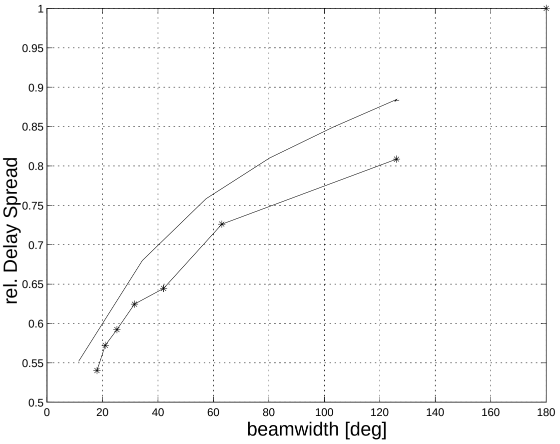

Figure 3: Rms delay spread vs. beamwidth relative to max. rms delay spread (--- model, -*- measurement)

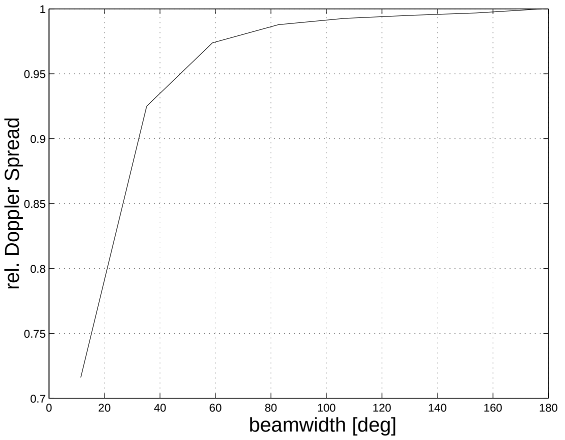

Figure 4: Doppler spread vs. Beamwidth relative to max. Doppler spread

4 Spatial Channel Measurements

The verification of spatial channel models requires extensive measurements in various representative test scenarios. However, only a few basic measurements were acquired so far. The results presented in the following sections show both the performance of the vector channel sounder and a promising match between measurements and channel parameters derived from the model investigated here.

4.1 Static measurements

The presented results are based on measurements in a court yard with a size of 63x45m. The building height is about 20m, surface materials are basically concrete and glass. The court yard consists of a crowded parking lot with some trees (see Figure 5). Four different antenna array positions and 14

Figure 5: Measurement scenario

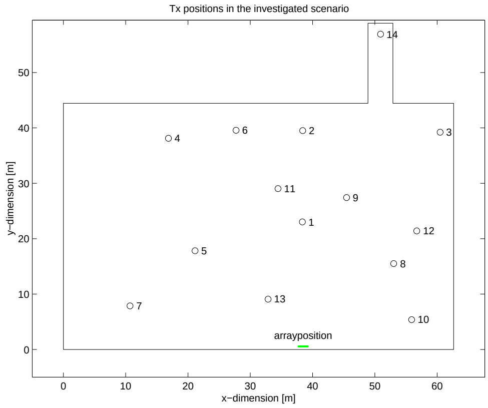

Figure 6: Transmitter and receiver positions

transmitter positions were defined corresponding to certain angle-distance combinations given in Figure 6. For every transmitter-receiver constellation 1000 impulse responses $h(t)$ were collected.

First, a mean value of the rms delay spread for this scenario, after removing contributions of 20 dB below the strongest path, was estimated to **34ns**. A second approach to get channel characteristics was the extraction of the delay, DOA and complex valued weight parameters using a 2D unitary ESPRIT algorithm. From this parameters the rms delay and angular spread histograms were derived (see Figure 7 and Figure 8). The relatively small number of Tx-Rx-constellations is not sufficient in a statistical sense. However, the characteristics of the estimated probability density functions show a good approximation of the expected statistics. The estimated mean rms delay spread of **37ns** is reasonable for the court yard scenario and matches the measurement results. The mean angular spread was estimated to **8°**.

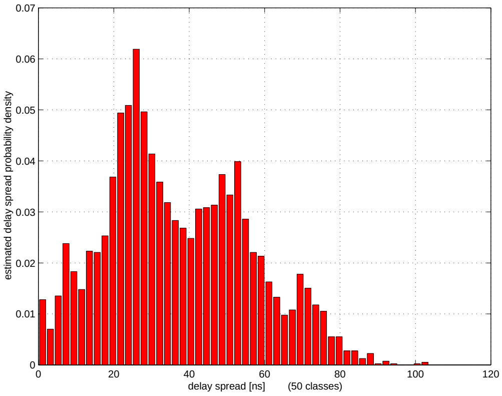

Figure 7: Rms delay spread probability density derived from joint delay-DOA estimation

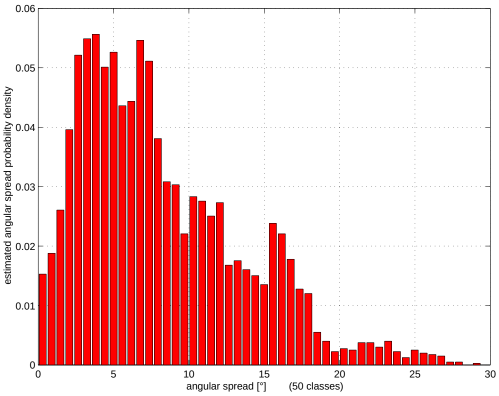

Figure 8: Rms angular spread probability density derived from joint-delay DOA estimation

In order to investigate the impacts of smart antennas on the channel characteristics, the impulse responses of N antenna elements are weighted using the beamforming approach

$$z(t) = \sum_{i=1}^{N} w_i^* y_i(t) \tag{7}$$

N … # antenna elements
w_i^* … complex conjugate weight
$y_i(t)$ … received signal at element i
$z(t)$ … beamformer output signal.

A beamformer impulse response $h_{bf}(t)$ can be derived as weighted sum of the single channel impulse responses $h_i(t)$:

$$h_{bf}(t) = \sum_{i=1}^{N} w_i^* h_i(t)\,. \tag{8}$$

Using the resulting impulse responses the rms delay spread for different sets of weights corresponding to different look directions and beamwidths can be determined. The half power beamwidth (*HPBW*) for a uniform linear array as a function of the number of elements can be estimated as [Lit]

$$HPBW = \frac{0.88\lambda}{A} \approx \frac{0.88\lambda}{(N-1)d}. \tag{9}$$

λ	...	wavelength of carrier signal	N	...	# antenna elements
A	...	array aperture	d	...	distance between two elements

Applying (4) and (5), a dependency between beamwidth and delay spread was derived. Figure 3 shows this dependency compared with the results from the model described above. For the model, only the parameter λ_e representing the scatterer distribution had to be adapted to get a good match between measurements and the model. Basically, the rms delay spread drops significantly with reduced beamwidth. However, this results are true for the selected scenario, but have to be validated for other scenarios as well.

4.2 *Dynamic measurements*

A dynamic measurement was performed in a car assembly hall at Daimler Benz AG. The hall with a length of about 150m contains several car-body assembly lines (two in a row, distance between rows is about 6m). First the Tx-antenna was moved away 65m from the receiver at an angle of 0°. The average speed was 3 m/s. Then the Tx-antenna moved 6m in an angle of 90° to the left between two assembly lines, where it lost LOS. Finally the antenna was moved back in the next lea without LOS.

Since only a single measurement drive was carried out, the presented results can only serve as a verification of the channel sounders ability to accurately measure such scenarios and to get a first estimate of the channel conditions. Figure 9 shows the measured impulse responses over time. The grayscale values correspond to the logarithmic power of $h(t)$. A strong LOS path can be detected for the first 37 seconds, afterwards only indirect paths arrive at the receiver. The gray areas give a rough impression about the changing rms delay spread (see also Figure 11).

As indicated in the Figure 10 and Figure 11, even in this scenario (long narrow corridor) the delay spread drops (dash-dotted line) when beamforming is applied to the impulse responses of all 8 channels, corresponding to a 3dB-beamwidth of 18°.

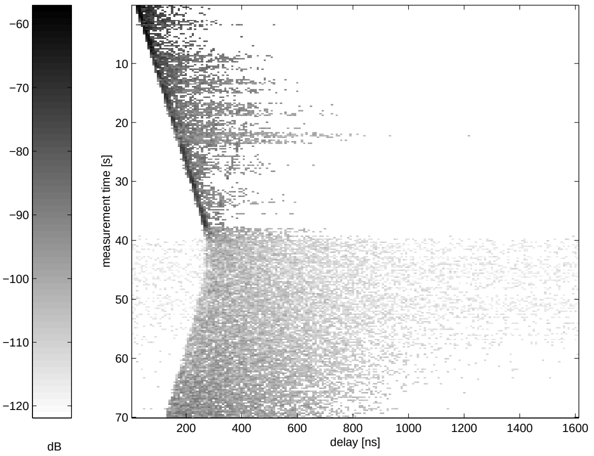

Figure 9: Power of $h(t)$ in dB vs. measurement time

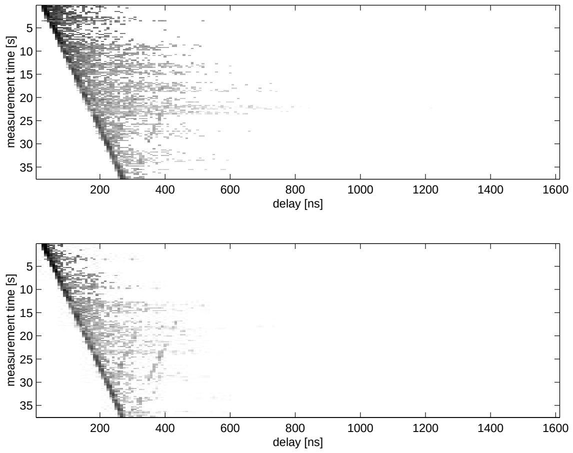

Figure 10: Power of unweighted and weighted $h(t)$ in dB vs. measurement time

5 Summary

The vector channel sounder RUSK ATM permits measurements that give access to a complete statistical radio channel description. This includes time variance, nonstationarities, and directions of arrival. A new statistical channel model was introduced for investigating the effective transmission channel improvement when utilizing adaptive antenna arrays. It has been shown that a significant reduction of the channel's delay and Doppler spread is possible. Measurements have been carried out to confirm the

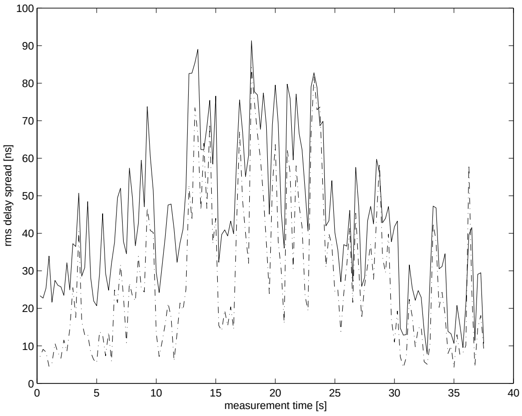

Figure 11: Rms delay spread vs. snapshot
(--- unweighted, -.- weighted)

model. The delay spread reduction achievable by beamforming applied to measured vector impulse responses is in compliance with the results calculated from the proposed model. A larger number of measurements is necessary to obtain a better statistical reliability of the results, and to ensure that this model is reasonable for a wider range of scenarios. This is planned for the future.

6 Acknowledgments

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