

COMPARISON OF MIMO CHANNEL CHARACTERISTICS COMPUTED BY 3D RAY TRACING AND STATISTICAL MODELS

R. Hoppe*, J. Ramulu[†], H. Buddendick[†], O. Stähler*, and G. Wölfle*

* AWE Communications, Germany, Reiner.Hoppe@AWE-Communications.com

[†] University of Stuttgart, Institute of Radio Frequency Technology, Germany

Keywords: MIMO channel, ray tracing, statistical models, delay spread, angular spread.

Abstract

Future wireless communication systems are expected to offer highly reliable broadband radio access in order to meet the increasing demands of emerging high speed data and multimedia services. In recent years information theoretic investigations have shown that multiple-input multiple-output (MIMO) systems can support extremely high data rates within rich scattering environments. To design high efficient MIMO wireless systems and predict system performance under various circumstances accurate MIMO wireless channel models for different scenarios are required. Recently, standardized double directional stochastic MIMO channel models have been proposed for different scenarios based on the statistical information evaluated from measured data.

In this paper the MIMO channel characteristics have been evaluated by using deterministic channel modelling and compared with the standardized Spatial Channel Model (SCM) in urban micro-cell scenario for non line of sight condition. A three dimensional ray tracing package has been utilized for deterministic channel modelling. The most crucial parameters of the spatial channel, such as delay spread and angular spreads at both base and mobile stations have been considered in the comparison.

1 Introduction

In 3rd generation (3G) and beyond-3G (B3G) wireless communication systems higher data rate transmissions and better quality of services are demanded. In the last few years multiple-input multiple-output (MIMO) systems, which deploy spatially separated multiple antenna elements at both ends of the transmission link, have emerged as one of the most promising approaches for high data rate and more reliable wireless systems. It was shown that the MIMO channel capacity grows linearly with antenna pairs as long as the environment provides sufficiently rich scattering effects. According to this the capacity gains ultimately depend on the propagation channel in which the system is operating. For attaining or at least approaching those capacities, sophisticated signal processing algorithms and coding strategies have been developed and corresponding research is

on going. In order to assess the benefits and possible problems of these algorithms, realistic models of the wireless propagation channel are required. Hence, the establishment of good spatial channel models is essential both for the development of new algorithms for signal processing, modulation, coding, and for the unified testing of different system proposals in standardization.

1.1 MIMO Radio Channel

In general, the radio propagation in urban environments is subject to multi-path, i.e. the signal from the transmitter propagates along different paths to the (mobile) receiver. In many cases there is no direct line-of-sight (LOS) and the only paths connecting transmitter and receiver are reflected, diffracted and scattered at a number of different obstacles (see Figure 1).

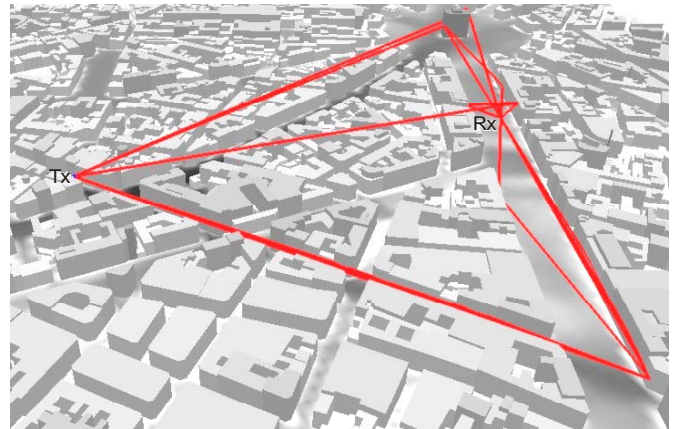


Figure 1: Multi-path propagation in urban environment.

The radio propagation can be characterized by the impulse response of the channel between the position of the transmitter (Tx) and the position of the receiver (Rx). This impulse response consists of all individual multi-path components (MPCs) and also represents their temporal and angular properties. Hence it is known as double directional channel impulse response and is given for a static (time invariant) channel by

$$h(\vec{x}_{Tx}, \vec{x}_{Rx}, \tau, \phi, \psi) = \sum_{n=1}^N h_n(\vec{x}_{Tx}, \vec{x}_{Rx}, \tau, \phi, \psi) \quad (1)$$

Here, τ, ϕ, ψ and N represent excess delay, azimuth angle of departure (AoD) at the transmitter, azimuth angle of arrival (AoA) at the receiver and the total number of multi-path components, respectively. Here only azimuth angles are considered for simplicity. For the planar waves, the contribution of the n^{th} MPC equals

$$h_n(\vec{x}_{\text{Tx}}, \vec{x}_{\text{Rx}}, \tau, \phi, \psi) = \alpha_n \delta(\tau - \tau_n) \delta(\phi - \phi_n) \delta(\psi - \psi_n) \quad (2)$$

where α_n, τ_n, ϕ_n and ψ_n represent the complex amplitude, delay, azimuth AoD and azimuth AoA, respectively, associated with the n^{th} MPC. For time variant channels, the parameters of all individual MPCs, the positions of Tx and Rx and also the number of MPCs may become functions of time. The impulse response can also be extended to consider polarization effects by including a polarimetric matrix, which describes the coupling between vertical (V) and horizontal (H) polarizations.

In contrast to conventional communication systems, MIMO systems are equipped with multiple antennas at both transmitter and receiver sides. For a MIMO system consisting of S transmit and U receive antennas, the linear time variant MIMO channel is represented by the $U \times S$ channel matrix:

$$\mathbf{H}(t, \tau) = \begin{pmatrix} h_{11}(t, \tau) & h_{12}(t, \tau) & \cdots & h_{1S}(t, \tau) \\ h_{21}(t, \tau) & h_{22}(t, \tau) & \cdots & h_{2S}(t, \tau) \\ \vdots & \vdots & \ddots & \vdots \\ h_{U1}(t, \tau) & h_{U2}(t, \tau) & \cdots & h_{US}(t, \tau) \end{pmatrix} \quad (3)$$

where $h_{u,s}(t, \tau)$ represents the variant impulse response between a single transmit antenna and a single receive antenna. The channel matrix includes the propagation effect and the antenna configuration.

1.2 Model Classification

The channel models can be generally classified into two groups: stochastic and deterministic models. Stochastic models describe the characteristics of radio channel by means of the joint probability density function of statistical parameters. These parameters are usually estimated from extensive measurement campaigns, or inferred from geometrical assumptions. Stochastic models usually need less information than deterministic ones, and they produce more general results, as many repetitions are considered. In the deterministic models, on the other hand, the Channel Impulse Response (CIR) is obtained by tracing the reflected, diffracted and scattered rays, based on databases that provide information about the size and location of the physical structures in addition to the electromagnetic properties of their materials. Deterministic models have the advantage of providing the ability to generate accurate site specific and easily reproducible information. But their usage requires more data and computational time compared to the stochastic models.

This paper compares MIMO channel characteristics computed by deterministic channel modelling (3D ray tracing) with the results generated by statistical channel models. The most

crucial parameters of the spatial channel such as delay spread and angular spreads at both base and mobile stations are considered in the comparison.

2 Statistical Channel Modelling

For the purpose of comparing different MIMO systems and algorithms, various organizations defined standardized MIMO channel models, which establish reproducible conditions. These models are an important tool for the deployment of new radio systems. They allow to assess the benefits of different techniques, such as signal processing, multiple access, etc., for enhancing capacity and improving performance. The only existing comprehensive MIMO channel model is the COST 259 Directional Channel Model [1]. In 2003, a wideband Spatial Channel Model (SCM) was proposed by 3rd Generation Partnership Project (3GPP) and 3GPP2 for both link and system level simulations [2]. This model represents the MIMO channel as a superposition of clustered constituents, with stochastic powers, angles of departure and arrival, as well as times of arrival. The proposed model is intended for the three most common cellular environments, such as suburban macro-cell, urban macro-cell and urban micro-cell. The model is parameterised by the system bandwidth and is designed for bandwidths up to 5 MHz in the 2 GHz band. In 2005, the SCM was extended to 100 MHz bandwidth for 2 GHz and 5 GHz frequency bands by the Wireless World Initiative New Radio (WINNER) consortium and it is known as Spatial Channel Model extended (SCME) [3]. Later this consortium developed a generic channel model for indoor and outdoor environments and channels at 5 GHz with a bandwidth of up to 120 MHz, which is known as WINNER channel model [4]. This model is based on double directional measurement campaigns carried out in the 5 GHz band during 2004 and 2005.

2.1 Spatial Channel Model

The Spatial Channel Model [2] is intended for three outdoor environments, such as urban micro, urban macro and suburban macro, relevant to the third generation (3G) and beyond 3G cellular system simulations. It provides a statistical description of the spatial, temporal parameters and their dependencies across a large geographical area. In this model all parameters are captured from earlier published wideband and multiple antenna measurements [5]. The given methodology is based on the summation of directional plane waves derived from the statistics of the spatial-time parameters and their dependencies. The model does not consider macroscopic terminal movement because it assumed that the time frame of the intended system simulations is short. The model is parameterised by the system bandwidth and is designed for bandwidths of up to 5 MHz.

The purpose of the model is to generate the channel coefficients between a given base station (BS) and mobile station (MS) based on the evaluation on three levels. In the first (macroscopic) level time averaged local properties of the channel are described (e.g. the average power, DS and AS). These parameters are log-normal distributed random variables

(narrowband parameters). In the second (mesoscopic) level, each narrowband energy-cluster is decomposed in to multiple paths with relative delays, angle of arrival (AoA) and angle of departure (AoD) consistent with the narrow band statistics. The path delays and average path powers are generated as realizations of random variables. At the last, microscopic level, each of these paths undergoes Rayleigh fading, generated from the temporal variability of the particular link. Each path is represented as a sum of sub paths modelled as plane waves.

For the urban micro-cell case, investigated in this paper, the BS antennas are located at rooftop level and the cell radius is approximately 500m. This results in angular spreads being large at the BS with a mean RMS of 19° , even though the delay spread is only moderate with mean RMS of 251 ns. The distribution of the angles of departure for the different paths has been taken as a uniform distribution $[-40^\circ, 40^\circ]$. The individual path delays also follow a uniform distribution between 0 and 1.2 μs . For the angular spread at MS a mean RMS of 68° is considered.

3 Deterministic Channel Modelling

Deterministic propagation models are generally based on ray-optical techniques where different rays emitted by the transmitting antenna are subject to reflection, scattering and diffraction at walls and edges of buildings and similar obstacles. The computations are performed with help of the universal theory of diffraction (UTD) and Fresnel coefficients for reflections or with empirical diffraction/reflection models. While empirical models for urban scenarios assume a dominant propagation from the transmitter to the receiver over the buildings' rooftops, deterministic models consider the physical 3D propagation paths. As a consequence, deterministic models cope with effects such as shadowing behind walls, wave guiding in street canyons, offer excellent accuracy and are able to provide additional parameters such as small-scale fading, delay and angular spread.

The main disadvantage of the deterministic prediction models is their excessive computation time. The most time-consuming part is the determination of all the relevant paths from transmitter to receiver. Different authors presented ideas to accelerate the path finding and some of them lead to considerable acceleration factors. However, often these approaches consider only the propagation in two dimensions or in two perpendicular planes (horizontal and vertical plane). In contrast to this a rigorous 3D approach is utilised in this paper, which is based on a pre-processing of the building database. The remaining computation time after the pre-processing is many orders of magnitude lower than that needed for the conventional analysis without pre-processing. The WinProp 3D ray tracing software [6] used for the deterministic modelling is based on the evaluation of 3D building data representing the considered environment (see Figure 1). The ray tracing propagation model is fully three dimensional and computes all rays with up to three interactions (incl. double diffraction, also in combinations with reflections). These settings lead to the best relation between computational effort and accuracy.

4 Comparison of Channel Characteristics

In this chapter the MIMO channel characteristics as computed by the 3D ray tracing model and the spatial channel model (SCM) are compared in an urban micro-cell scenario (2 GHz band) for cell radius of 500m in non line of sight condition. In the considered scenario (see Figure 2) most of the building heights are around 15m, only few towers are included.

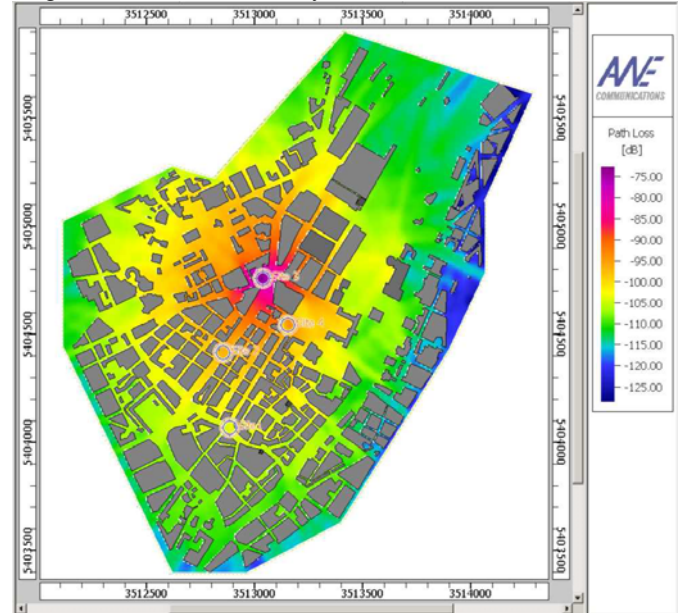


Figure 2: Considered micro-cell scenario for the analysis

4.1 Delay and Angular Spreads

The cumulative distributions of the channel parameters are evaluated for four different base station antenna sites (location) and varying heights around the roof top level by using the 3D ray tracing, while in case of the SCM the base station antenna height is fixed (slightly above the roof top level). The mobile station antenna height is fixed to street level. For both BS and MS omni-directional antenna patterns have been considered. The cumulative distribution functions of delay spread, angular spread (BS), and angular spread (MS) are presented in the following Figures for site no. 3.

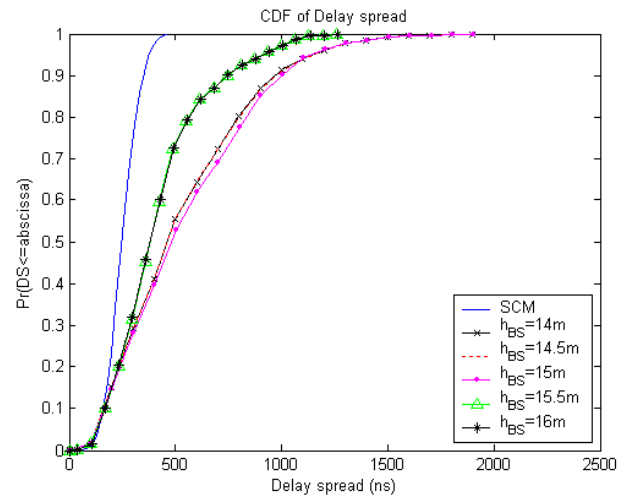


Figure 3: CDF of DS using SCM and deterministic model.

For all considered BS heights in deterministic modelling the delay spread values are higher compared to the SCM as shown in the Figure 3. In case the BS antenna is slightly above the roof top level (as assumed in the SCM) the delay spread distribution function computed by 3D ray tracing is approaching the SCM distribution. Reducing the BS antenna height below roof top level results in higher mean values of the DS distribution function.

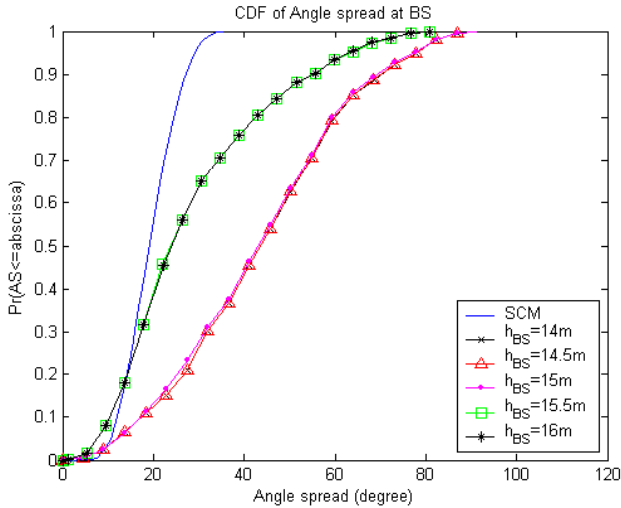


Figure 4: CDF of AS (BS) for SCM and deterministic model.

The results generated for the angular spread distributions (both for BS and MS) are also similar to the SCM distribution if the BS antenna is slightly above the roof top level (see Figures 4 and 5). However for the angular spread at BS in general higher values are predicted by the ray tracing model while for the angular spread at MS the SCM generates higher values. As shown in the Figures the distributions are differing considerably if the BS height is below roof top level. In this case the dominant rays propagate through the streets whereas in the latter case the dominant rays propagate over the roof tops. Hence, the urban canyon effect increases, when BS antenna height is changed from slightly above to below roof top level. Therefore the angular spread at BS is increased, while the angular spread at MS is reduced.

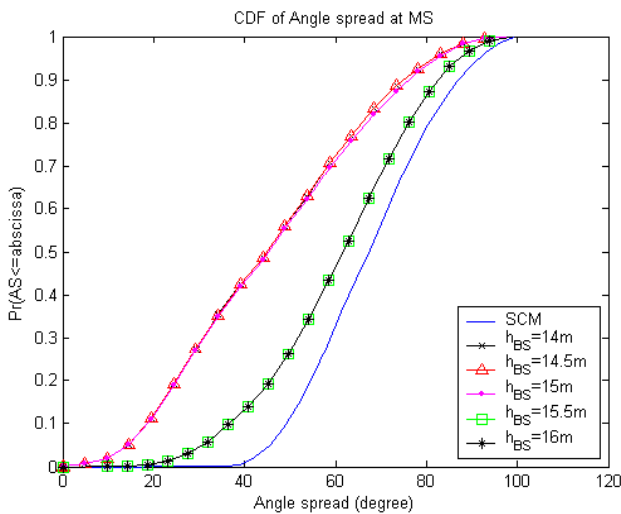


Figure 5: CDF of AS (MS) for SCM and deterministic model.

4.2 MIMO Channel Capacity

The frequency selective channel capacity in non line of sight condition has also been investigated for a 2x2 MIMO system (for 5 MHz bandwidth in the 2 GHz band) by using both the SCM and deterministic channel modelling. The results for the channel capacity are shown in Figures 6 and 7. In order to generalize the conclusions four different sites (different location of transmitters) in the urban scenario for the deterministic channel modelling are considered with two base station antenna heights; one is slightly below the roof top level and the other one is slightly above roof top level.

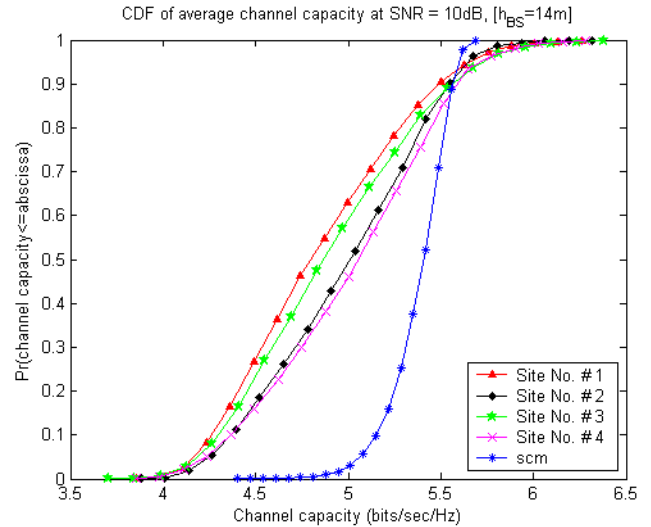


Figure 6: MIMO capacity for BS below roof top level.

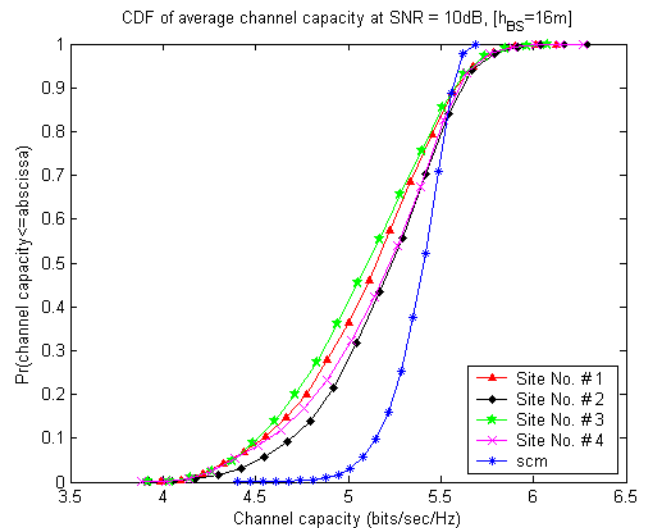


Figure 7: MIMO capacity for BS above roof top level.

In both cases the means of the CDFs of the average channel capacity are lower than the values obtained with the SCM. If the base station antenna height is below the roof top level (see Figure 6), the mean of the average capacity CDF is less than that of the case where the base station antenna height is slightly above the roof top level (see Figure 7). In both cases the standard deviation values are higher in the case of deterministic modelling compared to the SCM. From the

results it can be concluded that the BS antenna height (slightly above roof top level and slightly below roof top level) influences the propagation parameters, such as AS at BS and AS at MS. Hence, it also affects the channel capacity. The variation in the capacities can be understood from power azimuth spectrums which will be described in the next section.

4.3 Estimated Power Azimuth Spectrum

The estimated power azimuth spectrum (PAS) at BS and MS according to the SCM and the deterministic model are illustrated in Figures 8 and 9, respectively (for the two cases BS antenna height above and below the roof top level). In all the cases the received power is normalized to unity.

From Figure 8 it can be observed that the SCM has Gaussian estimated PAS at BS while the deterministic channel model has Laplacian estimated PAS at BS. In the deterministic channel modelling, if the BS height is below the roof top level, the standard deviation of Laplacian estimated PAS function is higher compared to the case where the base station antenna height is above the roof top level. This is due to the fact that the rays propagate rather through the streets which results in high AS values at BS (for BS height below the roof top level). If the BS antenna height is above the roof top level, the rays propagate rather over the roof tops of the buildings. Hence, it results in low AS values at BS. However, in the simulation, the spacing between BS antennas is 10λ so the effect of AS at BS on the channel capacity is limited. This is due to the fact that large spacing between antennas results in uncorrelated channels.

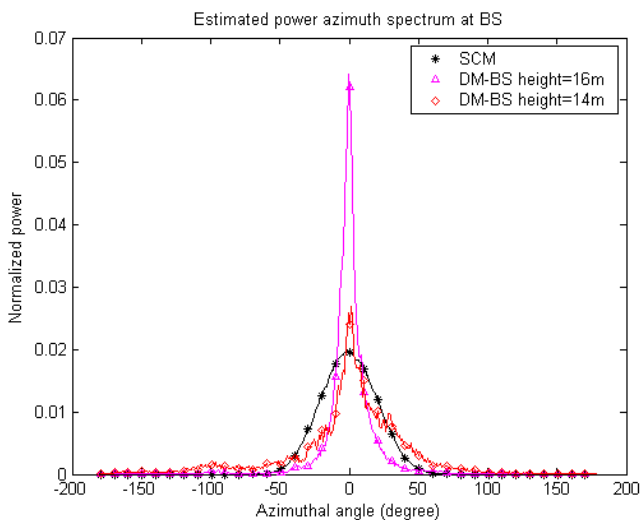


Figure 8: Estimated power azimuth spectrum at BS.

The estimated power azimuth spectrum at MS is shown in Figure 9. The spacing between the MS antennas is 0.5λ , i.e. the power azimuth spectrum at MS strongly influences the channel capacity.

In the case of SCM the estimated PAS at MS is truncated Gaussian shape whereas in the deterministic channel modelling the PAS corresponds to the Laplacian shape. If the BS height is above the roof top level, the standard deviation of the estimated PAS is higher compared to the case where

the BS antenna height is below the roof top level. Hence, the mean of the average capacity CDF is lower in the case of BS antenna height below roof top level compared to the case above roof top level (for a given SNR value). In the case of deterministic modelling, the estimated PAS for the links which have low capacity is Laplacian and for the links which have high capacity is closer to the Gaussian function.

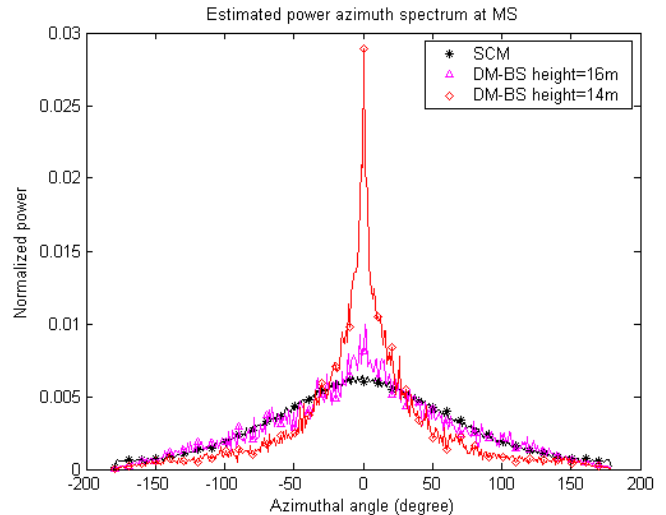


Figure 9: Estimated power azimuth spectrum at MS.

Acknowledgements

This work has been supported by the German Ministry for Education and Research (BMBF) within the EUREKA MEDEA+ project MIMOWA, which is kindly acknowledged.

References

- [1] A. F. Molisch, H. Asplund, R. Heddergott, M. Steinbauer, and T. Zwick, "The COST 259 directional channel model - I. Overview and Methodology," *IEEE Transactions on Wireless Communications*, 2001.
- [2] 3GPP, "Spatial channel model for MIMO simulations," TR 25.996 V6.1.0, Sep. 2003, [Online], Available: <http://www.3gpp.org>
- [3] Daniel S. Baum, Jari Salo, Giovanni Del Galdo, Marko Milojevic, Pekka Kyoesti, and Jan Hansen, "An interim channel model for beyond-3G systems," in *Proc. IEEE VTC 2005*, Stockholm, Sweden, May 2005.
- [4] H. El-Sallabi, D. S. Baum, P. Zetterberg, P. Kyosti, T. Rautiainen, C. Schneider, "Wideband spatial channel model for MIMO systems at 5 GHz in indoor and outdoor environments," in *Proceedings IEEE VTC 2006*.
- [5] K. I. Pedersen, P. E. Mogensen, and B. H. Fleury, "A stochastic model of the temporal and azimuthal dispersion seen at the base station in outdoor propagation environments," *IEEE Transactions on Vehicular Technology*, vol. 49, no. 2, pp. 437-447, March 2000.
- [6] AWE Communications: WinProp Software Package. Free evaluation version of a 3D ray tracing tool for urban and indoor environments. Available: <http://www.awe-communications.com/>