ON DIFFUSE AND NON-RESOLVED MULTIPATH COMPONENTS IN DIRECTIONAL CHANNEL CHARACTERISATION

W.A.Th. Kotterman[(1)], M. Landmann[(2)], G. Sommerkorn[(3)], R. Thomä[(4)]

[(1)] ***TU Ilmenau, Inst. Kommunikations- und Messtechnik, FG EMT,PSF 100 565, D-98684, Germany***
Email: Wim.Kotterman@TU-Ilmenau.de
[(2)] **As (1) but E-mail *Markus.Landmann@TU-Ilmenau.de***
[(3)] **As (1) but E-mail *Gerd.Sommerkorn@TU-Ilmenau.de***
[(4)] **As (1) but E-mail *Reiner.Thomae@TU-Ilmenau.de***

ABSTRACT

High-resolution parameter estimators, as applied in mobile propagation research, achieve their resolution through the use of data models, often plane-wave based. It has been noticed that the estimated, discrete, components do not account for all the received power. In our research at 5.2 GHz in ten different environments, strongly varying fractions of missing power of up to 90% (median values) are found, depending on the environment. This not-modelled or unresolved power consists of diffuse scattering, specular reflections with curved wave fronts, and non-resolved components. However, over a bandwidth varying from 20 to 120 MHz, we found stable to slightly increasing power fractions of this unresolved power and we conclude that (lack of) temporal resolution is not a likely source of unresolved power.

INTRODUCTION

MIMO systems exploit the double-directional properties of the mobile channel and in order to aid MIMO system design, this directionality should be characterised and modelled accurately. When using high-resolution parameter estimators to resolve the directional structure of the channel, it is explicitly modelled as consisting of a multitude of discrete multipath components (direct and specularly reflected waves). Often, but not necessarily, these waves are taken to be planar [1,2,3]. In mobile propagation research, it is a long-standing question whether really diffuse scattering is seen in mobile environments or that in the limit of infinite measurement bandwidth only discrete, scattered components would be found.

Recently published results show that the forementioned high-resolution schemes do not account for all the received power, resulting in not modelling the full information transfer potential of the channel [1,4,5,6]. This discrepancy must stem from model mismatch, from insufficient resolution or from both. For our analyses, based on plane-wave modelling, we conjecture that this not-modelled received power consists of contributions either from model mismatches like diffuse scattering, specular reflections with curved wave fronts, or from discrete components that are not resolved due to too small temporal bandwidths and/or too small spatial apertures, or from combinations of these. Diffuse and unresolved specular components are also known as Dense Multipath Components (DMC) [3,7], as yet unsufficient information is available on its nature.

In order to quantify the effect of temporal resolution, the processing of the measured data was repeated with varying bandwidth, ranging from 20 MHz to the full 120 MHz. Given the available measurements, we had little possibility to change the spatial resolution by varying the aperture. Measuring with devices with larger apertures than the present ones would demand a new measurement set-up and therefore we could not evaluate the spatial component of resolution influences. Also, direct tests on a diffuse nature of scattering are not available, as far as the authors are aware of. In other groups, the effect of wavefront curvature is investigated [2,8].

DATA MODEL AND HIGH-RESOLUTION ESTIMATION

The TU Ilmenau proprietary high-resolution parameter estimation scheme, called RIMAX, is a maximum likelihood joint estimation of amplitude, excess delay, angle-of-arrival, angle-of-departure, Doppler shift, noise level, and diffuse-field parameters [3,7]. The RIMAX scheme works on basis of a plane-wave data model for the discrete components and models the non-resolved DMCs as a negative-exponentially damped burst. Its strength is the gradient-based recursion, instead of SAGE, for faster convergence with ill-separated coherent paths.

Although the data model is plane-wave-based, calibration of the antenna arrays is done at 6 metres distance, due to limitations of the anechoic room. As a result, the angular resolution is optimal for components with corresponding wave front curvatures.

MEASUREMENTS AND PROCESSING

Several measurement campaigns were performed, indoors and outdoors, following deployment scenarios for the German national research project WIGWAM and the European IST project WINNER [6]:

- *Home Scenario*: autonomous self-configuring network
- *Office Scenario*: fixed network extension
- *Public Access Scenario*: cellular network extension for hot spots
- *High Velocity Scenario*: freeway and track information access

The measurements were performed with a RUSK ATM sounder at 5.2 GHz in 120 MHz bandwidth. The snapshot rate was between 49 and 109 snapshots per seconds, depending on the scenario, and the maximum excess delays varied between 1.6 and 3.2 µs. The antenna array constellations were a 16-element Uniform Circular Array (UCA) at the mobile side (omnidirectional in azimuth, dipole-like in elevation) and an 8-element Uniform Linear Array (ULA) at the stationary end (ca. 120° view in azimuth), using only the antenna ports for vertical polarisation.
TU Ilmenau's proprietary Rimax procedure was used to estimate both specular paths and DMCs. For the specular paths, excess delay, angle of departure (azimuth and elevation), angle of arrival (azimuth only), amplitude, and Doppler shift are jointly estimated according to a plane-wave model, over three consecutive snapshots. For the DMCs, the excess delay for maximum power density, the maximum power density, the exponential decay time (or coherence bandwidth), and the noise level are estimated. Parameters for specular paths and DMCS are jointly estimated. In an additional experiment, different bandwidths (around the centre frequency) were used during the processing: 20, 40, 60, 80, 100, and 120 MHz respectively. Using bandwidths smaller than 20 MHz during the processing hampers the DMC estimation: due to the increased sample interval, too few samples are available on the DMC-burst. Ultimately, the powers of the specular components are added and compared with the power in the DMC burst.

RESULTS

The ratio between the power in DMCs and power in specular components is environment-dependent, as shown in Figure 1. The highest fractions of DMC power are found in scattering-rich environments like the Munich main railway station hall, 'Station1' and 'Station2', or in environments with building walls in the vicinity, like indoors, 'Lobby' or outdoors in urban environments, 'Street1', 'Street2', 'Square1', and 'Square3', respectively. In open outdoor environments with high probability of LoS, like squares, 'Square2', the high basestation scenario 'Tower', and the highway bridge scenario 'Bridge', the least DMC power is found.
Results for varying bandwidth are given in Figure 2, for the high base station 'Tower' scenario (to the right) and the Munich main railway station hall (to the left; for computational reasons, a slightly different run has been processed). The effect of increasing bandwidth is an *increase* in the amount of DMC power, up to a maximum of 1.5 dB. Several tests have been done to find the cause of this unexpected result but no conclusions could be drawn. The behaviour of the instantaneous power ratios was very similar over bandwidth. No dependence on SNR was seen. An estimation quality measure from the Rimax procedure indicated that almost all information had been retrieved from the channel response, with very similar results over bandwidth. The measure is the difference (in [dB]) between the variance of the residual signal, i.e. after the specular components and DMCs have been subtracted, and that of white noise. This variance difference was within 0.5 dB for 90% of the time or more, with sporadic values of up to 4 dB higher, Figure 3. It was noticed, however, that these rare

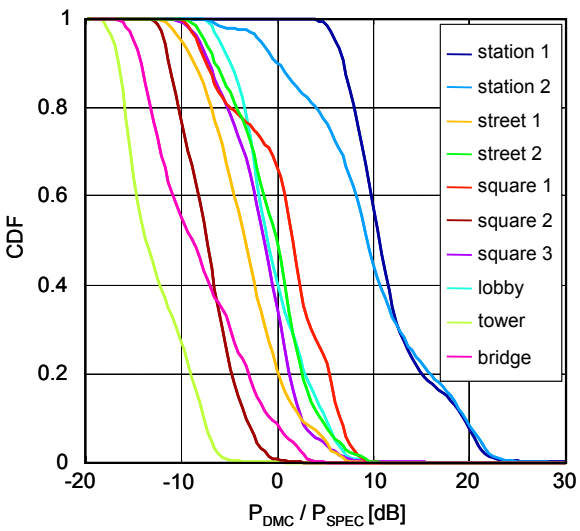

Figure 1 CDFs of ratios of power in DMCs and in specular components for various mobile environments

higher variances of the residual are coupled to higher DMC powers, suggesting that occasionally not all the specular components are retrieved. In another test, the singular value distributions of the instantaneous transmission matrices had no relationship with the amounts of power in the DMCs, indicating that no problem exists with over- or underestimating the number of specular components, not even in the cases with increased residual variance mentioned above.

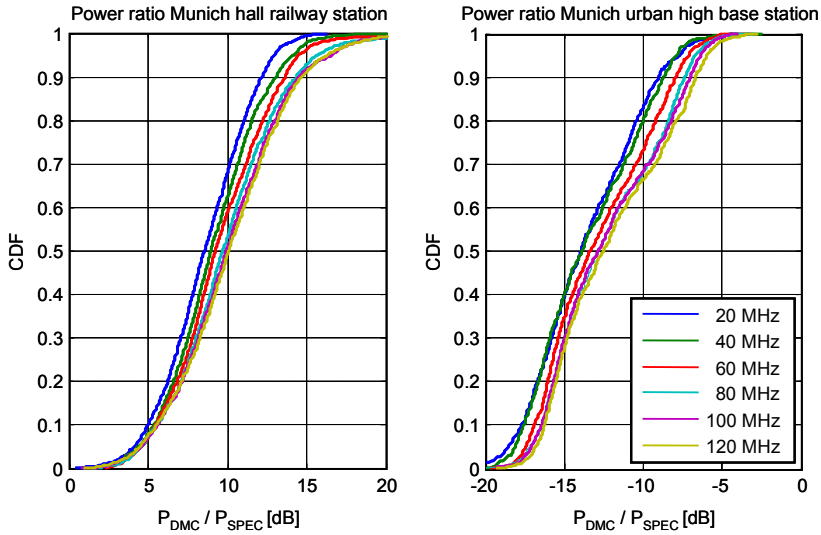

Figure 2 Variation of ratio between power in DMCs and in specular components over (processing) bandwidth for Munich main railway station hall (left) and Munich high base station scenario (right)

DISCUSSION

From the results it becomes clear that the environment determines the amount of power in the DMCs. Large amounts were found in scattering-rich environments, mostly in NLoS situations and/or with scattering objects in close vicinity, and smaller amounts in LoS in open environments. The latter is probably due to both the dominating direct components and the larger distances to scatterers. The tests performed did not indicate that estimator artefacts are a likely source of the DMCs, the estimation results being insensitive to actual SNR values and rank of the channel. Also, for most of the time, all the model-compliant information has been retrieved, seen the stable noise-like variance of the residual signal. The occasional excursions towards higher variances are burst-like and could therefore be caused by moving scatterers, but we had no possibility to verify this. Nevertheless, the clean line in Figure 3 suggests some relation between DMCs and estimator performance.

An unexpected effect of varying the bandwidth has been noticed with respect to the amount of power in the DMCs, the amount of DMC power increases slightly with increasing bandwidth. As the amount of power in DMCs does not decrease with increasing bandwidth, unsufficient temporal resolution is unlikely to be the source, at least not within this bandwidth range. Of course, the estimated components change with varying bandwidth, i.e. components are merged, but the amount of received power the estimation can account for, stays reasonably constant. If DMCs are assumed to be due to insufficient resolution, it must be the resolution in the angular domain, at least for the channels presented here, as the temporal resolution is much higher than the angular resolution for these bandwidths. We see no possibility with these data sets to simulate comparable resolutions in both domains. Smaller bandwidths than used here, i.e. below 20 MHz, hamper the estimation of the diffuse field parameters as the number of independent samples on the exponential decay curve of the DMCs becomes too small. Higher angular resolution would require new measurements with antenna arrays with much larger physical apertures, but then, one should ask oneself how these large structures influence the propagation conditions, especially indoors.

As regards the effect of model errors, recent experiments with changes to the data model to incorporate curved wave fronts indicated that part of the DMCs stem from model errors. After correction for this wave-front curvature, up to 3 dB reduction in the power of the DMCs was found for an indoor environment with scatterers at close range, i.e. at about one metre distance [8]. Note that in our experiments high amounts of DMC power were found in environments with nearby scatterers. However, in the Munich railway hall with up to 90% of the power in DMCs, the metal-rich roof support structure, supposedly the major scattering surface, was at twenty metres

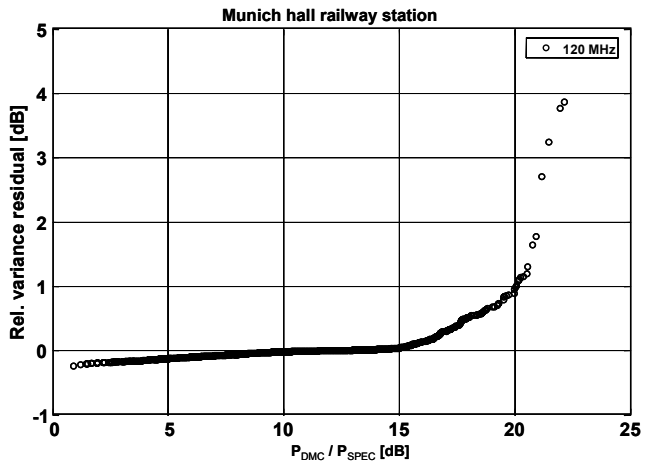

Figure 3 Variance of estimation residual, relative to white noise, vs. power ratio of DMCs and specular components (Munich railway hall, processed at 120 MHz)

distance or more. This causes model errors too but smaller than scatterers a few metres away.
One of the present research topics is to incorporate wave front curvature estimation into the estimation scheme. A problem could be that antenna array parameters have to be known with very high accuracy in order to be able to recompute antenna array responses for wave fronts with arbitrary curvature, based on the original calibration data.

CONCLUSIONS

For a number of mobile outdoor and indoor channels at 5.2 GHz, the ratio between power in specular components and in Dense Multipath Components has been determined. The high-resolution ML parameter estimation scheme used is the TU Ilmenau proprietary gradient-based RIMAX-procedure. Strongly varying amounts of DMC power were found, the ratios between power in specular components and in DMCs ranged from a few percent to 90 % (median values), depending on the environment. The least power in DMCs was found in LoS outdoor scenarios, the most in the large Munich main railway station hall with an abundance of metal construction elements.
When running the parameter estimation with different bandwidths, varying between 20 and 120 MHz, the fraction of power in DMCs seemed to *increase* slightly with increasing bandwidth. From this, we conclude that it is unlikely that, within the used bandwidth, DMCs stem from a lack of temporal resolution.
Future research is aimed at determining the influence of wave front curvature and incorporating wave-front curvature into the estimation process.

REFERENCES

[1] S. Wyne, P. Almers, J. Karedal, G. Ericsson, F. Tufvesson, and A.F. Molisch, "Outdoor to Indoor Office MIMO Measurements at 5.2 GHz", *VTC04F,* Los Angeles, USA, September 2004.

[2] J. Verhaevert, E. van Lil, and A. van de Capelle, "Extraction of Source Parameters from Broadband Measurements with the SAGE Algorithm", Revue HF, Belgian Journal of Electronics and Communications, no. 3, pp. 41-43, 2003.

[3] R.S. Thomä, M. Landmann, and A. Richter, "RIMAX – a Maximum Likelihood framework for parameter estimation in multidimensional channel sounding", *ISAP2004*, pp. 53-56, Sendai, Japan, August 2004.

[4] K. Haneda, J. Takada, and T. Kobayashi, "Double directional LOS channel characterization in a home environment with ultra wideband signal", *WPMC04*, Abano Terme, Italy, September 2004.

[5] A. Richter, C. Schneider, M. Landmann, and R.S. Thomä, "Parameter Estimation Results of Specular and Dense Multipath Components in Micro-Cell Scenarios", *WPMC04*, Abano Terme, Italy, September 2004.

[6] U. Trautwein, G. Sommerkorn, C. Schneider, and R.S. Thomä, "Measurement and Analysis of MIMO Channels in Public Access Scenarios at 5.2 GHz, *WPMC05*, Aalborg, Denmark, September 2005.

[7] A. Richter, "Estimation of Radio Channel Parameters: Models and Algorithms", *Ph.D thesis*, Technical University Ilmenau, Germany, 2005.

[8] M. Landmann and J. Takada, "On the plane wave assumption in indoor channel modelling", *IEICE Society Conference,* Sapporo, Japan, September 2005.