Full 3D MIMO Channel Sounding and Characterization in an Urban Macro Cell

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***Abstract*—5G networks will target on smaller cells serving more and more mobile users. Especially on the base station side new technologies are needed circling as buzzwords like *massive MIMO* and *elevation beamforming*. In that context more precise channel models are required focusing on the elevation characteristic of the radio channel at the base station. In this paper an extensive channel sounding campaign in an urban macro cell using circular antenna arrays on both link ends is described and statistical analysis results are discussed based on the high resolution parameter estimation framework RIMAX.**

Keywords – urban macro cell, full 3D MIMO, channel modeling, channel sounding

I. Introduction

FUTURE concepts for the 5th generation (5G) of mobile communication networks will consider approaches like smaller cells, massive multiple input multiple output (MIMO), elevation beamforming and/or coordinated multipoint [1]–[3]. The undoubted key to assess reliable performances figures of such advanced technologies is the understanding of the radio wave propagation and correct modeling of the performance determining parameters [4]–[6]. Standardized models [5], [7] and recently proposed models like the WINNER channel model family and COST273/2100/IC1004 [4], [8], [9] rely on an antenna independent channel modeling. This is a prerequisite for the performance analysis of MIMO concepts, in particular if the dimensions scale up to massive MIMO. While WINNER I/II considered multipath propagation parameters such as pathloss, shadow fading, K-factor, polarization, delay, azimuth of arrival and departure, WINNER+ has been introduced as an extension to a full 3D channel and antenna model [10]. This step is important since for massive MIMO and concepts like elevation/3D beamforming the channel description including elevation characteristics is implicitly required [6], [11]. Within many MIMO channel sounding campaigns and even within contributions from WINNER+ not all scenarios have been studied based on real full 3D channel measurement data sets [4]. Furthermore the multiuser separation by means of elevation beamforming has not been studied based on realistic multipath parameter identification. Within this contribution the characteristics of the so-called large scale parameter (LSP) distributions within a full 3D channel sounding campaign is investigated. The data sets are gathered in a typical urban scenario. Furthermore by analyzing the elevation characteristics of different user positions their potential separation due to a simple elevation beamformer is discussed.

Fig. 1. SPUCA2x8 at the transmitter in Cologne oriented to the Kölner Dom

Measurement Campaign	
Scenario	Urban macro cell
Location	City center of Cologne, Germany
Measurement Setup	full 3D MIMO

TABLE I
CAMPAIGN DESCRIPTION

II. Measurement Campaign and Data Processing

A. Measurement Campaign

The measurement campaign was performed in Cologne (Germany) using a RUSK MIMO channel sounder operating at 2.53 GHz. The fixed transmitter has been mounted on a roof top of an approx. 30m high building whereas the mobile receiver has been set up in a car. The Tables I and II summarize the measurement campaign and setup. In Figure 3 the mobile tracks are depicted and the base station position and orientation are denoted.

The application of high resolution parameter estimation algorithms require adequate antenna arrays. Therefore the measurements have been done using a stacked uniform circular array at the base station side (Tx) as well as at the mobile station side (Rx). Both arrays are linear dual polarized. More details of the antenna arrays are given in Table III.

B. Data Preparation

In order to obtain an antenna independent characterization of the radio channel the high resolution parameter estimation framework RIMAX [12] was used. RIMAX models the

Measurement System	
Channel Sounder	RUSK TUI-FAU (MEDAV GmbH)
Transmit power	46dBm
Center frequency	2,53GHz
Bandwidth	20MHz
CIR length	$12.8\mu s$
MIMO sub-channels	32x32 (#Tx x #Rx)
AGC switching	within MIMO sub-channels
Metadata	GPS and Odometer

TABLE II
MEASUREMENT SYSTEM

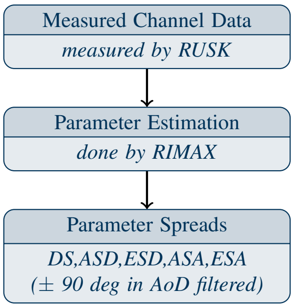

Fig. 2. Data preprocessing for analysis

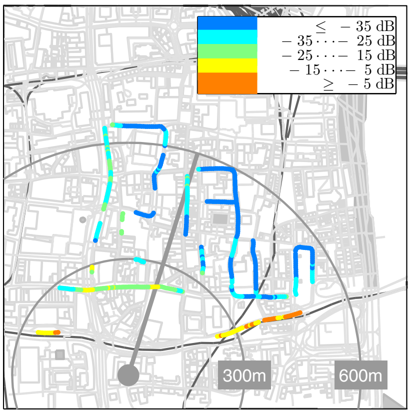

Fig. 3. Total received power (specular components only)

Measurement Antenna Setup	@Tx	@Rx
Name(type)	SPUCA2x8	SPUCA2x8
Geometry	8 elements per ring two rings	8 elements per ring two rings
dual polarized	yes	yes
number of ports	32	32
Mounting Height	approx.30m	2,30m

TABLE III
MEASUREMENT ANTENNA SETUP

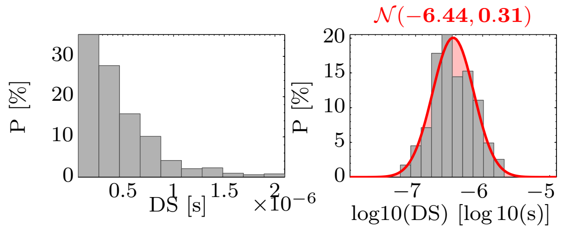

Fig. 4. PDF of the delay spread

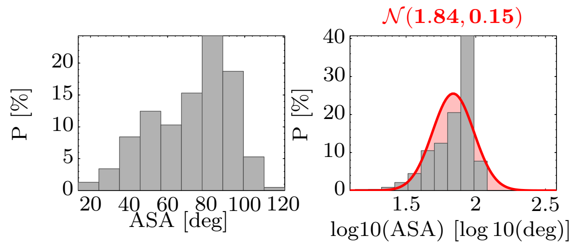

Fig. 5. PDF of the azimuth spread of arrival

channel as the superposition of a deterministic (specular) and a stochastic (dense multipath) part. The deterministic part resembles a multitude of plane waves that are resolvable by the estimator. Each plane wave is hereby described using its time-delay, angle-of-arrival (in azimuth and elevation), angle-of-departure (in azimuth and elevation) and the complex polarimetric path-weight. These parameters have been taken to derive the corresponding RMS parameter spreads within stationary intervals of approx. ten wavelengths. A spatial filtering in the azimuth of departure (AoD) has been applied to the spread calculation. An overview of the analysis strategy is given in Figure 2.

III. ANALYSIS

The organization of the analysis section is twofold. Firstly the large scale parameters (LSP) of the channel are evaluated. The derivation of the parameters is in accordance with the WINNER channel model and has been used in a variety of publications in the past [13]. Secondly the possibilities of elevation beamforming on the transmitter are discussed. It has to be noted that this analysis is not yet comprehensive but is the start of further investigations in the future.

A. Large Scale Parameter Analysis

Figures 4,5,6,7 and 8 depict the probability density functions (PDF) of the angular spreads of departure/arrival and the delay spread. Furthermore, the estimated log-normal distributions as known from WINNER are shown. The log-normal distribution parameters are in accordance to the reported WINNER II/+ C2 NLoS scenario.

B. Elevation Beamforming

A major goal of the measurement campaign presented in this paper is to investigate the possibility of separating two or more users in the scenario using beamforming in the elevation domain at the transmitter. In order to distinguish two users using elevation beamforming their corresponding power density spectra should be (partially) non-overlapping. If this is the

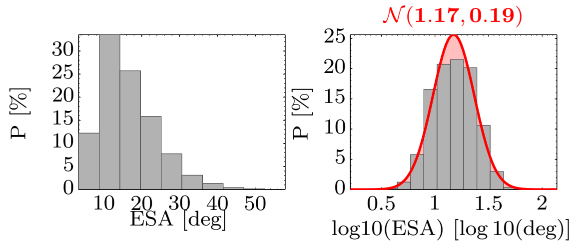

Fig. 6. PDF of the elevation spread of arrival

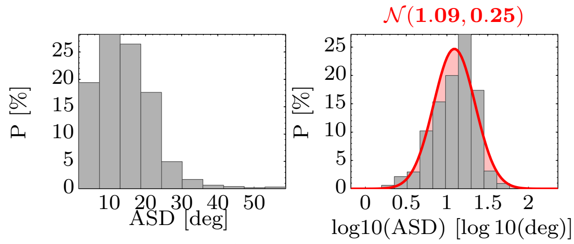

Fig. 7. PDF of the azimuth spread of departure

case the transmitter is able to create a certain beamformer that radiates power only in the non-overlapping regions and thus masking the other users out. It is apparent that this approach does not only depend on the power density spectrum of the radio channel but also on the antenna arrays used (affecting the possible beamformers). However, the evaluation of the elevation spectrum of the channel alone gives a good indication of the overall possibility of using this method. Therefore, the investigations presented in the following are only considering the radio channel leaving out the influence of the antenna arrays. Figure 9 shows the elevation center of gravity departure (ECD) for the different receiver locations. It can be seen that there exist combinations of receiver locations whose ECD is significant different. That indicates that a suitable beamformer approach is able to distinguish between them. The PDF of the ECDs is presented in Figure 10. However, the ECD alone is not sufficient to decide whether different elevation spectra overlap significantly, the width has also to be taken into consideration. Figure 11 shows the elevation spread of departure (ESD) of the power spectra for every receiver location which can serve as an indication of the width.

In order to characterize the amount of overlap of the elevation spectra of two hypothetical users (locations of the receiver) we propose a method that involves the comparison of spread and the center of gravity of the spectra. It is assumed that the shape of the elevation spectrum is similar (to a certain extent) to the PDF of a Gaussian distribution. The amount of overlap of two spectra is then characterized by the difference

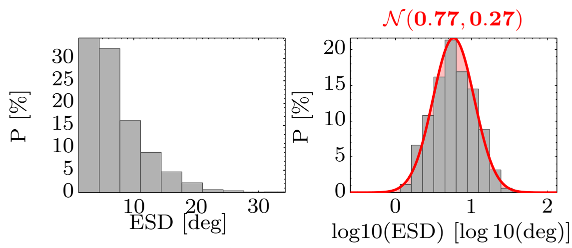

Fig. 8. PDF of the elevation spread of departure

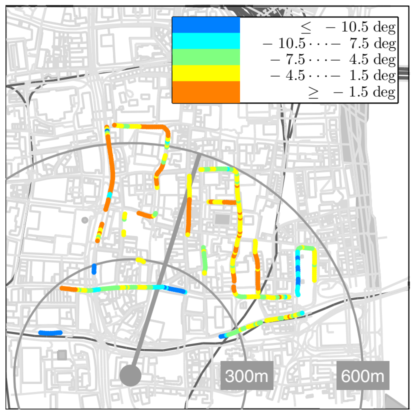

Fig. 9. Elevation center of gravity of departure along measurements tracks

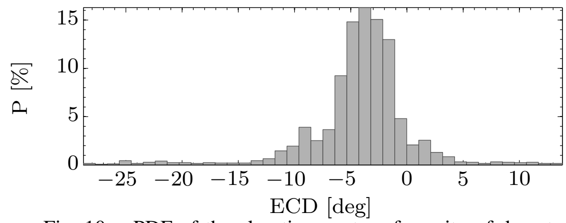

Fig. 10. PDF of the elevation center of gravity of departure

of the center of gravities subtracted by the sum of the RMS spreads.

$$
\begin{aligned}
\mathrm{r} &= |\Delta_{ij} ECD| - \Sigma_{ij} ESD \\
|\Delta_{ij} ECD| &= |ECD_i - ECD_j| \\
\Sigma_{ij} ESD &= ESD_i + ESD_j
\end{aligned}
\quad (1)
$$

With ECD_i being the elevation center of gravity departure and ESD_i the elevation spread of departure of the i'th receiver location. Figure 12 illustrates the principle of using the aforementioned metric of evaluating the amount of overlap.

It must be noted that, based solely on the value of r, it is difficult to decide whether two receiver locations can be separated in elevation. The minimal required value of r is again influenced by the properties of the beamformer and

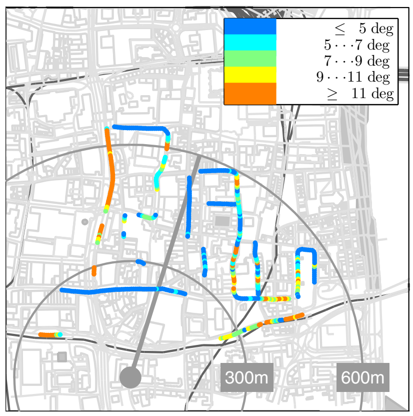

Fig. 11. Elevation spread of departure along measurements tracks

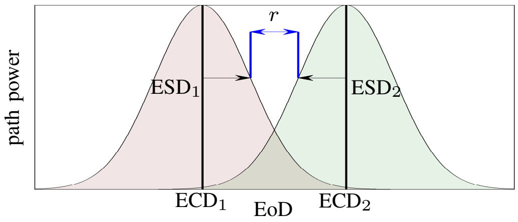

Fig. 12. Criterion for the separation of two users

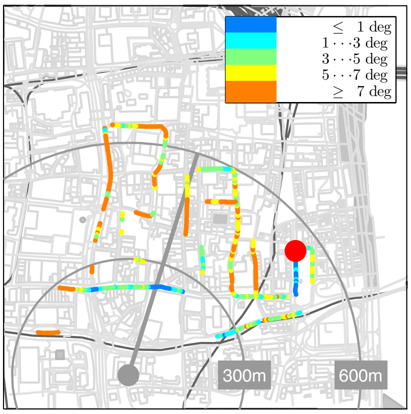

Fig. 13. $|\Delta ECD|$ for one selected position

the overall requirements on the interference between different users. However, we decided to define r $>= 0$ as a threshold that allows separation of users.

Figure 13 shows the $|\Delta ECD|$ between a single reference location (indicated by a red marker) and all other locations. The figure clearly shows that there are some locations where the ECD is significantly different from the ECD of the reference point. For an extensive treatment it would be necessary to calculate the $|\Delta ECD|$ between all combinations of measurement locations. In order to reduce the complexity, for each receiver location only locations within a local distance of 150m are considered and the $|\Delta ECD|$ was determined. Furthermore, the resulting distance metric r is presented in Figure 14. The threshold value of r $= 0$ is exceeded for a significant amount of receiver locations.

IV. Conclusion

This paper presents urban measurement data from channel sounding campaign that have been evaluated by the RIMAX framework. WINNER large scale parameters have been derived for azimuth and elevation of departure and arrival. Furthermore the application of elevation beamforming at the base station has been investigated.

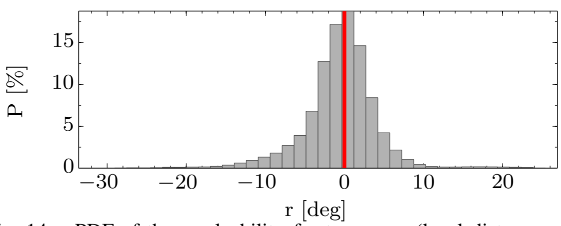

Fig. 14. PDF of the resolvability for two users (local distance of 150m)

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