Comparison of Time- and Angular Dispersion between Channel Sounding Measurements and Ray Tracing in CoMP–MIMO Channels

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1 Introduction

The need of incorporating Multiple–Input Multiple–Output (MIMO) technology into radio network planning and optimization rises dramatically for network operators. One main question to answer is how accurate MIMO channel models reflect the real MIMO channel. To answer, we already compared eigenvalue statistics of various single–user (SU) and multi–user (MU) Cooperative Multi–Point (CoMP)–MIMO scenarios [1, 2, 3, 4] to verify a 3D ray tracing channel simulator with channel sounding measurements in the 2.53 GHz range, a major frequency band for LTE transmission in Europe. This contribution adds a comprehensive verification of time- and angular dispersion characteristics by carefully analyzing results of a dedicated high–resolution measurement campaign. These extra measurement data allow for an intermediate step of high–resolution post–processing of the measurement data [5, 6] to estimate radio channel parameters. These estimated parameters are then directly compared with ray tracing channel simulation results, especially in the rarely analyzed angular domain.

2 Channel Measurements

This work is based on channel sounding measurements carried out in the 2.53 GHz range in downtown Dresden, Germany, in April 2009 in mostly sunny conditions. The map in Fig. 1(a) shows the deployment and measurement scenario. The azimuth sector orientation was chosen to measure a CoMP setup, so every

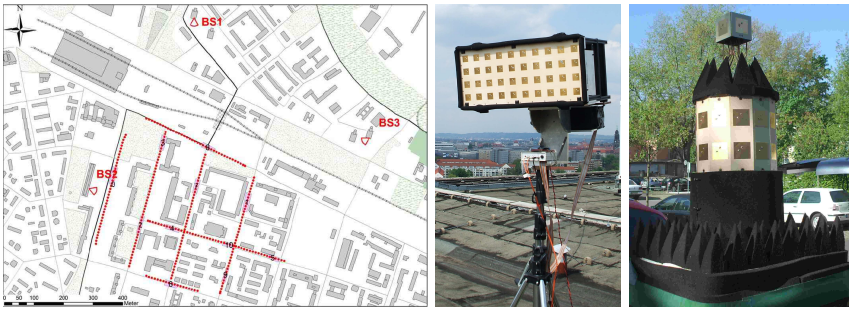

Figure 1: Measurement environment in Dresden (a), transmitter antenna (b), and receiver antenna (c).

transmitter has an orientation towards the middle of the measurement area, see the red sector symbols in Fig. 1(a). The antenna heights for BS1, BS2, and BS3 where 55 m, 34 m, and 52 m over ground, respectively. This area is a high–density area characterized by streets surrounded by buildings of about 30 m height. We applied a $\theta = 7°$ down–tilt at all transmitter positions, the inter–site distance is about 750 m. In Fig. 1(a), the red dotted line indicates the complete measurement track of about 3000 m.
At the transmitter the following antenna setup was used. The 4*10 polarized patch antenna array shown in Fig. 1(b) was adapted by using each column of patch elements as a single antenna element. The two outer columns were not used, but the eight inner columns have two polarization directions each. Together, we have a Stacked Polarized Uniform Linear Array (SPULA) with 16 antenna ports.
At the mobile station side, a Stacked Polarized Uniform Circular Array (SPUCA) with 2 * 12 polarized patch

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elements and a MIMO cube with 5 polarized patch elements on top was mounted onto the measurement car's roof, see Fig. 1(c). Together, we have a receiver antenna with 58 antenna ports.
Measurements were taken using the RUSK HyEff channel sounder [7] at 2.53 GHz using a multi–tone test signal with 100 MHz bandwidth. The measurement car's speed was about 2.6 m/s.

3 Measurement Data Post–Processing

In this analysis the direct measurement results have undergone an intermediate step before they were compared with the ray tracing channel simulation results: a high–resolution multi path radio channel parameter estimation using the RIMAX algorithm [5, 6]. This intermediate step requires the dedicated measurement antenna arrays described above [8], a sophisticated antenna calibration, and has a high computational effort. Then, the parameter estimation allows to resolve several propagation paths from measured channel impulse responses of every transmitter–receiver link considering the whole transmission bandwidth. The obtained paths are described by the radio channel parameters azimuth angle of arrival, delay, power, and polarization.

4 Ray Tracing Channel Simulation

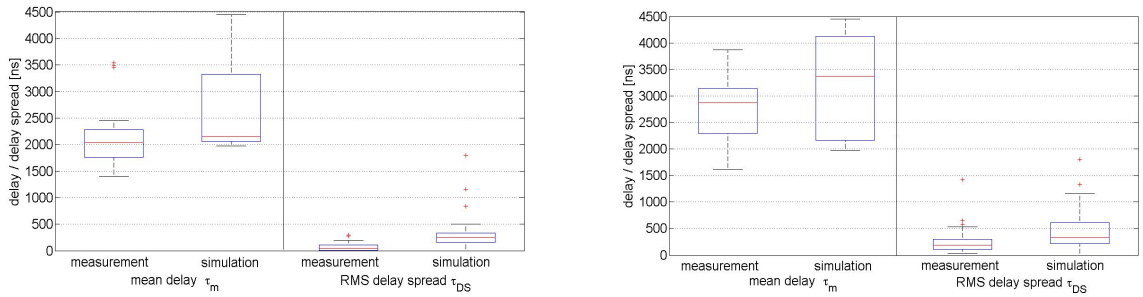
Ray tracing is a deterministic channel modeling method to simulate channel impulse responses in time, angular, and polarization domain. We use the ray launching approach, where a bundle of rays emanate from a transmitter that is modeled as a single point in the 3D environment. The rays are weighted with the complex value of the transmitter antenna pattern. Our ray launching algorithm uses a 3D vector data model (e.g., buildings and ground) of the same environment where the measurements were done to determine the nearest obstacle in the propagation direction of the ray. Once a ray hits an obstacle our algorithm (e.g., [1]) includes specular reflection and diffraction taking the relative permittivity $\epsilon_r(f)$ of the obstacle into account. Our receivers are placed along the measurement track and are modeled by horizontal square planes at 1.50 m height having complex patterns of the receiver antenna, see, e.g., [9] how to model them. The direct result of the ray launching algorithm is a set of radio propagation paths for every transmitter–receiver link, where each path is described by the same radio channel parameters like they result from the RIMAX algorithm.

5 Comparison

To compare statistics of the the measured/post–processed and simulated channel impulse responses we have to geographically map both data sets. In earlier studies (e.g., [1, 2]) we concluded that a lateral size of the receiver plane in the ray tracing channel simulator of 10 m is optimal. Therefore we have to map the measurement results to this receiver plane size. Taking the measurement parameters into account, then we have to map about 300 single estimated measurement snapshots into one simulator receiver plane for comparison.
Due to the high computational effort of the RIMAX algorithm, we could not estimate post–processed channel parameters for the complete 3000 m of the measurement track. Instead, we decided only to analyze eleven positions as indicated by the blue markers (0,..,10) in Fig. 1(a), which were carefully selected to represent characteristic propagation conditions, such as line–of–sight (LOS) or non–line–of–sight (NLOS).
Every of the selected eleven analysis positions has at least 1000 consecutive measurement snapshots to give a comprehensive statistic. These measurements snapshots map onto 3...4 simulation receiver planes each. Inside one simulation receiver plane we aggregated the post–processed measurement results. With respect to the accuracy of the measurement equipment [8] we further applied a dynamic range cutoff of 20 dB in receive power.
For each analysis position we calculated the radio channel parameters mean delay τ_{m}, rms delay spread τ_{DS}, mean azimuth receiver angle of arrival (AoA) $\phi_{\mathrm{m}}^{\mathrm{Rx}}$, and rms receiver azimuth AoA spread $\phi_{\mathrm{AS}}^{\mathrm{Rx}}$ for both, simulation and post–processed measurement data.

6 Results

We categorized our analysis into LOS and NLOS as well as into transmit antenna above rooftop (BS1, BS3) and at rooftop level (BS2) for a comprehensive comparison. In Fig. 2 box plots of the results of mean delay τ_{m} and rms delay spread τ_{DS} are shown for LOS/NLOS and the transmit antennas being over rooftop. In all box plots the red line represents the median value, the blue box marks the lower and upper quartile, while the lower and upper black whiskers mark the 5th and 95th percentile. Red crosses mark observation outliers. In general, we find a surprisingly good fitting of the analyzed second order statistics

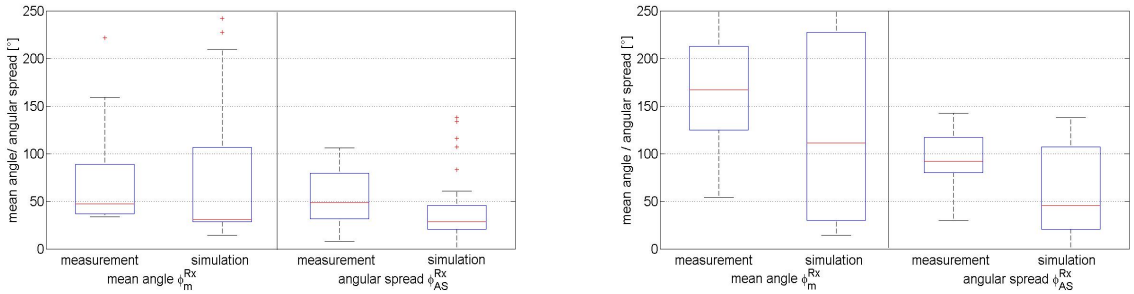


(a) Over Rooftop - LOS - Delay

(b) Over Rooftop - NLOS - Delay

Figure 2: Comparison for mean delay and rms delay spread.

of post–processed measurement and simulation data in the time domain, especially in the LOS propagation environment. In NLOS, we find a higher median value of the mean delay and a slightly more flat shape of the cumulative distribution function (CDF) of both statistics in our simulation data, which are through the deterministic environment model in the simulation. There is no environmental noise, such as trees, cars, people, traffic lights, and so on in our environment model. Also, the ray launching approach does not check for an unobstructed first Fresnel zone, especially in the close environment of the receiver. For these reasons we get less in count, but stronger NLOS paths in the simulation data that are more shaded in reality. In



(a) Over Rooftop - LOS - Rx Azimuth

(b) Over Rooftop - NLOS - Rx Azimuth

Figure 3: Comparison for mean Rx azimuth and rms Rx azimuth spread.

Fig. 3 box plots of the results of mean azimuth receiver AoA $\phi_{\mathrm{m}}^{\mathrm{Rx}}$ and the according rms angular spread $\phi_{\mathrm{AS}}^{\mathrm{Rx}}$ are shown for LOS/NLOS and the transmit antennas being over rooftop. The general good fitting of the second order statistics of our two data sources can for the angular domain only be confirmed for LOS. In NLOS, however, both analyzed statistics have a more flat shape of the according CDF in the simulation data. This is again based on strong NLOS paths in the simulation data, which come from more different directions than in reality. The differences in the mean AoA also show inconsistencies between the 3D environment model and the real environment. In the angular domain, the deterministic nature of the ray launching tool is a strong tool to show such differences especially in LOS, when correctly configured. Thus, especially in NLOS, the receiver azimuth angular spread analysis is unreliable. The data analysis for BS2 (transmit antenna at rooftop level) show even more unreliable results, especially in the angular domain and for NLOS.

7 Conclusions

Our analysis of second order statistics of simulated and measured channel impulse responses in a real CoMP–MIMO cellular network in time and receiver azimuth angular domain proves a good fit of the analyzed data in the time domain and an acceptable fit for LOS in the angular domain, when the transmit antennas are above the average building height. While the time domain is heavily analyzed in link level simulations, the angular spread is often used as a rough measure for the likelihood to have spatial multiplexity in MIMO communications in network level planning and optimization. Our investigations indicate a certain unreliability in receiver azimuth angular spread simulation data which are based on too deterministic ray tracing simulations. This result suggests to use more reliable ray tracing based eigenvalue- [1] or channel capacity [10] ratios for spatial multiplexing probability analysis in MIMO network planning and optimization.

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