Abstract—3D beamforming is a technique which allows the adaptation of the base station (BS) antenna downtilt per user equipment (UE). The selection of the appropriate downtilt depends on the propagation properties of the environment. This paper investigates the optimum downtilt angle in a typical non-line-of-sight (NLOS) urban outdoor environment. Therefore measurements with variable downtilt have been conducted in a real deployment scenario in Dresden. For different measurement locations the downtilts needed for maximum receive power at the UE are compared to predictions based on different existing propagation models for the vertical dimension of the radio channel. Since the testbed allowed also multi-cell operation, the benefits of downtilt adaptation on the signal-to-interference ratio (SIR) could be verified.

Keywords—3D beamforming; downtilt adaptation; beam coordination; field measurements, vertical channel model; multicell, SIR

I. INTRODUCTION

For cellular mobile communication systems a variety of multi-antenna schemes for realization of beamforming and MIMO transmission is available. Conventional cellular systems only have the capability to adapt the antenna pattern in the horizontal plane. The vertical antenna pattern is fixed, with a narrow half-power beamwidth (HPBW) usually in the range of 5 to 10°, selected to achieve good coverage all over the cell. The downtilt of the antenna is also fixed, so that the main lobe of the vertical pattern points to the ground at a fixed distance from the base station which is smaller than the cell radius. In consequence, many UEs within a cell do not benefit from the maximum antenna gain [1]. Also the interference in the adjacent cell is constant, independent of the location of the served UE. To overcome this drawback, 3D beamforming addresses the extension of beamforming towards UE-specific adaptation for the vertical antenna pattern. This can be applied solely or in combination with additional horizontal beamforming or MIMO techniques.

During the last years, 3D beamforming has been investigated theoretically. With the assumptions made for the vertical channel model it showed promising performance gains [e.g. 1, 2, 5]. For some specific scenarios [3, 4] even first lab and field experiments were reported and show, in simplified scenarios, that the 3D beamforming approach is basically feasible.

This paper provides measurement results taken in a large real deployment scenario. The scenario comprises two base stations facing each other and serving two cells between them. Besides the single cell receive power analysis per downtilt, this allowed also the evaluation of the impact of 3D beamforming on interference in a real propagation environment.

II. PROPAGATION MODELS

When applying beamforming in outdoor scenarios, the basic question is how the environment influences the selection of the optimum vertical beam pattern for a specific UE. Especially in NLOS conditions, the prediction of the appropriate UE-specific vertical antenna pattern, i.e. the best suited downtilt angle for the vertical main lobe, is not obvious. This angle depends on the reflections, diffractions and the number of different signal paths between BS and UE. Therefore, the downtilt angle for maximum receive power usually can differ significantly from the angle of the geometrical connection between the two nodes (= geometrical downtilt). An additional open question is the interference behavior. Major difference of the interference path compared to the wanted signal path is the larger distance to the UE, which might lead to more reflections and even larger discrepancies to the geometrical downtilt.

There are only few channel models for the prediction of the optimum downtilt for outdoor scenarios available. Most of the commonly used channel models do not particularly take into account the vertical properties of the radio channel. A widely used simulation model, proposed by 3GPP [7], defines a 3-dimensional antenna pattern, but the channel model is still 2-dimensional and assumes line-of-sight (LOS) characteristic in the vertical direction.

Another model, called "propagation over clutter" (PoC) and proposed in [6], explicitly takes high buildings into account with street canyons between them. Characteristic parameters used for downtilt prediction are the difference between the height of the BS (height_{BS}) and the height of the buildings in the vicinity of the UE (height_{building}), and the distance between BS and UE (dist(BS-UE)). The prediction of the downtilt for
maximum receive power at the UE, $DT_{PoC}$, is given according to

$$ DT_{PoC} = \tan^{-1}\left( \frac{\text{height}_{BS} - \text{height}_{building}}{\text{dist}(BS - UE)} \right) \quad (1) $$

This model concludes that the optimum downtilt needed to serve the UE in an NLOS environment is always lower than the geometrical downtilt given by a direct line between BS and UE. This implicitly gives rise to the suspicion that the expected interference reduction effect of 3D beamforming might be reduced. With the measurements presented in this paper the authors have generated a valuable database to assess the applicability of these models to real deployments and to verify the expected properties of 3D beamforming in a real propagation environment.

III. FIELD MEASUREMENTS

A. Trial Setup

Fig. 1. Picture of the field trial area taken on HBF base station site

The present paper aims at a field trial evaluation of the optimum downtilt adaptation and possible SIR improvement in NLOS scenarios of an outdoor deployment area. Therefore a testbed for field evaluations, located in Dresden, has been used (Fig. 1). From the same testbed, already some measurement results with variation of the downtilt have been provided in [4]. The testbed used for investigations consists of the two base stations BS1 and BS2 at the two different sites "HBF" and "Lennéplatz", illuminating the area between them (Fig. 2). The height of the base stations BS1 and BS2 is around 50 m; the average building height of other residential buildings in the surroundings is between 15 and 20 m. The downtilt of the BS antennas can be adjusted electronically from 6° to 15° in steps of 1°. On street level, a test UE mounted on a bicycle rickshaw moves along drive routes and measures the receive power level at various measurement points.

The test UE was equipped with two dipole antennas placed about 40 cm apart on a rotation table that was mounted on top of a measurement rickshaw. The measurement hardware enabled the estimation of the channel transfer function (CTF) via reference symbols (RS) that are transmitted twice every ms (in every slot) for each antenna on every sixth orthogonal sub-carriers over a bandwidth of 20MHz. To guarantee sufficient averaging of small scale fading, data from five different antenna positions was collected at every location using the rotation table. Each measurement was taken for a duration of 30ms. Further details on the measurement procedure are given in [4]. The measurements presented in this paper were done in the downlink. For measurement results that evaluate the impact of downtilt in the uplink in the same testbed we refer the reader to [9].

B. Measurements

Compared to [4], we analyze a larger number of additional measurement points in this paper. The measurement points selected for the investigations were arranged along 4 drive routes as indicated in Fig. 2: Route 1 corresponds to measurement points 22, 1, 23, … 27, Route 2 to 1, 30, … 34, Route 3 is represented by measurement points 6, 7, … 12 and Route 4 by points 9, 28, 13, 29 and 2.

Fig. 2. Testbed in Dresden. © Landeshauptstadt Dresden, Sandstein Neue Medien GmbH (http://stadtplan.dresden.de)

Fig. 3. Rx power level at measurement point 1 from BS 1 and BS 2
Together with some additional singular points a total of 30 measurement points in the area between base station 1 and 2 are taken into account. They were located in NLOS or partial NLOS locations relative to the base stations. Also few LOS points were considered. For all these points the receive power from each base station for each possible downtilt in the range from 6° to 15° has been measured. An exemplary result for measurement point 1 is shown in Fig. 3.

With this data base, for each measurement point the downtilt for maximum receive power can be derived (in the following referred to as "optimum downtilt"). These downtilt values then are compared to the "geometrical downtilt", which corresponds to the angle between horizontal plane and a direct line between base station and UE, without taking into account buildings in between. In addition, the PoC model described in [6] was adapted to the environmental parameters given by the testbed, and the downtilt values predicted by this model are compared to the measured values.

IV. SINGLE CELL ANALYSIS

A. Receive Power vs Downtilt

The diagrams given in Fig. 6 show comparisons of measured and predicted downtilts for the measurement points of the different drive routes. The optimum downtilt is derived from the measurements per point as indicated in Fig. 3. For some points no clear maximum could be identified, due to the limitation of the adjustment range of the antenna. In these cases the downtilt value has been extrapolated. Some of the measurement points are in LOS conditions or partial LOS (pLOS). In Fig. 6 this is indicated with LOS and pLOS, respectively.

B. Comparison with Models

In Fig. 6 for most of the measurement points the optimum downtilt is close to the geometrical downtilt or slightly lower, although the measurement points are located in NLOS areas. The downtilts according to the "propagation over clutter"-model [6], indicated as PoC in Fig. 6 are predicted too low. The reason is probably the fact that the distance between the buildings is rather large compared to the assumption made for the derivation of [6]. But even for the case of route 2, where the optimum downtilt is outside the adjustment range of the antenna, the geometrical downtilt is a good prediction of the extrapolated optimum downtilt. Only for the case of route 2, served from BS 2, the optimum downtilt of points 32 - 34 is lower than the geometrical downtilt and comes close to the PoC prediction. For some LOS and pLOS cases there is the conspicuous effect that the optimum downtilt is much lower than the geometrical downtilt, although this should be the best prediction. This implies that there is not a fully non-obstructed LOS condition, but strong reflections close to the UE in combination with a lower downtilt achieve higher receive power.

A comparison of the measured and the simulated channel power for a range of downtilts at a limited set of locations was given in [4]. Fig. 7 allows an extended evaluation of this aspect and compares measurement and simulation in the complete set of measurements. In the plotted curves the asterisk indicates the geometrical downtilt and the circle the maximum measured receive power, which are in line with the geometrical and optimum downtilt plotted in Fig. 6.

As in [4], the simulated curves were generated according to a simple propagation which assumes LOS and is described by an antenna pattern which is modeled by few parameters. In particular, the vertical channel gain is described by the vertical half-power beam width ($\text{HPBW}_v$), the side lobe level ($\text{SLL}_v$) in [dB] relative to the max gain of the main beam, the electrical downtilt angle $\Phi_{\text{tilt}}$, and the geometrical downtilt:

$$G_v(\Phi_{\text{geo}}) = \max \left( -12 \cdot \left( \frac{\Phi_{\text{geo}} - \Phi_{\text{tilt}}}{\text{HPBW}_v} \right)^2 , \text{SLL}_v \right)$$

Since two different antenna types were used (see [4] for details), $\text{HPBW}_v = 6.2 \text{ dB}$ at BS 1 and $\text{HPBW}_v = 7.5 \text{ dB}$ at BS 2.

Note that this model does not take total transmit power and the horizontal antenna pattern into account. Thus, we normalize the curves that were generated by this model such that the maximum value of the measurement and the simulation are equal. But also the measured values are normalized such that channel power is plotted relative to the strongest link which was measured at BS2 and measurement point 10. In general, we see a strong correlation of measurements and simulations. Typical deviations are about 3dB, larger values occur mostly because of remaining interstream interference which is visible for measurement points where channel power of BS 1 and BS 2 differ by about 25 dB. A detailed comparison of measurements and simulations allows the assessment whether the channel was showing characteristics of a LOS channel. For example, for BS 1 at point 23, 24, 31, 32 there is a coincidence between geometrical downtilt and optimum downtilt in Fig. 6 and the slope of the corresponding receive power versus downtilt curves in Fig. 7. This indicates a LOS-like behavior, even though non of the locations was pure LOS. For BS 2, at point 8, 13, 29, all of which are really LOS locations with Fresnel cell opening of about 70-90 %, Fig. 6 shows slight discrepancies between optimum and geometrical downtilt, which coincides with a different slope of the corresponding curves in Fig. 7. Points 7 and 23 are pLOS and NLOS, but show also good matching between optimum and geometrical downtilt. So it can be stated that in such an "obstructed" LOS environment a free line of sight between BS and UE is not necessarily aligned with pure LOS propagation behavior, and also some links without visible BS behave like LOS. But coincidence of optimum and geometrical downtilt is highly correlated with good matching of the slopes of the corresponding curves in Fig. 7.

V. MULTI-CELL EVALUATION

The variation range of the receive power level depending on the downtilt is important in a cellular system. It defines not only the achievable strength of the wanted signal, but also has impact on the interference power measured in the adjacent cell. So, it is expected that the downtilt adaptation has the potential to improve the signal to interference ratio (SIR) especially at cell edge. To verify this, the SIR at the measurement points in
the area between BS1 and BS2 has been investigated. From the measurement data base for each of the measurement points the resulting SIR values for all possible combinations of downtilts at the two base stations have been calculated. As an example, in Fig. 4 the SIR values for all downtilt combinations at measurement point 1 are shown. High SIR values, especially for measurement points at the cell edge, can be achieved with different downtilt combinations. This calculation uses the idealized assumption that the UE is served always with the best serving BS, i.e. with the BS achieving the highest SIR among all downtilt combinations. In Fig. 4 the serving BS is indicated by the brightness of the colors of each category of BS1 downtilt. The light colors indicate BS2 as serving BS, whereas the dark colors indicate serving BS 1. The maximum SIR is achieved for a downtilt of 12° at BS 1 and 14° at BS 2. Here the serving BS is BS 1. When using BS2 as serving BS, the highest SIR can be realized with downtilts of 6° at both BS.

To assess the SIR improvement capability of downtilt adaptation, the SIR cumulative density function (CDF) over all measurement points has been calculated. The results are given in Fig. 5. As a baseline the cases of fixed downtilts of 8°, 10° and 12° are plotted. The other curves correspond to two different strategies of dynamic downtilt adaptation. First, we consider the case of uncoordinated dynamic downtilt adaptation. Therefore the UE at each measurement point is assigned to the BS and downtilt which achieves the maximum receive power level. At the same time, it is assumed that in the adjacent cell all possible downtilts are applied with equal distribution. Combining all the resulting SIR values in one CDF curve leads to the curve indicated as "uncoordinated DT adaptation". Finally it is assumed that the base stations have full knowledge on the achievable SIRs of all possible downtilt combinations. With this knowledge the UEs at each measurement point are assigned to the BS and downtilts leading to the maximum SIR. It is therefore assumed that the second BS will always find a user to be scheduled with its resulting downtilt. Although this is an artificial assumption, it represents a best case situation showing an upper bound for the achievable SIR CDF over the measurement points in this specific two-cell scenario. This curve is labeled "coordinated DT adaptation".

The comparison of the SIRs shows that with 3D beamforming in combination with appropriate coordination a significant SIR improvement over the fixed downtilt cases can be achieved. Even with uncoordinated cell-individual downtilt adaptation the improvement especially in the lower SIR range reaches 3 dB. With ideal coordination more than 5 dB compared to standard fixed downtilt selections can be seen. Although these CDF curves do not represent the performance of the whole cell, the results clearly show that downtilt adaptation can provide a significant improvement of SIR and user experience for UEs in critical locations like cell edge areas.

Fig. 4. SIR values at measurement point 1 for every possible downtilt combination of BS 1 and BS 2 and best serving BS assumed. In each category "eNB1 =" the light colored bars indicate BS2 as serving BS, the dark colored bars correspond to BS1 as serving BS.

Fig. 5. SIR CDF for fixed and adaptive downtilts

VI. SUMMARY

This paper presents measurements of propagation properties of a mobile radio channel with adaptation of the base station antenna downtilt, which is a valuable database to verify the expected performance of 3D beamforming in an urban multi-cell deployment scenario. The evaluation of the measurements shows the basic behavior of UE receive power when varying the BS antenna downtilt in NLOS and partial LOS locations. In addition, different models for the prediction of the downtilt for the maximum receive power have been compared with the measurements. In the Dresden testbed scenario the geometrical downtilt turned out to be a good prediction, despite of partial LOS and NLOS UE locations, whereas the examined "propagation over clutter" (PoC) model predicted too low downtilt values. The reason therefore is most probably the fact that the BS are located high above rooftop so that only few reflections and diffractions between BS and UE occur. So the angle of departure at the BS is only slightly affected. This characteristic probably differs too much from the intended application scenario for PoC, which assumes smaller BS heights above rooftop. Future measurements in different
scenarios will be required to give more insight in the validity range of these models.

Furthermore, we also analyzed the SIR characteristics for a larger number of UE locations along several drive routes. By using coordinated downtilt adaptation, SIR gains of 5-10 dB were achieved compared to fixed downtilt settings. At the same time the fairness was improved because high gains were achieved at the cell edge. This verifies the increased strength of the wanted signal, as well as interference suppression from the adjacent cell due to downtilt adaptation at the UEs. So the results of our investigations have confirmed the potential for performance improvements with adaptive 3D beamforming.

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REFERENCES


Fig. 6. Comparison of measured optimum downtilt with geometrical downtilt and prediction with PoC model for different measurement routes.
Fig. 7. Comparison of measured and simulated relative channel power (0dB for maximum power measured at point 10 at BS 2) for four different measurement routes.