# Analysis of Multi-Cell MIMO Measurements in an Urban Macrocell Environment

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## ABSTRACT

In this paper we analyze the properties of Multiple Input Multiple Output (MIMO) channels in urban macro-cell environments based on a narrow-band measurement campaign with simultaneous measurements from two sites in the GSM-1800 band. We focus here on bulk parameters such as shadow-fading, angle-spread, and their variation in space and cross-correlation among different sectors. We also look on the dependence between Direction of Arrival and Direction of Departure, (DoA/DoD). Our analysis result shows virtually no cross-site correlation of the studied parameters, while cross-sector correlation is substantial.

## I. INTRODUCTION

Extensive measurements campaigns have been conducted in order to facilitate accurate propagation models for MIMO wireless systems. Most of these campaigns have focused on delivering typical propagation models for the channel behavior on a small scale i.e. for movements of the MS in local areas of some 20-40λ (wavelengths) size. Some exceptions are [1] and [2] where the channel statistics of local areas are summarized using parameters such as angle-spread, delay spread and log-fading. The distribution, spatial autocorrelation and cross-correlation of these parameters are analyzed in [1]. The 3GPP Spatial Channel Model (SCM) [3], uses a model for the statistics of these parameters. In this paper we try to extend this modeling approach by introducing correlation of the correlation of parameters across different Base-Station (BS) sites. In the measurements four directional transmit antennas which point in different directions are used at the Mobile Station (MS). This enables us to study DoA/DoD related properties such as the main received DoA angle and spread at the BS as a function of the MS pointing angle. The results show very little such dependencies which indicates that a single-bounce model is not accurate and that DoA and DoD can be regarded as quite independent. This independency however does not imply that the Kroneceker model is valid.

## II. MEASUREMENT CAMPAIGN

A measurement campaign was conducted in Stockholm city during the summer 2004. The area of the measurements can be characterized as a typical European urban with mostly six to eight stories high stone buildings and occasional higher buildings and church towers. The measurements were done in uplink were the MS transmitted four cosine waves (CWs), separated in frequency by approximately 1 kHz with a nominal carrier frequency of 1766.6 MHz, on four separate transmit (Tx) antennas. The four MS antennas are slanted patch with a half-power beam-width of 80-degrees which point in different directions offset 90-degrees from each other as seen in Fig.1 and 2. In this picture we have numbered the antennas to show their pointing direction relative the MS moving direction. This setup enables us to study correlation between DoA and DoD. When combining the information from all Tx antennas we can get a virtual omni-directional antenna, which is useful when evaluating the cross site correlations of bulk parameters. With the antennas pointing in different directions, one can assume that the fast-fading of the four channels would be independent as they will illuminate different scatterers.

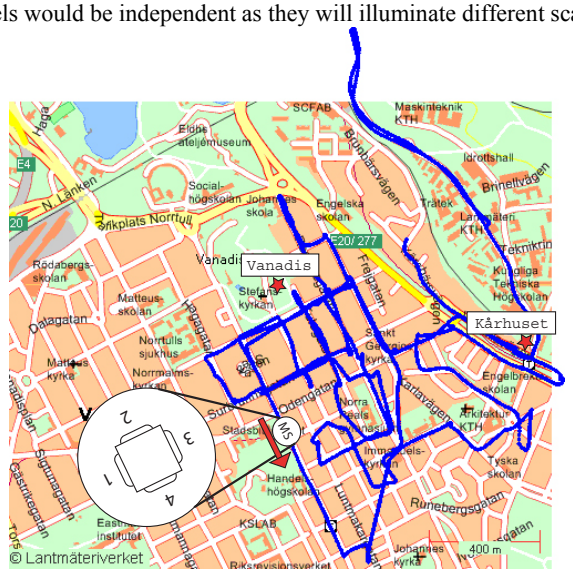


**Fig. 1. Measurement geography, and traveled route**

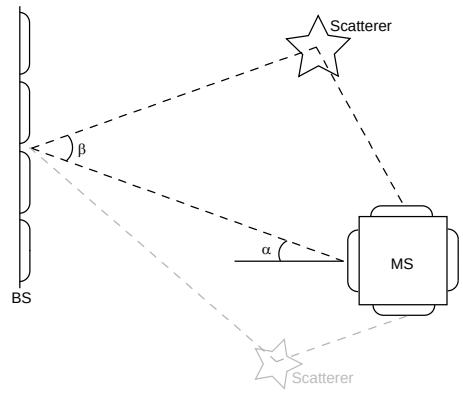


**Fig. 2. Antenna setups**

This assumption has indeed been confirmed by the measurements as shown in Section V. The CWs of the transmit antennas are not frequency locked and therefore an unknown phase-offset in the four vector channels between the mobile-station and one base-station (BS) will result. However, this is no loss of information as the fading of the four antennas is independent. The signals transmitted by the four antenna MS are received by two base-stations (BSs) simultaneously, down-converted to complex IQ base-band and saved on hard-disc. Both BSs are named after their geographical position see Fig.1. The blue lines display the route of the MS, and is the positioning as received from a GPS. One of the base-stations (Kårhuset-A) has four antennas in a uniform linear array (ULA) configuration, and is placed on a roof barely above the average building height in its sector of coverage. The other base-station has two four antenna ULAs connected (Vanadis-B and Vanadis-C) and is placed on a roof some ten meters above the average building height. The two arrays are located on different edges of the same building some 20-meters from each other and offset 120-degrees in pointing direction. Trees are located in front of Vanadis-B which may have an impact on the propagation. The distance between the two sites is 900m and the measurements were done with the mobile located in the area between the two BSs. The total measurement covers about 15km of mobile trajectory, and the route covered is shown in Figure 1. In addition to this, some cases where the mobile-station was stationary have also been measured. The path-loss slope in Kårhuset was estimated to be around 40- 45dB/dec while it is 25-30dB/dec at Vanadis location. Further information about the measurement campaign as well as photos of the measured area and antennas can be found in [4]. For abbreviation we refer to the BS sectors (antenna arrays) by their specific letter, i.e. for short Vanadis-C will be called BS-C.

## III. ESTIMATION OF SHADOW FADING

In this section we study the shadow fading component and its correlation between sectors and sites. The path loss is usually modeled as [5].

$$Pl(dB) = Pl_o(dB)+10log_{10}(d/d_o) + S(dB) \quad (1)$$

where $S(dB)$ is the random shadow fading component, d0 is a reference distance and d is the distance between the MS and BS. Using this the received power can written as,

$$P_{Rx} = P_{Tx} + G_{Rx} + G_{Tx} - Pl - X \quad (2)$$

Where $P_{Rx}$, $P_{Tx}$ is the power at transmitter and receiver respectively, $G_{Rx}$, $G_{Tx}$ is the gain and $X$ is the fast fading due to multipaths. Thus, we can calculate the large scale (shadow fading) variation by averaging signal power over segments of 30λ, where we assume the fast fading is zero-mean, and remove the path loss due to the distance separation between MS and BS. The distribution of the shadow fading component is usually modeled as a zero-mean Gaussian variable with environment specific standard deviation, and this is indeed confirmed by our measurements. The shadow fading is verified to be zero-mean, and has a standard deviation of 5.0, 5.6, 4.9 and 5.3 for Tx antennas 1 to 4 respectively and N(0,5.1) for the omni-directional antenna, evaluated at Vanadis-B.

### *A) Correlation of the Shadow Fading*

In this section we look at the autocorrelation function of the Shadow fading. This quantity tells us how fast the shadow fading parameter changes with MS traveled distance. The correlation is evaluated in steps of 5m which is roughly 30λ of trajectory. In Fig.3 we can see the shadow fading auto correlation for the link between the MS and BS-B for all TX antennas as well as the mean, which is the same as the omni-directional antenna. The main reason for studying sector B is because it contains the largest amount of measurement points.

The plot also contains the auto correlation function of an AR(1) process that drops to $e^{-1}$ in 55m as a reference. $e^{-1}$ is a common value for the decorrelation distance, and describes how fast the process varies. Another interesting aspect to observe is the cross site correlation of the Shadow Fading. Here we analyze the correlation of the Shadow Fading parameter between the two sites, Vanadis and Kårhuset. There is no clearly defined way of how to analyze this quantity. One straight forward ways is to analyze

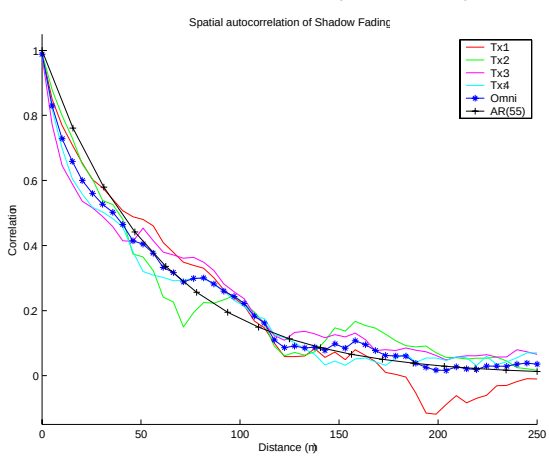


**Fig. 3. Autocorrelation of Shadow fading for links between MS and BS-B**

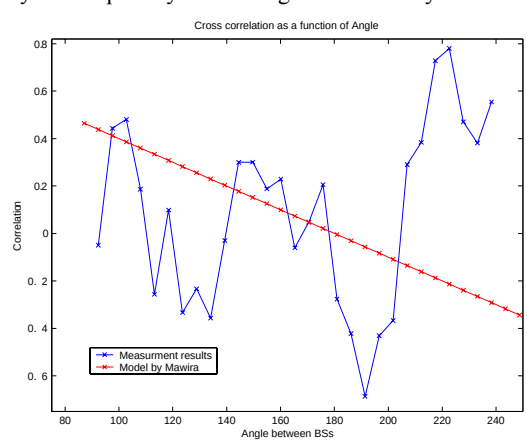


**Fig. 4. Cross-site correlation of Shadow Fading as a function of angles betwwn sites A and B.**

the cross-site correlation as a function the angle between the two base stations as seen from the MS. In [2] this particular dependency is studied and the correlation is experimentally found to follow the formula 0.9-|θ|/200, where θ is the angle between the two sites. Fig.4 shows this correlation calculated from our measurements and the value calculated by the formula from [2] for the same angles. As can be seen, our measurements do not fit the proposed model. One of the reasons for this can be the difference in determining the path-loss, where we do a linear fit to the measured data, whereas the author to [2] base the loss on a Hata-model. another reason could be a lack of measurement samples for some of the angles and/or the difference in site geography and the wide angle between the sites.

## IV. ESTIMATION OF AZIMUTH SPREAD AT THE BS

Consider a scenario having N rays with azimuth DoD, $\Phi_k$ and relative power $\tilde{p}_k$ where k=1,2,…,N We define the (power-weighted) azimuth spread, $\sigma_{AS}^2$ as in (4), where the mean angle $\bar{\theta}$ is given by:

$$\bar{\theta} = \sum_{k=1}^{N} \tilde{p}_k \theta_k \tag{3}$$

$$\sigma_{\mathrm{AS}}^2 = \min_{\bar{\theta}} \sum_{k=1}^{N} \tilde{p}_k \left(\theta_k - \bar{\theta}\right)^2 \tag{4}$$

To calculate the azimuth-spread from the narrowband data, we first estimate the beamforming gain with a steered directional beam. Then we obtain the angle-spread from a look-up table. Validation of this method showed that the method is an underestimate [4], but still gives a good indication of the angle-spread. Using this method the angle spread for all BSs is calculated for each of the MS antennas and for the combination of all MS antennas to get one virtual omni-directional element. The results can be seen in Table I.

| | **Kårhuset-A** | | **Vanadis-B** | | **Vanadis-C** | | |
|---|---|---|---|---|---|---|---|
| Antenna | Mean | Std | Mean | Std | Mean | Std | Antenna |
| 1 | 1.03 | 0.23 | 0.77 | 0.22 | 0.80 | 0.24 | 1 |
| 2 | 1.05 | 0.24 | 0.79 | 0.25 | 0.89 | 0.26 | 2 |
| 3 | 1.03 | 0.21 | 0.80 | 0.21 | 0.83 | 0.22 | 3 |
| 4 | 1.05 | 0.24 | 0.78 | 0.22 | 0.88 | 0.25 | 4 |
| Omni | 1.06 | 0.21 | 0.80 | 0.23 | 0.85 | 0.25 | Omni |

**Table I. Angle Spreads at the BS sites**

### *A) Autocorrelation of the Angle Spread*

To get information about how fast the Angle Spread varies at the BS as the MS moves along it's route we evaluate the autocorrelation of the Angle Spread as a function of traveled distance. Shown in Fig.5 is the estimated autocorrelation function of the Angle Spread at BS-B for all Tx antennas and the combined omni-directional antenna. The decorrelation distance for the Angle spread is 60 meters which is roughly the same as for the shadow fading. However, the curve is descending faster short distances which point towards faster variations. The autocorrelation for sites A and C are very similar.

### *B) Cross correlation of the Angle Spread*

We evaluate the cross site correlation of the angle spread both as a function of the angle between the two sites and as an average value over all the measurements. For the cross site correlation between BS site A and B the correlation is close to zero, thus no correlation can be found. For the cross-sector evaluation, for BS site B and C, we find a correlation of 0.4.

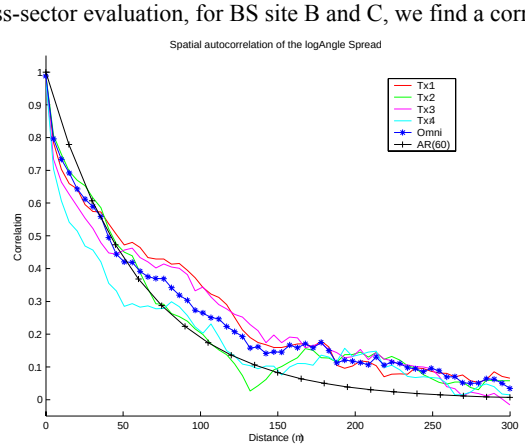


**Fig. 5. Autocorrelation of the Angle Spread**

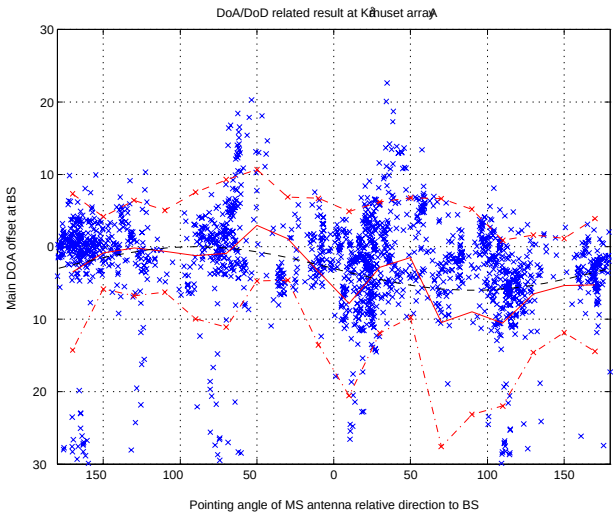


**Fig. 6. Dependencieas of α and β at Kårhuset-A**

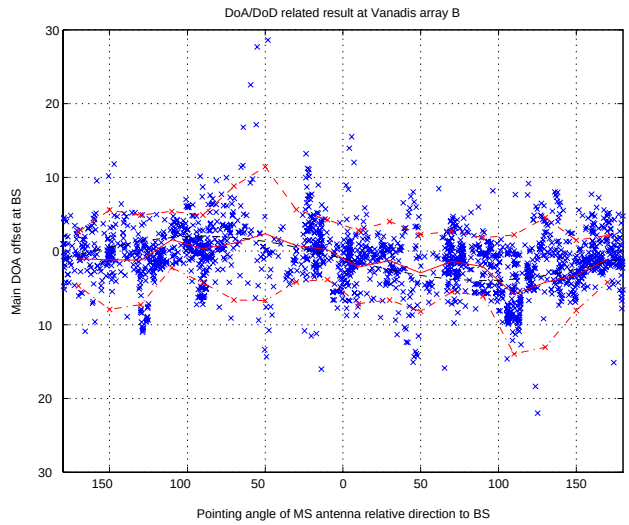


**Fig. 7. Dependencies of α and β at Vanadis-B**

## V. MAIN DOA AS A FUNCTION OF THE MS ANTENNA POINTING DIRECTION

The measurement setup with four antennas offset 90$^o$ from each other facilitated evaluation of different parameters as a function of the MS antenna pointing angle. In this section we look at the main DoA as a function of the MS antenna pointing angle. Consider the setup in Fig.1. We define the angle α to be the angle between the MS and the BS, and the angle β as the offset in angle between the true direction to the MS and the estimated DoA for the signal. If a one-bounce model is assumed for this scenario, a negative angle α would yield an positive β and vice versa. Fig.7 and 8, show β as a function of α for the two measurement sites A and B. On the x-axis we have the pointing angle of the MS antenna and on the y-axis we have the main DoA offset calculated at the BS. To these measurement data we have fitted a sine function to show the tendencies of correlation between α and β. As we can see the data shows very small such dependencies, and thus we can draw the conclusions that a one-bounce model is not valid for explaining the measurement scenario. We may also note, as previously known, that there is less offset in the estimated DoA at Vanadis, than at Kårhuset, due to the elevation above surrounding buildings.

## VI. CONCLUSION

Herein an extension to the model presented in [3] is proposed, where correlation between model parameters is introduced. The data analyzed was collected in an extensive measurement campaign conducted in 2004 using a narrowband transmitter MS, in the GSM-1800 band, and two receiving BS spatially separated. The result presented in this report shows almost no cross-site correlation between the analyzed parameters. One reason for this might be the large separation in angle between the two sites as seen from the MS. For correlation in these parameters to exist the two channels from different sites need to share more common paths. Another reason could be the difference in heights and surrounding geography of the two BSs.

## VIII. ACKNOWLEDGEMENTS

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