# Analysis of MIMO Multi-Cell Correlations and Other Propagation Issues Based on Urban Measurements

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***Abstract*—In this paper we analyze properties of Multiple-Input Multiple-Output (MIMO) channels in urban macro-cell environments based on a narrow-band measurements campaign with simultaneous measurements from two sites. We investigate joint properties of log-fading, angle-spread, and angular propagation at the Mobile-Station (MS). Furthermore, results related to the joint distribution of Direction of Arrival/Departure (DoA/DoD) and the Kronecker model is also presented.**

## 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 20-40 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 SCM model, [2], uses a model for the statistics of these parameters in a first step before randomizing the detailed channel realization in a local-area in a second step. In this paper we try to extend this type of modeling by bringing the correlation of the parameters across different Base-Station (BS) sites. However, the results show virtually no correlation – a result which may have to do with the locations of the sites and the measurement points as is discussed in Section VIII.

In the measurements four directional transmit antennas which point in different directions are used at the mobile-station. 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 dependences which indicates that a single-bounce model is not correct and that DoA and DoD can be regarded as quite independent. However, our results at the same time shows also that the Kronecker model give poor results which mean that separation of the DoA and DoD angular distributions should be interpreted in an average sense.

## II. MEASUREMENT CAMPAIGN

A measurement campaign was conducted in the Vasastan area of Stockholm city. The area 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 direction with a mobile-station transmitting four separate Cosine Waves (CWs) on four separate antennas with a frequency separation of approximately 1 kHz and a nominal carrier frequency of 1766.6MHz. The four MS antennas are slanted patch with a half-power beam-width of 80-degree which point in four different directions offset 90-degrees from each other. This should mean that the fast-fading of the four MS antennas should be independent as they illuminated different scatterers. This assumption has indeed been confirmed by the measurements. 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 will result. However, this is no loss of information as the fading of the four antennas is anyway independent. The signals transmitted by the four antenna MS are received by two base-stations, down-converted to complex I&Q base-band and saved on hard-disc. One of the base-stations (Kårhuset-A) has a four element antenna array and is placed on a roof barely above the average building height in its sector of coverage, see Figure 1. The other base-station has two four antenna arrays connected (Vanadis-B and Vanadis-C) and is placed on a roof some ten meters above the average building height, see Figure 2. 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. In front of Vanadis-B are some trees 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 BS. The path-loss slope in Kårhuset was estimated to be around 40-45dB/dec while it is 25-30dB/dec in Vanadis. The total measurement covers about 15km of mobile trajectory. In addition to this, some cases where the mobile-station was stationary has also been measured.

**Figure 1: View of "Kårhuset-A" Base-Station.**

**Figure 2: View from "Vanadis-B" Base-Station.**

## III. Estimation of Azimuth Spread at the Base-Station

In a scenario with N rays having azimuth direction of departures (DoDs), $\theta_k$ and powers $\tilde{p}_k$ (normalized to the total power) we define the (power-weighted) azimuth spread, $\sigma_{\mathrm{AS}}^2$, as

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

The azimuth-spread is estimated from the received narrow-band data by first estimating the gain with a steered directional beam and then obtaining the angle-spread from a look-up table (this method was also applied above). To validate the method we start by showing some results when applying the method to data generated from the WINNER implementation of the SCM model [2], using the urban setting with eight degrees BS angle-spread setting. The number of antennas at the base-station was set to four, with element diagrams and spacing to match that of the measurement system. The true versus the estimated angle spread are shown in Figure 3. Figure 4 and Figure 5 show histograms of the true and estimated angle-spread distributions using the eight and fifteen degree angle-spread setting of the urban SCM model. As the figures show the estimator has a tendency to under-estimate the angle-spread. However, it still serves to give a good indication of the angle-spread.

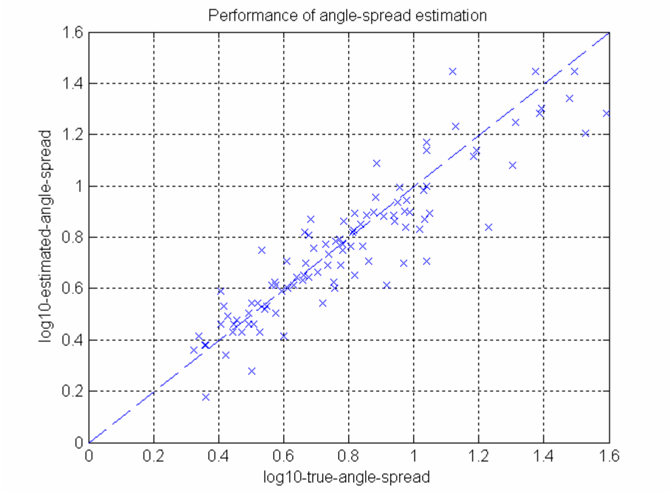


**Figure 3: Performance of the angle-spread estimator on the SCM model**

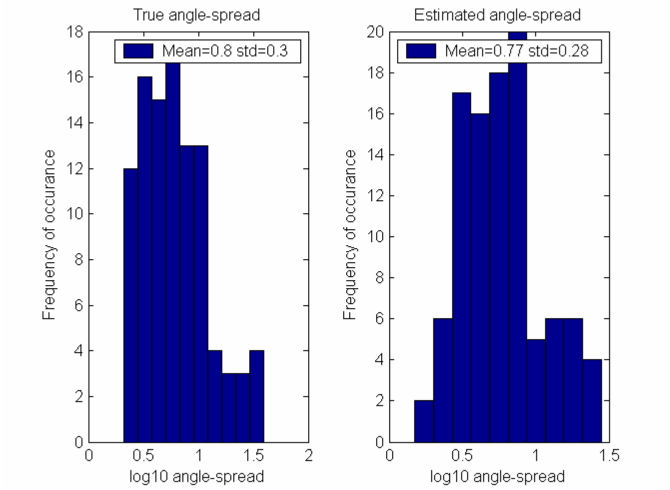


**Figure 4: Comparison of estimated and true angle-spread distribution with SCM angle-spread parameter set to ``eight''.**

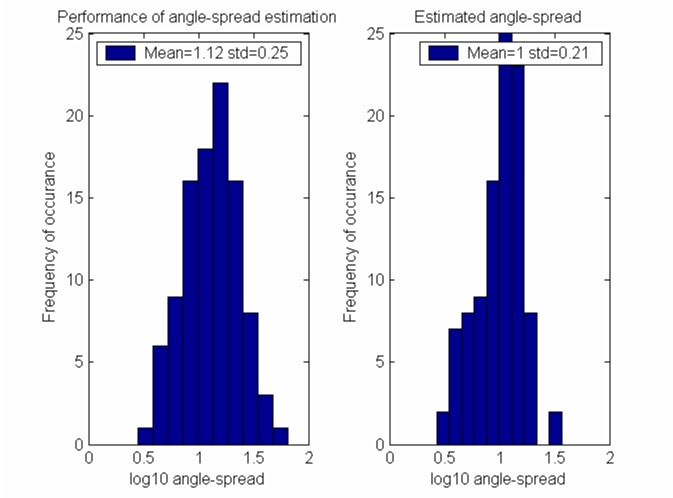


**Figure 5: Comparison of estimated and true angle-spread distribution with SCM angle-spread parameter set to ``fifteen''.**

The azimuth spread estimation method is applied to the data. This can be done using any of the four MS antennas or using the data from all MS antennas together which corresponds to the use of an omni-directional MS antenna. The obtained azimuth spread distributions can be well modeled as log-normal. The mean and standard-deviation of the log-angle-spread are listed in Table 1 below. From the table we note that the results for Kårhuset and Vanadis are very similar to the urban version of the SCM model, [1], with angular spread setting eight and fifteen degrees, respectively.

| Array | MS antenna | Mean | Standard Deviation |
|---|---|---|---|
| A | 1 | 1.03 | 0.23 |
| A | 2 | 1.05 | 0.24 |
| A | 3 | 1.03 | 0.21 |
| A | 4 | 1.05 | 0.24 |
| A | All | 1.06 | 0.21 |
| B | 1 | 0.77 | 0.22 |
| B | 2 | 0.79 | 0.25 |
| B | 3 | 0.80 | 0.21 |
| B | 4 | 0.78 | 0.22 |
| B | All | 0.80 | 0.23 |
| C | 1 | 0.81 | 0.24 |
| C | 2 | 0.89 | 0.26 |
| C | 3 | 0.83 | 0.22 |
| C | 4 | 0.88 | 0.25 |
| C | All | 0.85 | 0.25 |

**Table 1: Table of the mean and standard-deviation of log angle-spread.**

## IV. Correlation of Log-Fading and Angle-Spread Between Site and Sectors

The log-fading based on the four MS transmit antennas, as well as combing all MS transmit antennas together to form a basically omni-directional antenna, has been calculated. The correlation of the log-fading is shown in Table 1 below. The correlation between Sector A and C has been excluded as it contains much less data than the correlation between Sector A and B. The cross-site correlation (A and B) is virtually very small while it is substantial for the cross-sector (B and C) measurement although not full.

| | MS Antenna | | | | |
|---|---|---|---|---|---|
| Sectors | 1 | 2 | 3 | 4 | All |
| A & B | 27% | 7% | 9% | -9% | 10% |
| B & C | 86% | 77% | 84% | 77% | 84% |

**Table 1: Correlation of log-normal fading.**

The correlation of the angle-spread results is shown in Table 2. The correlation of the angle-spread is virtually zero between the sites and very small between the sectors.

| | MS Antenna | | | | |
|---|---|---|---|---|---|
| Sectors | 1 | 2 | 3 | 4 | All |
| A & B | 3% | -2% | -5% | -19% | -3% |
| B & C | 25% | 17% | 24% | 26% | 34% |

**Table 2: Correlation of angle-spread.**

The reason for the non-full correlation between the sectors of the same site (B & C) we believe is primarily due to the difference in base-station antenna pattern differences between the two sectors and secondly because the two sectors are mounted 20-meters apart. Note that the sector cross correlation is evaluated in an angular segment of width 20-degrees where the element patterns are oscillating. If the sectors had been more closely located and pointing in more similar directions we believe the correlation would be full. The correlation between A and B sectors was evaluated mostly in the main beam of the two sectors.

In [3] the correlation between sites of the log-normal fading is experimentally found to be given approximately by 0.9-$|\theta|$/200, where $\theta$ is the angle between the two base-stations as seen from the mobile station. For this measurement campaign this would correspond to on average a correlation coefficient of 40%. However, the correlation herein is much lower.

## V. Comparison of Strongest Beam at MS Between Sites and Sectors

Even if the properties at the base-stations are different it could be theorized that the channels at the mobile-stations were similar, for instance if the same scatterers are active in both connections. This property was investigated by indicating on map where the same mobile-station antenna is strongest (summed over all receive (BS) antennas) for the links to sector

A and B (i.e. different sites) in Figure 6 below. The results show no indication of any correlation. The corresponding plot for the cross-sector correlation is shown in Figure 7. The cross-site results in Figure 6 show no correlation. The same antenna was selected in only 29% of the cases. In fact, since not every antenna is selected with equal probability (probably due to unintended differences in tilt angle and reflections from the car), the 29% is consistent with completely uncorrelated antenna selection. In Figure 7 the cross-sector results are shown. Here, the correlation for distances larger than 300meters or so is almost full. The differences close to the base-station may be due to the 20meter distance between the two sector antennas.

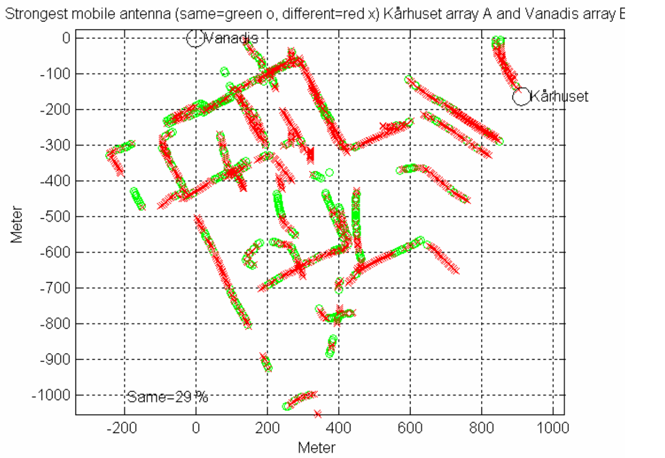


**Figure 6: Illustration of where the same MS antenna is the strongest in sector A and B (which are on different sites).**

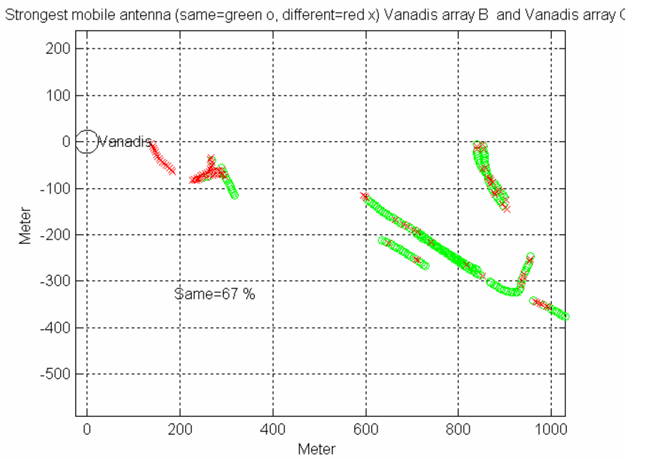


**Figure 7: Illustration of where the same MS antenna is the strongest in sector B and C (different sectors on same site).**

## VI. Main DOA offset as a function of MS of Antenna Pointing Angle

The main DoA direction is estimated for each local area by means of beamforming (the pointing direction in which the most energy is received). Since there are four mobile antennas four estimates are available from each of the mobile-station transmitting locations. Here we investigate the dependence between the pointing angle of the four mobile station antennas relative the direction of the base-station, $\alpha$, and the DOA of the incoming signal $\beta$, relative the geographical angle, $\alpha$, of the mobile, see Figure 8. The angle $\beta$ is obtained by combining the estimated main DOA and the GPS information, while $\alpha$ is obtained from the GPS information together with knowledge of the direction of travel and the mounting of antennas on the vehicle.

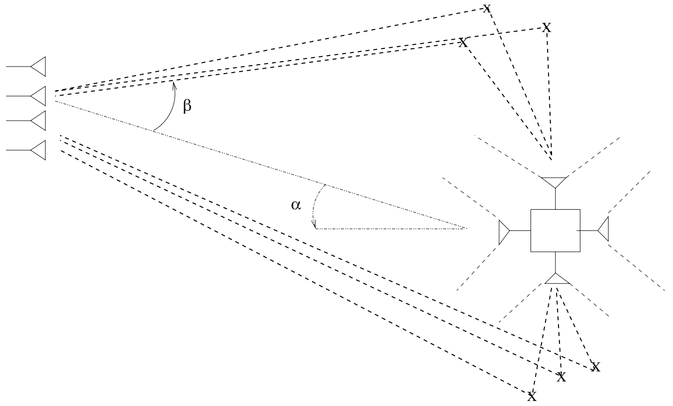


**Figure 8: Illustration of the dependence between the pointing angle of the MS antenna (relative direction of BS) and the main DOA at the base-station.**

If a once-bounce model is valid, as indicated in the figure, then a positive $\alpha$ should imply a negative $\beta$. To investigate this conjecture Figure 9 and Figure 10 where generated where the x-axis of each 'x' marks the pointing direction of an MS antenna, $\alpha$, and the y-axis the main DOA offset $\beta$ estimated at the base-station (not all points are included to increase clarity). Also included are the mean of the DOA offset values $\beta$ as a function of the MS-antenna pointing angle $\alpha$, and the mean of this curve, and curves indicating the range of plus minus one standard deviation. In addition, a sinusoid curve has been fitted. The results show that there is a *very small* tendency of the effect indicated by Figure 8.

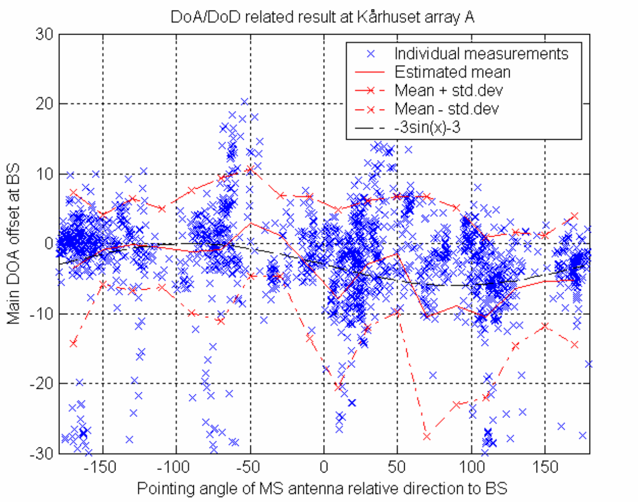

**Figure 9: Main DoA offset at the BS site Kårhuset as a function of the MS pointing angle.**

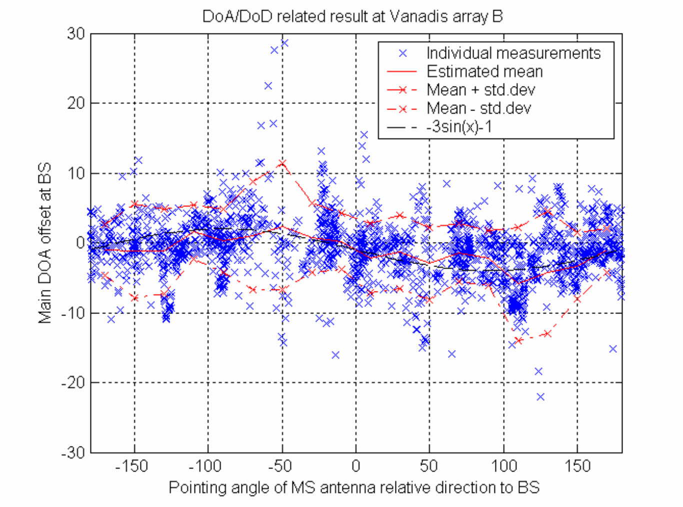


**Figure 10: Main DoA offset at BS site Vanadis as a function of the MS pointing angle.**

A related measure is the probability that the MS antenna pointing most directly towards the base-station has the smallest DOA offset when received at the base-station. This probability is found to be around 20%. These two statistics indicate that the *very* long-term DoD and DoA distributions may be modeled as independent. This should not be confused with the Kronecker model being valid as it operates on a shorter term. The correlation of the DoA offset between antennas is found to be 0-50%.

The angle-spread at the base-station was also investigated as a function of mobile-station antenna pointing angle and found independent. The probability that the antenna pointing mostly to wards the base-station should have the smallest angle-spread was found to be 28% at Kårhuset and 41% at Vanadis. In the Vanadis case this is a significant result. This is somewhat surprising in the light of the small (or practically non-existing) average spread versus MS pointing angle dependence. Therefore this dependence is also not worthwhile modeling. The correlation of angle-spreads among the MS antennas is found to be 26-55% at Kårhuset and 50-70% at Vanadis.

## VII. Applicability of Kronecker Model

The Kronecker structure based MIMO channel model is a popular model for indoor Non Line of Sight (NLOS) environment. In this section, we investigate the model error of the Kronecker structure based on the outdoor NLOS MIMO channel measurements. The measured data has been segmented in order to study the local statistics of outdoor MIMO channels. We have calculated the model error of the Kronecker structure of MIMO channel covariance matrix. Given MIMO channel matrices, $\mathbf{H}$, of dimension 4x4, the MIMO channel covariance matrix $\mathbf{R}_{\mathbf{H}}$, the transmit and receive covariance matrices $\mathbf{R}_{\mathrm{TX}}$ and $\mathbf{R}_{\mathrm{RX}}$ are estimated as described in [5].

The model error $\psi$ is defined and evaluated the difference between $\mathbf{R}_{\mathbf{H}}$ and $\mathbf{R}_{\mathrm{RX}} \otimes \mathbf{R}_{\mathrm{TX}}$ in a normalized Frobenius sense i.e.

$$\psi\left(\mathbf{R}_{\mathbf{H}}, \mathbf{R}_{\mathrm{RX}} \otimes \mathbf{R}_{\mathrm{TX}}\right) = \frac{\left|\mathbf{R}_{\mathbf{H}} - \mathbf{R}_{\mathrm{RX}} \otimes \mathbf{R}_{\mathrm{TX}}\right|_{\mathrm{F}}}{\left|\mathbf{R}_{\mathbf{H}}\right|_{\mathrm{F}}}.$$

For the measured 4x4 MIMO channel realizations, it is found that the mean values of model errors are 19%, 20%, and 25% for sector A, B and C respectively. Thus the Kronecker model does not apply very well. Other results that also points to deficiencies of this model can also be found in [4]. The independence between the angular distributions at the MS and BS of previous section should be regarded as an average over many realizations.

## VIII. Discussion

The results showed surprisingly little evidence of cross-correlation between various properties between sites. For such correlations to exist, the sites may have to be at similar heights, distances and directions from the mobile so that many obstacles are in common.

The results of the paper indicate that the long term joint properties of the angular distributions at the base- and mobile-station are independent. However, for a given local-area this does typically not apply and the Kronecker model does therefore not fit well to the measurements.

## IX. Acknowledgement

This work has been performed in the framework of the IST project IST-2003-507581 WINNER, which is partly funded by the European Union.

## X. REFERENCES


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