# Cross Correlation Characteristics of Large Scale Parameters in Urban Macro Cell

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*Abstract*—Extensive analysis of channel measurement data for the investigation of new channel models plays a fundamental role in designing and evaluating wireless communication systems. Besides the knowledge of the parameters and their distribution functions, the cross correlation between them is of great interest and can be exploited for more realistic channel simulations. In this contribution the cross correlation characteristics of the large scale parameters (LSP) in the power and delay domain are investigated. Different parameter estimation procedures are applied taking the spatial filtering due to directional antennas into account or neglecting it. Various distance ranges between base station (BS) and mobile station (MS) as well as different antenna heights are considered.

Index Terms—Channel Sounding, Channel Modeling, Parameter Estimation

# I. INTRODUCTION

The modeling of the mobile radio channel is indispensable for the development of new wireless communication systems. Recent channel models like COST [1] and WINNER [2] belong to the geometry based stochastic channel models which describe the channel by small and large scale parameters (LSP). It is not only necessary to analyze the values and the distribution of these parameters but it is also essential to take their de-correlation distance and the cross correlation coefficients into account. Especially the last named property is important for analyzing the joint behavior of the parameters. General results for this aspect can already be found amongst others in [2], [3] or [4]. However it is important to analyze on which conditions these statistics are dependent on, e.g., the antenna setup and the associated parameter estimation procedure, the propagation condition or the distance between the base station (BS) and the mobile station (MS) as well as the antenna height. In this contribution the cross correlation characteristics of the LSPs in the power and delay domain, which includes delay spread (DS), shadow fading (SF), narrowband K-factor as well as the horizontal (h) and vertical (v) cross polarization ratio (XPR) are investigated with regard to different parameter estimation procedures, to various distance ranges as well as to different base station antenna heights. Due to the fact that a circular array with directional antennas (patch elements) was used at the MS and that the channel sounder provides the possibility to switch the automatic gain control

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(AGC) for each MIMO channel within one snapshot, these AGC values, which are quantized in steps of 3 dB can be used to group the MIMO channels corresponding to the same value. This entails individual noise cutting levels for each group and hence, channel contributions with only low power can be held. Then the LSPs are calculated separately for each group. It is investigated if this is necessary or if it is sufficient to take the conventional way for the estimation procedure as it is used in WINNER [2]. Furthermore the dependency of various distance ranges between MS and BS as well as different antenna heights on the correlation coefficients is analyzed following [6].

# II. MIMO CHANNEL MEASUREMENT CAMPAIGN

Our MIMO channel measurement campaign focuses on gathering realistic channel data in an urban macrocell environment in the 3GPP Long Term Evolution (LTE) band. The channel sounding is performed at 2.53 GHz in a band of  $2 \times 45$  MHz with the RUSK TUI FAU channel sounder [7]. To allow high resolution path parameter estimations, dedicated

|                                    | GENERAL PROPERTIES                                   |                           |  |  |  |  |
|------------------------------------|--|---------------------------|--|--|--|--|
| Scenario                           | Urban macrocell                                      |                           |  |  |  |  |
| Location                           | City center, Ilmenau, Germany                        |                           |  |  |  |  |
| Measurement setup                  | 3 BSs, 1 re  | elay station,             |  |  |  |  |
| ĩ                                  | 22 track   | s, MIMO                   |  |  |  |  |
| Intersite distances                | BS 1-2: 680 m,                                       | BS 2-3: 580 m,            |  |  |  |  |
|                                    | BS 3-1   | : 640 m                   |  |  |  |  |
| CHAN                               | INEL SOUNDER PROPERTI                                | ES                        |  |  |  |  |
| Туре                               | RUSK TUI-FAU   | J, Medav GmbH             |  |  |  |  |
| Transmit power @ PA                | 460  | 1Bm                       |  |  |  |  |
| Center frequency $f_c$             | 2.53   | GHz                       |  |  |  |  |
| Bandwidth                          | 2x45   | MHz                       |  |  |  |  |
| Time sample spacing $T_s$ 13.1 ms  |  |                           |  |  |  |  |
| Frequency sample spacing $F_s$     | 156.25 kHz   |                           |  |  |  |  |
| MIMO sublinks                      | 928 ( $N_{\rm TX} = 16, N_{\rm RX} = 58$ )           |                           |  |  |  |  |
| AGC switching                      | In MIMO sublinks                                     |                           |  |  |  |  |
| Positioning                        | Odometer and GPS                                     |                           |  |  |  |  |
|                                    | ANTENNA PROPERTIES                                   |                           |  |  |  |  |
|                                    | TX array   | RX array                  |  |  |  |  |
| Туре                               | PULPA8   | SPUCPA 2x12               |  |  |  |  |
|                                    |  | + MIMO-cube               |  |  |  |  |
| Height                             | 25 m, 15 m   | 1.9 m                     |  |  |  |  |
| Beamwidth, azimuth (3dB)           | 100°   | 360°                      |  |  |  |  |
| Beamwidth, elevation (3dB)         | 24°  | 80°                       |  |  |  |  |
| Tilt                               | 5° down  | 0                         |  |  |  |  |
| Maximal velocity  v <sub>max</sub> | 0  | $\approx 10 \text{ km/h}$ |  |  |  |  |
| Polarization                       | vertical (v), horizontal (h) vertical (v), horizonta |                           |  |  |  |  |

TABLE I Measurement setup

antenna arrays are used at the transmitter (Tx) and the receiver (Rx). On the Tx side (base station) a uniform linear array is used with 8 dualpolarized (h/v) elements, each of which consists of a stack of 4 patches in order to form a narrow transmit beam in elevation. At the mobile station (passenger car) a circular array with 2 rings of 12 patches with h/v polarizations is used. Additionally, a MIMO cube with 5 elements is placed on top. For each of the tracks and for each measured snapshot, geo-data information based on GPS, odometer and separated distance measurements via laser is available. Additionally we used automatic gain control (AGC) for each antenna patch within one MIMO snapshot. In total the measurement campaign covers 3 base station positions with a height of 25 m and 15 m. The intersite distance between the base stations is found to be for BS1-BS2 = 680 m, BS2-BS3= 580 m and BS3-BS1 = 640 m. More than 20 individual tracks with more than 120 measurement runs (including nonline-of-sight (NLOS) and line-of-sight (LOS)) have been performed. A typical length of a track is 50 m-70 m. The distance for NLOS ranges from 68 m-628 m for the antenna height of 25 m and 228 m-628 m for 15 m base station height. In the LOS case the distance for the antenna height of 25 m and 15 m varies from 68 m-521 m and from 245 m-345 m, respectively. Table I summarizes the measurement properties. For more information about the measurement campaign we refer to [8] and [9].

# **III. ESTIMATION PROCEDURES**

A circular array with directional antennas at the MS and AGC switching for each MIMO subchannel within one snapshot has been used. This leads to a higher directional resolution for high resolution multipath parameter estimations like RIMAX [10]. Additionally, this provides more precise measurements because of holding all the dynamic of the channel and therefore having a better quality of the data. This is caused by the fact that, if the different AGC values are used to group the MIMO channels with regard to the same AGC values, the calculated cutting levels (CL) of the following noise reduction depend on the dynamic of each individual group. Thus also low power contributions of the channel can be held and this results in a better quality of the data. Is it necessary to take these aspects into account or is it sufficient to estimate the parameters on the conventional way, i.e., without any grouping? This question leads to two main approaches for the large scale parameter estimation. The first one, taking the quasi directional dependent information into account, utilizes the different AGC values (which are quantized in steps of 3 dB) of the channels to group the

| An alarsta Mada al                     | AGC       | Maximum       | Individual    | Quality   |  |
|--|-----------|---------------|---------------|-----------|--|
| Analysis Method                        | dependent | Cutting Level | Cutting Level | Threshold |  |
| GRageCLmax                             | ×         | ×             |               |           |  |
| GR <sub>no</sub> CL <sub>max</sub>     |           | ×             |               |           |  |
| GR <sub>no</sub> CL <sub>ind</sub>     |           |               | ×             |           |  |
| GR <sub>agc</sub> CL <sub>max</sub> QT | ×         | ×             |               | ×         |  |
| GR <sub>no</sub> CL <sub>max</sub> QT  |           | ×             |               | ×         |  |
| GR <sub>no</sub> CL <sub>ind</sub> QT  |           |               | ×             | ×         |  |

 TABLE II

 Overview of the different analysis procedures

measured data. This results in individual noise cutting levels for each group and holds all the dynamic of the channel. Then the parameters are calculated separately for each group with the same AGC value (denoted by  $GR_{agc}$ ). The second approach which calculates the parameters over all channels at once (denoted by  $GR_{no}$ ) neglects this additional information.

Furthermore, two different ways of estimating the CL for the noise reduction from the data is introduced. On the one hand a maximal CL (denoted by CL<sub>max</sub>) is considered for each AGC group or for all channels, respectively, and on the other hand a threshold for each individual channel is estimated, which is the same for the grouping or the non-grouping method (denoted by CL<sub>ind</sub>). An additional aspect is the influence of a 20 dB quality threshold (QT) on the cross correlation values (denoted by QT if used). That means only the 20 dB below the maximum peak of the power profile is considered. Altogether 6 different estimation procedures are presented and results in 6 different power delay profiles (PDP). An overview of all the procedures is presented in table II. Based on these PDPs the corresponding values for the LSPs are estimated. The calculation steps are the same considering the grouping or the non grouping method. For a detailed description of the estimation of the considered parameters the reader is referred to [6] and [5].

# IV. DISTANCE RANGES AND ANTENNA HEIGHT

The influence of the distance between the MS and the BS and of the antenna height of the BS on the cross correlation coefficients is investigated following [6]. Three different distance ranges (60 m-200 m, 200 m-400 m and 400 m-640 m) as well as two different antenna heights of the BS (15 m and 25 m) are considered. The MS height is constant at 2 m.

# V. CROSS CORRELATION

For the estimation of the cross correlation coefficients, all LSPs are normally distributed with certain values of the mean and the standard deviation, i.e., SF, XPR and K-factor are indicated in dB and the DS is transformed into  $\log_{10}(DS)$ . Then the cross correlation coefficient between two different LSPs x and y is calculated as follows:

$$\rho(x,y) = \frac{\sum_{i=1}^{N} (x(i) - \overline{x})(y(i) - \overline{y})}{\sqrt{\sum_{i=1}^{N} (x(i) - \overline{x})^2 \sum_{i=1}^{N} (y(i) - \overline{y})^2}},$$
 (1)

with  $\overline{x}$  and  $\overline{y}$  are the means of the datasets x and y and N is the setsize. This is conform to [2] and [3].

# VI. RESULTS

All MIMO subchannels except of the channels corresponding to the MIMO cube are taken. Furthermore all BSs and all tracks are considered at once, but separated between NLOS and LOS with a ray tracing algorithm.

# Estimation Procedures

Table III shows the values of the cross correlation coefficients between the delay spread (DS), shadow fading (SF) and the K-factor for the different estimation approaches for the antenna height of 25 m and 15 m. The correlation between

| 25 m                                   | DS & S   | SF [dB] | DS & K-            | factor [dB] | SF & K-factor [dB] |       |  |  |
|--|----------|---------|--------------------|-------------|--------------------|-------|--|--|
|  | NLOS LOS |         | NLOS               | LOS         | NLOS               | LOS   |  |  |
| GR <sub>agc</sub> CL <sub>max</sub>    | -0.36    | -0.18   | -0.12              | -0.18       | 0.20               | 0.32  |  |  |
| GR <sub>no</sub> CL <sub>max</sub>     | -0.42    | -0.40   | -0.06              | 0.31        | -0.04              | -0.33 |  |  |
| GR <sub>no</sub> CL <sub>ind</sub>     | -0.64    | -0.77   | 0.18               | 0.44        | -0.22              | -0.37 |  |  |
| GR <sub>agc</sub> CL <sub>max</sub> QT | -0.24    | 0.07    | -0.12              | -0.13       | 0.22               | 0.35  |  |  |
| GR <sub>no</sub> CL <sub>max</sub> QT  | -0.17    | -0.27   | 0.05               | 0.28        | -0.03              | -0.35 |  |  |
| GR <sub>no</sub> CL <sub>ind</sub> QT  | -0.49    | -0.66   | 0.26               | 0.45        | -0.22              | -0.38 |  |  |
| 15 m                                   | DS & S   | SF [dB] | DS & K-factor [dB] |             | SF & K-factor [dB] |       |  |  |
|  | NLOS     | LOS     | NLOS               | LOS         | NLOS               | LOS   |  |  |
| GR <sub>agc</sub> CL <sub>max</sub>    | -0.65    | 0.02    | -0.20              | -0.28       | 0.15               | 0.33  |  |  |
| GR <sub>no</sub> CL <sub>max</sub>     | -0.73    | -0.28   | -0.16              | -0.26       | 0.00               | -0.21 |  |  |
| GR <sub>no</sub> CL <sub>ind</sub>     | -0.71    | -0.51   | 0.31               | 0.35        | -0.43              | -0.21 |  |  |
| GR <sub>agc</sub> CL <sub>max</sub> QT | -0.59    | -0.10   | -0.18              | -0.39       | 0.16               | 0.33  |  |  |
| GR <sub>no</sub> CL <sub>max</sub> QT  | -0.46    | -0.26   | 0.04               | -0.28       | 0.01               | -0.19 |  |  |
| GR <sub>no</sub> CL <sub>ind</sub> OT  | _0.60    | _0.32   | 0.47               | 0.29        | -0.41              | -0.19 |  |  |
| Ortho O Dinu Q 1                       | -0.03    | 0.02    | 0.11               | 0.20        | 0.11               | 0.10  |  |  |

#### TABLE III

CROSS CORRELATION COEFFICIENT OF DELAY SPREAD, SHADOW FADING AND K-FACTOR FOR DIFFERENT ESTIMATION APPROACHES (25M, 15M).

the DS and the SF is expected to be negative, which is in line with the results from [11]. With decreasing power of the LOS component the SF decreases and therefore the PDP gets more uniformly distributed and this results in larger values for the DS. This relation is fulfilled in almost all cases. In addition, the values of the coefficients for the lower antenna height are larger then for the antenna height of 25 m in the NLOS case and vice versa for LOS. The results for the NLOS case corroborate the outcomes in [3].

However, the algebraic sign of the correlation coefficient switches regarding the SF and the K-factor as well as regarding the K-factor and the DS. Nevertheless, the cross correlation between the DS and the K-factor is expected to be negative. The values of the K-factor increase with the power of the LOS or the strongest multipath/cluster component. But therefore the DS decreases with the power of the NLOS components. The comparison with the results in Table III affirms that the AGC dependent processing method (whether the QT is used or not) is the more precise way for the estimation of the LSPs, using circular antennas with directional patches at the MS for the measurements. The correlation values for the K-factor and the SF confirm this assumption. They have consequently to be positive, due to the negative correlation between DS and SF

| 25 m   | DS & X  | PR <sub>h</sub> [dB]   | SF & X   | PR <sub>h</sub> [dB]  | K-factor & XPR <sub>h</sub> [dB]                          |  |  |  |
|--|---|--|--|---|---|--|--|--|
| -  | NLOS LOS  |  | NLOS LOS   |   | NLOS  | LOS  |  |  |
| GR <sub>agc</sub> CL <sub>max</sub>  | -0.22   | -0.15  | 0.32   | 0.73  | 0.25  | 0.43   |  |  |
| GR <sub>no</sub> CL <sub>max</sub>   | -0.24   | -0.35  | 0.46   | 0.81  | 0.10  | -0.19  |  |  |
| GR <sub>no</sub> CL <sub>ind</sub>   | -0.54   | -0.65  | 0.46   | 0.80  | -0.01   | -0.22  |  |  |
| GR <sub>agc</sub> CL <sub>max</sub> QT   | 0.06  | 0.06   | 0.31   | 0.73  | 0.27  | 0.45   |  |  |
| GR <sub>no</sub> CL <sub>max</sub> QT  | 0.12  | -0.21  | 0.45   | 0.80  | 0.10  | -0.19  |  |  |
| GR <sub>no</sub> CL <sub>ind</sub> QT  | -0.14   | -0.58  | 0.45   | 0.80  | -0.01   | -0.22  |  |  |
|  |   |  |  |   |   |  |  |  |
| 15 m   | DS & X  | PR <sub>h</sub> [dB]   | SF & X   | PR <sub>h</sub> [dB]  | K-factor  | & XPR <sub>h</sub> [dB]  |  |  |
| 15 m   | DS & X<br>NLOS  | PR <sub>h</sub> [dB]<br>LOS  | SF & X<br>NLOS   | PR <sub>h</sub> [dB]<br>LOS   | K-factor<br>NLOS  | & XPR <sub>h</sub> [dB]<br>LOS   |  |  |
| 15 m<br>GR <sub>agc</sub> CL <sub>max</sub>  | DS & X<br>NLOS<br>-0.44                                     | PR <sub>h</sub> [dB]<br>LOS<br>-0.45   | SF & X<br>NLOS<br>0.22                                 | PR <sub>h</sub> [dB]<br>LOS<br>0.20   | K-factor<br>NLOS<br>0.16                                  | & XPR <sub>h</sub> [dB]<br>LOS<br>0.35   |  |  |
| 15 m<br>GR <sub>agc</sub> CL <sub>max</sub><br>GR <sub>no</sub> CL <sub>max</sub>  | DS & X<br>NLOS<br>-0.44<br>-0.45                            | $PR_{h} [dB]$<br>LOS<br>-0.45<br>0.25  | SF & X<br>NLOS<br>0.22<br>0.28                         | PR <sub>h</sub> [dB]<br>LOS<br>0.20<br>0.32                                 | K-factor<br>NLOS<br>0.16<br>0.19                          | & XPR <sub>h</sub> [dB]<br>LOS<br>0.35<br>-0.55  |  |  |
| 15 m<br>GR <sub>agc</sub> CL <sub>max</sub><br>GR <sub>no</sub> CL <sub>max</sub><br>GR <sub>no</sub> CL <sub>ind</sub>  | DS & X<br>NLOS<br>-0.44<br>-0.45<br>-0.57                   | $\begin{array}{c} \text{PR}_{h} \ [\text{dB}] \\ \hline \text{LOS} \\ \hline -0.45 \\ 0.25 \\ -0.50 \end{array}$                         | SF & X<br>NLOS<br>0.22<br>0.28<br>0.26                 | PR <sub>h</sub> [dB]<br>LOS<br>0.20<br>0.32<br>0.32                         | K-factor<br>NLOS<br>0.16<br>0.19<br>-0.12                 | & XPR <sub>h</sub> [dB]<br>LOS<br>0.35<br>-0.55<br>-0.55   |  |  |
| 15 m<br>GR <sub>agc</sub> CL <sub>max</sub><br>GR <sub>no</sub> CL <sub>max</sub><br>GR <sub>no</sub> CL <sub>ind</sub><br>GR <sub>agc</sub> CL <sub>max</sub> QT  | DS & X<br>NLOS<br>-0.44<br>-0.45<br>-0.57<br>-0.20          | $\begin{array}{c} \text{PR}_{h} \ [\text{dB}] \\ \hline \text{LOS} \\ \hline -0.45 \\ 0.25 \\ -0.50 \\ \hline -0.49 \end{array}$         | SF & X<br>NLOS<br>0.22<br>0.28<br>0.26<br>0.23         | PR <sub>h</sub> [dB]<br>LOS<br>0.20<br>0.32<br>0.32<br>0.20                 | K-factor<br>NLOS<br>0.16<br>0.19<br>-0.12<br>0.18         | $\begin{array}{c} \& \ \text{XPR}_h \ [\text{dB}] \\ \hline \ \text{LOS} \\ \hline \ 0.35 \\ -0.55 \\ -0.55 \\ \hline \ 0.35 \end{array}$    |  |  |
| 15 m<br>GR <sub>agc</sub> CL <sub>max</sub><br>GR <sub>no</sub> CL <sub>max</sub><br>GR <sub>no</sub> CL <sub>ind</sub><br>GR <sub>agc</sub> CL <sub>max</sub> QT<br>GR <sub>no</sub> CL <sub>max</sub> QT | DS & X<br>NLOS<br>-0.44<br>-0.45<br>-0.57<br>-0.20<br>-0.05 | $\begin{array}{c} \text{PR}_{h} \ [\text{dB}] \\ \hline \text{LOS} \\ \hline -0.45 \\ 0.25 \\ -0.50 \\ \hline -0.49 \\ 0.25 \end{array}$ | SF & X<br>NLOS<br>0.22<br>0.28<br>0.26<br>0.23<br>0.29 | PR <sub>h</sub> [dB]<br>LOS<br>0.20<br>0.32<br>0.32<br>0.20<br>0.20<br>0.32 | K-factor<br>NLOS<br>0.16<br>0.19<br>-0.12<br>0.18<br>0.20 | $\begin{array}{c} \& \ \text{XPR}_h \ [\text{dB}] \\ \hline \text{LOS} \\ \hline 0.35 \\ -0.55 \\ -0.55 \\ \hline 0.35 \\ -0.53 \end{array}$ |  |  |

|               | DS & S   | SF [dB] | DS & K-  | factor [dB] | SF & K-factor [dB] |      |  |  |  |  |
|---------------|----------|---------|----------|-------------|--------------------|------|--|--|--|--|
|               | NLOS LOS |         | NLOS LOS |             | NLOS               | LOS  |  |  |  |  |
| 60m-200m/25m  | -0.51    | -0.19   | -0.32    | 0.13        | 0.53               | 0.49 |  |  |  |  |
| 200m-400m/25m | -0.00    | -0.17   | -0.06    | 0.03        | 0.22               | 0.50 |  |  |  |  |
| 400m-640m/25m | -0.71    | -0.68   | -0.08    | -0.30       | 0.30               | 0.43 |  |  |  |  |
| 60m-200m/15m  | n.a.     | n.a.    | n.a.     | n.a.        | n.a.               | n.a. |  |  |  |  |
| 200m-400m/15m | -0.72    | 0.02    | -0.09    | -0.28       | 0.16               | 0.33 |  |  |  |  |
| 400m-640m/15m | -0.74    | n.a.    | -0.22    | n.a.        | 0.25               | n.a. |  |  |  |  |
| WINNER II     | -0.4     | -0.4    | n.a.     | -0.4        | n.a.               | 0.3  |  |  |  |  |

TABLE V Cross correlation coefficient (for  $GR_{AGC}CL_{MAX}$ ) of delay SPREAD, SHADOW FADING AND K-FACTOR FOR DIFFERENT ANTENNA HEIGHTS AND DISTANCE RANGES.

and between DS and K-factor and this occurs only for the AGC depending method. Even if it is not really clear which are the right values for the cross correlation coefficients by now, it is distinct from the above mentioned results of the correlation analysis, that the estimation procedure regarding the AGC values is the more precise way.

Nevertheless, the values of the correlation coefficients for the non AGC dependent analysis are mostly higher. This entails that if the measurement is done with AGC switching and the following analysis is performed without considering the directional dependency the correlation might be overrated. This effect can also be observed for the cross correlation involving the cross polarization ratios (XPR<sub>h</sub>, XPR<sub>v</sub>). Table IV summarizes the results for both antenna heights. Exemplarily the horizontal cross polarization ratio is chosen, but the values including the vertical one behave the same way. Table IV also confirms the assumption, that the values for the cross correlation are higher for smaller antenna heights in the NLOS case, but smaller where a LOS exist.

# Distance Ranges and Antenna Height

For the analysis regarding the distance between BS and MS as well as regarding different BS antenna heights, the AGC dependent method without considering an additionally QT is used. This is due to the outcomes in [5], the results mentioned above and the outlier in the correlation between DS and SF for LOS as well as between DS and XPR<sub>h</sub> for LOS and NLOS when the QT is used. Hence, in the following only the procedure GRagcCLmax is considered. In Table V and VI the cross correlation coefficients with regard to various listance ranges and different antenna heights are summarized. t can be seen that for small distances there is a significant correlation between the different LSPs for NLOS and the intenna height of 25 m, which is conform to our observation

| GR <sub>no</sub> CL <sub>ind</sub> QT  | -0.14   | -0.58                | 0.45    | 0.80                 | -0.01  | -0.22 |               |        |                      |        |                      |            |                       |
|--|---------|----------------------|---------|----------------------|--|-------|---------------|--------|----------------------|--------|----------------------|------------|-----------------------|
| 15 m                                   | DS & XI | PR <sub>h</sub> [dB] | SF & XI | PR <sub>h</sub> [dB] | R <sub>h</sub> [dB] K-factor & XPR <sub>h</sub> [dB] |       |               | DS & X | PR <sub>h</sub> [dB] | SF & X | PR <sub>h</sub> [dB] | K-factor & | XPR <sub>h</sub> [dB] |
|  | NLOS    | LOS                  | NLOS    | LOS                  | NLOS   | LOS   |               | NLOS   | LOS                  | NLOS   | LOS                  | NLOS       | LOS                   |
| GR <sub>agc</sub> CL <sub>max</sub>    | -0.44   | -0.45                | 0.22    | 0.20                 | 0.16   | 0.35  | 60m-200m/25m  | -0.62  | 0.58                 | 0.73   | 0.43                 | 0.59       | 0.33                  |
| GR <sub>no</sub> CL <sub>max</sub>     | -0.45   | 0.25                 | 0.28    | 0.32                 | 0.19   | -0.55 | 200m-400m/25m | 0.21   | -0.02                | 0.32   | 0.82                 | 0.14       | 0.49                  |
| GR <sub>no</sub> CL <sub>ind</sub>     | -0.57   | -0.50                | 0.26    | 0.32                 | -0.12  | -0.55 | 400m-640m/25m | -0.24  | -0.61                | 0.42   | 0.62                 | 0.13       | 0.27                  |
| GR <sub>agc</sub> CL <sub>max</sub> QT | -0.20   | -0.49                | 0.23    | 0.20                 | 0.18   | 0.35  | 60m-200m/15m  | n.a.   | n.a.                 | n.a.   | n.a.                 | n.a.       | n.a.                  |
| GR <sub>no</sub> CL <sub>max</sub> QT  | -0.05   | 0.25                 | 0.29    | 0.32                 | 0.20   | -0.53 | 200m-400m/15m | -0.20  | -0.45                | 0.29   | 0.20                 | 0.11       | 0.35                  |
| GR <sub>no</sub> CL <sub>ind</sub> QT  | -0.33   | -0.50                | 0.26    | 0.32                 | -0.11  | -0.53 | 400m-640m/15m | -0.35  | n.a.                 | 0.29   | n.a.                 | 0.15       | n.a.                  |

TABLE IV

CROSS CORRELATION COEFFICIENT OF HORIZONTAL CROSS POLARIZATION RATIO, DELAY SPREAD, SHADOW FADING AND K-FACTOR FOR DIFFERENT ESTIMATION APPROACHES (25M, 15M).

TABLE VI

CROSS CORRELATION COEFFICIENT (FOR GRAGCCLMAX) OF HORIZONTAL CROSS POLARIZATION RATIO, DELAY SPREAD, SHADOW FADING AND K-FACTOR FOR DIFFERENT ANTENNA HEIGHTS AND DISTANCE RANGES.



Fig. 1. Cross correlation coefficient of delay spread and shadow fading vs distance in 20 m steps for the antenna height of 25 m (NLOS).



Fig. 2. Cross correlation coefficient of delay spread and K-factor vs distance in 20 m steps for the antenna height of 25 m (NLOS).

that the correlation decreases with increasing distance. For the lower antenna height the largest cross correlation values are obtained for the distance range of 400 m–640 m. For LOS the highest values of the cross correlation can be found for the distance range of 200 m–400 m, especially for the cross correlation values where the DS is not included. This can be explained by the beampattern of the antenna and the degree of elevation at the BS. Additionally for large distances, the possibility that the waves change their polarization increases. Due to these aspects, for small and large distances the clear disjunction between h and v components is not ensured anymore and thus the correlation decreases.

To get a better insight into the dependency of the cross correlation coefficients on the distance, Fig.1 - Fig.4 show the cross correlation coefficients versus the distance for different LSPs for NLOS and the antenna height of 25 m. The distance range for which they are estimated is 20 m and the number of samples which are used for the calculation is depicted in Fig. 5. While the values for the coefficients are very large around the range of 100 m and satisfy the expected positive or negative correlation, we have almost always an erroneous behavior in the range of 200-300 m. A possible explanation can be a strong reflection or diffraction of the cluster or multipath components due to a special geometry of the scenario. If the outlier in the range of 200 m-300 m are neglected, a clear trend, that the coefficients decrease with increasing distance is visible, especially in Fig. 3 and Fig. 4. The values for the antenna height of 15 m behave almost the same way, however the decreasing tendency is less observable. But they have similar outliers in the range between 200 m and 300 m.

For an additional overview of the joint behavior of the LSPs Fig. 6 and Fig. 7 show the corresponding scatter plots for



Fig. 3. Cross correlation coefficient of shadow fading and K-factor vs distance in 20 m steps for the antenna height of 25 m (NLOS).



Fig. 4. Cross correlation coefficient of shadow fading and cross polarization ratio (h) vs distance in 20 m steps for the antenna height of 25 m (NLOS).

NLOS. Fig. 8 and Fig. 9 depict the same for the LOS case.

# VII. CONCLUSION AND OUTLOOK

The cross correlation characteristics of the LSPs in the power and delay domain for different estimation procedures, various distance ranges and different antenna heights have been investigated. The relation between the parameters regarding the expected correlation is always fulfilled for the parameter estimation procedure taking the AGC dependent grouping into account and thus considering directional filtering properties of the receive antenna, whereas for the AGC independent procedures the results are partly non consistent. It follows that if measurements were done with a circular array including directional antenna patches at the MS and with AGC switching within one snapshot, the estimation procedure has to be done directional dependent. The analysis regarding the distance ranges and antenna heights shows interesting results. Strong negative dependencies were found when the DS is included for decreasing BS antenna height under NLOS propagation and vice versa for LOS. The values for the cross



Fig. 5. Number of samples per distance range for the antenna height of  $25\,\mathrm{m}$  (NLOS).



Fig. 7. Scatter plots for different antenna heights (NLOS).

correlation coefficients between SF, K-Factor and XPR are in general larger for the higher antenna height in the NLOS and LOS case. Furthermore dependencies on the distance between MS and BS where found, but with unclear trend, except the cross correlation values for NLOS and the antenna height of 25m. They show a consistent behavior in that way that the strongest correlation is obtained for the smallest distance range. These results provide a better insight into the behavior of the cross correlation characteristics between the LSPs and allow a more precise description of the joint behavior using these values. Thus, a next step will be to take the cross correlation of the LSPs between one BS and different MSs and their dependency on the distance into account.

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Fig. 8. Scatter plots for different antenna heights (LOS).



Fig. 9. Scatter plots for different antenna heights (LOS).

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