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Correlation Properties of Large Scale Parameters from 2.66 GHz Multi-site Macro Cell Measurements

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***Abstract*—Multi-site measurements for urban macro cells at 2.66 GHz are performed with three base stations and one mobile station. In order to analyze the correlation properties of large scale parameters, we split up the routes into subsets, where it can be assumed that wide-sense stationarity (WSS) applies. The autocorrelation distance and correlation properties of large scale parameters for each link are analyzed. By comparing these properties with the corresponding parameters from the COST 2100 and WINNER II models, we can see that the measured autocorrelation distance of the shadow fading as well the autocorrelation distance of delay spread have similar properties as in the two models. The shadow fading and delay spread from the same link are negatively correlated and match the two models well. Based on the WSS subsets, we can see that large scale parameters for different links can be correlated, also when two BSs are far away from each other. In those cases the correlation of different links tends to be positively correlated when both base stations are in the same direction compared to the movement of the MS, otherwise the two links are usually negatively correlated.**

***Index Terms*—Multi-site, correlation, large scale parameters, channel model, channel measurements.**

I. Introduction

In order to make realistic wireless channel models, such as the COST 2100 [1], WINNER II [2], measurements are required so that parameters for channel models can be extracted. Among parameters of interest, there are so called large scale parameters describing the main characteristics of the environment, such as shadow fading, angular spread and delay spread. In the literature, many investigations of the shadow fading correlation in a single MIMO link can be found. In [3], the autocorrelation of shadow fading is modeled as an exponential function of the distance. The joint correlation properties of angular spread, delay spread and shadow fading are investigated in [4]. The two recent models mentioned above also include all these correlation properties between the large scale parameters, but usually these parameters are studied for the single MIMO link. Due to the use of base station cooperation, the behavior of multi-site MIMO wireless channels become more and more interesting as well. Often it is assumed that there is no correlation between two links if the two links are far away from each other [5]. In [6] the correlation of shadow fading for separate base stations is discussed and substantial correlation for closely located base station is found, but still not enough measurements are performed to form a generic model. In [7], it has been found that the shadow fading can be correlated also for widely separated base stations in the indoor case. Recently, in [8] the correlation properties for large scale parameters between different links in an outdoor scenario have been studied from measured data, but without considering limitation from the stationarity regions for the large scale parameters. Willink analyzed WSS regions for urban MIMO channels based on the first and second moments [9]. There it was seen that a homogeneous building has high possibility to give larger WSS regions. However, a parking lot between homogeneous buildings will break up the WSS regions.

In this paper, we propose a WSS region definition based on a map and the environment. This is validated by considering the local scattering function and estimates of the average WSS distance. The correlation properties of large scale parameters are investigated both inside each link and between different links in a urban macro scenario based on small WSS subsets. The autocorrelation distance and correlation inside each link are evaluated and compared with the corresponding values in the COST 2100 and WINNER II models. The correlation between different links provide a basis to model the inter-site correlation when base stations are separated.

The paper is organized as follows: In section II, a short introduction to the measurement campaign and data processing is given. Large scale parameter estimation is discussed in section III. Section IV presents an analysis of the autocorrelation distance for the large scale parameters for each link. Section V gives a deep analysis for the large scale parameters correlation properties when the routes are divided into small WSS subsets. Finally the conclusions are given in section VI.

II. Multi-site Measurement Campaign and Data Processing

A. Measurement Campaign

The measurements were performed in a urban macro cell environment in Kista, Stockholm, Sweden, see Fig. 1. Three base station (BS) sites with one antenna each are used, which are referred as BS1, BS2 and BS3 in the following. At the mobile station (MS) side two dipole antennas and two loop antennas are placed on the roof of a measurement van 30 cm from each other. The measured center frequency is 2.66 GHz with a bandwidth of 20 MHz. The transmit power of each BS

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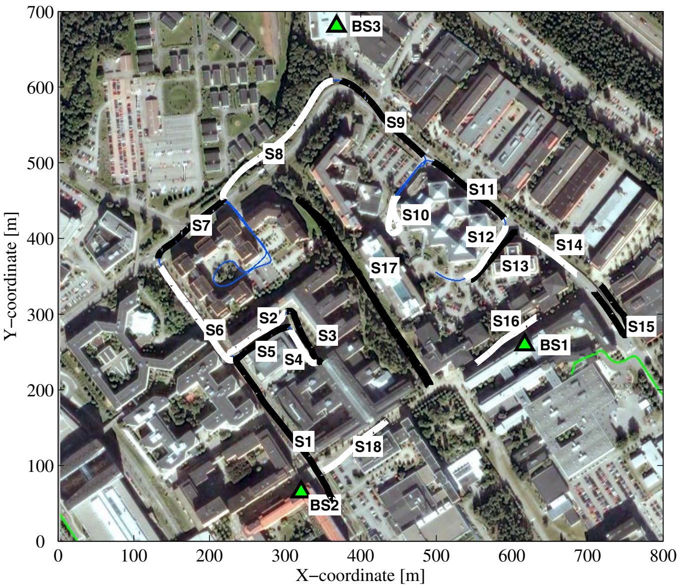


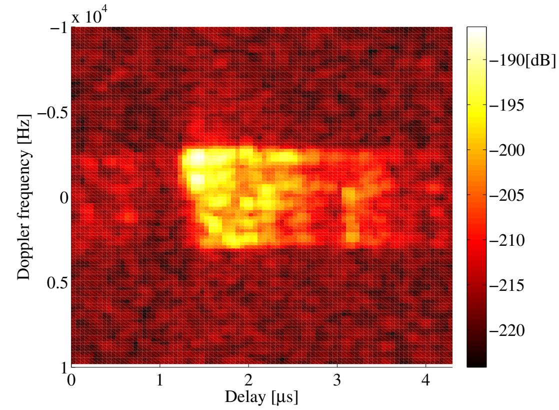
Fig. 1. Subsets of measured routes.

is 0 dBm. The MS traveled along the routes in Fig. 1 and the GPS positions of the MS were also recorded together with the channel samples. Along the routes, the links between the BSs and MS experience line-of-sight (LOS), obstructed line-of-sight (OLOS) and non line-of-sight (NLOS) conditions. The distance between BS1 and BS2 is approximately 354, 489 m between BS1 and BS3, and 617 m between BS2 and BS3. A 4-by-3 MIMO channel matrix over 432 frequency bins is obtained for each measured snapshot. The links from the BSs to each MS are called link 1, link 2 and link 3 corresponding to the index for each BS, respectively.

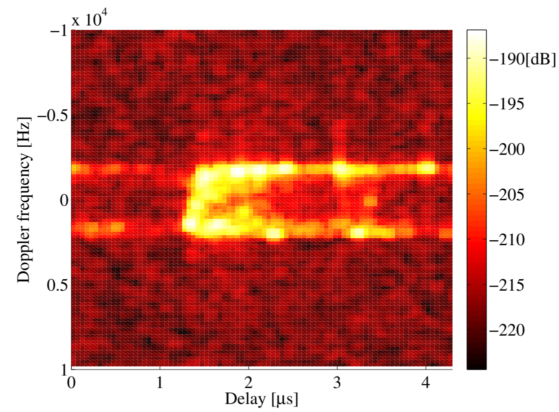
B. Data Processing

In order to extract the large scale parameters in a proper way, we consider four rules for further analysis when dividing the route into 18 subsets which are referred as S_i. First, the NLOS and LOS scenarios have to be separated. Second if the environments are not homogeneous we also need to separate the routes into small subsets. For BS2 as an example, S9 and S11 have to be separated, since S9 is in a large open area without any building in the south west direction whereas S11 will be shadowed a lot by a building. Third, if the traveling routes are perpendicular we also need to split them, this applies e.g. to S2 and S3. Finally, the difference in angle seen from the BS to the routes in a subset can not be too large. The antenna gain have to be constant over the “sector” considered and the same main propagation processes should be maintained.

At the same time, a WSS distance is estimated according to the methodology in [10]. The snapshot repetition time is 0.0053 s, and the MS is moving with velocity of 30 km/h in average. The estimated WSS distances are 75, 99 and 42 meters for three links respectively with the assumption that the correlation threshold is 0.9. Generally it can be said that the WSS distances have a good agreement with the averaged subset length.



(a) Local scattering function from S2



(b) Local scattering function from S3

Fig. 2. Comparison of local scattering function for perpendicular routes.

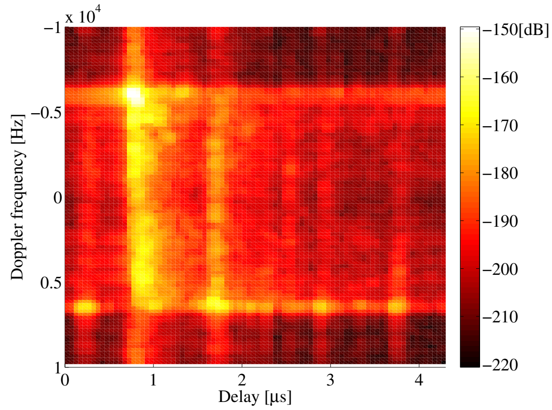
The local scattering function describes the nonstationarity of channel. When the traveling routes are perpendicular, a significant difference in the local scattering function (LSF) will happen, see Fig. 2, which gives the necessity to split up perpendicular routes into different subsets. This change is evident for scenario change as well, and Fig. 3 show LSFs when the propagation conditions change from NLOS to LOS.

III. Large Scale Parameter Estimation

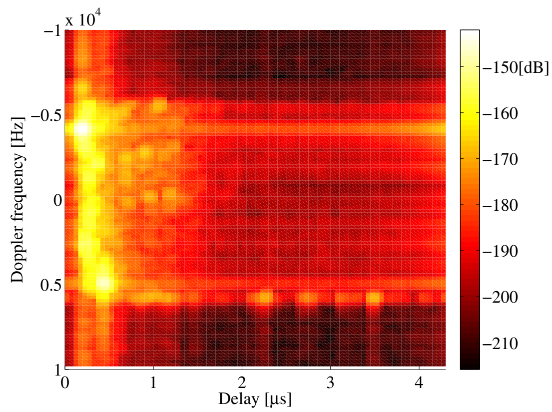
The most widely used large scale parameters for wireless channel modeling and analysis are shadow fading, angular spread, cross polarization discrimination and delay spread. In this work two parameters are investigated in detail, shadow fading and delay spread. The antenna arrangements do not allow a straightforward analysis of angular properties.

A. Shadow Fading

Shadow fading (SF) is the power fluctuation over a large area where the small scale variations are averaged out. Usually the small scale fading is removed by averaging the received



(a) Local scattering function for NLOS



(b) Local scattering function for LOS

Fig. 3. Comparison of local scattering function for NLOS and LOS scenarios.

TABLE I

SUBSETS FOR EACH LINK WITH ROUTE LENGTH, PATH-LOSS EXPONENT n, AND STANDARD DEVIATION OF THE SHADOW FADING.

Subset	Length [m]	n	SF std	Scenario
S1,S3,S4,S6,S17	1145	3.83	4.78	NLOS
S2,S5,S7,S8,S12,S13	697	4.12	3.15	NLOS
S9	150	1.56	2.06	NLOS
S10	110	4.92	2.93	LOS
S11,S14,S15	357	0.23	3.14	NLOS
S16,S18	207	0.23	3.14	LOS

(a) Link 1

Subset	Length [m]	n	SF std	Scenario
S1	230	-0.59	3.34	LOS
S2,S5,S7,S8,S12,S13	697	2.82	4.51	NLOS
S3,S4,S17,S11,S14,S15	1164	3.30	3.63	NLOS
S6	159	4.58	3.35	NLOS
S9	150	-5.34	1,58	NLOS
S10	110	5.43	1.58	NLOS
S16,S18	207	0.03	2.25	LOS

(b) Link 2

Subset	Length [m]	n	SF std	Scenario
S1,S6,S3,S4,S17	1145	7.16	6.40	NLOS
S2,S5,S12,S13,S16,S18	566	8.76	5.73	NLOS
S7,S8	338	0.25	3.20	LOS
S9,S11	270	1.44	5.63	LOS
S10	110	11.06	4.24	LOS
S14,S15	288	6.00	5.32	NLOS

(c) Link 3

power inside a 10 wavelengths window [11]. Then the averaged received power level can be modeled as

$$P(d) = P_0 - n * \log_{10}(\frac{d}{d_0}) + SF(d), \quad (1)$$

where d is the distance, n is the path-loss exponent and P_0 is a reference value at the distance d_0. To determine the shadow fading, a linear regression is performed and the deviation from the linear trend (in the log-domain) is determined.

In Table I, the extracted shadow fading parameters for the subsets are given. It can be seen that the path-loss exponents sometimes are negative, see S1 and S9 in link 2. One reason might be in the short route lengths here. The power varies a lot due to obstacles and the path-loss model parameter estimation becomes unreliable. Similarly, if the MS route is below the BS, when the MS and BS are quite close, the shadow might be shadowed by the building where the BS is placed.

B. RMS Delay Spread

The RMS delay spread (DS) is estimated based on the power delay profile (PDP) [11]. The PDP is extracted based on a quasi-stationarity time span, and a window with 10 wavelengths is used in this work. The RMS delay spread is estimated in each time span according to:

$$S_\tau = \sqrt{\frac{\Sigma_{i=1}^{N_{bin}} P_h(\tau_i)\tau_i^2}{\Sigma_{i=1}^{N_{bin}} P_h(\tau_i)} - T_m^2}, \quad (2)$$

where

$$T_m = \frac{\Sigma_{i=1}^{N_{bin}} P_h(\tau_i)\tau_i}{\Sigma_{i=1}^{N_{bin}} P_h(\tau_i)} \quad (3)$$

and P_h is the PDP for each time span, N_{bin} is the number of delay bins and τ is the delay.

IV. AUTOCORRELATION DISTANCES OF LARGE SCALE PARAMETERS

The large scale parameters do not change within a few wavelengths distance, and when the MS is moving the large scale parameters change slowly. The autocorrelation distance reflects how fast the large scale parameters are changing over the route. The autocorrelation distances of large scale parameters are quite important for channel models such as the COST 2100 and WINNER II models. In the WINNER II model, the autocorrelation distance is supported by measurements and is around 45/50 m (LOS/NLOS) for the outdoor-to-outdoor scenario. In the COST 2100 model 100 m is used

TABLE II
ESTIMATED AUTOCORRELATION DISTANCES.

	Link 1	Link 2	Link 3	COST 2100	WINNER II C2
SF LOS/NLOS [m]	35/56	50/185	90/86	100	45/50
DS LOS/NLOS [m]	28/62	45/40	80/90	100	40/40

for both scenarios. In this work, we estimate the autocorrelation distance for each link of the multi-site measurements according to the method in [8]. The autocorrelation distance is calculated by sorting the data into separate groups, with 40 m between two adjacent groups. Then correlation coefficients are evaluated based on groups with different distances. The autocorrelation distance is defined as the distance when the correlation coefficient decreases to e^{-1}.

In Table II, the autocorrelation distance are separated into LOS and NLOS. For link 1 and 2, the LOS routes are quite short, and the autocorrelation might be underestimated. In link 3 the LOS conditions dominate, and the value is in a good agreement with the COST 2100 model. Under the NLOS conditions, all the extracted autocorrelation distances agree quite well with the values used in both of the two models, except for one extreme case in link 2.

V. Correlations of Large Scale Parameters

The lager scale parameters describe the wireless channel from different aspects, and they are usually correlated with each other [4]. When there are several BSs in the measured environment, the multi-path components from BSs to MS might have the same traveling route or at least some common traveling route. It is of interest to investigate these dependencies as they should be included into the wireless channel models. The large scale parameters in each link are usually correlated, which is called the intra-site correlation. The correlation of large scale parameters in different links is called inter-site correlation [8]. Next, we will investigate both intra-site correlation and inter-site correlation for multi-site measurements in the measured urban macro cell.

A. Intra-site correlation

The intra-site correlation between shadow fading and delay spread at each link is extracted from the whole MS traveling route according to:

$$\rho\langle a, b\rangle = \frac{\sum_i^N (a_i - \bar{a})(b_i - \bar{b})}{\sqrt{\sum_i^N (a_i - \bar{a})^2 \sum_j^N (b_i - \bar{b})^2}}, \tag{4}$$

where $\bar{a}$ and $\bar{b}$ are the means of sample sets $\{a_i\}$ and $\{b_i\}$ with length N. The correlation coefficient is calculated in the log-domain as in [12]. The intra-site correlation is included both in the COST 2100 and WINNER II C2 model for the macro cell, with values -0.6 and -0.4 respectively. In Table III, the correlation coefficient between shadow fading and delay spread for all small subsets are shown. Nearly all have negative values which means that when the shadow fading becomes larger, there is usually a large delay spread. The mean values for all NLOS scenarios is -0.65 and -0.47 for LOS scenario, which more or less match the COST 2100 and WINNER II models well.

TABLE III
INTRA-SITE CORRELATION FOR ALL SUBSETS.

Subsets	SF-DS L1	SF-DS L2	SF-DS L3
1	-0.70	-0.71	-0.67
2	-0.50	-0.87	-0.90
3	0.07	-0.22	-0.53
4	-0.82	-0.77	-0.69
5	-0.58	-0.87	-0.91
6	-0.35	-0.77	-0.83
7	-0.66	-0.91	-0.60
8	-0.89	-0.78	-0.43
9	-0.83	-0.45	-0.61
10	-0.37	-0.34	-0.51
11	-0.83	-0.15	0.03
12	-0.26	-0.75	-0.92
13	0.07	-0.60	-0.93
14	-0.80	-0.93	-0.45
15	-0.79	-0.54	-0.68
16	-0.80	-0.28	-0.90
17	-0.81	-0.61	-0.90
18	-0.51	-0.43	-0.58

B. Inter-site correlation

Until now there are not too many studies on inter-site correlation, the main reason is the lack of multi-site measurements. It is usually assumed that there is no correlation between different links. However inter-site correlation exists and affects system performance [13]. The inter-site correlation is evaluated based on the same approach as when we generated the groups of subsets, only inter-site correlation of subsets in homogeneous groups are analyzed, see Table IV.

One interesting thing is that the distance from the MS to BSs and distance of two BSs can not be used to determine the inter-site correlation. For example, S7 and S8 are far away from BS1 and BS2 and a quite small inter-site correlation is observed. S1 and S6 are also far away from BS1 and BS3, but instead a large shadow fading correlation is obtained for these two links. Further, consider S2 and S5, link 1 and 3 are highly correlated with respect to shadow fading and delay spread which are far from the MS and far from each other. It also can be seen that if the MS is placed in between two BSs, the link inter-correlations tend to be higher, e.g. S2 and S5 for link 2 and 3.

S17 has high inter-site correlation for all links, since S17 is aways between two links in our measurements. When we take a look at link 1 and 2, the MS is moving towards both BSs in S17, and then a positive correlation is obtained for both shadow fading and delay spread. But for link 1 and 3, and for link 2 and 3, the MS is always moving towards one BS and moving away to the other one, then a negative correlation is obtained. S2 and S5 also have the similar properties in link

TABLE IV
INTER-SITE CORRELATION BASED ON SUBSETS.

Subsets	SF-SF	DS-DS	SF-DS	DS-SF	Scenario
S2,S5	0.31	-0.26	-0.2	0.20	NLOS
S7,S8	0.16	0.05	0.08	-0.22	NLOS
S12,S13	0.48	-0.05	-0.25	0.21	NLOS
S3,S4	0.48	0.21	0.07	-0.51	NLOS
S6	-0.23	-0,39	-0.06	0.50	NLOS
S17	0.62	0.58	-0.43	-0.45	NLOS
S11,S14,S15	-0.11	-0.27	0.09	0.54	NLOS
S16,S18	-0.13	0.51	0.13	-0.03	LOS

(a) Inter-site correlation of Link 1 and 2

Subsets	SF-SF	DS-DS	SF-DS	DS-SF	Scenario
S1,S6	-0.4	-0.06	0.48	0.08	NLOS
S3,S4	0.60	0.05	-0.3	0.08	NLOS
S17	-0.5	-0.78	0.62	0.79	NLOS
S2,S5	0.82	0.26	-0.7	-0.24	NLOS
S12,S13	-0.49	-0.1	0.51	0.07	NLOS
S14,S15	-0.16	-0.19	0.10	0.38	NLOS
S10	-0.31	0.16	-0.06	0.16	LOS

(b) Inter-site correlation of Link 1 and 3

Subsets	SF-SF	DS-DS	SF-DS	DS-SF	Scenario
S3,S4	0.22	-0.04	-0.2	0.07	NLOS
S6	0.16	-0.36	0.13	0.23	NLOS
S17	-0.39	-0,69	0.56	0.71	NLOS
S2,S5	0.59	0.53	-0.63	-0.51	NLOS
S12,S13	-0.08	-0.36	0.16	0.31	NLOS
S14,S15	-0.14	-0.36	0.21	0.49	NLOS

(c) Inter-site correlation of Link 2 and 3

1 and 3, high positive inter-site correlation is observed. In general, when the MS is between two BSs and also the main lobe of BSs face to the routes, a high inter-site correlation often exists even if the BSs are far away from each other. If the MS is moving towards, or away from both BSs, positive inter-site correlations are obtained otherwise negative correlations are obtained.

Here, we analyze mainly the NLOS scenario since we do not have enough measurements for the LOS scenario. Only one inter-correlation is given for S16 and S18 in link 1 and 2, which are highly correlated in delay spread and the other for S10 in link 1 and 3 with high negative correlation in shadow fading.

VI. CONCLUSIONS

In this paper, the properties of large scale parameters are analyzed and compared to the existing COST 2100 and WINNER II models. The autocorrelation distances for shadow fading and delay spreads more or less agree with the two models. The intra-site correlations from measurements have all negative values, and the average intra-site correlation have a good match with the two models. Another interesting observation is the inter-site correlation between multi-BSs. A study of the inter-site correlation properties, especially for the shadow fading and delay spread, is presented. From the results, we can confirm that the inter-site correlation exists, even when the two links are far away from each other, with high or low correlation coefficients. Sometimes high correlation appeared for the different large scale parameters in different links. The shadow fading has shown negative correlation between different links when the MS is moving towards one BS but away from the other BS. On the other hand, when MS is moving towards both BSs, the shadow fading is positively correlated. Similar behavior was shown for the delay spread inter-site correlations. It is quite important to include all these properties in wireless channel models. However, more multi-site measurements are needed to make a generic model for these properties and provide more realistic models.

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