Channel Measurements and Analysis for Very Large Array Systems At 2.6 GHz

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Channel Measurements and Analysis for Very Large Array Systems At 2.6 GHz

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***Abstract*—Very large MIMO is a technique that potentially can offer large network capacities in multi-user scenarios where the users are equipped only with single antennas. In this paper we are investigating channel properties for a realistic, though somewhat extreme, outdoor base station scenario using a large array. We present measurement results using a 128 element linear array base station and 26 different user position in line-of-sight (LOS) and 10 different user position in non line-of-sight (NLOS). We analyze the Ricean K-factor, received power levels over the array, antenna correlation and eigenvalue distributions. We show that the statistical properties of the received signal vary significantly over the large array. Near field effects and the non-stationarities over the array help decorrelating the channel for different users, thereby providing a favorable channel conditions with stable channels and low interference for the considered single antenna users.**

I. Introduction

Very large MIMO, where a base station equipped with a large number of antennas (say 50-400) is serving several simultaneous single antenna users, is a new research field that shows many promising properties. The technology can be an enabler for the next generation power and spectral efficient cellular systems [1] [2]. It has shown very promising performance characteristics based on theoretical studies, but there are many open questions when it comes to practical implementations. One such question is whether the environment and setup provide enough decorrelated channels for different users in a multiuser scenario. The inner product between the propagation vector of different users is of special interest since it in some sense will determine the interference. If we increase the number of antenna elements and this inner product grows slower compared to the propagation vector itself, the interference will eventually approach zero [2]. In this paper we analyze propagation properties for very large MIMO based on measurements. Especially we are interested in answering the following question: What are the specific propagation phenomena that have to be taken into account for large array channel modeling when using a physically large linear array? We specifically target received power levels, singular value distribution, antenna correlation, angular power spectrum, and near field effects. To the authors' best knowledge there are no previous measurement based investigations of channel properties when using physically large arrays in cellular scenarios. Previous investigations using a large circular, but not physically large, antenna array showed a good potential for low correlation and good performance also for less complex linear precoders [5]. With this measurement campaign we are aiming to analyze further channel properties and to identify any differences when going for a very large array that also is physically large.

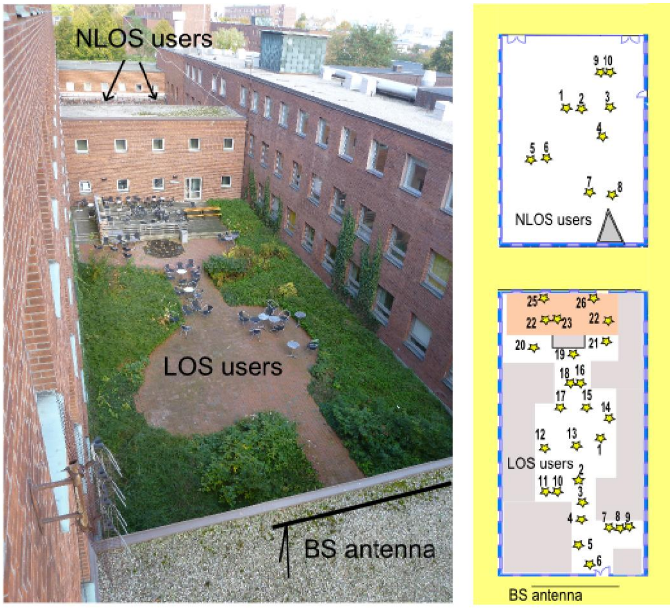

Fig. 1. Overview of the measurement area.

II. Measurement Setup

The measurements are performed at 2.6 GHz with a 128 element virtual linear array as a base station. There are 36 different single antenna user positions acting as transmitters, 10 of those are in non line-of-sight (NLOS) court whereas 26 of the users are in line-of-sight (LOS) court. The measurements are taken with a vector network analyzer measuring the transfer function, H, at 1601 frequency points over the bandwidth of 50 MHz. We estimate that there are 4- 6 independent frequency samples given the measured delay spread. The antenna spacing is half a wavelength, hence the antenna array is 7.3 m long. The measurements are performed in a controlled outdoor environment, in two court yards of the E-building, LTH, Lund University, see Fig. 1, where there are no movements in the two court yards. To extend the range a RF-over-fiber system was used for the transmitter together with a power amplifier. This ensured a high SNR and low distortion in all measurements. The block diagram of the system is shown in Fig. 2. It can be noted that the scenario is somewhat extreme but not unrealistic, with many strong scatterers (e.g. walls) relatively close to users and the base station antenna array.

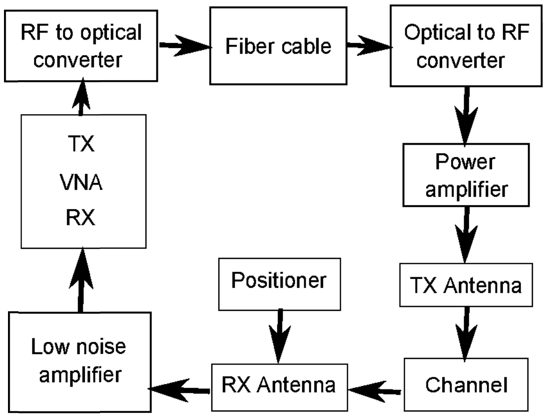

Fig. 2. Block diagram of the measurement setup.

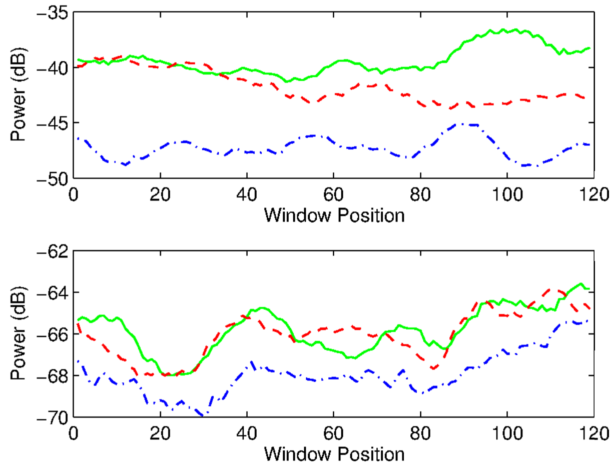

Fig. 3. Channel gain over the array for different users. Top: LOS users 1 (solid green), 8 (dash dotted blue), 21 (dashed red). Bottom: NLOS users 1 (solid green), 5 (dash dotted blue), 9 (dashed red).

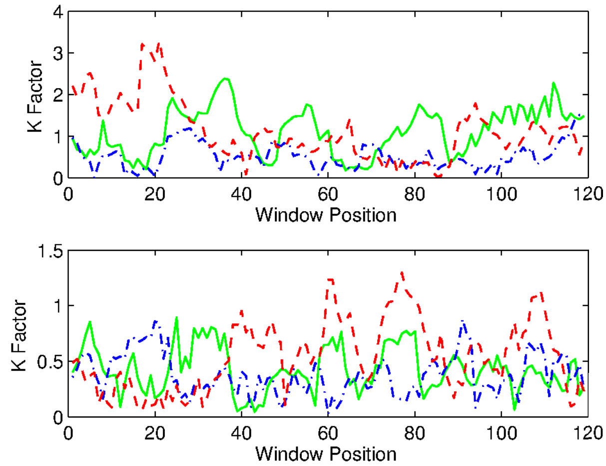

Fig. 4. Estimated K-factors over the array for different users. Top: LOS users 1 (solid green), 8 (dash dotted blue), 21 (dashed red). Bottom: NLOS users 1 (solid green), 5 (dash dotted blue), 9 (dashed red).

III. Measurement Results

After compensating for power imbalances between users, the received amplitudes showed a Rayleigh characteristic for both court yards (i.e. NLOS and LOS), and also for each user. A more detailed study revealed, however, that there are large variations over the array with respect to received power levels, small scale fading distribution and angular power spectrum. In order to analyze variations over the array we apply a sliding window including 10 neighboring antenna elements, which we estimated as the stationarity area. Measurements from 10 consecutive antenna elements, with varying window positions, and the 1601 frequency samples for each antenna then provide an ensemble for further analysis.

A. *Channel gain*

To study the channel gain we are calculating the average channel gain within the sliding windows, by averaging over the frequencies and the 10 antenna positions, and we look at the results over the windows. In Fig. 3 the mean channel gain is shown for the 118 window positions over the array for 3 randomly selected LOS users and 3 randomly selected NLOS users. Window position 1 is located to the right in Fig. 1. As seen, the gain variations for those users is in the range of 4-6 dB over the array.

B. *K-factor analysis*

A detailed statistical analysis showed that the small scale fading, within the sliding window can be described by a Ricean or Rayleigh distribution. The K-factor of the received amplitudes was estimated using the method of moments [3] and showed variations in the range 0-3.5, where a K-factor close to zero means a Rayleigh distribution. The variations were present for the users both courts yards, but in general the users in the NLOS court showed somewhat smaller K-factors. Fig. 4 shows the K-factor variations for the same users as in Fig. 3. It is evident that the K-factors vary significantly over the array and hence that the small scale fading shows a varying distribution over it.

C. *Angular power spectrum*

Next we analyze the angular power spectrum (APS) for each user using the same sliding window of 10 antenna elements. For each window position the APS is estimated using Capon's beam former [4]. In Fig. 5 we show an example of the APS for user 9 in NLOS and in Fig. 6 we show the same thing for user 21 in LOS. In the NLOS case most of the scatterers are in quite a narrow sector, but we can see variations in the power received from various angles over the array. In the LOS scenario, strong contributions from various angles can also be seen. The LOS gradually moves from an angle of 100 deg. to 80 deg. over the array showing that a plane wave assumption over the array is not valid. It can also be seen that the power of the LOS component varies significantly and that new scatterers are appearing for certain window positions.

In order to further analyze the angular properties, we used the space-alternating generalized expectation maximization (SAGE) algorithm for high resolution parameter estimation [6]. This enabled extracting the AOA as well as the complex amplitude and delay. These results could be used for identi-

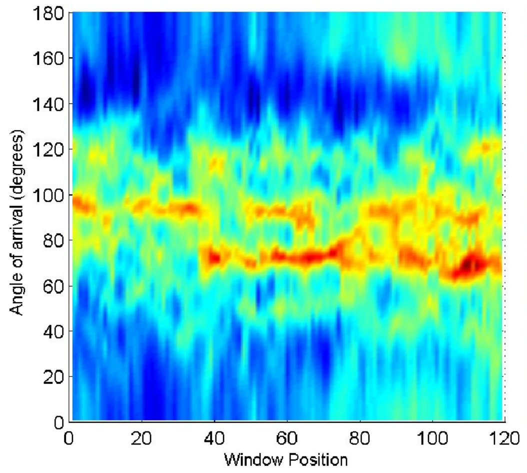

Fig. 5. Angular power spectrum over the array, user 9 NLOS.

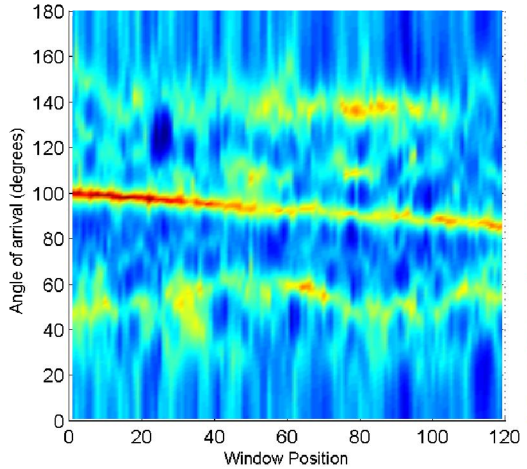

Fig. 6. Angular power spectrum over the array, user 21 LOS.

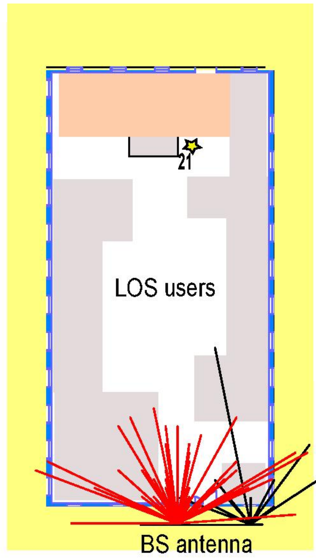

Fig. 7. Estimated multipath components for two different window positions, LOS user 21, window positions 15 and 80.

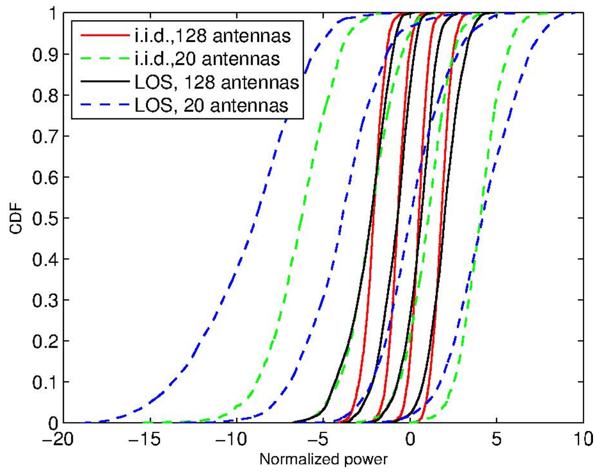

Fig. 8. Distribution of the eigenvalues for 4 randomly selected users in the LOS court.

fying physical scatterers and determining clusters visible over the array. We will not get into it in this paper, but this is left for further analysis. We estimate 200 multipath components in SAGE using a synthetic array response based on the assumption of omni-directional pattern. The used antennas (SkyCross SMT-2TO6MB-A) are more or less omni directional in the azimuth plane, but shows some variation in the elevation plane. We make a 2D parameter extraction and exclude the elevation effect and any cross polarization effects, which might cause some errors in the extracted parameters. The estimated angle-of-arrivals of the multipath components for user 21, window position 15 (black) and 80 (red), are shown in Fig. 7. Here the dynamic range is set to 20 dB and the length of the multipath components are scaled with the respective power in dB. As can be seen in the figure the number of multipath components within the dynamic range differs significantly, and so do the angle-of-arrivals. In window position 15 there is a clear LOS contribution, but this has more or less disappeared at window position 80.

D. Eigenvalue distribution

The CDF of the ordered eigenvalues of HH^H averaged over 1000 random 4-permutations of 26 and 10 users in LOS and NLOS courts are shown in Fig. 8 and Fig. 9, respectively.

To extract those eigenvalue distributions we normalize the power so that the mean received power of each user is unity, i.e.,

$$\frac{1}{N_f N_R}\sum_{f,i}\|H(i,j,f)\|^2 = 1, \tag{1}$$

where i is the Rx antenna number, j is the user number, f is frequency, N_f is the number of frequency points and N_R is the number of Rx antenna elements. As it could be seen in Fig. 8 and Fig. 9, using 128 antennas, these eigenvalues have a relatively low spread and low variations. The behavior is not too different from an i.i.d. case. As a comparison, by using 20 antennas, there are larger variations and distances

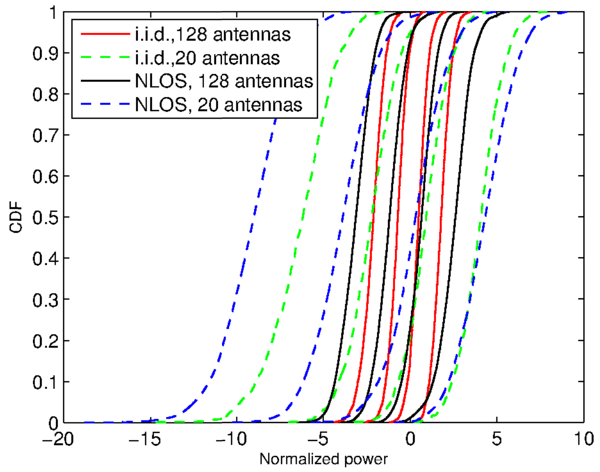

Fig. 9. Distribution of the eigenvalues for 4 randomly selected users in the NLOS court.

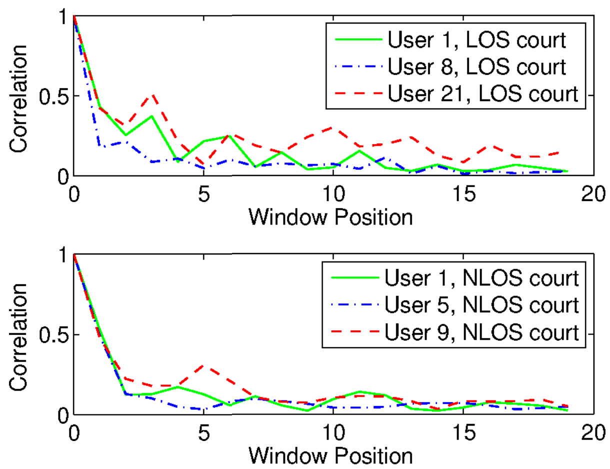

Fig. 10. Correlation for different antenna spacings at the base station side.

between the eigenvalues. Briefly speaking, it could be seen that in very large array case, eigenvalues have low variances (stable behavior) and a low spread.

E. Base station antenna correlation

Now, we switch the attention to correlation for different antenna spacings at the base station side. For convenience we make an average over the whole array, though it might not be strictly correct in a statistical sense due to the non-stationarities over the array. The resulting absolute values of the estimated complex correlation coefficients are presented in Fig. 10.

As could be seen, for the users who are located in the NLOS court, there is actually somewhat higher average and less varying correlation compared to the users in the LOS court. This is due to the relatively small angular spread and more stationary conditions in the NLOS court. There are larger fluctuations in the LOS court, which result in larger correlation variations; both higher and lower base station antenna correlation can be seen for the users in the LOS court depending on the specific user position.

F. User correlation

Finally, we analyze the correlation between different users, which is related to the inner product between propagation vectors. Again, we estimate the correlation coefficients between different user channels using all 128 antennas, (R_{128}^{LOS} and R_{128}^{NLOS}) and when using a subset of 20 neighboring antenna elements (R_{20}^{LOS} and R_{20}^{NLOS}) starting at antenna 1. In the LOS court, we randomly select users 6, 20, 5, 18 and in the NLOS court users 7, 3, 8, 10. The amplitudes of the complex correlation coefficients between the users are estimated to be

$$R_{128}^{LOS} = \begin{pmatrix} 1.0000 & 0.0207 & 0.0716 & 0.0308 \\ 0.0207 & 1.0000 & 0.0119 & 0.0125 \\ 0.0716 & 0.0119 & 1.0000 & 0.0166 \\ 0.0308 & 0.0125 & 0.0166 & 1.0000 \end{pmatrix}$$

$$R_{20}^{LOS} = \begin{pmatrix} 1.0000 & 0.0634 & 0.0933 & 0.0208 \\ 0.0634 & 1.0000 & 0.0320 & 0.1199 \\ 0.0933 & 0.0320 & 1.0000 & 0.0264 \\ 0.0208 & 0.1199 & 0.0264 & 1.0000 \end{pmatrix}$$

$$R_{128}^{NLOS} = \begin{pmatrix} 1.0000 & 0.0452 & 0.0641 & 0.0145 \\ 0.0452 & 1.0000 & 0.0369 & 0.0270 \\ 0.0641 & 0.0369 & 1.0000 & 0.0291 \\ 0.0145 & 0.0270 & 0.0291 & 1.0000 \end{pmatrix}$$

$$R_{20}^{NLOS} = \begin{pmatrix} 1.0000 & 0.1396 & 0.1681 & 0.0320 \\ 0.1396 & 1.0000 & 0.0858 & 0.0654 \\ 0.1681 & 0.0858 & 1.0000 & 0.0825 \\ 0.0320 & 0.0654 & 0.0825 & 1.0000 \end{pmatrix}$$

By using a large number of antennas the user correlation is quite low. As expected the correlation coefficients decrease (on the average) when using a lower number of antennas. In the 20 antenna case, some of the users suffer from high correlation due to less independent channels. The channel seems in this case to be rich enough to provide independent channels for the different users. It is left as future work to test how realistic algorithms perform when using the measured data, but the measurement results indicate that the system could perform well in this scenario.

IV. Modeling Consequences

The most important observation from the measurements is that the channel can not be seen as wide sense stationary over the large array, which has implications for modeling, simulation and theoretical analysis. It should also be noted that the Rayleigh distance of the large antenna array is 945 m. This means that all significant scatterers, as well as all users in this case, are in the near field of the antenna and that a plane wave approximation over the array is not suitable. In the measurements some/many scatterers are not visible over the whole array. This means that for modeling some kind of shadowing/visibility process has to be implemented. For scatterers being visible over the whole array, the power contribution might vary considerably, which also calls for some shadowing process. The same is true in case there is a LOS component. The results indicate that there is a need for modeling a LOS component with varying power contribution to account for the small scale fading variations, i.e., the transitions from Rayleigh to Ricean fading and vice versa. Our current working assumption is that an extended COST 2100 geometric stochastic channel model could be used as a base line for modeling. The extension is to use the visibility region concept also for the base station in order to account for the power variations over the array. Then each cluster of scatterers, or single multipath components, are associated with a visibility region defining the large scale fading over the array for the particular cluster or multipath component. As a remark, we think that the propagation conditions, from a large array point of view, are actually better than expected. The near field effects and the non-stationarities over the array help decorrelating the channel for different users, thereby providing a favorable channel conditions with stable channels and low interference for the considered single antenna users.

V. Conclusions

In this paper we have analyzed propagation characteristics from measurements of an outdoor large array base station scenario. The propagation characteristics, such as small scale fading, channel gain, and angular power spectrum vary significantly over the 7.3 m long linear array. In the measured scenario it is not suitable to use a far field approximation of the incoming waves, and the variations over the array call for modeling some kind of shadowing process at the base station.

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