THIRD DIMENSION FOR MEASUREMENT OF MULTI USER MASSIVE MIMO CHANNELS BASED ON LTE ADVANCED DOWNLINK

Saeid Aghaeinezhadfirouzja ,Hui Liu ,Bin XIA ,Qun Luo and Weibin Guo

Shanghai Jiao Tong University and Shenzhen Institute of Radio Testing
P.R. China
s.aghaei@sjtu.edu.cn

ABSTRACT

We characterize third-dimension (3D) of channel measurements based on two dimension channel model with fully-synchronize propagation of first time LTE-A multi-user centralized multiple-input, multiple-output(MU-MIMO) with sixteen transmitter antennas and three users. By exploiting the spatial correlation of signals originating from neighboring receiving antennas, there is a need for an accurate and actual radio propagation model around Shanghai Jiao Tong University (SJTU) campus network. The paper describes our real-time implementation and several test results are reported in the forthcoming LTE-A release. Measurements show the experimental characteristics of the sensitivity of the spatial correlation with the different array of polarization antennas between users that can be well approximated by a Kronecker production. In addition; we analyze the capacity of MU-MIMO systems to explain the achievable capacity rate of current LTE-A antenna configuration at the user side.

Index Terms: 3D, LTE-A, MU-MIMO ,Antenna polarization

1. INTRODUCTION

LTE-A requires MU-MIMO sharing the same radio resource such as time, frequency and spatial stream. The latest LTE-A standard [1] , for instance, can support up to 8-layer transmission which is equivalent to at least 8 antennas at the base station (BS) and 8 antennas at the mobile station (MS) [2].Since 3D channel measurement techniques are still not possible directly by the current LTE-A release, the 3rd generation partnership project (3GPP) is working on defining the required technical specifications [3] [4].

In this paper, a study has been conducted regarding the 3D measurement of spatial correlation MU-MIMO channels for outdoor scenario based on the on-going 3GPP on channel model MU-MIMO for LTE-A at 2.670 GHz to 2.680 GHz.Under the Kronecker model, the spatial correlation depends directly on the eigenvalue distributions of the correlation matrices between transmitters (R_T) and receivers (R_R). Each eigenvector represents a spatial direction of the channel and its corresponding eigenvalue describes the average channel/signal gain in this direction [5].

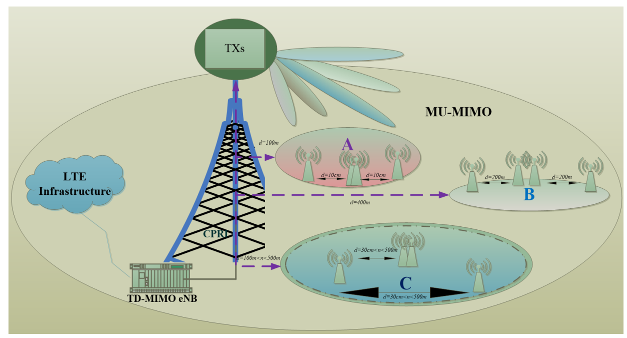

Fig. 1: *Multi-user MIMO transmission model system*

The greatest challenge for spatial correlation of future cellular network is to separate channels between users by different techniques including antenna positioning.Three areas were selected as static and dynamic locations for different group of users capturing signals, as shown in Figures 1 and 2 .The locations are in a triangular formation with each one having a certainly specific received power and antenna gain.

The first location A(UE1, UE2, UE3) line-of-sight (LOS) is set very close to the BS , the second B(UE1, UE2, UE3) LOS and (non-line-of-sight) NLOS ,with high and low density of the users are set at 150, 700 respectively. For the dynamic C(UE1, UE2, UE3) aspect, locations were set to be moving in a circular formation in reference to the original positions at the speed of 30 km/hr. The base station height is about 35 meters from the ground and the USRPs reception antenna's heights in all groups were 100 centimeters. Measured data were processed offline by Matlab software.

With multiple antennas at the receiver where the antenna is linearly polarized (vertically or horizontally) both vertically ($0°$) or horizontally ($90°$), the correlation is much higher than when it is dually- polarized ($0/90°$- one vertically and one horizontally). The high correlation degrades the MU-MIMO

This work is supported in part by the Shenzhen-Hong Kong Innovative Technology Cooperation Funding (Grant No. SGLH20131009154139588), and the State Major Science and Technology Special Projects (Grant No. 2015ZX03001035).

Fig. 2: *Schematic diagram of the experimental set-up*

performance. However in realistic propagation environments, the expected theoretical gains are not realized due to the significant spatial correlation present in the MU-MIMO channel [6], [7].We also investigated, in an ergodic capacity analysis, the channel correlation matrices that can be well approximated by the Kronecker product correlation model. However, in outdoor scenarios with a LOS, the capacity drops significantly when the users are close together, due to high correlation at both transmitters and receivers side of the channel.

This work helps to reveal the 3D propagation channels and improve the applicability of the international telecommunication union (ITU) spatial channel models in realistic 3D channel simulations. To the best of the authors knowledge, 3D-LTE-A measurements of MU-MIMO performance based on real channel data has never been performed so far.

The main technical contributions of practical MU-MIMO LTE-A downlink includes a) the development of an achievable scheme for 3D-LTE-A testbed of multiple antennas wide-band systems focusing on data transmission over continuous-time and dispersive MU-MIMO channels where the receiver knows all channels, b) compare separately the spatial aspects of multi user matrix correlations and their achievable capacity in a particular space, c) show an important practical factor that can degrade MU-MIMO system performance where empirical evaluation of spatial correlation was a key objective of the study.

2. MATHEMATICAL MODEL FOR MULTI-USER MIMO SYSTEM

The main attribute of the base station is to transmit the same message to the multiple-user data streams to be decoded by K independent users to increase the degrees of freedom. The downlink MU-MIMO communication model assumes that *K* users simultaneously receive signals from the BS. The channel matrix between the user $U_k; k = 1, ..., K$ and the BS is denoted by $H_k(M_k \times N)$. Each user receives a signals vector with the dimension $(M_k \times 1); k = 1, ..., k$ in terms of the interference signals coming from multiple users. Such is given as :

$$Y_k = H_k.X_k + \sum_{j \neq k}^{k} (H_k.X_j) + B_k; k = 1, ...K \quad (1)$$

$B_k; k = 1, ..., K$ is an additive noise signal vector size $(M_k \times 1)$.

With the presence of multiple antennas, the MU-MIMO system is represented by random matrix *H* with the dimension of 16×3 decomposed into K parallel of users. The downlink channel known as a broadcast channel in which $x \in C^{N_B \times 1}$ is the transmit signal from BS and $y_u \in C^{N_M \times 1}$ is the received signal at the *u*th user, $u = 1, 2, ..., K$.The received signal at the *u* th user is expressed as: where z_u is additive noise at the *u* th user . The overall system can be represented as :

$$y_u = H_u^{DL} x + z_u, u = 1, 2, ... \quad (2)$$

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} H_1^{DL} \\ H_2^{DL} \\ H_3^{DL} \end{bmatrix} x + \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \end{bmatrix} \quad (3)$$

Let $H_u^{DL} \in C^{N_M \times N_B}$ represent the channel gain between BS and the *u* th user [8]

3. SYSTEM IMPLEMENTATION

3.1. Hardware

The MU-MIMO channel correlation is performed in an outdoor environment. The BS is mounted at the rooftop of the Biomedicine building of SJTU campus as shown in Figure 2. There are sixteen transmit (eight pairs) of cross-polarized antenna elements and three users served as receivers. Three USRP's were used to capture multiple signals from a transmitter. Channel measurement and waveform data processing at a baseband unit is processed at USRPs.

3.2. Software

On the software side, the MU-MIMO application framework uses LabVIEW. In order to meet the Nyquist criterion, LTE-A sampling rate must be done at least 15.36 Mbps with 10MHz bandwidth. The USRP efficiently meets this requirement and acts as a host in a local network, and the communication with the computer is done over IP address. Once a connection is set up, the USRP sends the sampled data at the request of LabVIEW.

3.3. Frame Structure

The frame structure based on TDD configuration 2 is currently being used at the SJTU campus network. In this case of 10

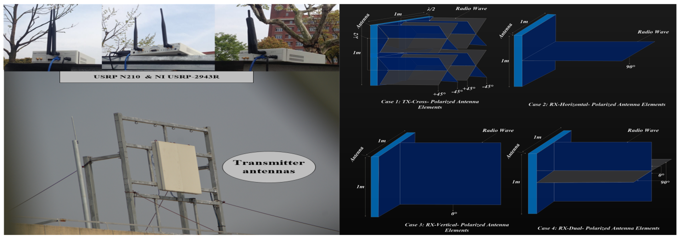

Fig. 3: *Centralized transmitter with multiple antennas and multiple users*

MHz bandwidth, our IFFT size is 1024, in accordance with LTE-A standards. 140 symbols were divided into 20 slots (each radio frame is consists of 10 sub frames of 1 ms duration). 600 subcarrier (50 RBs) were also used for transmission with the specification of physical downlink channel.

3.4. Antenna Configuration

In 3D MIMO system, the BS antennas are more likely to be placed in a 2D planar array [9]. Different cases of antenna configurations are illustrated in Figure 3. Sixteen antennas are employed using eight pairs of cross-polarized (X-Pol) antenna elements with +/-45 degrees polarization slant angle in the transmitter side and three users platform universal software radio peripheral (USRP) N210 and national instrument (NI) USRP-2943R at the receiver side with single and multiple antennas vertically, horizontally and ducally polarized. The spacing between two neighboring co-located cross-polarized antennas is $\frac{\lambda}{2}$.

4. SYSTEM MEASUREMENTS

Measurements made in the lab and extensive field trials show that LTE-A performs well in the physical layer. We extract the channel from the measured data and investigate the channel characteristics of MU-MIMO. The results of the frame transmission and subsequent analysis in accordance with the signal-to-noise ratio (SNR) for all antenna configurations and models of transceiver location used are listed in this section.

4.1. Spatially Correlation Channel

The propagation conditions characterize the channel correlation function in spatial domains [10].In practice, the channels between different antennas are often correlated and therefore the potential multi-antenna gains may not always be attainable [11].We focus and analyze the spatial correlation of the receivers including the effect of antenna polarization based on practical multi-path wireless communication environment.

The correlation matrix for a multiple antennas channel model is defined and for the performance evaluation of LTE, the so-called Kronecker product is generally used. With the perfect knowledge of the channel state information (CSI) , to

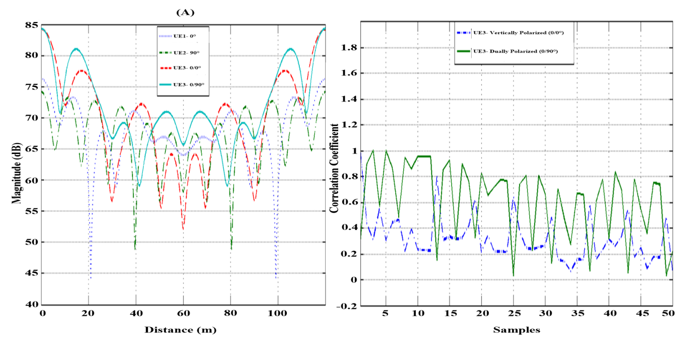

Fig. 4: *The receiver complex spatial correlation coefficient over group A for the different polarized antennas .The result consistently shows low and high spatial correlation depending upon antenna spacing*

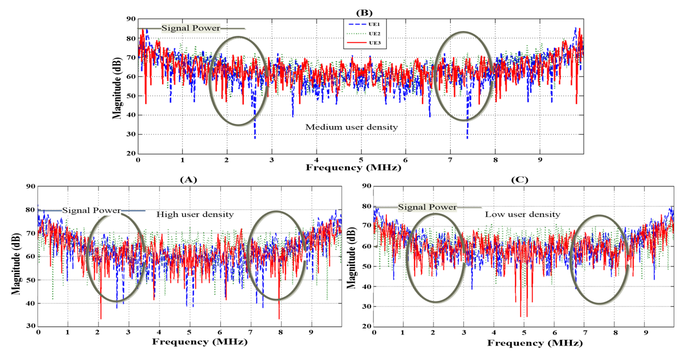

Fig. 5: *Representative plots showing the magnitude of the channel response between transmute antenna 4 and users with single and multiple antennas at conditions A, B and C with different correlation results depending upon user spacing*

generate the covariance matrix R_H the spatial correlation between the channels are defined as:

$$R_H = vec(H)vec(H)^H \tag{4}$$

$$R_H = \begin{pmatrix} h_{11}h_{11}^* & h_{11}h_{21}^* & \cdots & h_{11}h_{316}^* \\ h_{21}h_{11}^* & h_{21}h_{21}^* & \cdots & h_{21}h_{316}^* \\ \vdots & \dots & \ddots & \\ h_{316}h_{11}^* & h_{316}h_{21}^* & \cdots & h_{316}h_{316}^* \end{pmatrix} \tag{5}$$

where H is an $N \times M$ channel matrix then $h_{m,k}$ denotes the channel coefficient between the pair of $k-th$ user and $m-th$ receiving antenna.

Figure 4 shows the plot of spatial correlation coefficient between two polarized antennas which are vertically and dually polarized. Vertical or horizontal antennas that have high spatial correlation and two orthogonal (dual- 0/90) antennas, one vertical and one horizontal that have low spatial correlation when users are at condition A. The result shows that both configurations have significant different spatial correlation. Its required that low-correlated antennas are placed

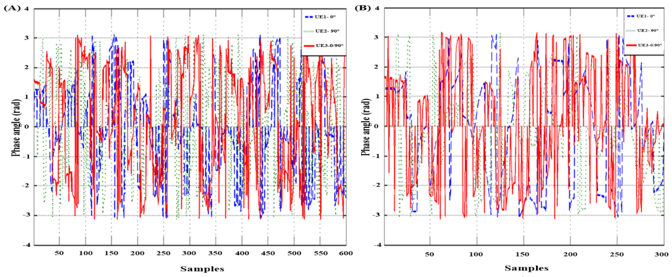

Fig. 6: *Phase response of channel between transmute antenna 4 and receiver antenna 1 and 2 for UE 3*

physically far apart from each other if wireless devices tend to be physically large.

Figure 5 shows typical plots of the magnitude of the channel response between transmit antenna 4 and users 1, 2 and 3 with different antenna spacing configurations. It is observed that the sensitivity of antenna correlations and the density of users equipped with multiple antennas will degrade the performance of MU-MIMO. In the case of A when users (antennas vertical, horizontal, dual) are close to each other, the received signal is affected and with strong correlation, the channel is ill-conditioned. In case B with spatially separated users, there is just a little correlation between polarized receivers. In the case of C, the users are dynamically separated from each other with 30-500 meter radius from where TX is mounted.

It can be seen that the signal quality in case C is almost the same with case A when high correlation is considered. So even with high SNR the density of users can degrade the communication performance compared with the low mobility of users. In all cases, it is observed that when users are not well-separated, the antenna spacing does not make the system effective. Figure 6 shows the phase of the channel response with the same data as in Figure 5.The phase profiles are observed to be poorly-correlated with the magnitude of the channel response (both cases A and B) over the same distance range. In two linear polarization (Dual) antennas, if the horizontal has a delay of 90 degrees, its phase will be compared to vertical polarization with the same amplitude with respect to prorogation. They will then get circular polarization and receive better signal. It can be seen, the performance of a MU-MIMO system can be shown depending upon the correlation of the complex channel response, not on the correlation of the magnitude of the response alone.

4.2. Channel Capacity

The channel capacity is always degraded by the receive-side spatial correlation as it decreases the number of spatial directions where the signal is received [11]. For each user channel matrix H, the channel capacity is computed by using the following expression:

$$C = log_2(det\left(I_M + HH^H\right))bps/Hz \tag{6}$$

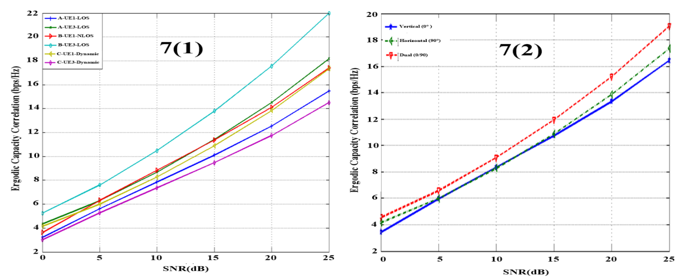

Fig. 7: *The channel capacity of different spatial correlations*

where, *det(.)* denotes the determinant ,H is the channel matrix of complex path gain,I_M is the identity matrix,H^H is the Hermitian of H.If the channel has low spatial condition number, its correlation is low and its diversity is high thus, making its capacity better [12]. Based on user density, when CSI is available at the receiver, the ergodic MU-MIMO capacity is depicted as shown in Figure 7(1). The user at high SNR in condition A with single receiver performs a lower capacity than user B when UE is at a medium SNR with less user density.From the picture, it can be seen that with multiple antennas at condition A, with high user density and SNR, the performance of MU-MIMO is much lower than when the user is in low spatial correlation with well separated users even if UE is farther from base station. Furthermore the channel capacity has been analyzed for different antenna polarization scheme. There have been different polarizations for different spatial channels.

It is seen in Figure 7(2) that for MU-MIMO receiver antennas, the results show that ergodic capacity proportionally increases with the number of antennas.The use of additional antenna improves the performance of communication system when it is polarized at 0/90 degrees. It is clear that a single receiver antenna sometimes has better performance, when the correlation between antenna elements including, the capacity is reduced.

5. CONCLUSION

This paper presents field experimental result characterizing the channel correlation and capacity of an outdoor MU-MIMO channel for LTE-A around Shanghai Jiao Tong University. An investigation has been conducted in the effect of the spatial correlation on the performance of MU-MIMO system when user density is low with multiple antennas. There is a high spatial correlation if the antenna spacing is not large enough. However, considering multiple correlations at all nodes, the use of lesser antenna increases the system performance. Channel measurement from this study has been used to examine the potential increase in capacity that can be achieved through different spatial channel. Ergodic capacity is computed as a function of correlation for both single and multiple receiver antennas. These results may also be used for antenna array design and MU-MIMO for outdoor setting.

6. REFERENCES

[1] S. H. Lim and S.-W. Lee, "Lte-advanced ca features in 3gpp rel-12 and its future," *The Journal of Korean Institute of Communications and Information Sciences*, vol. 39, no. 9, pp. 497–507, 2014.

[2] S. Wu, C.-X. Wang, H. Haas, E.-H. M. Aggoune, M. M. Alwakeel, and B. Ai, "A non-stationary wideband channel model for massive mimo communication systems," *Wireless Communications, IEEE Transactions on*, vol. 14, no. 3, pp. 1434–1446, 2015.

[3] A. Kammoun, H. Khanfir, Z. Altman, M. Debbah, and M. Kamoun, "Preliminary results on 3d channel modeling: From theory to standardization," *Selected Areas in Communications, IEEE Journal on*, vol. 32, no. 6, pp. 1219–1229, 2014.

[4] J. Wang, R. Zhang, W. Duan, S. X. Lu, and L. Cai, "Angular spread measurement and modeling for 3d mimo in urban macrocellular radio channels," in *Communications Workshops (ICC), 2014 IEEE International Conference on*. IEEE, 2014, pp. 20–25.

[5] E. Björnson, E. Jorswieck, and B. Ottersten, "Impact of spatial correlation and precoding design in ostbc mimo systems," *Wireless Communications, IEEE Transactions on*, vol. 9, no. 11, pp. 3578–3589, 2010.

[6] D.-S. Shiu, G. J. Foschini, M. J. Gans, and J. M. Kahn, "Fading correlation and its effect on the capacity of multielement antenna systems," *Communications, IEEE Transactions on*, vol. 48, no. 3, pp. 502–513, 2000.

[7] M. Kang and M.-S. Alouini, "Capacity of correlated mimo rayleigh channels," *Wireless Communications, IEEE Transactions on*, vol. 5, no. 1, pp. 143–155, 2006.

[8] Y. S. Cho, J. Kim, W. Y. Yang, and C. G. Kang, *MIMO-OFDM wireless communications with MATLAB*. John Wiley & Sons, 2010.

[9] K. Schalau, "Full-dimension mimo (fd-mimo) for next generation cellular technology," p. 1, 2015.

[10] S. Stefania, T. Issam, and B. Matthew, "Lte-the umts long term evolution: From theory to practice," *A John Wiley and Sons, Ltd*, vol. 6, pp. 136–144, 2009.

[11] C. Wang and R. D. Murch, "Adaptive downlink multi-user mimo wireless systems for correlated channels with imperfect csi," *Wireless Communications, IEEE Transactions on*, vol. 5, no. 9, pp. 2435–2446, 2006.

[12] H.-C. Lo, D.-B. Lin, T.-C. Yang, and H.-J. Li, "Effect of polarization on the correlation and capacity of indoor mimo channels," *International Journal of Antennas and Propagation*, vol. 2012, 2011.