Channel measurements and Angle Estimation for Massive MIMO Systems in a Stadium

LI Wenjuan*, LIU Liu*, TAO Cheng*[†], LU Yanping*, XIAO Jingcheng*, LIU Pengyu*

*Insititude of Broadband Wireless Mobile Communications, Beijing Jiaotong University, Beijing 100044, P.R.China

[†]National Mobile Communications Research Laboratory, Southeast University, Nanjing 210096, P.R.China

{13120105, liuliu, chtao, 13111030, 13120147, 13125028}@bjtu.edu.cn

***Abstract*—Massive multiple input and multiple output (MIMO) systems can increase the spectrum and energy efficiency of existing cells, and because of this, massive MIMO has been considered as a potential technique for next generation wireless communication networks. Since a thorough knowledge of the propagation channel is a prerequisite of reliable communication systems, massive MIMO channels are of great current interest. However, few investigations have been done on massive MIMO channels, especially for the angle properties. In this paper, based on the realistic massive MIMO channel measurement in a typical stadium environment at 1.4725 GHz, the angle spread properties are investigated. By employing the high resolution angle estimation method MUSIC and space-alternating generalized expectation maximization (SAGE) algorithm, the angular power spectrum in azimuth at each element along the virtual linear array are obtained.**

***Keywords*—Massive MIMO, channel measurement, Angular power spectrum (APS), MUSIC, SAGE, angle estimation;**

I. INTRODUCTION

Massive MIMO is an emerging and hot communication technique in recent years, whose use can substantially improve system spectrum efficiency, data rate and radiated energy efficiency [1], [2], [3]. In massive MIMO systems, the base-station is equipped with a large number (e.g., more than 100) antenna elements, whereas the mobile user terminal has few (one, or likely no more than two) antennas. A key assumption of massive MIMO systems is that the channels tend to pairwise orthogonal with increasing the asymmetrical antenna pairs [4].

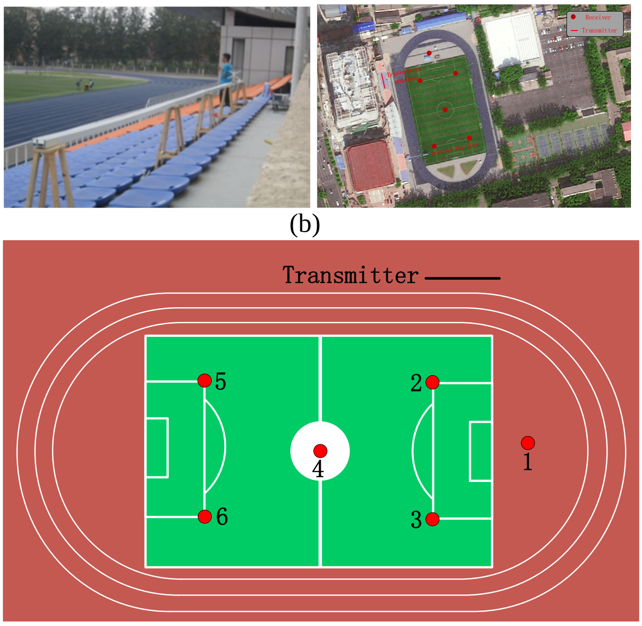
An accurate knowledge of the radio propagation channel is a vital element for study and performance evaluation of any communication systems. However, few investigations have been done on massive MIMO channels. To date, most published research results are mainly from a single institution, Lund University. These researchers used two types of antenna arrays to conduct the measurements in traditional environments: a virtual linear antenna array and a cylindrical antenna array. Channel measurements in [5] and[6], at 2.6GHz using a 128-element virtual uniform linear array (ULA), the Rice factor, angular power spectrum (APS), received power level and antenna correlation were extracted from the measurement data, the results showed that the angular power spectrum (APS) of the incoming waves varies significantly along the physically ULA. It also indicate that large-scale fading across the array is an important mechanism when dealing with physically large arrays. In [7], for comparison, the uniform cylindrical array (UCA) of patch antennas was used, also can find a similar effect of variation can be experienced over the array. In [8], the researcher simplified the APS from each user, they just show from which directions the incoming energy is strongest. The results provide an intuitive understanding of the distribution of incoming energy from different users in real channel. In [9], a cluster-based parameterization method was used for channel characterization. The channel parameters included the total number of clusters, the APS and the corresponding cluster power, their visibility regions and visibility gains. In [10], the authors proposed a theoretical non-stationary 3-D wideband twin-cluster channel model for massive MIMO systems. It was assumed that clusters may disappear or appear on both the array and time axes. All these previous studies are focused on traditional application scenarios, whereas in this paper, we look at a more novel setting.

The Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS) project has as one of its aims to lay foundations for future mobile and wireless system [11]. In this project, 12 test cases were proposed for practical application. However, some application scenarios have not been studied yet, including stadiums, shopping halls, etc. A typical stadium is an open propagation environment in which a huge wireless traffic demand occurs during an event. However, little channel characterization work has been done in this type of propagation scenario.

The main contribution of this paper is to investigate the angle properties over a large size antenna array in a stadium. Based on realistic experimental data, first, we will give an account of our measurements campaign with a scalable virtual antenna array consisting of up to 128 elements. After the serial correlation operation, the raw channel impulse response can be obtained. By using the high resolution angle estimation method MUSIC and SAGE algorithm, we respectively extract the angle of departure at the base-station side, and obtain the angular power spectrum (APS) in azimuth at each element along the virtual linear array.

The rest of the paper is organized as follows. In Section. II, the measurement campaign is described. In Sec. III, we will discuss the measurement data processing and angle properties that are observed from the measured data. Finally we summarize our contributions and draw conclusions in Sec. IV.

II. CHANNEL MEASUREMENTS



(b)

(c)

Figure 1. Photographs of the measurement. (a). The structure of virtual linear antenna array; (b). Google map of measurement site; (c). The different receiver positions

The measurement was performed at a center frequency of 1.4725 GHz and a signal bandwidth of 91MHz. We use a 128-element virtual linear antenna structure at the transmitter, as shown in Fig.1 (a). There is only one single antenna element moving along the track. The virtual antenna spacing is half a wavelength, hence the antenna array approximates 13m. A pair of bi-conical antennas are used at both the transmitter and receiver, the bi-conical antenna has an omnidirectional pattern.

We conducted the measurement in a stadium scenario at Beijing Jiaotong University. Fig. 1 (b) shows an overview of the propagation environment. The standard stadium ground covers 8,000 m^2approximately. A grandstand lies at the west side, and two tall buildings stand behind the grandstand. The main propagation condition is open and clear. We placed the transmitter antenna array on the grandstand, with a height of 5 m from the ground, and set the receiver equipment in the ground field, at six different receiver positions indexed with red spots in Fig .1 (c). The Tx-Rx distance was ranged from 50 to 150 meters. Due to equipment limitations of the virtual linear antenna array, specifically the time required to take all measurements at all elements of the array, we are initially investigating static channels. This ensures the channel coherence time is larger than our measurement time. Thus we ensured that there were few and rarely occurring moving objects and people near the measurement site when conducting the measurement.

In our measurement, we use a vector signal generator (R&S SMBV100A) as the transmitter. The receiver is consists of a RF down-converter and a high-speed digitizer card. In order to obtain the angle characteristics, the transmitter and the receiver must be accurately synchronized, hence, we used a rubidium frequency source trained by a GPS clock for synchronization. Then the clock systems of the transmitter and receiver were connected with a fiber.

The measurement parameters are listed in TABLE I.

TABLE 1. MEASUREMENT SYSTEM SPECIFICATIONS

Central frequency	1.4725GHz
Bandwidth	91MHz
Antenna number	128×1
Synchronization	Rubidium + GPS.
Excitation signal	Zad-off Chu sequence
Code Length	2047
Tx antenna height	8m (grandstand is include)
Rx antenna height	2.5m

III.MEASUREMENT RESULTS

A. *Data processing*

Sliding correlation in the time domain is the most popular channel sounding method. At the transmitter, the complex-valued Zad off Chu (ZC) sequence with length of 2,047 was employed as the excitation signal due to its excellent correlation properties and constant amplitude. At the receiver, the raw channel impulse response (CIR) can be calculated by the serial correlation operation between the received raw baseband signal and the local transmitting copy signal, which can provide the knowledge of multipath components (MPCs) in term of resolvable delays. Let $r(m,l)$ be the raw baseband received signal with l the delay index at antenna element$m$ m , and then the CIR can be calculated by the serial correlation operation as

$$h_1(m,l) = \frac{1}{N}\sum_{n=0}^{N-1} r(m,l+n)c^*(n), \tag{1}$$

where N is the size of the correlation window 2047, n represents the time index and l the delay, $c(n)$ is the local ZC signal, and $*$ denotes the complex conjugation. Due to the nature of the surrounding environment, the number of paths and the relative time delay are different. The phenomenon of time delay spread in CIRs could be attributed to the multipath effect, of which traits can be depicted by power delay profile (PDP). We average 900 snapshots in order to remove the environmental impacts on the measurement results and enhance the signal to noise ratio performance. The PDP can expressed as

$$P_{PDP}\left(it_{av},k\Delta\tau\right) = \frac{1}{L}\sum_{n=iL}^{(i+1)L-1}\left|h\left(nt_{rep},k\Delta\tau\right)\right|^2, \tag{2}$$

where t_{av} and $\Delta\tau$ represents the average of time delay interval and time delay resolution, respectively, t_{rep} denotes the snapshot repletion period. In order to accurately extract the MPCs from each snapshot, we use the dynamic variable noise floor to eliminate noise, and then utilize the local maximum method to extract the MPCs. Fig .3 show an example of PDP and MPCs.

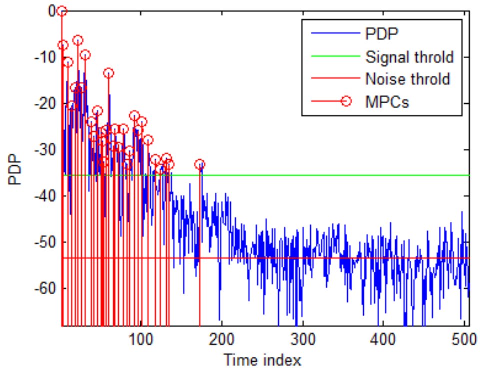


Figure 2. An example of PDP and MPCs.

B. *Estimation of Departure angles*

One basic assumption of the massive MIMO system is that the channels are pairwise orthogonal. In practice, however, this termed favorable propagation condition does not meet in all propagation environments such as the LOS component dominant scenario. This is because in LOS scenarios, the channels are correlated to some degree, which may degrade the transmission performance of a massive MIMO system. In this section, we will use the high resolution angle estimation method MUSIC and SAGE to extract the angle properties at the base-station side.

The MUSIC algorithm is a relatively simple and efficient method of the angle estimation. The algorithm is based on the assumption that the noise subspace eigenvectors U_N are orthogonal to the array steering vectors $\boldsymbol{c}(\phi)$. The noise subspace can be estimated by the eigenvalue decomposition of the estimated array correlation matrix or singular value decomposition of the data matrix, after the eigenvalue decomposition, sorted the eigenvalues from largest to smallest, then we can divide the matrix into two subspace, i.e., the noise subspace and the signal subspace. Once the noise subspace U_N has been estimated, a search for angle in the range is made by looking for steering vectors that are orthogonal to the noise subspace as possible. This can accomplished by searching for peaks in the MUSIC spectrum.

Let $y_i(t)$ denote the received signal from the i th transmit antenna element with the channel gain α_i, delay τ_i and AOD ϕ_i. The transmitted signal of each path consists number of unresolvable signals around the mean of AOD in each antenna element. A vector of the received signals $\boldsymbol{y}(t)=[y_1(t),y_2(t),\cdots,y_{128}(t)]^T$ from the uniform linear transmit antenna array (ULA) of 128 elements can be expressed as

$$\boldsymbol{y}(t)=\sum_{i=1}^{I}\alpha_i\boldsymbol{c}(\phi_i)x(t-\tau_i)+\boldsymbol{N}(t), \tag{3}$$

where I denotes the number of paths in each antenna element and $\boldsymbol{c}(\phi)$ is an array steering vector. The array steering vector is defined as

$$\boldsymbol{c}(\phi)=[c_1(\phi),c_2(\phi),\cdots,c_M(\phi)]^T, \tag{4}$$

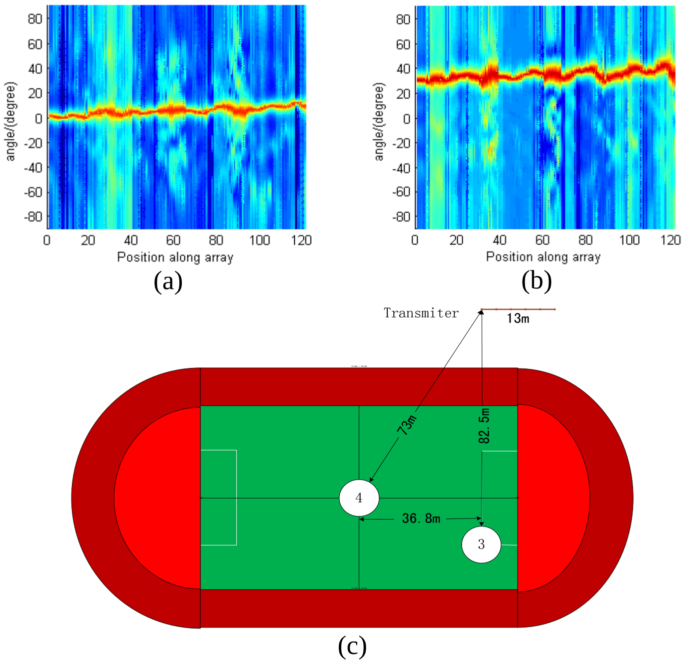
where $c_m(\phi)=e^{-j2\pi(m-1)(d/\lambda)\sin\phi}, m=1,2,\cdots,128,$ Then we can obtain the data covariance matrix from the received signals, it can calculated by

$$R=E[y(t)y(t)^H], \tag{5}$$

Since the array steering vector $\boldsymbol{c}(\phi)$ is orthogonal to the noise subspace U_N, calculate eigenvalues and eigenvectors of the data covariance matrix, then we can from the orthogonality of the signal and noise subspace, estimate the AOD base on peaks of the MUSIC spectrum.

$$P_{MUSIC}(\theta)=\frac{1}{c^H(\phi)U_N U_N^H c(\phi)}, \tag{6}$$

As shown in Fig. 3(c), the connection line between the position 3 and the first antenna element of the antenna array is vertical to the antenna. According to the geometry relation between the position 3 and the antenna array, the theoretical AOD will change from 0 to 9 in degree.



(a)

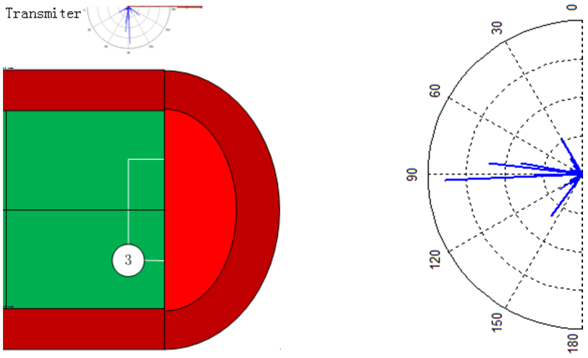
(b)

(c)

Figure 3. Angular power spectrum over the array.(a)position 3;(b)position 4;(c) the geometry relation between the receiver and the antenna array

The estimated AOD of this environment using the MUSIC algorithm is plotted in Figure.3. For the user at position 3 and position 4 are provided. From Fig.3 (a), we can see that in the line of sight (LOS) component dominant environment, the angle of departure of the LOS signal gradually moves from an angle of 0 to 10 in degree. The extracted results match to the existing geometry of our measurement environment where the transmitter and the receiver as shown in Fig. 3(c). The similar results extracted from the position 4 measurement data are shown in Fig. 3 (b).

In order to further analyse the angular properties, we used the space-alternating generalized expectation maximization (SAGE) algorithm for high resolution parameter estimation [12]. This algorithm enabled extracting the PAS, i.e. AOD of the signal as well as its complex amplitude. In our data processing, we use 900 temporal channel snapshots for the PAS extraction. The estimated PAS by utilizing the estimated AODs for each MPCs and their estimated powers is shown in Fig. 4. The length of the lines in the PAS indicates the power of the MPCs in dB scale. From the Fig. 4 (b), we can see that the AODs of MPCs with significant power are concentrated in a narrow angle spread due to the LOS dominant propagation. Meanwhile, the multipath components in the APS are comparatively weaker than the LOS component. From the measurement environment we have discussed in Section. II, there have two tall buildings stand behind the transmitter, so we can see several MPC with relatively high strength emitted from the transmitter, as shown in Fig. 4(b).



(a) (b)

Figure 4. The PAS for the antenna array

IV. CONCLUSIONS

Based on realistic measurements, this paper have analysed the angle characteristics of Massive MIMO in stadium scenario. The results show that in the LOS components dominant environment, the DOAs of the LOS signal changes with the geometrical position in the environment. Meanwhile, there are several MPC spread in the angle domain due to the reflection from the building at back of the transmitter antenna array.

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Wenjuan Li received the B.E degree from Agricultural University of Hebei, Baoding, China, in 2013. She is currently pursuing the M.S. degree of institute of Broadband Wireless Mobile Communications, School of Electronic and Information Engineering, BJTU. Her general research interest focuses on channel measurement and modeling under different scenarios**.**