Propagation Characteristics Investigation in Measured Massive MIMO Systems at 1.4725GHz

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***Abstract*—Massive multiple-input multiple-output (MIMO), as a candidate technology for the 5th generation (5G) of wireless communication systems, theoretically presents a highly promising solution to meet the demanding requirements of even higher network capacity, throughput, spectrum- and energy-efficiency than ever before. Recently a significant number of propagation and channel modeling papers have reported. However, few investigations have been done on Massive MIMO channels equipped with more than 100 of antennas. A thorough knowledge of a reliable and realistic channel model serves as the enabling foundation for practical design and testing of the Massive MIMO communication systems, so Massive MIMO channels are of great current interest. This paper provides a critical review of the fading correlation derived from propagation measurements. More channel parameters like rms delay spread, correlation bandwidth, and angle power spectrum are detailedly discussed. Examples are given and comparisons are made of results from analyzes in a typical open stadium and meeting hall scenarios respectively at 1.4725 GHz. These results reveal the fading correlation characteristics in the line of sight (LOS) component dominant environment of Massive MIMO channels, and provide the basis for the practical deployment of Massive MIMO systems.**

***Keyword*—Massive MIMO, wireless channel, channel measurement, Multipath component, frequency correlation, Angle of depart.**

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I. INTRODUCTION

THE rapid development of the internet and mobile communication speeds up the research of the 5th generation (5G) wireless communication systems. Internet of things is also the primary driver to the 5G. Massive multiple input and multiple output (Massive MIMO), as a potential technique for the 5G wireless communications systems, has got a lot of attention in recent years, which can substantially improve system spectrum efficiency, data rate and radiated energy efficiency[1], [2], [3]. In massive MIMO systems, due to the large number of antenna array elements, the system performance can be greatly improved whether by utilizing the spatial multiplexing technology to increase the channel capacity or by spatial diversity technology to enhance the link reliability. So far the research results in theory are mostly under an assumption that the channels tend to pairwise orthogonal with increasing the asymmetrical antenna pairs [4]. In practice, the condition is not hold, even in the benign environment such as a dense scattering environment or a line of sight (LOS) propagation scenario, which have been proposed in The Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS) which aims to lay foundations for future mobile and wireless system [5]. In such propagation channels, the multipath components are correlated to some degree, which must generate the system's performance degradation in consequence.

To data, most researches are based on traditional MIMO system, which are equipped no more than 8 antennas. However, few investigations have been done on massive MIMO channels. In light of the published research results from Lund University, one of the earliest teams to study the Massive MIMO based on practical measurements. They used two types of antenna arrays to conduct the measurements in traditional environments: a virtual linear antenna array and a cylindrical antenna array. In [6], performance of antenna selection on transmitter side in realistic environment was investigated. In [7], the Rice factor, received power level and antenna correlation were extracted from the measurement data at 2.6 GHz. In [8], the time delay spread properties in line-of-sight (LOS) and non line-of-sight (NLOS) scenarios were studied. In [9], linear pre-coding performance was investigated using the realistic massive MIMO measurement data. In [10], a cluster-based parameterization method was used for channel characterization. The channel parameters included the total number of clusters, their visibility regions and visibility gains.

The fading correlation in frequency domain is an indicator of the coherence bandwidth. In this paper, based on the realistic measurement data, we estimate the frequency correlation (FCE) of massive MIMO channels. The FCE is derived from the channel transfer function, which shows a significantly difference while using the traditional method of derivation via a Fourier transform of the channel's average power delay profile. The difference is mainly cause by the reason that frequency correlation characteristics are a function of frequency, rather than just frequency deviations, and multipath signals are correlated. Measured data are presented to verify the conclusions.

The Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS) project which aims to lay foundations for future mobile and wireless system has proposed 12 test cases for practical application[5]. However, little work has been done on some of the scenarios, including stadiums, meeting halls, etc. A stadium is a typical open propagation environment where a heavy wireless traffic may outbreak for dense crowds. Yet a meeting hall is a typical close radio environment to occur huge communication demand during a event such as lecture or conference.

The main contribution of this paper is to investigate the radio propagation fading characteristics of Massive MIMO channels in an open stadium and a meeting hall scenarios based on realistic experimental data. We focus on some channel parameters, including multipath distribution, frequency correlation and angle properties.

The paper is organized as follows: in Section II, we describe our Massive MIMO channel measurements, the measurement setup and data primary processing are introduced. In Sec. III, we will discuss the channel parameters extraction from the measurement snapshots. Here two measurement examples are presented and measurement results are compared. Finally we summarize our contributions and draw conclusions in Sec. IV.

II. CHANNEL MEASUREMENTS

A. Channel measurement setup

The investigations are based on channel measurements in outdoor and indoor scenarios respectively. In both campaigns we employ a 128-element virtual uniform linear array (ULA) at base station, which is realized by moving a omni-directional antenna in 128 fixed positions of a rail track with an adjacent distance of half a wavelength at 1.4725GHz. The array is physically large and spans more than 13 m in space. The signal bandwidth is 91MHz. It takes around half an hour to record the data of one user spot when the antenna finished all of the 128 position.

A vector signal generator (R&S SMBV100A) is used as the excitation source. A 128-element virtual linear structure antenna works at the transmitter side. The special advantage of the bi-conical antenna is that it has an almost equal gain in the H-plane, therefore different directional signals can reach the receiver with the same antenna gain. The data collector is composed of a RF down-converter and a high-speed digitizer card and a data storage unit. The time synchronism is maintained by using the rubidium clock trained by the GPS. Then the clock standard is transmitted to far end using a fiber for the accurate synchronization performance.

B. Data primary processing

The complex-valued Zad-Off Chu sequence with the length of 2,047 is employed as the excitation signal due to its orthogonality and constant amplitude. Here, let $r(m;k)$ be the raw baseband signal with k time index at antenna *m*, and then the channel impulse response (CIR) can be calculated by the serial correlation operation as

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

where N is the size of the correlation window, n represents the time index, $c(n)$ is the local transmitting copy signal, and * denotes the conjunction operation.

Then the channel's power delay profile (PDP) can be denote as below

$$P_{PDP}(m;n)=\frac{1}{L}\sum_{i=1}^{L-1}\left|h(m;n+iL)\right|^2\,, \qquad (2)$$

where L represents the number of record samples.

In order to accurately extract the MPCs from the noise in each snapshot, we use the dynamic variable noise floor to eliminate noise, and then utilize the local maximum method to extract the MPCs. Fig .1 show an example of MPCs separation.

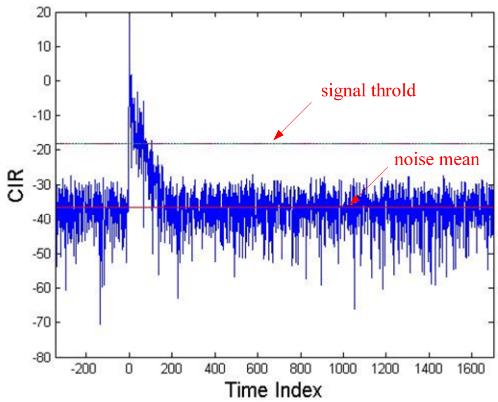

Fig. 1. Example of MPCs separation

III. MEASUREMENT RESULTS

The following sections demonstrate the analysis of data measured on Massive MIMO radio channels. Two examples are given. The first example is an outdoor LOS scenario, while In the second example, a typical indoor meeting hall scenario is chosen.

The received radio waves are composed of many components, due to the possible reflection, scattering, diffraction and so on, which is so-called multipath effect. These components arrive the receiver with different amplitude, phase and time delay, which cause the signal fading and dramatically affect the system performance. So multipath component (MPC) is the primary interest of wireless channel research works. Unlike multipath is illustrated directly in time domain, frequency corrlation is another important point, which connected with the correlated bandwidth. As to Massive MIMO system, the correlation between transmit and receive antennas is also an important aspect. Considering a SIMO (Single Input Multi Output) channel, It depends on the angle-of-depart (AoD) of each multi-path component. So it is necessary to bring in AOD to investigate the channel's spacial characteristics, since the huge number of antenna has extended the research dimension to space domain.

A. *Outdoor measurement scenario: open stadium*

We conducted the measurement in a stadium at Beijing Jiaotong University. The standard stadium propagation is open and clear. A grandstand lies at the west side, and two tall buildings stand behind the grandstand. 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. Because the measurement was performed at night, there were very few objects, cars or people, moving around the area, so that the channel can be more static. Fig. 2 shows the measurement scenario.

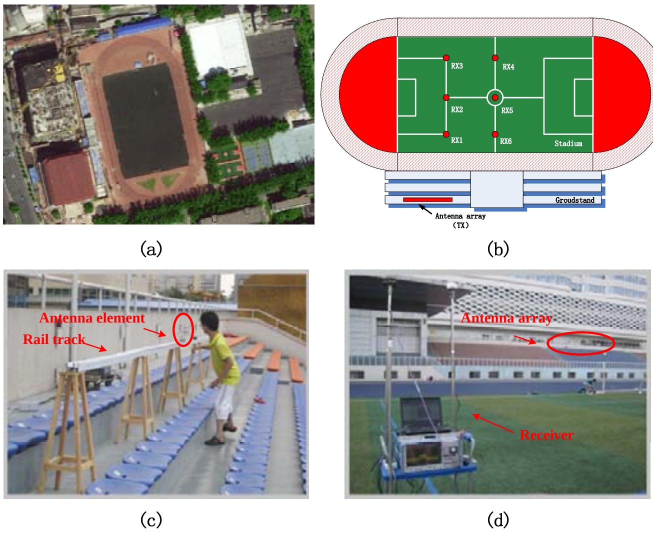

Fig. 2. Measurement in stadium scenario
(a) Google map of the measurement spot; (b) the measurement scenario sketch map; (c) sight from the transmitter in-field; (d) sight from the receiver in-field.

1) *Multipath distribution over the antenna array*

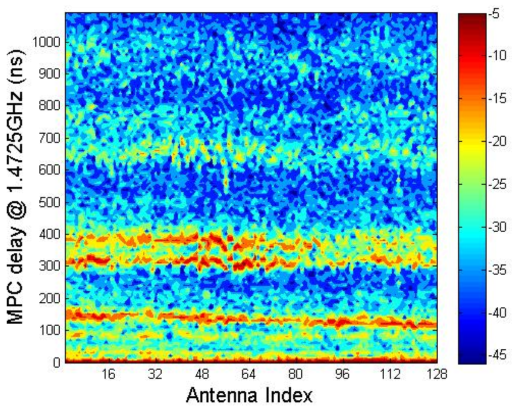

Fig. 3. MPCs distribution in outdoor scenario

Fig. 3 plots the distribution of the multipath power components over the antenna array at the stadium position 6. The distance between transmitter and receiver is about 100m. From Fig. 3, many MPCs can be seen clearly. But It is obvious that the power of LOS signal is significantly larger than other NLOS components. Some of MPCs of each antenna do not change significantly with the antenna, while some of them vary, which is clearly an birth and death process. In some antenna positions, the MPC is existed and continuous, but from other antenna position, the MPC can't be observed. From the above introduction about measurement environment, we know that there are two tall buildings standing behind the transmitter, so it is quit reasonable for several MPCs with relatively high strength in receive signals.

2) *Frequency correlation*

The low-pass channel transfer function can be expressed as

$$H(f;t)=\int_{-\infty}^{\infty} h(\tau;t)\cdot e^{-j2\pi f\tau}\,d\tau \quad , \tag{3}$$

where τ represents the time delay.

Let $\{a_i \mid a_{i,j}=H(f_i;t_j)\}$ be a frequency related power in frequency of f_i, which equals to the complex amplitudes of the channel transfer function at different spectral lines, setting f_{ref} to be the reference frequency, and $\Delta f = f_i - f_{ref}$, then the estimation of frequency correlation can be derived as below [11]

$$R_H(\Delta f)=\frac{\gamma_H\left(a_{ref},a_i\right)}{\sqrt{\gamma_H\left(a_{ref},a_{ref}\right)\gamma_H\left(a_i,a_i\right)}}\,, \tag{4}$$

where $\gamma_H\left(a_{ref},a_i\right)$ represents the cross-correlation between set $\{a_i\}$ and $\{a_{ref}\}$, can be expressed as

$$\gamma_H\left(a_{ref},a_i\right)=\frac{1}{N}\sum_{j=1}^{N} a_{ref,j}a_{i,j}^{*} \quad . \tag{5}$$

Similarly, $\gamma_H\left(a_{ref},a_{ref}\right)$ and $\gamma_H\left(a_i,a_i\right)$ respectively represent the auto-correlation of set $\{a_i\}$ and $\{a_{ref}\}$, N represents the number of the recorded samples.

In Fig. 4, the frequency correlation characteristics are illustrated. The horizontal axis shows the frequency deviation relative to the reference frequency. The vertical axis shows the relative variation of the frequency correlation coefficient.

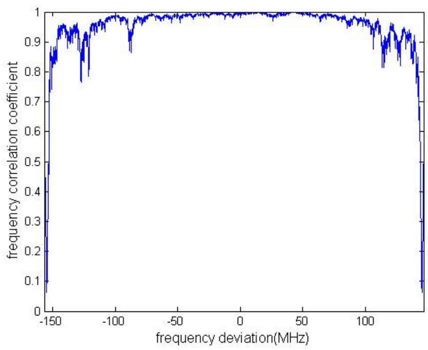

Fig. 4. Frequency correlation in outdoor scenario

3) AOD distribution over the antenna array

In order to analyse the angular properties, we used the space-alternating generalized expectation maximization (SAGE) algorithm for high resolution parameter estimation [12]. We respectively extract the angle of departure at the base-station side, and the result is shown in Fig. 5. The solid red line denotes the best fitting line of the AODs over the whole antenna array. The blue circles represent the caculated results from the measurement data of every antenna.

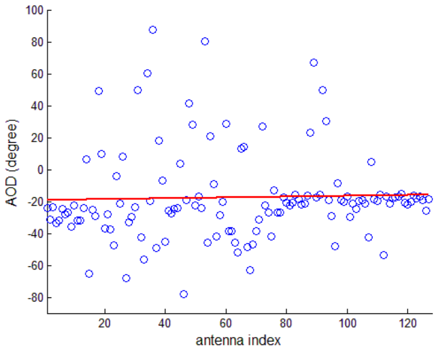

Fig. 5. AOD over the antenna array in outdoor scenario

From Fig. 5, we can see that the AODs of MPCs with significant power are distributed in a broad angle range due to the abundant MPCs. Because the multipath components are comparatively weaker than the LOS component, the trend of angle fluctuation seems right.

B. Indoor measurement scenario: meeting hall

For the purpose of evaluating the system performance and getting more comparable results, another measurement campaign has been conducted in a meeting hall at Beijing Jiaotong University, which is about 23 m in length, 20.5 m in width, and the height of 5 m in front of the auditorium, decreasing to 4 m in the back seats, can accommodated 420 person at a time. We placed the transmitter antenna array on the stage, with a height of 2.2 m from the ground,and set the receiver equipment in the auditorium, at four different receiver positions. Fig. 6 shows the measurement scenario.

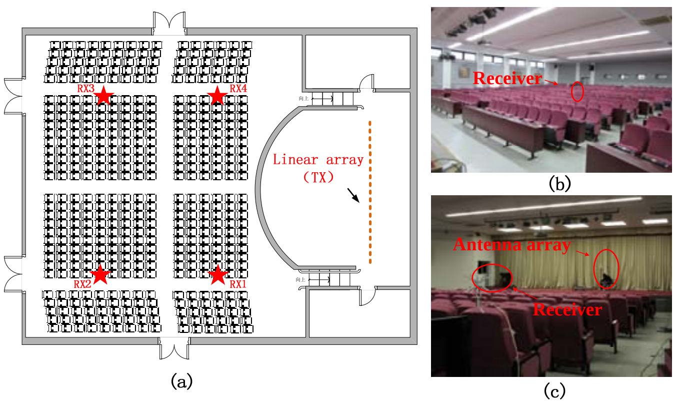

Fig. 6. Measurement in meeting hall scenario
(a) The measurement scenario sketch map; (b) sight from the transmitter in-field; (c) sight from the receiver in-field.

1) Multipath distribution over the antenna array

Fig. 7 shows the multipath power component distribute along the antenna array at measurement spot 1, which is at the nearest distance of about 8m away from the array. It is quit different from the outdoor scenario because more scatterers cause NLOS componnets strong contribute to the receiver power. Meanwhile, the small time delay of multipath power components leads to the number of distinguishable multipath rapidly decreased. So the channel CIR envelope is smoother. Compare to the results at stadium, it is intuitive that NLOS signals generate more contribution to the channel fading.

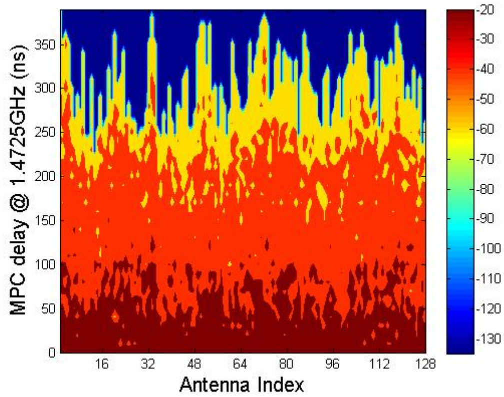

Fig. 7. Multipath power component distribution in indoor scenario

2) Frequency correlation

The frequency correlation characteristic of indoor scenario is illustrated in Fig. 8. It is clear that the curve is quit flat over the frequency deviation. To compare with the result of outdoor measurement, the fluctuation of correlation coefficient seemly keep unchanged within signal bandwidth. The reason for the indoor curve is flatter is that, when the radio propagation is limited in a very short distance in the indoor environment, and the walls generate plenty of components due to reflection and scatering, because of propagation difference is so tiny, in the receiver many undistinguishable multipath components composite to one component. So many details can't be extracted from the caculate result of indoor scenario.

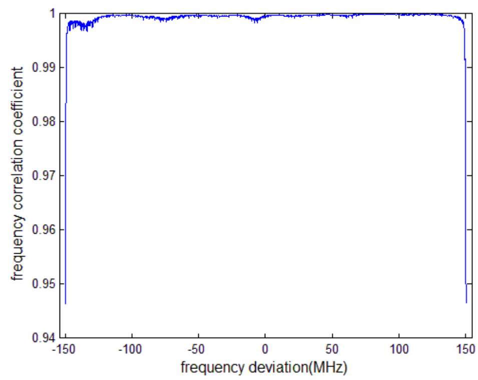

Fig. 8. Frequency correlation estimate in indoor scenario

3) AOD distribution over the antenna array

In indoor measurement, we can get the more ideal AOD results, illustrated as Fig. 9. The solid red line is the fitting line of the AODs. We can see that the AODs are concentrated in a narrow range of the fitting line due to the LOS dominant propagation and litter number of MPCs. Because the distance between the transmitter and receiver is not so far comparing with the antenna array physical size, the AODs vary from -48 degree to about zero degree.

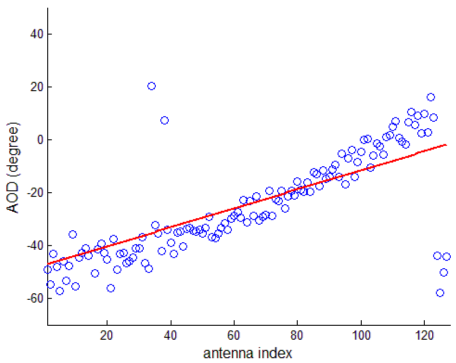

Fig. 9. AOD over the antenna array in indoor scenario

IV. Conclusions

This work investigated the channel characteristics of Massive MIMO channels based on experimental data. The measurement performed in indoor and outdoor scenarios respectively, and the results are compared. Although as we know, in LOS scenario, the LOS component is the key factor to the channel characteristic, it is obvious that the NLOS components strongly influence the channel behaviours. On the channel represented by measured data in the first example, the strong NLOS MPCs lead to the fading fluctuation over the antenna array. In the second example, a goodness of fit with theoretical result are observed due to weak and little MPCs.

These results may be helpful to parameters design in wireless communication systems.

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