Elevation angle characteristics of urban wireless propagation environment at 3.5 GHz

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***Abstract*—It is known that channel model of propagation characteristics are crucial in the research and evaluation of three-dimensional multiple-input multiple-output (3D-MIMO) technique, especially the elevation angle (EA) model. In this paper, the results of 3D-MIMO channel measurement in the urban macro-cell (UMA) scenario at 3.5 GHz are presented. Based on the measurement data, it is find that the mean value of elevation angle has a offset angle to line-of-sight (LOS) angle especially in not-line-of-sight (NLOS) situation. And the offset angle is depend on the azimuth distance between BS and MS which can be modeled as a function that use distance as a parameter. A novel way to model mean angle of elevation angle is proposed at the end of this paper. The relation between Circular angular spread (CAS) and distance is also studied, the measurement result shows that the effects caused by distance can be neglected.**

I. Introduction

As the fast development of mobile internet and increasing of smart device users, mobile data service presents explosive growth momentum. In newest standard Release 12 released by 3rd Generation Partnership Project (3GPP) at September 2012, higher frequency band (such as 3.5 GHz) is recommended in mobile communication network, whereas to improve the quality of network coverage, the cell will be much smaller than before. When the cell become smaller, the vertical domain that omitted in existing channel model cannot be ignore any more especially in indoor environment. Thus, in order to enhance the existing network performance and base on the research of beam-forming involved in Release 11, three dimensional MIMO is born. The 3D-MIMO is approached by dynamically weighting the antenna element both in horizontal and vertical plane. From this point, the 3D-MIMO can also be called as 3D beam-forming which point different beams to different users in 3D space. It is well known that channel model is crucial in the evaluation of 3D techniques and the elevation angle is an important parameter when we come to 3D space. Considering the two ends of a complete communication link, the statistics property of elevation angle is necessary in modeling 3D space signal propagation, i.e. elevation angle of departure (EAOD) and elevation angle of arrive (EAOA).

Channel measurement is a popular way to capture the channel characteristics [1]. However, with respect to the elevation domain of the radio channel, measurement results are largely insufficient. Little or no measurement support is available. The main purpose of this work is to improve the cognition of how wave travels in elevation domain as well as how the distance impact on the modeling of angle of arrival/department.

(a) omni-directional array (ODA)

(b) uniformed panel array (UPA)

Fig. 1. Measurement antenna

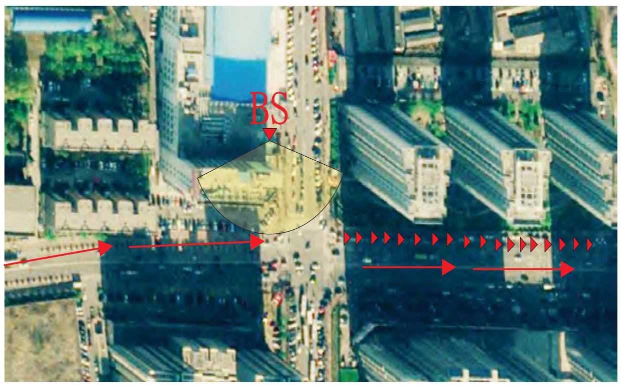
In this paper, measurement of 3D-MIMO channel is carried out in a typical macro-urban scenario in Beijing at 3.5 GHz. Elevation angle data are extracted from the measurement results by Space-Alternating Generalized Expectation maximization (SAGE) algorithm. The rest of this paper is organized as follows. Section II describe the measurement environment and system. In section III the data progressing are presented. The result analysis is in section IV. The paper is concluded in section V. Acknowledgements are noted in the last section.

II. measurement environment description

A. Measurement system

The measurements utilize the Elektrobit Propsound Channel Sounder which has been used in WINNER project [2] at a carrier frequency of 3.5 GHz. A dual-polarized uniformed panel array (UPA) with maximum 32 elements is employed at Base Station (BS), whereas a dual-polarized omni-directional array (ODA) is used at Mobile Station (MS). The illustrations of these two antennas are shown in Fig. 1. The UPA can simulate the real world BS array work, and it has 4 rows of dual-polarized pattern in the vertical direction so it has a sensitive resolution ratio in the vertical direction. The ODA have great omnidirectional, can capture all the incoming wave information. All the elements of both UPA and ODA antenna are used in order to get sufficient information of elevation angle. Time domain multiplexed fast switching is used for the BS and MS arrays to ensure the measured time less than the channel correlation time.

(a) Measurement environment of LOS scenario



(b) Measurement environment of NLOS scenario

Fig. 2. measurement scenario

B. *Measurement scenario*

To simulate urban macro-cell scenario, we choose a commercial district in Beijing, China. The base station antenna was set on the rooftop of the five-storey mall, about 25 m high above the ground. The highest surrounding building is about 78 m while the lowest is about 11 m. The BS-MS distance is range from 84 m to 280 m in LOS and from 102 m to 328 m in NLOS. The specific information about the measurement parameter setting can be seen in Tab.I.

Long distance routes (red line in Fig. 2) and fix spots (red triangle in Fig. 2) were chosen to cover the whole scenario. The Global Positioning System (GPS) information of the BS and MS were recorded by small lightweight GPS receiver and can be used to get the distance information of BS and MS.

LOS and NLOS situation are all available, the figure of the LOS and NLOS can be seen from Fig. 2(a) and Fig. 2(b) To compare these two conditions, we choose many fix measurement spots and long continuous measurement routes along the main street of this area. Each fix spot has 500 samples and space with same distance. Through compare each spot field sounding result, we can find how distance related with EAOA and EAOD parameter.

TABLE I
MEASUREMENT PARAMETERS SETTING.

Parameters	Setting
Carrier Frequency	3.5 GHz
Bandwidth	50MHz
Code Length	63 chips
Tx Antenna Number	32(UPA)
Rx Antenna Number	56(ODA)
BS height	25 m
MS height	2 m

III. DATA PROCESSING

In data post processing, the channel impulse response (CIR) results are calculated from the raw data firstly. Then the CIR field results were post-processed using the SAGE algorithm [3]. SAGE is an extension of the expectation-maximization (EM) algorithm, emerges with fast convergent rate, and is availability for the estimation of parameters and applicability for almost every type of antenna array. Every 4 snapshots combined to SAGE to extract one set of channel parameters, each set contain 100 discrete propagation paths information$\{\tau_l\left(\varphi_{AOA,l},\phi_{AOA,l}\right),\left(\varphi_{AOD,l},\phi_{AOD,l}\right),\alpha_l,f_l\}$, they are estimation of delay, AOA, AOD, polarization matrix and Doppler shift of the l th path.

A. *Mean value of elevation angle*

When we need connect the elevation angle with the power of path, the Power Angle Spectrum (PAS) is a better way to illustrate angle information of propagation paths. And through the PAS we can get the statistical first order central moment of the angle. Using the PAS we first estimate the Power-Distribution-Function (PDF) (1)

$$PDF(x_i,p)=\frac{P(x_i,p)}{\sum\limits_{i=1}^{numel(\mathbf{X})}P(x_i,p)}, \tag{1}$$

where $PDF(x_i,p)$ is the probability of path with angle x_i and power p, X is a set of the possible path angles.

Then we can apply the PAS to attain the first order moment (mean value) of elevation angle,

$$\overline{x}(p)=\sum_{i=1}^{numel(X)}x_i\cdot PDF(x_i,p) \tag{2}$$

B. *circular angular spread*

The angular spread (AS) of channel, which is the second moment of the propagation angles, can be calculated using the mean value of propagation angle. To avoid the problem of angular blur, we use the method used in the 3GPP Spatial Channel Model (SCM) [4], the circular angular spread. Taking elevation angle for example, $x_i(\Delta)$ is the EAOD of the i index. The AS is defined as the minimum value of all the step angles Δ. Here we make the $\Delta=2$ degrees,

$$
\begin{aligned}
\sigma_{rms} &= \min_{\Delta} \sigma_{rms}(\Delta) \\
&= \min_{\Delta} \sqrt{\sum_{l=1}^{L} (x_i(\Delta) - \overline{x}(\Delta))^2 PDF(x_i(\Delta), p)},
\end{aligned} \tag{3}
$$

where,$x_i(\Delta)$ and $x_i(\Delta) - \overline{x}(\Delta)$ are normalized into the range of $\left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$, i.e.

$$
x_i = \begin{cases} \pi + x_i & , if \ \ x_i < -\frac{\pi}{2} \\ x_i & , if \ \ |x_i| \le \frac{\pi}{2} \\ \pi - x_i & , \ if \ \ x_i > \frac{\pi}{2} \end{cases} \tag{4}
$$

IV. RESULT ANALYSIS

A. *Offset angle*

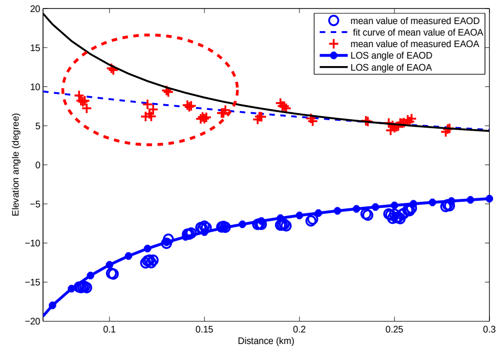
Elevation angle model is a key factor in 3D-MIMO channel modeling. In this paper we focus on the way to model it effectively. In the current published channel model, the LOS direction is set as the mean value of azimuth arrival angles and departure angles. Taking the ITU-R [12] for example, the azimuth arrival angle is generated by adding these variations.

$$
\varphi_n = X_n \varphi_n' + Y_n + \varphi_{LOS}, \tag{5}
$$

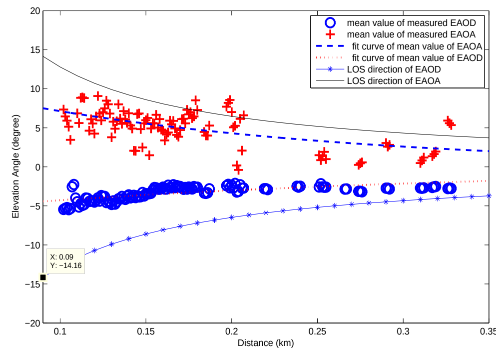
where φ_n' is generated by applying the inverse Gaussian function with parameter path power P_n and root mean square (RMS) angle spread σ, X_n is uniform distribution random variable to the discrete set of $\{-1, 1\}$, Y_n is Gaussian distribution random variation, φ_{los} is the LOS direction. When we turn to the elevation dimension, based on the real channel data, the mean value is not the LOS direction. As shown in Fig. 3 the coming wave may not along the LOS direction because of the scatters with different height. From the measurement results, it is found that there is difference between the mean value of elevation angle and LOS direction which can be modeled as a offset angle value and the offset angle is distance depended.

Path information was exacted by SAGE algorithm which have same BS-MS distance in NLOS situation but have different route or spot index are anaylsed to find out how the power weighted mean value of EAOD and EAOA change with distance.

Fig. 4 illustrates the power weighted mean value of EAOD/EAOA of distance from 84 m to 328 m. The zero degree stand for the horizontal direction as the reference direction, if the path is coming above the antenna, the elevation angle value is positive, and when the coming path is below the antenna the elevation angle value is negative. From the measurement result , mean value of EAOD and EAOA fit the LOS direction well in LOS situation except when distance is less than 150 m as marked by red dash ellipse in Fig. 3(a). When the BS and MS are close, there are lots of coming waves received by MS that are reflected by ground. Thus, the mean angle is smaller than LOS angle, but when distance is long enough, the reflected component reduced, then the mean angle is similar with LOS direction. The dot and dash-dot lines are fit curves of mean value of EAOD and EAOA. Compare the fit curve of mean value and LoS direction, the offset value is decreasing when the BS-MS distance is increasing



(a) mean angle and LOS direction of LOS



(b) mean angle and LOS direction of NLOS

Fig. 3. measurement scenario

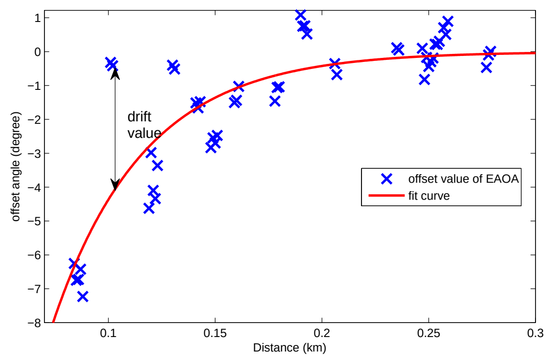
and the curve of mean value converge to LOS direction when the distance is larger than 300 m where BS height is 25 m. Because there are coming paths reflected by ground, so the mean value of EAOA is smaller than LOS direction. When the BS-MS distance is large enough, the coming angle of ground reflected path is near zero degree, then the mean value is in accordance with LOS direction.

However, when comes to the NLOS situation, as the Fig. 4 (b) shows, the power weighted mean value of EAOD and EAOA is not along with the LOS direction. The mean value of EAOD is close to zero degree and almost as a constant when the distance is larger than 200 m. Though the mean value of EAOA has greater dispersion, there still a trend that the angle may become smaller when the distance is getting large and both the EAOD and EAOA are more close to zero degree than the LOS situation.

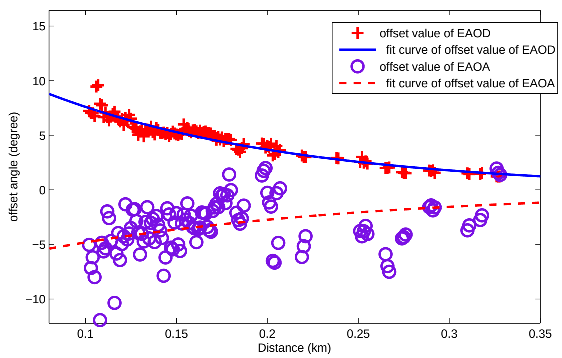
In Fig. 5, offset angle of different situations are presented. From the figure, the offset angle values can modeled as a function of distance. In LOS situation, the offset angle value of EAOA is fitted with exponential function. And the fit equations is

$$
\theta_{offLOS-EAOA} = -45.12 \cdot \exp(-23.35 \cdot d), (MS) \tag{6}
$$

where stand for BS-MS distance in units of kilometers. In NLOS situation, the offset angle value is much larger. The EAOD is fit with power function, and the EAOA is fit with



(a) offset angle in LOS case



(b) offset angle in NLOS case

Fig. 4. measurement scenario

exponential function.

$$\theta_{offNLOS-EAOD} = 15.7 \cdot \exp(-7.257 \cdot d), (BS) \quad (7)$$

$$\theta_{offNLOS-EAOA} = -8.468 \cdot \exp(-5.638 \cdot d), (MS) \quad (8)$$

However, because of the offset angle has large dynamic range, the fit curve cannot capture all the characteristics of offset angle value. In order to include the stochastic character, the drift value which is difference value between offset angle and fit curve value that at the same distance is modeled as a random variable, as marked in Fig. 5. It is found that the drift value fit the logistic distribution well in all condition. And the expression of logistic distribution is as (9)

$$f(\theta; \mu, s) = \frac{e^{-\frac{\theta-\mu}{s}}}{s(1+e^{-\frac{\theta-\mu}{s}})^2} \quad (9)$$

The parameter of the logistic distribution of each case is listed in Tab.II

TABLE II
DISTRIBUTION PARAMETER.

Scenario	μ	variance	s
LOS EAOA	0.062343	1.82656	0.745123
NLOS EAOD	0.134769	0.584461	0.421491
NLOS EAOA	0.0826501	13.5285	2.02785

B. Model method of mean angle value of elevation angle

Here we present our model method of mean angle of elevation angle.

- **step 1**: Calculate the LOS direction angle value by using equation (10) where height difference of BS and MS antenna h and the distance between BS and MS d .

$$\theta_{LoS} = \arctan\left(\frac{h}{d}\right), \quad (10)$$

- **step 2**: Choose the equation (6-8) for different scenario to generate offset angel θ_{off} at distance d .
- **step 3**: Generate random angle value θ_{drift} based on logistic distribution with parameters in Tab.II.
- **step 4**: Add the offset angle and random angle to θ_{LoS} as shown in equation (11) to get mean angle of elevation angle.

$$\theta_{mean} = \theta_{LOS} + \theta_{off} + \theta_{drift} \quad (11)$$

After we got the mean value of the elevation angle. The elevation angle is generated based on the mean angle similar as modeling of azimuth angle.

C. Circular Angular Spread

The relation between CAS and distance is also the topic of interest in this article. The CAS in one distance is averaging from the CAS value that have same distances. Fig. 5 shows the CAS value on different distance and the fitting curve of the CAS. From the figure, it is found that the CAS value is partly distance depended. In LOS case, the linear fit of ESD of LOS case shows that the ESD value barely change with distance, also the variation of ESA value in NLOS case has no obvious regularity when distance changes. Both of them have low correlation with distance. The ESA value in LOS case may getting lower when distance increasing. The same phenomenon can be seen in ESD of NLOS case but with smaller slope. The fitting curveas of ESA in LOS case and ESD in NLOS case are listed below,

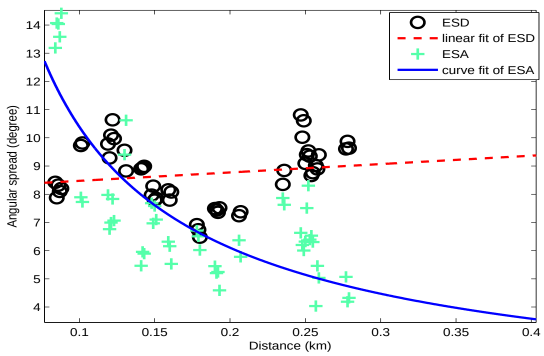
$$ESA = 1.775 \cdot d^{-0.7673}(LOS) \quad (12)$$

$$ESD = 2.899 \cdot d^{-0.339}(NLOS) \quad (13)$$

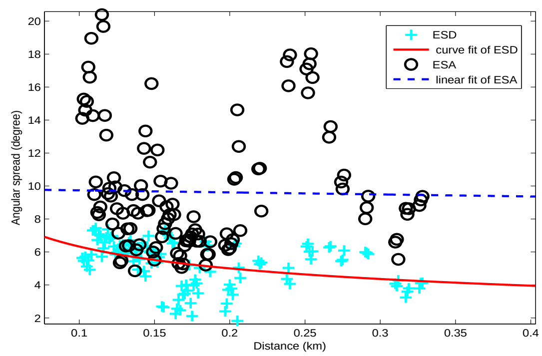
where d stand for BS-MS distance and the unit is kilometer. Because of the low correlation between the ESD in LOS case or ESA in NLOS case and the distance. These two parameters are modeled as random variable and the detailed distribution parameters are in Tab.III.

TABLE III
CAS DISTRIBUTION PARAMETERS.

Scenario	distribution	mean	variance
ESD LOS	norm	10.265	0.028
ESA NLOS	lognorm	9.981	0.329



(a) CAS in LOS case



(b) CAS in NLOS case

Fig. 5. measurement scenario

V. CONCLUSION

In this paper, we give the characteristic of elevation angle in UMA scenario. First, we find the existing of offset angle in elevation domain , and the offset value cannot be ignored in NLOS situation. It is also found that the offset value is related with BS-MS distance. Second, the offset angle can be modeled as a function depends on BS-MS distance except for the offset angle of EAOA in NLOS case which is independent with distance and is fit as logistic distribution. Third ,we proposal a model method to model mean angle of elevation angle in UMi scenario. The model only makes minimal changes in ITU model so that is easy to approach and reduce unnecessary coding work. At the last of this paper, the relationship of CAS and BS-MS distance is studied. the result shows that the CAS value is distance depended, but the ESA and ESD have different correlation of distance .

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