Elevation Angle Research in Three-Dimension Channel Model Using Ray-Tracing

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Abstract

By adopting elevation domain beamforming and spatial domain multiplexing, 3 Dimensional (3D) Multiple Input and Multiple Output (MIMO) antenna system is the key technology in providing high throughput in modern communication systems. However, the conventional channel modeling method mainly focuses on 2 dimensional (2D) MIMO channels which neglect the vertical plane. It inspires scholars to do research on the characteristics of 3D channel models' elevation parameters. In this paper, we propose an automatic measurement approach for 3D MIMO channel by using ray-tracing algorithm. This method delivers the characteristics of the elevation angle for low-rise floors in Outdoor to Indoor (O2I) scenario, which have accurately matched the classical experimental results. In addition, further investigation for high-rise floors is successfully made by this proposed methodology as well.

1. Introduction

MIMO channel modeling has been widely discussed in both academy and industry. The 2D channel modeling method has been proposed by [1, 2] and has been widely adopted by industry and organizations. The 3D channel modeling approaches are proposed in [3] and [4], its modeling method has been discussed in [5, 6], where the innovation of the 3D models are the elevation domain parameters. Specifically, Elevation Angle of Departure (EOD) and Elevation Angle of Arrival (EOA) are new parameters in elevation domain of the 3D channel model, where their power angle spectrum (PAS) severely influences the 3D MIMO performance. In particular, the PAS are strongly associated with the deployment scenarios for 3D MIMO. Researchers use channel sounder to manually detect PAS of the elevation angle in different scenarios, such as Urban macro-cell (UMa) [7], Urban micro-cell (UMi) [8, 9, 11] and O2I [9, 10, 11], to make 3D MIMO models accurate. However, current existing experimental studies are limited to manual testing, which may miss some important measurement spots. As a result, researchers may miss some critical experimental phenomenon and get some one-sided conclusions. In this paper, we propose a method that using ray-tracing to detect characteristics of the elevation angle. All the measurement results are obtained from mathematical derivation, which enables the 3D MIMO measurement automations.

1. By using electronic map to build up O2I scenario and applying ray-tracing method to measure the elevation angle of 3D channel in all the positions, our simulation results for low-rise floors perfectly matches the manual testing results in [9, 10, 11]. The proposed measurement method is successfully verified.
2. Through further data analysis, we have found that the PAS of the elevation angle for high-rise floors are significantly different from low-rise floors.
3. According to the simulation results, a new distribution model is proposed to model the PAS for high-rise floors.

Therefore, as the example in measuring the elevation angle in O2I scenario, it demonstrates that the automatic measurement for 3D MIMO channel is feasible.

The paper is organized as follows: Section 2 gives a brief introduction of the elevation domain of 3D channel. Section 3 introduces the virtual O2I scenario. In Section 4, we present results of virtual measurement about EOD and EOA for low-rise floors which could be compared with the experimental results mentioned above. In Section 5, more detailed measurement results about EOD and EOA for high-rise floors are provided. Conclusion is drawn in Section 6.

2. The Channel Model

A simplified 3D channel model only considering elevation domain is shown in Figure 1. Definition of EOD is illustrated by $\theta_{n,m,i,EOD}$ in the figure, transmitters and receivers are numbered by $\boldsymbol{n}$ and $\boldsymbol{m}$ respectively, and the number $\boldsymbol{i}$ indicates the i-th elevation angle of departure. The RMS elevation angle spread of departure (ESD) is defined as

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$$\delta_{n,m,ESD} = \sqrt{\frac{\sum_{i=1}^{I} P(\theta_{n,m,i,EOD})(\theta_{n,m,i,EOD} - \varphi_{n,m,mean,EOD})^2}{\sum_{i=1}^{I} P(\theta_{n,m,i,EOD})}} \tag{1}$$

where $P(\theta_{n,m,i,EOD})$ is PAS of EOD and $\varphi_{n,m,mean,EOD}$ is given by the equation shown below

$$\varphi_{n,m,mean,EOD} = \frac{\sum_{i=1}^{I} P(\theta_{n,m,i,EOD})\theta_{n,m,i,EOD}}{\sum_{i=1}^{I} P(\theta_{n,m,i,EOD})} \tag{2}$$

Similarly, the EOA and the RMS elevation angle spread of arrival (ESA) can be defined in the same way. In this paper, we mainly investigate the characteristics of these parameters in O2I scenario.

3. Description of the Virtual Measurement

The virtual measurement scenario shown in figure 2 is located in a typical urban area of a city. An omnidirectional antenna which works at 2.1 GHz is installed on the rooftop of a low-rise building. The height of the antenna is 25 meters, higher than other low-rise buildings but lower than surrounding high-rise buildings which are of 30 floors with 90 meters high. In engineering, we rarely use a transmitter to cover a severely blocked high-rise building, so line-of-sight (LOS) buildings are taken as research objects. In the LOS buildings, we set a measurement spot every 25 square meters. Moreover, to ensure that the spots which are a little far away from the windows could receive LOS signal, we set the distance between transmitter and high-rise building in the range of 100 meters to 500 meters.

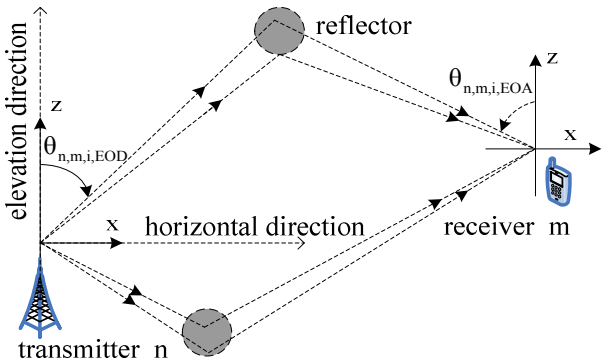


Figure 1. Simplified 3D channel model in vertical domain

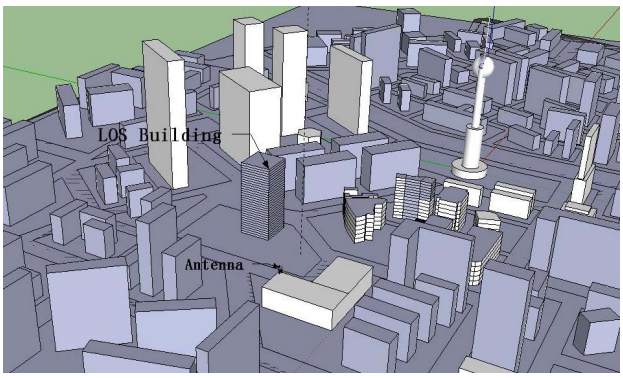


Figure 2. Virtual outdoor to indoor scenario

4. Results Comparison between Experimental and Virtual Measurement

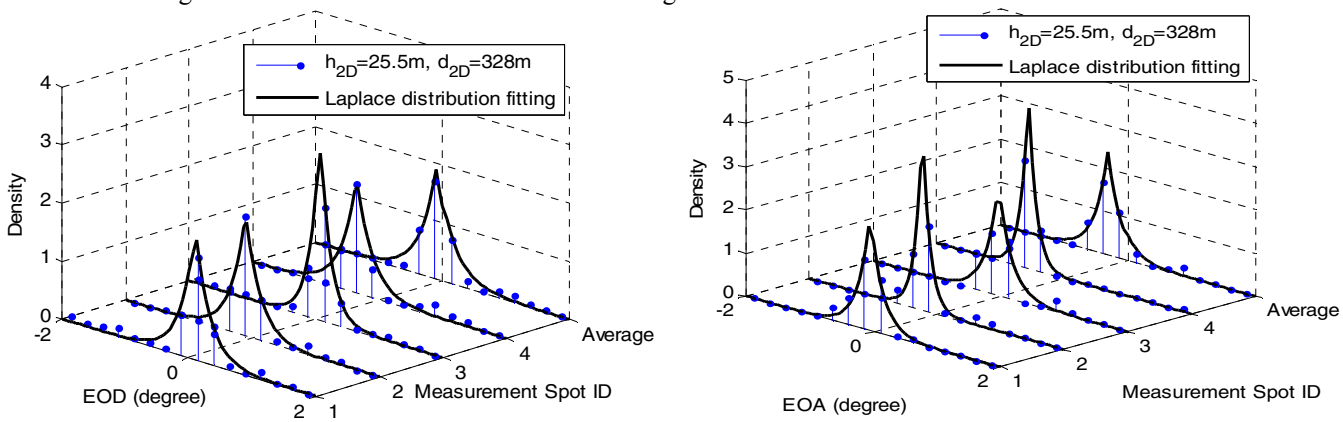
By using ray-tracing simulator, in which all the main physical objects are appropriately modeled and the effects of reflection, diffraction and penetration are considered, we investigate the characteristics of EOD and EOA of 3D channel in O2I scenario. It is important to note that all the obtained raw data are classified by measurement spots and the mean values got at different spots are respectively normalized to 0 when analyzing the elevation PAS.

Figure 3 (a)-(b) show the PAS of the elevation angle and their fitting shapes for the 8th floor in a LOS building. Measurement results of 4 spots are presented as representatives and the word 'Average' on 'Measurement Spot ID' axis represents the average PAS of the elevation angle of all the measurement spots on the 8th floor. As shown in the figures, the PAS of EOD and EOA are well fitted by Laplace distribution. Their angle spreads are limited in the range of -2 degree to 2 degree.

The Probability density of the RMS elevation angle spread is shown in figure 4. The distributions of ESD and ESA are well fitted by normal distribution. The mean value and the standard deviation of the normal distribution for different floors are given in table 1. Since the 8th floor has almost the same height with the antenna, a great part of measurement spots on the 8th floor are in LOS state. As a result of it, the ESD and ESA have little difference on the 8th floor. With floor number increasing or decreasing from 8, the number of measurement spots in LOS state decreases and

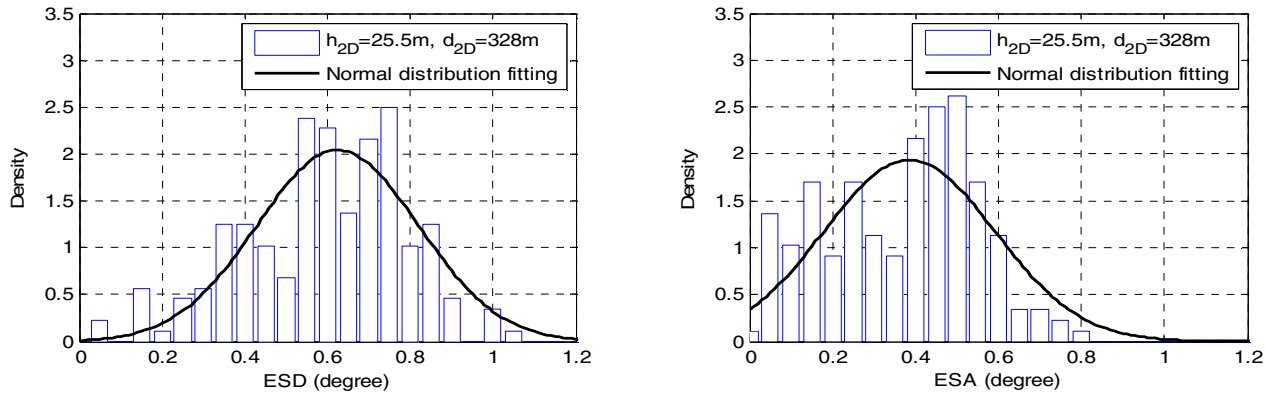
the elevation angle spread increases. On slightly higher floors, the spread of ESA is significantly larger than ESD, because scatters in indoor scenario, such as floor, ceiling and desktop, will bring more multi-path in elevation domain.

By comparison, one thing should be noted that although the absolute values from our proposed ray-tracing and the field tested results in [9, 10, 11] are different, the results from all measurements lead to the same statistic characteristics. Specifically, the differences in the absolute numbers are caused by the 2D distance setting between antenna and LOS building, where it is 328 meters in our approach, which is much longer than the existing field tested settings. The angle variation is alleviated due to the longer distance, which indicates that the distance between antenna and LOS building should be taken into account when modeling 3D channel in O2I scenario.



(a) (b)

Figure 3. Elevation angle spectrum for the 8th floor in O2I scenario



(a) (b)

Figure 4. Probability density of RMS elevation angle spread for the 8th floor in O2I scenario

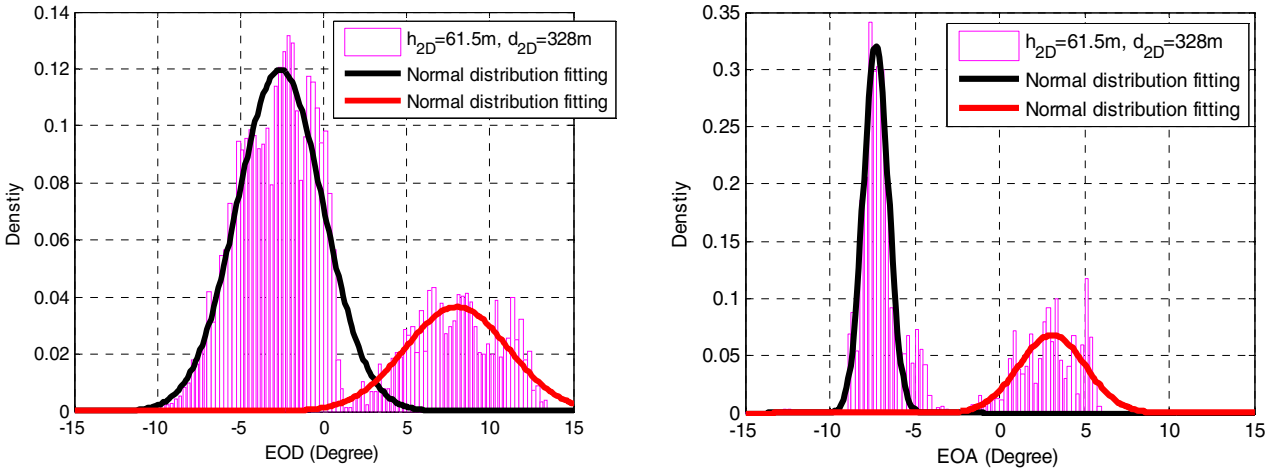
Table 1. ESD and ESA in O2I scenario

Parameters		Floor number (O2I scenario)							
		7	8	9	10	11	12	13	14
ESD (degree)	μ	0.637	0.594	0.893	1.27	1.638	1.887	2.395	2.966
	σ	0.201	0.175	0.285	0.215	0.218	0.181	0.192	0.17
ESA (degree)	μ	0.807	0.506	0.54	0.607	1.477	2.129	2.58	3.2
	σ	0.23	0.161	0.332	0.359	0.594	0.563	0.587	0.754

5. Further Virtual Measurement Results

Through further data analysis, we find the characteristics of the elevation angle distribution for high-rise floors are significantly different from the low-rise floors. As shown in the figure 5 (a)-(b), the PAS of the elevation angle has two peaks. Both of the peaks are independent and well fitted by normal distribution. This is because, on high-rise floors, the LOS rays almost disappear and the rays received at measurement spots are mainly from the reflection of high-rise buildings' outer walls and low-rise buildings' rooftops. The rays affected by such two types of reflectors have completely different propagation pathes. It is also the reason that the spread of EOD is larger than EOA. So when

modeling 3D channel for high-rise floors in O2I scenario, we strongly recommend that the Laplace distribution is not applicable and the independent double Gaussian distribution would be a good alternative.



(a) (b)

Figure 5. Average elevation angle spectrum for the 20th floor in O2I scenario

6. Conclusion

This paper does some researches on the characteristics of the PAS of the elevation angle in O2I scenario. Laplace distribution is proposed to fit the PAS shapes for low-rise floors. This result well matches the manually experimental measurements in [9, 10, 11]. Furthermore, independent double Gaussian distribution is proposed for the high-rise floors by investigating the PAS of the elevation angle, which is significantly different from low-rise floors.

The proposed measurement method utilizing the ray-tracing algorithm is successfully verified to be an effective way for researching 3D channel in O2I scenario. On account of the fact that all the measurement results are got from mathematical derivation, the ray-tracing method could be applied in different scenarios and the measurement results could be considered to be reliable. So the automated 3D channel measurements are possible and friendly for lab environment.

7. References

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