Article:

Wang, Y., Shi, P., Liao, X. et al. (1 more author) (2022) Statistical channel modelling of full-angle 3.5 GHz OAM in indoor corridor scenario. Electronics Letters, 58 (14). pp. 560-562. ISSN 0013-5194

https://doi.org/10.1049/ell2.12524

Statistical channel modelling of full-angle 3.5 GHz OAM in indoor corridor scenario

Yang Wang,[1,✉] Panpan Shi,[1] Xi Liao,[1] and A. Tennant[2]

[1] *School of Communication and Information Engineering, Chongqing University of Posts and Telecommunications, Chongqing, China*

[2] *Department of Electronics and Electrical Engineering, The University of Sheffield, Sheffield, UK*

✉ Email: wangyang@cqupt.edu.cn

A 3.5 GHz OAM antenna with ±1 mode was designed and fabricated, and the channel measurement in frequency domain was used to measure the channel in full angle domain under indoor multipath scenarios. Then, the modified probability density function of Gaussian distribution, Laplacian distribution, and Von Mises distribution are used to establish the OAM full-angle statistical channel model. The fitting curve results well represent the statistical characteristics of OAM in indoor multipath scenario.

Introduction: In the post-5G and future 6G era, indoor communication is one of the hottest scenes as data explosion. Orbital angular momentum (OAM), with its unique orthogonal eigenstates, will bring high security and ultra-fast data transmission to future communications [1]. Many pieces of research focus on the OAM antenna design [2] and OAM multiplexing [3]. In addition, some scholars have established ideal deterministic multipath model to represent the propagation state of OAM beam in the actual environment. The proposed model conditions are too strict and the verification work is insufficient [4]. Few studies have been conducted on OAM channel sounding in real scenarios [5]. To verify the channel characteristics of OAM in the indoor scenes, this letter gives an initial study of the microwave OAM full-angle channel based on measurements. Also, we present the detailed design structure of OAM antenna and modified probability density function fitting process.

The OAM antenna design: In this section, a 3.5 GHz ±1 mode OAM antenna based on the patch antenna is designed and manufactured, and completed testing of far-field radiation characteristics.

As shown in Figure 1, the structure of OAM array antenna based on micro-strip patch antenna has been given in detail, and all dimensions are in millimetres. From the structure that feeders of different lengths increase the phase of the antenna array element of +1 mode counterclockwise, the phase of the array element in −1 mode increases in a clockwise direction. After the OAM antenna was made, the near-field plane radiation characteristics were measured in the microwave anechoic chamber, and the 500 mm × 500 mm plane was swept with the probe antenna.

The obtained amplitude and phase profiles shows the obvious vortex phase and hollow phenomenon, which represents the OAM antenna are designed well. However, a slightly elliptical in amplitude plot are caused by asymmetrical layout and anisotropic radiations of array elements. The antenna operates at 3.5 GHz with 3% bandwidth.

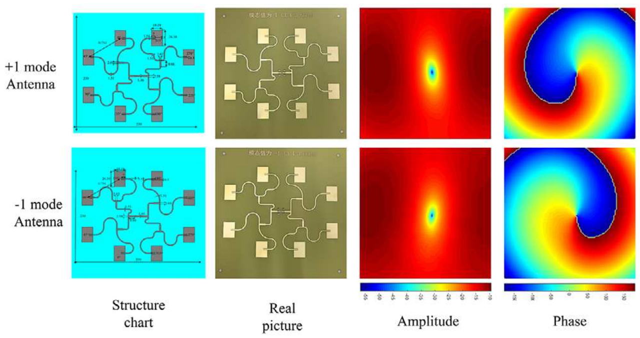

Fig. 1 *The structure diagram, profile display, amplitude, and phase of ±1 mode array OAM antenna*

Indoor multipath corridor full-angle domain channel sounder: Schematic diagram of an indoor multipath corridor full-angle domain channel sounder is shown in Figure 2a, where the OAM channel sounder system consists of the designed OAM antennas and vector network analyser (Keysight N5235B). Besides, D is the initial array centre distance and θ is the horizontal axis offset angle. Note that α denotes the angle of horizontal rotation. Moreover, in the paper, the uniform circular array we use is based on an eight-element patch antenna array.

Modified angular distribution probability density function:

$$f_{\text{Gaussian}}(\alpha) = a \cdot \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(\alpha-\mu)^2}{2\sigma^2}} \tag{1}$$

$$f_{\text{Laplace}}(\alpha) = b \cdot \frac{1}{2\lambda} e^{-\frac{|\alpha-\mu|}{\gamma}} \tag{2}$$

$$f_{\text{Von Mises}}(\alpha) = c \cdot \frac{e^{(\kappa \cos(\alpha-\mu))}}{2\pi I_0(\kappa)} \tag{3}$$

where $f_{\text{Gaussian}}(\cdot)$, $f_{\text{Laplace}}(\cdot)$, and $f_{\text{Von Mises}}(\cdot)$ respectively represent the modified probability density functions of Gaussian, Laplacian, and Von Mises distributions. a, b, and c represent the amplitude correction factor for changing the probability density function, respectively. σ is coefficient of standard deviation, γ denotes scale parameter, κ represents the concentration of azimuth AoA/AoD, $I_0(\kappa)$ is the first class of zero-order modified Bessel functions, μ is the location parameter.

Measurements of indoor multipath corridor OAM full-angle domain channel: The whole measurement steps are as follows: firstly, the vector network analyser is calibrated and the initial distance between antenna height is determined. Then, the rotation angle and horizontal deviation angle of the receiver antenna were changed successively, Next, the receiver antenna is changed until the last group of experiments is finished. In Figure 2b, the measurement is carried out in an indoor corridor environment with a dimension of 17 m × 10 m × 3.2 m. During the test, the Tx and Rx antennas were strictly the same height. For facilitate understanding, the detailed parameter settings is given in Table 1. It is worth noting that we specify a positive angle for clockwise rotation.

Numerical results: In this section, the modified probability density function fits the original test data and the cumulative distribution function are analysed. The root mean square error function value was used to measure the accuracy of the modified model.

Figure 3 shows when $D = 9\lambda$ and $\theta = 15°$, the modified Gaussian distribution, Laplacian distribution and Von Mises probability density function curves are well-fitted at different receiving mode, respectively. Then, although the receiving antenna mode is changed, we found that the offset of the main peak of the probability density function is almost equal to the horizontal offset angle. Besides, after setting the constant threshold value, we found that values exceeding the threshold value would occur within the range of 60° of horizontal offset angle, and the angle

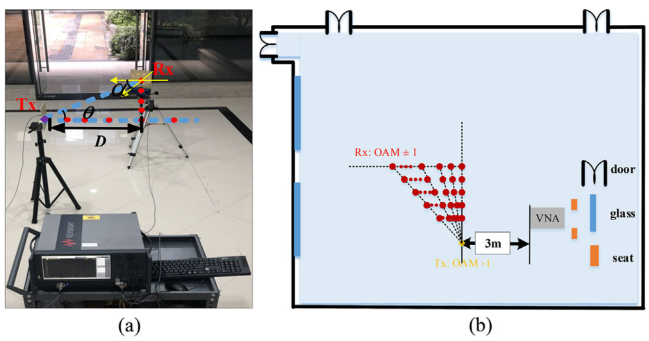

Fig. 2 *The space diagram of indoor multipath corridor full-angle domain channel model. (a) Channel sounder; (b) top view of test scenario*

Table 1. Measurement parameter setting

Parameters	Settings
Transmitter mode (L)	-1
Receiver mode (L)	± 1
Radius of Tx and Rx antenna R (in λ)	0.9
Antenna height (m)	1.48
Transmitter power (dBm)	0
Measurement frequency range (GHz)	3.5–3.6
IF bandwidth (Hz)	1000
Sweep frequency points	201
Transceiver antenna distance D (in λ)	3 5 7 9
Misaligned horizontal angle θ (in degree)	0 15 30 45
Rotation angle of receiving antenna α (in degree)	-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90

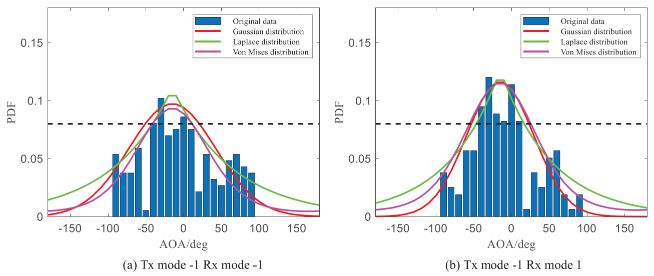

Fig. 3 *When $D = 9\lambda$, the modified Gaussian distribution, Laplacian distribution, and Von Mises probability density function curves are fitted at different offset angles (a) Tx mode -1 Rx mode -1 ; (b) Tx mode -1 Rx mode 1*

Table 2. Fitting model parameter setting for Tx mode = 1

Receiver modal value			-1		
θ	0	15	30	45	60
a	0.49	0.244	0.254	0.27	0.29
σ	1.5	1	1	1	1
b	0.218	0.158	1.138	0.158	0.152
λ	1.205	1.405	1.505	1.505	1.505
c	0.255	0.215	0.235	0.255	0.259
κ	1.91	1.51	1.51	1.51	1.51
Receiver modal value			1		
θ	0	15	30	45	60
a	0.26	0.3	0.34	0.34	0.44
σ	1.1	1.3	1.3	1.2	1.8
b	0.14	0.21	0.175	0.18	0.14
λ	1.305	1.205	1.205	1.305	1.405
c	0.212	0.265	0.24	0.25	0.155
κ	1.51	1.51	1.51	1.61	2.81
μ	0	$-\pi/12$	$-\pi/6$	$-\pi/4$	$-\pi/3$

value of each value was not uniform, which may be due to the influence of multiple reflection paths (Table 2).

Figure 4 shows the root mean square error results of the fitted models. On the whole, the root mean square error of Laplacian distribution is lower than that of other distributions, which indicates that Laplacian distribution can better represent the variation law of amplitude

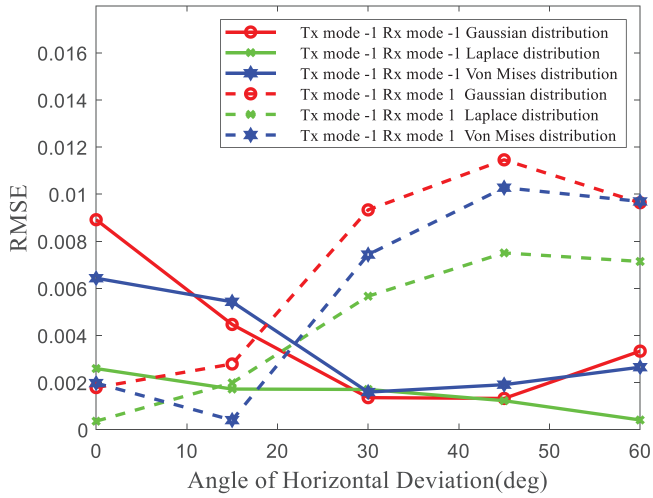

Fig. 4 *When $D = 9\lambda$ and Tx mode -1 Rx mode 1 or -1, the fitting error results of modified Gaussian distribution, Laplacian distribution, and Von Mises probability density function models*

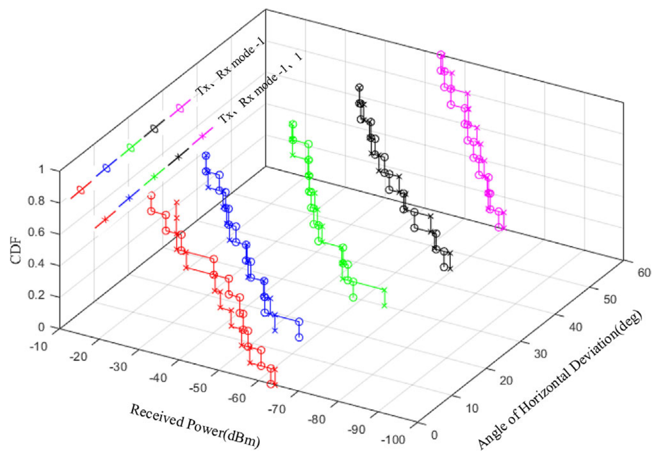

Fig. 5 *The Results of cumulative distribution functions of different receiving modes*

intensity of OAM with the changed of offset angle. Moreover, when Rx mode is -1, the RMSE value of the fitted models show a trend of increasing first and then decreasing with the increasing offset angle, while Rx mode is the same of Tx mode, the RMSE value shows a downward trend with the increase of the offset angle, which means that the accuracy of the revised statistical model is higher when using the same mode reception. However, for some angles such as 7° to 23°, the error values of Von Mises distribution is smaller than other distributions, which means model accuracy of Von Mises distribution is higher.

Figure 5 is about the accumulative distribution function of different angle domains and different mode reception. No matter the receiving antenna is in mode 1 or mode -1, when the horizontal offset angle is 30°, the cumulative distribution function is almost the same. It means that the multipath environment has almost the same influence on the OAM beam. Moreover, when the offset angle is 0 degrees, the modes at the receiver end are 1 and -1, and the difference between the two curves is the largest, indicating that the multipath environment at this time has a great influence on the OAM beam.

Conclusion: We have established a two-dimensional plane OAM angular domain statistical channel model based on the modified probability density functions of Gaussian, Laplacian, and Von Mises distributions. On the one hand, it makes up for the gap of 3.5 GHz band OAM channel model in the absence of indoor multipath scenarios. On the other hand, the statistical model can contribute to post-5G and 6G network planning and OAM communication. A detailed analysis of indoor 3D OAM channel study with frequency extending to millimetre wave band will be investigated in future works.

Acknowledgment: This work is supported by the National Natural Science Foundation of China (62171071), the Natural Science Foundation of Chongqing (cstc2019jcyj-msxmX0288).

Conflict of interest: The authors declare no conflict of interest.

Received: *5 March 2022* Accepted: *11 May 2022*
doi: 10.1049/ell2.12524

Funding information: the National Natural Science Foundation of China, Grant/Award Number: 62171071; the Natural Science Foundation of Chongqing, Grant/Award Number: cstc2019jcyj-msxmX0288

References

1 Zhang, Z.Q., Xiao, Y., Ma, Z., Xiao, M., Ding, Z.G., Lei, X.F., Karagiannidis, G.K., Fan, P.Z.: 6G wireless networks: vision, requirements, architecture, and key technologies. *IEEE Veh. Technol. Mag.* **14**(3), 28–41 (2019)

2 Zhang, C., Chen, D.: Large-scale orbital angular momentum radar pulse generation with rotational antenna. *IEEE Antennas Wireless Propag. Lett.* **16**, 2316–2319 (2017)

3 Chen, R., Long, W.X., Wang, X.D., Li, J.D.: Multi-mode OAM radio waves: generation, angle of arrival estimation and reception with UCAs. *IEEE Trans. Wireless Commun.* **19**(10), 6932–6947 (2020)

4 Jie, W.J., Wang, Y., Hu, T., Liu, J., Yang, D.H., Zhang, J.: Propagation model for UCA-based OAM communications in six-ray canyon channels. In: *Proceedings of IEEE European Conf. Antennas Propag. (EUCAP)*, pp. 1–4. IEEE, Piscataway, NJ (2020)

5 Wang, Y., Shi, P.P., Liao, X., Zhang, J., Tennant, A.: Measurements of 3.5 GHz OAM misaligned channels in indoor corridor scenarios. In: *Proceedings of IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting*. (APS/URSI), pp. 235–236. IEEE, Piscataway, NJ (2021)