Tao JIANG, Jianhua ZHANG, Pan TANG, Lei TIAN, 2021. A study of uplink and downlink channel spatial characteristics in an urban micro scenario at 28 GHz. *Frontiers of Information Technology & Electronic Engineering*, 22(4):488-502. https://doi.org/10.1631/FITEE.2000443

A study of uplink and downlink channel spatial characteristics in an urban micro scenario at 28 GHz

Key words: Channel measurements; Millimeter-wave (mmWave); Uplink; Downlink; Azimuth angle of arrival

Corresponding author: Tao Jiang
E-mail: jet@bupt.edu.cn
ORCID: https://orcid.org/0000-0001-5369-8068

Items of this work

- Motivation of this work
- Experiment design and environment description
- Channel characteristics in the analysis
  - Power angular spectrum
  - Angular spread and power weighted mean AoAs
  - Cluster method and cluster number
  - Cluster power and cluster width
- Modeling methods of azimuth angle of arrival
  - Modeling methods of cluster AoA in standard models
  - New modeling methods of rays' angle and power

Motivation of this work

- **At present**

  Standard models only assume the downlink channel. For uplink, arrival and departure parameters have to be swapped, based on the channel reciprocity.

- **However**

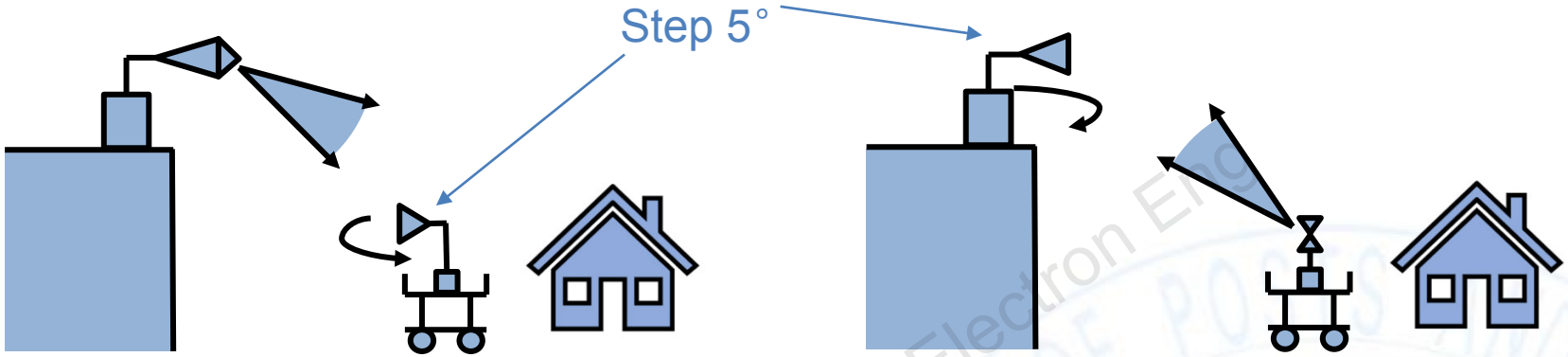
  The channel reciprocity may be influenced by link conditions.

  There are few articles studying the channel reciprocity in mmWave.

- **Thus**

  The best way to study uplink and downlink angular characteristics is conducting measurement in the real field.

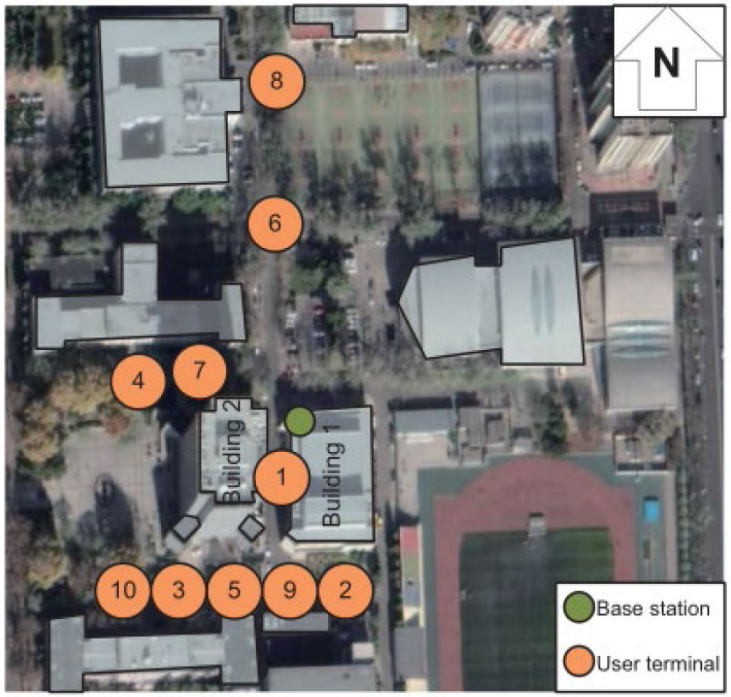
Experiment design and environment description



(a) Downlink measurement

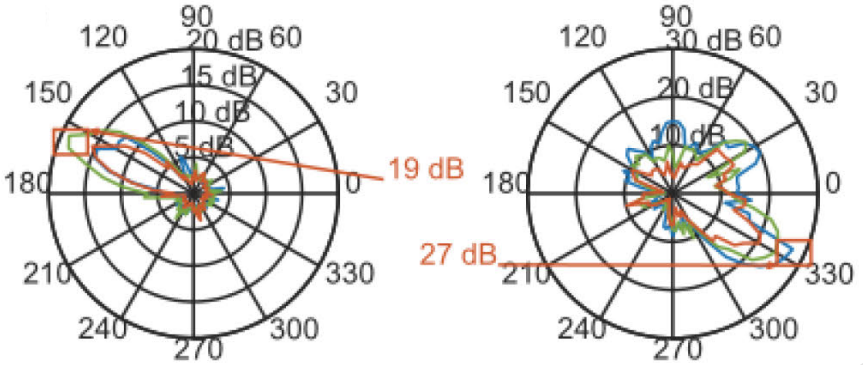
(b) Uplink measurement

	Downlink	Uplink
Frequency	28 GHz	
Bandwidth	800 MHz	
TX antenna	Sector antenna	Biconical antenna
RX antenna	Horn antenna	
TX height	12.4 m	1.8 m
Elevation angle of TX	Mainly: [0°, 10°, 20°] P1: [40°, 50°, 60°]	[0°, -10°, -20°]

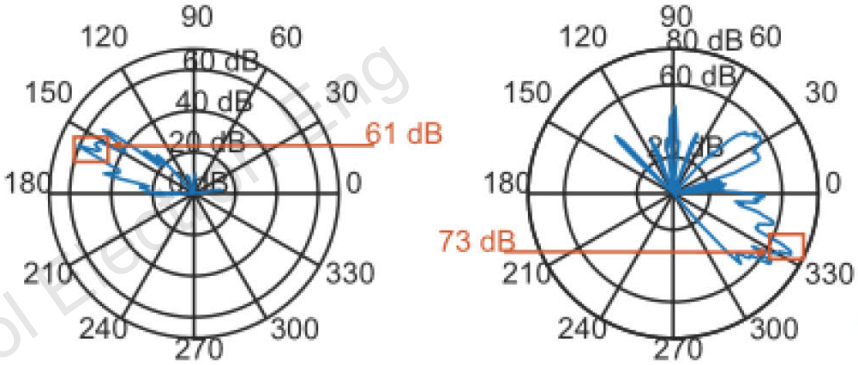


Channel characteristics and analysis

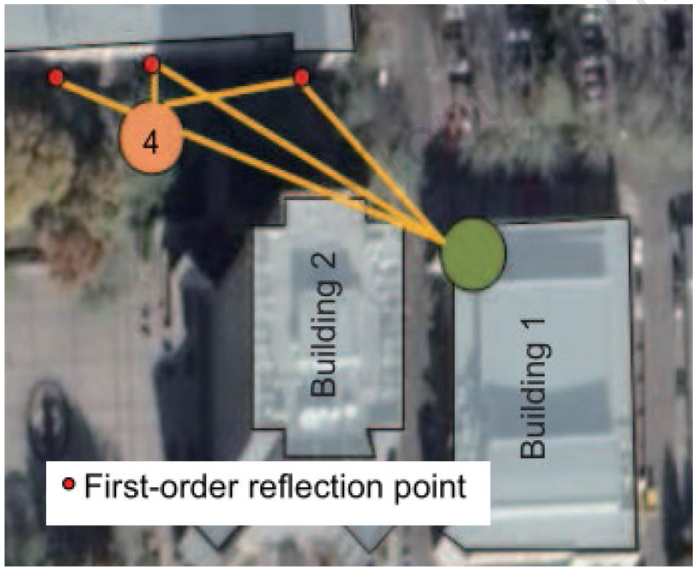
Power angular spectrum-LoS case



(a) Scanning PAS of downlink (left) and uplink (right)



(b) SAGE PAS of downlink (left) and uplink (right)

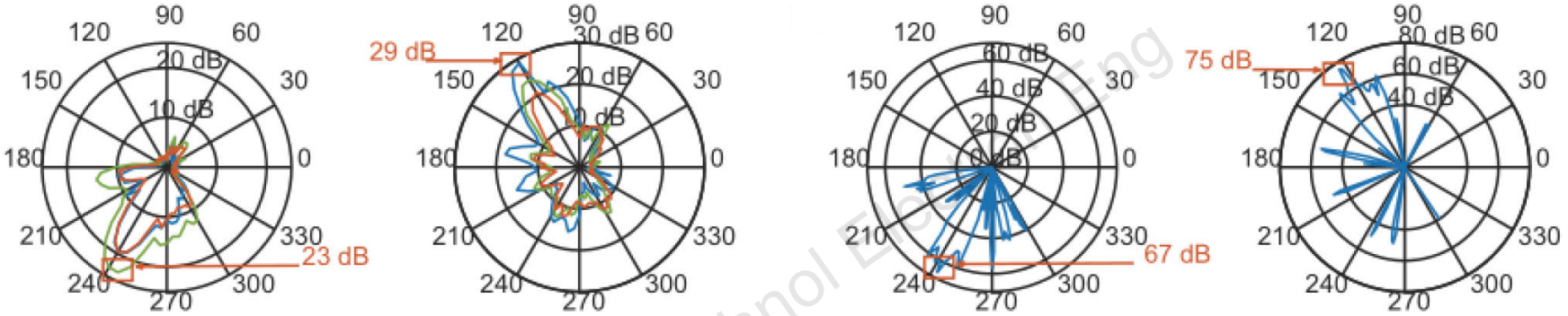


(c) Multipath matching with environment

Direction paths and first-order reflection paths are the main parts in LoS cases.

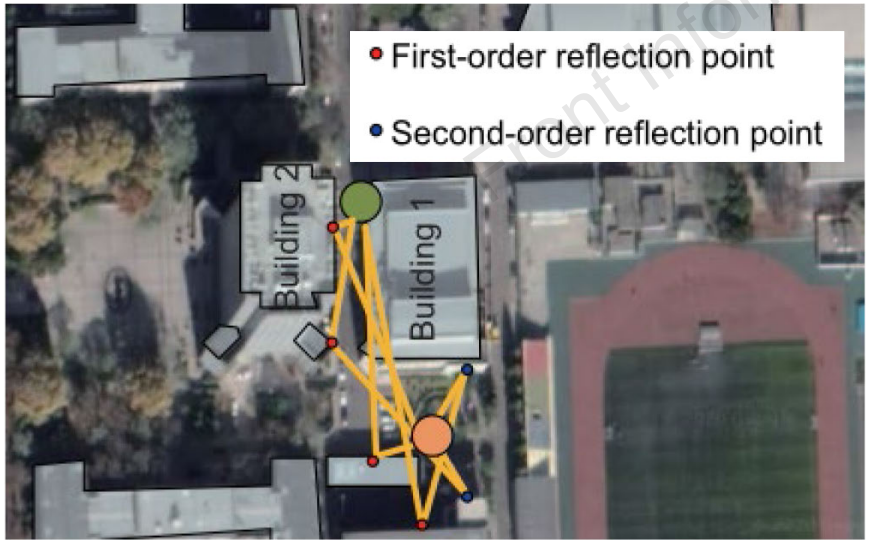
Channel characteristics and analysis

Power angular spectrum-NLoS case



(a) Scanning PAS of downlink (left) and uplink (right)

(b) SAGE PAS of downlink (left) and uplink (right)

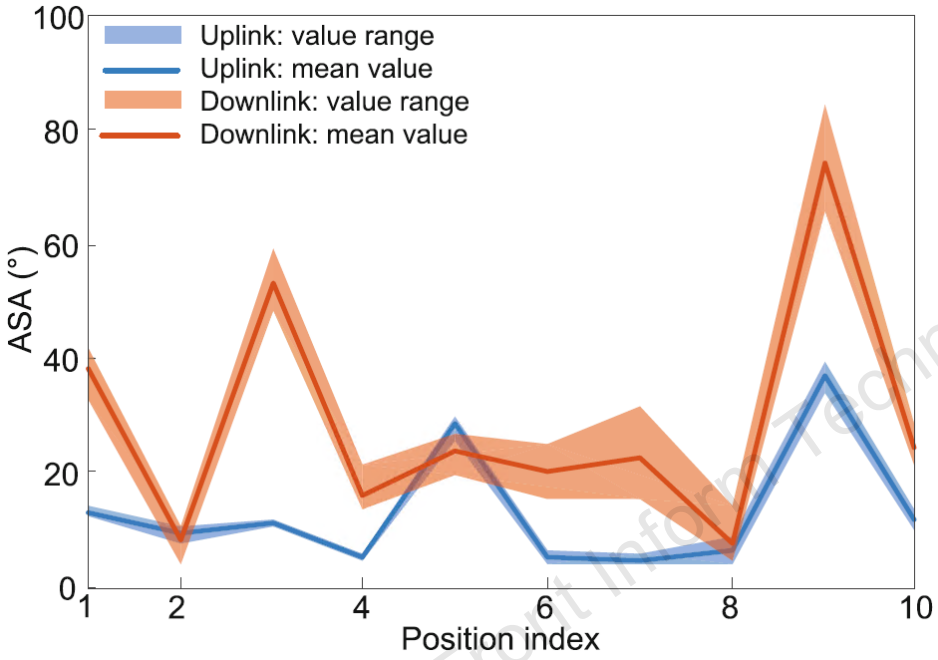


(c) Multipath matching with environment

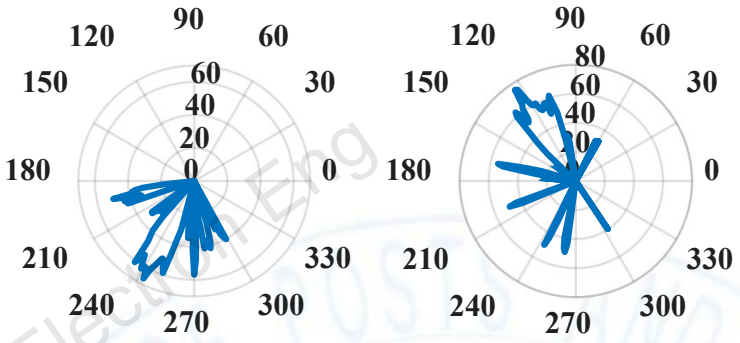
Direction paths, first-order reflection paths and second-order reflections (0.13%) are the main parts in NLoS cases.

Channel characteristics and analysis

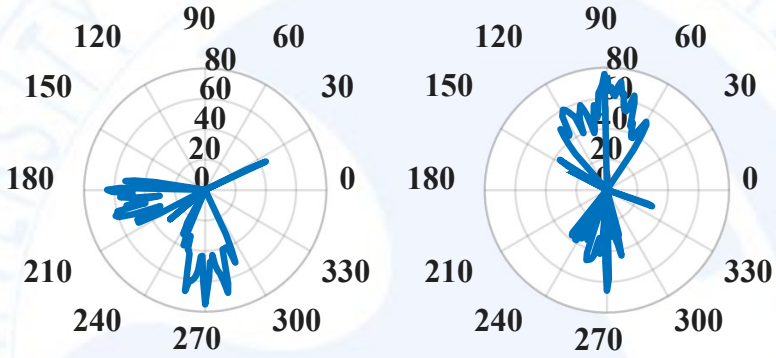
ASA of uplink and downlink



(a) Angular spread at different positions



(b) P2



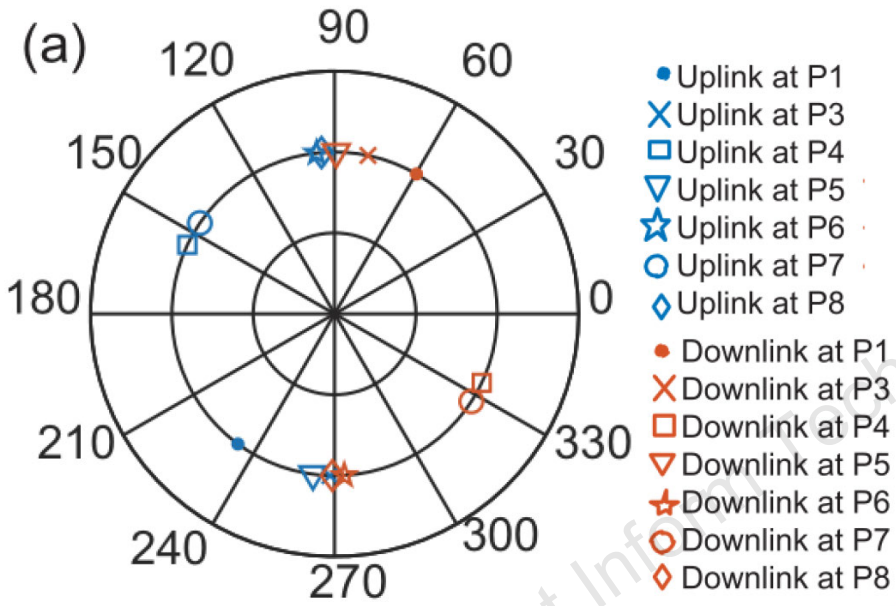
(c) P5

Define: $\varphi_{\mathrm{UL}} - \varphi_{\mathrm{DL}} = \varphi_{\mathrm{diff}}$ (1)

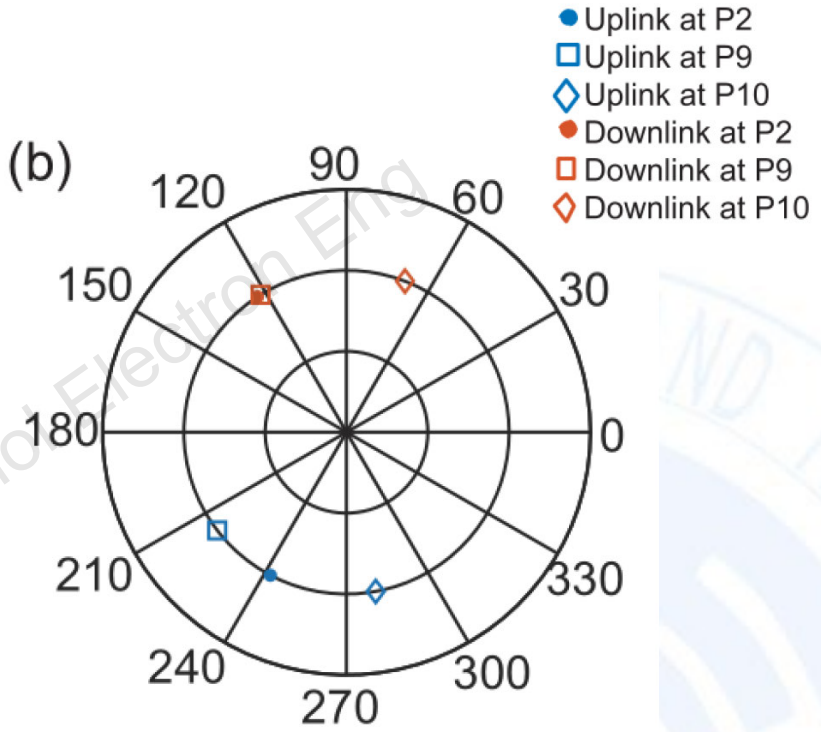
φ_{diff} is from -42.1° to 6° .

Channel characteristics and analysis

Power weighted AoA



(a) Mean AoA of LoS cases



(b) Mean AoA of NLoS cases

Mean AoAs are symmetrical about the original point.

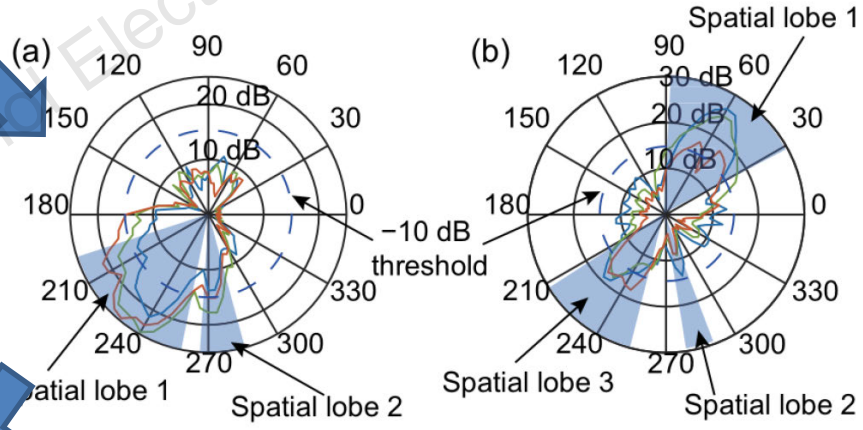
Mean AoAs are symmetrical about the *x* axis.

Channel characteristics and analysis

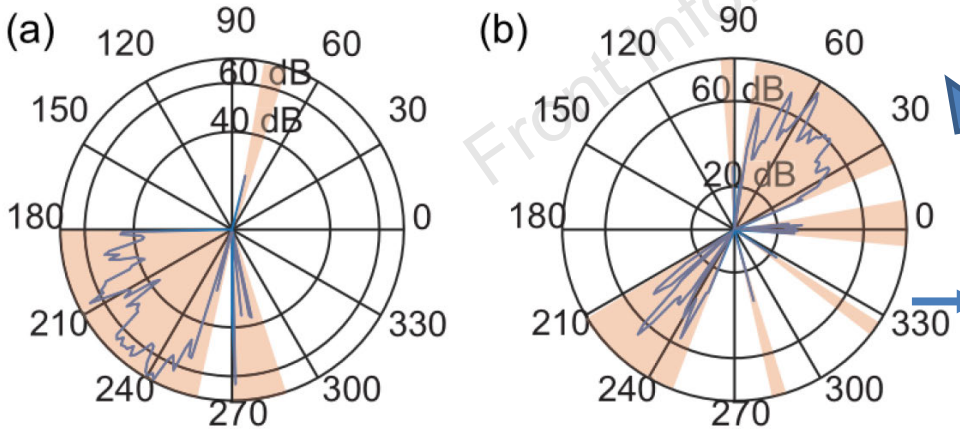
Cluster properties

Cluster method

K-PowerMeans needs to assign different weight factors to parameters



(a) Cluster in lobe-shaped



(b) Cluster multipath in lobe-shaped

Multipaths whose interval is larger than 5° will be split into different clusters.

Channel characteristics and analysis

Cluster properties

Cluster number

	Uplink	Downlink
P1 (LoS)	3	6
P2 (NLoS)	6	7
P3 (LoS)	5	7
P4 (LoS)	4	7
P5 (LoS)	4	4
P6 (LoS)	4	7
P7 (LoS)	3	10
P8 (LoS)	2	7
P9 (NLoS)	4	4
P10 (NLoS)	5	5
Average	4	6

	Uplink		Downlink	
	LoS	NLoS	LoS	NLoS
TR 38.901	12	19	12	19
mmMAGIC	2	3	2	3
TCSL	1.9	1.6	1.8	1.6
Measurement	3.5	5	6.9	5.3

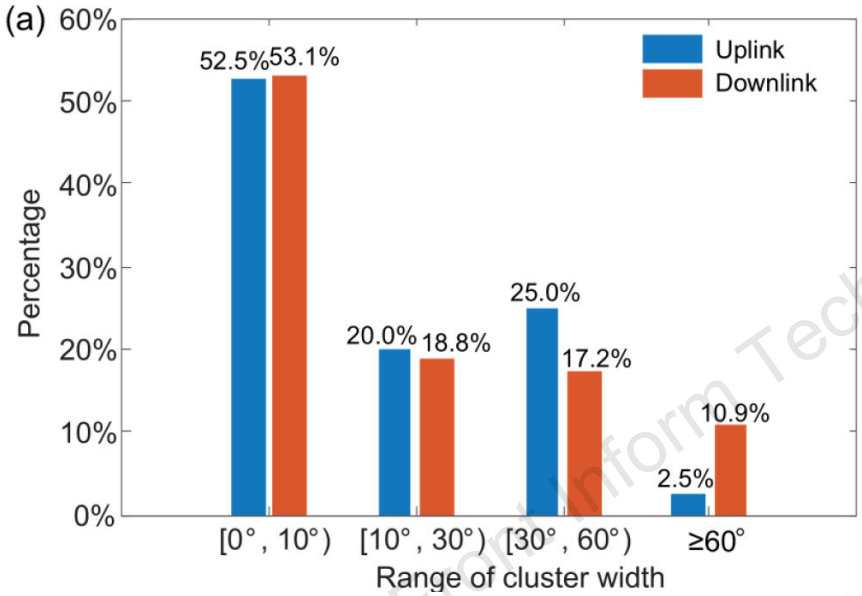
Table 5 Average cluster number in UMi scenarios

Reference	Frequency (GHz)	Cluster number	
		LoS	NLoS
Ko et al. (2017)	28	–	4.58
Nguyen et al. (2016)	15	5.67	10.33
	28	6.50	10.33
Park et al. (2016)	28	2.20	2.30
	38	5.90	6.60
Zhang PZ et al. (2020)	28	–	4.46
	39	–	3.35
	28	3.50	4.80
	39	2.60	3.82

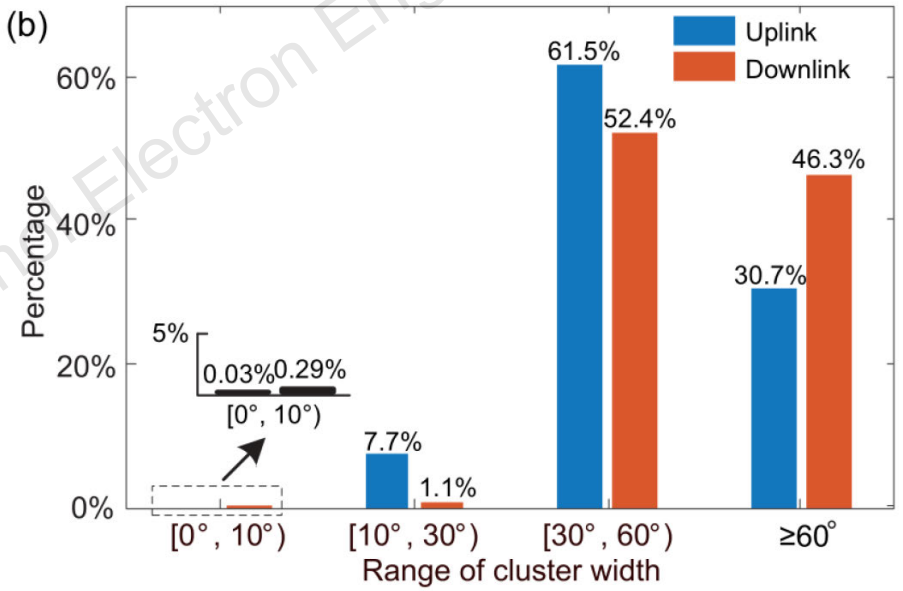
Channel characteristics and analysis

Cluster properties

Cluster power and width



(a) Percentage of cluster width in different ranges



(b) Percentage of cluster power in different ranges

Range 1: [0° , 10°]
Range 2: [10° , 30°]
Range 3: [30° , 60°]
Range 4: >60°

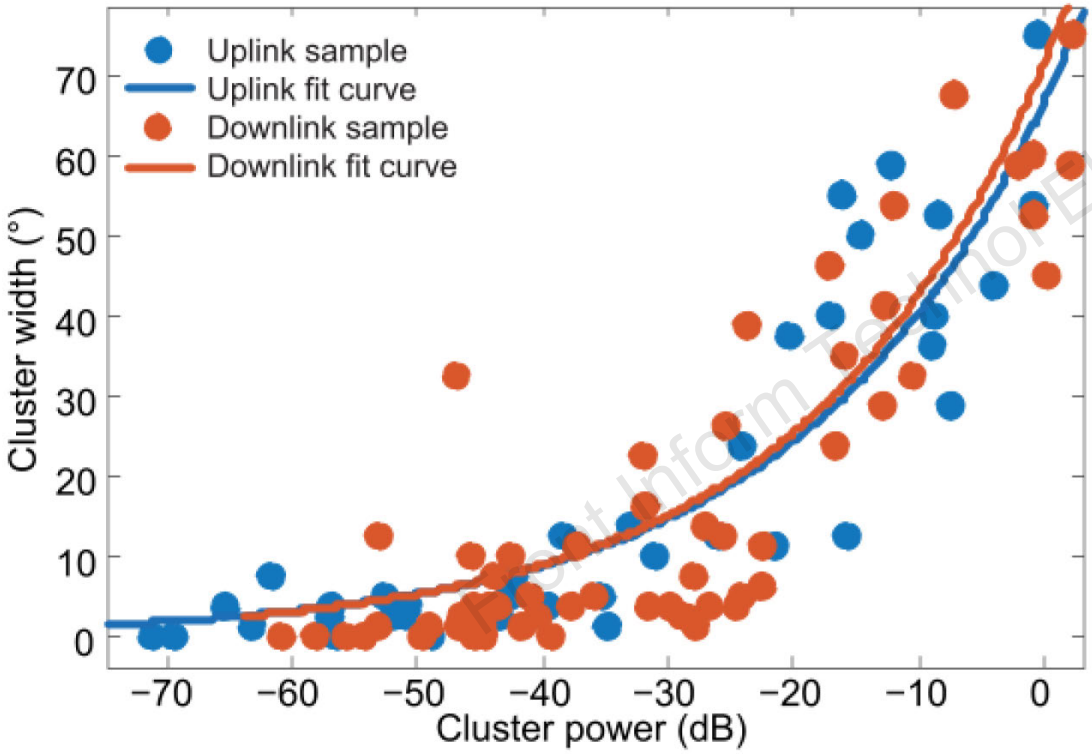
$$\mathrm{Per}_{\mathrm{num},R1}^{\mathrm{UL}} = \frac{N_{R1}^{\mathrm{UL}}}{N_{R1}^{\mathrm{UL}}+\cdots+N_{R4}^{\mathrm{UL}}} \quad (1)$$

$$\mathrm{Per}_{\mathrm{pow},R1}^{\mathrm{UL}} = \frac{P_{R1}^{\mathrm{UL}}}{P_{R1}^{\mathrm{UL}}+\cdots+P_{R4}^{\mathrm{UL}}} \quad (2)$$

Channel characteristics and analysis

Cluster properties

Cluster power and width

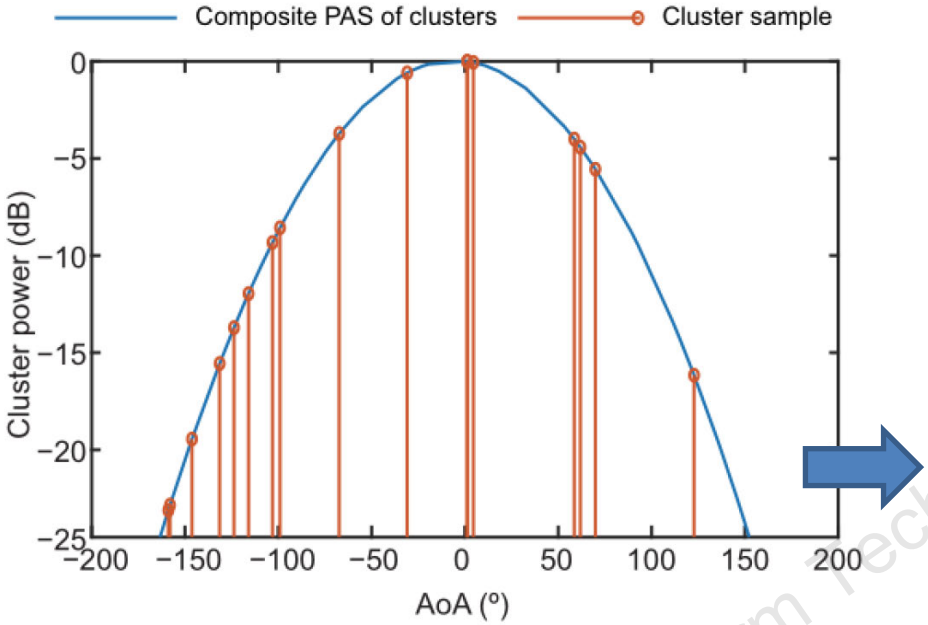


(a) Relationship of cluster power and width

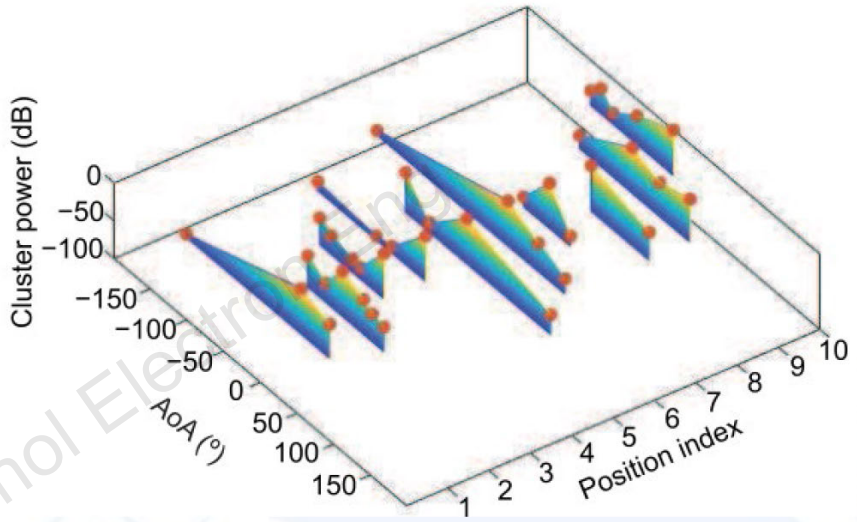
$$W = p_1 \cdot \exp(p_2 \cdot P)$$

	p_1	p_2
Uplink	67.12	0.0503
Downlink	72.08	0.0517

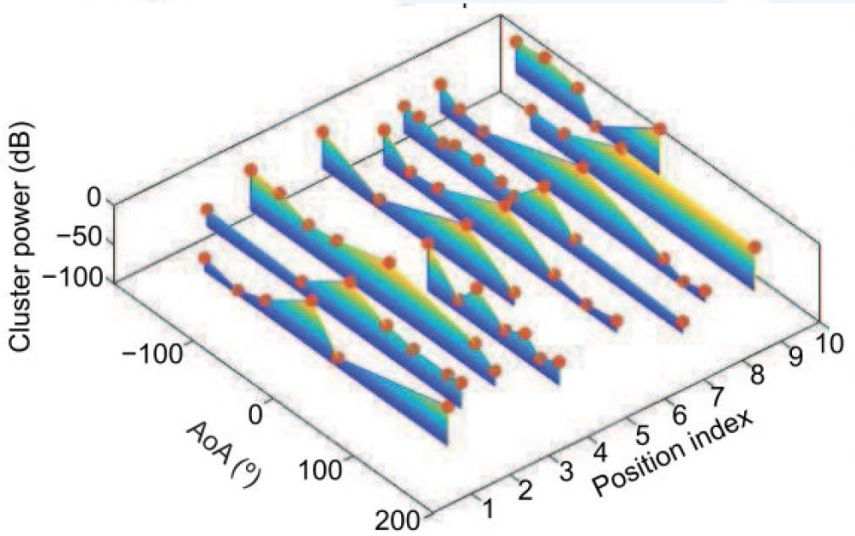
Modeling methods of cluster AoA



(a) Composite PAS in azimuth of clusters



(b) Composite PAS in azimuth of uplink

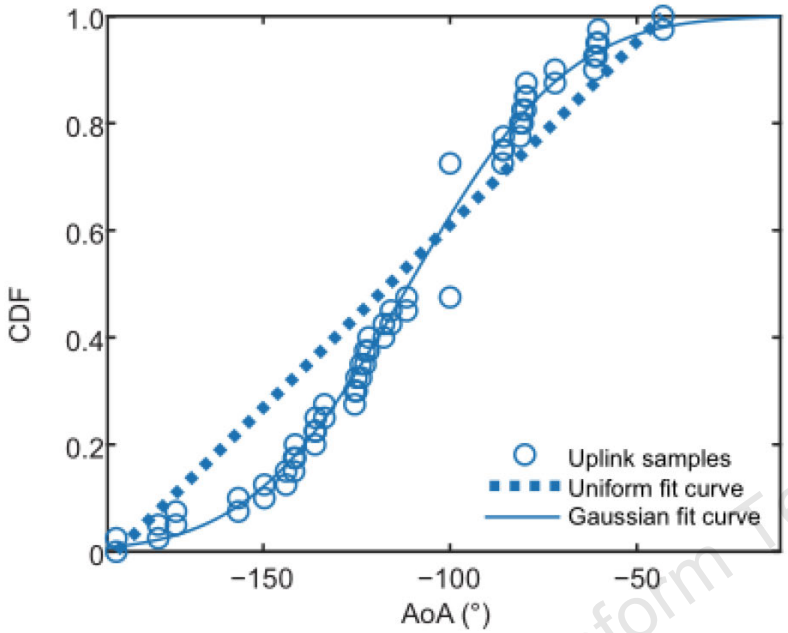


(c) Composite PAS in azimuth of downlink

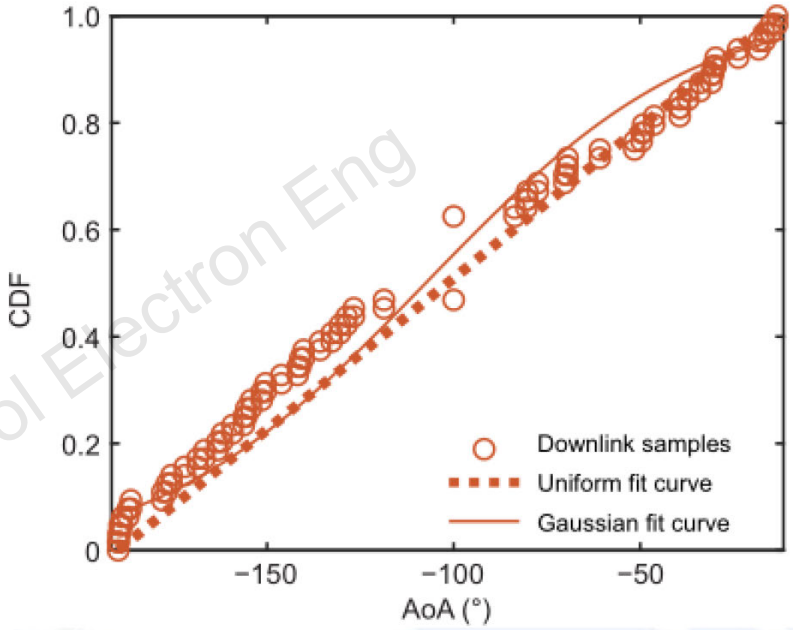
$$\varphi_n = X_n \varphi'_n + Y_n + \varphi_{\mathrm{LOS}} \qquad (1)$$

$$\varphi'_n = \frac{2(\varphi_{\mathrm{ASA}}/1.4)\sqrt{-\ln(P_n/\max_n P_n)}}{C_\varphi} \qquad (2)$$

Modeling methods of cluster AoA



(a) Distribution of cluster AoA in uplink

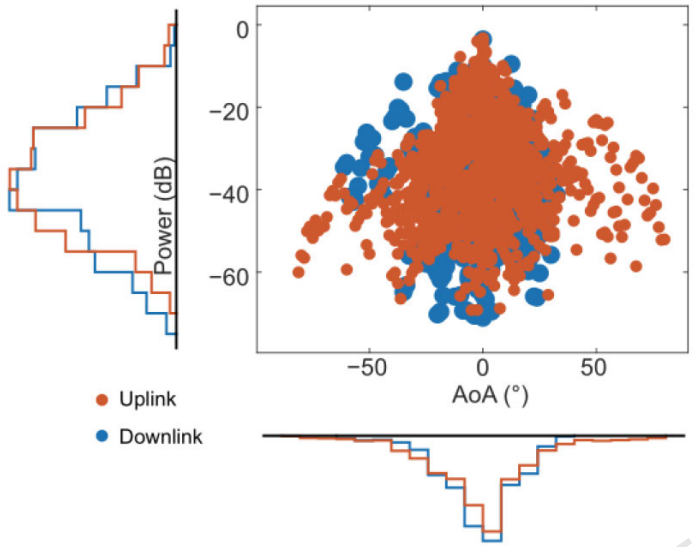


(b) Distribution of cluster AoA in downlink

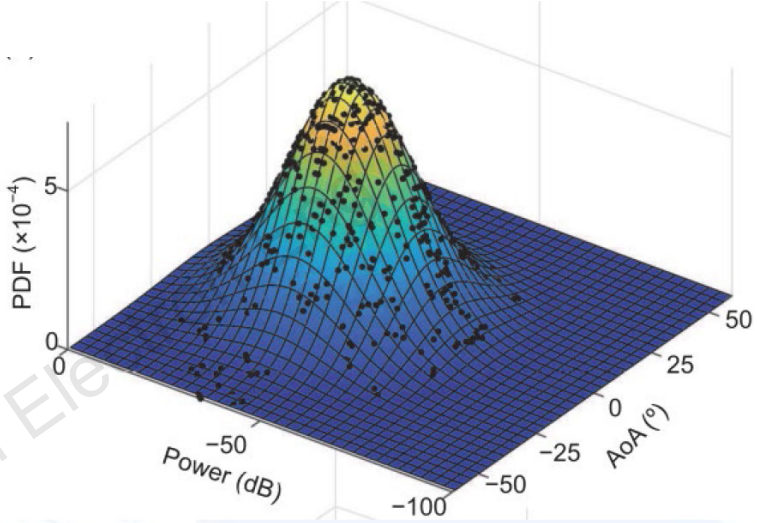
Table 6 p **values of the KS test in the measurement**

Condition	p	
	Gaussian	Uniform
Uplink	0.2829	0.1119
Downlink	0.5519	0.3319

Modeling methods of rays' AoA and power



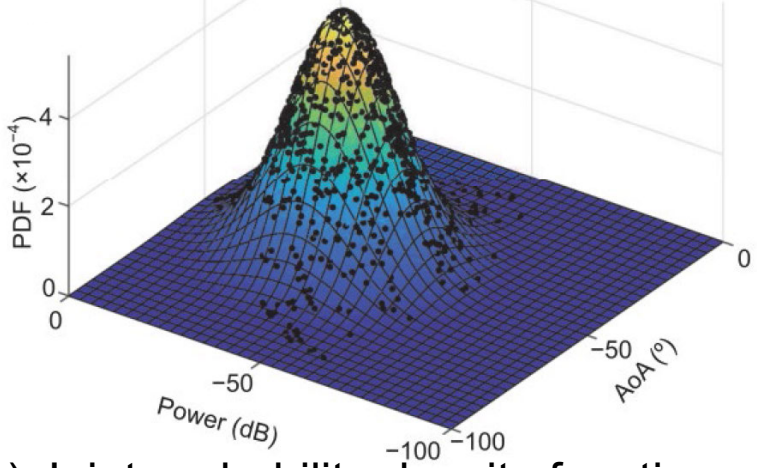
(a) Distribution of rays' AoA



(b) Joint probability density function of rays' AoA and power in uplink

$$p(x_1, x_2) = \frac{1}{2\pi|\Sigma|^{\frac{1}{2}}} \exp[-\frac{1}{2}(\vec{x} - \vec{\mu})^T \Sigma^{-1}(\vec{x} - \vec{\mu})]$$

	$\vec{\mu}$	Σ
Uplink	$[-2.5, 38.2]$	$\begin{bmatrix} 254.4 & -2.6 \\ -2.6 & 193.2 \end{bmatrix}$
Downlink	$[-1.1, 36.8]$	$\begin{bmatrix} 546.1 & 23.9 \\ 23.9 & 157.6 \end{bmatrix}$



(c) Joint probability density function of rays' AoA and power in downlink