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Radio propagation measurement and cluster-based analysis for millimeter-wave cellular systems in dense urban environments

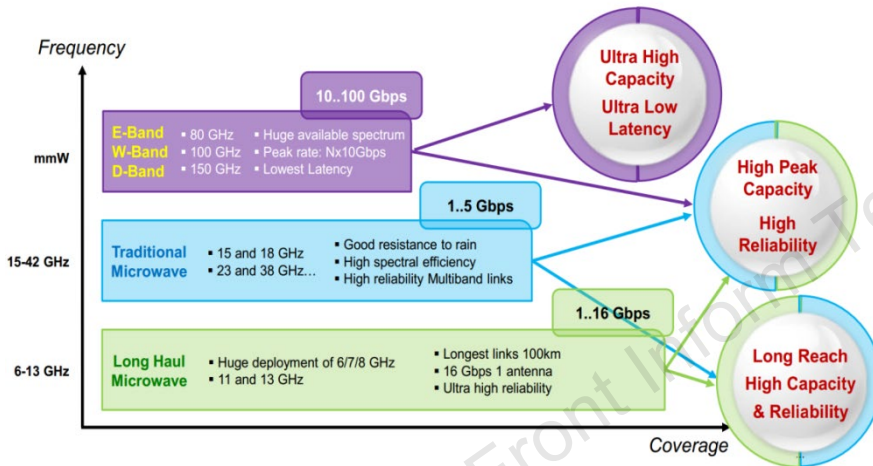
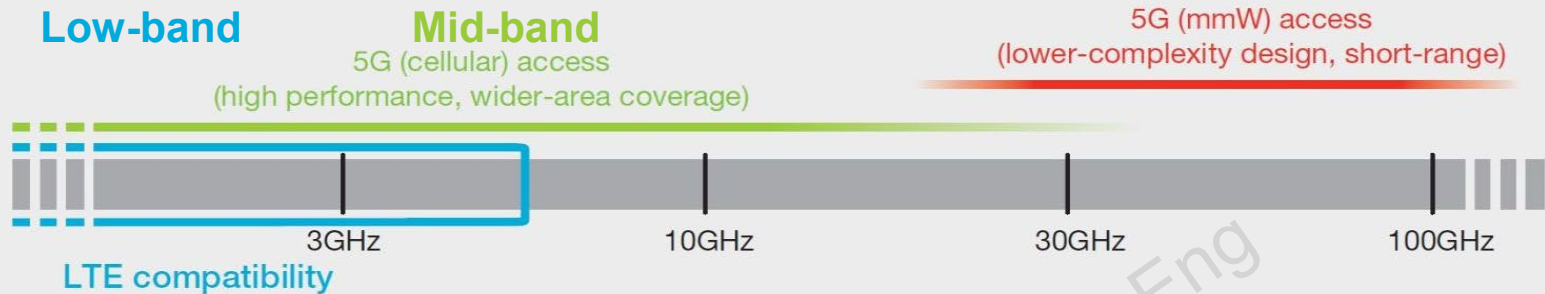
Key words: Millimeter-wave communication; Clustering; Diffraction; Multipath channels; Propagation measurement

Corresponding author: Haiming WANG

E-mail: hmwang@seu.edu.cn

 ORCID: <https://orcid.org/0000-0002-6156-258X>

Motivation (1/2)



(a) Interdependence among frequency, capacity, and availability [1]

>6 GHz Global/Regional IMT Identified Bands in WRC-19



- **24.25 – 27.5 GHz**
- **37 – 43.5 GHz**
expected portions allocated per region
- **66.0 – 71.0 GHz**
(Except possibly some countries in the Americas)
Co-existence IMT and other non-IMT to be developed
- **47.2 – 48.2 GHz**
Americas+~100 countries
Africa, Middle East, Asia (Korea, Japan, India...),
some in Europe

✓ mmWave communications will greatly increase wireless capacity and speeds for future 5G/B5G, but still in its early stages for commercial deployments.

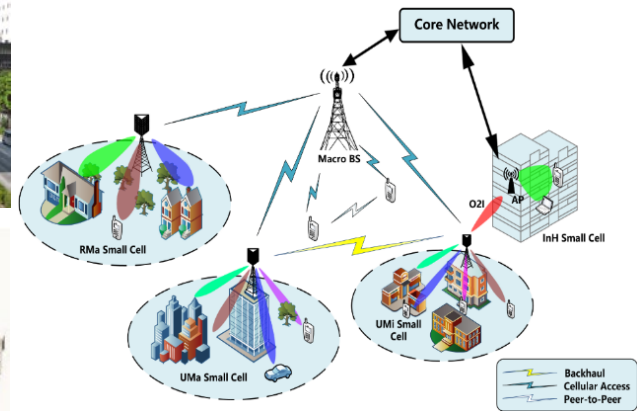
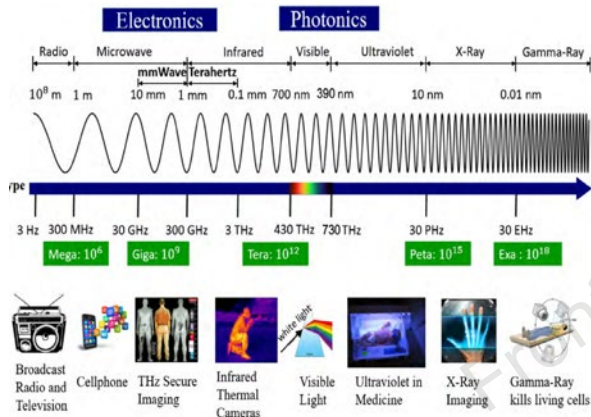
Motivation (2/2)

Channel measurements and modeling: transmission scheme and network deployment

All frequency bands:
sub-6 GHz, **mmWave**,
THz, VLC

All scenarios: InH, UMi,
UMa, RMa, V2X, UAV,
IIoT, backhaul, ...

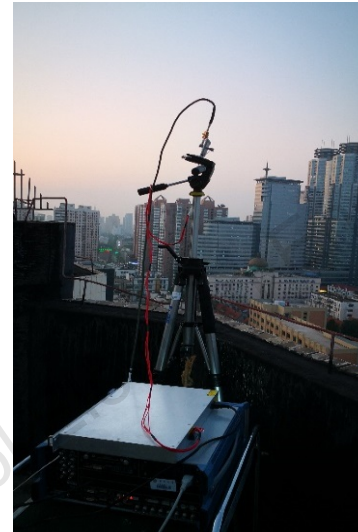
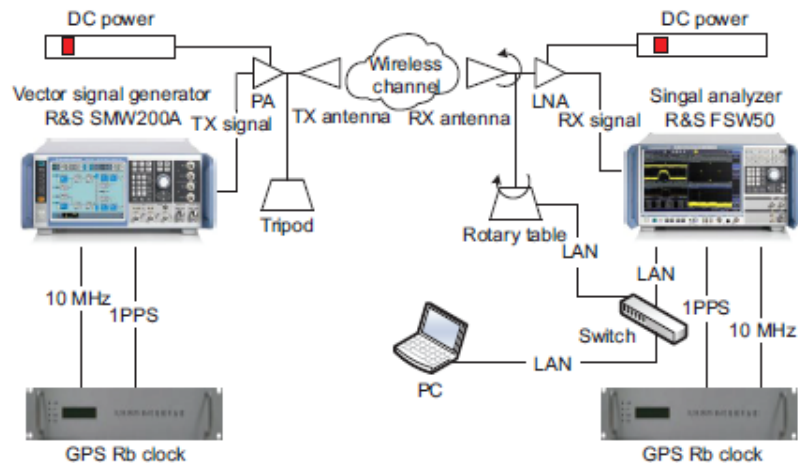
All applications:
directional transmission
and network architectures



- ✓ Propagation measurements and channel modeling are the fundamental prerequisites for 5G/B5G network design and deployment;
- ✓ Standard bodies need channel models to support multiple frequency bands and scenarios.

Channel measurement campaigns (1/2)

❑ Channel sounder hardware



TX



RX

■ Scheme

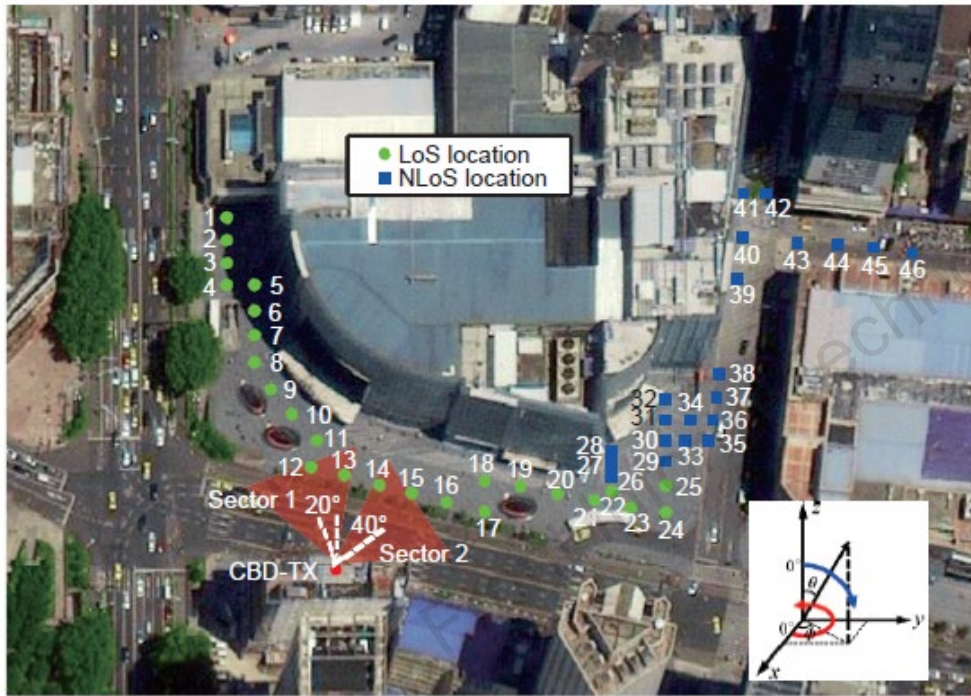
- Transmit signal: **periodic Golay pair with perfect complementary autocorrelation**;
- Wideband vector signal generator transmits known sequences and the signal analyzer acquires received signals while narrow-beam horn rotates for angle information.

■ Advantage

- **Flexible**: measurements for **multi-frequency bands** and **multiple scenarios** using different antenna configurations;
- **Highly efficient**: **36 s for TX/RX directional antenna sweeps** in the entire 2π azimuth plane;
- **Stable**: using **Commercial Off-The-Shelf** instruments with **the overall measurable path loss of 159 dB @39 GHz**.

Channel measurement campaigns (2/2)

□ Urban macrocell scenarios



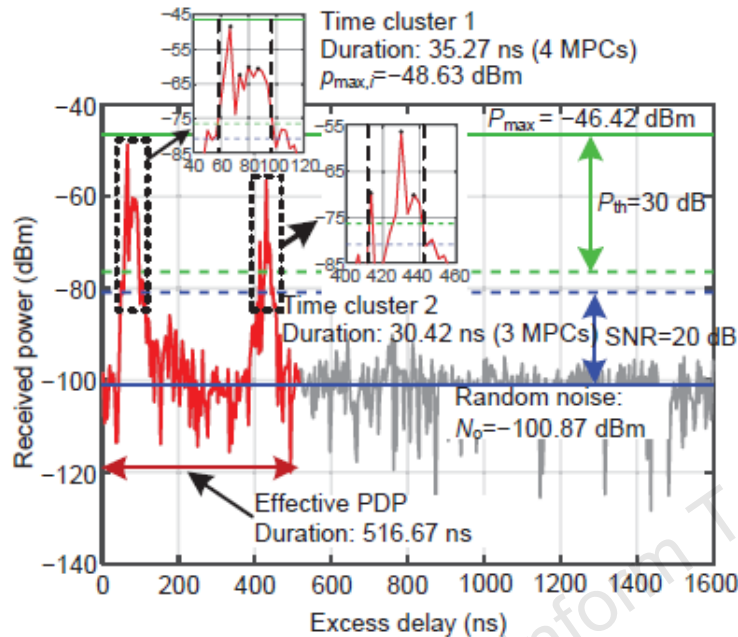
**CBD: central business district
in Xinjiekou, Nanjing**



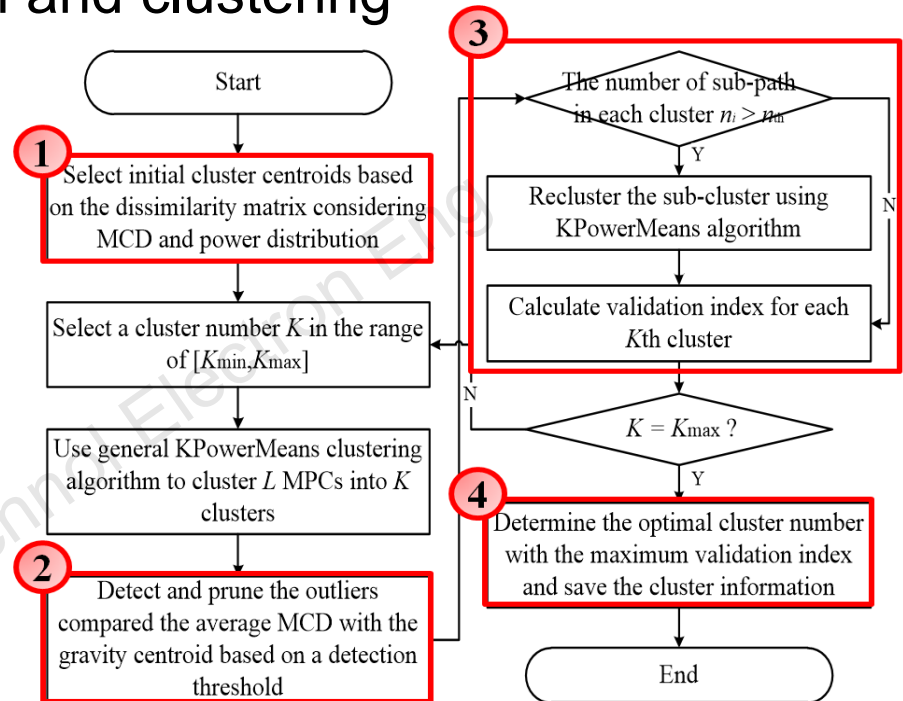
**DRA: dense residential area
in Zhangfuyuan, Nanjing**

Multipath clustering

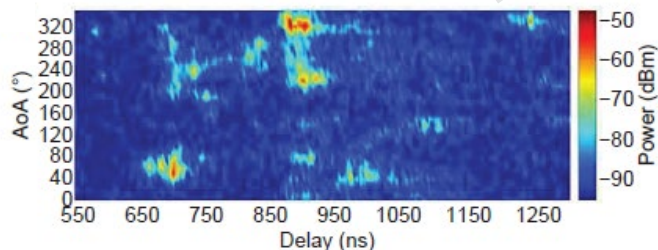
□ Multipath component estimation and clustering



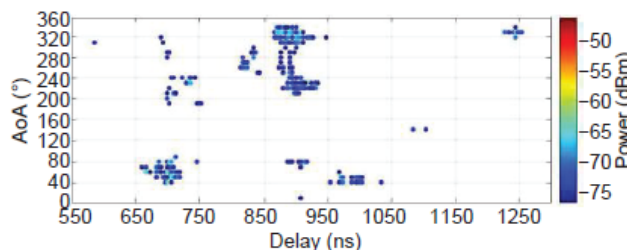
(a) MPC estimation via the peak detection algorithm



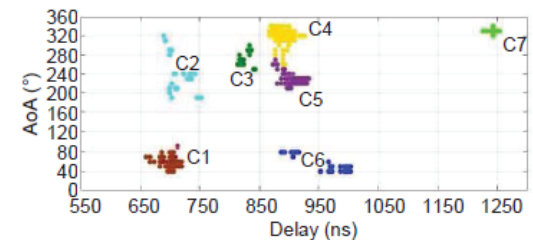
(b) Flowchart of the two-step KPowerMeans clustering algorithm



(c) Measured PDAP



(d) Estimated MPCs

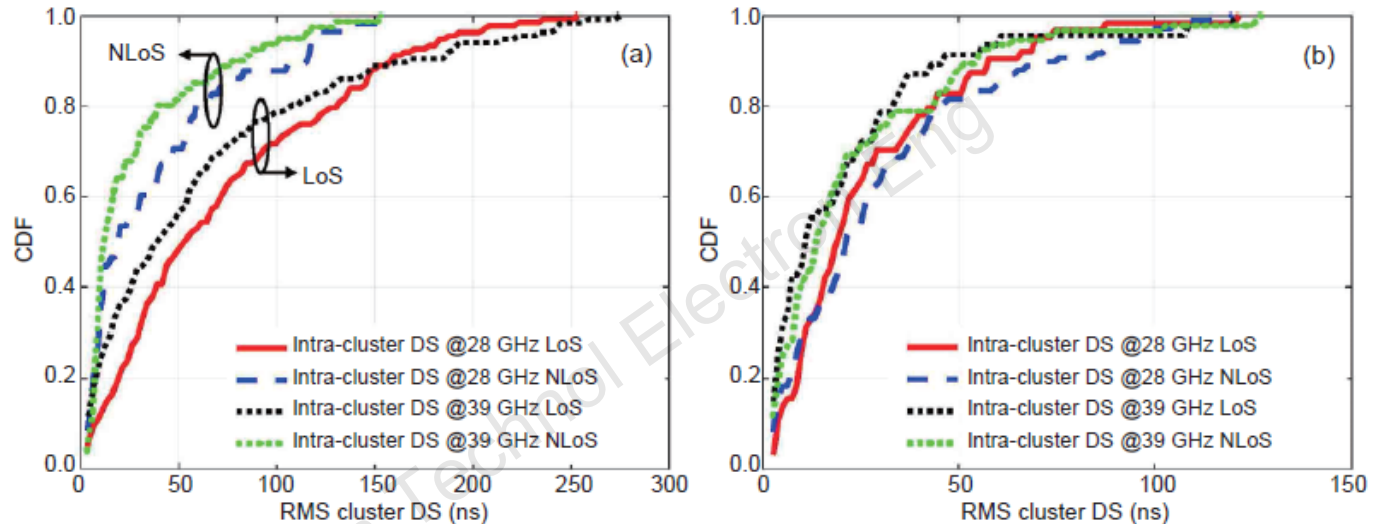


(e) Clustering results

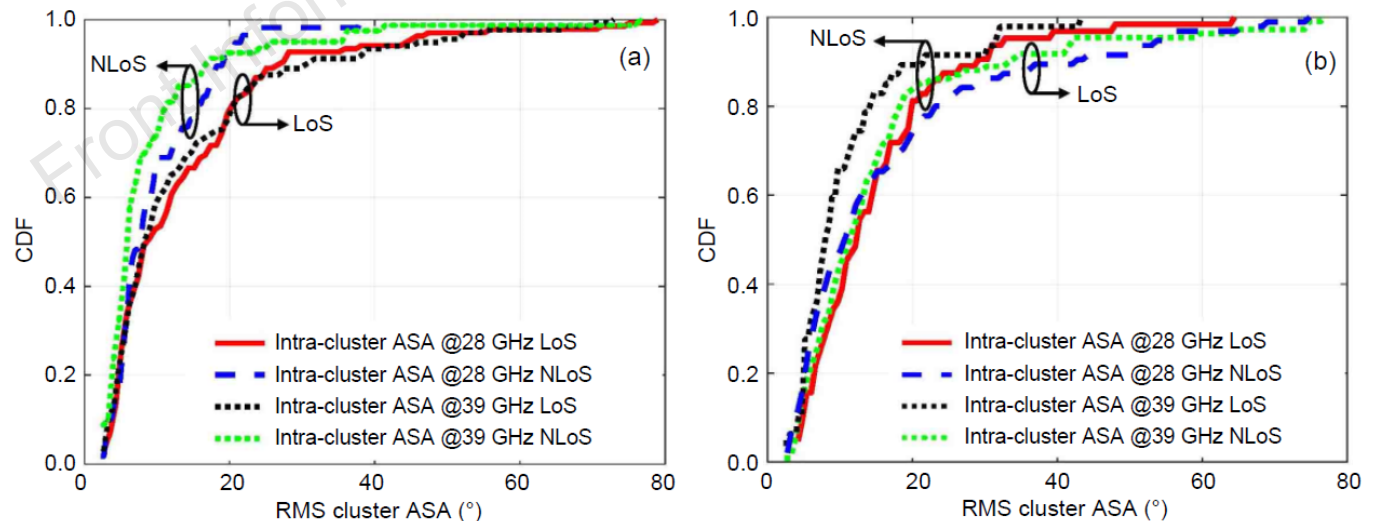
Cluster-based channel modeling (1/3)

□ Intra-cluster delay and angular spreads

✓ CDF for cluster-level delay spread

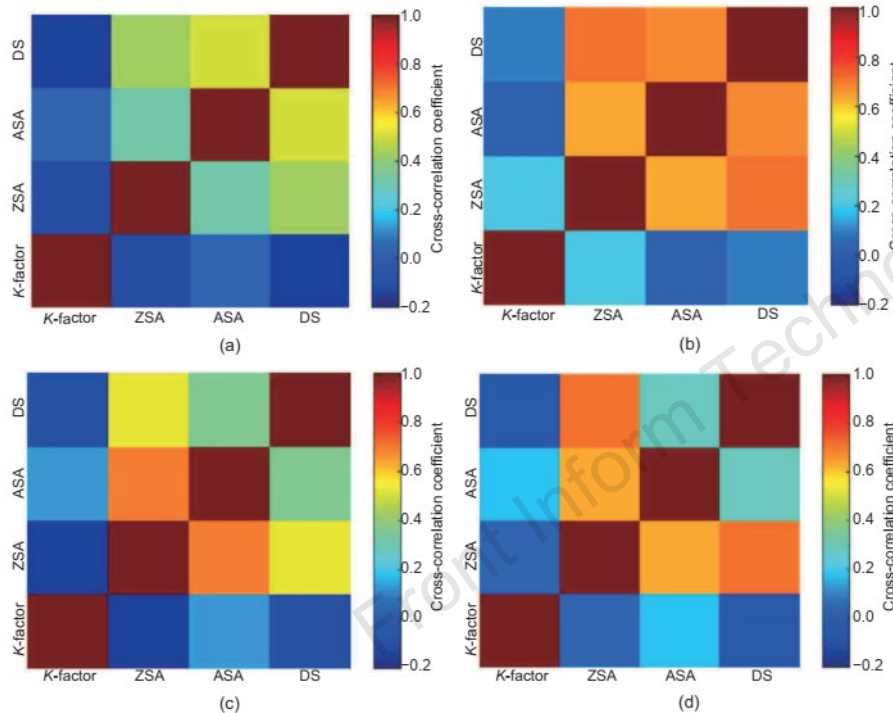


✓ CDF for cluster-level azimuth angular spread

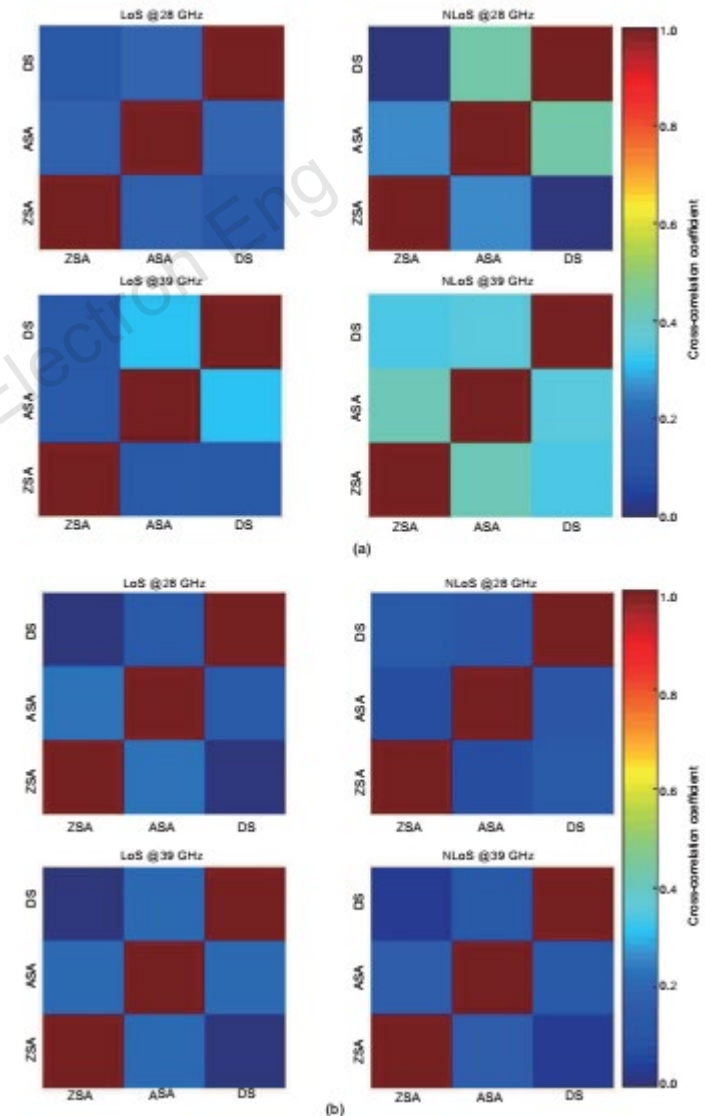


Cluster-based channel modeling (2/3)

Correlations among several cluster-level channel parameters



Inter-cluster channel parameters



Intra-cluster channel parameters

Cluster-based channel modeling (3/3)

Statistics of cluster-based channel modeling parameters

Table 3 Statistics of inter- and intra-cluster channel parameters for UMa scenarios at 28 and 39 GHz bands

Scenario	Composite DS ⁺ (lg(s))		Composite ASA* (lg(°))		Composite ZSA* (lg(°))		Ricean <i>K</i> -factor	
	μ	σ	μ	σ	μ	σ	μ	σ
UMa, CBD, 28 GHz LoS	-6.73	0.26	1.84	0.20	0.90	0.13	7.34	2.68
UMa, CBD, 28 GHz NLoS	-7.00	0.23	1.76	0.30	0.87	0.09	NA	NA
UMa, CBD, 39 GHz LoS	-6.81	0.33	1.77	0.30	0.83	0.19	6.27	2.28
UMa, CBD, 39 GHz NLoS	-7.28	0.23	1.71	0.33	0.85	0.20	NA	NA
UMa, DRA, 28 GHz LoS	-7.02	0.23	1.79	0.21	1.00	0.15	7.71	1.07
UMa, DRA, 28 GHz NLoS	-6.79	0.29	1.87	0.29	0.97	0.11	NA	NA
UMa, DRA, 39 GHz LoS	-7.08	0.29	1.62	0.44	1.00	0.19	6.37	2.02
UMa, DRA, 39 GHz NLoS	-6.88	0.33	1.88	0.38	0.95	0.11	NA	NA

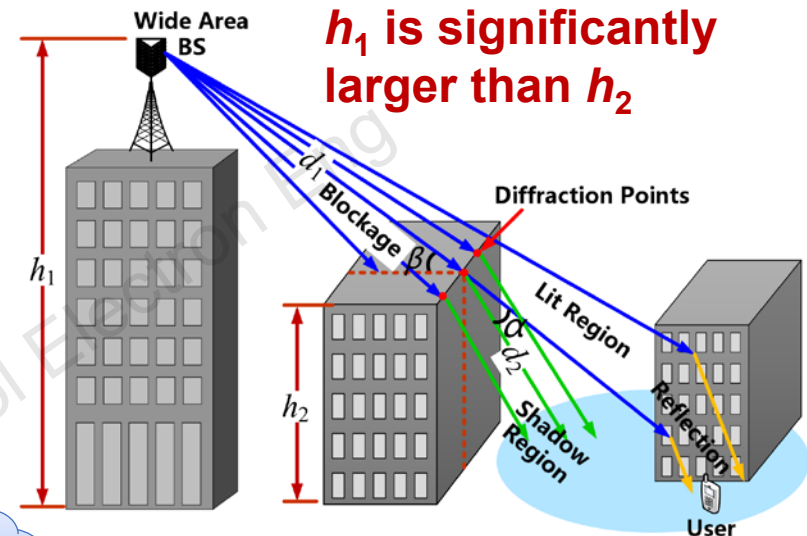
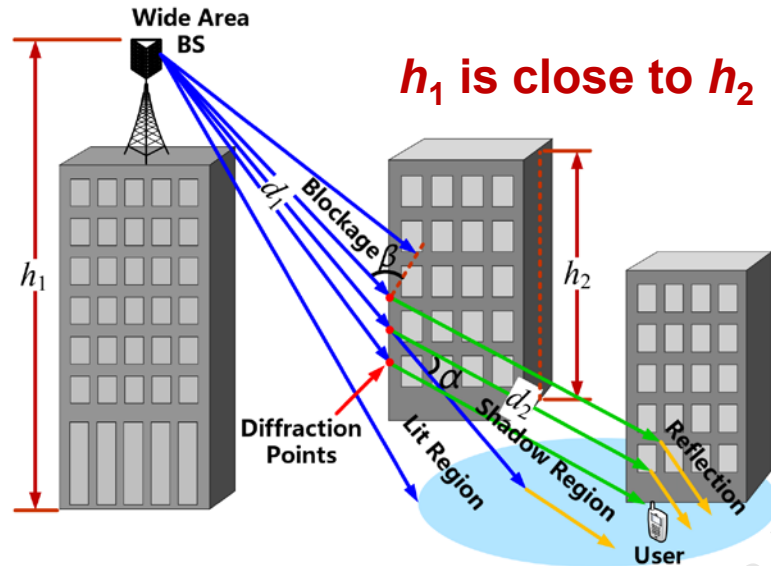
Scenario	Cluster No.		Cluster DS (ns)		Cluster ASA (°)		Cluster ZSA (°)	
	μ	σ	μ	σ	μ	σ	μ	σ
UMa, CBD, 28 GHz LoS	7.28	2.46	72.13	41.16	14.48	10.40	7.29	3.14
UMa, CBD, 28 GHz NLoS	5.92	1.89	37.37	31.10	10.12	6.82	6.56	2.22
UMa, CBD, 39 GHz LoS	7.13	3.03	62.81	46.26	12.66	11.21	7.03	2.96
UMa, CBD, 39 GHz NLoS	5.78	2.16	28.30	29.95	8.16	6.59	8.05	2.63
UMa, DRA, 28 GHz LoS	6.08	1.98	27.00	23.59	13.95	9.15	9.98	3.90
UMa, DRA, 28 GHz NLoS	6.30	3.36	30.56	27.97	14.24	11.79	7.50	3.18
UMa, DRA, 39 GHz LoS	5.42	2.68	21.09	24.99	11.17	10.23	7.90	4.11
UMa, DRA, 39 GHz NLoS	5.42	2.26	23.09	23.03	13.93	12.51	7.09	2.83

UMa: urban macrocell; CBD: central business district; DRA: dense residential area; LoS: line-of-sight; NLoS: non-line-of-sight; DS: delay spread; ASA: azimuth angular spread of arrival; ZSA: zenith angular spread of arrival; NA: not available. The upper part shows the composite channel parameters (Zhang et al., 2019), and the lower part shows the cluster-level channel parameters.

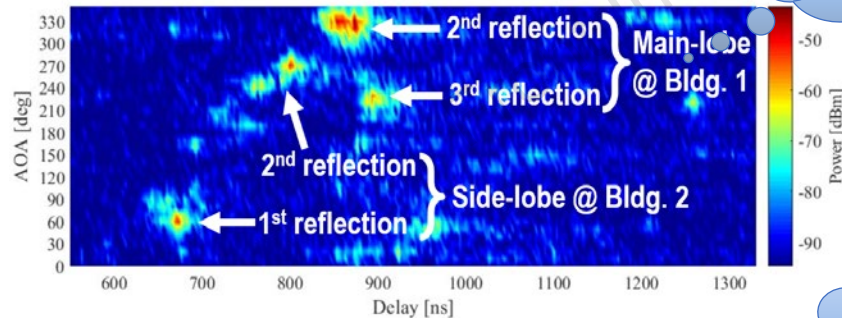
⁺: The threshold of 8 dB above the noise floor is used for effective PDPs estimation (Wang et al., 2019) and RMS composite delay spread calculation (Rappaport et al., 2015). *: The threshold of 25 dB below the peak level of the power angular profile is used for RMS angular spread calculation (ITU, 2017)

Analysis of propagation mechanisms

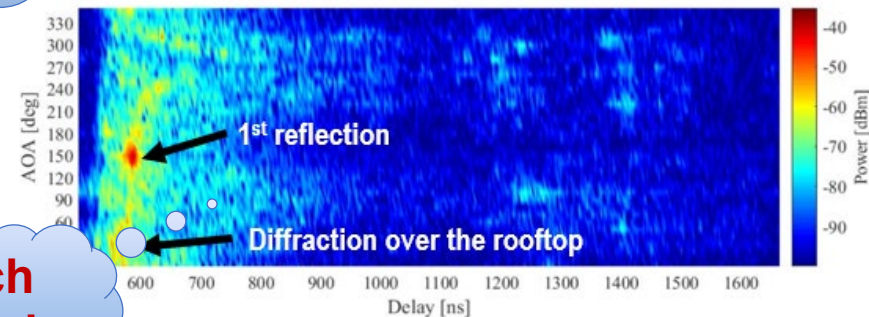
□ Mapping virtual clusters to physical scatterers



Sparse channel



(a) PDAP for CBD environment



(b) PDAP for DRA environment

Rich scattering

Conclusions

- ❑ Highly efficient wideband mmWave channel sounder for multiple frequency bands and scenarios
 - Support outdoor **long-distance LoS/NLoS measurements**
 - Support **double-directional measurements**, e.g., AoA/AoD in azimuth and elevation
 - Support **flexible measurement setting**, e.g., omni/dir. ant., 0.9–40 GHz
- ❑ Cluster-level propagation characteristics and channel modeling in dense urban environments
 - **Reflection and diffraction** extend the coverage of mmWave networks with the radius up to **200 m** in NLoS links;
 - Finite number of strong clusters (e.g., 5–7) would be enough to describe mmWave multipath channels for UMa LoS/NLoS links;
 - Spatio-temporal cluster spreads DS and ASA generally reduce with increasing frequency, but ZSA is probably frequency-independent.
- ❑ Enable real-world deployment of mmWave cellular networks with enhanced coverage.

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Peize ZHANG received the BS degree from Beijing University of Posts and Telecommunications, Beijing, China, in 2015, and the MS degree from China Academy of Telecommunications Technology, Beijing, China, in 2018, both in Electrical Engineering. He is currently pursuing the PhD degree at the State Key Laboratory of Millimeter Waves, Southeast University, Nanjing, China. His current research interests include millimeter-wave radio propagation measurements, channel modeling, and network planning.



Haiming WANG was born in 1975. He received the MS and PhD degrees in Electrical Engineering from Southeast University, Nanjing, China, in 2002 and 2009, respectively. He joined the State Key Laboratory of Millimeter Waves, Southeast University, in April 2002. Now he is a Professor. His current research interests include radio propagation measurement and channel modeling, signal processing for MIMO wireless communications, and millimeter-wave wireless communications.



Wei HONG received the BS degree in Radio Engineering from the University of Information Engineering, Zhengzhou, China, in 1982, and the MS and PhD degrees in Radio Engineering from Southeast University, Nanjing, China, in 1985 and 1988, respectively. Since 1988, he has been with the State Key Laboratory of Millimeter Waves, Southeast University, where he has been the Director since 2003. He is currently a Professor with the School of Information Science and Engineering, Southeast University. His current research interests include numerical methods for electromagnetic problems, millimeter-wave theory and technology, antennas, electromagnetic scattering, and RF technology for mobile communications.