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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

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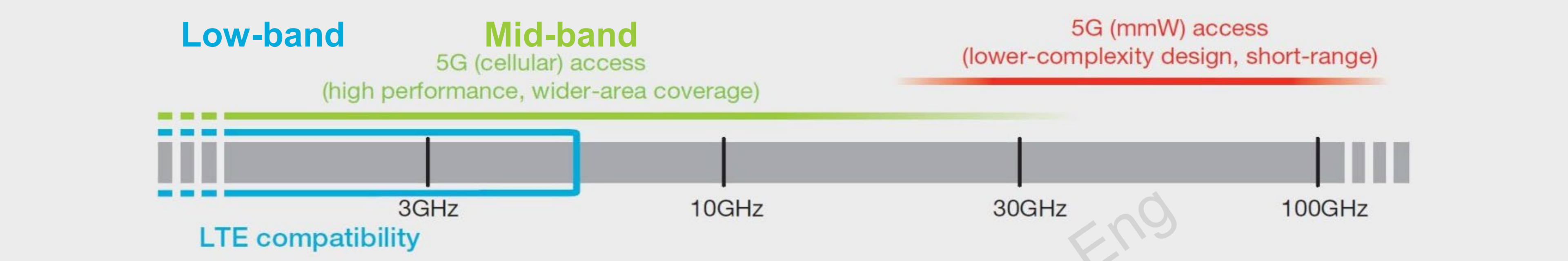
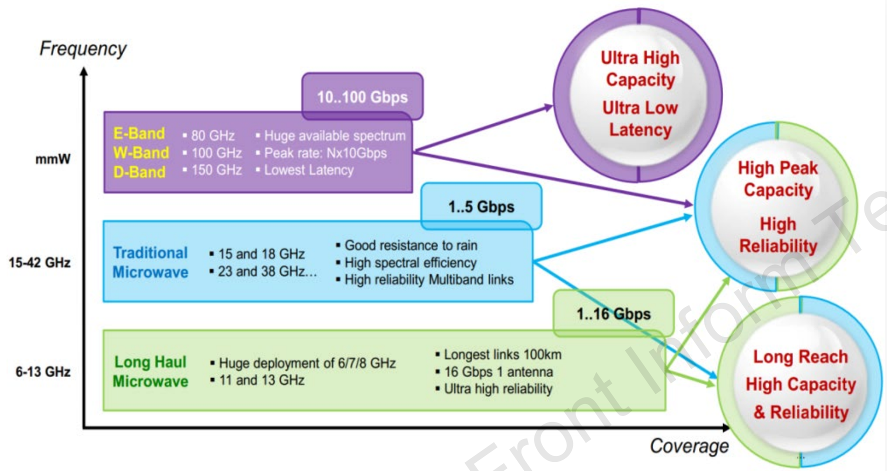
Motivation (1/2)





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

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

ITUWRC SHARM EL-SHEIKH2019
28 October - 22 November
Sharm El-Sheikh, Egypt

- **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.**

[1] ETSI White paper No. 25, Microwave and Millimeter-Wave for 5G Transport (1st Ed.), Feb. 2018

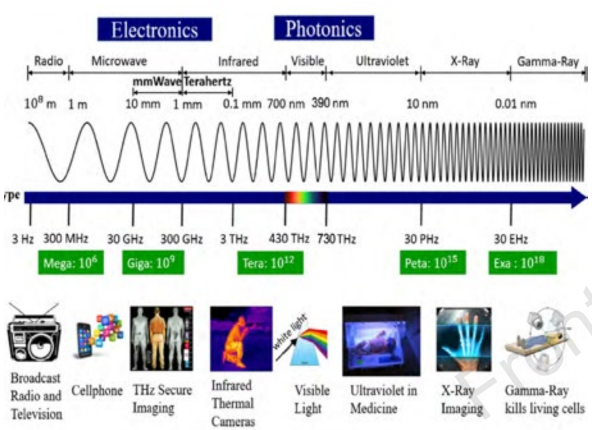
Motivation (2/2)

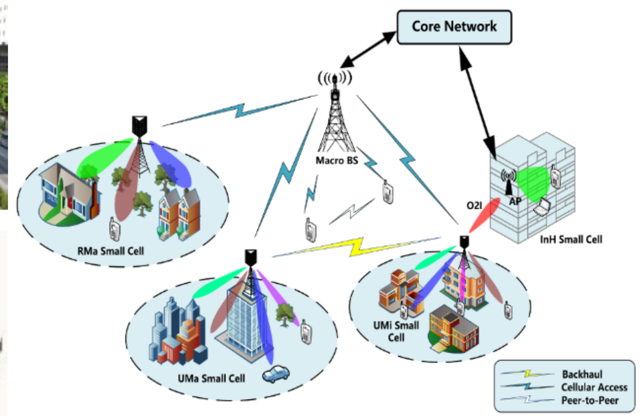
Channel measurements and modeling:
transmission scheme and network deployment

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

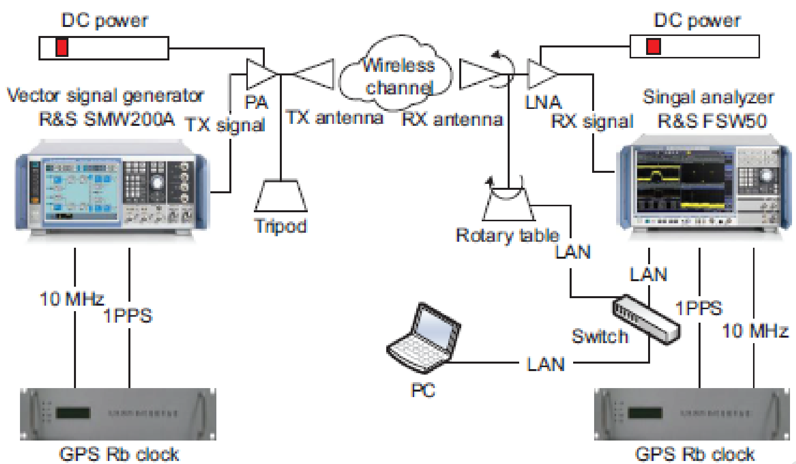


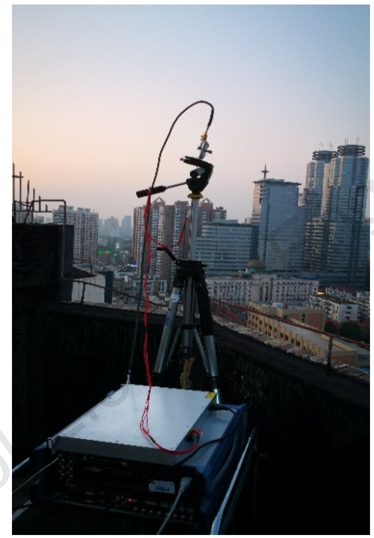


- ✓ **Propagation measurements and channel modeling are the fundamental prerequisites for 5G/B5G network design and deployment;**
- ✓ **Standard bodies need channel models to support multiple frequency bands and scenarios.**

Channel measurement campaigns (1/2)

☐ Channel sounder hardware





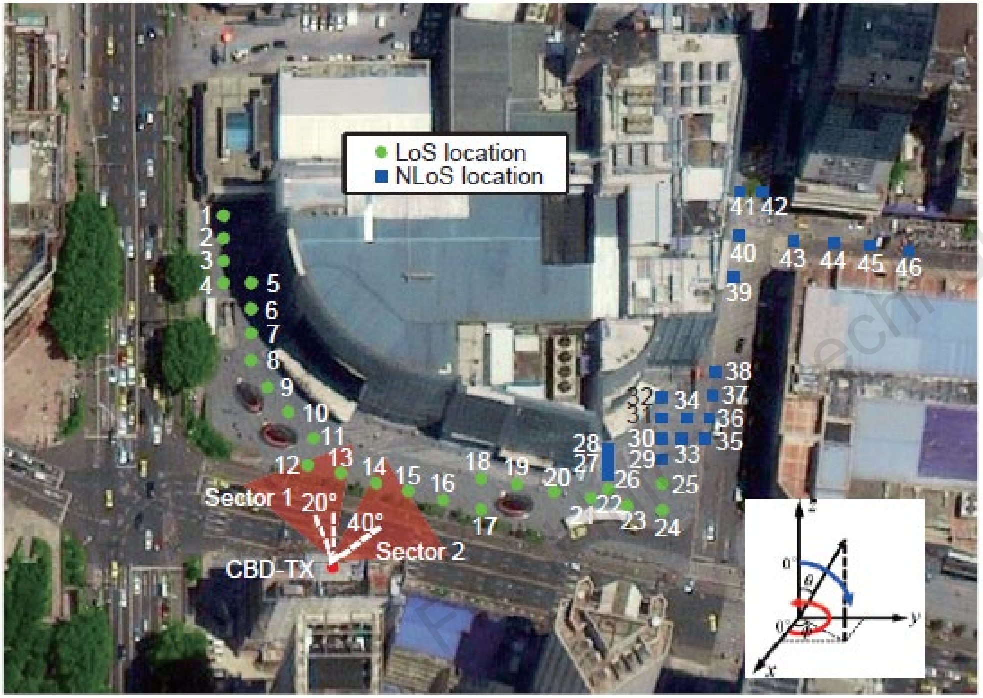
TX

RX

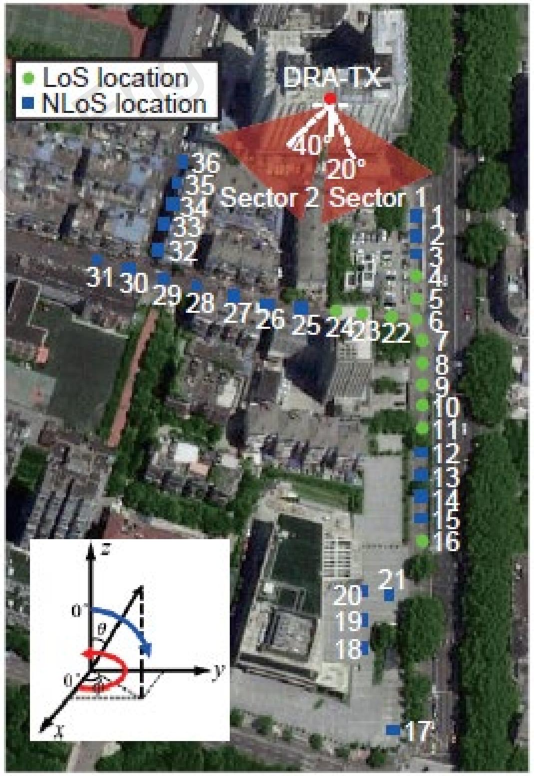
- **Scheme**
  - Transmit signal: **periodic Golay pair with perfect complementary autocorrelation**;
  - Wideband vector signal generator transmits known sequences and the signal analyzer acquires received signals while narrow-beam horn rotates for angle information.
- **Advantage**
  - **Flexible:** 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 **C**ommercial **O**ff-**T**he-**S**helf instruments with **the overall measurable path loss of 159 dB @39 GHz.**

Channel measurement campaigns (2/2)

- Urban macrocell scenarios



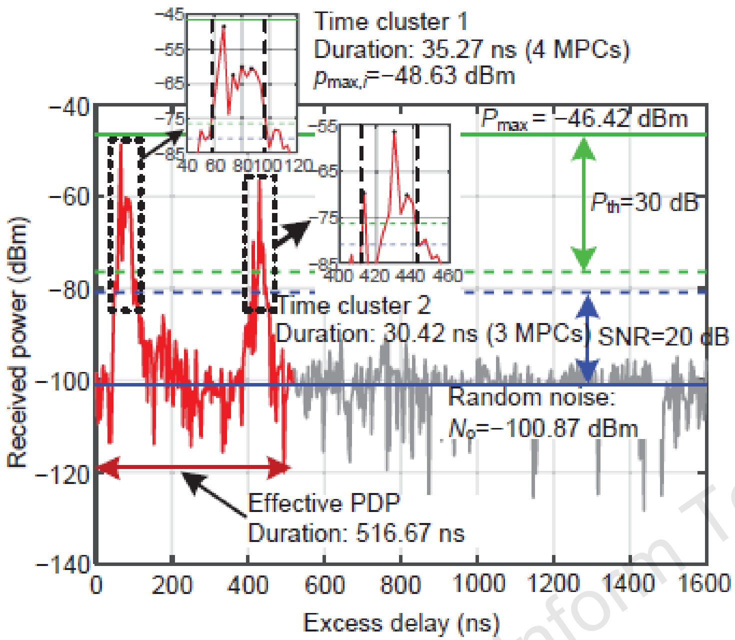
CBD: central business district in Xinjiekou, Nanjing



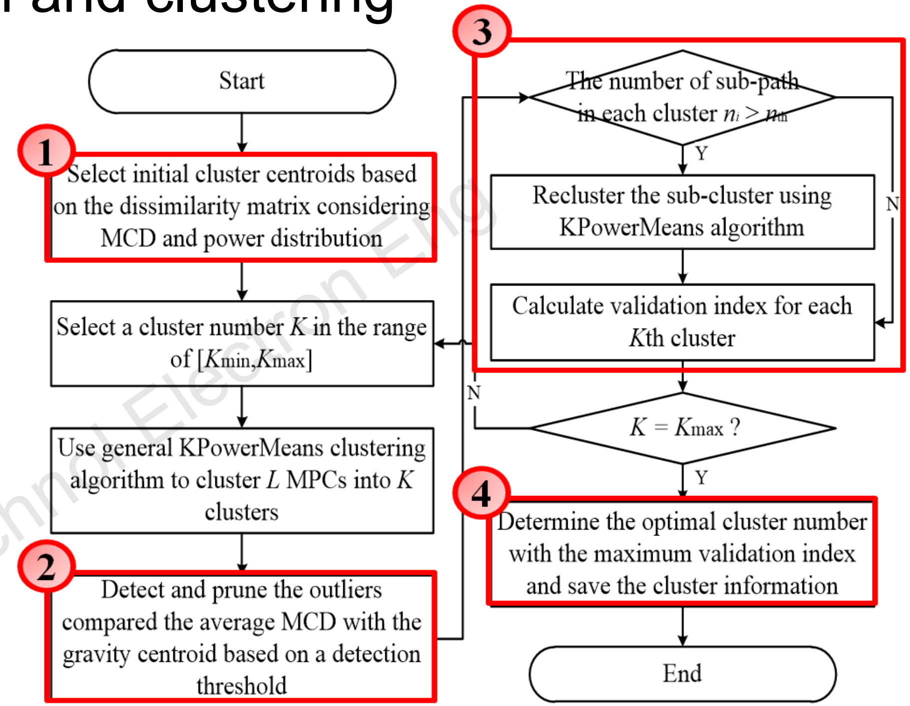
DRA: dense residential area in Zhangfuyuan, Nanjing

Multipath clustering

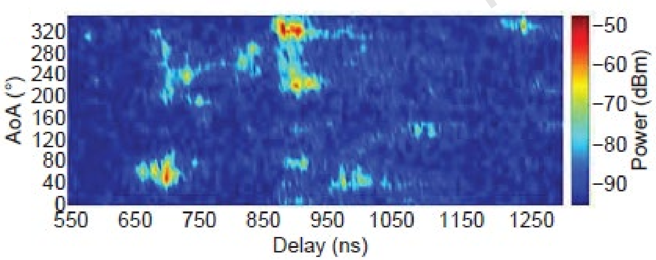
□ Multipath component estimation and clustering



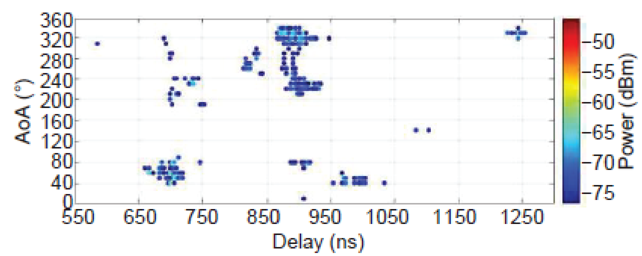
(a) MPC estimation via the peak detection algorithm



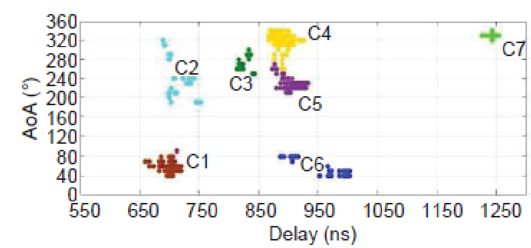
(b) Flowchart of the two-step KPowerMeans clustering algorithm



(c) Measured PDAP



(d) Estimated MPCs

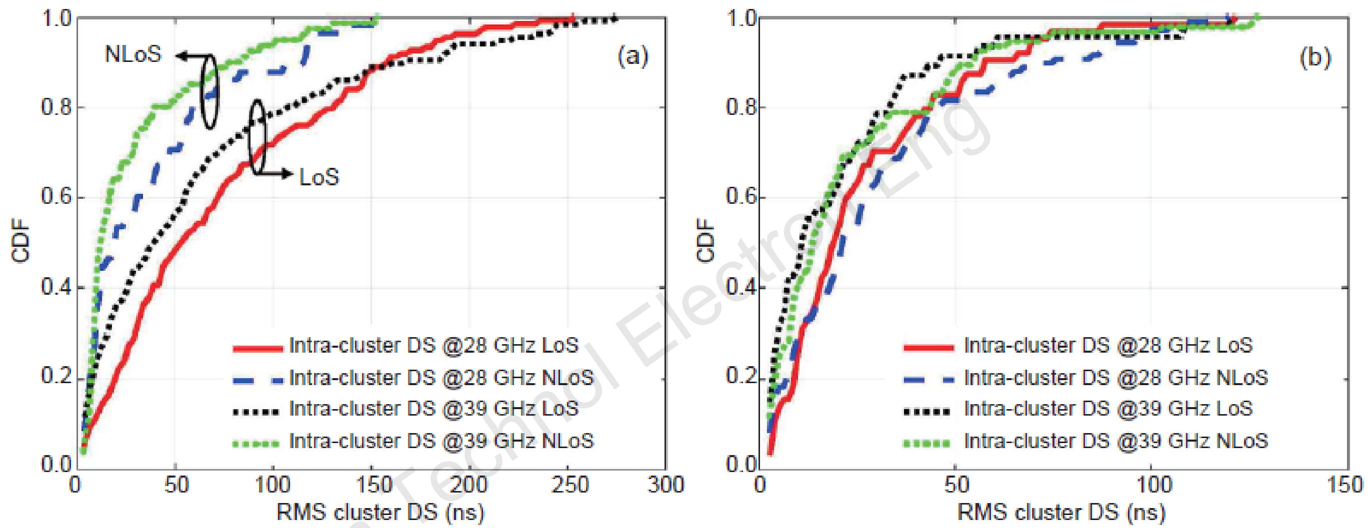


(e) Clustering results

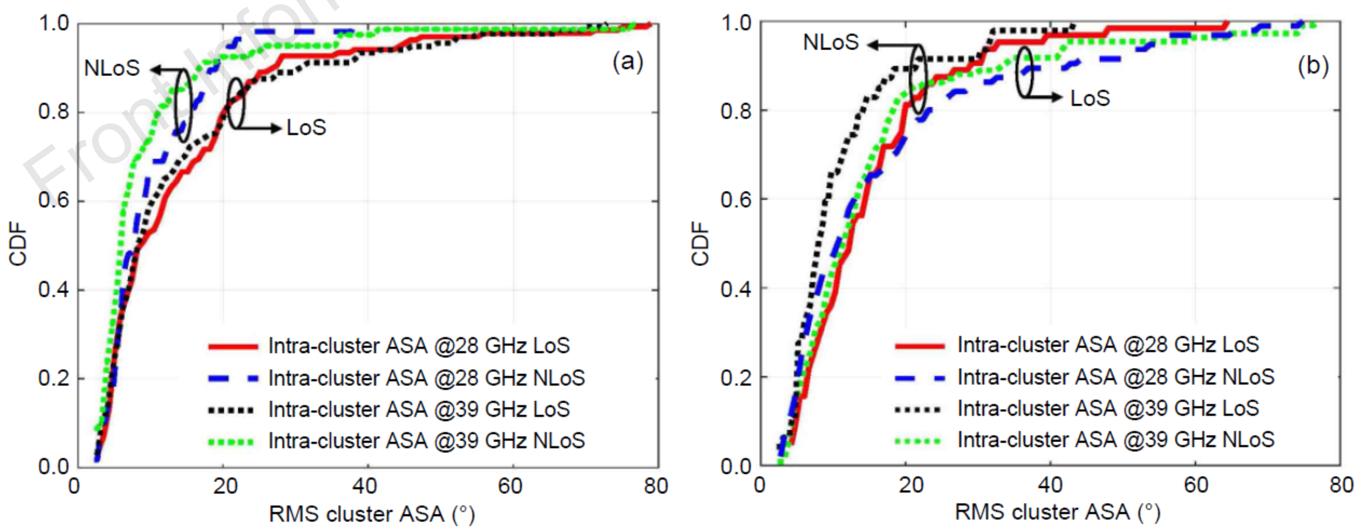
Cluster-based channel modeling (1/3)

□ Intra-cluster delay and angular spreads

✓ **CDF for cluster-level delay spread**

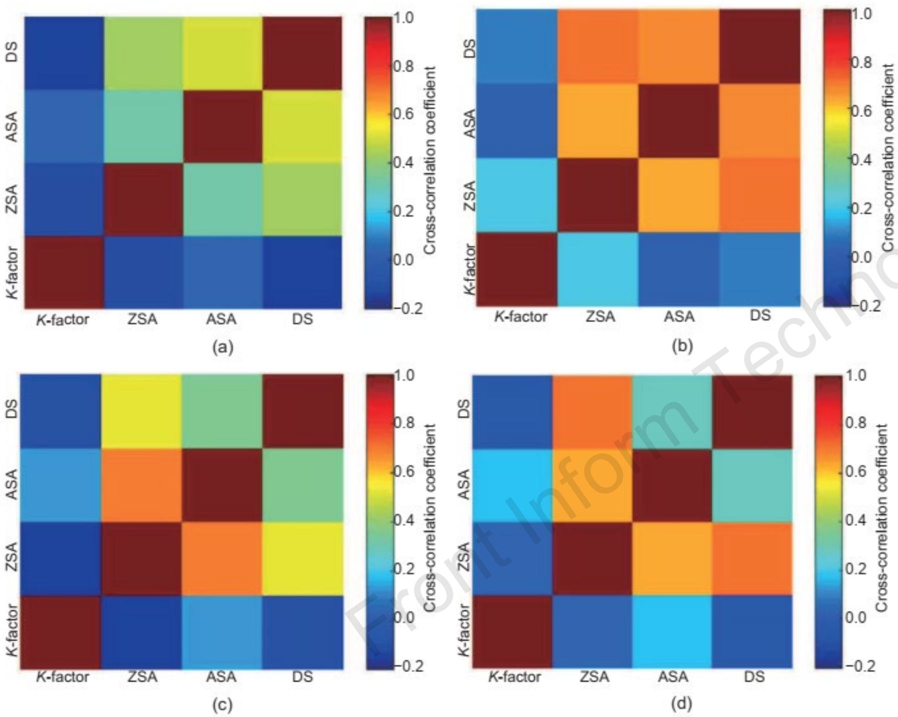


✓ **CDF for cluster-level azimuth angular spread**

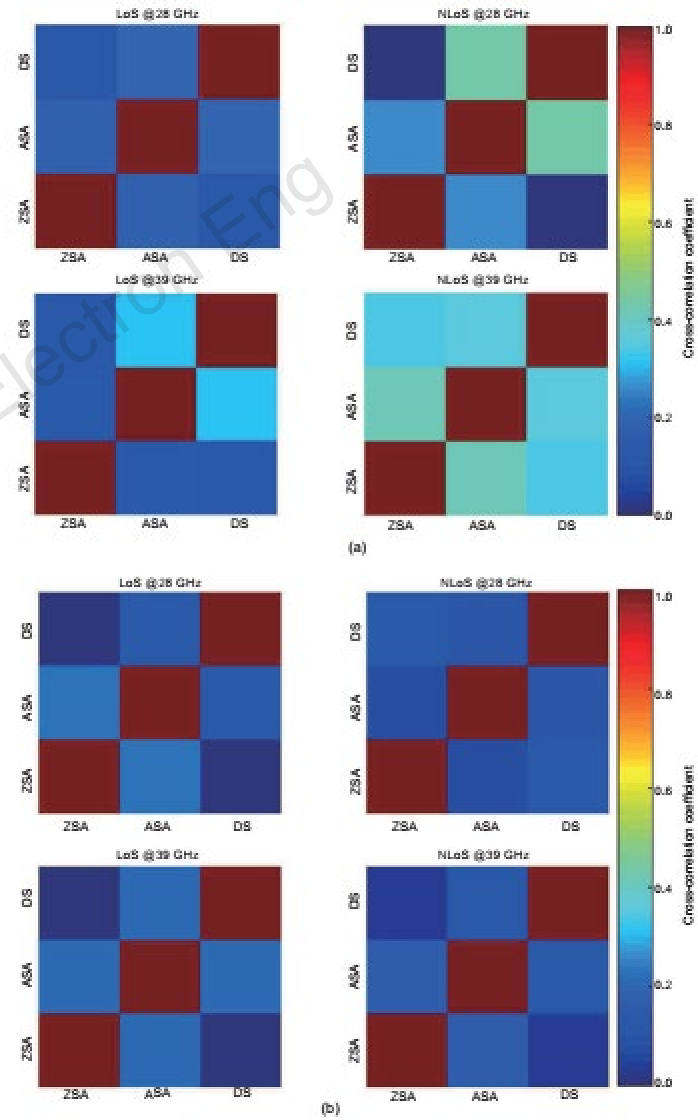


Cluster-based channel modeling (2/3)

- 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 K-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

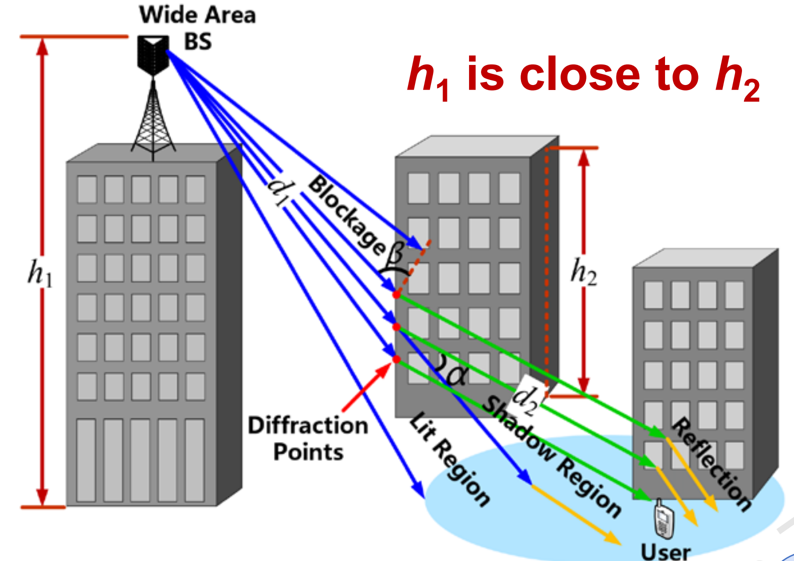
Scenario	Cluster No.		Cluster DS (ns)		Cluster ASA (°)		Cluster ZSA (°)	
	μ	σ	μ	σ	μ	σ	μ	σ
UMa, CBD, 28 GHz LoS	7.28	2.46	72.13	41.16	14.48	10.40	7.29	3.14
UMa, CBD, 28 GHz NLoS	5.92	1.89	37.37	31.10	10.12	6.82	6.56	2.22
UMa, CBD, 39 GHz LoS	7.13	3.03	62.81	46.26	12.66	11.21	7.03	2.96
UMa, CBD, 39 GHz 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)

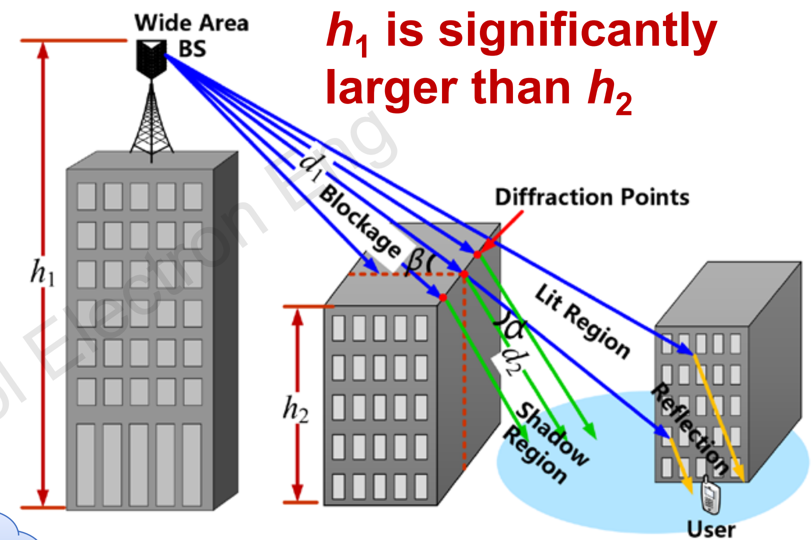
Analysis of propagation mechanisms

- Mapping virtual clusters to physical scatterers

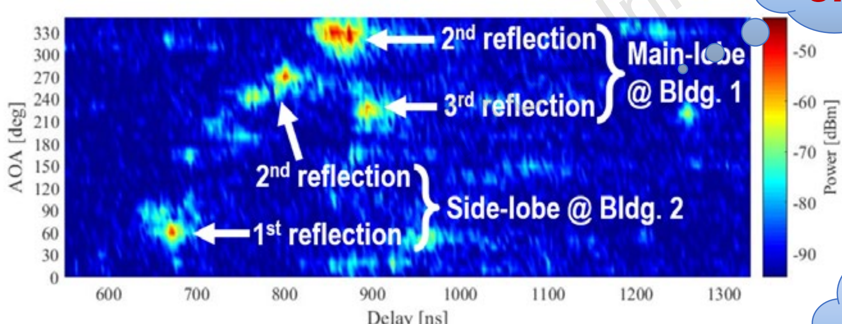
h_1 is close to h_2



h_1 is significantly larger than h_2

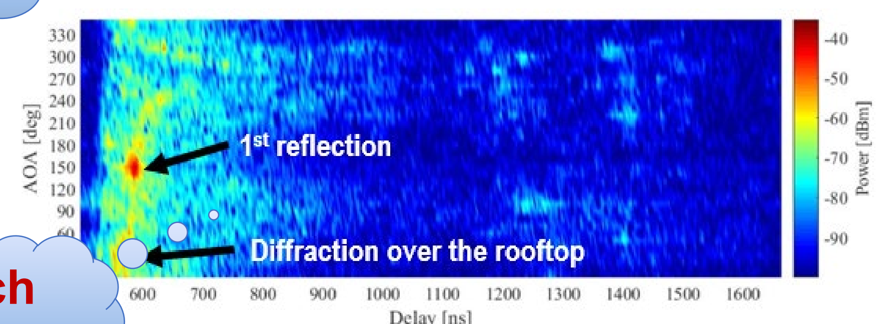


Sparse channel



(a) PDAP for CBD environment

Rich scattering



(b) PDAP for DRA environment

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.

References

[1] Wang HM, Zhang PZ, Li J, et al., 2019. Radio propagation and wireless coverage of LSAA-based 5G millimeterwave mobile communication systems. *China Commun*, 16(5):1-18. https://doi.org/10.23919/j.cc.2019.05.001

[2] Li J, Zhang PZ, Yu C, et al., 2019. High-efficiency wideband millimeter-wave channel sounder system. Proc 13th European Conf on Antennas and Propagation, p.1-5.

[3] He RS, Ai B, Molisch AF, et al., 2018. Clustering enabled wireless channel modeling using big data algorithms. *IEEE Commun Mag*, 56(5):177-183. https://doi.org/10.1109/MCOM.2018.1700701

[4] Czink N, Cera P, Salo J, et al., 2006. A framework for automatic clustering of parametric MIMO channel data including path powers. Proc IEEE Vehicular Technology Conf, p.1-5.

[5] Zhang PZ, Wang HB, Zhou Y, et al., 2017. An improved three-dimensional auto-clustering algorithm for indoor millimeter-wave multipath propagation analysis. Proc IEEE/CIC Int Conf on Communications in China, p.1-6. https://doi.org/10.1109/ICCChina.2017.8330409

[6] Rappaport TS, MacCartney GR, Samimi MK, et al., 2015. Wideband millimeter-wave propagation measurements and channel models for future wireless communication system design. *IEEE Trans Commun*, 63(9):3029-3056. https://doi.org/10.1109/TCOMM.2015.2434384

[7] Zhang PZ, Li J, Wang HB, et al., 2018. Indoor small-scale spatiotemporal propagation characteristics at multiple millimeter-wave bands. *IEEE Antenn Wirel Propag Lett*, 17(12):2250-2254. https://doi.org/10.1109/LAWP.2018.2872051

[8] Zhang PZ, Li J, Wang HM, et al., 2019. Millimeter-wave space-time propagation characteristics in urban macrocell scenarios. Proc IEEE Int Conf on Communications, p.1-6. https://doi.org/10.1109/ICC.2019.8761087

[9] 3GPP, 2018. Study on Channel Model for Frequency from 0.5 to 100 GHz. 3GPP TR 38.901 (V15.0.0).

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