Channel Model for Outdoor Open Area Access Scenarios

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Abstract

- **In this contribution, the channel measurement results in an outdoor environment in Niigata university campus at an mm-wave band of 58.5 GHz assuming an open area outdoor hotspot access scenario will be introduced.**

Outline

- Background
- Channel measurement
- Ray tracing simulation
- Mechanism identification results
- Channel modeling
- Summary

Background

- **IEEE802.11ay**
  - Multi-Gb/s data throughput for WLANs
  - In May 2015, the IEEE802.11 TGay group started for development of the new standard enhancing the efficiency and performance of existing IEEE 802.11ad specification providing WLANs connectivity in 60 GHz band
- **Increase the data transmission rates defined in IEEE 802.11ad from 7 Gbps up to 30 Gbps for growing demands of new broadband indoor and "*outdoor applications*"**

Channel Models

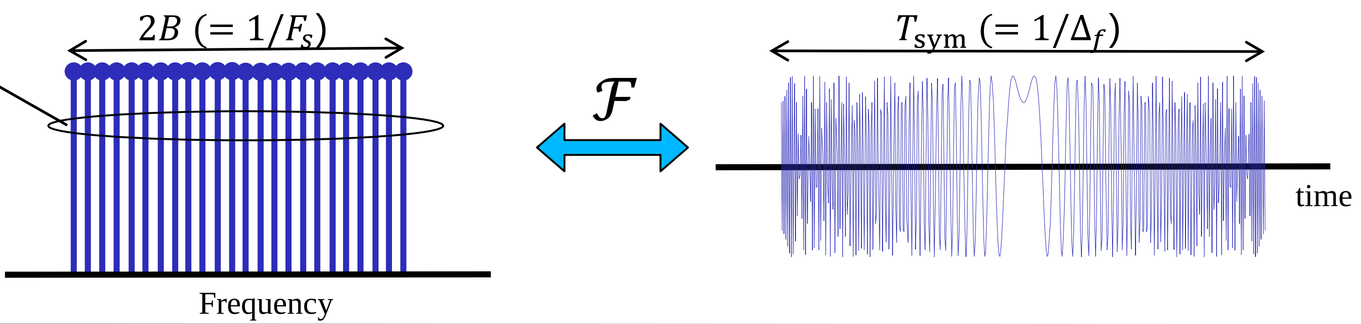
- **Indoor scenarios:**
  - Extension based on existing IEEE802.11ad model [3]
- **Outdoor scenarios:**
  - Extensive ray-tracing simulations and the results of new measurements are needed
  - Existing MiWEBA model [1]
- **Our contribution**
  - Measurement campaign in an outdoor open area hot spot access scenario
  - Investigation of dominant propagation mechanisms
  - Channel model parameter extraction (Q-D model)

Measurement Campaign

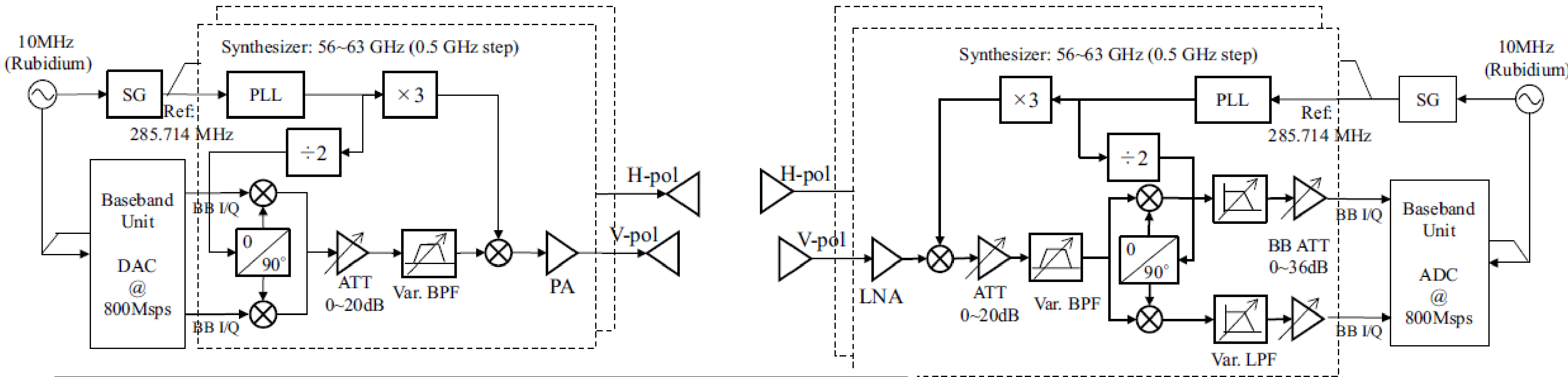
Mm-Wave MIMO Channel Sounder

- **Hardware configuration [6]**
  - Baseband: MIMO software defined radio testbed
  - RF: commercial product (V60TXWG1/V60RXWG1, VubIQ)
  - Feature
    - Double directional measurement：rotating high gain horn antennas
    - Full polarimetric measurement: dual-polar 2x2MIMO
- **Sounding signal：Newman phase multi-tone**

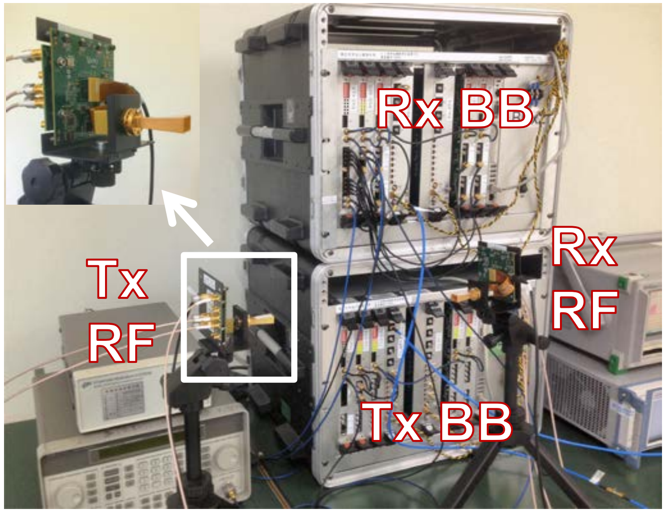
$$\phi_n = \frac{n^2\pi}{N}$$



Channel Sounder Specifications



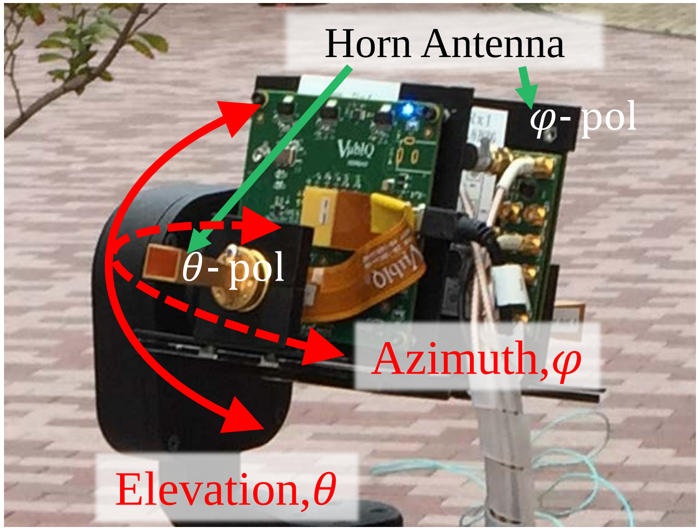
Carrier frequency	58.5 GHz
Signal bandwidth	400 MHz
Sampling rates (f_s)	800 MHz (R_{ov}=2)
Sounding signal	Unmodulated multitone (No. tones (N) = 256)
FFT length (N_f)	512
Cyclic prefix (N_{CP})	512
Total length (N_{sym})	$1,024$
Tone spacing (Δ_F)	1.563 MHz
Delay resolution	2.5 ns
Maximum delay	640 ns
Multiplexing scheme	Time Division Multiplexing (TDM)

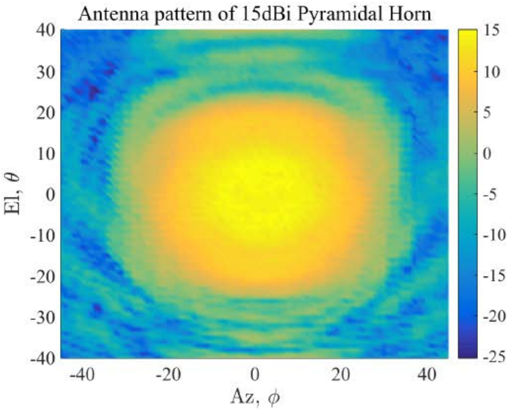


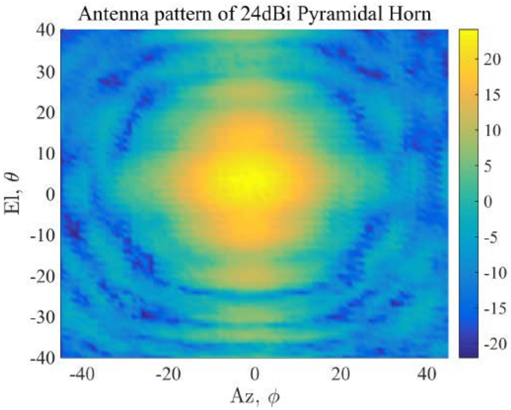
Channel Sounder Specifications (cont'd)

Full polarimetric double-directional measurement

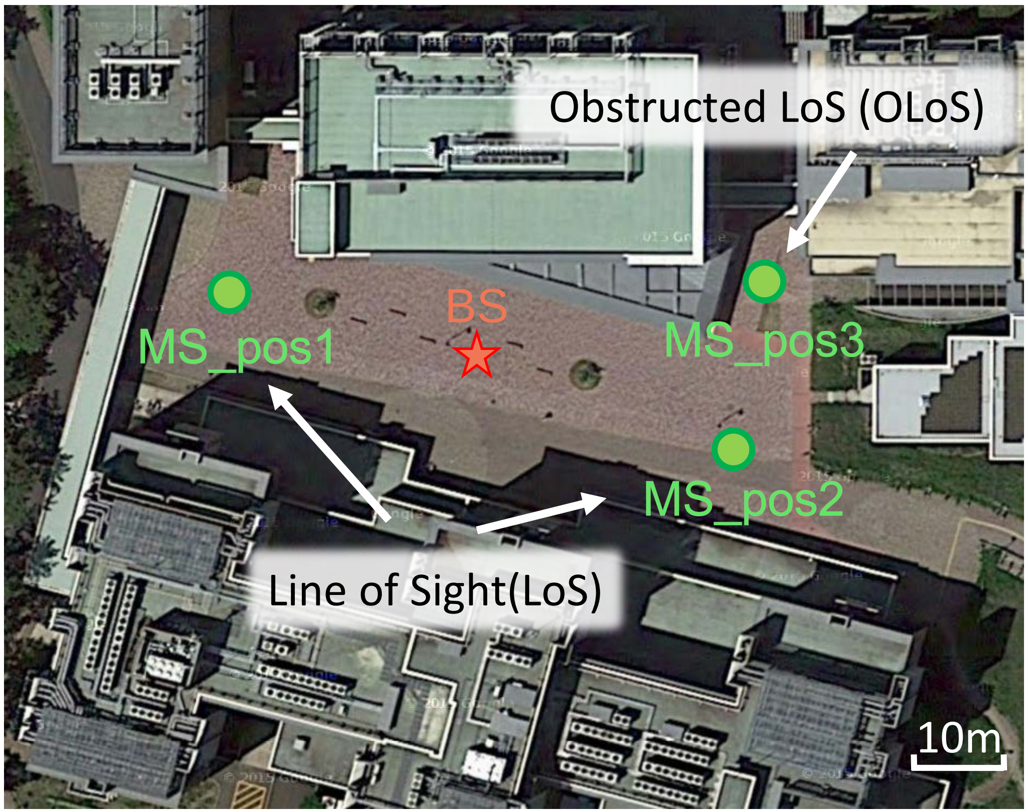
Tx Antenna	24dBi Pyramidal Horn
Rx Antenna	15dBi Pyramidal Horn
Tx Antenna Rotation	Az:-180~+180, El:-24~+24 Step:12 deg.
Rx Antenna Rotation	Az:-180~+180, El:-30~+30 Step:30 deg.







Measurement Campaign



Map data @Google, ZENRIN

Base Station(BS)

Mobile Station(MS)

Data Processing

- **Double directional channel impulse response**

$$h_{\mathrm{qp}}\left(\tau, \vartheta_i, \varphi_j, \vartheta'_m, \varphi'_n\right) = \mathcal{F}^{-1}\{H_{\mathrm{qp}}(f, \underbrace{\vartheta_i, \varphi_j}_{\text{AoA}}, \underbrace{\vartheta'_m, \varphi'_n}_{\text{AoD}})\}$$

Polarization

$\mathrm{p} \in \{\vartheta, \varphi\}$
$\mathrm{q} \in \{\vartheta, \varphi\}$

- **Double directional angle delay power spectrum (DDADPS)**

$$P_{\mathrm{qp}}\left(\tau, \vartheta_i, \varphi_j, \vartheta'_m, \varphi'_n\right) = \left|h_{\mathrm{qp}}\left(\tau, \vartheta_i, \varphi_j, \vartheta'_m, \varphi'_n\right)\right|^2$$

Data Processing (cont'd)

- **Synthetic spectrum (omni-directional)**

Angular power spectrum $$\mathrm{APS}_{\mathrm{qp}}(\vartheta_i, \varphi_j) = \frac{1}{\zeta_{\mathrm{Tx}}} \sum_{\tau,m,n} P_{\mathrm{qp}}(\tau, \vartheta_i, \varphi_j, \vartheta'_m, \varphi'_n)$$

Power delay profile $$\mathrm{PDP}_{\mathrm{qp}}(\tau) = \frac{1}{\underbrace{\zeta_{\mathrm{Tx}}\zeta_{\mathrm{Rx}}}_{\text{Gain correction}}} \sum_{i,j,m,n} P_{\mathrm{qp}}(\tau, \vartheta_i, \varphi_j, \vartheta'_m, \varphi'_n)$$

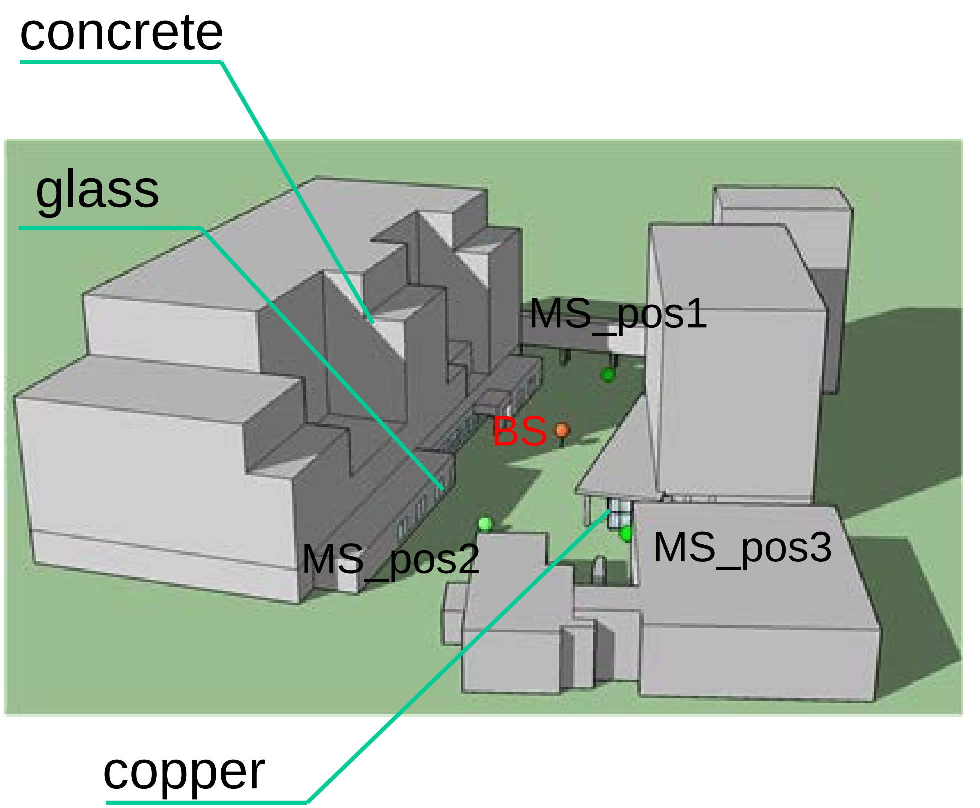
- **Polarization combination**

$$\mathrm{APS}_{\Sigma}(\vartheta_i, \varphi_i) = \frac{1}{2} \sum_{\mathrm{p}\in\{\vartheta,\varphi\}} \sum_{\mathrm{q}\in\{\vartheta,\varphi\}} \mathrm{APS}_{\mathrm{qp}}(\vartheta_i, \varphi_j)$$

$$\mathrm{PDP}_{\Sigma}(\tau) = \frac{1}{2} \sum_{\mathrm{p}\in\{\vartheta,\varphi\}} \sum_{\mathrm{q}\in\{\vartheta,\varphi\}} \mathrm{PDP}_{\mathrm{qp}}(\tau)$$

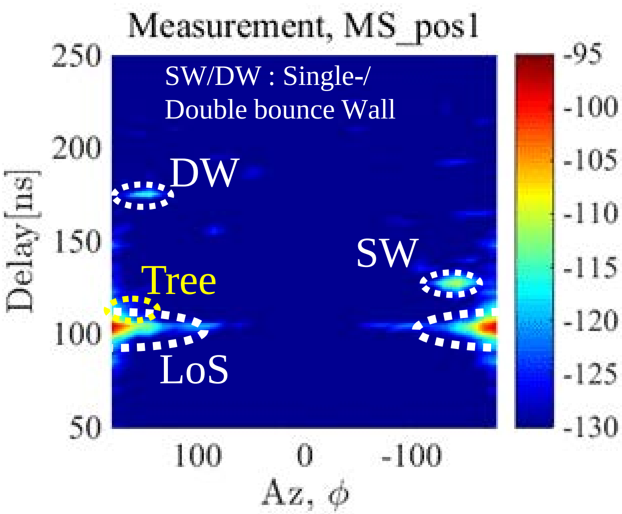
Ray Tracing Setup

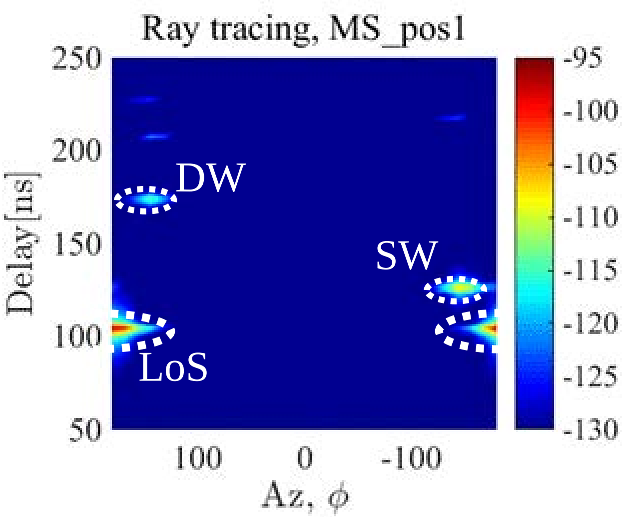
Frequency	58.5 GHz	
Antenna	Omni directional	
Polarization	0 and 90 deg.	
Reflection count	3	2
Penetration count	LoS (MS_pos1,2) 2	OLoS (MS_pos 3) 2
Diffraction count	0	1
Calculation method	Imaging method	
Ground material	earth	

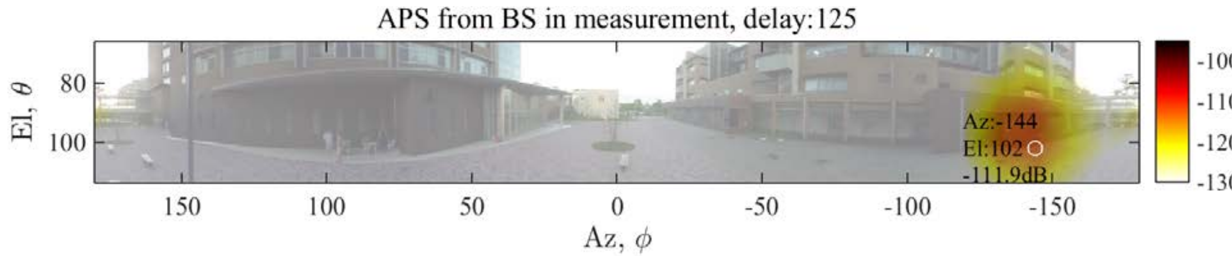


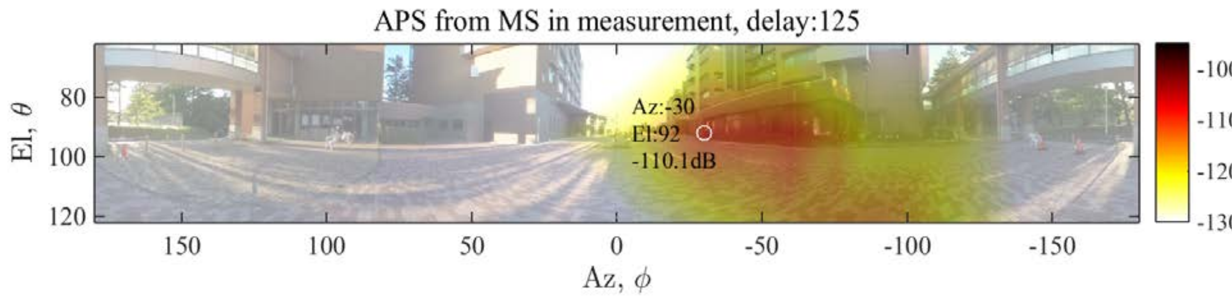
Propagation Mechanism (MS_pos1)

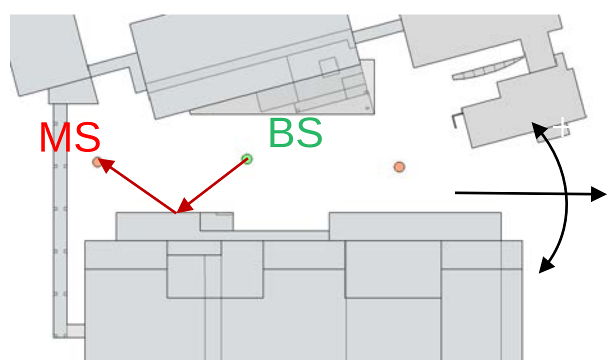
Single-Bounce Wall (SW) Reflection





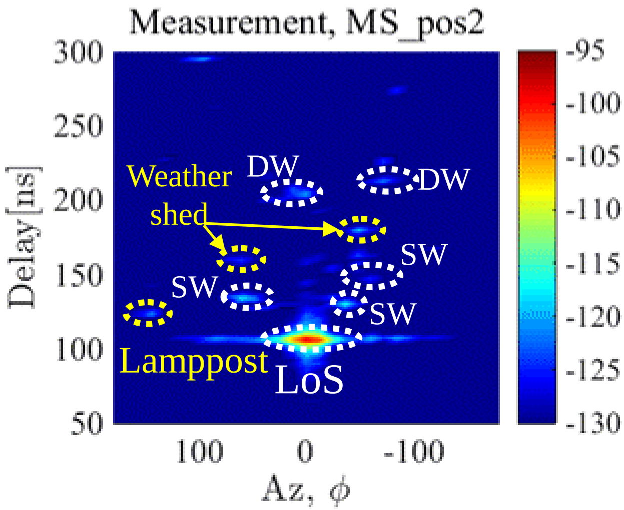


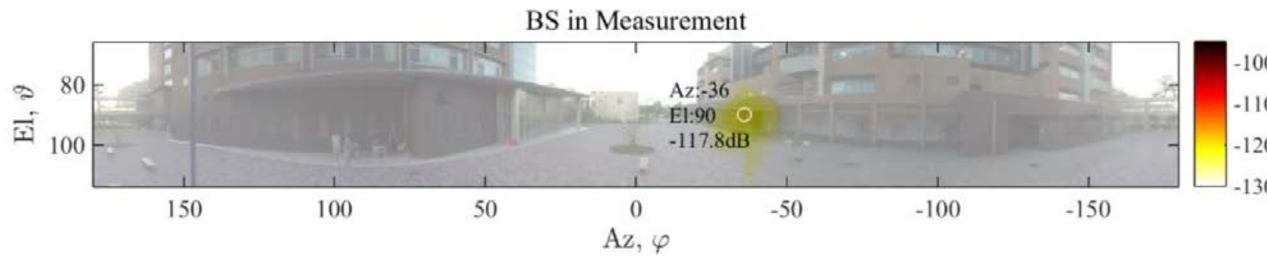


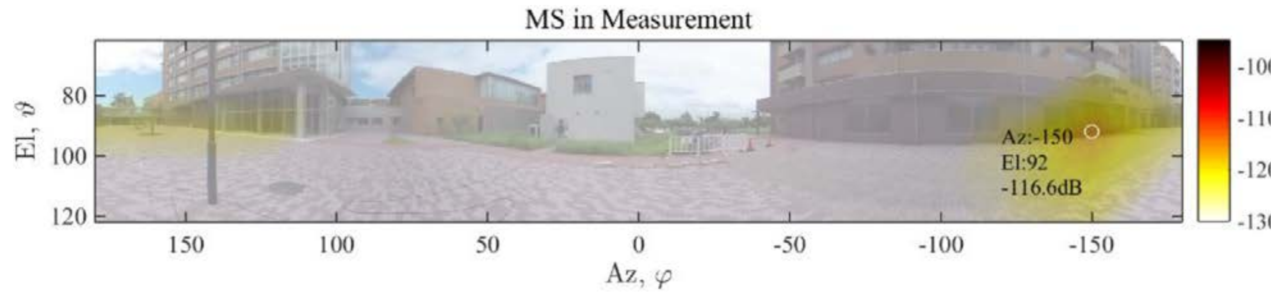


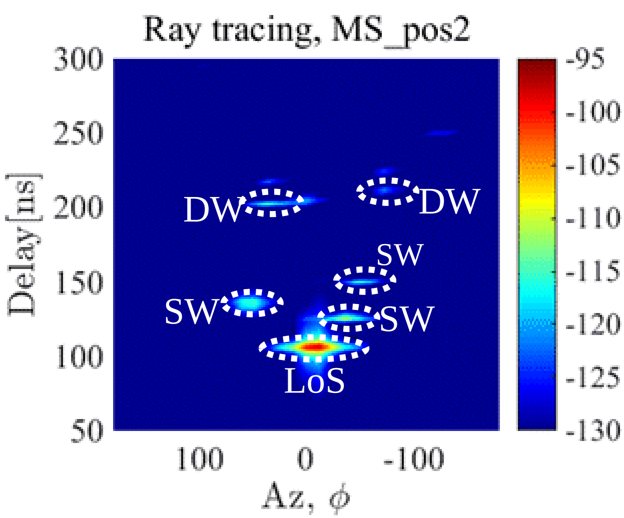
Propagation Mechanism (MS_pos2)

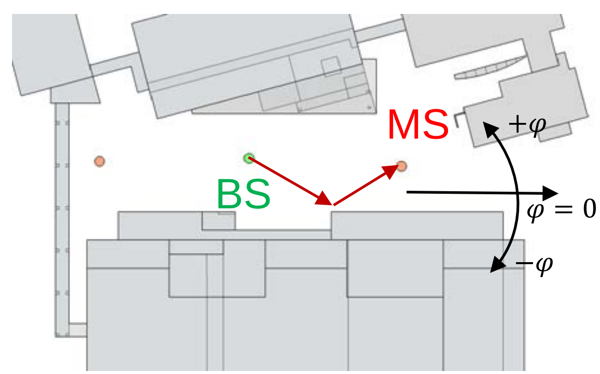
Single-Bounce Wall (SW) Reflection





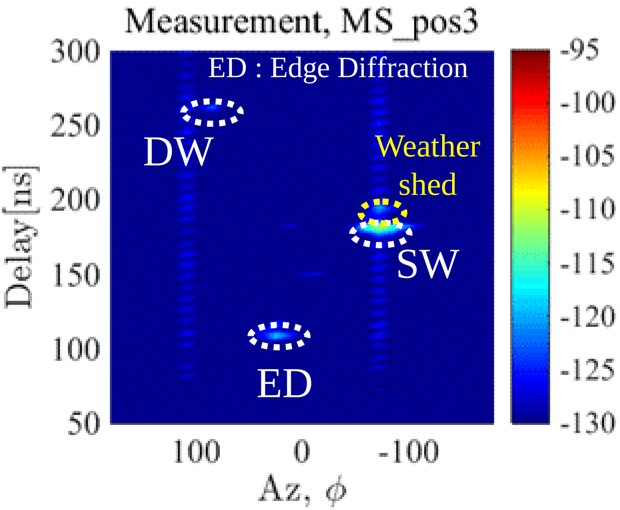


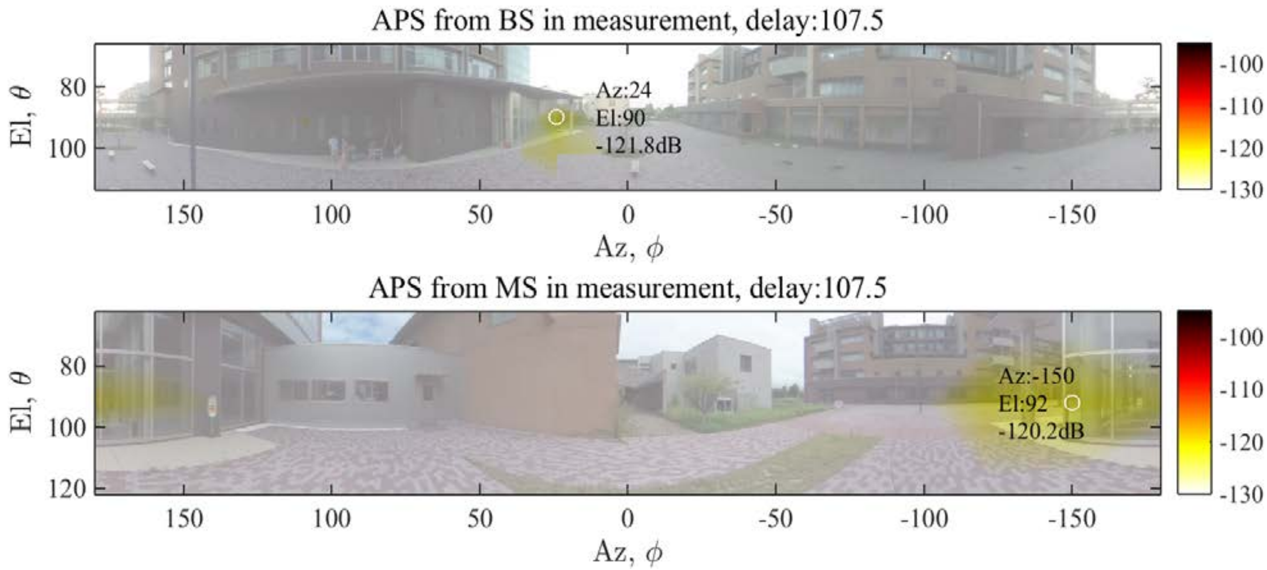


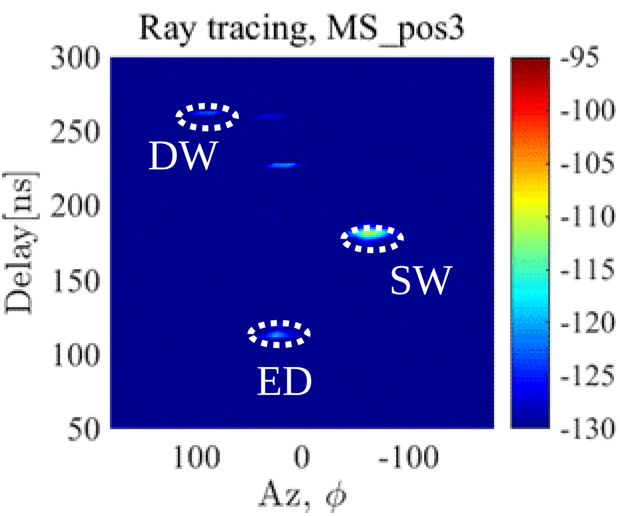


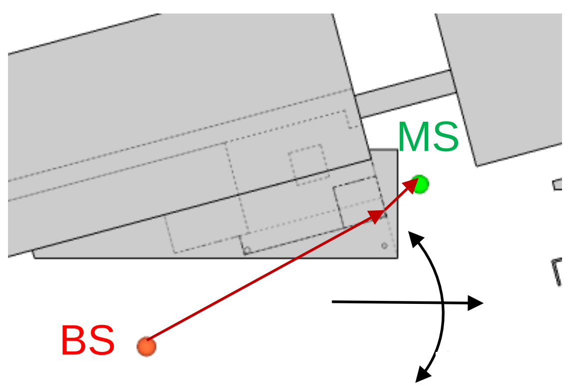
Propagation Mechanism (MS_pos3)

Edge Diffraction (ED)









Scattering

Interacting Obj.	Lamppost
Path gain	-112.6dB
Difference from direct path	-17.3dB

Interacting Obj.	Tree
Path gain	-115.5dB
Direct path from direct path	-17.7dB

Interacting Obj.	Weather Shed
Path gain	-115.5dB
Direct path from direct path	-17.7dB

Scattering
-17.7~-17.3 dB

Single-bounce
-16~-10 dB

Double-bounce
-19~-15 dB

Diffraction
-17.25 dB

Propagation Mechanism Summary

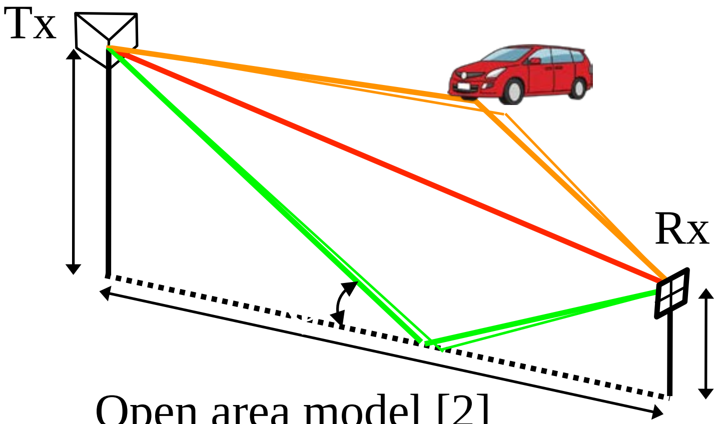
Propagation Mechanism	MS Position	Path Gain [dB]	Difference from direct path [dB]	Average [dB]	XPR(TxV)	XPR(TxH)
Single-bounce Reflection	MS_pos1	-105.6	10.3	13.86	6.39	2.5
	MS_pos2	-113.5	15.7		8.31	6.98
	MS_pos2	-113.7	15.9		8.36	8.91
	MS_pos3	-108	10.25		13.85	14.36
Double-bounce Reflection	MS_pos1	-110.4	15.1	18.49	10.16	6.41
	MS_pos2	-117.6	19.8		4.54	3.26
	MS_pos2	-116.3	18.5		4.29	6.87
	MS_pos3	-117	19.25		3.27	2.56
Diffraction	MS_pos3	-115	17.25	17.25	0.45	10.14
Scattering (Lamppost)	MS_pos2	-115.5	17.7	18.03	7.13	6.65
Scattering (Tree)	MS_pos1	-112.6	17.3		13.86	13.94
Scattering (Weather Shed)	MS_pos2	-116.6	18.8		1.64	8.09
Scattering (Weather Shed)	MS_pos2	-115.5	17.7		6.57	8.47
Scattering (Weather Shed)	MS_pos3	-116.2	18.45		6.45	0.8

Strong single-bounce reflection from nearby buildings should be deterministically modeled

Channel Modeling

IEEE802.11ay Outdoor Channel Model

- **Quasi-deterministic model based on MiWEBA [2]**
- **Deterministic components**
  - LoS, Ground reflection, Near-wall reflection
  - Determined by the location of Tx and Rx in the surrounding environment
- **Random components**
  - Reflection from far-away static objects and random objects
  - Statistically modeled



Open area model [2]

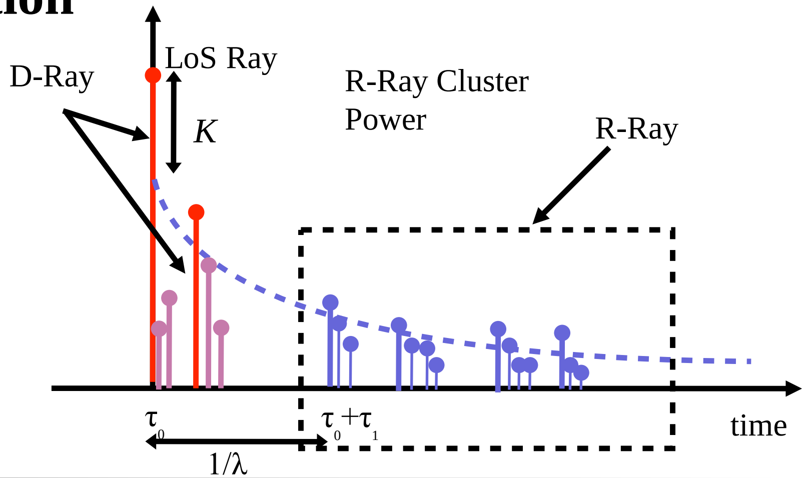
Channel Parameters

Deterministic components

- **Loss is calculated by Friis equation and Fresnel reflection equation**
- **AoA (Angle-of-arrival), AoD (Angle-of-departure) and delay are determined by the location of Tx and Rx**

Random components

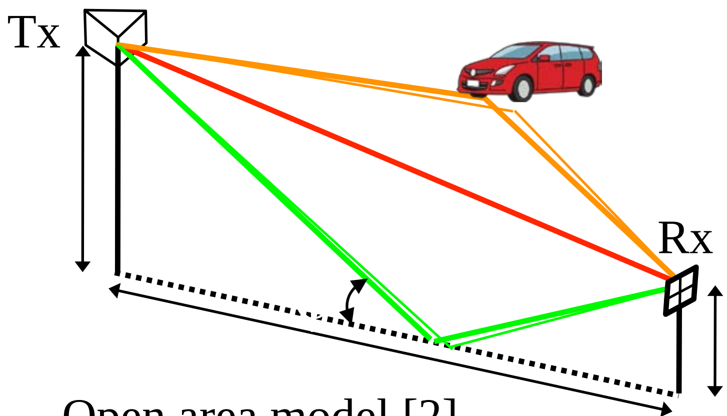
- **No Clusters, N_c**
- **Cluster arrival rate, λ**
- **Cluster power-decay constant, γ**
- **Ray K factor**
- **AoA and AoD**



Developed Channel Models

CM1

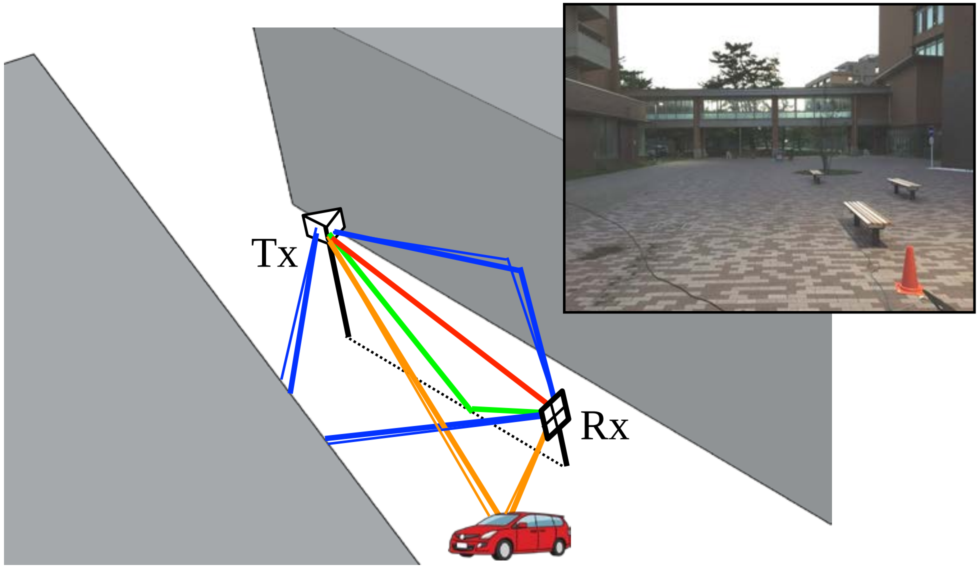
- Existing open area model
- D-Ray: LoS and GR



Open area model [2]

CM2

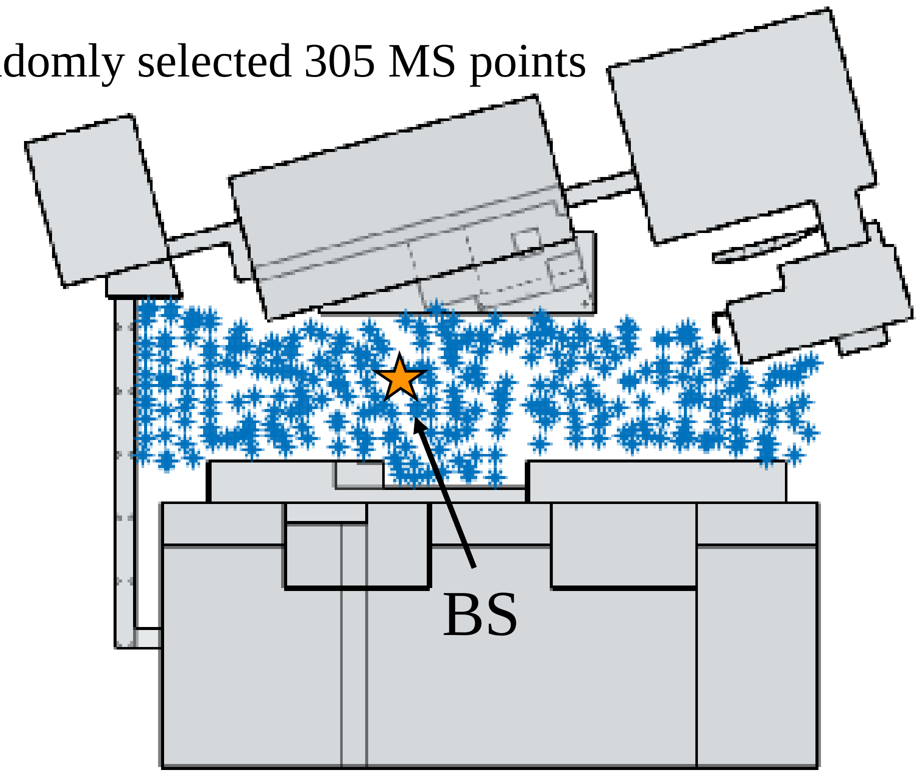
- Reflection from nearby buildings are taken into account as D-Ray
- D-Ray: LoS, GR and single-bounce reflections from near walls



Developed Channel Models

- **Statistical parameters of R-Ray were extracted from ray tracing simulations**

Randomly selected 305 MS points



RT sim (Ref. cnt <=3)

↓

Elimination of LoS and GR

↓

Removal of single-bounce wall reflection (>-10dB LoS) ← RT sim (Ref. cnt<=1)

↓

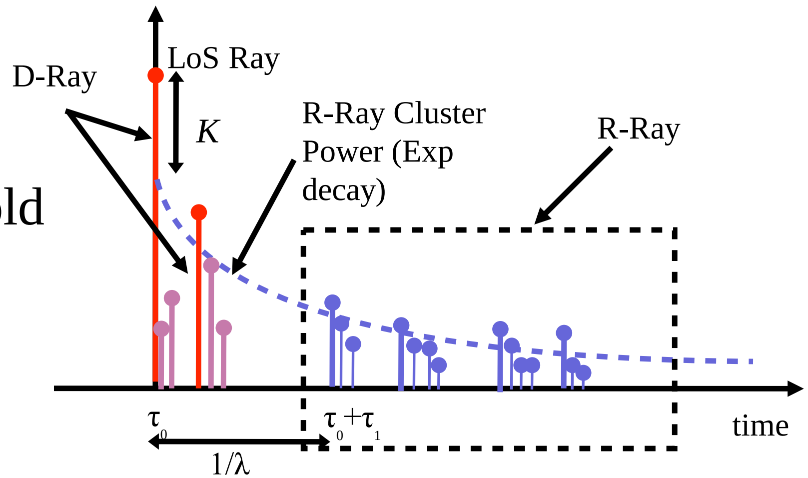
Bandwidth limit & Peak detection

↓

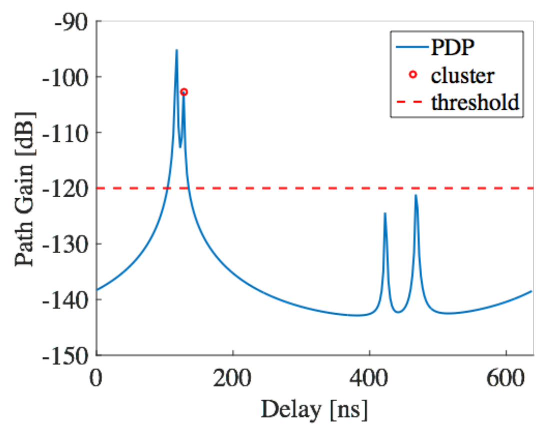
R-Ray Parameterization

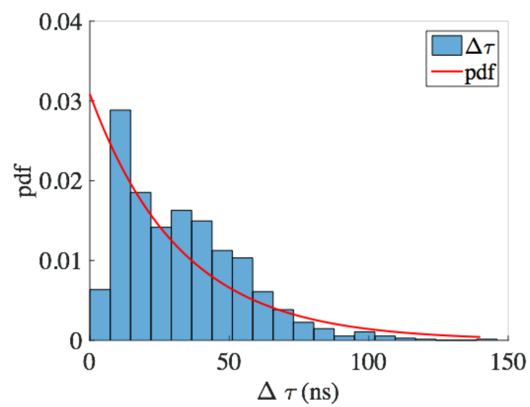
Delay Domain Parameters

- **No. Clusters, N_c**
  - Peak detection with -120 dB threshold
- **Delay parameters**
  - Cluster delay, τ_k
    Exponential distribution
    $p(\tau_k|\tau_{k-1}) = \lambda e^{-\lambda(\tau_k - \tau_{k-1})}$
  - Cluster arrival rate, λ
    $\mathrm{E}[\Delta\tau] = 1/\lambda$
    where $\Delta\tau = \tau_k - \tau_{k-1}$



Structure of impulse response



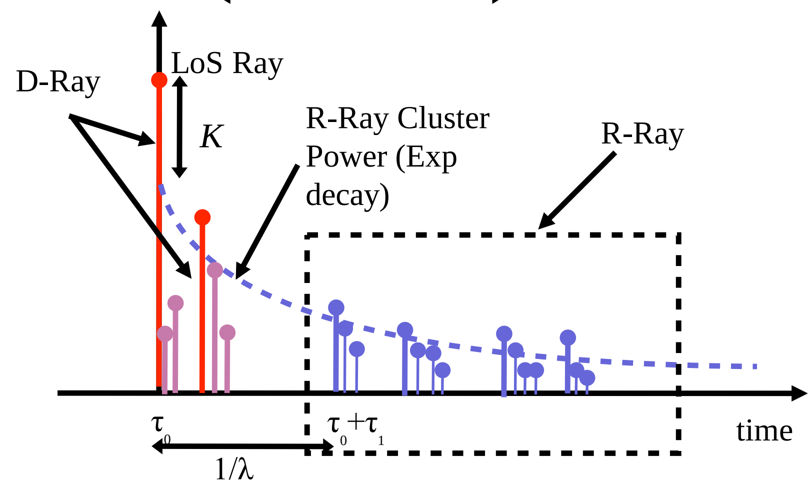


Delay Domain Parameters (Cont'd)

- **Impulse response**

$$h(\tau) = \sum_{k=1}^{N_c} \beta_k e^{j\theta_k} \delta(t - \tau_k)$$

τ_k: arrival time of the k-th cluster measured from the arrival time of the LOS ray
β_k and θ_k: gain and phase of the k-th cluster



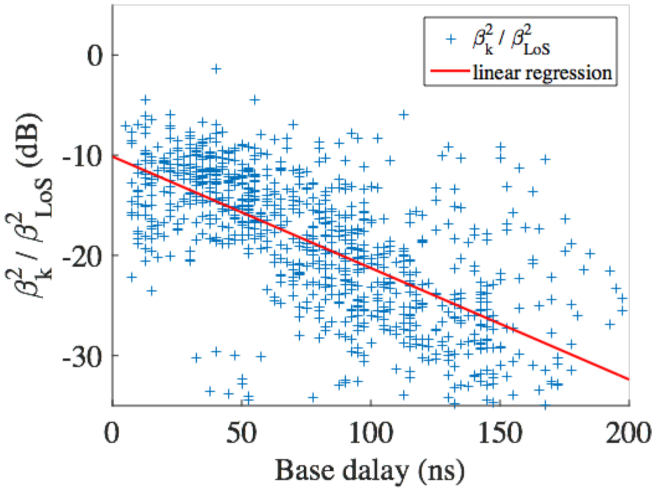
Structure of impulse response

- **Average gain**

$$\overline{\beta_k^2} \equiv \overline{\beta^2(\tau_k)} = \overline{\beta^2(0)} e^{-\tau_k/\gamma}$$

where $\overline{\beta^2(0)} = \beta_{\mathrm{LoS}}^2 / K$

β_{LoS}^2: power gain of the LOS ray
K: maximal ratio of LOS to NLOS component
γ : power-decay constant

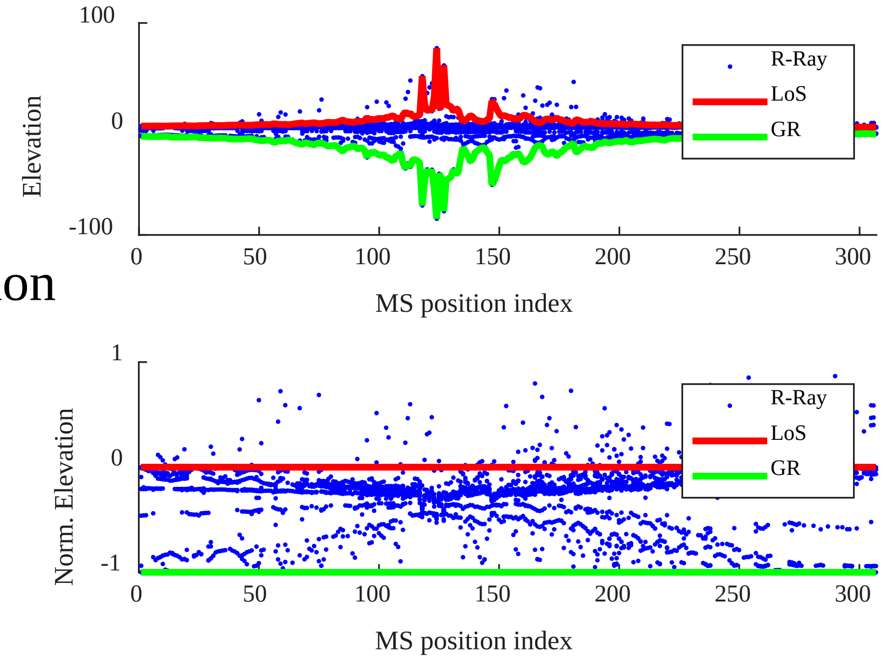


Angular Domain Parameters (Cluster Angle)

- **Azimuth angle**
  - Uniform distribution
- **Elevation angle**
  - Uniform distribution
  - Depends on Tx and Rx position
  - Normalized elevation angle

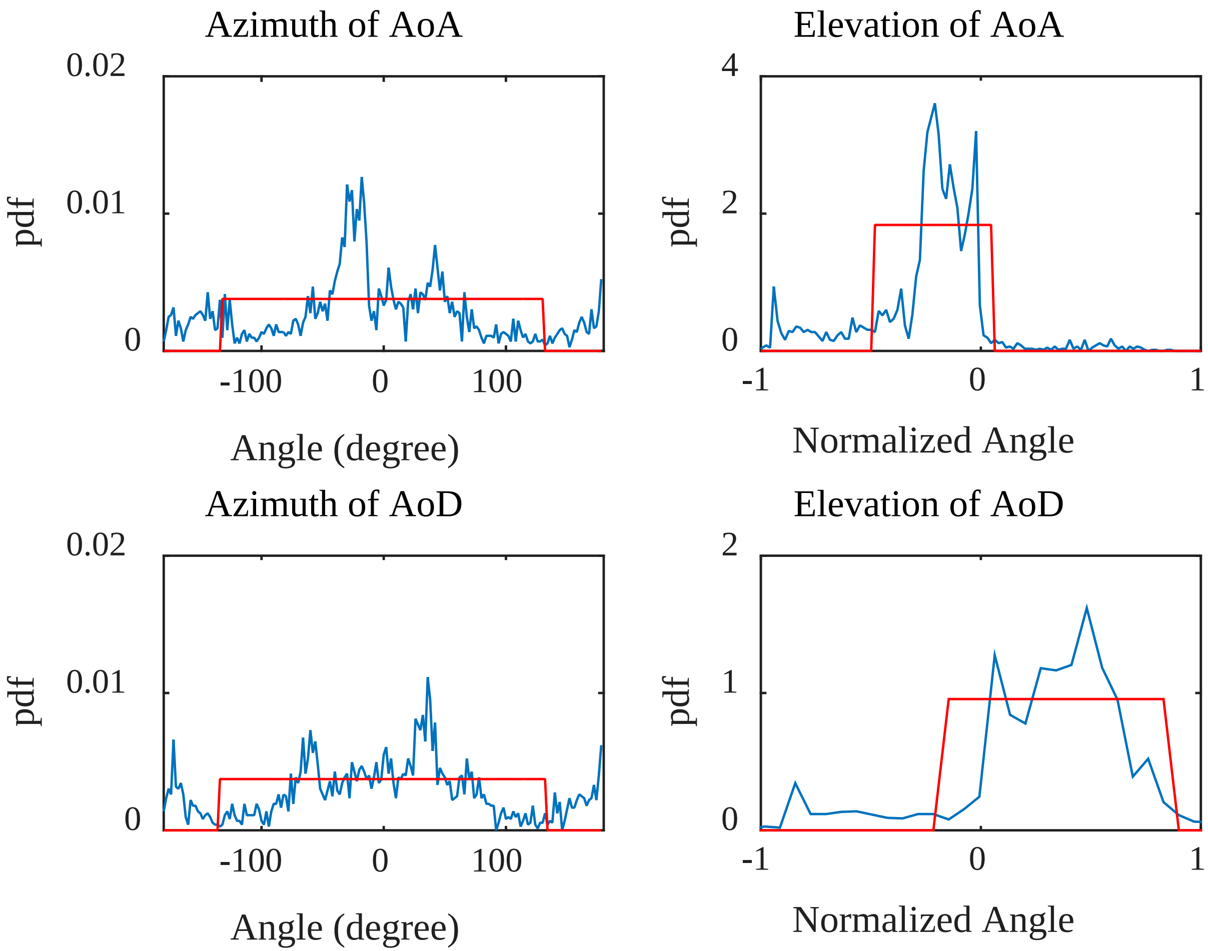
$$\hat{\theta} = \frac{\theta - \theta_{\mathrm{D0}}}{|\theta_{\mathrm{D0}} - \theta_{\mathrm{G0}}|}$$

D0: Direct path
G0: Ground Reflection



Angular Domain Parameters (Cluster Angle)

CM2



Summary of R-Ray Parameters

			CM1	CM2	IEEE802.11ay[4]
Delay	No. Clusters, N_c		3	3	3
	Cluster arrival rate, λ		0.03 ns^{-1}	0.03 ns^{-1}	0.05 ns^{-1}
	power-decay constant, γ		34 ns	45 ns	15 ns
	K factor		9 dB	12.6 dB	6 dB
Angle	AoA	Elevation	Norm. Elevation U[−0.52 : 0.11]	Norm. Elevation U[−0.5 : 0.1]	U[-20 : 20°]
		Azimuth	U[−100 :100°]	U[−110 : 110°]	U[−180 : 180°]
	AoD	Elevation	Norm. Elevation U[−0.29 : 0.68]	Norm. Elevation U[−0.22 :0.71]	U[-20 : 20°]
		Azimuth	U[−100 : 100°]	U[−110 : 110°]	U[−180 : 180°]

Summary

- **The dominant propagation mechanism in an outdoor open area environment**

  Reflection: single-bounce (-16~-10dB), double-bounce (-19~-15 dB)

  Diffraction (-17.25 dB)

- **Statistical parameters of R-Ray from ray tracing simulation**
  - New model (CM2) considers the reflection from the nearby walls as D-Ray
- **Future works**
  - Detail investigation of the objects causing non-specular reflection
  - Further measurements and channel modeling

References

[1] MiWEBA, FP7 ICT-2013-EU-Japan, http://www.miweba.eu

[2] METIS, FP7 ICT-317669-METIS, http://www.metis2020.eu

[3] "Channel Models for 60 GHz WLAN Systems," *IEEE Document 802.11-09/0334r8*, May 2010.

[4] "Channel Models for IEEE 802.11ay," *IEEE Document 802.11-15/1150r2*, Sept. 2015.

[5] Minseok Kim, Karma Wangchuk, Shigenobu Sasaki, Kazuhiko Fukawa, Jun-ichi Takada, "Development of Low Cost Mm-Wave Radio Channel Sounder and Phase Noise Calibration Scheme," COST Action IC1004(EU), TD(15)12036, Jan. 2015 (Dublin, Ireland).

[6] Minseok Kim, Kento Umeki, Karma Wangchuk, Jun-ichi Takada, Shigenobu Sasaki, "Polarimetric Mm-Wave Channel Measurement and Characterization in a Small Office," Proc. *PIMRC 2015*, Aug. 2015.