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Abstract: In this document, an outdoor dual-band channel measurement in two typical scenarios of a street canyon at 154 and 300 GHz is conducted and presented. This document provides 360-degree azimuth scanning in both transmitter and receiver sides. In the measurement, the narrow-beam directional horn antennas were used at both sides of the transmitter and the receiver to investigate the double directional full azimuth scattering processes, while they were fixed at tilting angles in the elevation plane to save the measurement time. The measured and modeled transmission losses are investigated with model parameters fitting, highlighting the potential of utilizing multipaths in THz outdoor applications, even in the absence of the line-of-sight path. Then, the large-scale parameters in terms of route mean square delay spread, K-factor and angle spread are evaluated.

Purpose: Information document for IEEE 802.15 SC THz

Street Canyon Channel Characteristics at 154 GHz and 300 GHz

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Abstract

- The quick results of the street canyon outdoor measurement are reported.
- This document presents the results in terms of path loss and large-scale parameters.
  - Two scenarios (LoS and NLoS)
  - 30 Rx points
  - Full azimuth scanning range (360 deg. at both Tx and Rx)
  - 10-80 m Tx-Rx separation distance range

Outline

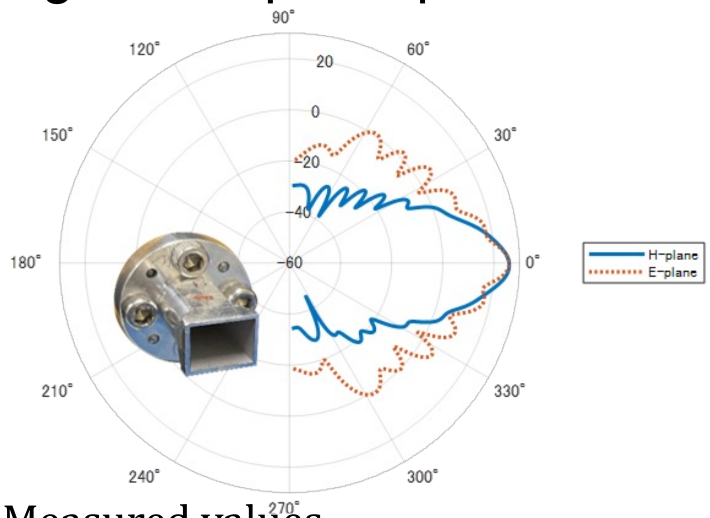
- 154/300-GHz Dual-Band Channel Sounder[1]
- High resolution
    - Bandwidth: 4 and 8 GHz
    - Beamwidth: 9° at Rx and Tx
- Full azimuth angle sweeping range and fixed elevation angle
- Channel Measurement and Results
    - LoS/NLoS scenarios in a Street Canyon
        - Measurement and post processing
        - Omnidirectional and best-beam PL with models fitting
        - Large scale parameters (delay/angle spread, and K-factor)
- Summary and Future Works

Channel Sounder Setup and Parameters

■ Channel sounder setup

Parameters	Description or Value	Parameters	Description or Value
Freq.	154/300 GHz	Delay span	640 ns
Signal BW	4/8 GHz	Dynamic range	60~80 dB
Sounding signal	NPM (N=2,560/5,120)	Polarization	Vertical
Sampling rates	64 GSa/s (AWG), 32 GSa/s (Digitizer)	EIRP (dBm)	2.1/-2.9
Delay resolution	250/125 ps	Tx/Rx height	3.0/1.2 m

■ Angle sweep setup

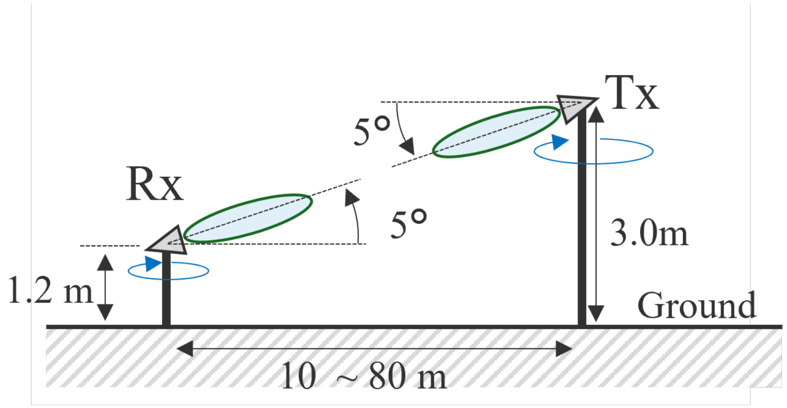


Measured values

$G_{\mathrm{Ant\_154GHz}} = 26.4$ dBi

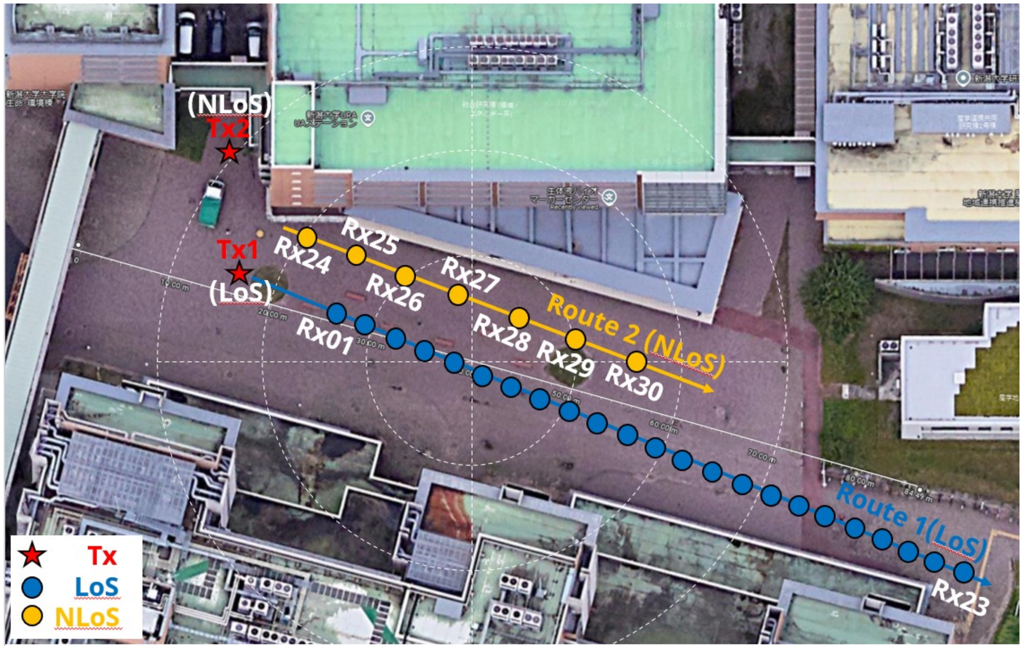
$G_{\mathrm{Ant\_300GHz}} = 25.8$ dBi

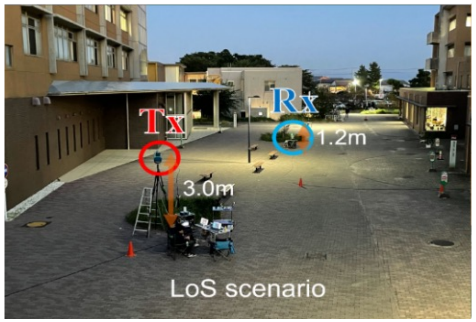
Tx full azimuth [deg]	0:9:351 (40)
Fixed Tx elevation [deg]	95
Rx full azimuth [deg]	0:9:351 (40)
Fixed Rx elevation [deg]	85

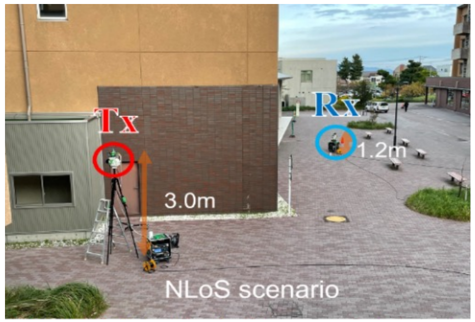


Measurement Setup

- LoS scenario
  - 23 Points (Route 1: 10 m to 80 m)
  - Tx1: Fixed in the middle area at the end of the street canyon
- NLoS scenario
  - 7 points (Route 2: 10 m to 50 m)
  - Tx2: Fixed behind the corner of a building

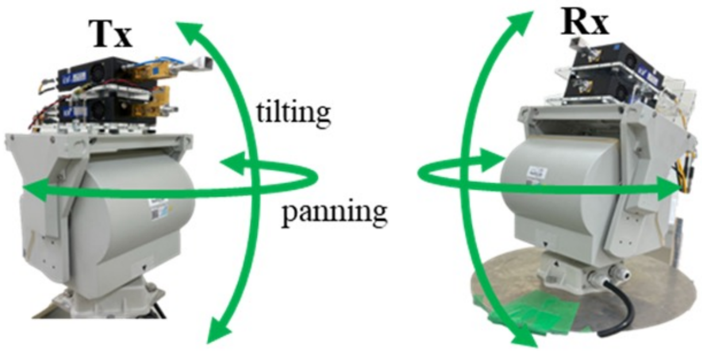






Post Data Processing

- Double-Directional Angle Delay Power Spectrum
  - $P(\check{\tau},\check{\phi}_\mathrm{T},\check{\phi}_\mathrm{R}) \triangleq \mathbb{E}\left|h(\check{\tau},\check{\phi}_\mathrm{T},\check{\phi}_\mathrm{R})\right|^2$
- Noise-filtered DDADPS [2]:
  - $P'(\check{\tau},\check{\phi}_\mathrm{T},\check{\phi}_\mathrm{R})$
- Power Angular Profile (PAP)
  - $\mathrm{PAP}_{\mathrm{T/R}}(\check{\phi}_{\mathrm{T/R}}) = \sum_{n_{\check{\tau}},n_{\check{\phi}_{\mathrm{R/T}}}} P'$
- Synthesized Power Delay Profile
  - $\mathrm{PDP}_{\mathrm{max-hold}}(\check{\tau}) = \max_{n_{\check{\phi}_\mathrm{T}},n_{\check{\phi}_\mathrm{R}}} P$
  - $\mathrm{PDP}_{\mathrm{sum-hold}}(\check{\tau}) = \sum_{n_{\check{\phi}_\mathrm{T}},n_{\check{\phi}_\mathrm{R}}} P'$

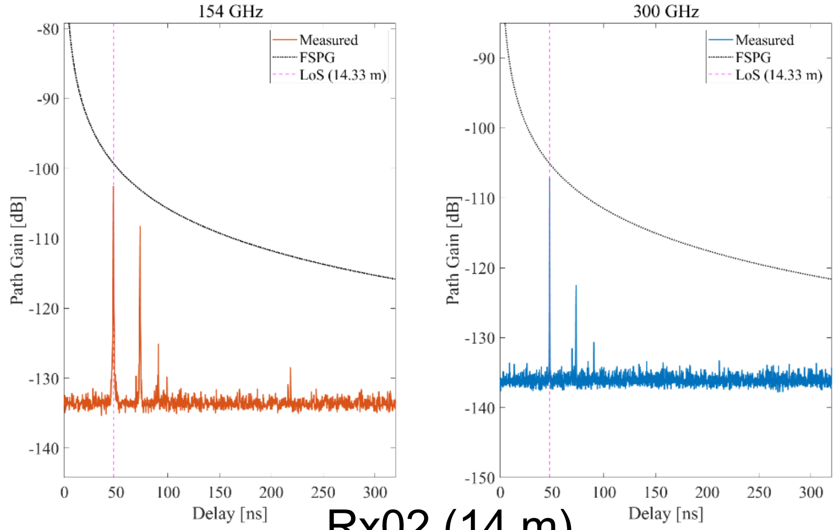


$\check{\tau}$	Delay bin ($\check{\tau} = n_{\check{\tau}}\Delta_\tau$)
$\check{\phi}_\mathrm{T}$	Pointing angle of Tx ($\check{\phi}_\mathrm{T} = n_{\check{\phi}_\mathrm{T}}\Delta_{\phi_\mathrm{T}}$)
$\check{\phi}_\mathrm{R}$	Pointing angle of Rx ($\check{\phi}_\mathrm{R} = n_{\check{\phi}_\mathrm{R}}\Delta_{\phi_\mathrm{R}}$)

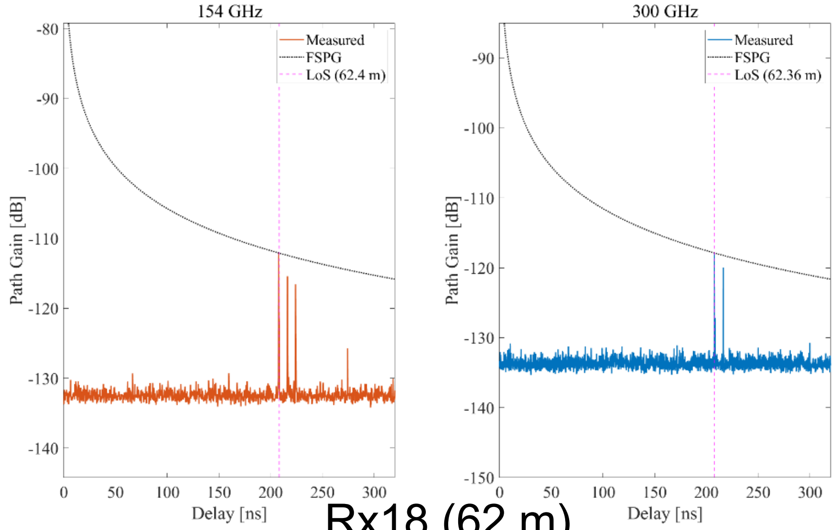
* n and Δ denote the sample indices and sampling intervals of the subscripted domain.

Measurement Results

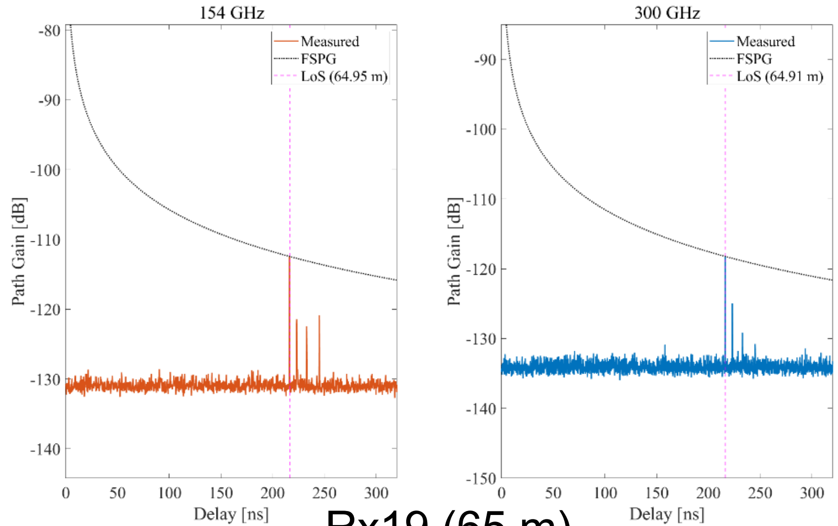
- Max-hold PDP visualization



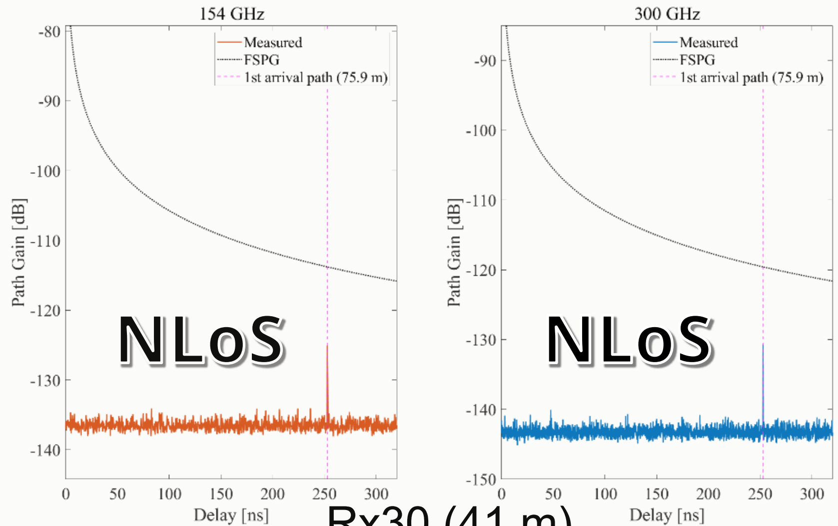
Rx02 (14 m)



Rx18 (62 m)



Rx19 (65 m)



Rx30 (41 m)

Path Loss (PL) and Models

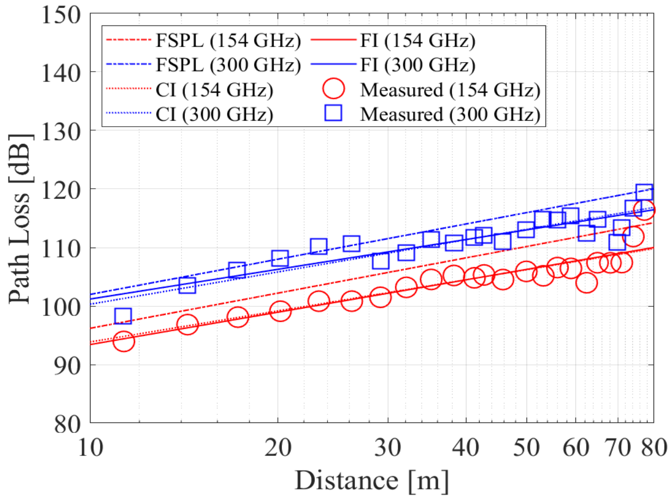
- Omnidirectional path loss
  - $\mathrm{PL_{omni}}\ [\mathrm{dB}] = -10\log_{10}\left(\sum_{\forall} P'(\check{\tau}, \check{\phi}_{\mathrm{T}}, \check{\phi}_{\mathrm{R}})\right)$
- Best beam path loss
  - $\mathrm{PL_{B}}\ [\mathrm{dB}] = -10\log_{10}\left(\sum_{n_{\check{\tau}}} P'(\check{\tau}, \check{\phi}_{\mathrm{T_B}}, \check{\phi}_{\mathrm{R_B}})\right)$

  where $(\check{\phi}_{\mathrm{T_B}}, \check{\phi}_{\mathrm{R_B}}) = \arg\max_{\check{\phi}_{\mathrm{T}}, \check{\phi}_{\mathrm{R}}} \sum_{n_{\check{\tau}}} P'(\check{\tau}, \check{\phi}_{\mathrm{T}}, \check{\phi}_{\mathrm{R}})$, means the angle pair when Tx and Rx antennas are in the best beam alignment.
- Path Loss Models:
  - Close-in free space (CI)
    - $L_{\mathrm{CI}}(d)\ [\mathrm{dB}] = 10n\log_{10}(d) + 20\log_{10}\left(\frac{4\pi f_{\mathrm{GHz}} \times 10^9}{c}\right)$

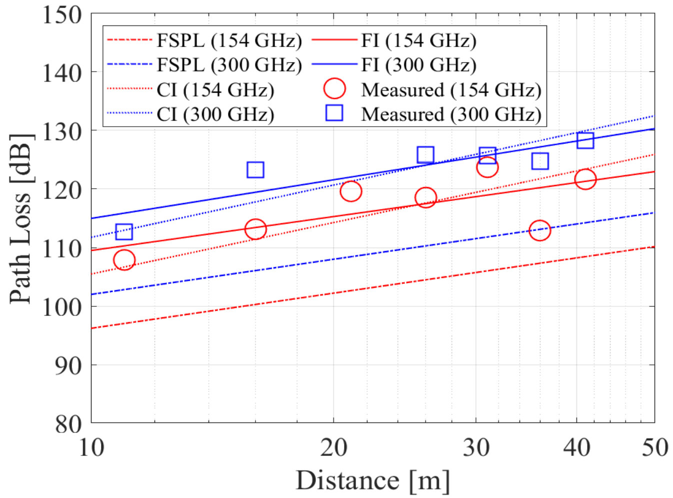
      d: propagation distance, f_{GHz}: frequency in GHz, n: path loss exponent
  - Floating-intercept (FI)
    - $L_{\mathrm{FI}}(d)\ [\mathrm{dB}] = 10\alpha\log_{10}(d) + \beta$, where α and β are the slope and floating intercept

PL and Model Fitting Results

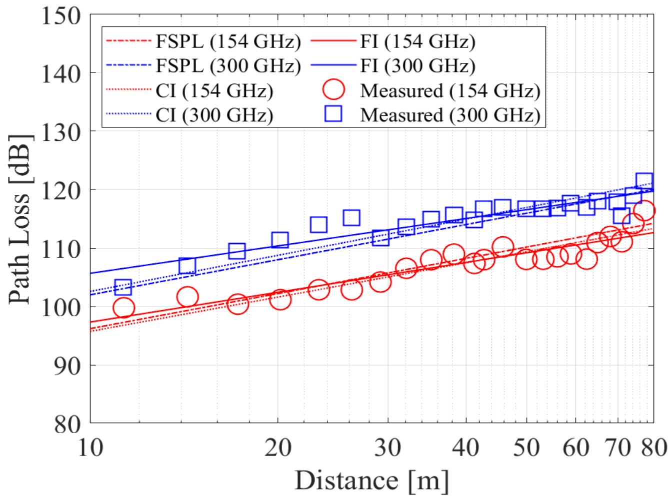
- Fitting omnidirectional PL and best-beam PL with CI and FI models



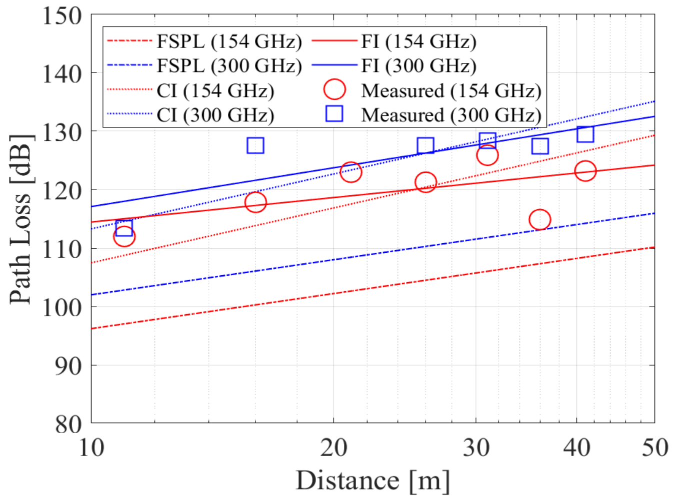
LoS scenario: $\mathrm{PL_{omni}}$



NLoS scenario: $\mathrm{PL_{omni}}$



LoS scenario: Best-beam PL



NLoS scenario: Best-beam PL

PL Model Fitting Parameters

- Fitting results:

Scen.	PL	Freq.	CI Model (n, σ)	FI Model (α, β, σ)
LoS	Omnidirectional	154 GHz	$(1.77, 1.94)$	$(1.84, 75.02, 1.93)$
		300 GHz	$(1.83, 1.98)$	$(1.69, 84.28, 1.95)$
	Best-beam	154 GHz	$(1.95, 1.72)$	$(1.70, 80.34, 1.61)$
		300 GHz	$(2.06, 1.95)$	$(1.56, 90.07, 1.54)$
NLoS	Omnidirectional	154 GHz	$(2.93, 4.53)$	$(1.93, 90.18, 4.05)$
		300 GHz	$(2.98, 3.10)$	$(2.20, 93.00, 2.58)$
	Best-beam	154 GHz	$(3.13, 5.42)$	$(1.40, 100.48, 4.12)$
		300 GHz	$(3.13, 4.12)$	$(2.21, 94.98, 3.59)$

- Observations
  - The PLE values of the omnidirectional PL at both frequencies in the LoS scenario are smaller than two, demonstrating the potential for utilizing multipaths
  - The CI and FI models show similar deviations in the LoS scenario

Large Scale Parameters (LSP)

- Root Mean Square Delay Spread (RMS DS)

$$\mathrm{DS_{RMS}} = \sqrt{\frac{\sum_{n_\tau} \check{\tau}^2 \mathrm{PDP}(\check{\tau})}{\sum_{n_\tau} \mathrm{PDP}(\check{\tau})} - \left(\frac{\sum_{n_\tau} \check{\tau} \mathrm{PDP}(\check{\tau})}{\sum_{n_\tau} \mathrm{PDP}(\check{\tau})}\right)^2}$$

- K-Factor: the distribution of the MPC over the delay domain

$$\mathrm{K} = \frac{\sum_{n_\tau \in \mathcal{R}} \mathrm{PDP}(\check{\tau})}{\sum_{n_\tau} \mathrm{PDP}(\check{\tau}) - \sum_{n_\tau \in \mathcal{R}} \mathrm{PDP}(\check{\tau})}$$

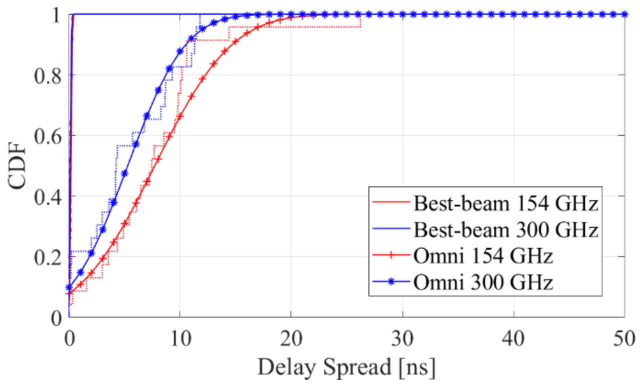
where $\mathcal{R}$ represents the set of delays of MPCs belongs to the LoS cluster.

- Angle Spread of Arrival/Departure (ASA/ASD)
  - ASA/ASD:

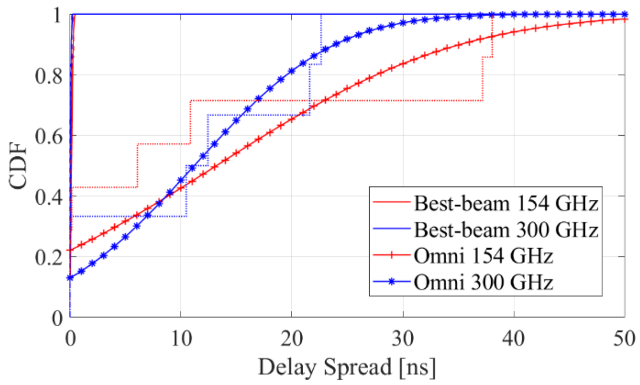
$$\mathrm{ASA/D} = \sqrt{-2\ln\left|\frac{\sum_{n_\Omega} \exp\left(j\breve{\Omega}\right) \mathrm{PAP}\left(\breve{\Omega}\right)}{\sum_{n_\Omega} \mathrm{PAP}\left(\breve{\Omega}\right)}\right|}$$

LSP results: RMS DS and K-factor

- RMS DS results
  - 154 GHz band has slightly larger DS in both scenarios;
  - Best-beam has very small DS values.

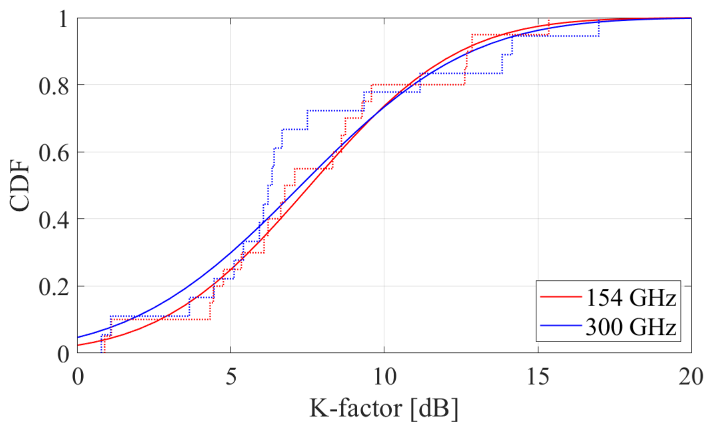


LoS scenario



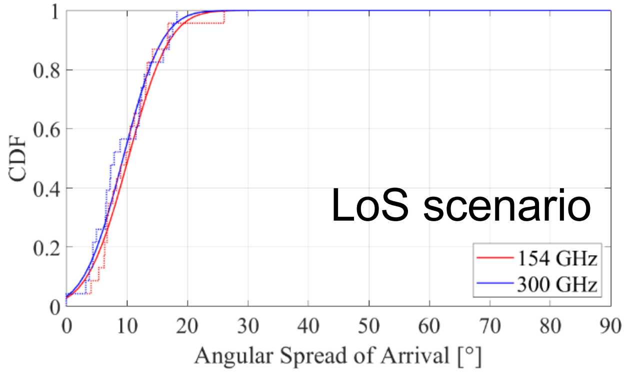
NLoS scenario

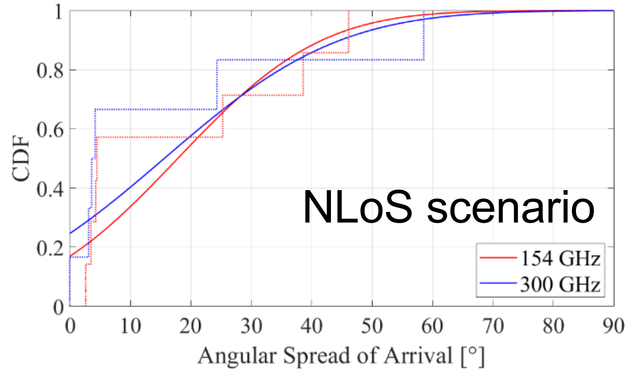
- K-factor
  - The 154 GHz band has slightly larger K-factor, indicating that LoS propagation is more dominant at 154 GHz
    - Due to the sparser MPCs and higher interaction losses of reflected paths at higher frequencies



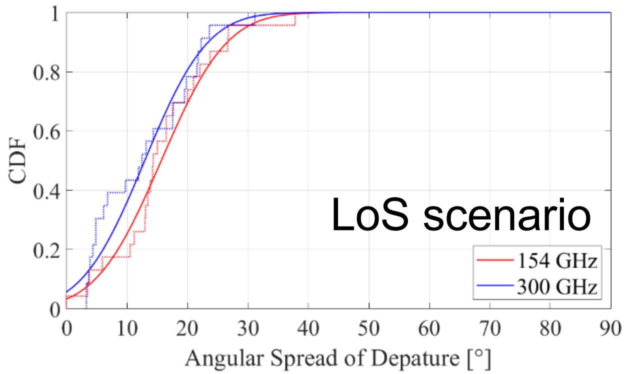
LSP results: ASA and ASD

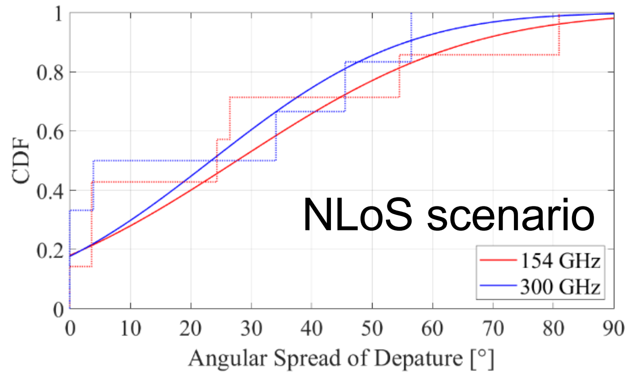
- ASA/ASD
  - 300 GHz band has smaller ASA/ASD
    - Due to more sparsity of MPC





  - NLoS scenario exhibits larger ASA/ASD
    - Due to the absence of LoS components





  - The differences in the ASA and ASD are caused by the structure of the walls which are close to Rx positions.

LSP results

Extracted parameters

LSP	Param.	LoS 154 GHz	LoS 300 GHz	NLoS 154 GHz	NLoS 300 GHz
DS [ns] Best beam	μ_{DS}	0.15	0.08	0.12	0.03
	σ_{DS}	0.09	0.08	0.11	0.05
DS [ns] Omnidirectional	μ_{DS}	7.70	5.26	13.19	11.19
	σ_{DS}	5.43	4.07	17.18	9.92
ASA [°]	μ_{ASA}	10.22	9.35	17.85	15.61
	σ_{ASA}	5.35	5.10	18.66	22.78
ASD [°]	μ_{ASD}	15.68	12.94	27.64	23.35
	σ_{ASD}	8.52	8.18	30.26	25.21
K [dB]	μ_K	7.58	7.28	-	-
	σ_K	3.82	4.35	-	-

Observation

- The 300 GHz band has lower values for all LSP parameters than the 154 GHz band in both PL cases and scenarios.

Summary

- Channel characterization in typical outdoor LoS and NLoS scenarios at 154 GHz and 300 GHz is presented.
- The characteristics of both omnidirectional PL and best-beam PL are derived by fitting the measurement data to standard models.
- Omnidirectional PLEs at both frequencies in the LoS scenario are smaller than two, demonstrating the potential for utilizing multipaths, while the 300 GHz band experiences less shadowing.
- LSP results were extracted, showing a slightly larger RMS DS for the 154 GHz band. However, the smaller azimuth angle spread and slightly lower K-factor at 300 GHz indicate sparser MPCs and higher interaction losses for reflected paths at the higher frequency.

Thank You

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References

[1] M. Mao, M. Kim, S. Sasaki, "154/300 GHz Dual-band Double-Directional Channel Measurements in a Large Conference Room Environment", doc.: IEEE802.15-24-0240-01-0thz

[2] A. Ghosh, et al., "Double-Directional Channel Characterization of an Indoor Corridor Scenario at 300 GHz," in IEEE GLOBECOM 2023, Kuala Lumpur, Malaysia, 2023, pp.1465-1470.