XG Mobile Promotion Forum

Abstract of
Beyond 5G White Paper
6G Radio Technology Project
“Radio Propagation Technology”

September 30, 2025

Contents of radio propagation white paper

- **The World's First White Paper Focused on Single 6G Propagation Technology**
- **Announced on May 7, 2025, confirmed by all radio propagation WG members**

Contents			Author
Overall Coordinator			Mr. Ito（KDDI research） Mr. Kuno（NTT docomo）
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		1.1.2 ITU-R	NTT・SoftBank
	1.2 Recent Academic Activities	1.2.1 Channel model	Niigata Univ.
		1.2.2 ISAC	NTT
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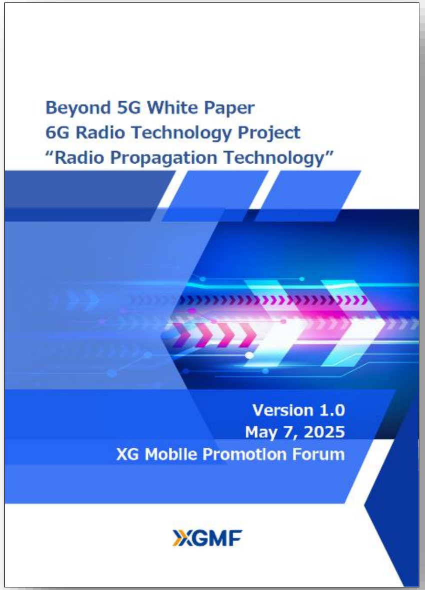


106 pages

1． Trends of Radio Propagation towards Beyond 5G/6G

- **World trends in standardization and academic societies and trends in Japan are introduced.**

Category	Topic	Author
I-1. Recent Standardization Activities	I-1.1. 3GPP Release 19 I-1.1.1. 7 to 24 GHz Band Channel Modelling I-1.1.2. ISAC Channel Modelling	SHARP Mr. Fukui, Ms. Hirata, Dr. Yokomakura NTT docomo Mr. Kuno, Dr. Suyama
	I-1.2. ITU-R I-1.2.1. NTN I-1.2.2. ITU-R SG3 and SG5 WP5D	SoftBank Dr. Omote NTT Dr. Yamada
I-2. Recent Academic Activities	I-2.1. MmWave and Sub-THz Channel Modeling	Niigata Univ. Prof. Kim
	I-2.2. Radio Propagation for ISAC	NTT Dr. Yamada
	I-2.3. RIS-Based Propagation Modeling	KDDI research Mr. Matsuno
	I-2.4. Radio Propagation for HAPS / NTN	SoftBank Dr. Omote
	I-2.5. Radio Propagation Emulation for Digital Twin	KDDI research Mr. Nagao
	I-2.6. Radio Propagation Simulation for CPS	NTT docomo Mr. Kuno, Dr. Suyama

2. Recent Activities of Radio Propagation in Japan

- **Propagation research results related to 6G carried out so far in Japan are introduced.**

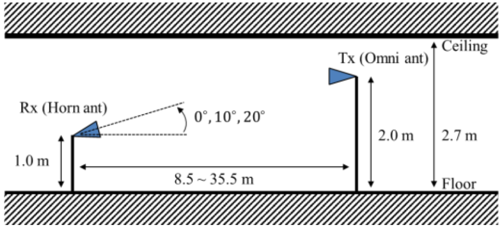
Category	Topic	Author
II-1. Measurement	II-1-1. Indoor Propagation Channel Measurements in 160 GHz	NTT docomo
	II-1-2. 300GHz Band Propagation Loss in the vicinity of the human body	KDDI research
	II-1-3. 300GHz Band Propagation Characteristics in the Indoor and Outdoor Environment	KDDI research
	II-1-4. Path Loss Characteristics from Microwave to Sub-Terahertz Bands in Urban Environment for Beyond 5G	NTT
	II-1-5. Terahertz Band Building Penetration Loss Characteristics for Beyond 6G	NTT
	II-1-6. Millimeter-Wave Urban Cellular Channel Characterization and High-Precision Site-Specific Simulation	Niigata Univ.
	II-1-7. THz Channel Characterization and Modeling Towards 6G Networks	Niigata Univ.
II-2. Simulation	II-2-1. Fast Propagation Simulation by CI Method for CPS Realization	NTT docomo
	II-2-2. AI-Based Radio Propagation Modeling and Data Augmentation	KDDI research
	II-2-3. Study on Machine Learning Propagation Loss Estimation Model using Point Cloud Data	Kozo Keikaku Engineering
	II-2-4. Investigation of Automatic 3D model Construction Techniques of the Surrounding Environment for Ray Tracing	Kozo Keikaku Engineering
	II-2-5. Radio Zone Interpolation by Kriging Method	NTT
	II-2-6. RNN Based Prediction Method of Wireless Communication Quality	NTT
	II-2-7. Deep Learning Propagation Loss Estimation Model Using Building Images	NTT
	II-2-8. Achievable Channel Capacity of Multi-Beam MIMO Transmission at 300 GHz	Niigata Univ.
	II-2-9. AI/ML-based Radio Propagation Prediction Technology	Tokyo Denki Univ.

II-1.1. Indoor Propagation Channel Measurements in 160 GHz

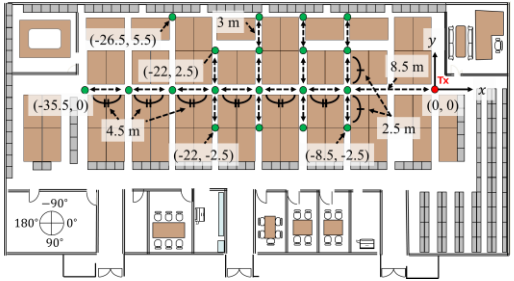
- **Expected use of the sub-terahertz band (100~300 GHz), which has dramatically wider bandwidth**
- **Understanding the radio wave propagation characteristics of each usage environment is essential for optimal area and system design.**
- **Measurement and analysis of delay time and direction-of-arrival characteristics in 160 GHz band in indoor office environment**

Parameters

Subjec	Value
Center freq.	160 GHz
Mod.	OFDM
BW	2 GHz
Tx antenna	Omni-directional Max gain：4.98 dBi HPBW: 26.5 deg.
Rx antenna	Horn Max gain：20 dBi HPBW: 17 deg.
Height of Tx	2 m
Height of Rx	1 m
Delay resolution	0.5 ns
Max delay	128 ns



Antenna position

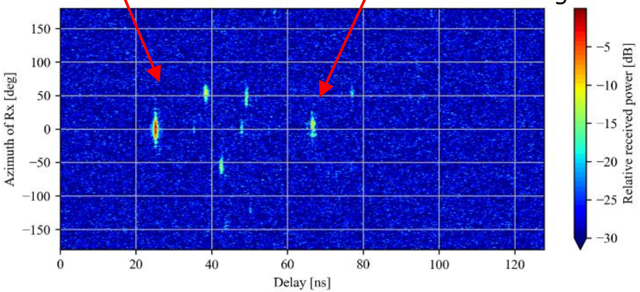


Environment

The propagation parameters necessary for area design and system design were analyzed by measuring delay time and direction of arrival in indoor office environment of 160 GHz band.

28.3ns direct wave

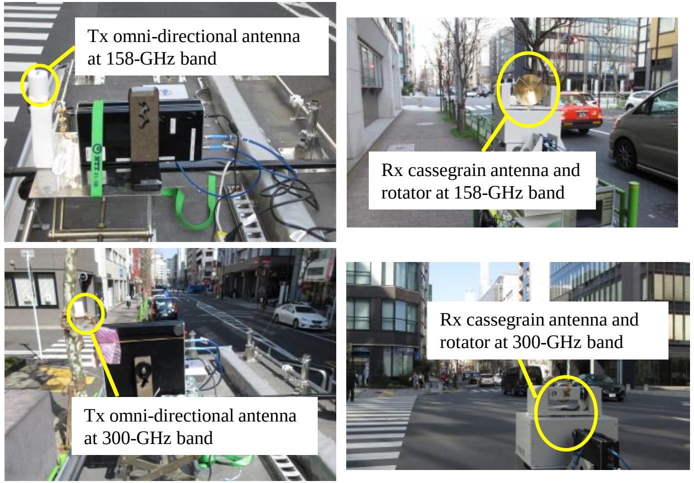
70ns etc: Reflect wave from floor and ceiling

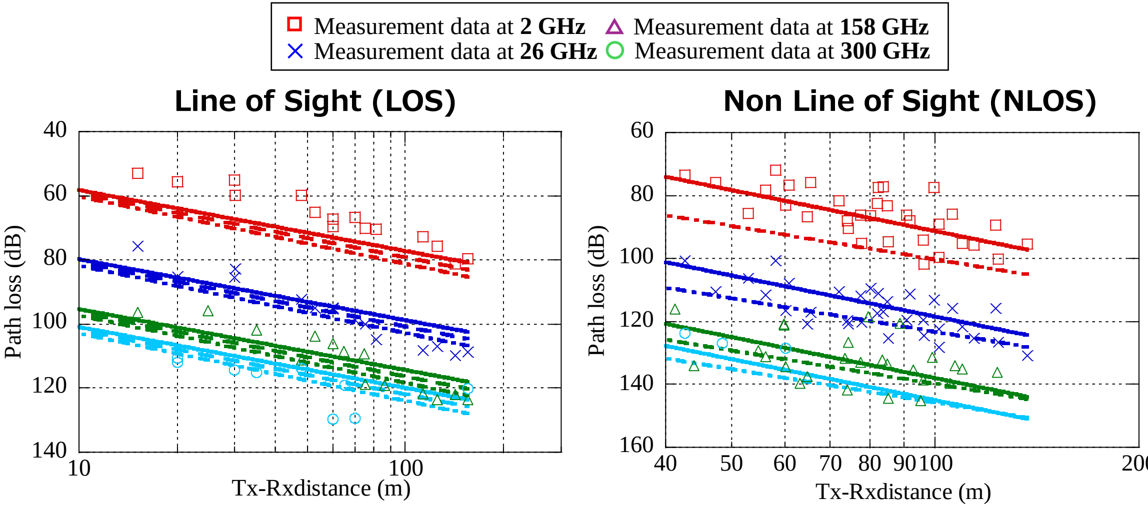


Delay-Angular profile at Point（-8.5, -2.5)

II-1.4. Path Loss Characteristics from Microwave to Sub-Terahertz Bands in Urban Environment for Beyond 5G

- **Propagation loss from 2 GHz to 300 GHz in an urban macrocell (UMi: Urban Microcell) was measured. Compare characteristics in LOS and NLOS environments**
- **These measurement results have already been input to ITU-R SG3 and SG5 to contribute to international standardization.**





		n	Constant loss (dB)	X_σ^{CI} (dB)
LOS	CI_{meas}	1.9	32.4+20log$_{10}$ f_{GHz}	6.04
	FSPL	2.0	32.4+20log$_{10}$ f_{GHz}	6.21
	M.2412	2.1	32.4+20log$_{10}$ f_{GHz}	6.86

		A	β	γ	X_σ (dB)
NLOS	ABG_{meas}	4.34	-4.1	2.52	6.19
	M.2412	3.53	22.4	2.13	9.22

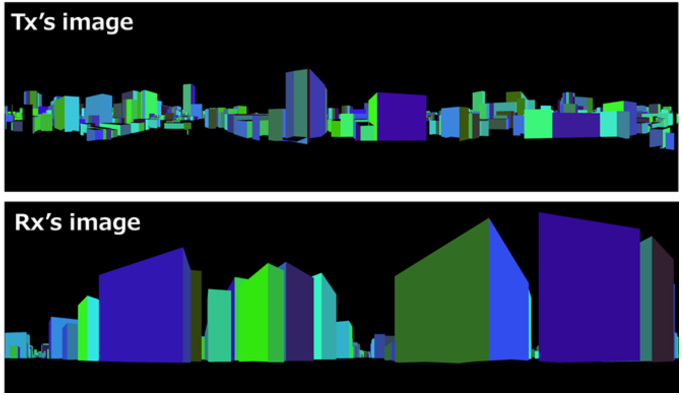
II-2.1. Fast Propagation Simulation by CI Method for CPS Realization

- **Super-fast propagation emulation method must be studied for optimization of 6G by CPS (Cyber-Physical System).**
- **A color image method is devised in which a distinguishing color (e.g., RGB) is assigned to a wall surface of a building and converted into an image viewed from a transmission and reception point, and a wall surface with a matching color code from both images is regarded as a scattering wall surface, and received power is calculated based on the number of pixels.**
- **Image processing techniques can be hundreds to thousands of times faster than traditional ray tracing methods**
- **Received power calculation using the area of the scattering wall enables high-precision estimation for the ray tracing method**

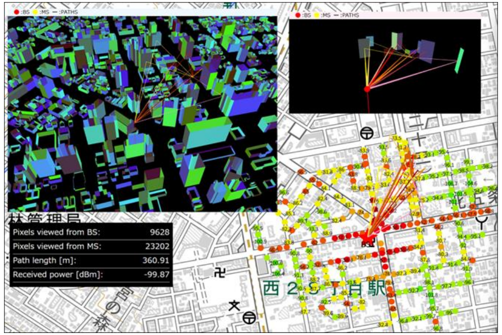
The received power of the scattered wave is calculated by multiplying the number of pixels and the coefficient of the color of the scattered wall.

$$\boxed{\text{Received Pow.} P_{\mathrm{R}} = \sum_i k(i) \cdot N_{\mathrm{P,T}}(i) \cdot N_{\mathrm{P,R}}(i)}$$

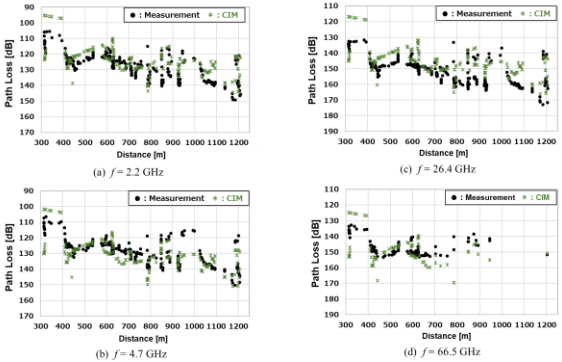
$k(i)$: **Coefficients, depends on reflection from walls, arrival and departure angle etc.**



The color images viewed from the Tx and the Rx



Simulation Tool

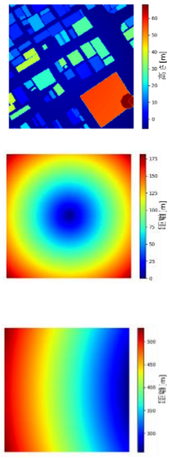


Compared results

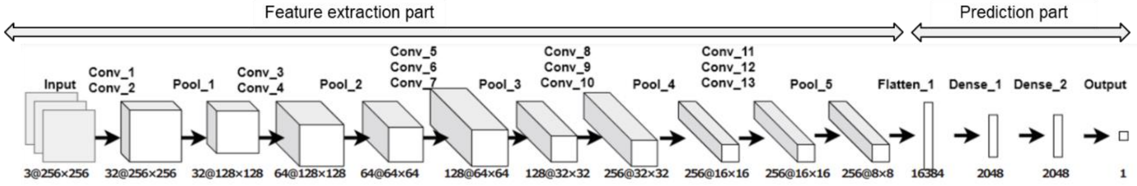
II-2.9. AI/ML-based Radio Propagation Prediction Technology

- **Propagation loss estimation method by deep convolutional neural network (DCNN) using BS distance map, MS distance map and building map as input is proposed.**
- **The features extracted in DCNN are visualized by Grad-CAM (Gradient-weighted Class Activation Mapping), and the judgment basis of propagation loss estimation is analyzed.**

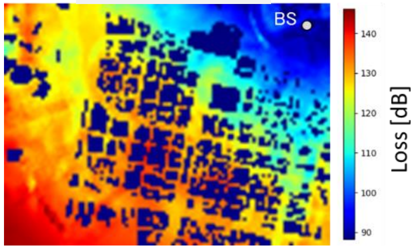
Input data



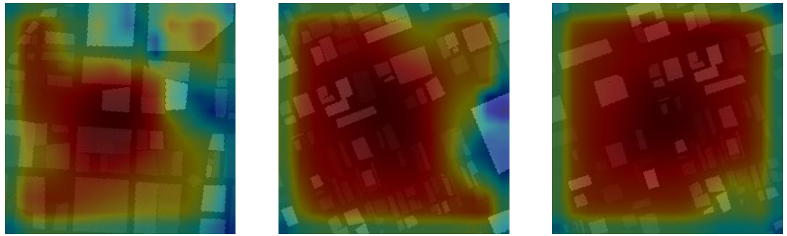
Configuration of DCNN



Est. results



Output from Grad-CAN



Point A Point B Point C

Compared results