ITU AI/ML in 5G Challenge | Challenge Program
Estimation of Site-specific radio propagation loss

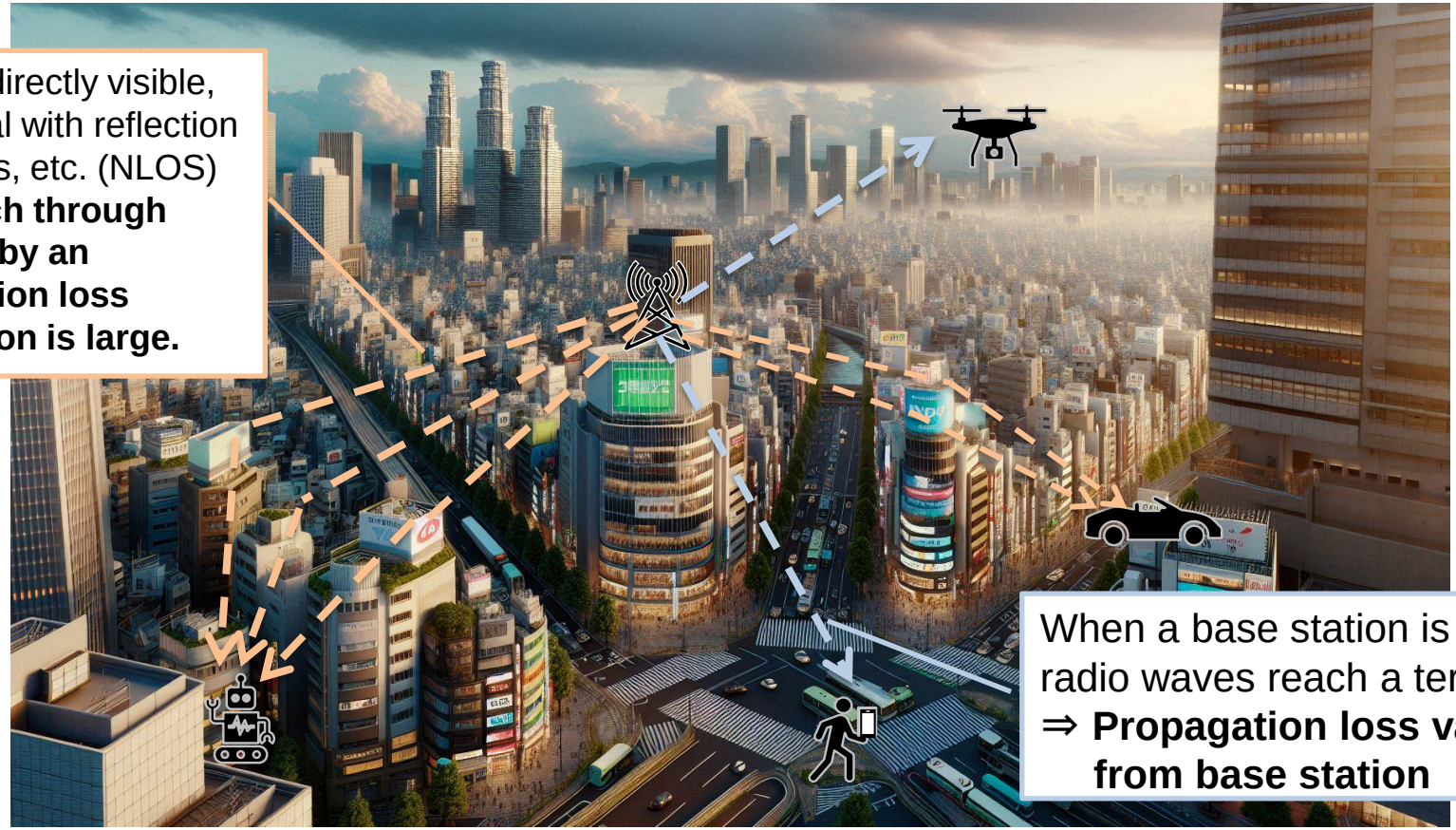
September 6th, 2024

KDDI Research, Inc.

Background

- **Site-specific radio propagation is important for realizing stable mobile communications.**
- **The radio propagation can be obtained to know the propagation loss of each location, which varies by places due to environmental influences such as buildings.**

When a base station is not directly visible, radio waves reach a terminal with reflection and diffraction from buildings, etc. (NLOS)
⇒ **Since radio waves reach through various paths effected by an environment, propagation loss variation in each location is large.**



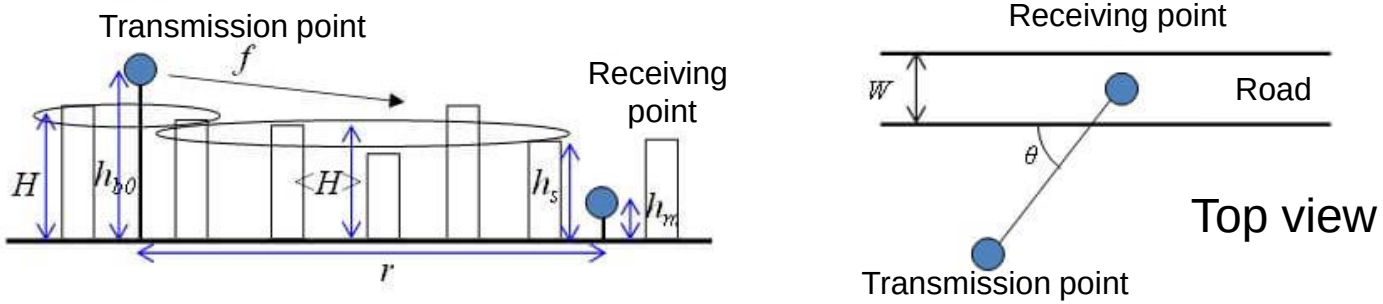
When a base station is directly visible, radio waves reach a terminal directly (LOS)
⇒ **Propagation loss varies with distance from base station**

LOS: Line of sight, NLOS: Non line of sight

Conventional radio propagation model

- **The model is resolved by measured data and statistical parameters in an environment such as average building height and average road width.**
  - ⇒ **It consistents statically across locations, but it is different from actual propagation loss values in each location.**

Example of conventional method (based on extended Sakagami formula[1])



$$L = 100 - 7.1logW + 0.023\theta + 1.4logh_s + 6.11log < H > -\ldots$$

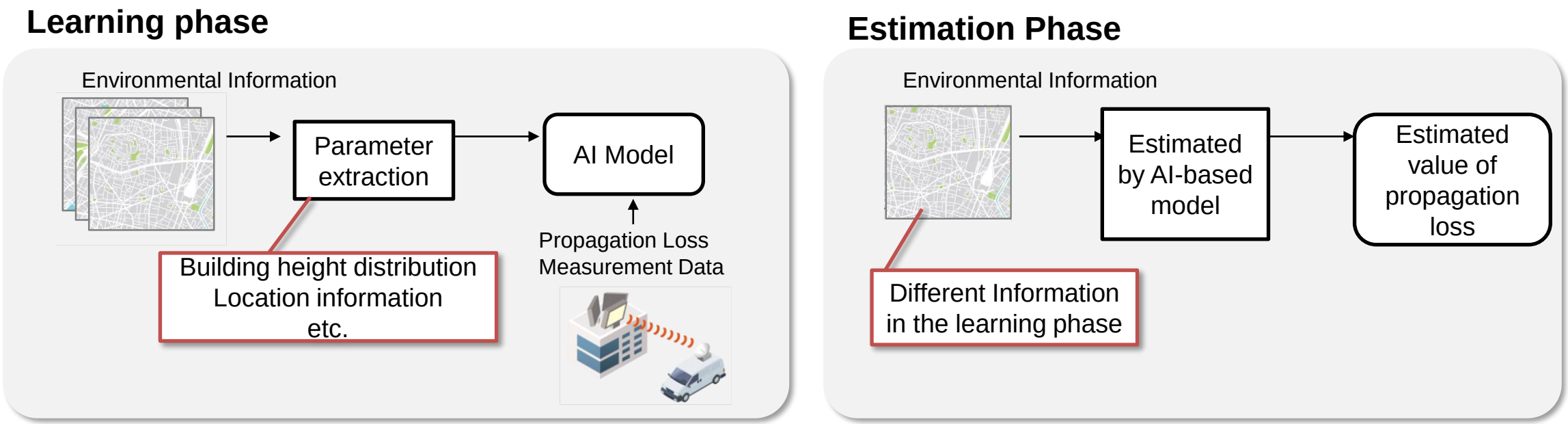
L: Propagation loss, *W:* Width of the road near receiving point,
θ: Angle between line of transmitting and receiving points and direction of the road,
h_s: Building height at the roadside, <*H*>: Average of the building heights between transmission and receiving point

[1] https://www.ieice.org/cs/ap/misc/denpan-db/prop_model_db/model_list/extended_sakagami/ (in Japanese)
[2] T. Fujii, "Delay profile modeling for wideband mobile propagation," IEEE 60th Vehicular Technology Conference, 2004. VTC2004-Fall. 2004, Los Angeles, CA, USA, 2004, pp. 38-42 Vol. 1, doi: 10.1109/VETECF.2004.1399914. (https://ieeexplore.ieee.org/document/1399914)

AI-based radio propagation model

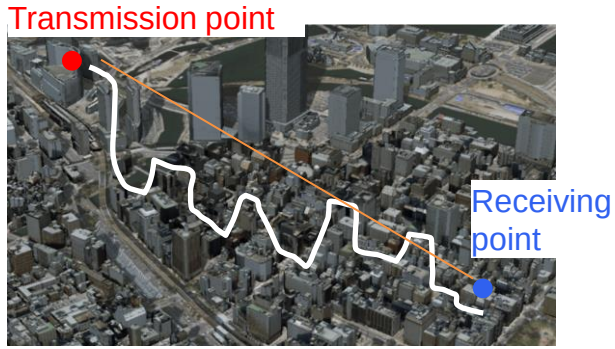
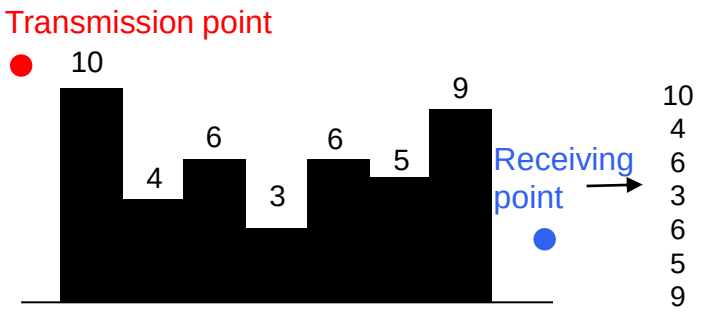
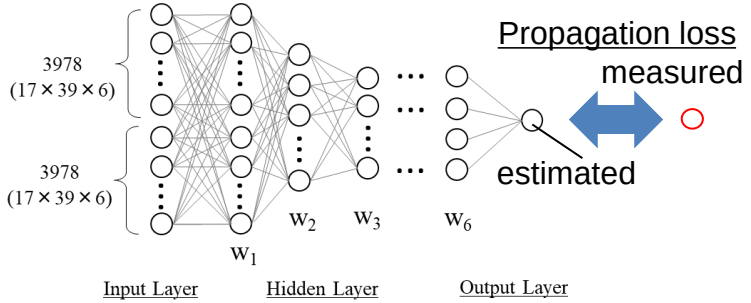
- **The AI-based model with learning environmental information are studied to estimate site-specific radio propagation more accurately.**
  - The model is created based on parameters extracted from the environmental information such as map data and measured propagation loss data.

- **This enables estimation of radio propagation with different environment.**



Considered points of constructing the AI-based model

- **Points： How to design (1) Characteristic of the environment, (2) Parameter extraction method, and (3) Learning model**
- **The following description is only an "example“.**
  You should be considered to increase the accuracy of estimation of radio propagation loss.

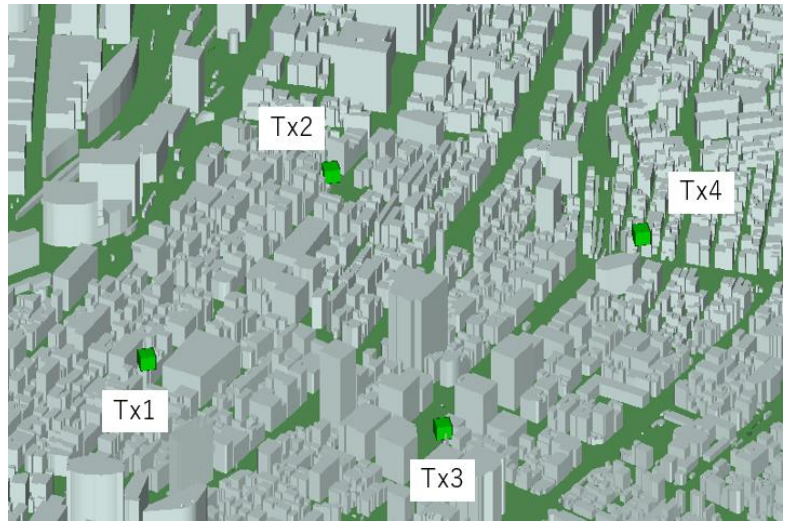
Item	(1) Characteristic of the environment	(2) Parameter extraction method	(3) Learning model
Example	Height of the building between transmission and receiving point 	Height with fixed intervals on between transmition and receiving points 	Weights for network connection is learned from propagation measurement data in same position 
Consider	Environment characteristics to be correlated with radio propagation loss.	How to extract the characteristics, how to process them (e.g., leave as is or normalize), and how to represent them.	What AI/ML model to use to estimate radio propagation loss from the parameters

Tasks of this program

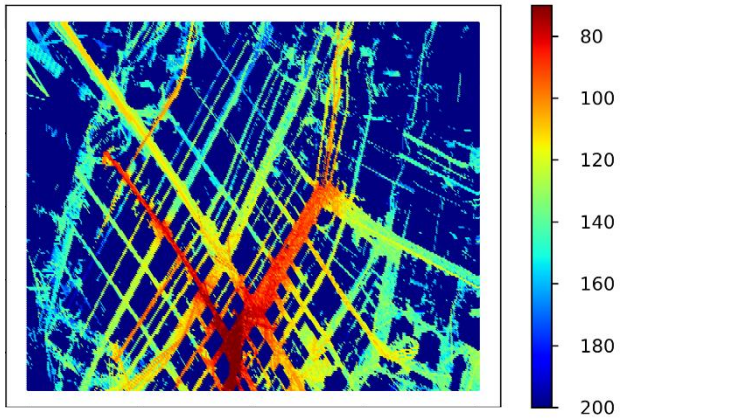
- **Estimates propagation loss within a certain area from a transmission point (Tx) using 3D map data and propagation loss data from multiple Txs.**
- **Tasks**
  - Task 1 (Basic): Frequency = **800 MHz**
  - Task 2 (Advanced): Frequency = **7 GHz**
  - Task 3 (Advanced): Frequency = **28 GHz**
    - Due to the increased influence of the environment, the difficulty level becomes higher in the order of Task 1 to 3.
- **Dataset**
  1. 3D map data
     - Converting the file format of PLATEAU data(*)
     - OBJ file format
  2. Propagation loss data per Tx
     - Created using ray tracing simulation considering up to 4 reflections and 1 diffraction at most
     - Propagation loss values for each Rx coordinate from a Tx point can be obtained

(*) The data is from "PLATEAU Open Data 3D Urban Model Chuo-ku[1] and Chiyoda-ku[2]" (Ministry of Land, Infrastructure, Transport and Tourism, Japan). The offered data is created by a file format conversion.
[1] https://www.geospatial.jp/ckan/dataset/plateau-13102-chuo-ku-2023
[2] https://www.geospatial.jp/ckan/dataset/plateau-13101-chiyoda-ku-2023

3D map data



Visualized propagation loss data



Propagation loss [dB]

Model Evaluation

- **"Propagation loss data per Tx" includes data sets for 4 transmission points (Tx#1 to #4) in the same frequency band and location.**

- **Cross-validation (CV) to evaluate your AI model of radio propagation loss, as in the following example in CV#1:**
  - Trained with environmental data and propagation loss data values from Tx #1-3, and Estimated propagation loss with environmental data from Tx #4
  - Evaluate the accuracy of the estimated value with propagation loss data values of Tx #4

	Tx #1	Tx #2	Tx #3	Tx #4
CV #1	learning	learning	learning	evaluation
CV #2	learning	learning	evaluation	learning
CV #3	learning	evaluation	learning	learning
CV #4	evaluation	learning	learning	learning

Model Evaluation (continued)

Procedures

- (1) Create an AI model for radio wave propagation loss using the training data for each CV.
- (2) Estimate the radio wave propagation loss at the receiver points (X, Y, Z) in the evaluation data for each CV using the AI model.
- (3) Calculate the Root Mean Square Error (RMSE) from the propagation loss value *M* included in the evaluation data and the estimated value *E* from (2).

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(E_i - M_i)^2}$$

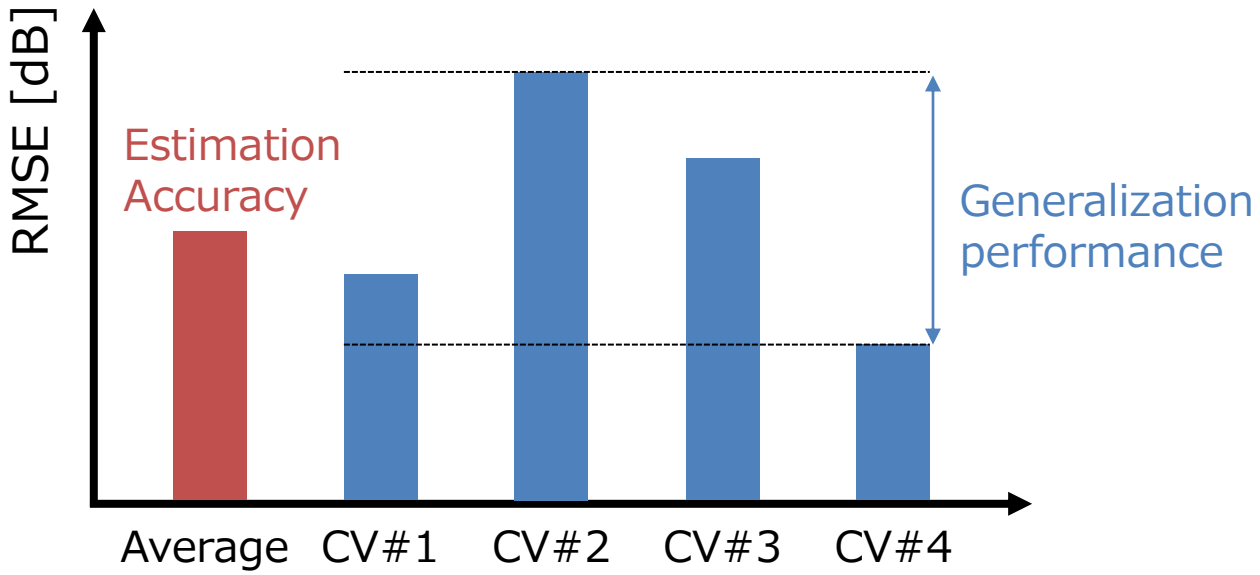
Conditions

- (a) For each CV, the evaluation data must not be used for training, but only for the evaluation in (3).
- (b) Learning/evaluation use the propagation data in the same frequency band.
- (c) AI modeling methods and training methods can be freely considered.
  - How much of the propagation loss data (three Tx) is used when training each CV
  - Characteristic parameters from the dataset
  - AI model used for learning

Evaluation Criteria

- **Criteria #1: Usefulness of your AI-model**
  - Estimation accuracy: Average of RMSE from CV#1 to CV#4
  - Generalization performance: variance of RMSE from CV#1 to CV#4
  - A method with both good estimation accuracy and generalization performance would be useful.
- **Criteria #2: Modeling Methods**
  - Overall evaluation of originality and complexity

Image of Criteria #1



Submission Requirements

Please submit 2 materials.

- **(1) Presentation Material (PDF file, assumed maximum of 20 slides)**
  - Language： English or Japanese
    - In the case of Japanese, the winner or team is required to create a presentation material in English.
  - What should be included:
    - Front cover
    - Your team structure: organization, participants, role
    - Results on evaluation Criteria #1
      - Estimation accuracy: RMSE of each of CV#1 to #4, and the dB value average across all of them
      - Generalization performance: variance values of RMSE for each of CV#1 to #4
    - Description of your developed model (to be used for evaluation of Criteria #2)
      - Please describe your design of (1) the characteristics that describe the environment, (2) the parameters, and (3) how the learning model was designed in "Considered points of constructing the AI-based model" page of this document.
      - Please include reference, if necessary.
      - Please describe the details and characteristic of your consideration.
    - Processing time measurement for processing
      - Implementation environment: OS, development environment, CPU, memory, storage, GPU (if used)
        [Example] Windows 10, Python3 with XXX library, Intel Core i5-10310U, 32GB, 256GB SSD, Nvidia GeForce 4080 SUPER (16GB)
      - Time (in seconds) for processing each of CVs #1 through #4.
        You do not have to include the time for data conversion or loading, but measure the time required for learning and estimation.

Submission Requirements (continued)

■ (2) Evaluated data by your AI/ML model for each CV (CSV file)

- You need to submit 4 files (each Tx) per a frequency (Task).
- The CSV format is shown as below.
  - Please add a column 14 of “predicted path loss” to the file “Propagation loss data” in the dataset.
  - The detail format of propagation loss data is explained “Data set description” in this document.

COLS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Header	X	Y	Z	PL	Lon	Lat	Attitude
Name	Coordinates of Rx point (x, y, z)			Propagation loss value (dB)	Latitude, longitude and height from ground [m] of Rx point		

COLS	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Header	X	Y	Z	Lon	Lat	Attitude	**Predicted PL**
Name	Coordinates of Tx point (x, y, z)			Latitude, longitude and height from ground [m] of Tx point			**Predicted path loss [dB]**

Submission Method/Questions/Schedule

Submission Method

- Deadline: Friday, November 1, 2024
- Please submit via the ITU submission form

Questions

- Deadline: Friday, October 25, 2024 23:59 JST (UTC+9)
- Please use the form below to submit your question. We will reply in approximately 2 business days.
  https://forms.office.com/r/TrNK6As1h9
- If you wish to send a file, please use a file transfer service. You need to write the URL, username and password for downloading, and other necessary information in the above form.

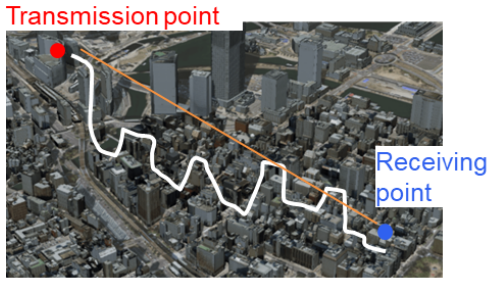
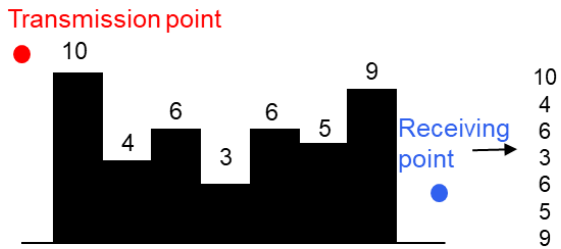
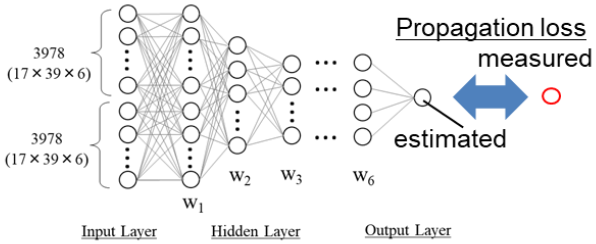
Schedule (2024)

- Oct 25th — Question deadline
- Nov 1st — Submission deadline
- By Nov 15th — Decision of winner person or team
- Nov 25th week — Winner person of team presentation in TTC/Japan webinar (English)
- Dec mid — Winner person of team presentation in ITU webinar (English)

Detail examples of propagation loss estimation methods and Data set description

Detail procedures of propagation loss estimation

- **To estimate propagation loss, steps (1) through (3) in the table below must be performed.**
- **Detail procedures are described in the following slides. However, it is only an example, Please consider how each challenger can improve the propagation loss estimation results (i.e., get closer to the actual values).**
  - For the detail contents described in the following slides, the presentation material in the conference are included as reference.

Item	(1) Characteristic of the environment	(2) Parameter extraction method	(3) Learning model creation
Example	Height of the building between transmission and receiving point 	Height with fixed intervals on between transmition and receiving points 	Weights for network connection is learned from propagation measurement data in same position 
Consider	Environment characteristics to be correlated with radio propagation loss.	How to extract the characteristics, how to process them (e.g., leave as is or normalize), and how to represent them.	What AI/ML model to use to estimate radio propagation loss from the parameters

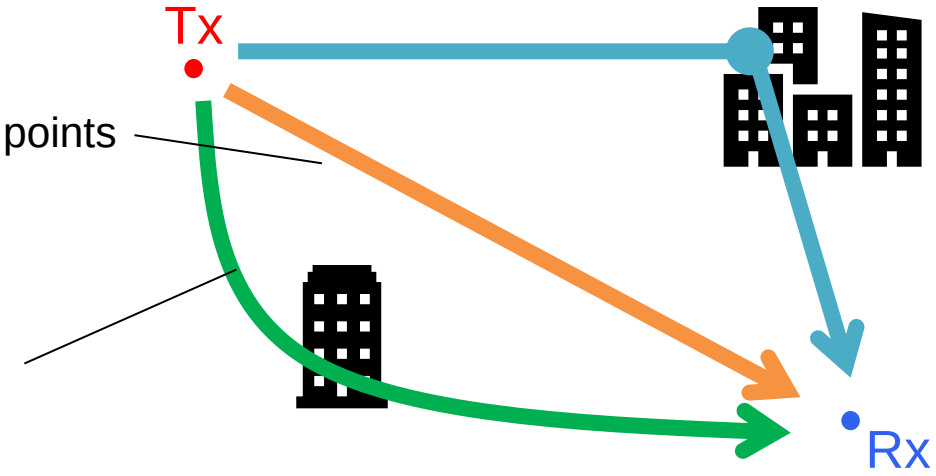
Same table In Page 5

(1) Characteristics of the environment

- **Considering environmental characteristic to be correlated with propagation loss based on the paths through which the radio waves pass.**
- **Path types and their effect on propagation loss**

Direct path
- No structure exists on the path between the sending and receiving points
- Propagation loss tends to be small

Diffraction path
- A path where the radio waves bend around obstacles.
- Propagation loss tends to be large



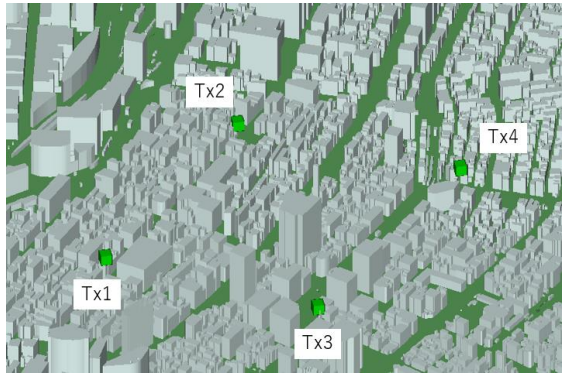
Reflection path
- A path where the radio waves reflect off structures and reach the receiving point.
- Propagation loss tends to be greater than the direct path and smaller than the diffracted path.

- **Consideration example**
  - Correlation with propagation loss
    - Longer paths: greater propagation loss
    - Fewer structures between Tx and Rx: smaller propagation loss
    - Overlapping reflections and diffractions: Propagation loss increases
  - The environmental characteristic represents "Distance between Tx and Rx" and "Surrounding structures".

(2) Parameter extraction method

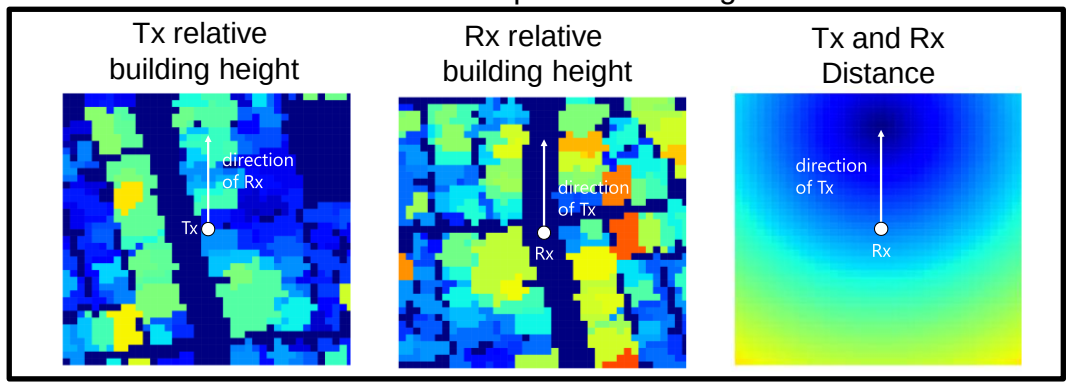
- **Considering methods of extracting the characteristic determined in (1).**
- **Consideration example**
  - Consideration of extracting characteristic of “Distance between Tx and Rx" and “Surrounding structures”
    ⇒ Extraction as an image (2D array) is effective to represent the relationship between positional and shape of surrounding structures.
  - From the 3D map data in the data set, the following items are represented by images.
    - Distance between Tx and Rx
    - Relative height of surrounding structures with respect to TX and RX as the reference point.

3D map data (from the data set)



making

Extracted parameter images

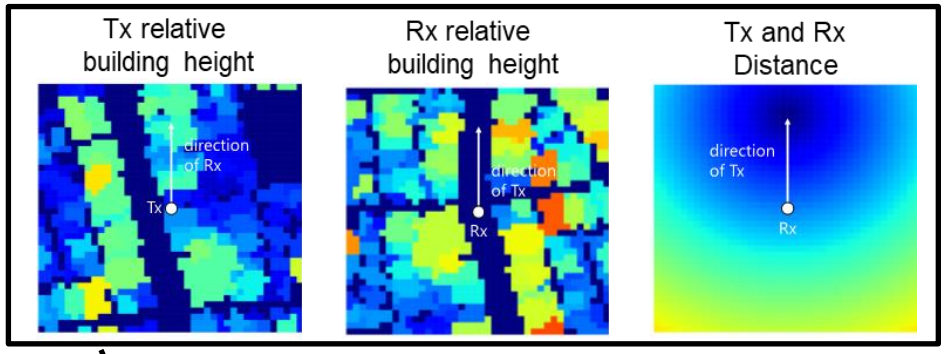


- **You will consider various methods for extracting the characteristic from the 3D map data, such as images looking down from Tx position and 360° panoramic images of the surroundings from RX position.**

(3) Learning model

- **Considering learning method using parameters determined in (2)**
- **Consideration example**
  - Considering the learning model using "Tx and Rx distance image" and "Tx/Rx relative building height image”
  - It requires a model that can be used for image recognition and can be trained efficiently.
    ⇒ Apply ResNet

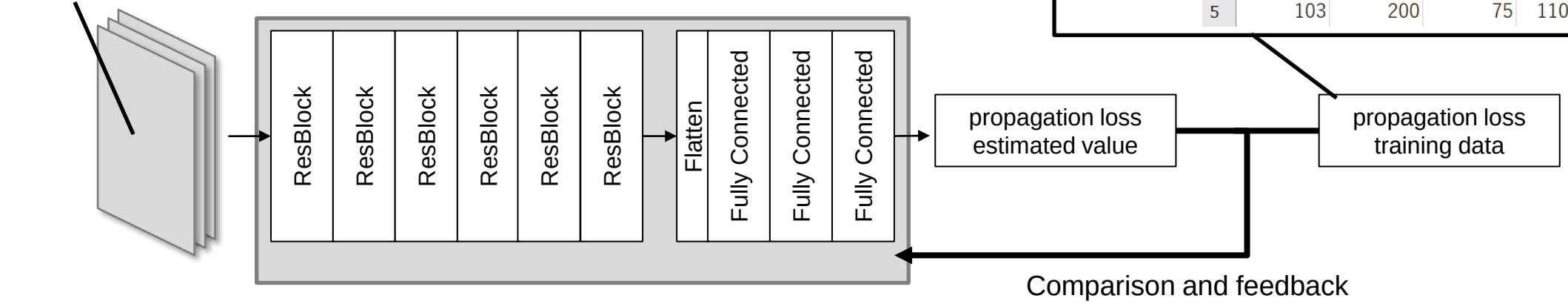
Parameters for the learning model * Contents in (2)



Propagation loss data (in the data set)

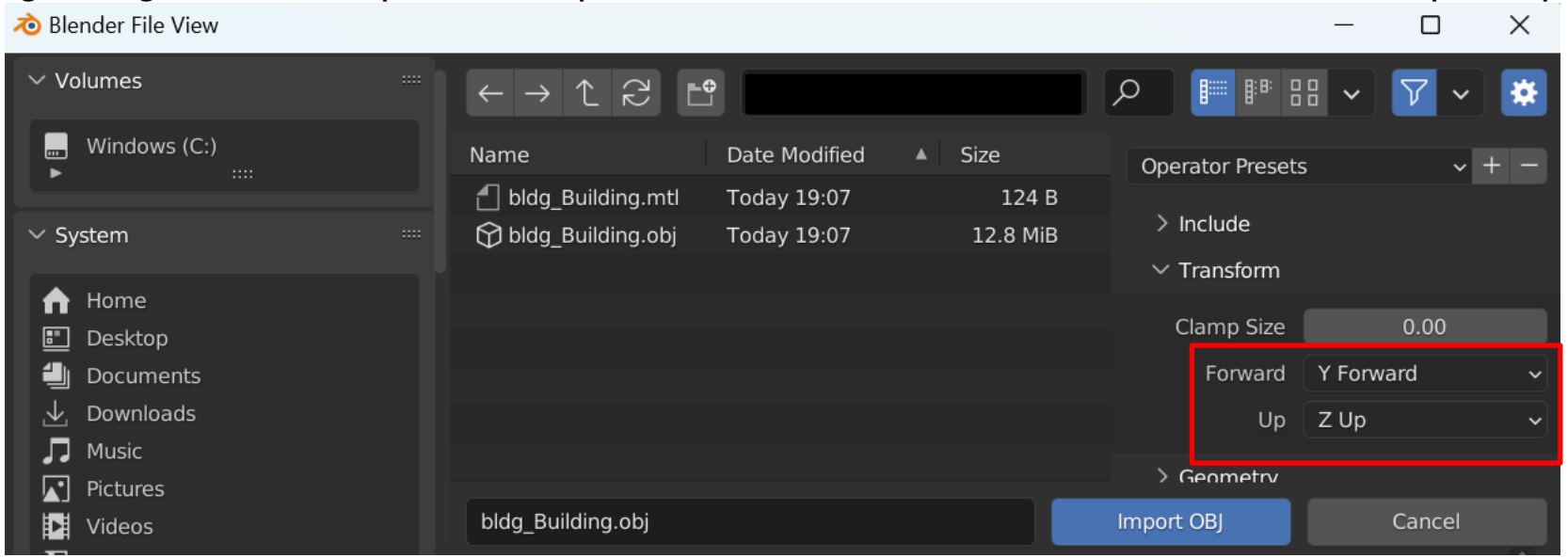
Propagation loss associated with
the coordinates on the 3D map data of Tx and Rx

	A	B	C	D
1	x	y	z	PL
2	100	200	75	101.173
3	101	200	75	113.739
4	102	200	75	119.734
5	103	200	75	110.604



Data set description: (A) 3D map data

- **Data on structures etc. in "(1) Environmental Characteristics" can be obtained, and this data is used in "(2) Extraction of Parameters".**
- **OBJ format file.**
  - Text file
  - There are many xplanations of file formats on the Web.
    - https://en.wikipedia.org/wiki/Wavefront_.obj_file
  - This file can be viewed and edited with 3DCG software Blender, etc.
    - https://www.blender.org/
    - The following configuration is required to import this data in Blender: Forward=Y Forward, Up=Z Up



Data set description: (B) Propagation loss data

- **There are 12 files for each frequency (800MHz, 7GHz, 28GHz) with 4Tx position.**
- **For each frequency, 3 Tx are used for training, and 1 Tx is used for evaluation**
- **CSV file format is as follows:**

COLS	1	2	3	4	5	6	7
Header	X	Y	Z	PL	Lon	Lat	Attitude
Name	Coordinates of Rx point (x, y, z)			Propagation loss value (dB)	Latitude, longitude and height from ground [m] of Rx point		
Use for	Used as Rx position in AI model when comparing propagation loss values to estimates in AI model.			• For learning of propagation loss (teacher data) • Data for evaluation	Those can be used to extract parameters such as the actual distance between the Tx and Rx positions.		
Remarks	(A) Same coordinate system as 3D map data			Created by Ray Tracing Simulation	Using in (2) for parameter extraction as needed		

COLS	8	9	10	11	12	13
Header	X	Y	Z	Lon	Lat	Attitude
Name	Coordinates of Tx point (x, y, z)			Latitude, longitude and height from ground [m] of Tx point		
Use for	Used as Tx position in AI model when comparing propagation loss values to estimates in AI model.			Those can be used to extract parameters such as the actual distance between the Tx and Rx positions.		
Remarks	(A) Same coordinate system as 3D map data			Using in (2) for parameter extraction as needed		

References

- **There is a lot of research being conducted in this field.**
  Please search for “radio propagation prediction machine learning“.
  You will find many papers related to this program.

- **The following are some references of KDDI Research’s study related to this program.**
  - The detailed method of how to estimate radio propagation loss in AI/ML is described, but should be treated as an example only.
  - T. Hayashi, T. Nagao and S. Ito, "A study on the variety and size of input data for radio propagation prediction using a deep neural network," 2020 14th European Conference on Antennas and Propagation
    https://ieeexplore.ieee.org/document/9135876
    - Due to copyright consideration, please download the paper from IEEE Xplorer
    - We have included the presentation material of this paper. Please refer to the details of example considerations described in this document.
  - T. Nagao and T. Hayashi, "A Study on Path Loss Modeling using ResNet and Pre-Training with Free Space Path Loss," 2022 IEEE 33rd Annual International Symposium on Personal, Indoor and Mobile Radio Communications
    https://ieeexplore.ieee.org/document/9977760
  - T. Nagao and T. Hayashi, "A Study on Urban Structure Map Extraction for Radio Propagation Prediction using XGBoost," 2021 15th European Conference on Antennas and Propagation
    https://ieeexplore.ieee.org/document/9411102

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