Estimating the Physical Distance between Two Locations with Wi-Fi Received Signal Strength Information Using Obstacle-aware Approach

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Background

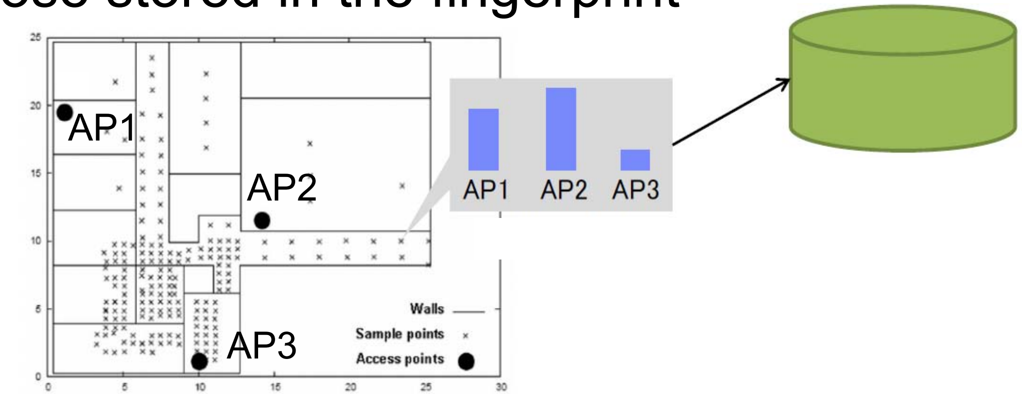
- **Wi-Fi** has become a common infrastructure in the society
  - Therefore, Wi-Fi access points (APs) are commonly installed in buildings

- Many researchers are developing **context recognition techniques for indoor context-aware services based on Wi-Fi signals**

Existing techniques based on Wi-Fi

Attempt to estimate **<u>the Indoor Coordinates</u>** of a receiver

- Ex. Wi-Fi Fingerprinting (RSSI-based)
  - Store RSSI information in a database along with the known coordinates in an offline phase
  - During the online phase, the current RSSI vector at an unknown location is compared to those stored in the fingerprint



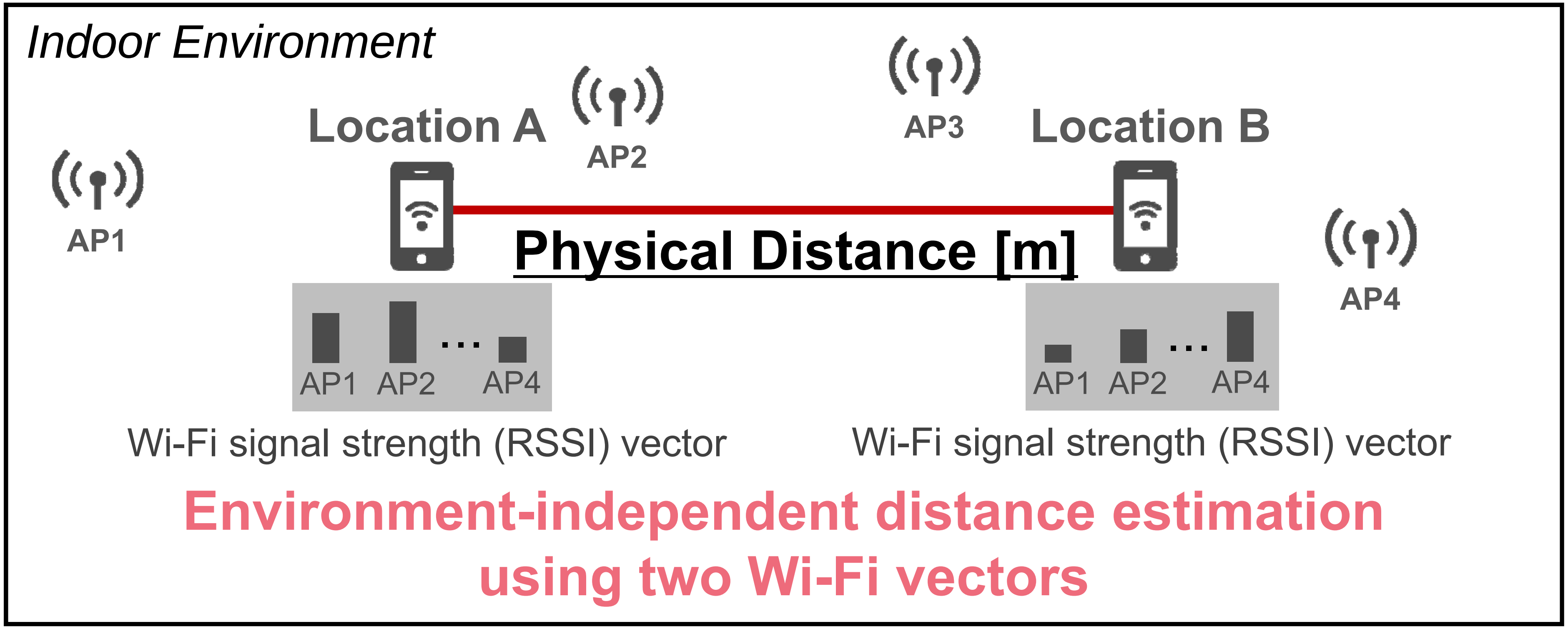
Existing techniques have huge installation cost

- Site survey (ground truth collection)

Goal

To estimate **new context information** based on Wi-Fi infrastructure

- Estimate **the physical distance between two locations** by using **Wi-Fi signal strength vectors observed at the two locations** by receivers
- Without using labeled data collected in an environment of interest

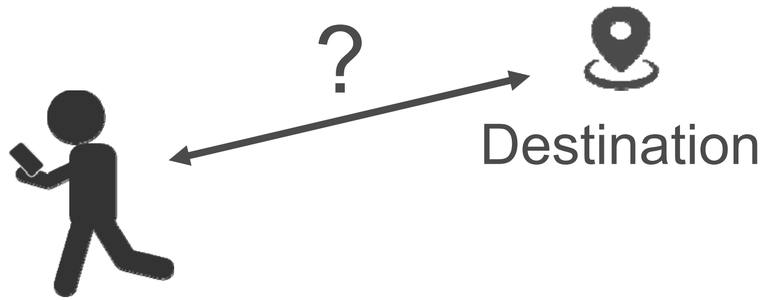


Advantage of our approach to distance estimation

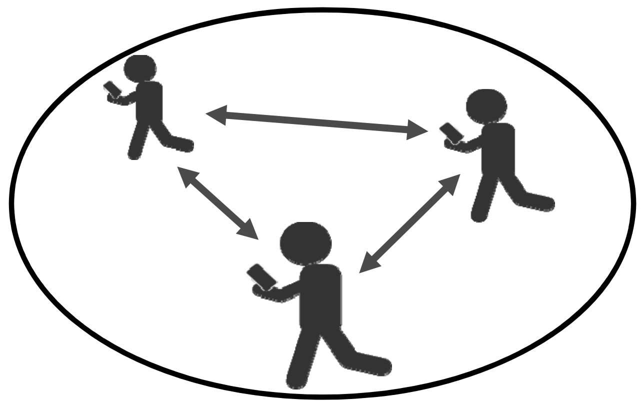
- **Do not need labeled data** in target environment
  - Our method uses labeled training data collected **in other environments**
- **Low installation cost**
  - Use existing Wi-Fi infrastructure

[Applications]

Simple indoor navigation



Analysis and Discovery of communities

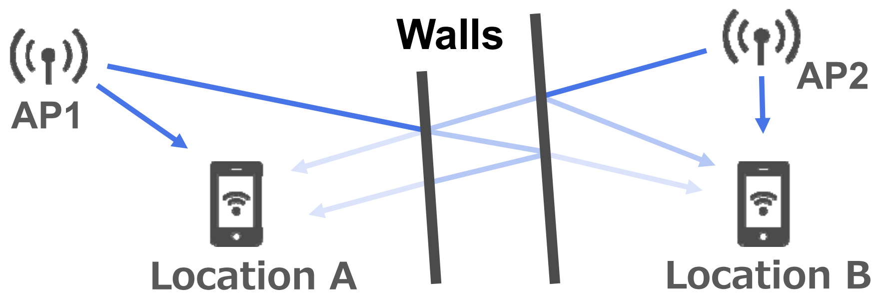


Approach

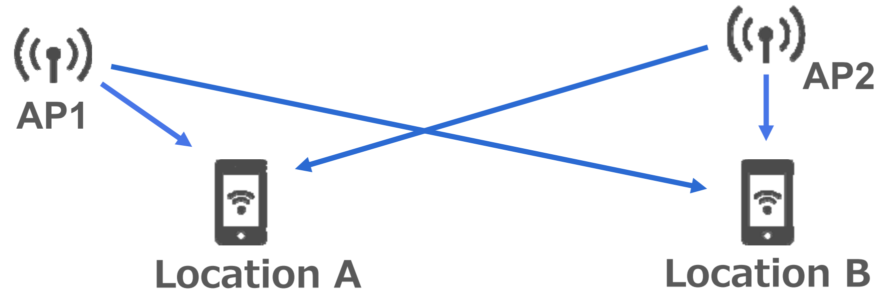
<u>Obstacle-aware</u> approach

- Estimate whether or not there are walls between the two locations before distance estimation

There are **<u>walls</u>** between the two locations



There is **<u>no wall</u>** between the two locations



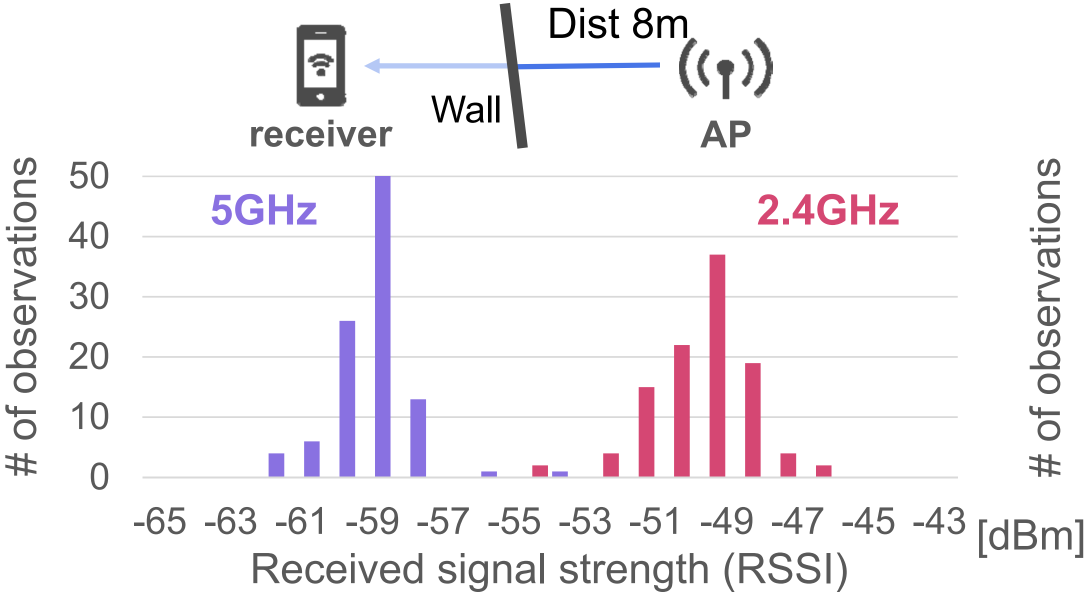
Walls between the two locations significantly change signal propagations

- Details:
  - Calculate **<u>the probability</u>** with which there are walls between the two locations
  - Use the calculated probability to estimate the physical distance precisely

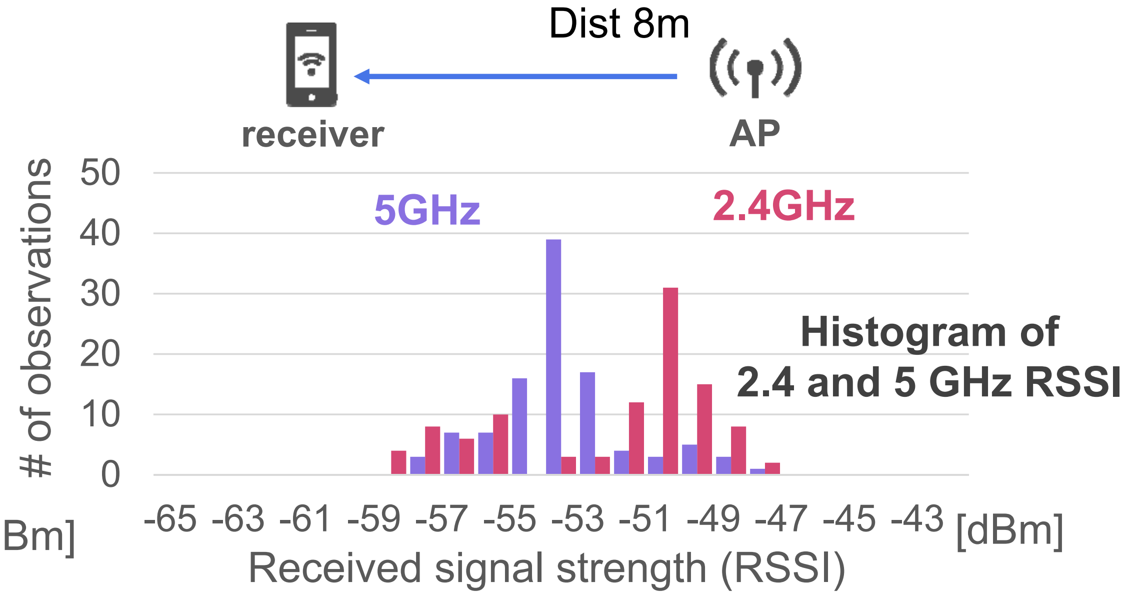
Investigations: Signal attenuation on wall

Investigate the signal attenuation properties of 2.4 and 5 GHz

There is **wall** between AP and receiver



There is **no wall** between AP and receiver



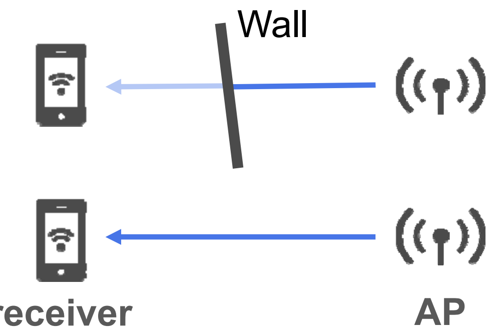
The effect of the wall on the 2.4GHz is small, but 5GHz is greatly affected by the wall

We harness the difference in the signal characteristics to obtain information about obstacles

Investigations: Wall detection

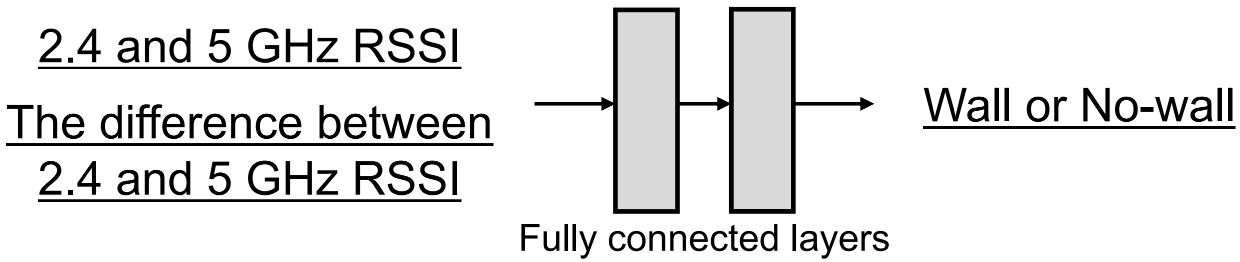
Consider detection of the presence of wall between a dual-band AP and a receiver

- It can help design our method



- Experiments of wall detection

Neural network for wall detection



Dataset (contains wall and no-wall)

Environments	Laboratory, Conference room, House
Distance between AP and receiver	2, 4, 6, 8, 10 [meter]
# each Wi-Fi vectors	40

Classification results

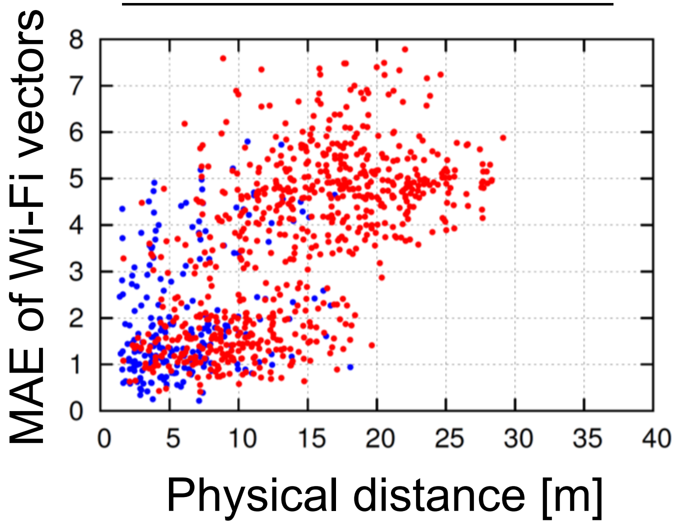
	Precision	Recall	F1-score
Wall	0.98	1.00	0.99
No-wall	1.00	0.98	0.99
Average	0.99	0.99	0.99

Investigations: Existing distance metrics (Wi-Fi distances)

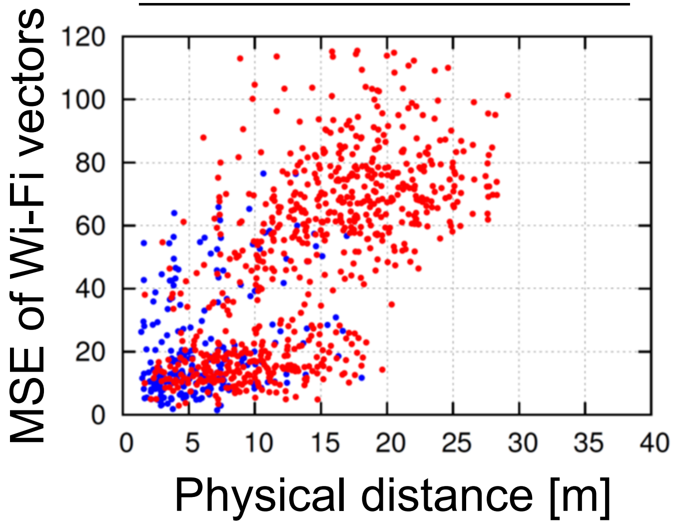
Investigate the existing distance metrics for Wi-Fi vectors

- Ex. Mean absolute error (MAE), Mean squared error (MSE)

MAE vs Physical distance
<u>when all APs are used</u>



MSE vs Physical distance
<u>when all APs are used</u>



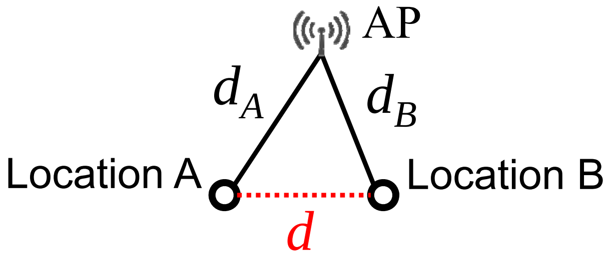
● There are **<u>walls</u>** between two locations

● There is **<u>no wall</u>** between two locations

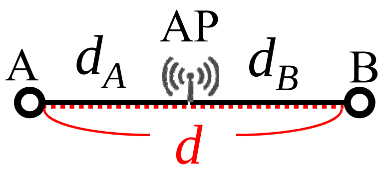
Investigations: Useful APs

Consider useful APs based on geometric investigation

- The goal of this study is to estimate the distance d
- Consider extreme cases where d takes its maximum (minimum) value

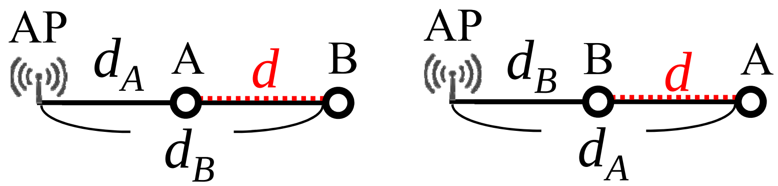


Geometric relationship



Maximum case

$d_{max} = d_A + d_B$



Minimum case

$d_{min} = \max(d_A, d_B) - \min(d_A, d_B)$

- The range of possible value of d is described as follows

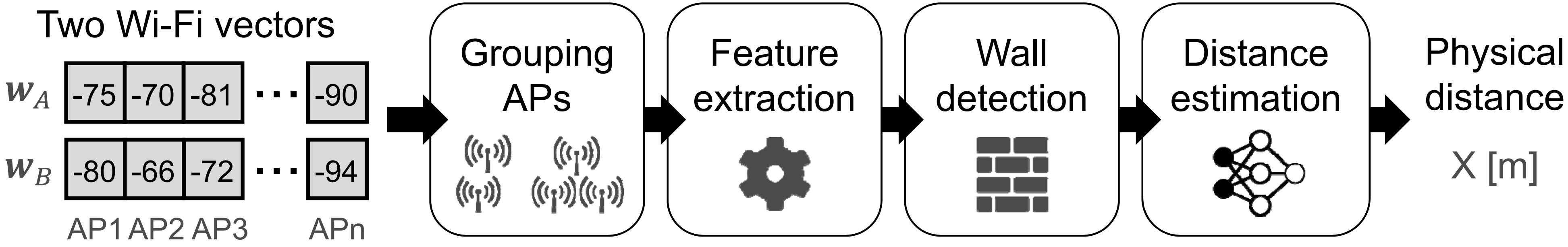
$$d_{max} - d_{min} = 2\min(d_A, d_B)$$

⇨ It is good to use an AP with the small range of possible value

Useful AP: "small $\boldsymbol{min(d_A, d_B)}$" ⇒ "large $\boldsymbol{max(rssi_A, rssi_B)}$"

Method: Overview

- Overview of the physical distance estimation



Grouping APs

- Construct two sets of APs

1. A set for 2.4 GHz APs
2. A set for dual-band APs

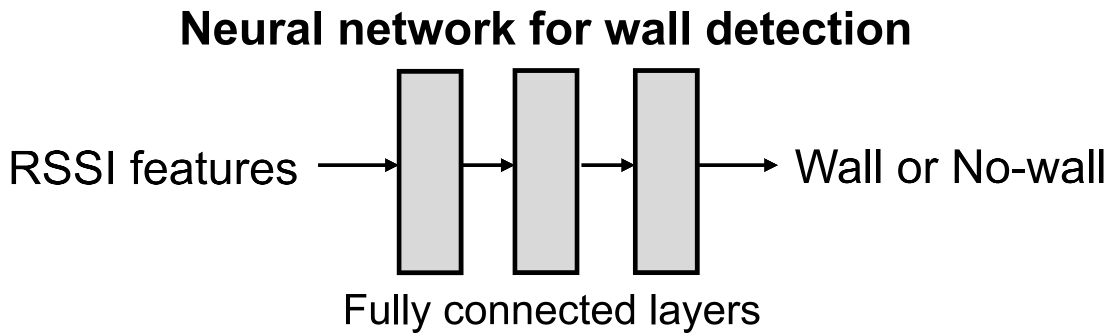
Feature extraction

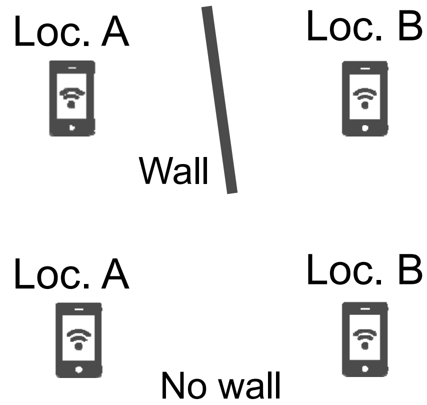
- Compute <u>Wi-Fi distances</u> using Wi-Fi vectors for the 2.4 GHz signals
  - Compute MAE, MSE, Euclidean, Minkowski, Chebyshev distance
    - Using only useful APs

Method: Wall detection

Construct a binary classifier based on a neural network

- Estimate whether or not there are walls between two locations



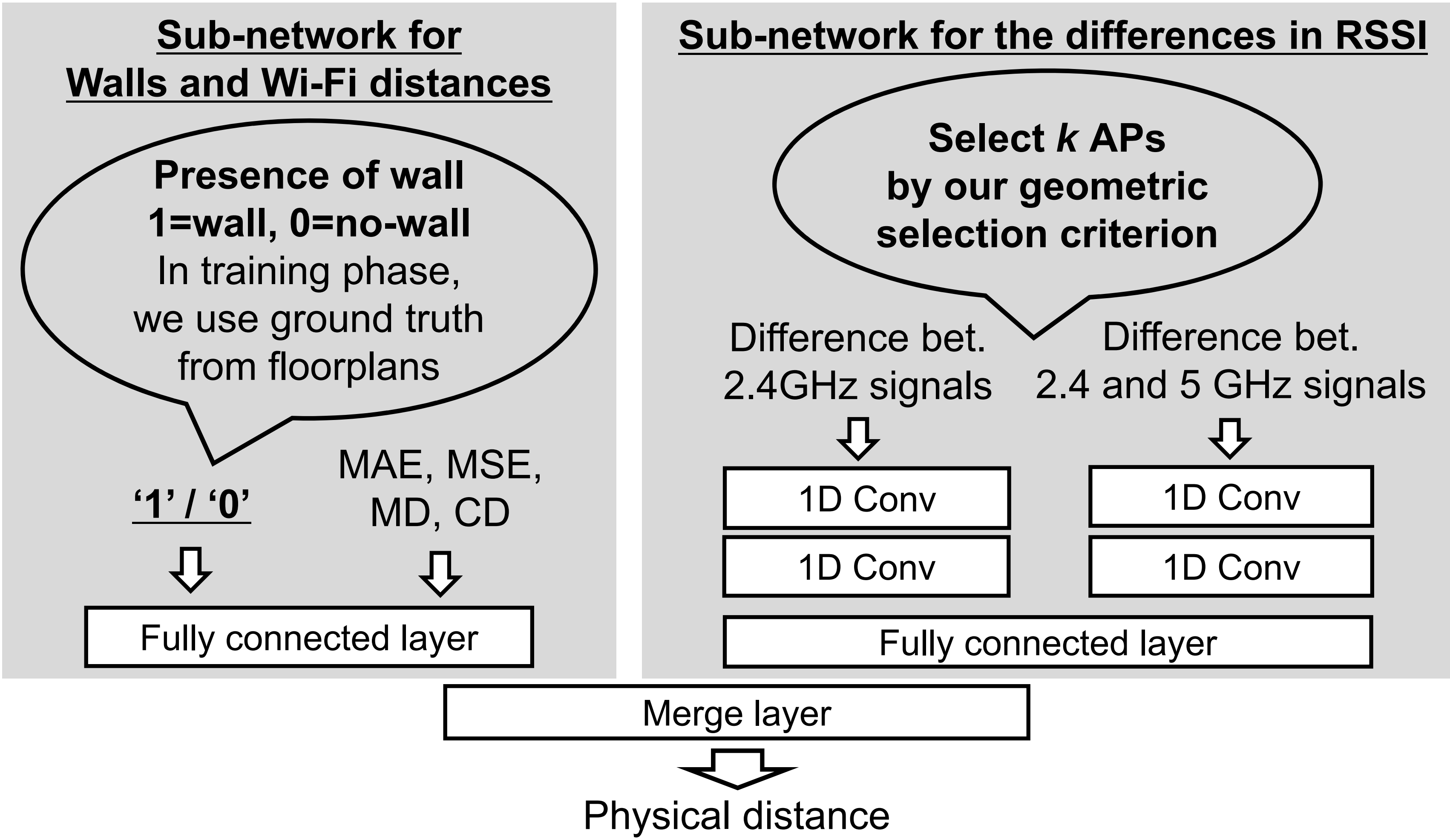


<u>Inputs</u> for the networks

- Difference between 2.4 and 5 GHz RSSI for selected k_d dual-band APs(k_d=3)
  - Select according to our usefulness of APs
- Difference in RSSI of selected k APs (k=10) between two locations
- MAE
- Variance ratio
  - Compute the variance ratio of the two locations for k APs (k=10)

Method: Distance estimation

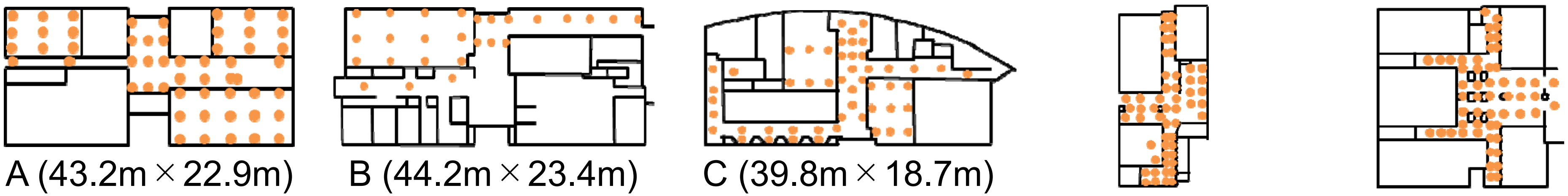
Neural network for distance estimation consists of two sub-networks



Evaluation: Dataset and Methodology

- Dataset: Five different buildings in our university

Env	# locations	# 2.4GHz APs	# dualband APs	avg. distance[m]	max distance[m]	min distance[m]	# instances
A	54	81	17	11.68	37.15	0.26	396
B	26	44	13	11.91	41.26	2.75	152
C	51	71	17	10.90	27.70	1.40	184
D	53	33	5	9.94	22.09	1.14	348
E	54	29	2	10.24	25.27	0.96	884



A (43.2m × 22.9m) B (44.2m × 23.4m) C (39.8m × 18.7m) D (13.7m × 28.0m) E (30.5m × 28.0m)

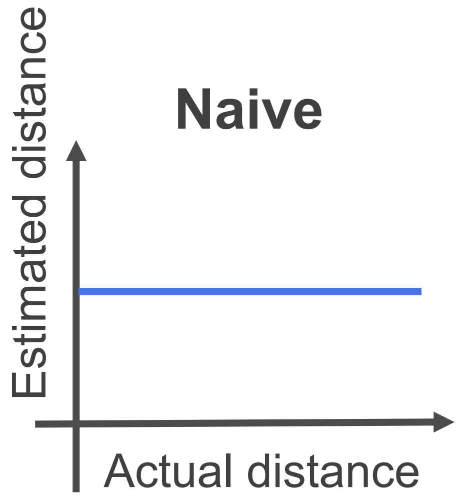
The locations where we collected Wi-Fi data

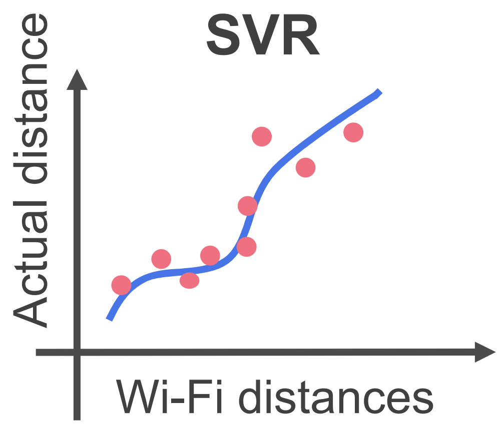
- Methodology
  - Estimate the distance between each pair of two locations
  - Use “leave-one-environment-out” cross validation
  - Evaluate using MAE between predictions and ground truth

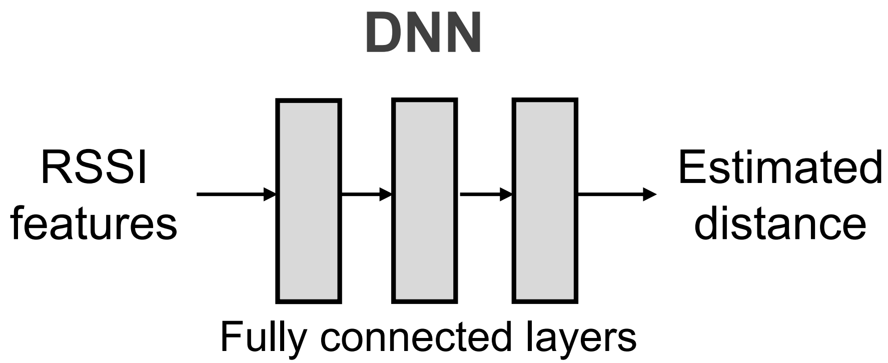
Evaluation: Comparative method

We prepared three comparative method

- **Naïve**
  - Simply estimates the distance using average distance for training data
- **SVR**
  - Employ support vector regression (SVR)
  - Wi-Fi distances are used as input features
- **DNN**
  - Neural network consisting of three layers
  - <u>Inputs are the same as proposed method except a feature for the presence of walls</u>





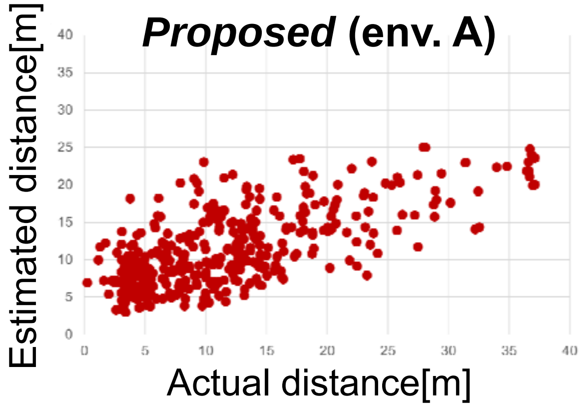


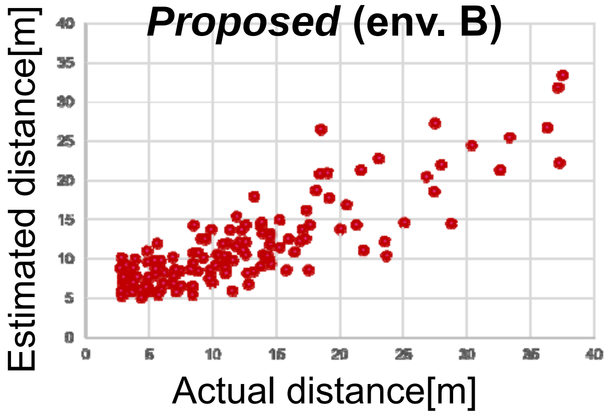
Results: Distance estimation performance

- Results of the Galaxy Nexus
  - ***Proposed*** reduced avg.MAE by about 15% from DNN
  - In other devices (Nexus 7, Nexus 6P), ***Proposed*** also achieved good results (about 10%)

	env. A	B	C	D	E	avg. MAE	avg. MAE @20m
Naïve	6.09	6.28	5.35	4.65	4.86	5.44	4.48
SVR	5.12	4.95	4.19	4.10	4.13	4.50	3.82
DNN	5.16	4.46	3.85	4.07	4.68	4.44	3.82
Proposed	**4.56**	**3.44**	**3.29**	**3.70**	**3.46**	**3.69**	**3.26**

※MAE@20m: MAE using only pairs of locations whose actual distances are smaller than 20m





Results: Wall detection performance

- The Wall detection accuracies of three devices
  - The accuracies for environments A, B, C are high, but D, E are poor, which could be because walls in D, E are thin and few dual-band APs

	env. A	B	C	D	E
Galaxy Nexus	0.76	0.74	0.82	0.63	0.65
Nexus 7	0.83	0.82	0.74	0.71	0.55
Nexus 6P	0.74	0.75	0.77	0.50	0.61

Conclusion

We presented the new task of
estimating the physical distance between two locations using Wi-Fi data observed at the two locations

- Designed to precisely estimate the distance taking into account **obstacles** between the two locations

- Future work
  - Plan to design a new neural network based on recurrent neural network enables us to input signal information from arbitrary numbers of APs