Wi-Fi Indoor Positioning System (IPS)

based on

Trilateration Technique + K-Nearest Neighbor Algorithm

STAT 4/510: Basic Consulting Skills

Group: Go With the Flow

Table of Content

1

Introduction

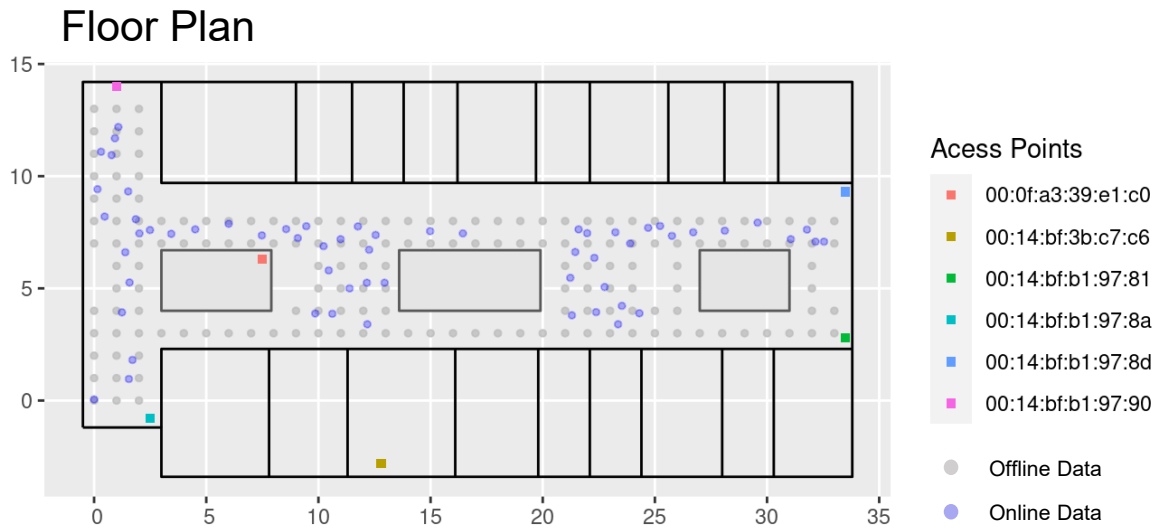
Overview

Problem

Identify the physical location of devices that are connected to the network.

Goal

- Create a model that takes a set of signal strengths of the relevant access points to a connected device.
- Predicts the physical location of that device.
- Quantify the accuracy and precision of the model.



Data Set

Raw Data

```
# timestamp=2006-02-11 08:31:58
# usec=250
# minReadings=110
t=1139643118358;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-38,2437000000,3;00:14:bf:b1:97:90=-56,2427000000,3;00:0f:a3:39:e1:c0=-53,2462000000,3;00:14:bf:b1:9
t=1139643118744;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-38,2437000000,3;00:0f:a3:39:e1:c0=-54,2462000000,3;00:14:bf:b1:97:90=-56,2427000000,3;00:14:bf:3b:c
t=1139643119002;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-38,2437000000,3;00:0f:a3:39:e1:c0=-54,2462000000,3;00:14:bf:b1:97:90=-57,2427000000,3;00:14:bf:b1:9
t=1139643119263;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-38,2437000000,3;00:14:bf:b1:97:90=-52,2427000000,3;00:0f:a3:39:e1:c0=-54,2462000000,3;00:14:bf:b1:9
t=1139643119538;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-46,2437000000,3;00:0f:a3:39:e1:c0=-55,2462000000,3;00:14:bf:b1:97:90=-57,2427000000,3;00:14:bf:3b:c
t=1139643119818;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-37,2437000000,3;00:0f:a3:39:e1:c0=-54,2462000000,3;00:14:bf:b1:97:81=-65,2422000000,3;00:14:bf:b1:9
t=1139643120075;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-38,2437000000,3;00:0f:a3:39:e1:c0=-54,2462000000,3;00:14:bf:b1:97:90=-56,2427000000,3;00:14:bf:b1:9
t=1139643120335;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:90=-55,2427000000,3;00:0f:a3:39:e1:c0=-55,2462000000,3;00:14:bf:3b:c7:c6=-65,2432000000,3;00:14:bf:b1:9
t=1139643120587;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-46,2437000000,3;00:0f:a3:39:e1:c0=-55,2462000000,3;00:14:bf:b1:97:90=-57,2427000000,3;00:14:bf:b1:9
t=1139643120851;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-39,2437000000,3;00:0f:a3:39:e1:c0=-53,2462000000,3;00:14:bf:b1:97:90=-57,2427000000,3;00:14:bf:b1:9
t=1139643121115;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-43,2437000000,3;00:0f:a3:39:e1:c0=-50,2462000000,3;00:14:bf:b1:97:90=-56,2427000000,3;00:14:bf:b1:9
t=1139643121375;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:90=-56,2427000000,3;00:0f:a3:39:e1:c0=-51,2462000000,3;00:14:bf:3b:c7:c6=-66,2432000000,3;00:14:bf:b1:9
t=1139643121627;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:0f:a3:39:e1:c0=-51,2462000000,3;00:14:bf:b1:97:90=-56,2427000000,3;00:14:bf:b1:97:8d=-66,2442000000,3;00:14:bf:3b:c
t=1139643121879;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-43,2437000000,3;00:0f:a3:39:e1:c0=-51,2462000000,3;00:14:bf:b1:97:90=-55,2427000000,3;00:14:bf:b1:9
t=1139643122135;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:0f:a3:39:e1:c0=-51,2462000000,3;00:14:bf:b1:97:8d=-66,2442000000,3;00:0f:a3:39:dd:cd=-66,2412000000,3;00:14:bf:b1:9
t=1139643122387;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:0f:a3:39:e1:c0=-52,2462000000,3;00:14:bf:b1:97:90=-56,2427000000,3;00:14:bf:3b:c7:c6=-68,2432000000,3;00:14:bf:b1:9
t=1139643122647;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-42,2437000000,3;00:0f:a3:39:e1:c0=-50,2462000000,3;00:14:bf:b1:97:90=-57,2427000000,3;00:14:bf:b1:9
t=1139643122899;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:0f:a3:39:e1:c0=-51,2462000000,3;00:14:bf:b1:97:90=-55,2427000000,3;00:14:bf:3b:c7:c6=-66,2432000000,3;00:14:bf:b1:9
t=1139643123151;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-39,2437000000,3;00:0f:a3:39:e1:c0=-50,2462000000,3;00:14:bf:b1:97:90=-57,2427000000,3;00:14:bf:3b:c
t=1139643123403;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-38,2437000000,3;00:0f:a3:39:e1:c0=-51,2462000000,3;00:14:bf:3b:c7:c6=-67,2432000000,3;00:14:bf:3b:c
t=1139643123671;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-38,2437000000,3;00:0f:a3:39:e1:c0=-52,2462000000,3;00:14:bf:b1:97:90=-58,2427000000,3;00:14:bf:b1:9
t=1139643123923;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-39,2437000000,3;00:0f:a3:39:e1:c0=-51,2462000000,3;00:14:bf:3b:c7:c6=-66,2432000000,3;00:0f:a3:39:e
```

Cleaned Data

	timeStamp	posX	posY	orientation	MAC	RSSI	angle	direction	posXY	medSignal	avgSignal	num	sdSignal	iqrSignal	apX	apY	dist
1	2006-02-11 07:31:58	0	0	0.0	00:0fa3:39:e1:c0	-53	0	E→	0, 0	-51.0	-51.15455	110	1.4089254	2.00	7.5	6.3	9.7948966
2	2006-02-11 08:03:44	0	1	0.7	00:0fa3:39:e1:c0	-49	0	E→	0, 1	-51.0	-50.57273	110	2.1986614	3.00	7.5	6.3	9.1836812
3	2006-02-11 11:46:02	0	10	0.9	00:0fa3:39:e1:c0	-53	0	E→	0, 10	-56.0	-56.20000	110	1.1235592	1.00	7.5	6.3	8.3630138
4	2006-02-11 11:54:05	0	11	0.4	00:0fa3:39:e1:c0	-53	0	E→	0, 11	-53.0	-54.68182	110	3.4212821	7.00	7.5	6.3	8.8509886
5	2006-02-11 12:02:32	0	12	0.2	00:0fa3:39:e1:c0	-54	0	E→	0, 12	-55.0	-56.60000	110	3.5612594	7.75	7.5	6.3	9.4201911
6	2006-02-11 12:14:12	0	13	0.1	00:0fa3:39:e1:c0	-57	0	E→	0, 13	-57.0	-56.83636	110	1.4240868	1.00	7.5	6.3	10.0568385
7	2006-02-11 08:26:28	0	2	0.3	00:0fa3:39:e1:c0	-58	0	E→	0, 2	-60.0	-59.95455	110	2.6626412	4.00	7.5	6.3	8.6452299
8	2006-02-11 08:47:06	0	3	0.2	00:0fa3:39:e1:c0	-53	0	E→	0, 3	-55.0	-55.53636	110	2.1786170	3.00	7.5	6.3	8.1939002
9	2006-02-11 09:05:57	0	4	0.5	00:0fa3:39:e1:c0	-48	0	E→	0, 4	-47.0	-48.09091	110	2.6769333	5.00	7.5	6.3	7.8447435
10	2006-02-11 11:22:44	0	7	0.3	00:0fa3:39:e1:c0	-58	0	E→	0, 7	-57.0	-57.30000	110	2.0116632	2.00	7.5	6.3	7.5325958
11	2006-02-11 11:31:51	0	8	0.7	00:0fa3:39:e1:c0	-50	0	E→	0, 8	-48.0	-49.77273	110	5.8225425	3.00	7.5	6.3	7.6902536
12	2006-02-11 11:38:04	0	9	0.3	00:0fa3:39:e1:c0	-59	0	E→	0, 9	-49.0	-50.99091	110	4.5443693	2.00	7.5	6.3	7.9711982
13	2006-02-11 07:46:17	1	0	0.0	00:0fa3:39:e1:c0	-45	0	E→	1, 0	-50.0	-48.59091	110	2.9717182	5.00	7.5	6.3	9.0520716
14	2006-02-11 08:11:49	1	1	0.4	00:0fa3:39:e1:c0	-60	0	E→	1, 1	-52.0	-54.00909	110	7.2104606	3.00	7.5	6.3	8.3868945
15	2006-02-11 10:31:54	1	10	0.1	00:0fa3:39:e1:c0	-56	0	E→	1, 10	-61.0	-59.52294	109	2.7941617	5.00	7.5	6.3	7.4793048

Fingerprinting

About

In position estimation, the prior collected and stored measurements of the environment are called **fingerprints**.

The process of collecting signal strength (RSSI) values from the signal transmitter (e.g., smart devices) is called the **offline stage**.

The offline stage creates the foundation for the **online stage**, where a detectable object is placed in the environment to create fingerprints from nearby devices.

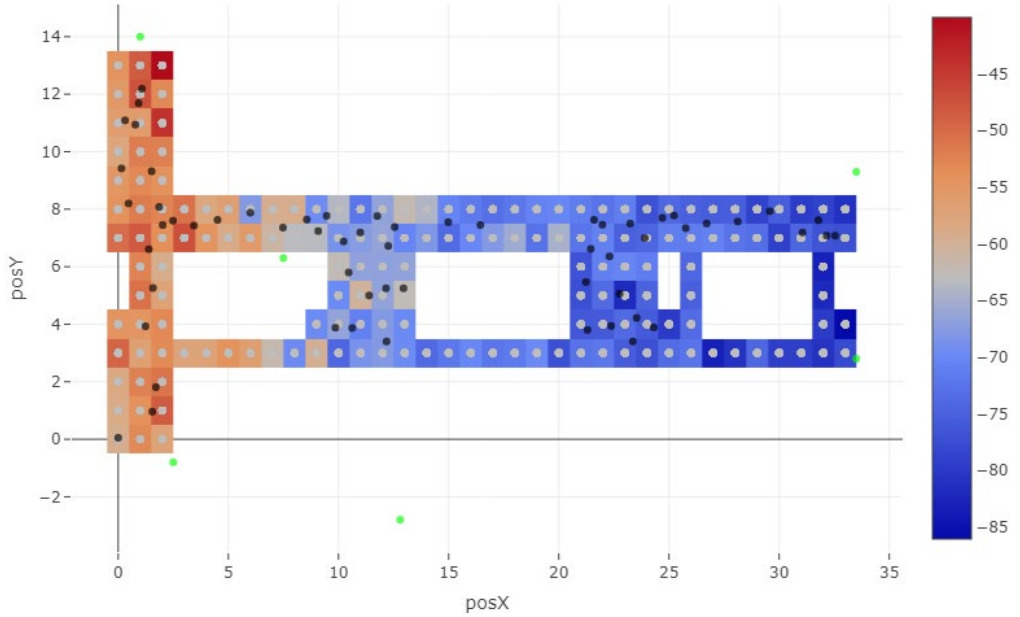
Advantages

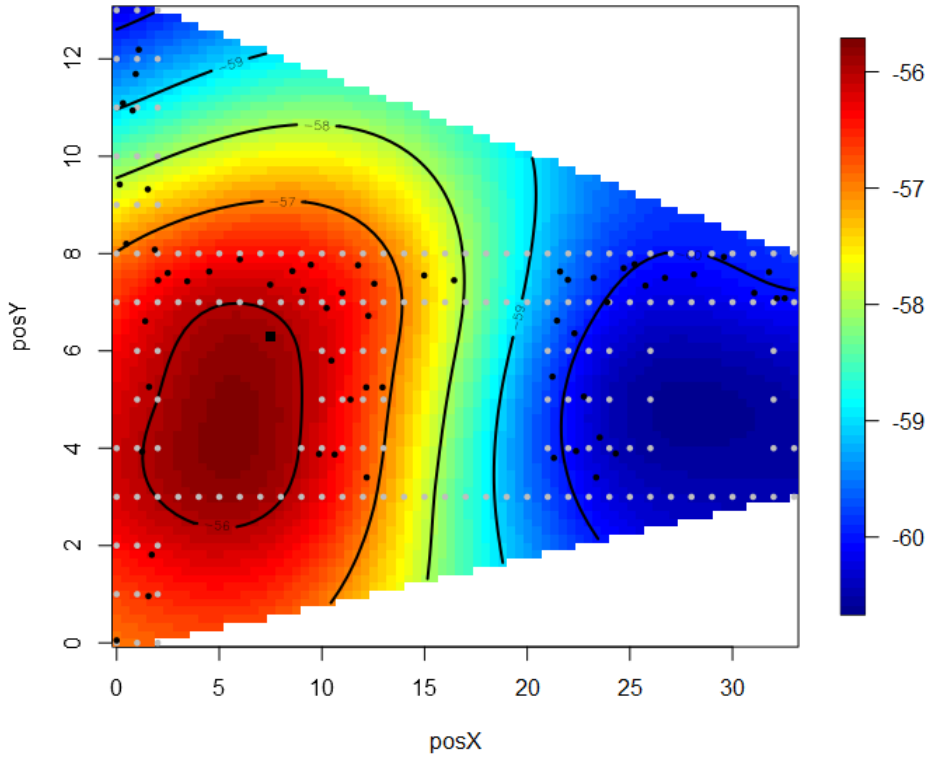
- Relatively good accuracy is achievable provided that fingerprints are available for small distance intervals.
- Fingerprinting technique is not as vulnerable as radio signal phenomena.

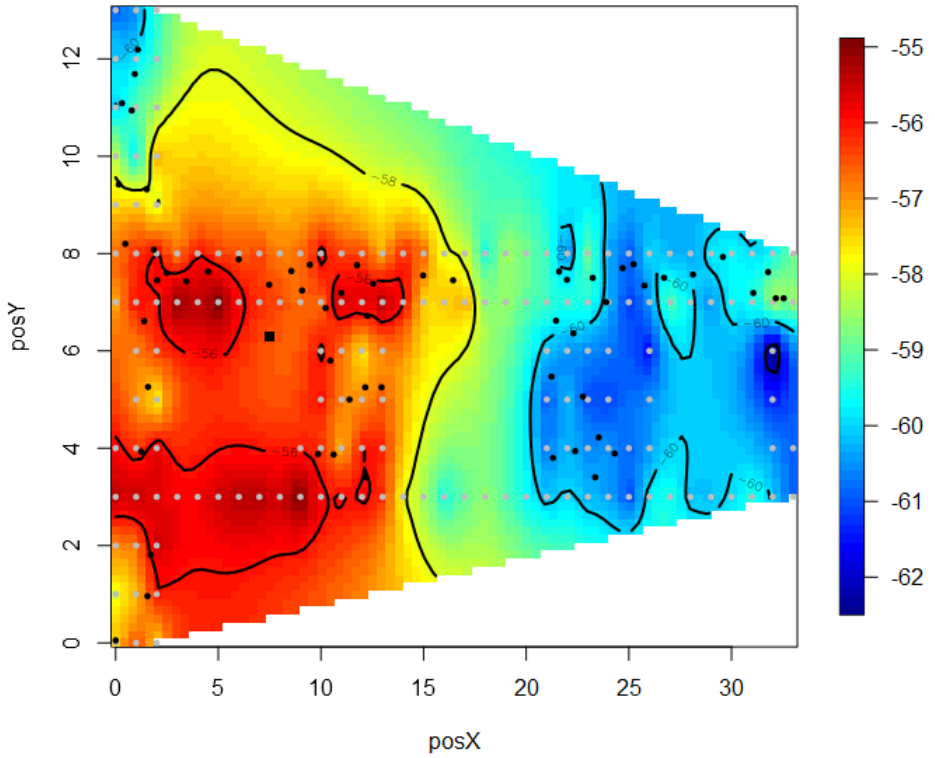
Disadvantages

- Accuracy decreases as signal propagates or changes throughout the space.
- The offline phase may be time consuming and may need to be conducted periodically due to environmental changes.

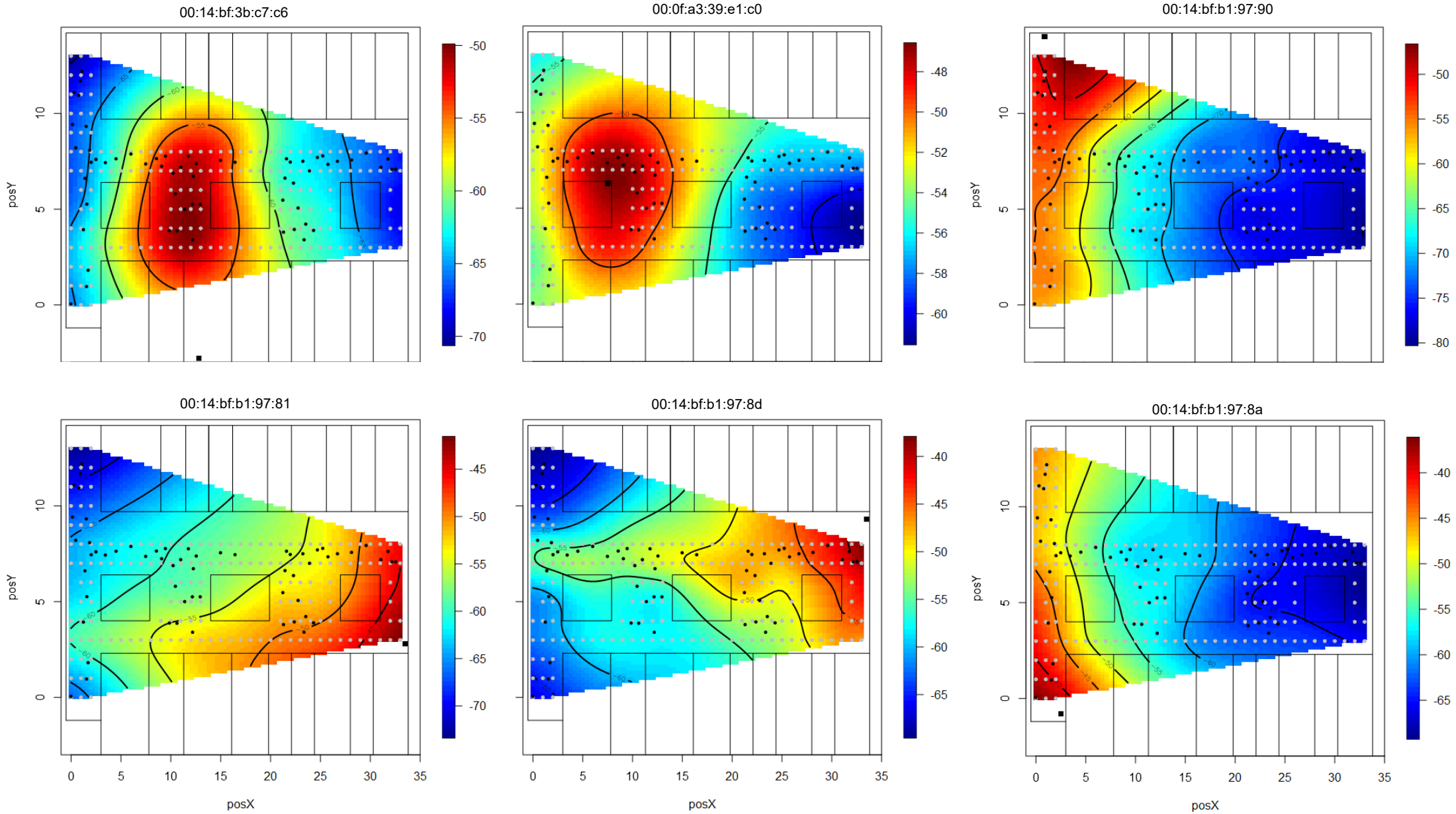
RSSI Heat Map







RSSI Heat Map

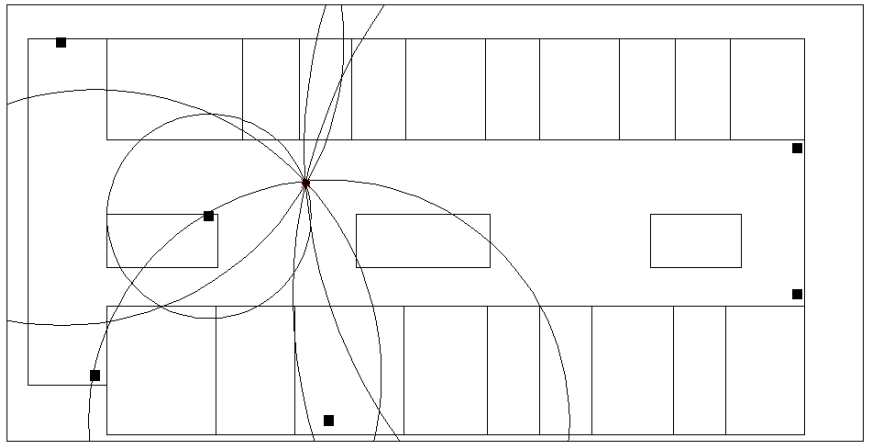


Approaches

Trilateration Technique

Position estimation based on measurements and distance estimates from three (or more) signal transmitters

Uses linear models to estimate distance and minimizes distance error.



Nearest Neighbors Technique

Position estimation based on RSSI value of an online fingerprint matching with closest neighbors of offline fingerprints.

The position of the device is then estimated to be the corresponding position of the fingerprint in the offline data having the smallest distance.

Applications

In the Public

- Emergency services
- Indoor map
- Route information, etc.

In the Industry

- Using closest resource in the enterprise
- Privileges based on security regions
- Enhanced 911 (E911) services, etc.

In the Military

- Identification/segregation
- Indoor mapping
- Indoor striking mission, etc.

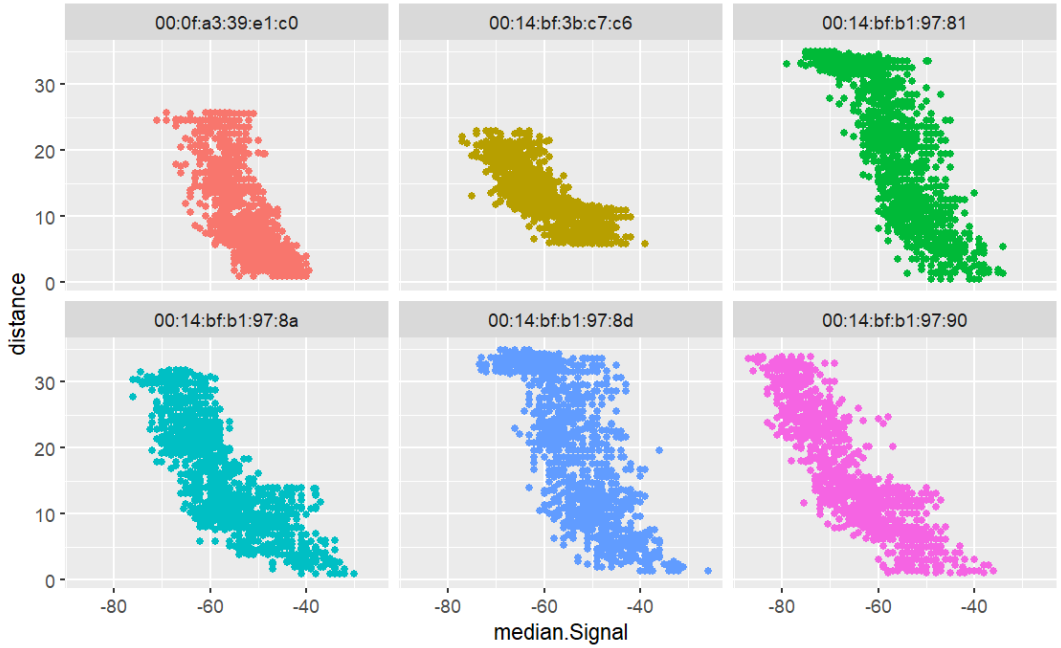
2

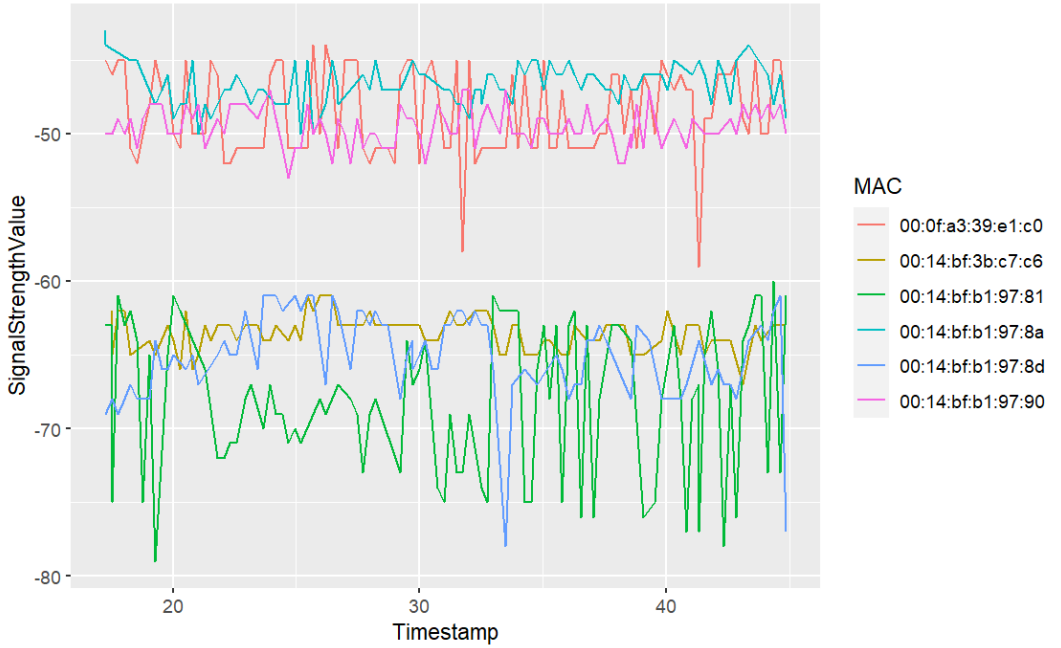
Trilateration Technique

About

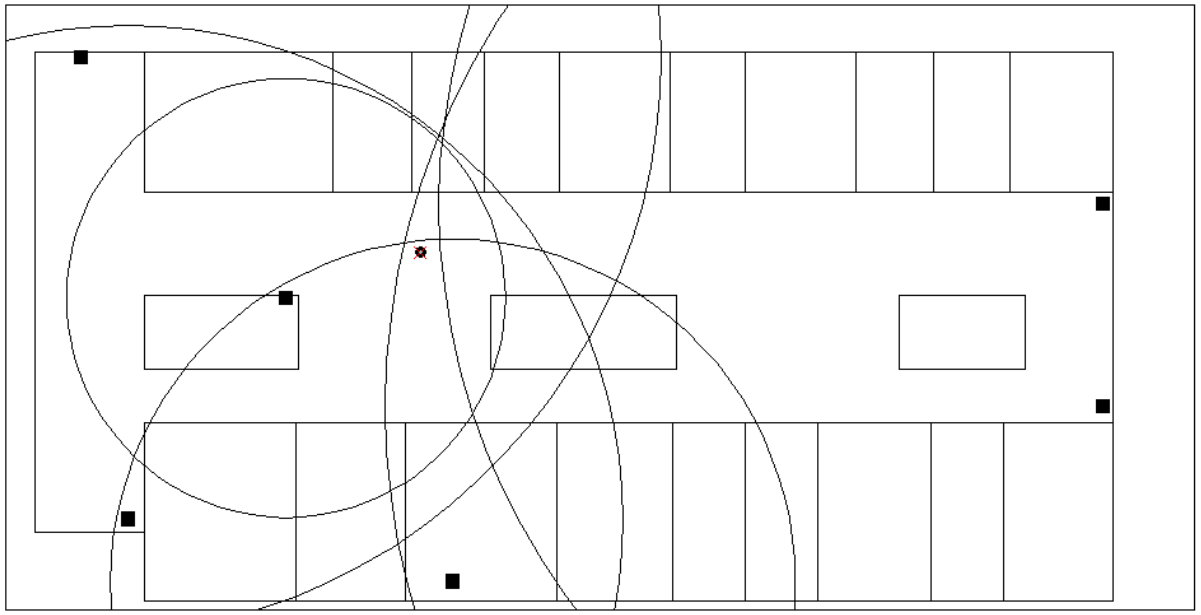
Trilateration/Multilateration

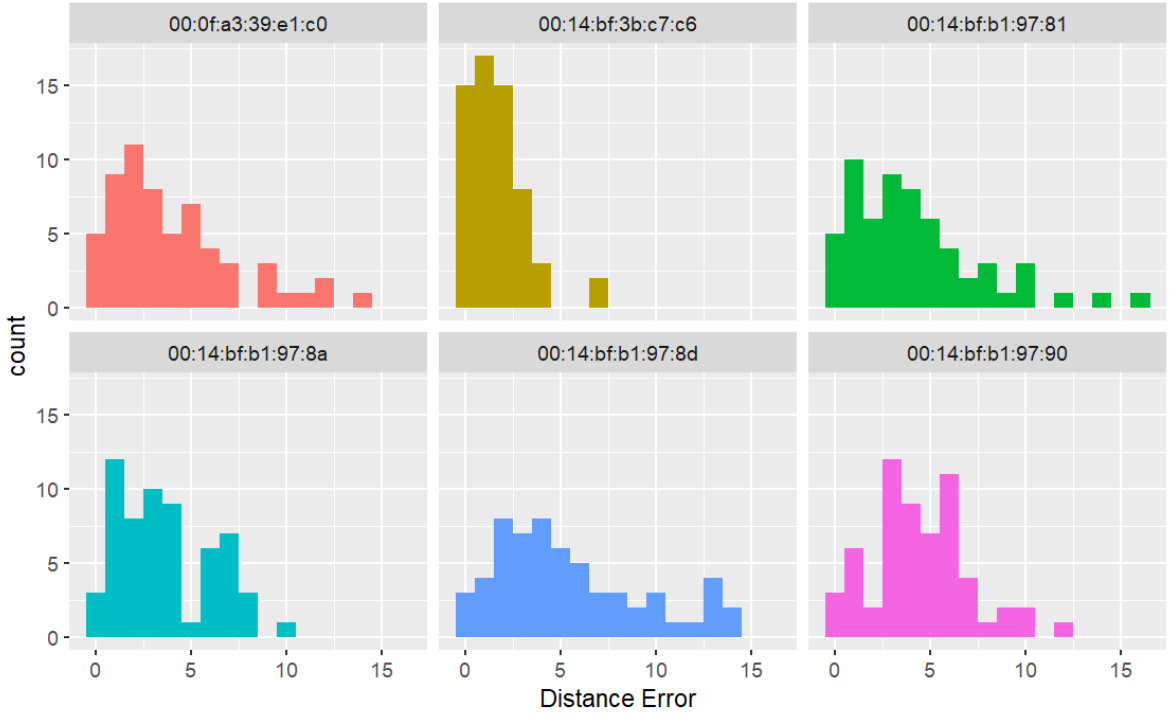
- Signal Strength → Estimated Distances → Estimated location
- Simple Linear Model (per MAC address) to estimate distance from Signal Strength
- Optimization algorithm; takes estimated distances, minimizes sum square errors for x or y position





Visualizations





Comparison

Advantages

- Trilateration only requires relatively few computations for position estimation.
- The Trilateration approach generally does not require a comprehensive offline stage.
- No data storage is required other than knowing the location of the signal transmitter.
- The Trilateration algorithms hold potential for estimating precise positions which are not constrained by some predefined granularity.

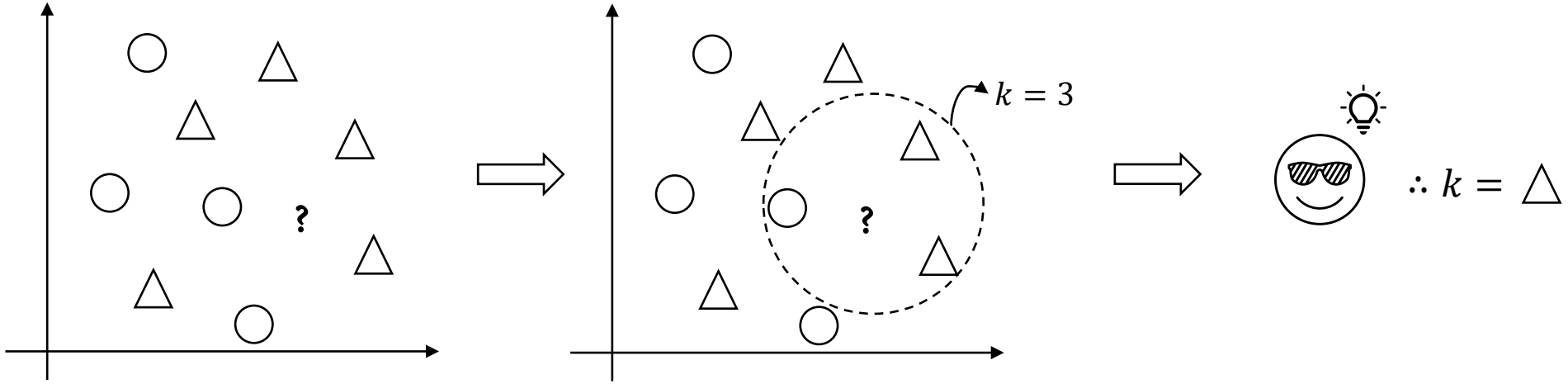
Disadvantages

- The techniques using time stamps, require special-purpose hardware such that these can be measured precisely.
- The algorithms are vulnerable to radio propagation phenomena like multipath fading, which may result in signals propagating in an indirect line from transmitter to receiver
- If the environment changes significantly, the radio propagation model must be recalibrated.

3

K-Nearest Neighbor (KNN) Algorithm

About



PosX	PosY	Angle	AP1	AP2	AP3	…	AP6
X_1	Y_1	A_1	$RSSI_{11}$	$RSSI_{12}$	$RSSI_{13}$	$RSSI_{...}$	$RSSI_{16}$
X_2	Y_2	A_2	$RSSI_{21}$	$RSSI_{22}$	$RSSI_{23}$	$RSSI_{...}$	$RSSI_{26}$
X_3	Y_3	A_3	$RSSI_{31}$	$RSSI_{32}$	$RSSI_{33}$	$RSSI_{...}$	$RSSI_{36}$
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Online Data

AP	RSSI	PosX	PosY	Angle
AP1	$RSSI_1$	X_1	Y_1	A_1
AP1	$RSSI_2$	X_2	Y_2	A_2
AP1	$RSSI_3$	X_3	Y_3	A_2
AP2	$RSSI_4$	X_3	Y_3	A_2
⋮	⋮	⋮	⋮	⋮

Offline Data

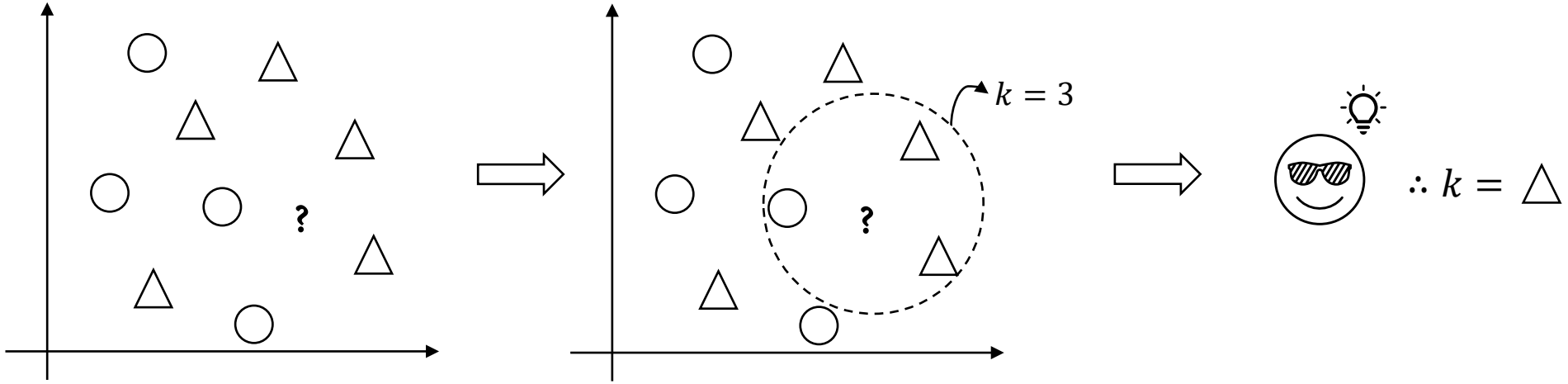
For $k = 1$

X_1	Y_1

||

X_1	Y_1

About



PosX	PosY	Angle	AP1	AP2	AP3	…	AP6
X_1	Y_1	A_1	$RSSI_{11}$	$RSSI_{12}$	$RSSI_{13}$	$RSSI_{...}$	$RSSI_{16}$
X_2	Y_2	A_2	$RSSI_{21}$	$RSSI_{22}$	$RSSI_{23}$	$RSSI_{...}$	$RSSI_{26}$
X_3	Y_3	A_3	$RSSI_{31}$	$RSSI_{32}$	$RSSI_{33}$	$RSSI_{...}$	$RSSI_{36}$
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Online Data

AP	RSSI	PosX	PosY	Angle
AP1	$RSSI_1$	X_1	Y_1	A_1
AP1	$RSSI_2$	X_2	Y_2	A_1
AP1	$RSSI_3$	X_3	Y_3	A_1
AP2	$RSSI_4$	X_3	Y_3	A_2
⋮	⋮	⋮	⋮	⋮

Offline Data

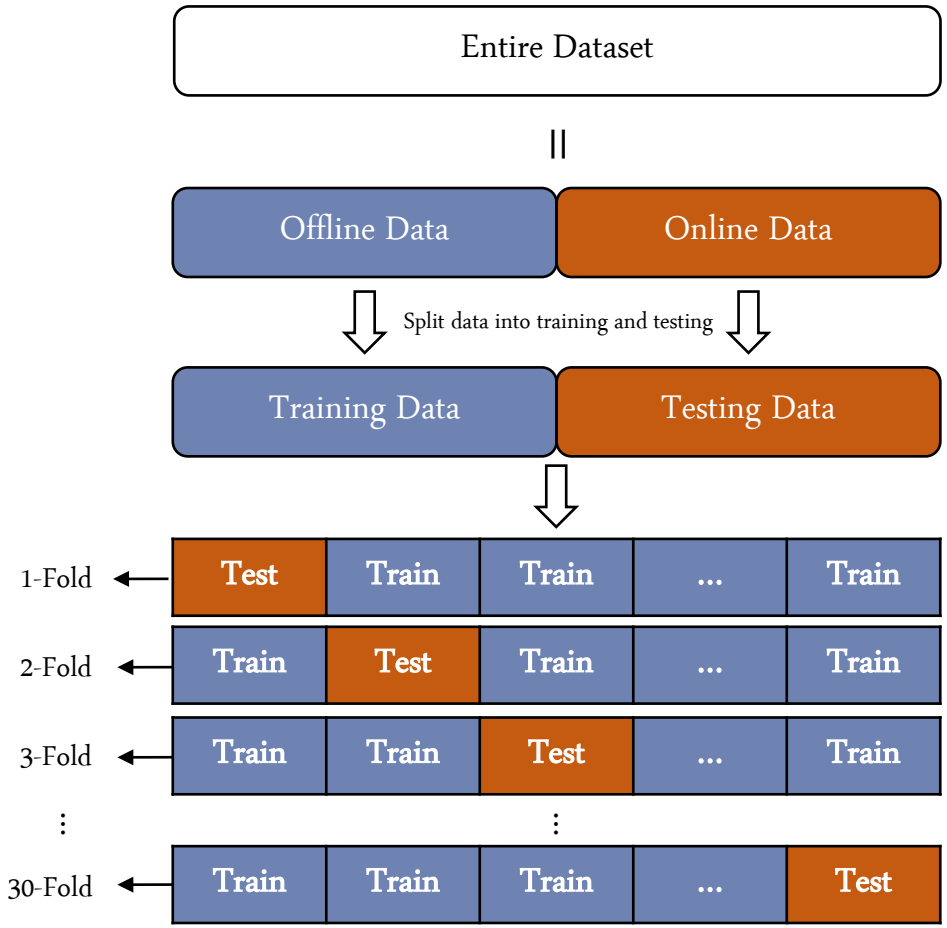
For $k = 1$

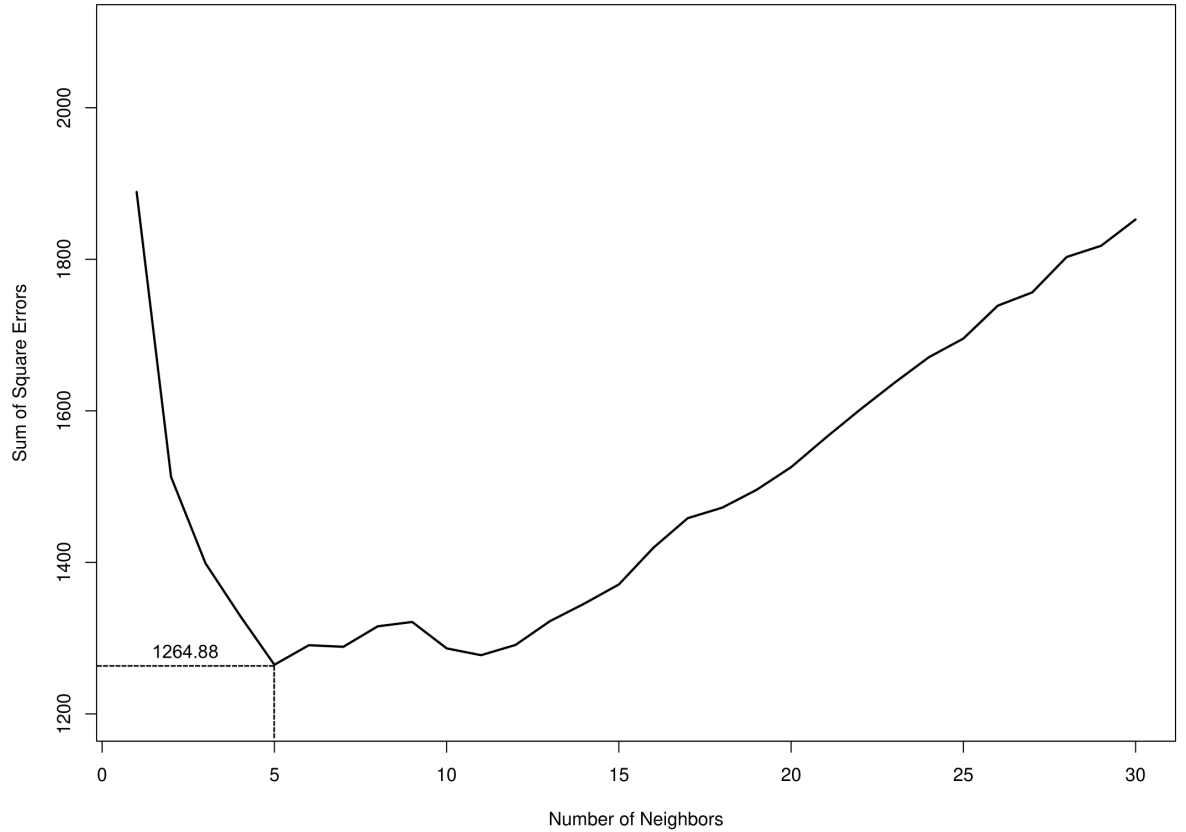
X_1	Y_1

X_1	Y_1
X_2	Y_2
X_3	Y_3

$$(x_1, y_1) = \min\left(\sqrt{(RSSI_i - RSSI_{11})^2}\right)$$

K-fold Cross Validation

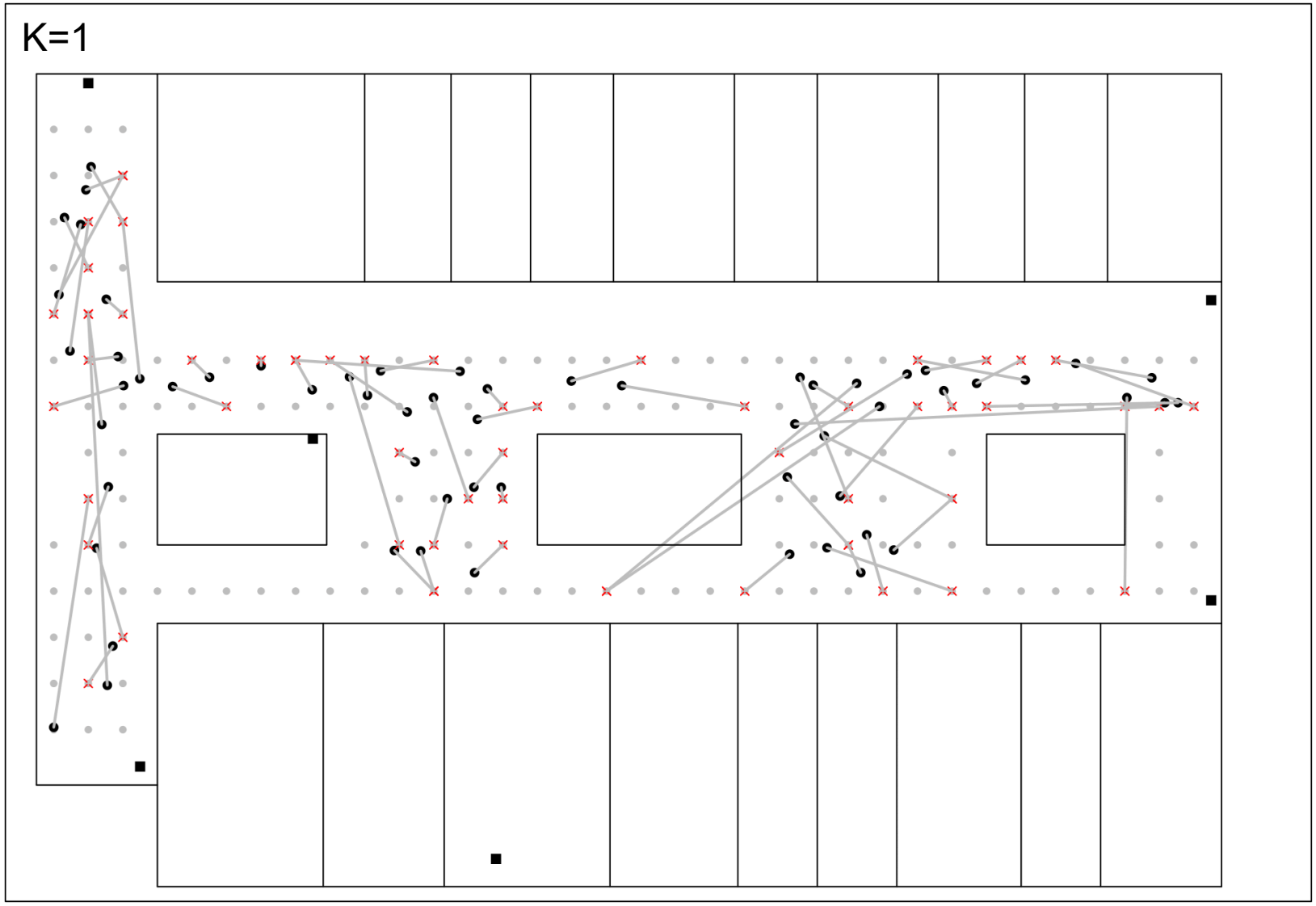




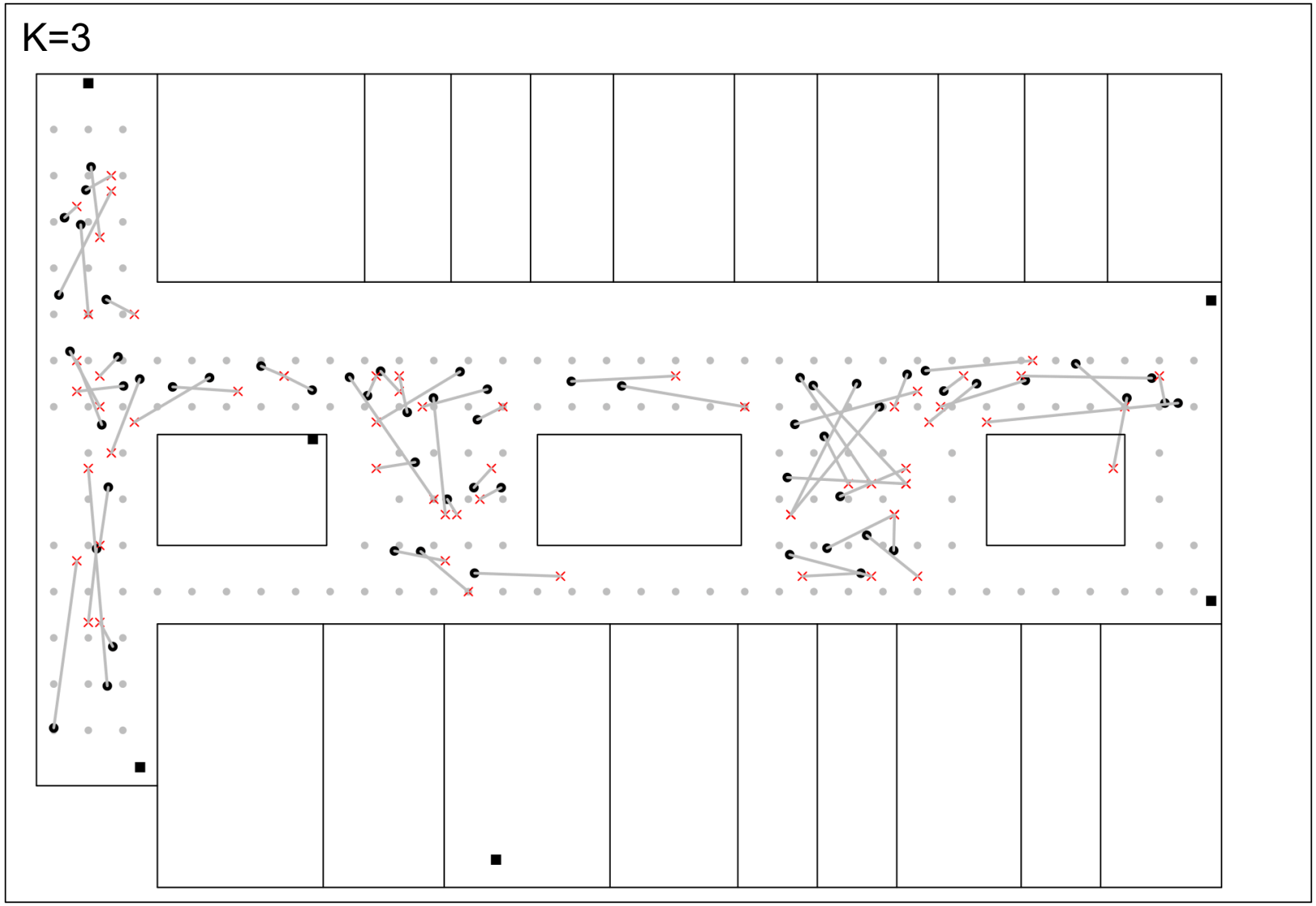
$$SSE_1(XY_{act}, XY_{est})$$
$$SSE_2(XY_{act}, XY_{est})$$
$$SSE_3(XY_{act}, XY_{est})$$
$$SSE_{30}(XY_{act}, XY_{est})$$

$$\texttt{k=which.min}\left(SSE_i(XY_{act}, XY_{est})\right), i \in \{1, 2, 3, \dots, 30\}$$

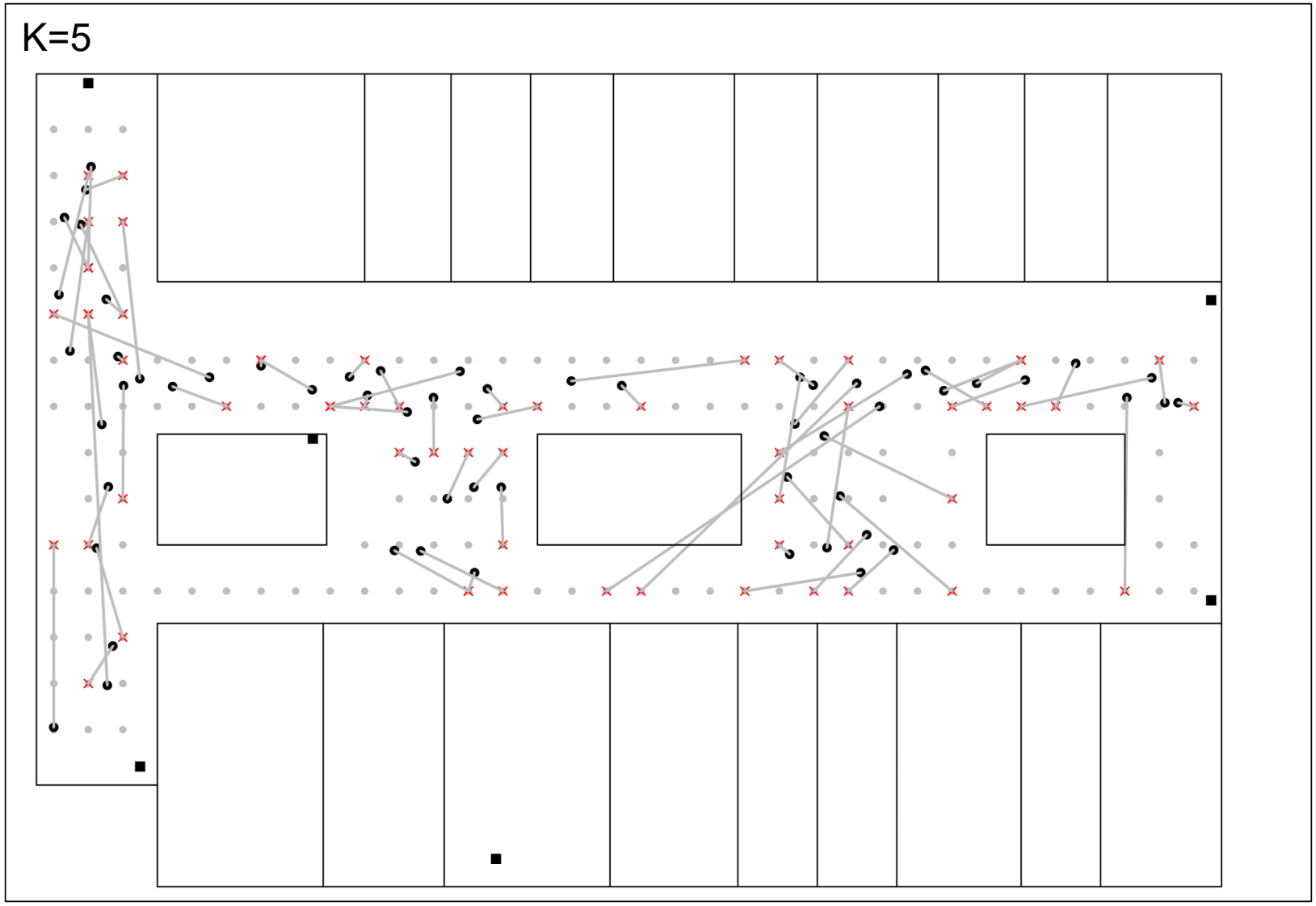
Visualizations



Visualizations



Visualizations



Comparison

Advantages

- Very flexible, data-driven
- Simple, fast training process
- Robust to noisy training data
- Effective with large amount of data, where predictor levels are well represented, has good performance

Disadvantages

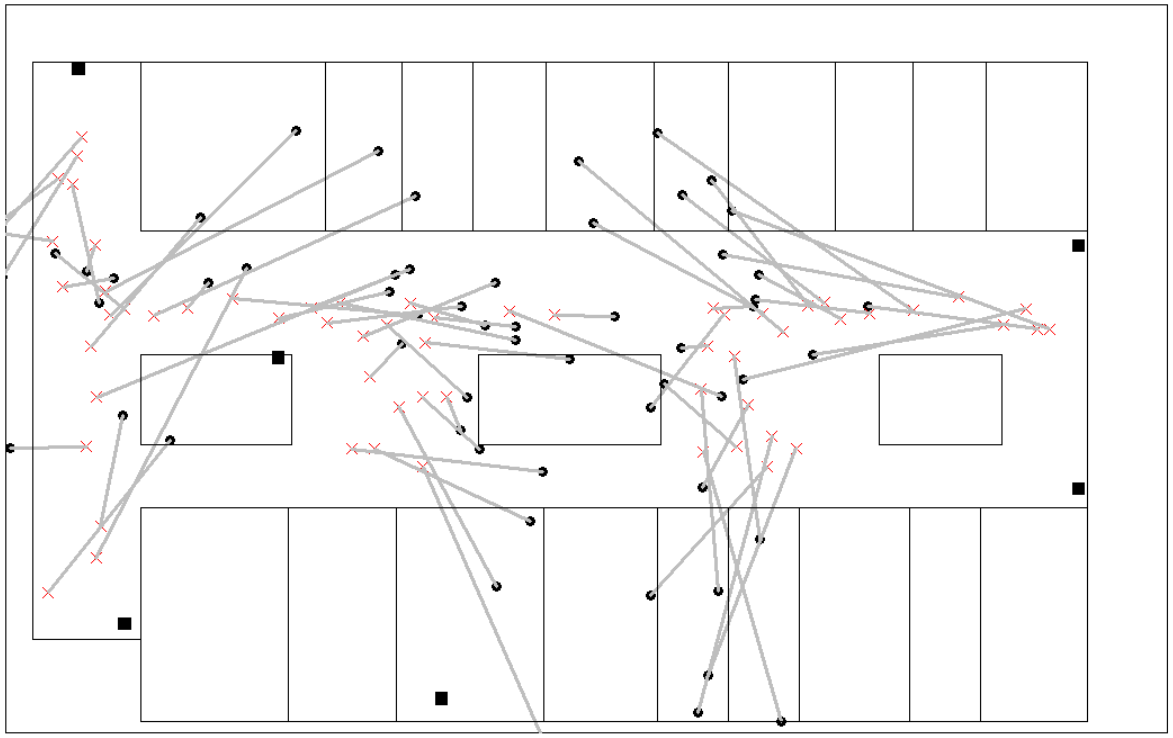
- Biased by value of *k*
- Computationally intensive for large *k*
- Runs slow being a supervised lazy learning algorithm
- Need LOTS of well-represented training data

4

Evaluation

Trilateration vs. KNN

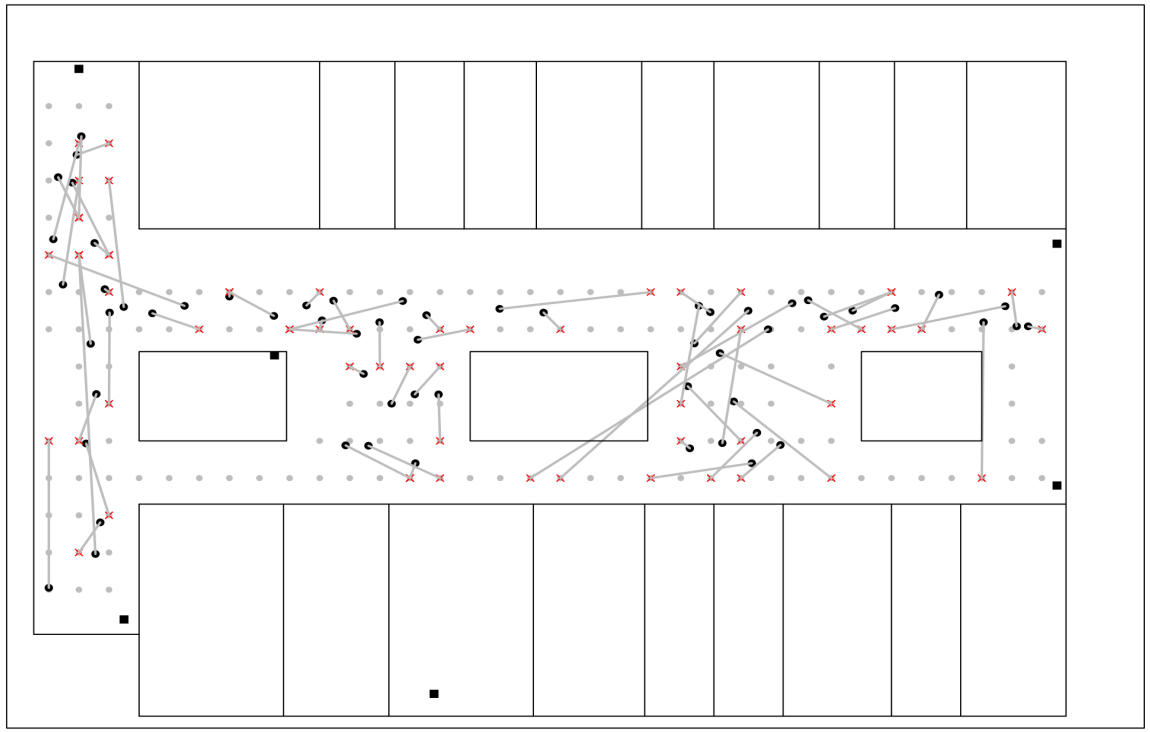
Trilateration Method



Average Error Distance: 4.832989 m

Median Error Distance: 4.955922 m

KNN Method ($k = 5$)



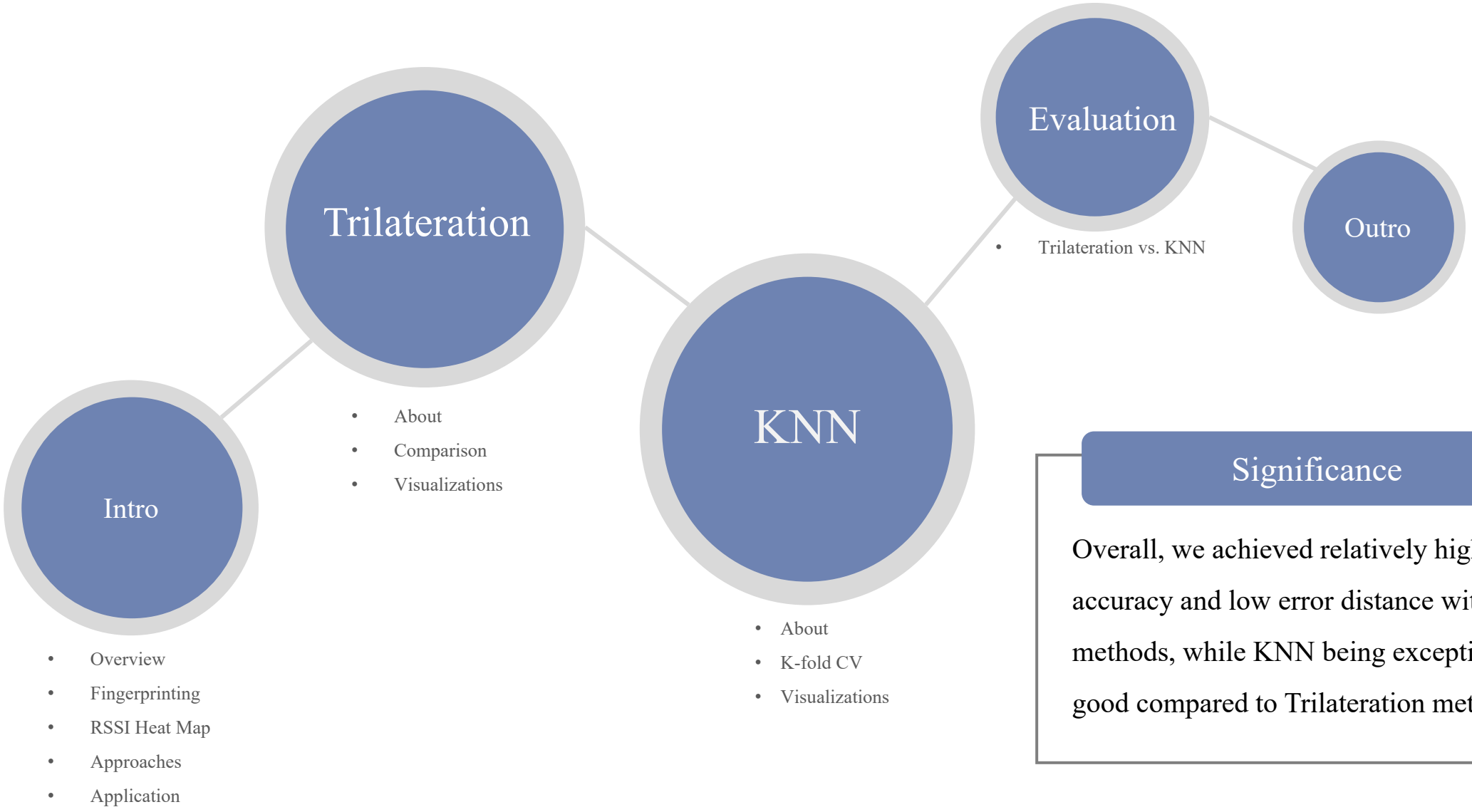
Average Error Distance: 2.517842 m

Median Error Distance: 1.902775 m

5

Conclusion

Road Map



Significance

Overall, we achieved relatively high accuracy and low error distance with both methods, while KNN being exceptionally good compared to Trilateration method.

THANKS

Questions?

Dec. 6, 2022