

Indoor Positioning System using Near Real-time Radio Maps in Fingerprinting based on Bluetooth Low Energy

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Introduction



Wireless Communication Technology



TM



ZigBee®



Bluetooth®



Bluetooth®
SMART

| | Wi-Fi | ZigBee | Bluetooth | BLE |
|--------------------------|---------------------------|----------|-----------|----------|
| Power consumption | High | Very Low | Low | Very Low |
| Deployment | Depending on existing APs | Easy | Easy | Easy |
| Supported by smartphones | Yes | No | Yes | Yes |
| Cost | High | Low | Medium | Low |

Fingerprinting

- Off-line phase
- Radio maps

Beacon

RSSI

A

-80

B

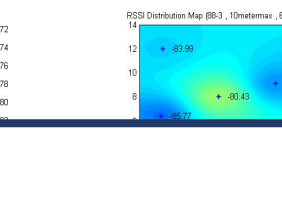
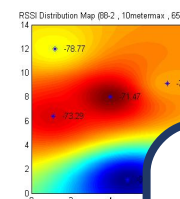
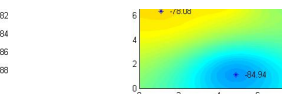
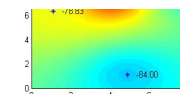
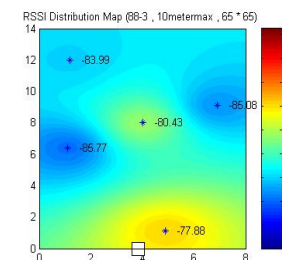
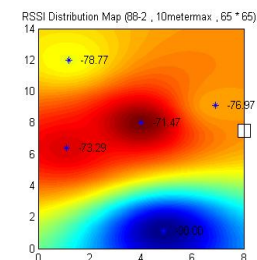
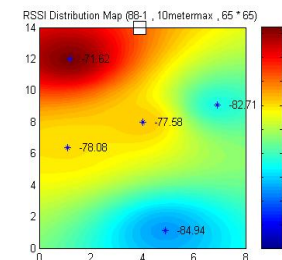
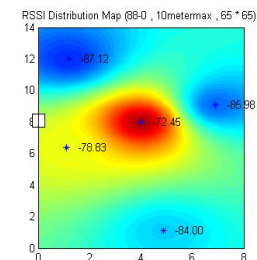
-85

C

-70

D

-89



A Beacon

Coordinate

RSSI

| A Beacon | | A Beacon | |
|------------|---------------------|------------|---------------------|
| Coordinate | RSSI | Coordinate | RSSI |
| $(x, y)_1$ | $\{RSSI_1, \dots\}$ | $(x, y)_1$ | $\{RSSI_1, \dots\}$ |
| $(x, y)_2$ | $\{RSSI_2, \dots\}$ | $(x, y)_2$ | $\{RSSI_2, \dots\}$ |
| \vdots | \vdots | \vdots | \vdots |
| $(x, y)_n$ | $\{RSSI_n, \dots\}$ | $(x, y)_n$ | $\{RSSI_n, \dots\}$ |

Motivation and Purpose

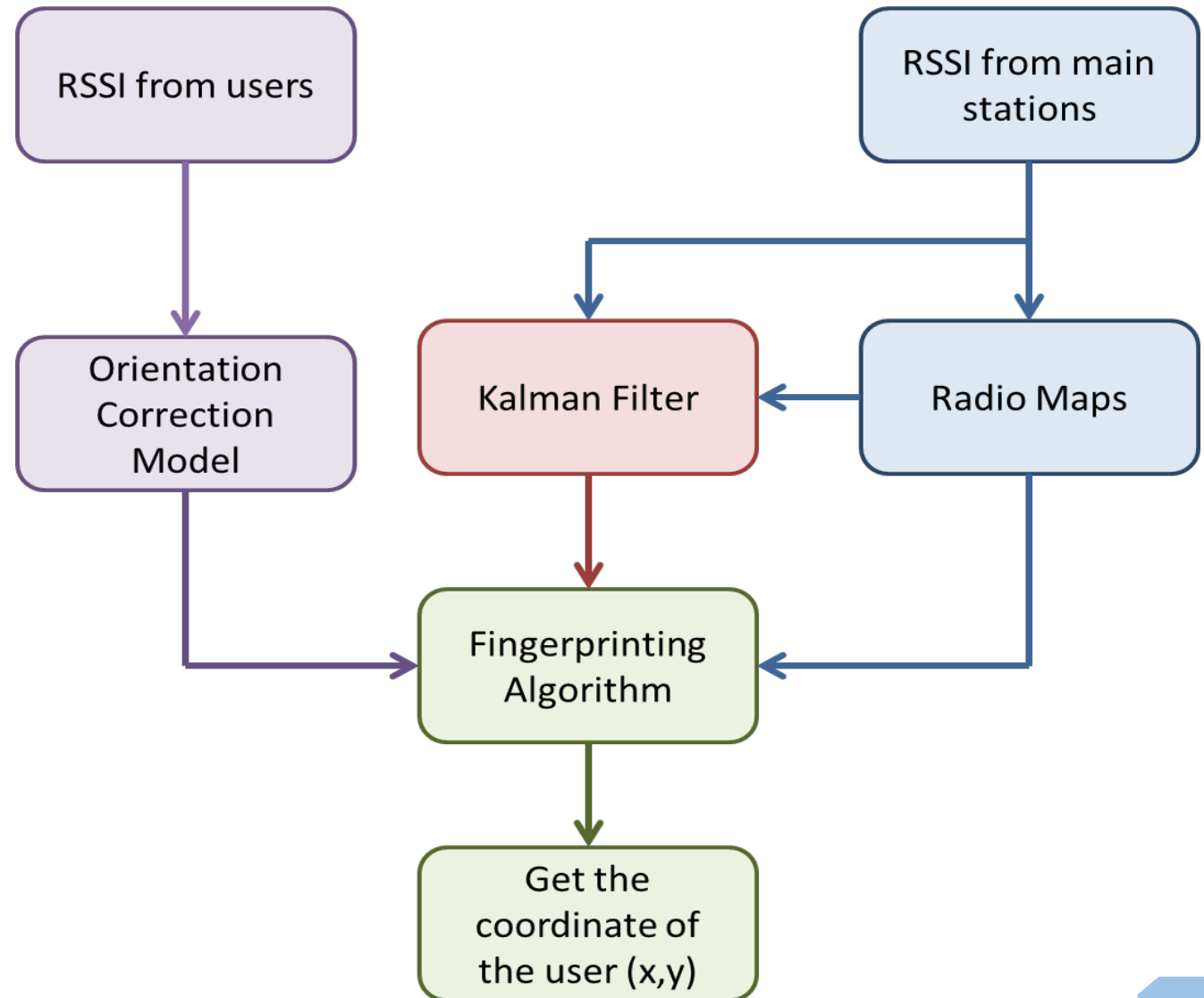
- Time consuming
- The environment presented by radio maps is different from the on-line phase
- Shorter calibration beforehand
- Less efforts to construct and maintain radio maps

Methodology

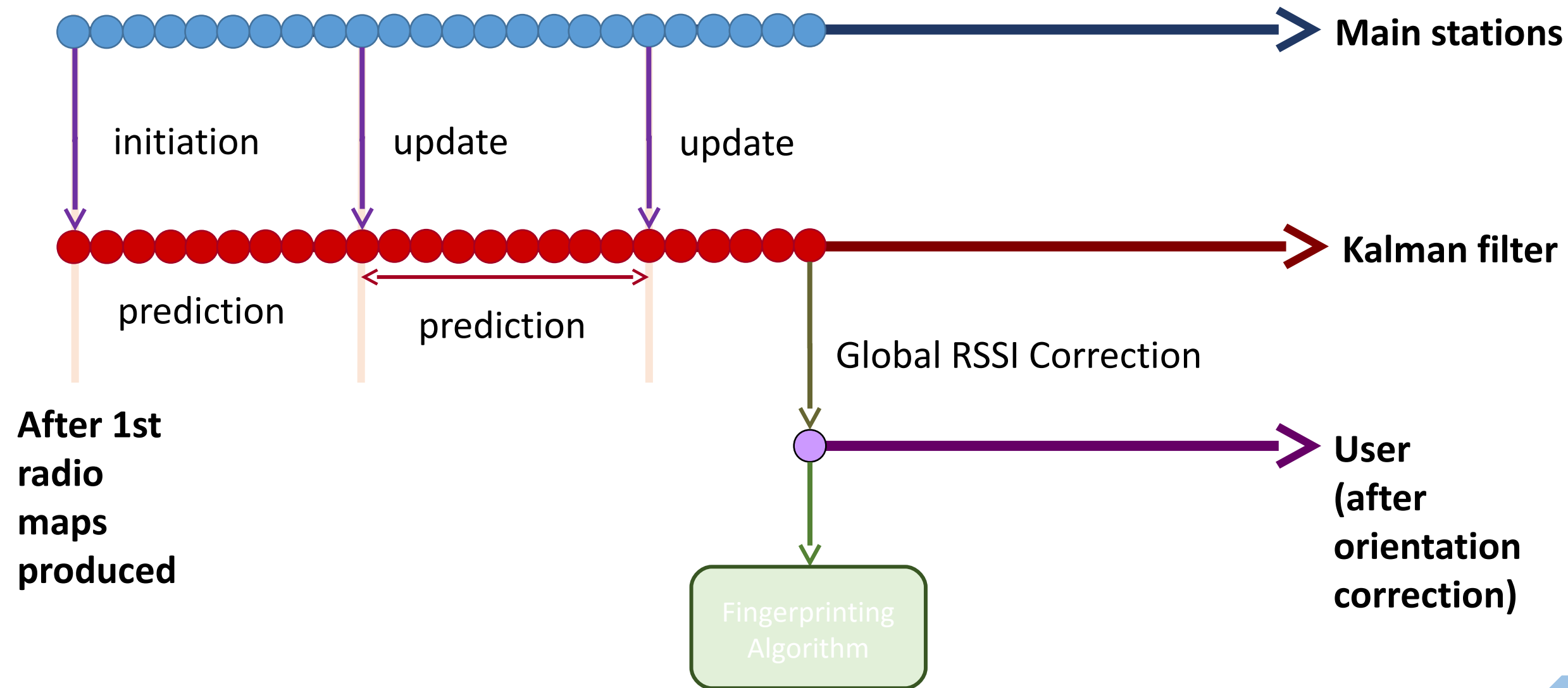


Flow chart

- Main stations
 - Radio map
 - Kalman filter → estimate global RSSI corrections



Methodology



Radio Maps Production-IDW

- **Inverse Distance Weighting (IDW)**

$$RSSI_{esti} = \sum_{j=1}^N w_j RSSI_j$$

$$w_j = \frac{d_j^{-u}}{\sum_{j=1}^N d_j^{-u}} \quad , \quad d_j = \sqrt{(x_j - x)^2 + (y_j - y)^2}$$

- $j = 1, \dots, N$, N is the number of main stations
- (x_j, y_j) : the coordinate of j -th main station
- u : exponent parameter

Global RSSI Correction (Δ_g)

- 5 main stations ; 4 beacons

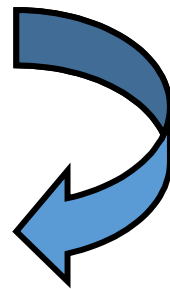
- $M = \begin{bmatrix} \overline{RSSI}_{11} & \cdots & \overline{RSSI}_{14} \\ \vdots & \ddots & \vdots \\ \overline{RSSI}_{51} & \cdots & \overline{RSSI}_{54} \end{bmatrix}_{5 \times 4}$ \rightarrow used to produce radio maps

\overline{RSSI}_{54} \rightarrow Received by 1 st main station from 4 th beacon

- $MS = \begin{bmatrix} RSSI_{11} & \cdots & RSSI_{14} \\ \vdots & \ddots & \vdots \\ RSSI_{51} & \cdots & RSSI_{54} \end{bmatrix}_{5 \times 4}$ \rightarrow used to update KF

- $\Delta = MS - M = \begin{bmatrix} \Delta_{11} & \cdots & \Delta_{14} \\ \vdots & \ddots & \vdots \\ \Delta_{51} & \cdots & \Delta_{54} \end{bmatrix}_{5 \times 4}$

- $\Delta_g = \begin{bmatrix} \Delta_1 \\ \Delta_2 \\ \vdots \\ \Delta_4 \end{bmatrix}_{4 \times 1}$



$$\Delta_1 = \frac{\Delta_{11}}{|RSSI_{11}|} + \frac{\Delta_{21}}{|RSSI_{21}|} + \cdots + \frac{\Delta_{51}}{|RSSI_{51}|}$$

$$S_1 = \frac{1}{|RSSI_{11}|} + \frac{1}{|RSSI_{21}|} + \cdots + \frac{1}{|RSSI_{51}|}$$

Fingerprinting algorithm-EWKNN

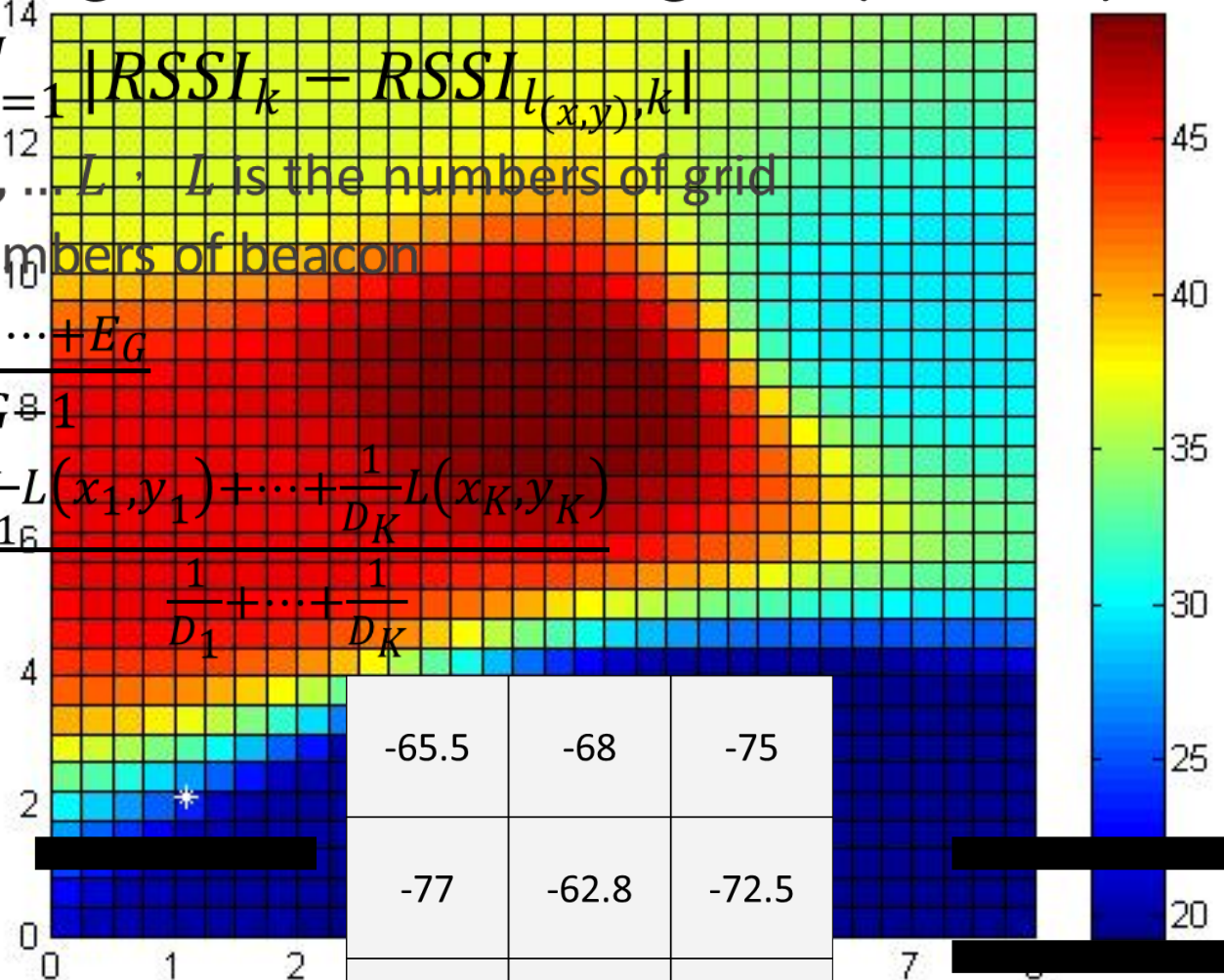
- Enhanced Weighted K-nearest Neighbor (EWKNN)

$$D_{l(x,y)} = \sum_{k=1}^N |RSSI_k - RSSI_{l(x,y),k}|$$

- $l = 1, 2, 3, \dots, L$: L is the numbers of grid
- N : the numbers of beacon

$$R(E) = \frac{E_2 + \dots + E_G}{G - 1}$$

$$P(x, y) = \frac{\frac{1}{D_1} L(x_1, y_1) + \dots + \frac{1}{D_K} L(x_K, y_K)}{\frac{1}{D_1} + \dots + \frac{1}{D_K}}$$



| | | |
|-----|-----|-----|
| -67 | -67 | -67 |
| -67 | -67 | -67 |
| -67 | -67 | -67 |

| | | |
|-------|-------|-------|
| -65.5 | -68 | -75 |
| -77 | -62.8 | -72.5 |
| -80 | -67 | -70 |

| | | |
|-----|-----|-----|
| 1.5 | 1 | 8 |
| 10 | 4.2 | 5.5 |
| 13 | 0 | 3 |

Experiments and Analysis

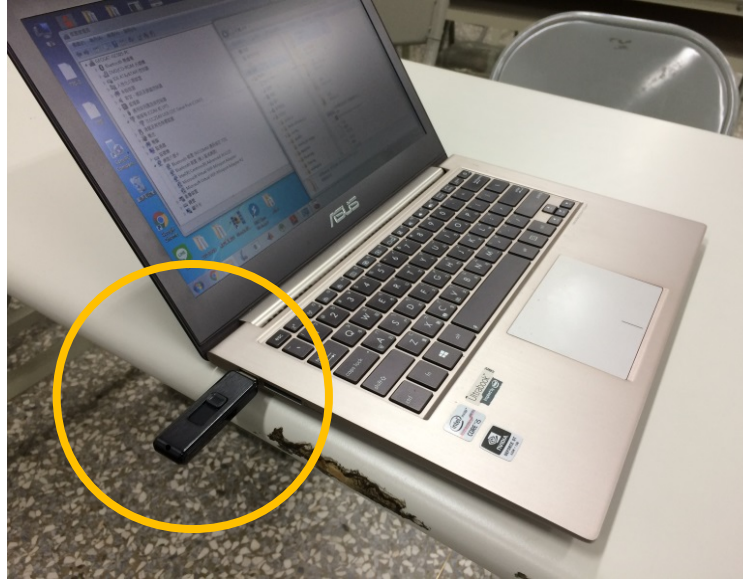


Devices



Beacon

Power : 10 metermax



**Main station
(USBeacon)**

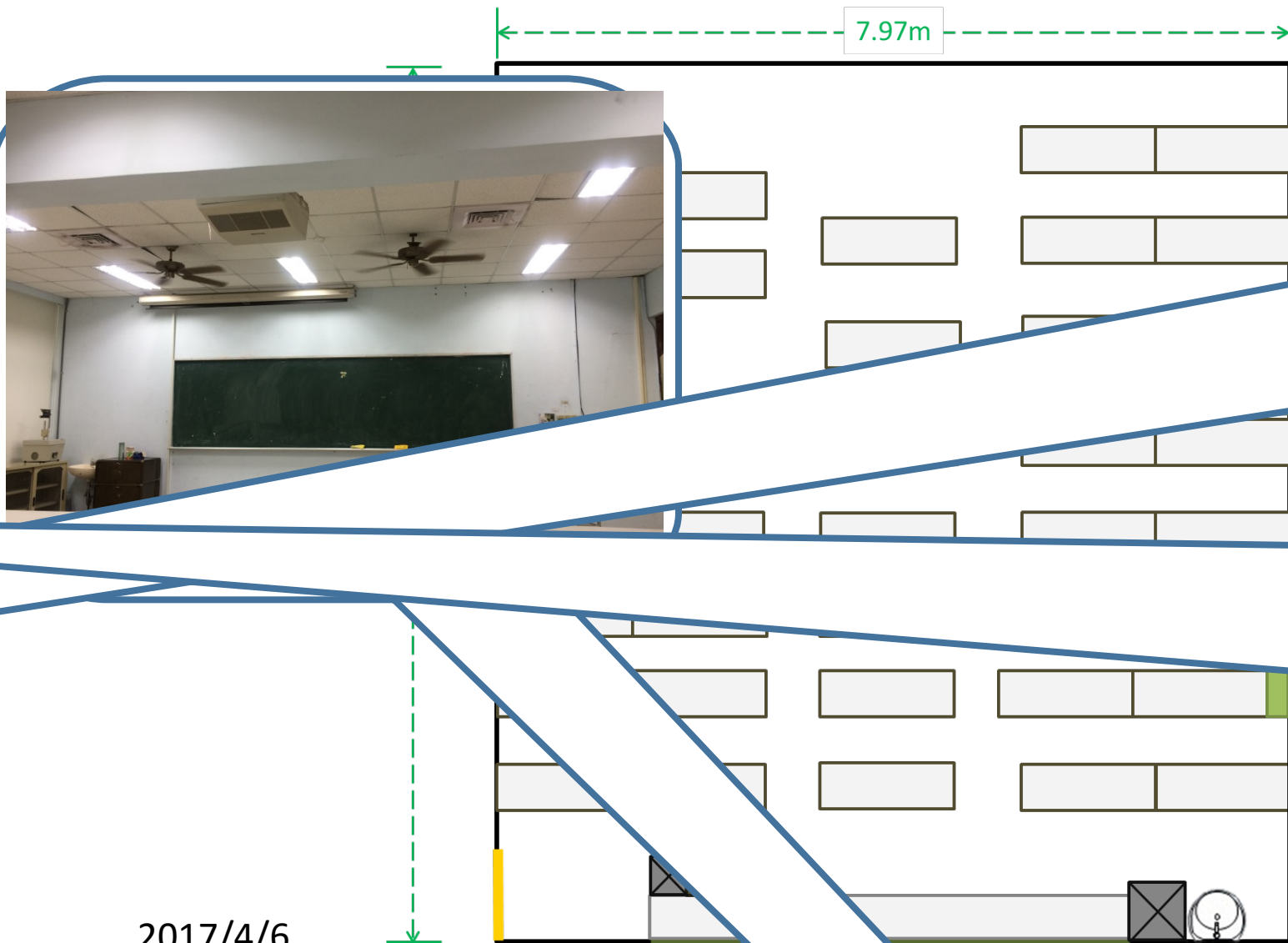
Scanning frequency : 1 Hz



**User
(iPhone 5s)**

Scanning frequency : 1 Hz

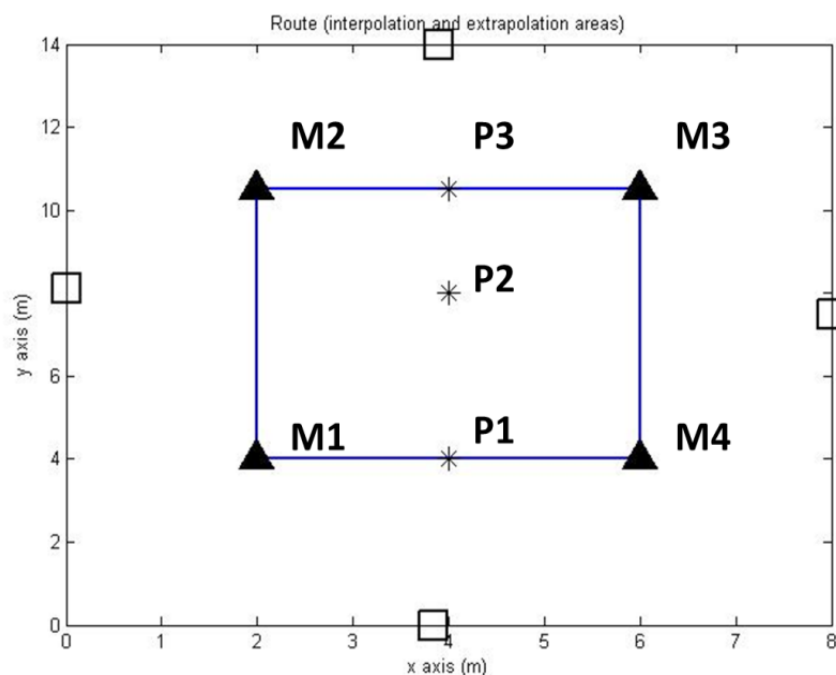
Experimental scenarios



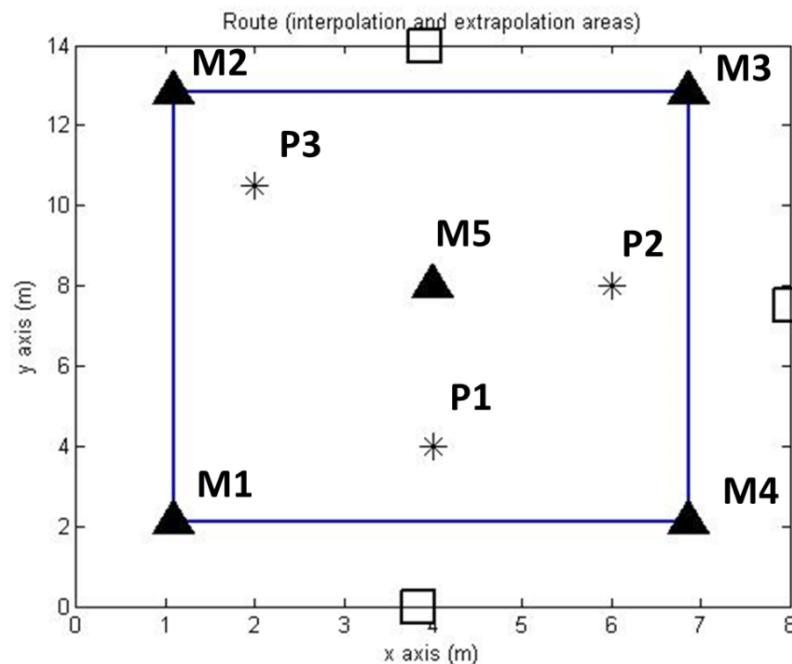
2017/4/6

Experiments

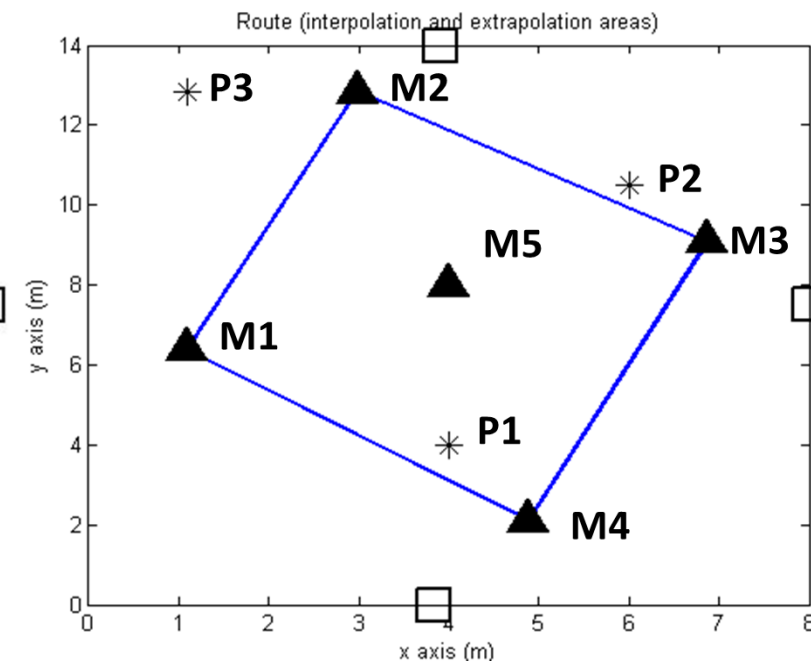
- Exponent parameter in radio maps & orientation correction
- Placement and number of main stations
- Updating frequency of KF



Smaller Interpolation Area



Maximum Interpolation Area



Main Station Closed to Beacon

Exponent parameter and orientation correction

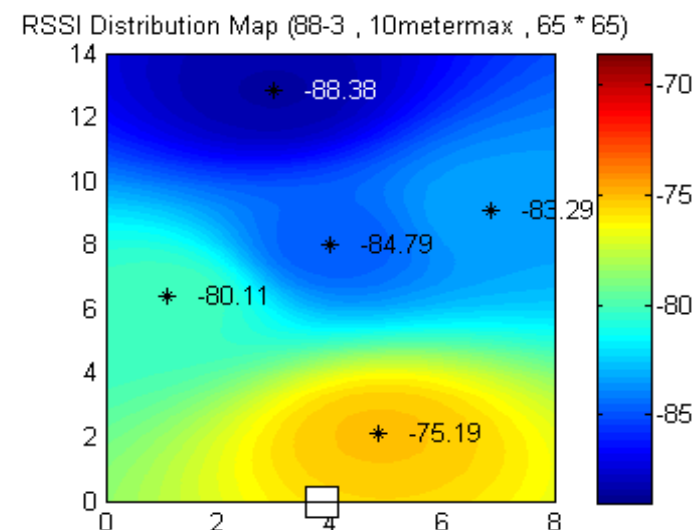
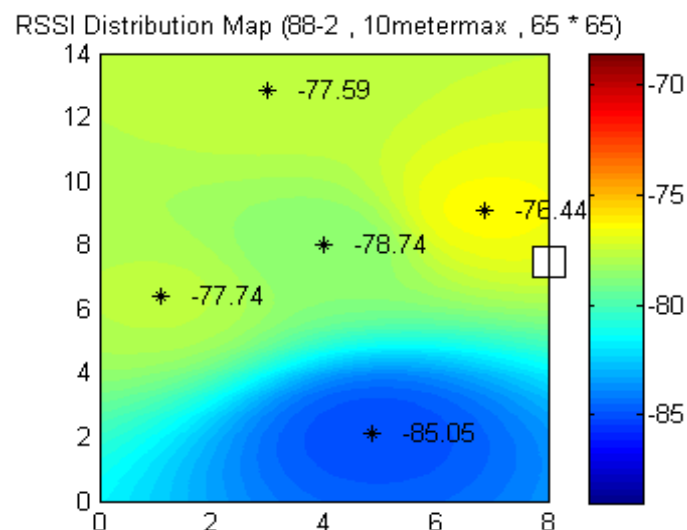
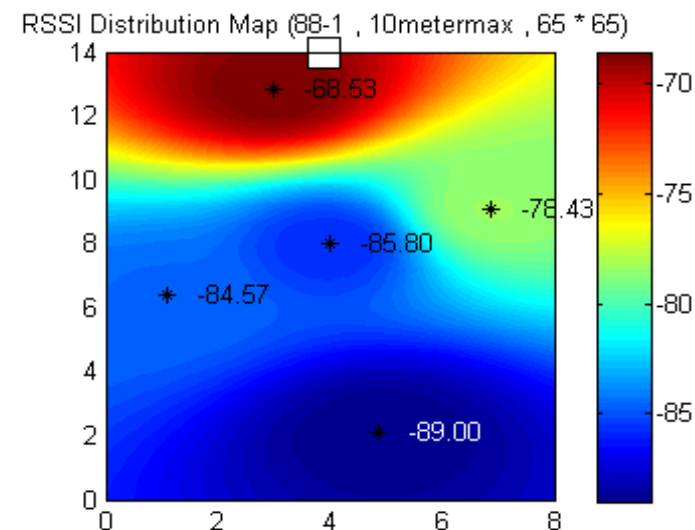
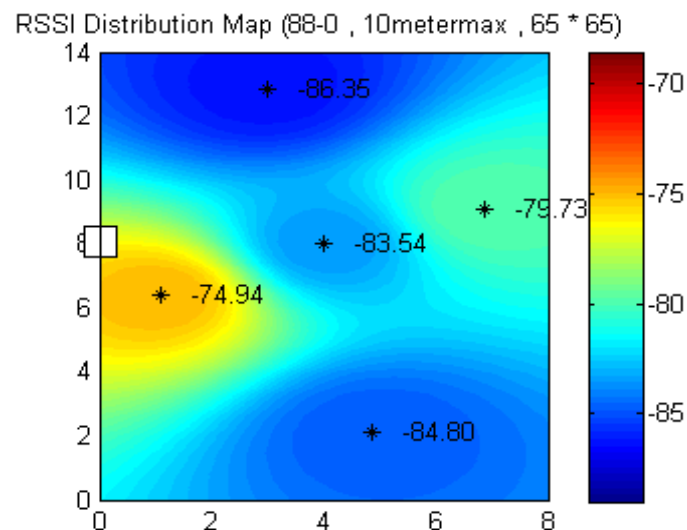
Case

Smaller
Interpolation Area

Maximum
Interpolation Area

Main Station
Closed to Beach

2017/4/6



orientation
model

od

od

od

od

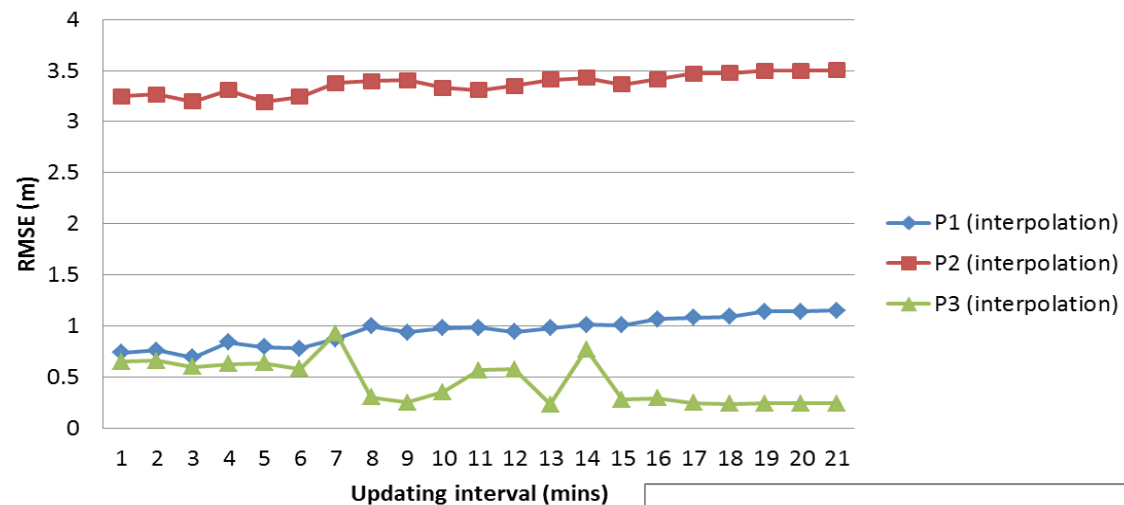
od

od

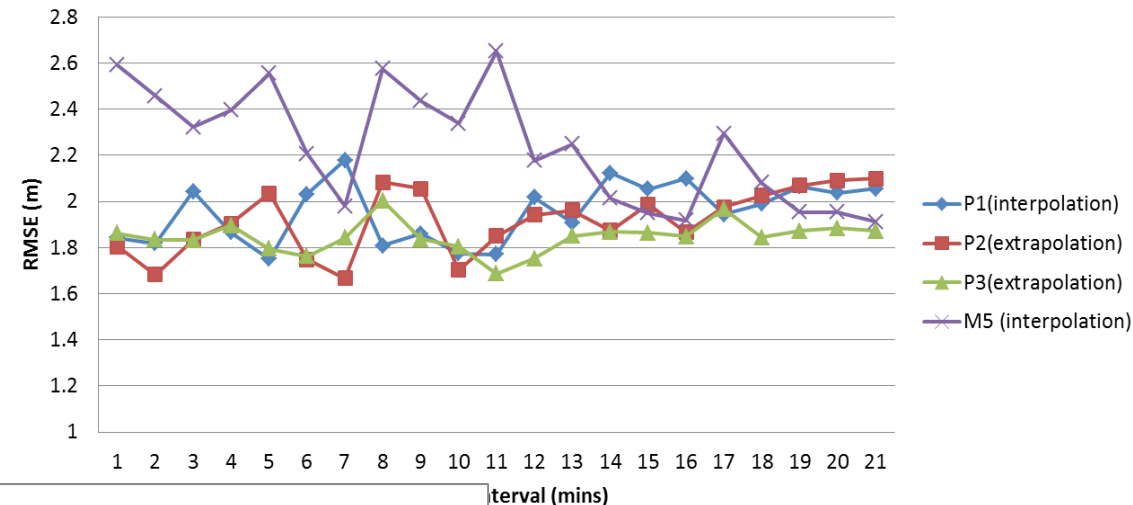
od

Placement - 4 Main Stations

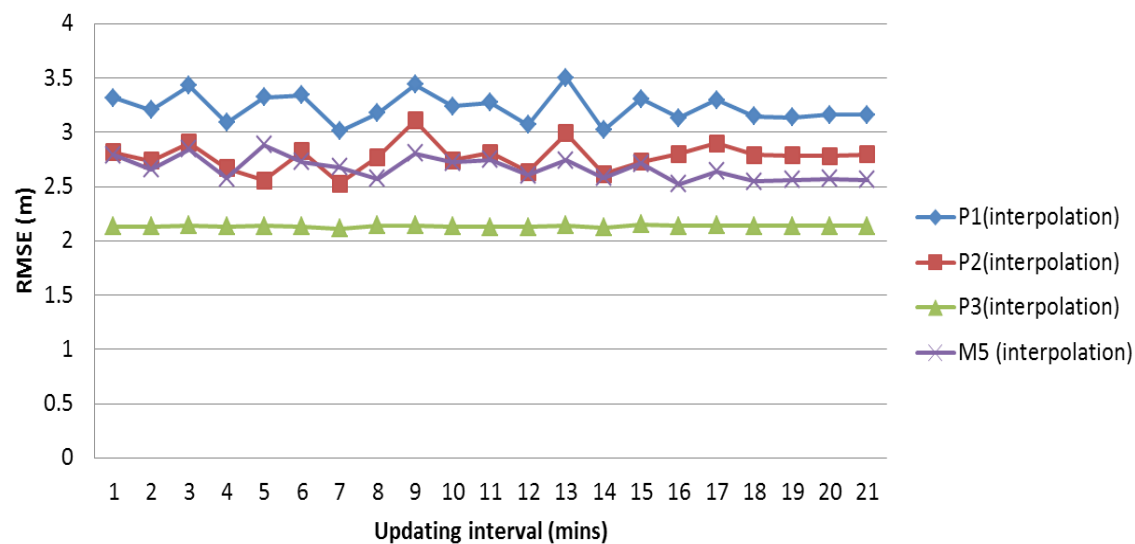
RMSE (smaller interpolation area)



RMSE (main stations closed to beacon)

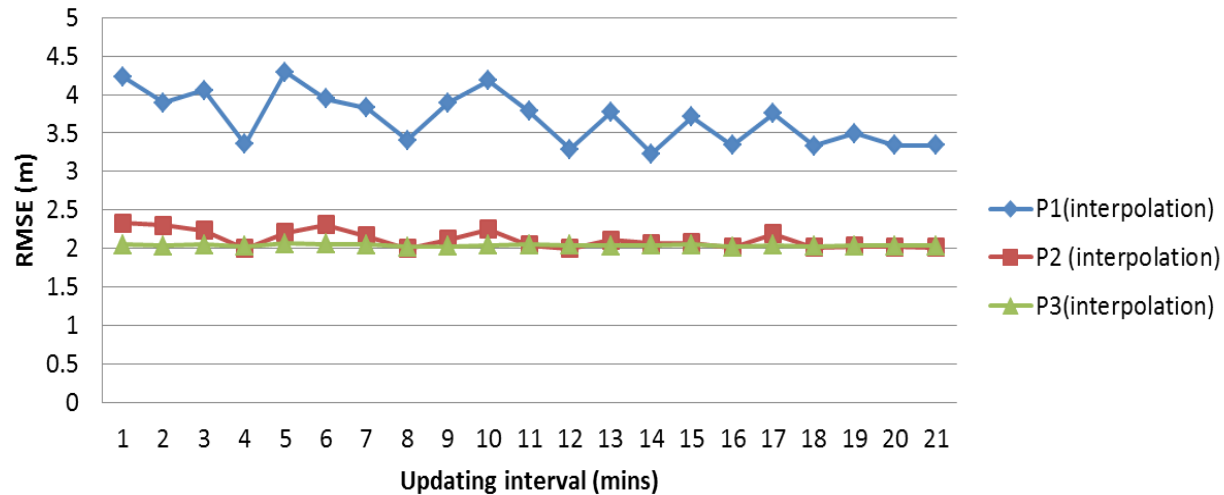


RMSE (maximum interpolation area)



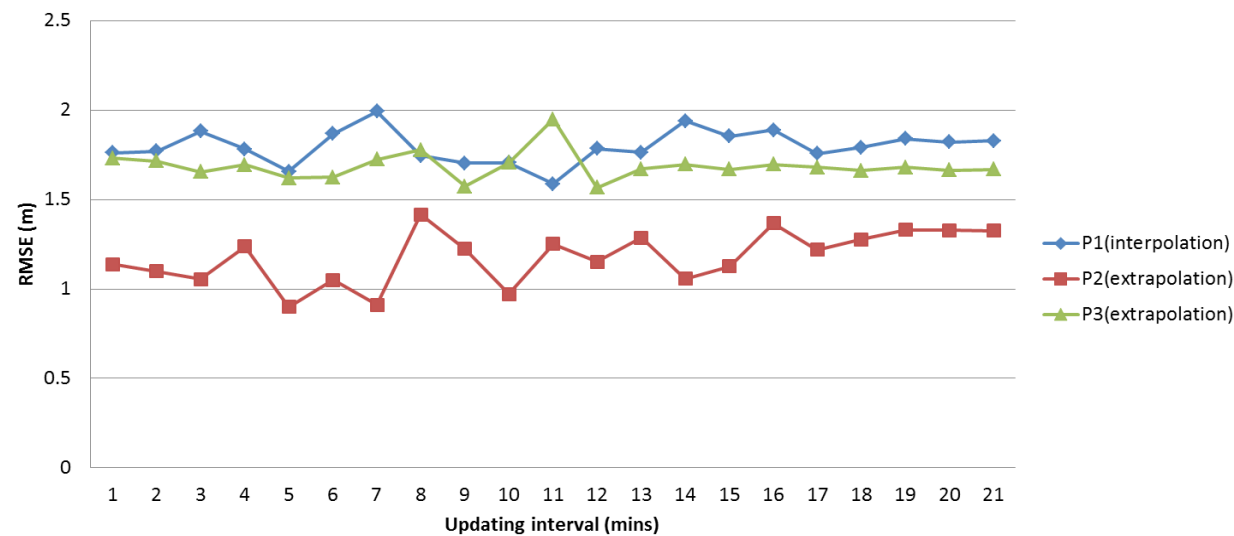
Placement - 5 Main Stations

RMSE (maximum interpolation area)



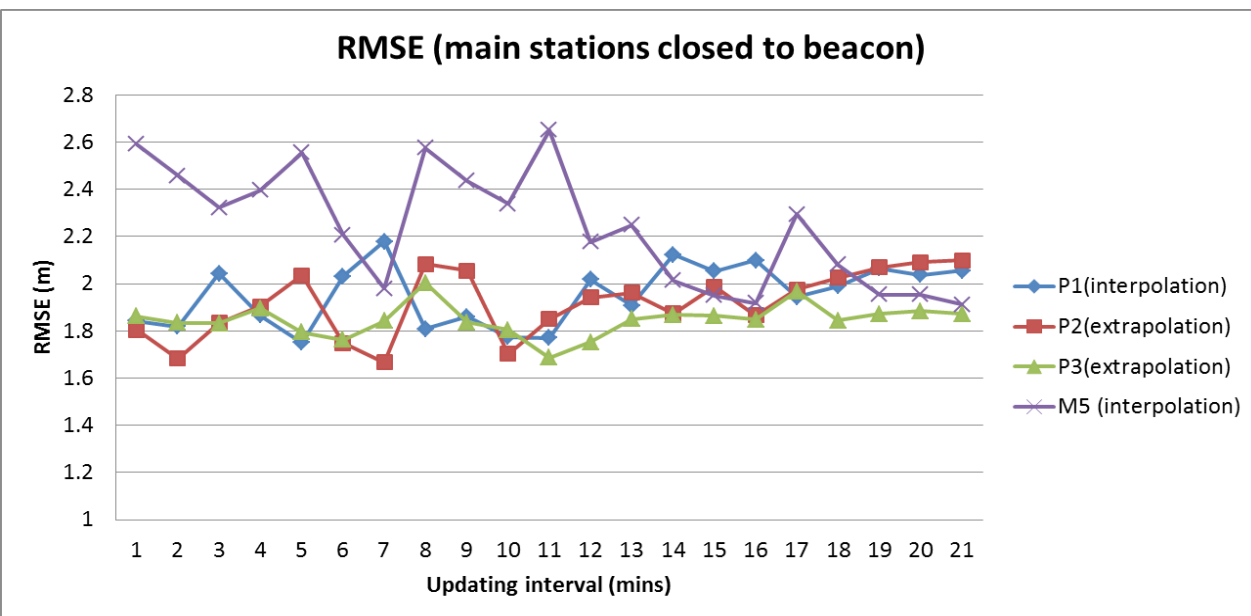
Maximum Interpolation Area

RMSE (main stations closed to beacon)

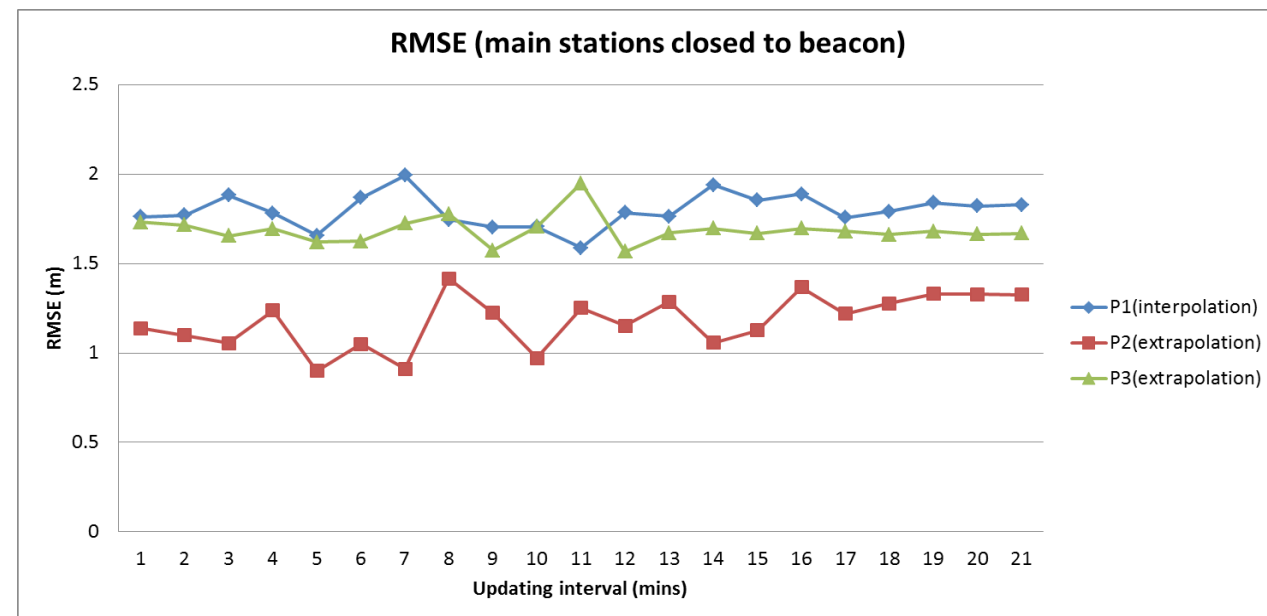


Main Station Closed to Beacon

Number of Main Station

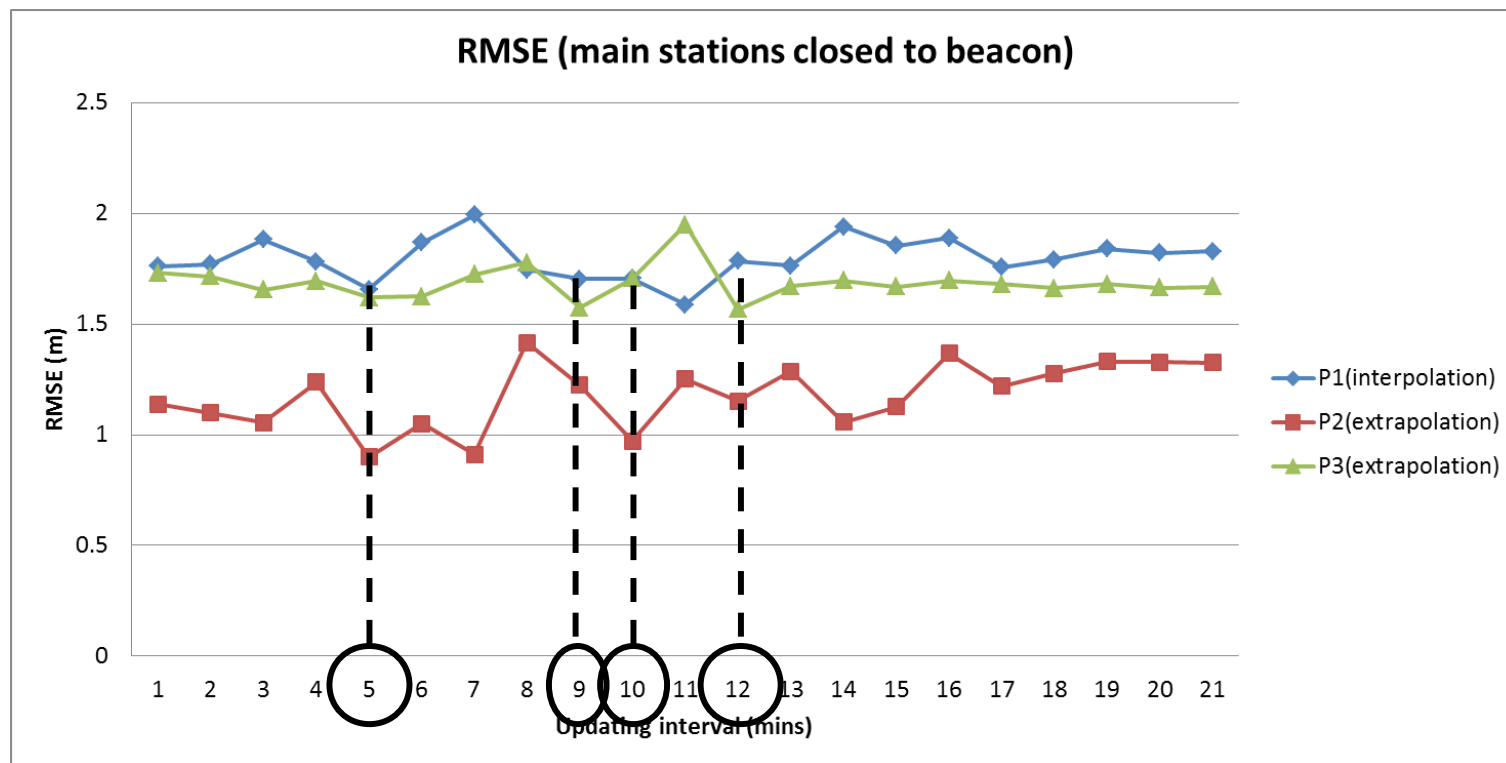


4 main stations



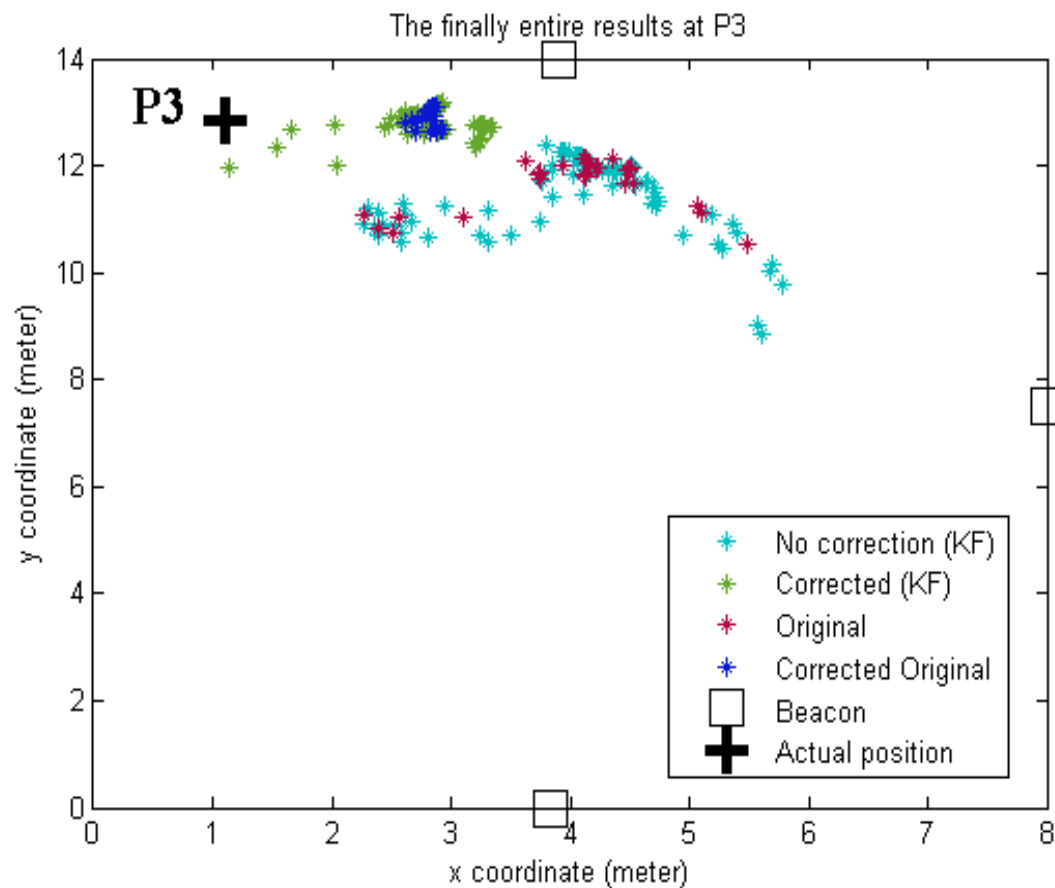
5 main stations

Updating frequency of KF



| | 5 mins | | 9 mins | | 10 mins | | 12 mins | |
|------|--------|-------|--------|-------|---------|-------|---------|-------|
| | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 |
| Mean | 1.52 | 0.633 | 1.534 | 0.979 | 1.540 | 0.702 | 1.628 | 0.952 |
| Std | 0.659 | 0.638 | 0.739 | 0.732 | 0.734 | 0.673 | 0.731 | 0.650 |
| RMSE | 1.657 | 0.898 | 1.703 | 1.222 | 1.706 | 0.972 | 1.784 | 1.153 |

Performance of the Proposed System



| | P1 | P2 | P3 |
|---------------------|--------|--------|--------|
| Original RSSI (m) | 2.0521 | 2.4329 | 2.8929 |
| Proposed system (m) | 1.6569 | 0.8983 | 1.6199 |
| | 19.3% | 63.1% | 44.0% |

Conclusions and Future works



Conclusions

- Radio maps
 - updated every 30 minutes
 - Exponent parameter (u) : 3
- Main stations
 - Let one main station near to a beacon
 - One main station is in the center
- Kalman filter
 - Updated every 5 mins

Conclusions

- Positioning accuracy : 0.9 to 1.6 meters
- Construction and maintenance of radio maps are finished automatically
- Provide stable indoor positioning accuracy with several low-cost beacons and main stations

Future works

- Perform in different circumstances for evaluating its repeatability
- The effect of human on BLE signals
- Wi-Fi beacon for real-time positioning system
- Combine with PDR