Radio Propagation Aided Indoor Localization

Indoor localization by applying Proportionate Measurement Localization (PML) using Bluetooth Low Energy tags.

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- Introduction and objective
- Localization technique: hardware
  - UHF RFID
  - Bluetooth Low Energy
- Localization method: software
  - Proximity approach
  - Distance approach
- Tests and results
- Conclusions and recommendations

Introduction

Navigation and mapping apps are the third-most-used category of smartphone apps, ranking higher than gaming, news, and shopping.

Introduction

Yet, as important as location is, its dependence on satellite-based positioning systems prevents it from playing a significant role indoors.

90% of our lives take place inside!

Introduction: objective

The objective of this research is to propose a suitable technique and method to accomplish indoor localization which can be applied for LBS in semi-public spaces.

These semi-public spaces are assumed to be complex and large buildings potentially holding multiple users.

Therefore the localization technique and method should be low cost, adaptive and robust.

Introduction

Make the physical world searchable down to the object level.

Introduction

Make smart devices responsive to their environment: tool for organizing, discovering, and accessing information and services about our environment.

Introduction

Enable universal tracking and monitoring of people and physical assets.

Introduction

Improve wayfinding to your actual destination

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  - Distance approach
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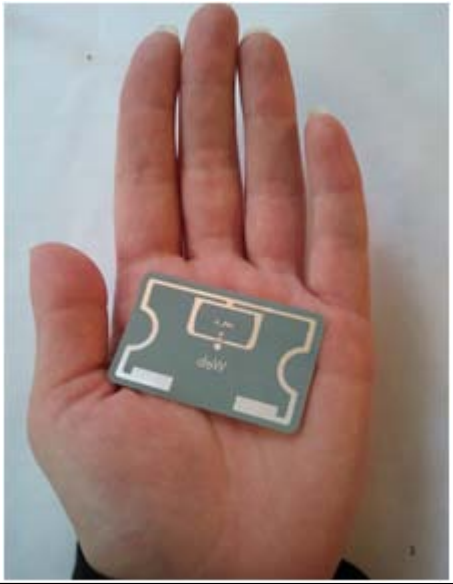
Hardware: UHF RFID

UHF RFID systems consist of a sensor and passive tags.



Hardware: UHF RFID

What is RFID currently used for?

Hardware: UHF RFID

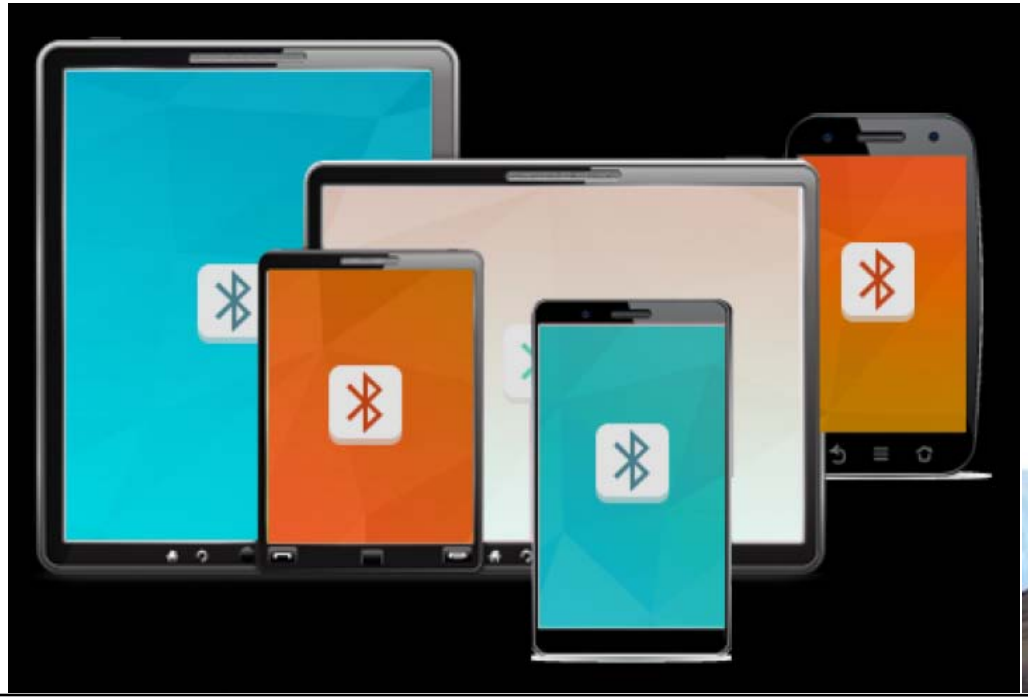
What is RFID currently used for?

Hardware: Bluetooth Low Energy

BLE systems consist of a sensor (smartphone) and active tags.

Hardware: Bluetooth Low Energy

Current applications of BLE.

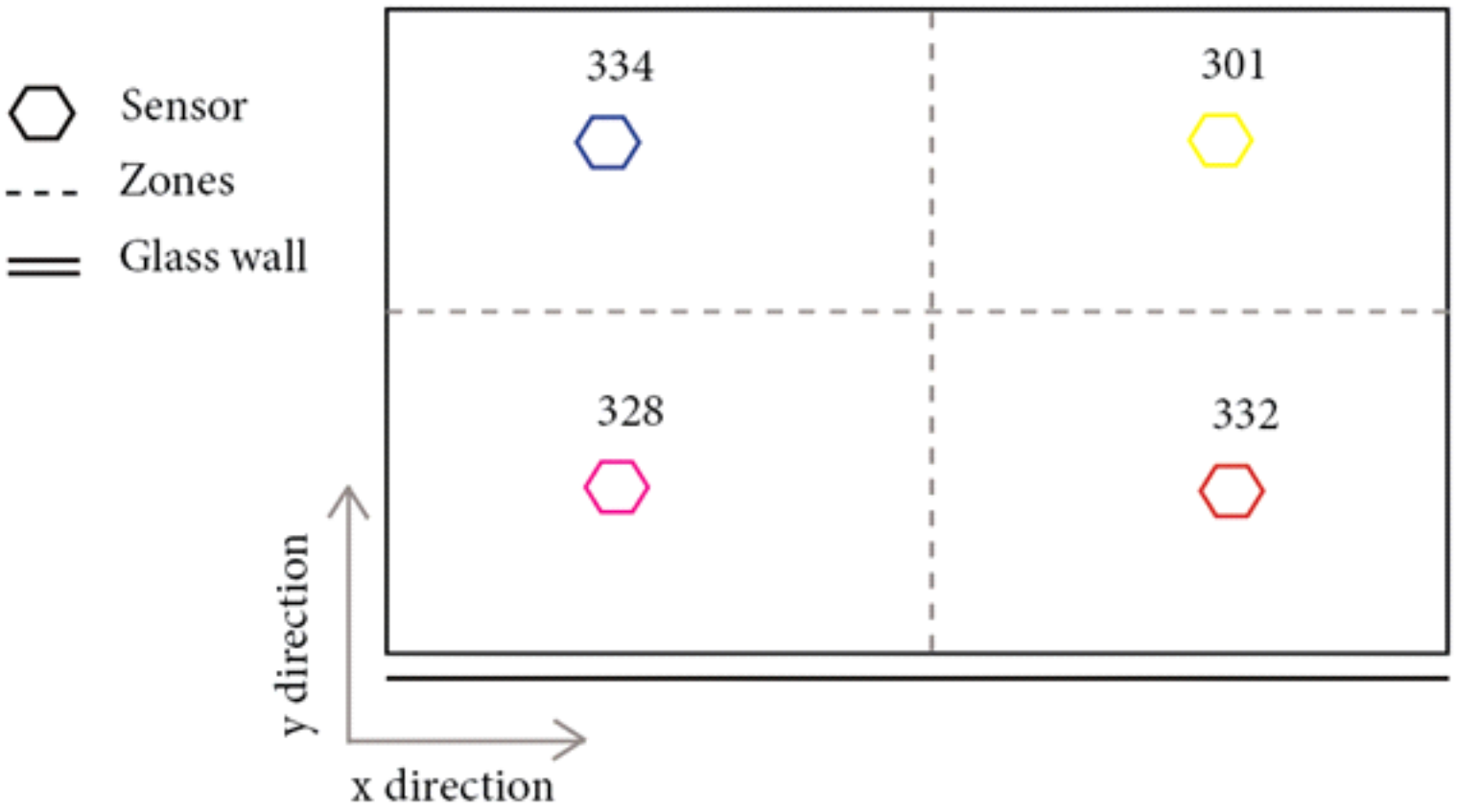


Hardware: localization technique

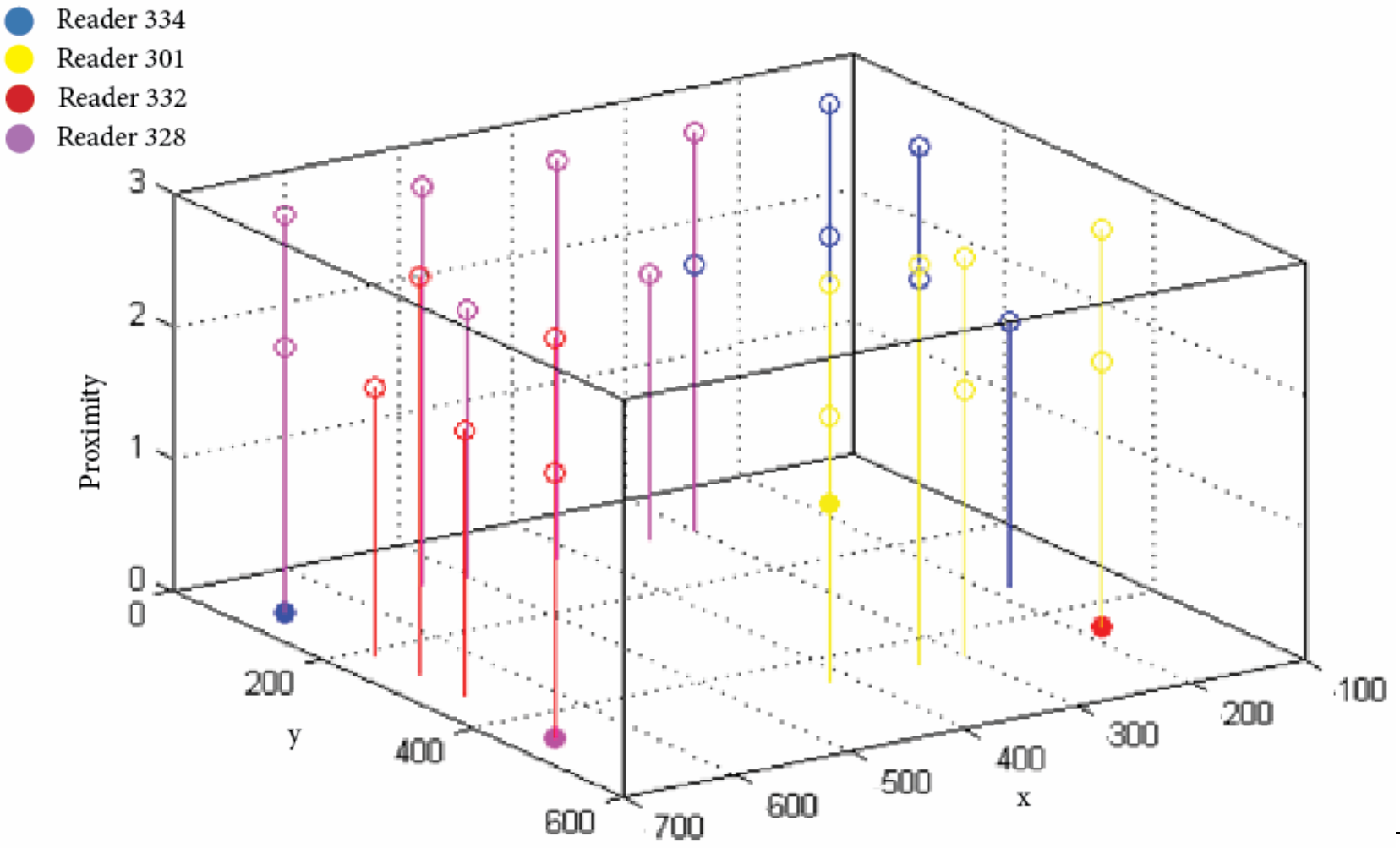
What should the hardware be capable of in practice?

- It should sense beacons when in range
- It should give some indication of proximity.

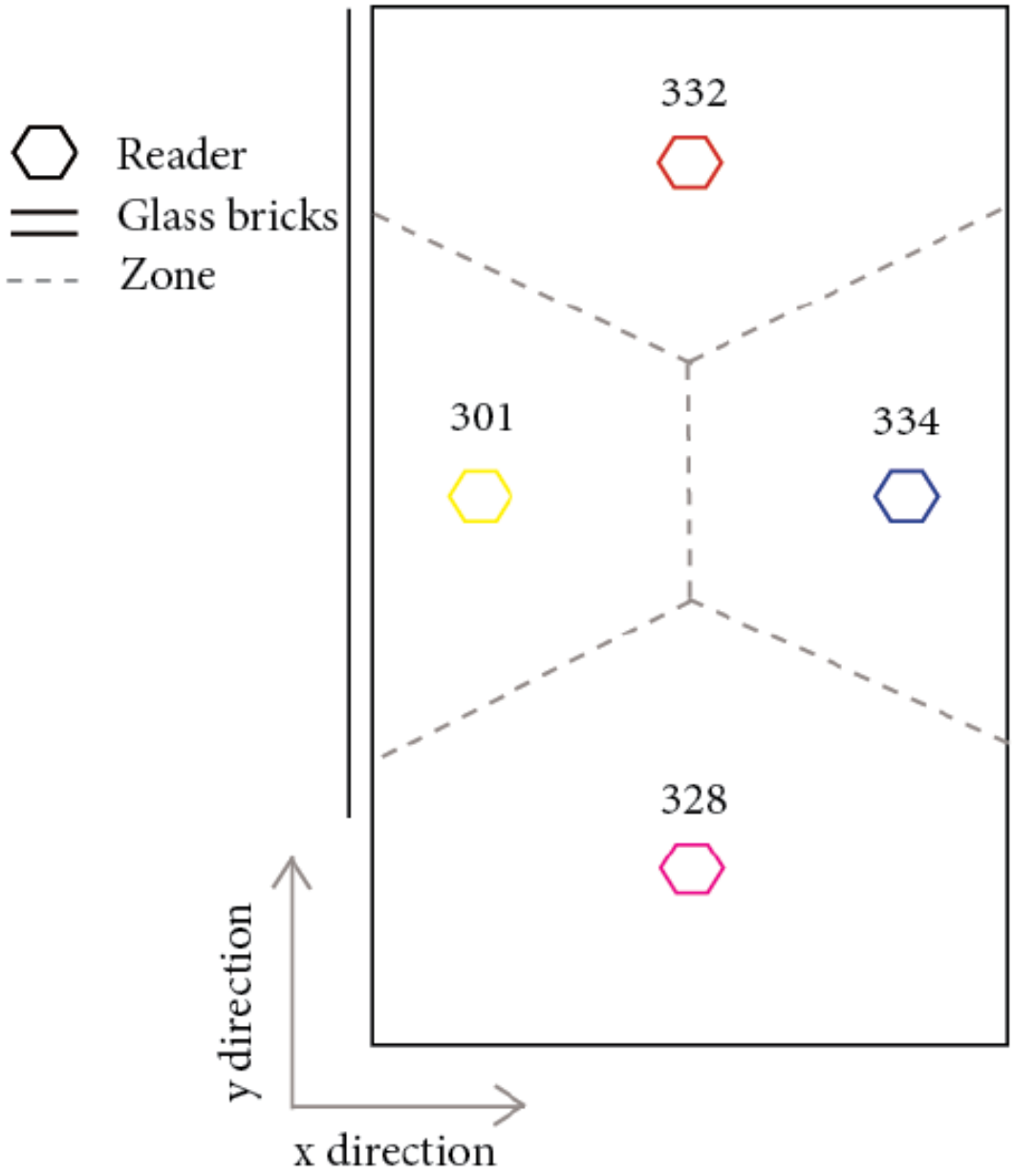
Hardware: UHF RFID



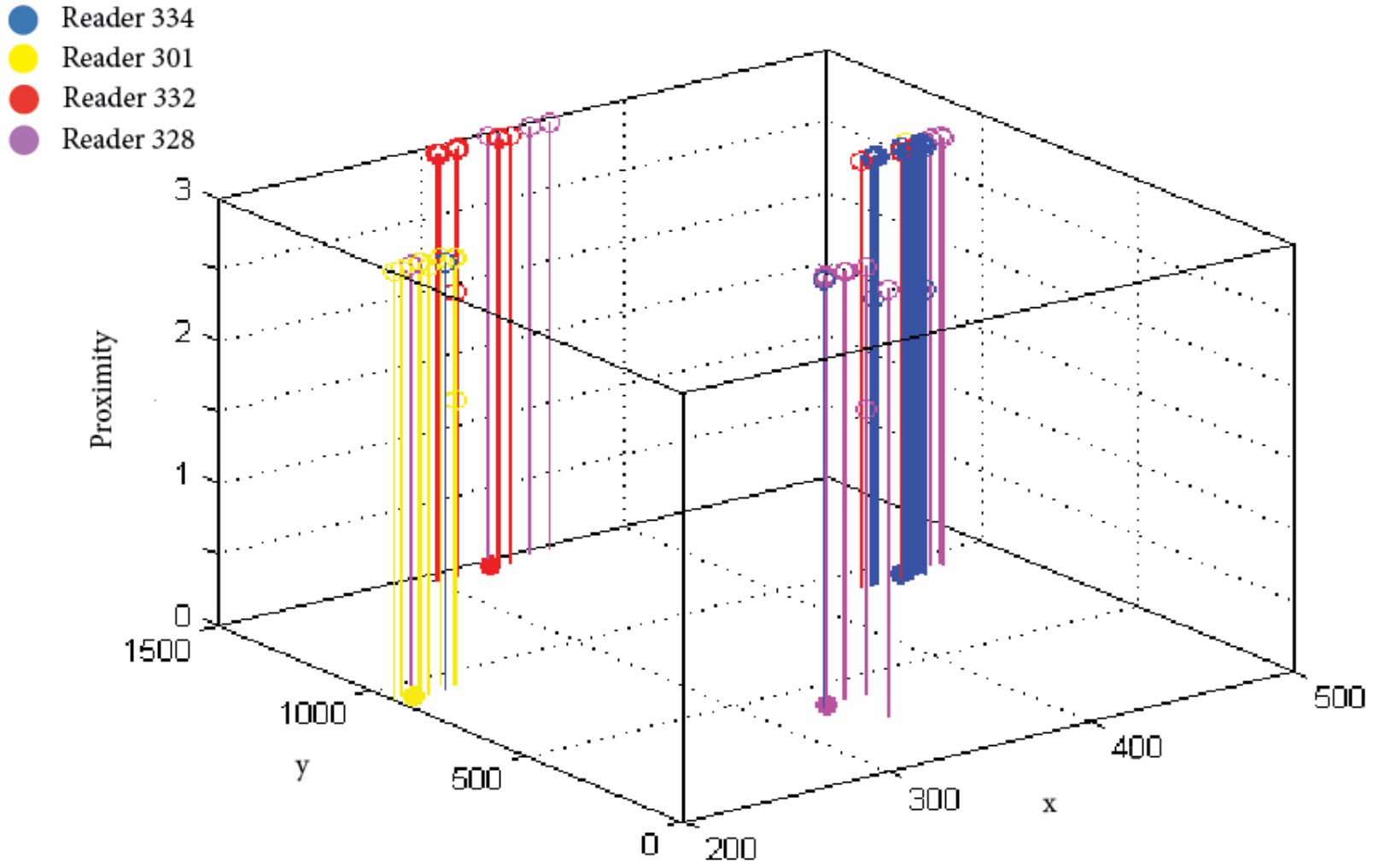
Hardware: UHF RFID



UHF RFID


Reader
Glass bricks
Zone
332
301
334
328
y direction
x direction

Hardware: UHF RFID



Hardware: UHF RFID

	percentage of measurements while subject located inside zone (%)				Percentage of measurements while subject located outside zone (%)		
Proximity (%)							
Sensor301 (yellow)	95.56				4.44		
Percentage	0	4.65	95.35		0	0	100
Sensor328 (purple)	58.33				41.67		
Percentage	0	7.14	92.86		0	0	100
Sensor334 (blue)	99.42				0.58		
Percentage	0	5.54	94.46		0	0	100
Sensor332 (red)	98.10				1.90		
Percentage	0	0.488	99.52		0	0	100
Average	87.85				12.15		
Average Proximity	0	4.45	95.55		0	0	100

Table 7. Table with the percentages of the measurements in and outside the zone and proximity for the static tests.

Why?

Emitted waves interact with the environment which leads to fading. Fading is the phenomenon where a wide variety of signal strengths is received with a small change in frequency or position.

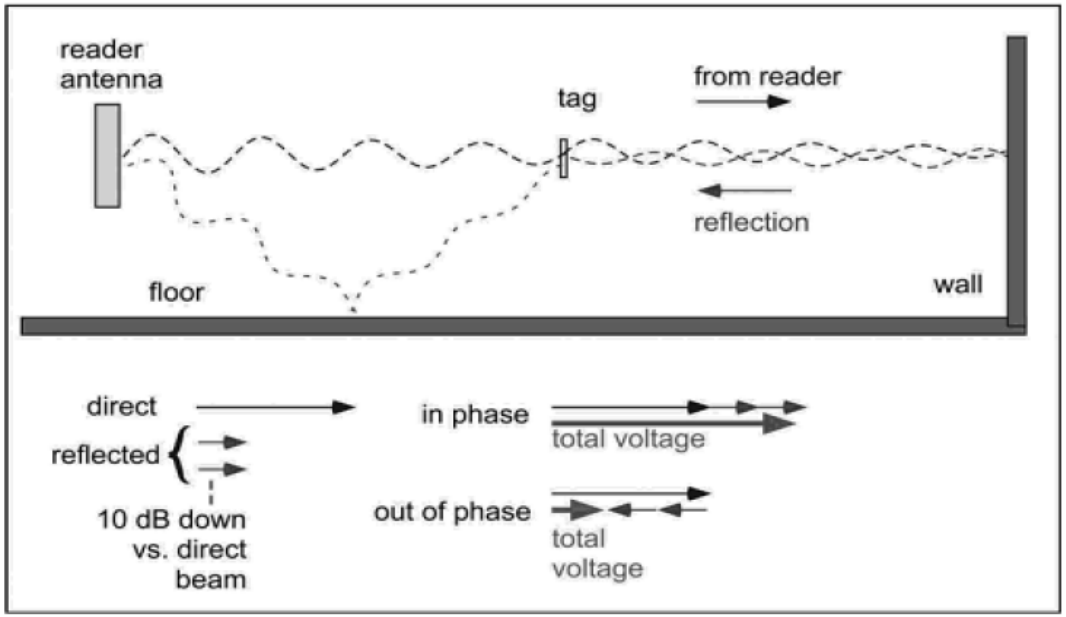


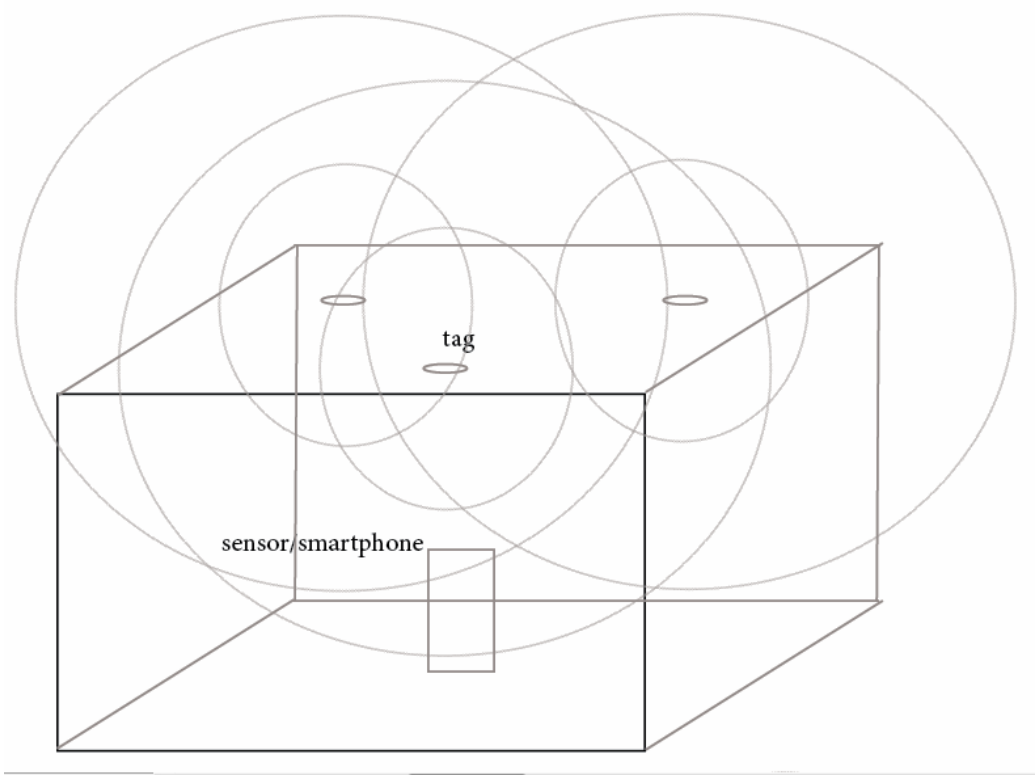
Figure 11. Dobkin, 2012. P.94. direct and reflected beams can interfere.

Hardware: UHF RFID

UHF RFID is very well capable of noting the presence of tags in general. Although the potential of this technique is huge, it is not considered suited for this application. This technique has proven not to be consistent in its proximity indication which is a requirement for this research in order to localize indoors.

Hardware: Bluetooth Low Energy

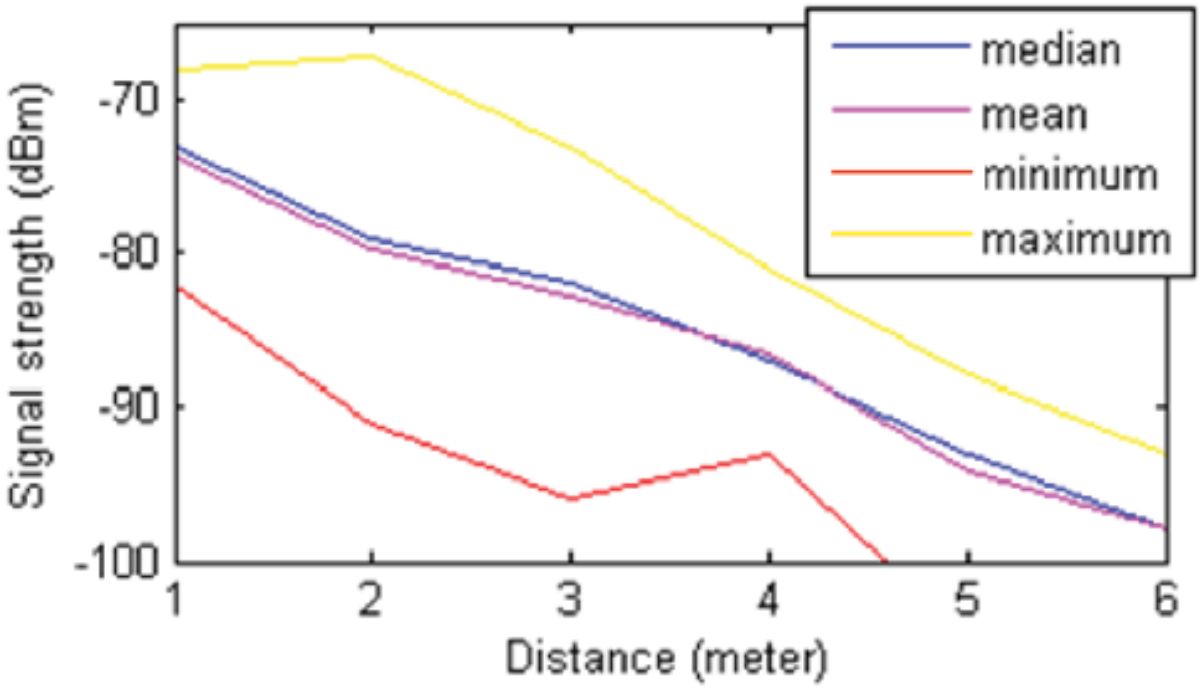
Tags are attached to the ceiling



Hardware: Bluetooth Low Energy

Between 1 and 6 meters the median seems to approach a linear relationship between distance and RSSI.

$$d_i = -5 * s_i - 68$$



Hardware: Bluetooth Low Energy

In most cases the final mean value is approached before or around 10 to 15 measurements.

The Inter Quartile Range varies between 3 and 5. The Inter Quartile Range is a measurement of dispersion, 50% of the measurements are between these quartiles. It is assumed that every measurement done could have ranged with 4 dBm.

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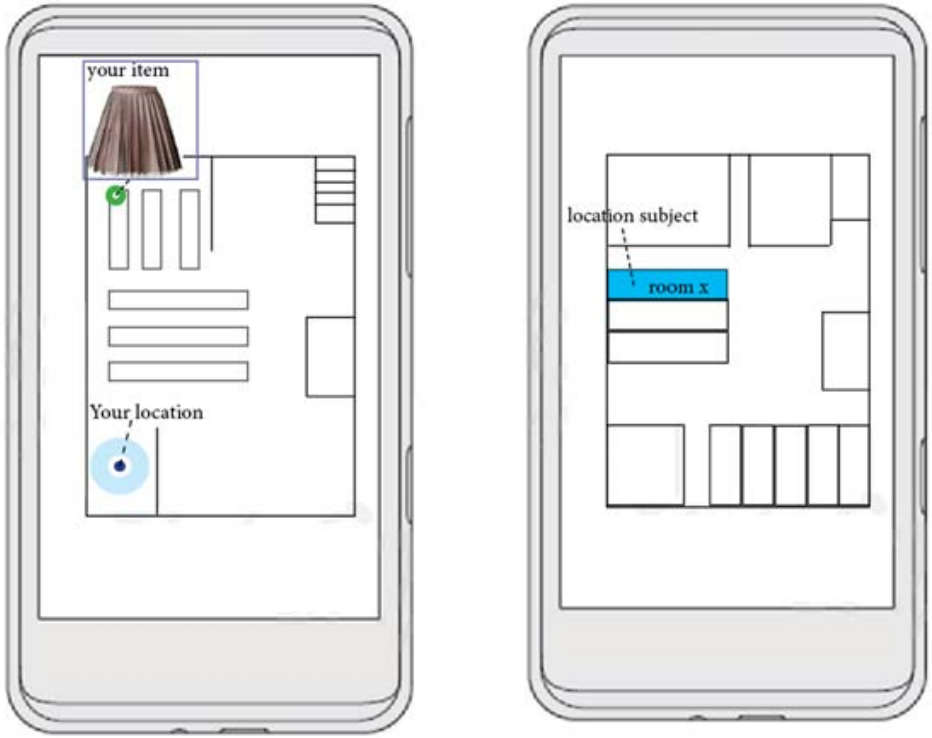
Software: indoor localization method

The goal of the application (LBS) determines the localization granularity.



Software: indoor localization method

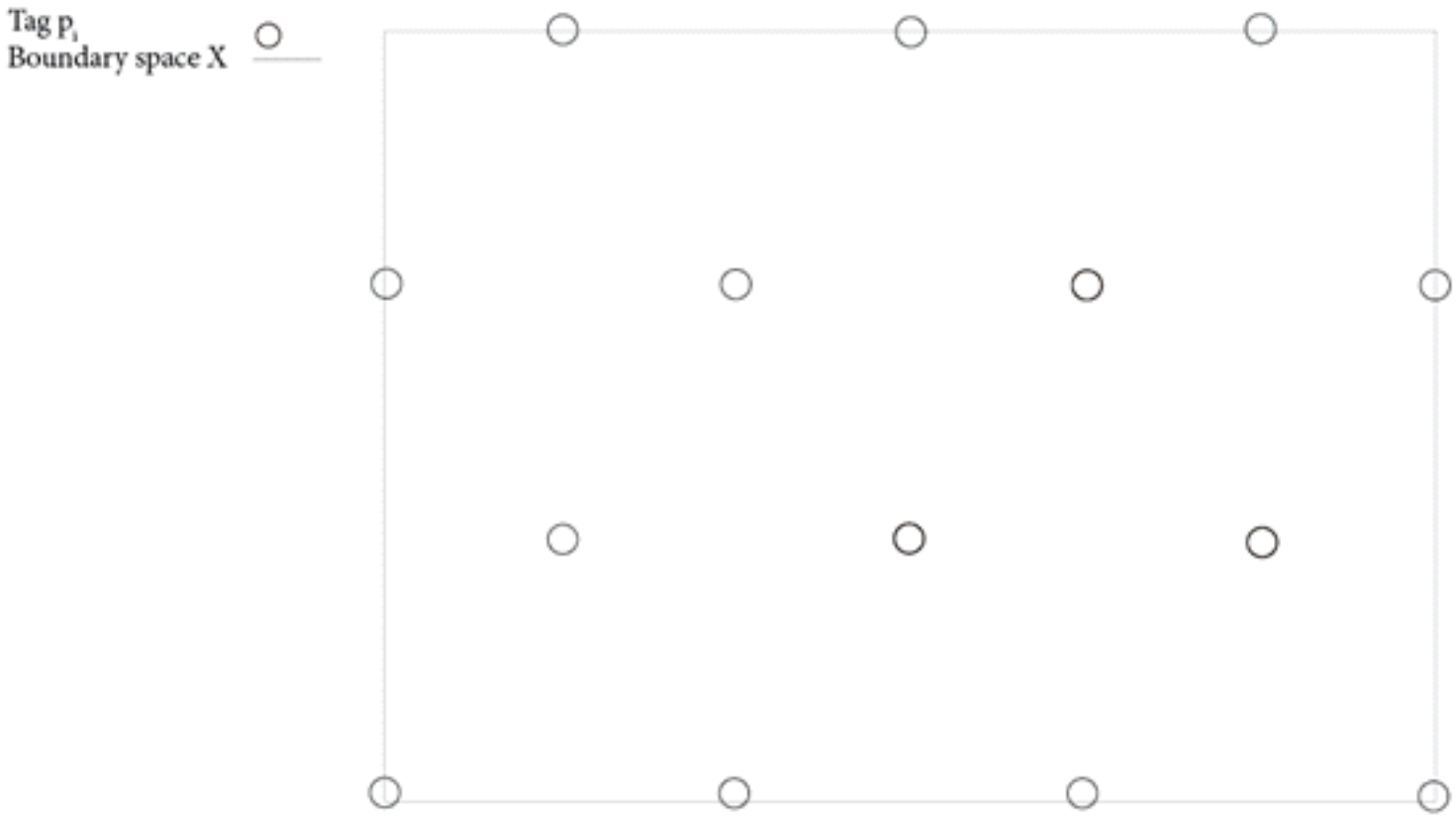
- Proximity approach:
  - Step 1: Area of interest
  - Step 2: zone selection → coarse localization granularity
- Distance approach → fine localization granularity
  - Option 1: Dependent algorithm
  - Option 2: PML

Software: indoor localization method

The main assumption of the proximity approach is when the subject enters the range of the sensor, the subject is near the sensor.

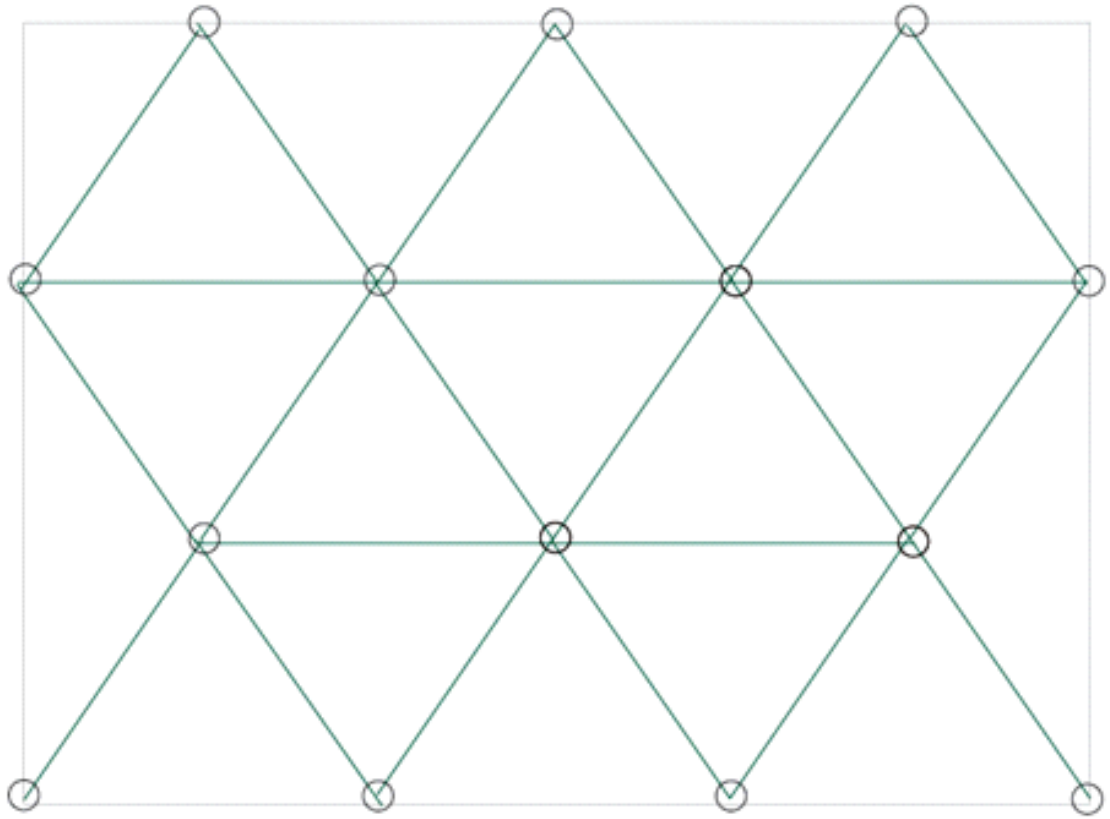
Distant estimation is done by applying range measurement techniques so the object can be localized.

Proximity: area of interest

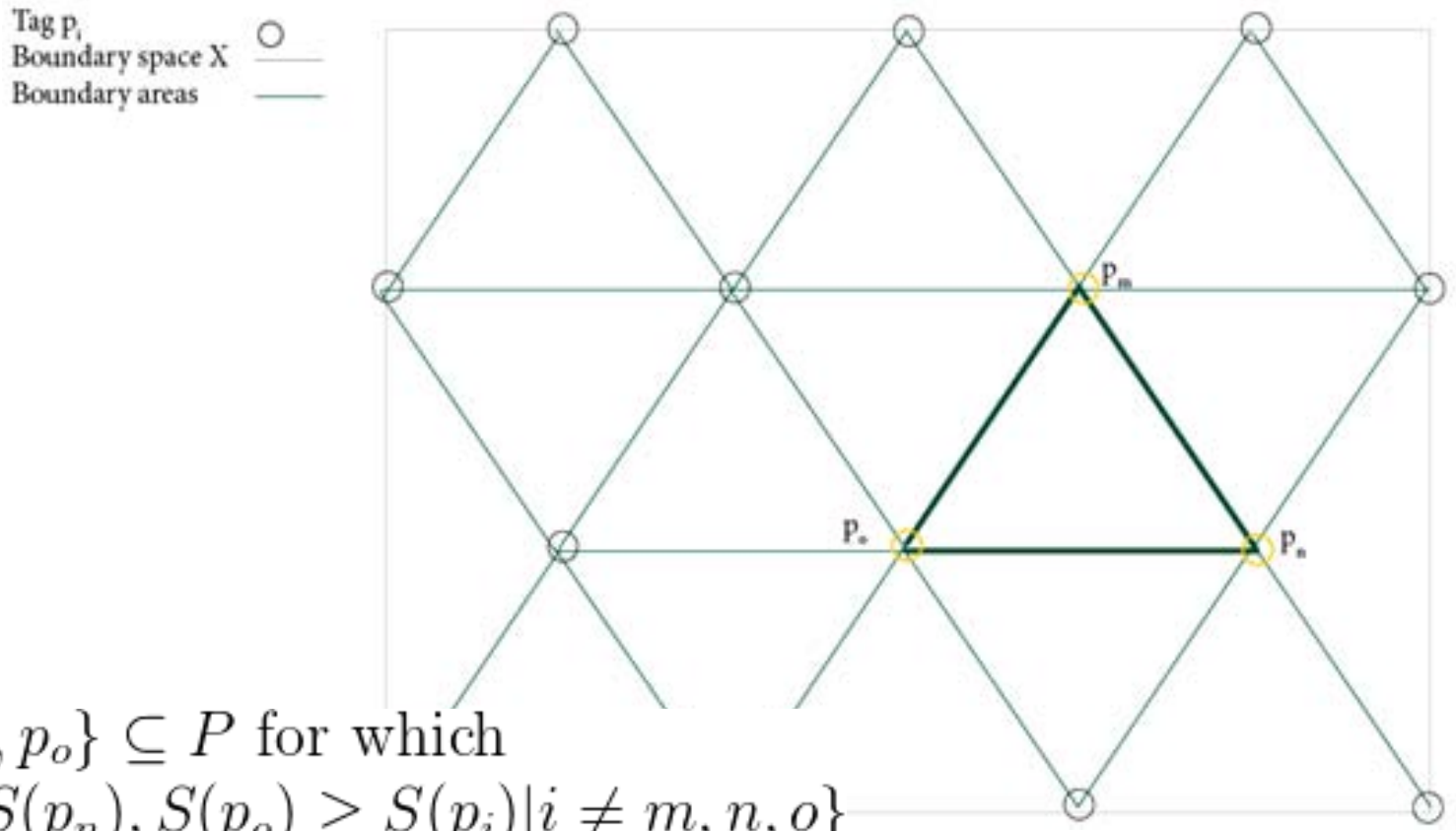


Proximity: area of interest

$$S_i = \frac{1}{n} \sum_{t=1}^{n} s_t$$

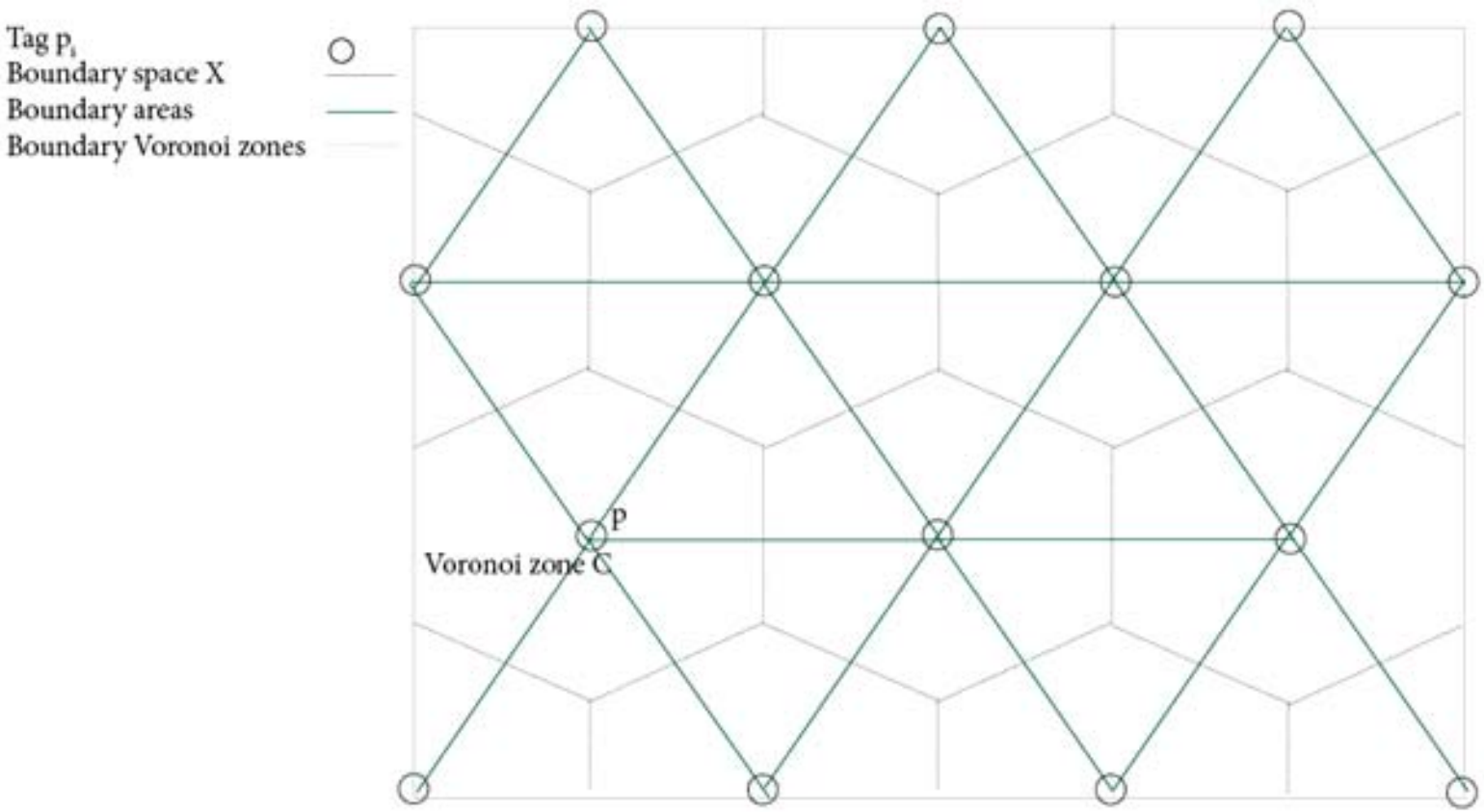


Proximity: area of interest



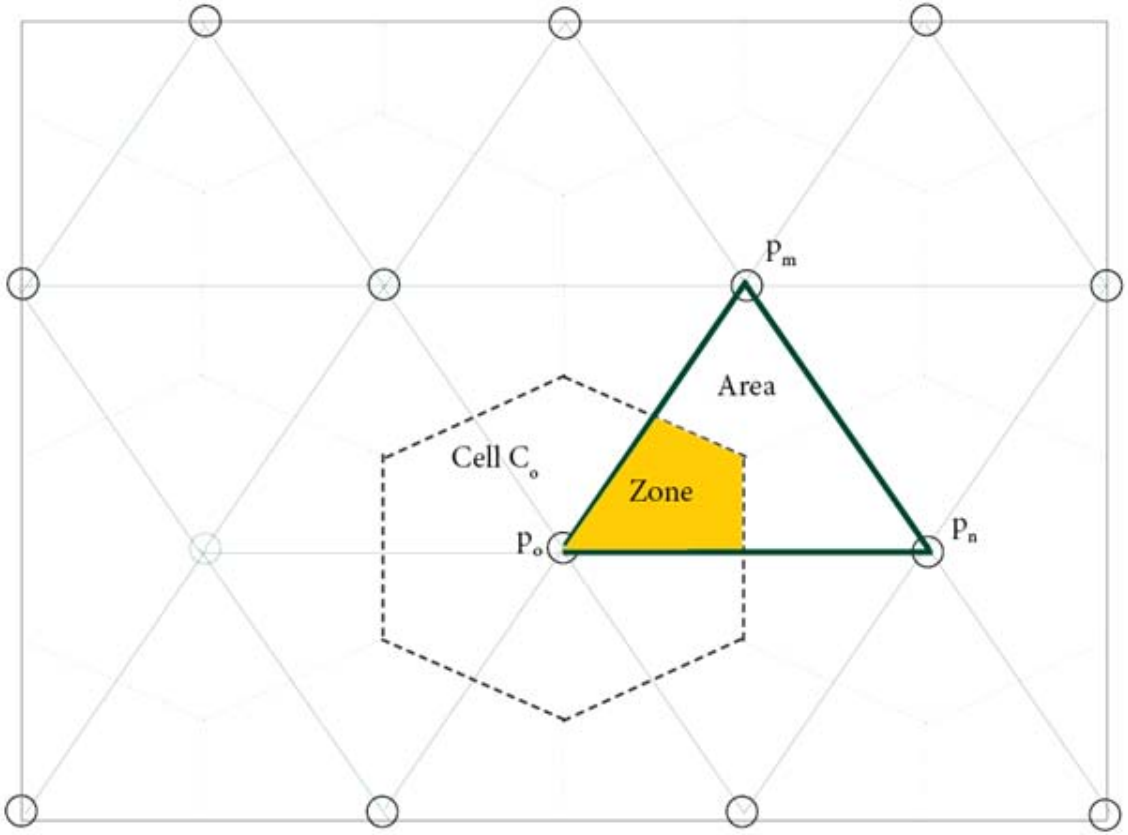
$$\{p_m, p_n, p_o\} \subseteq P \text{ for which}$$
$$\forall\{S(p_m), S(p_n), S(p_o) \geq S(p_i) | i \neq m, n, o\}$$

Proximity: zone selection



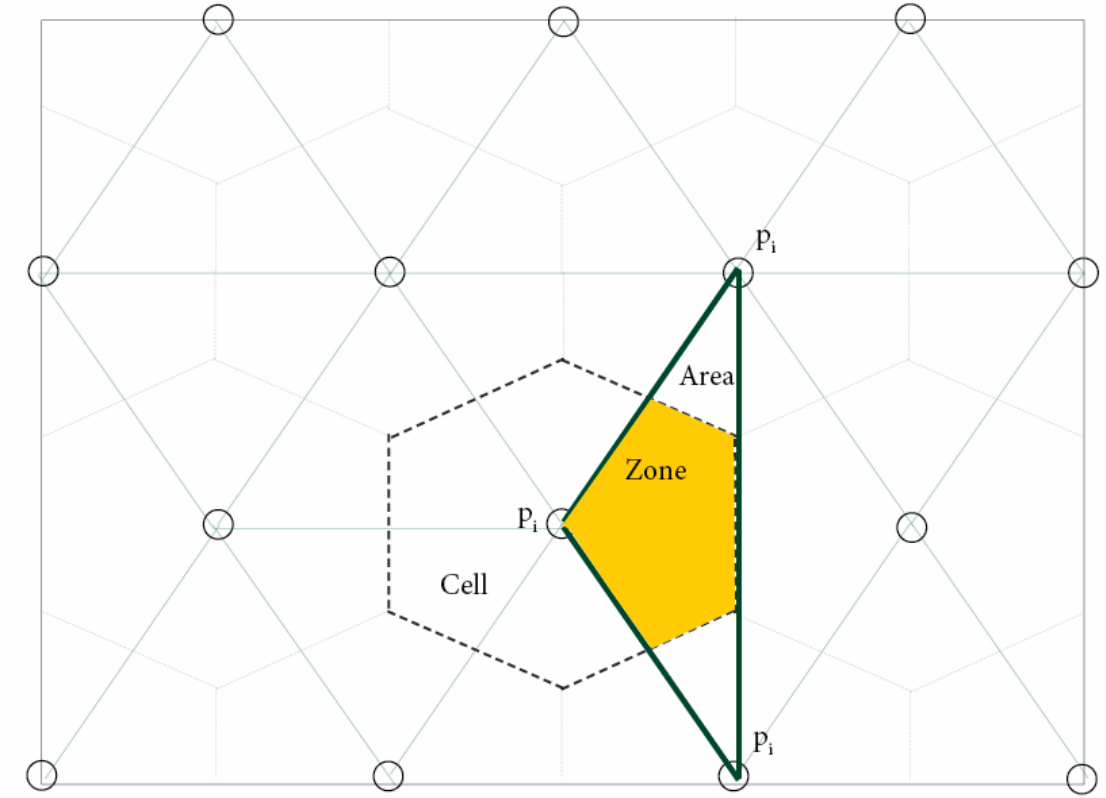
Proximity: zone selection

$$C_i \bigcap \Delta_i$$



Proximity: zone selection

Combining zones to create virtual places that are connected to a real places.



Software: indoor localization method

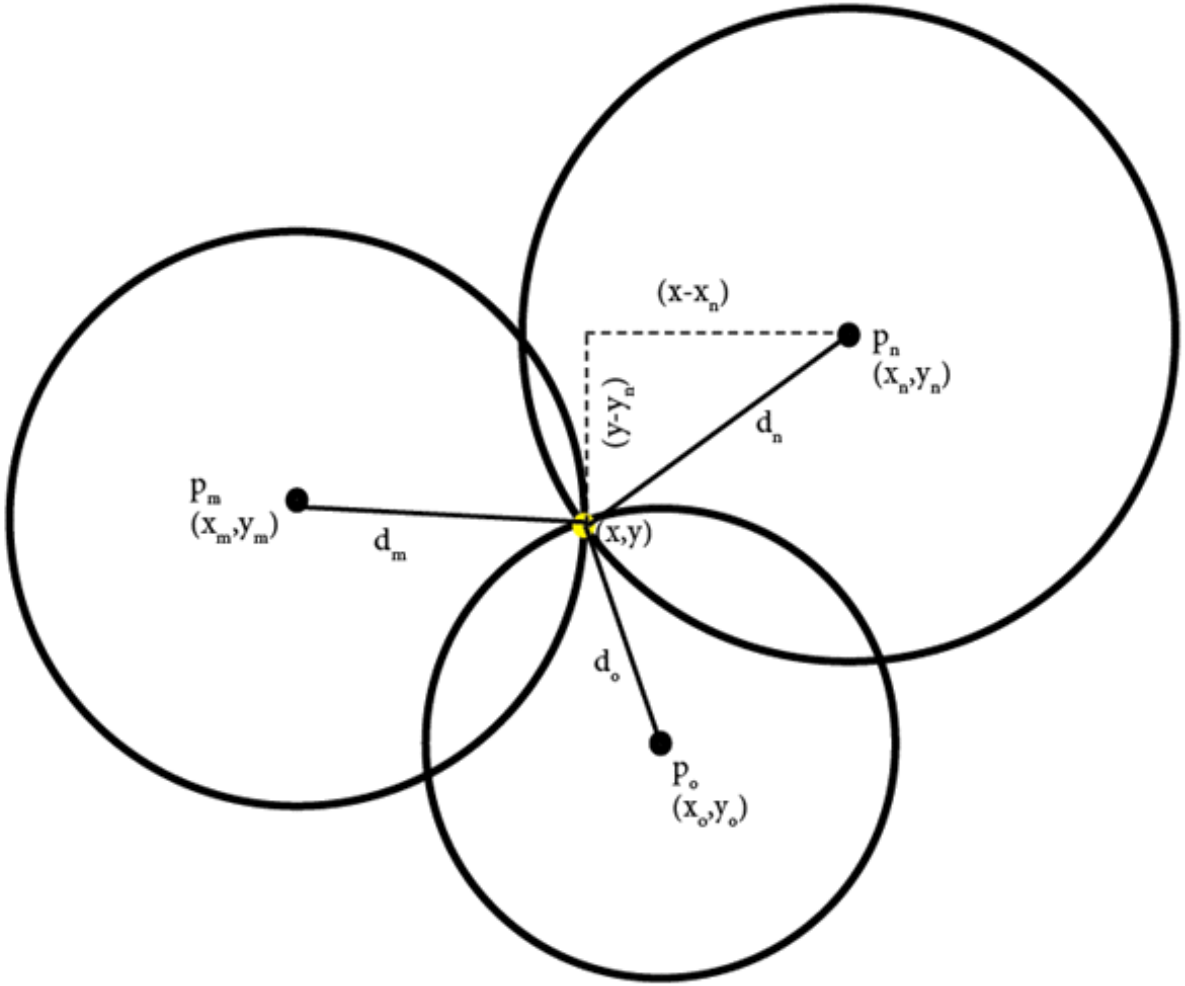
- Proximity approach:
  - Step 1: Area of interest
  - Step 2: zone selection → coarse localization granularity
- Distance approach → fine localization granularity
  - Option 1: Dependent algorithm
  - Option 2: PML

Distance approach: dependent algorithm

The dependent algorithm makes use of the earlier defined correlation between the distance and signal strength:

$$d_i = -5 * s_i - 68$$

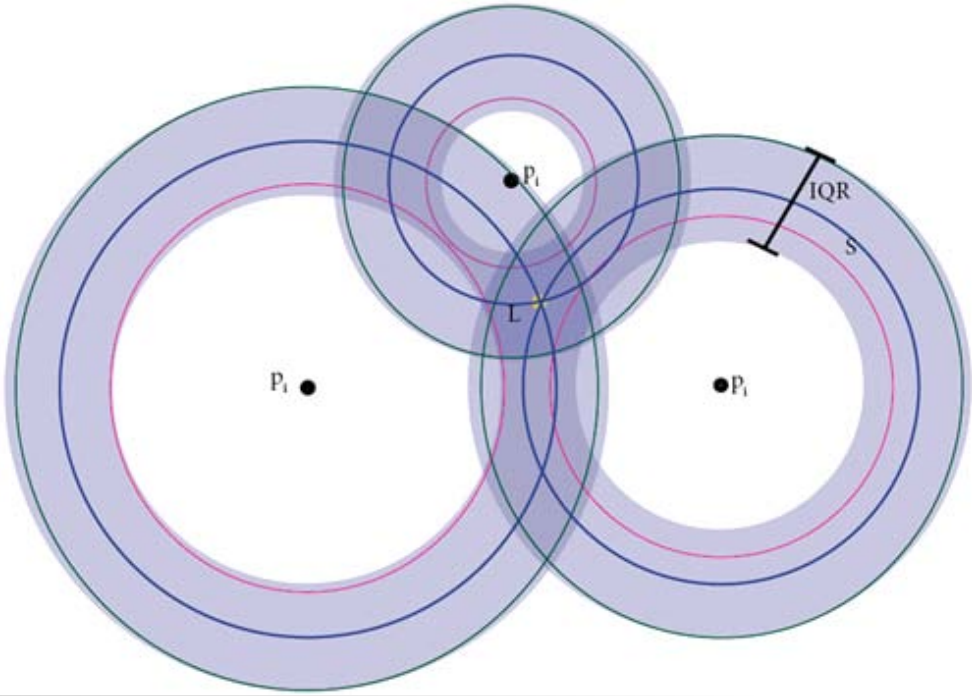
Distance approach: dependent algorithm



Dependent algorithm: computation

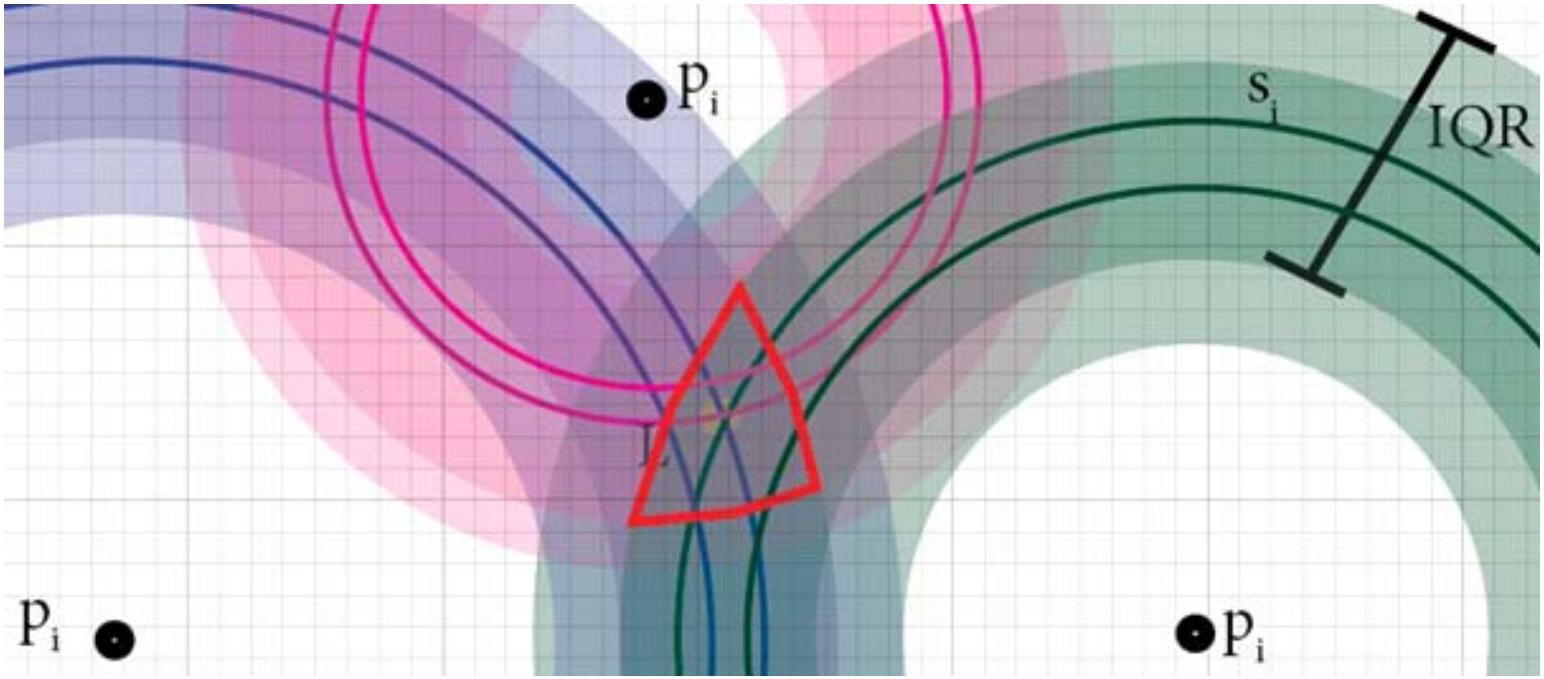
The Inter Quartile Range (measurement of dispersion) is quite large.

This means that the distances can vary with about half a meter which can lead to multiple intersection points, or no intersection points at all.



Dependent algorithm: computation

All cells with the distance belonging to the RSSI of the measurement is assigned a higher probability creating a circle of height probability cells around every tag.



Distance approach: PML

PML stands for Proportionate Measurement Localization.

PML is a method of localization done without any pre-knowledge of the sensor. For that reason, PML can be applied with any BLE sensor in hand.

Distance approach: PML

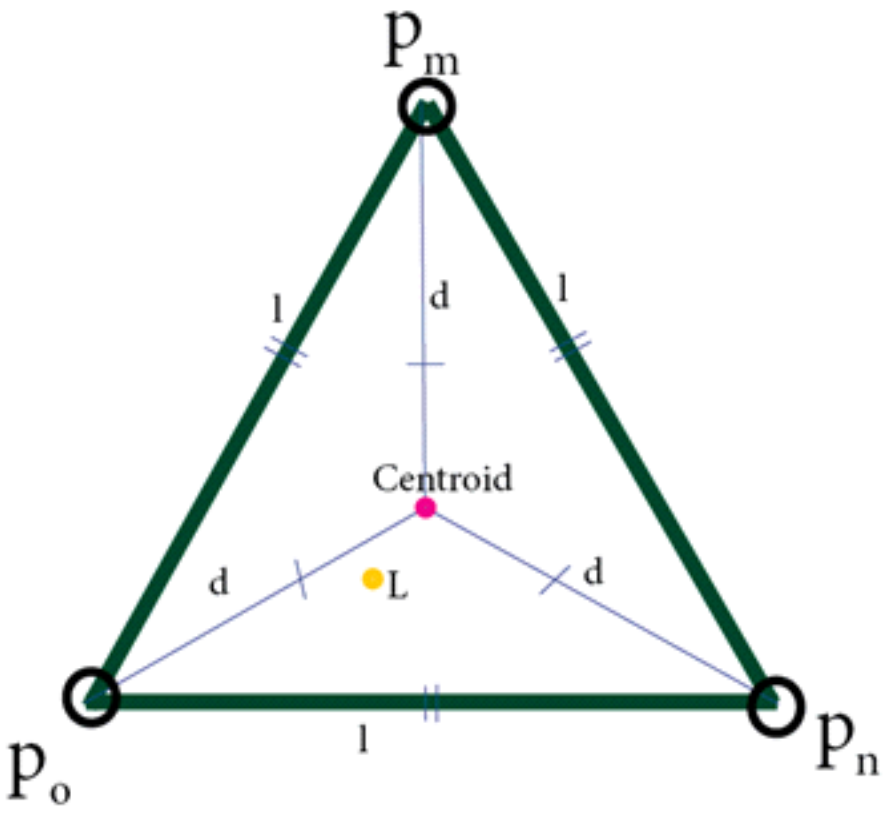
Assumption:

The linear correlation between the distance and signal strength is consistent no matter what sensor is used.

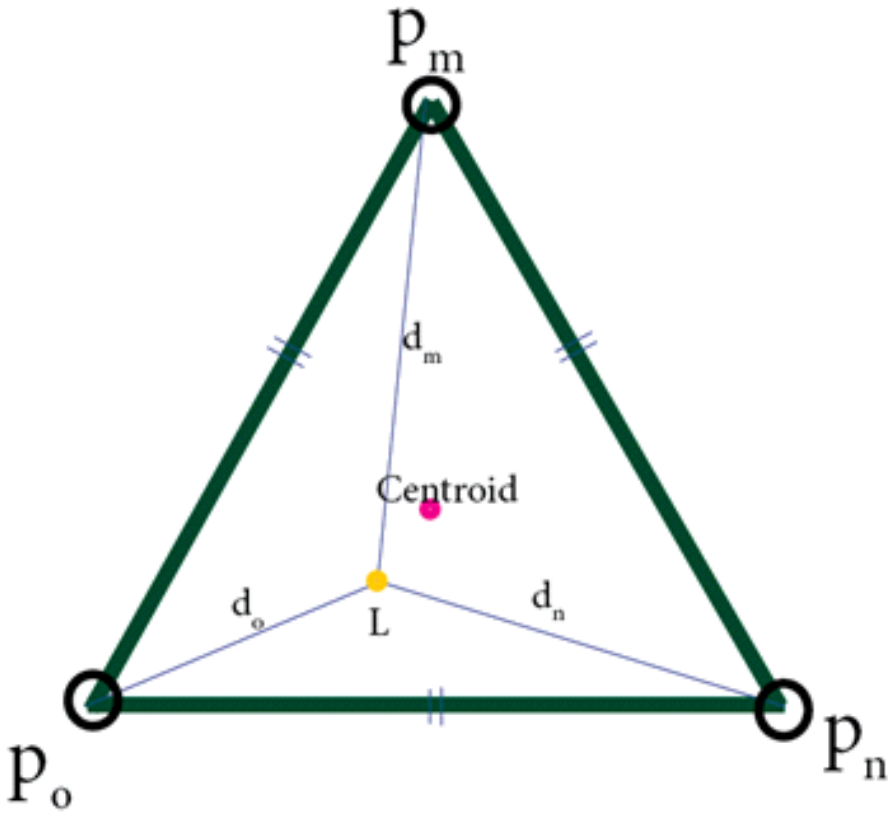
This means that in the function $d_i = -5 * s_i - 68$, the value -68 is no longer known. However, the slope of -5 is known and constant.

This means that every meter the tag and sensor are removed from each other, the RSSI decreases with 5.

Distance approach: PML

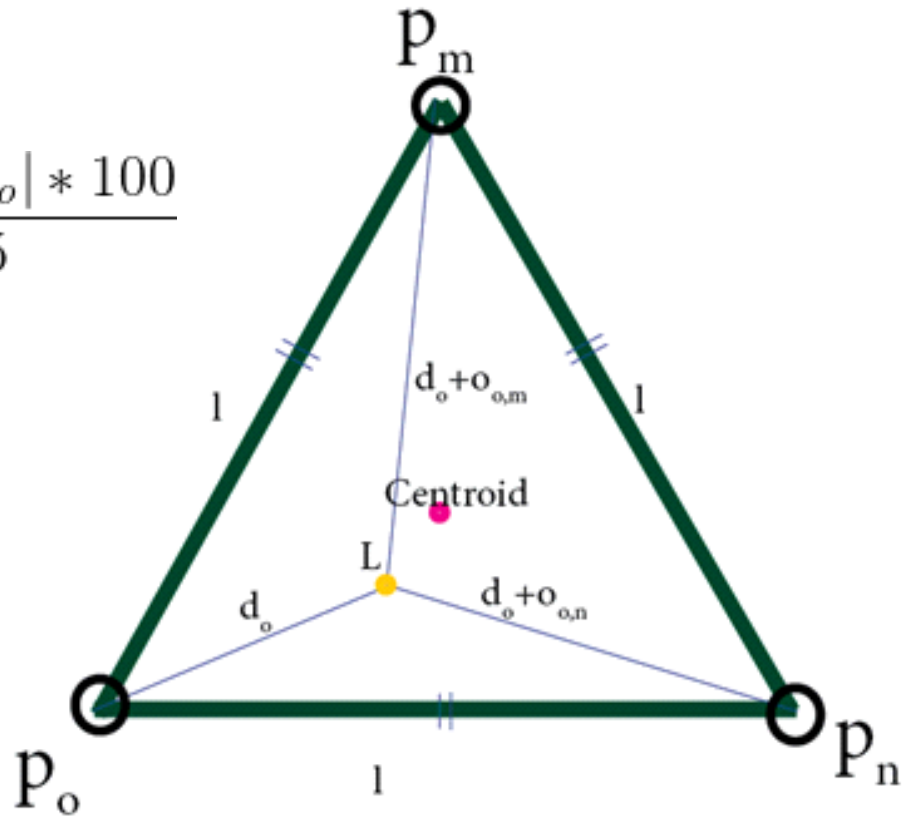


Distance approach: PML



Distance approach: PML

$$o = \frac{|S_n - S_o| * 100}{5}$$



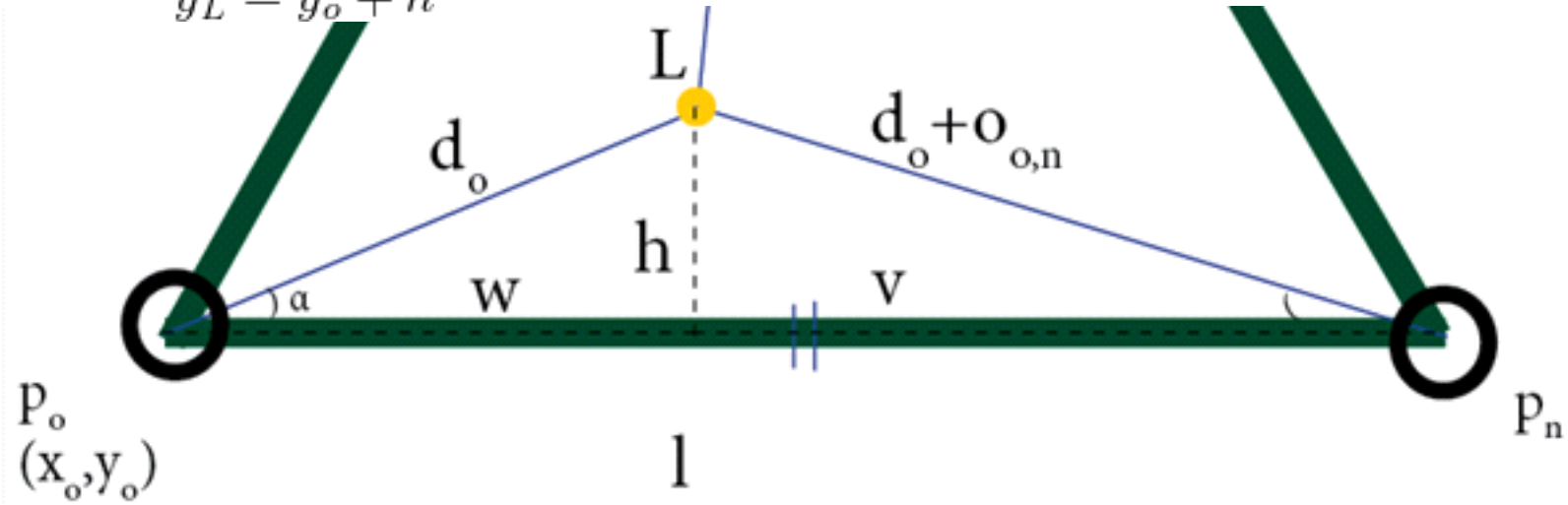
Distance approach: PML

$$\alpha = \cos^{-1}\left(\frac{l^2 - 2d_o o_{o,n}}{2l d_o}\right)$$

$$w = \cos(\alpha) * d_o$$
$$h = \sin(\alpha) * d_o$$

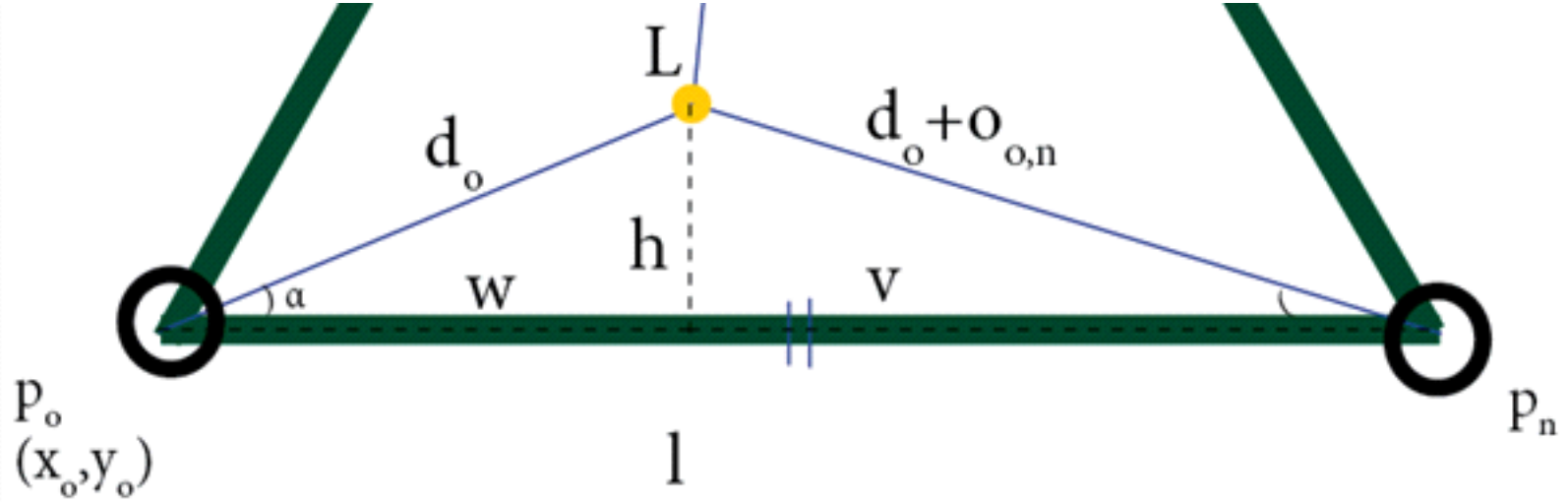
$$x_L = x_o + w$$

$$y_L = y_o + h$$



Distance approach: PML

The issue is solved computationally by applying an iteration implicitly finding the d_o for which $w + v = l$



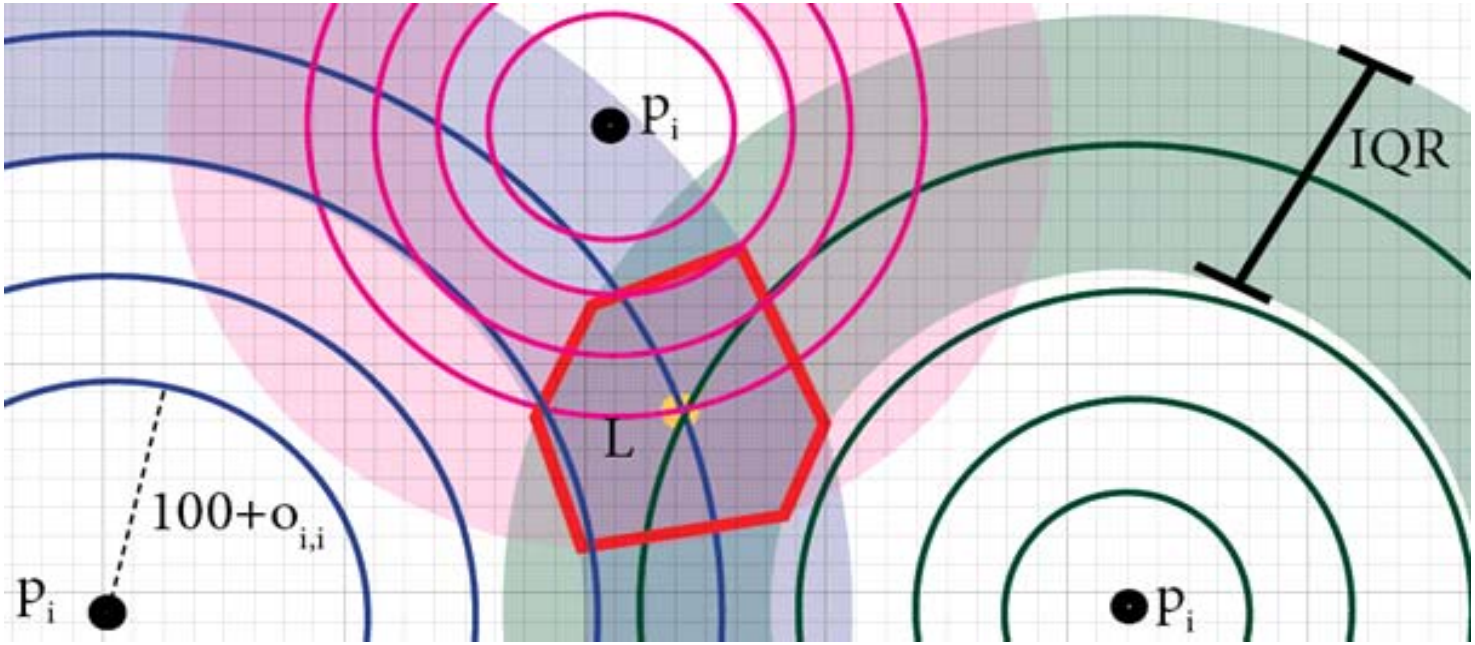
PML: computation

Circles are created around each tag with a radius equal to 100 cm + the offset o.

The circles are simultaneously enlarged until they overlap.

PML: computation

The grid cells within the IQR of the measurement are assigned a probability, when the three circles overlap, the probability of these grid cells increase.



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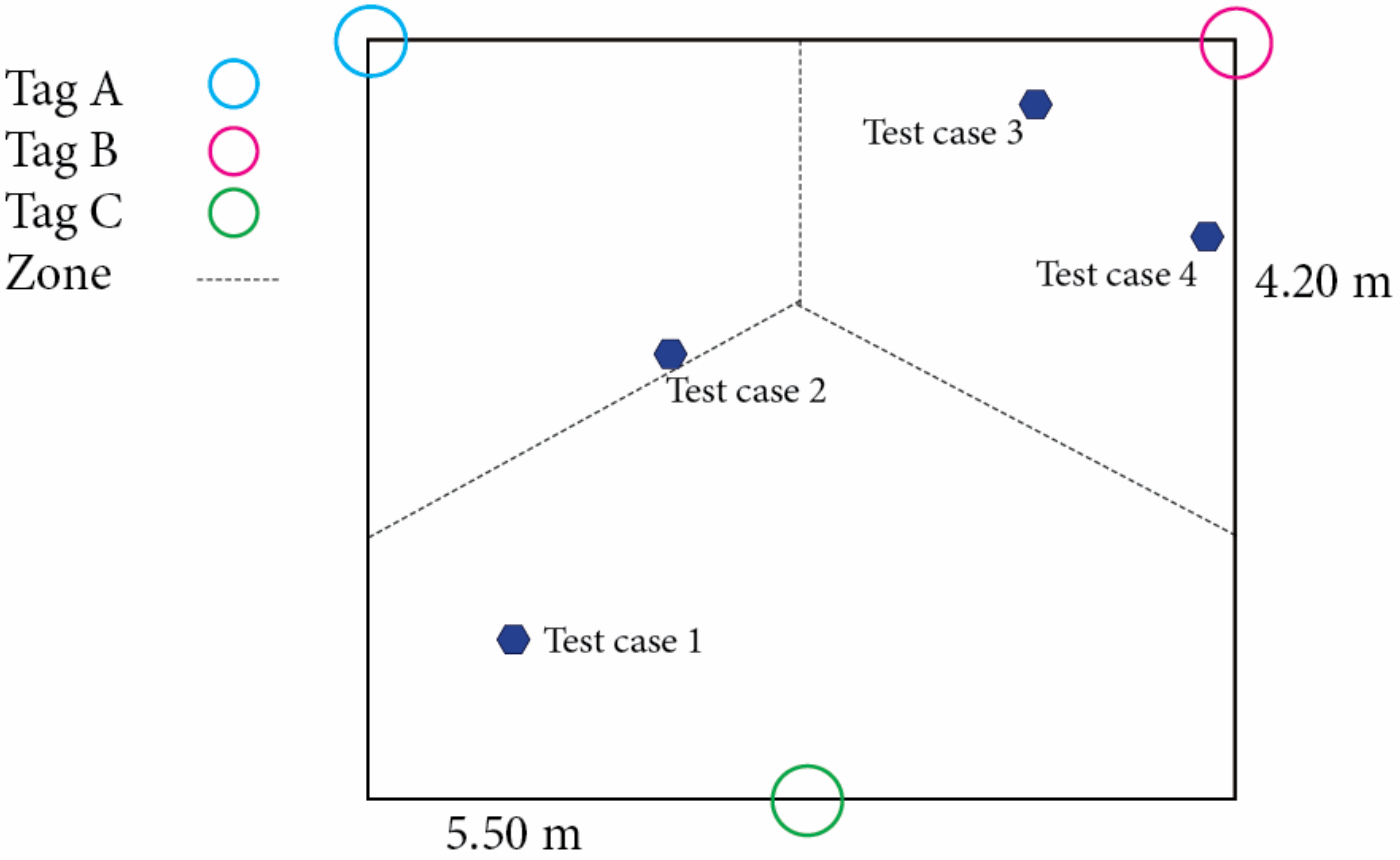
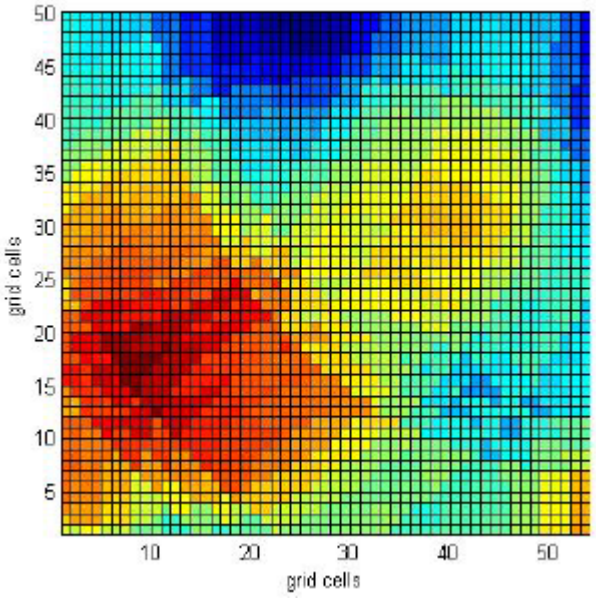
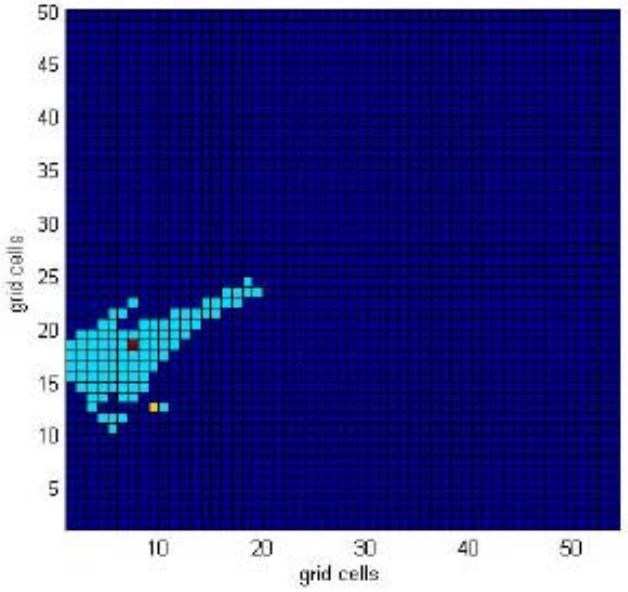
- Tests and results
  - Test case 1: clear difference in distance from each tag
  - Test case 2: the boundary of two zones
  - Test case 3 and 4: distinction comparable locations
- Conclusions and recommendations

Tests and results

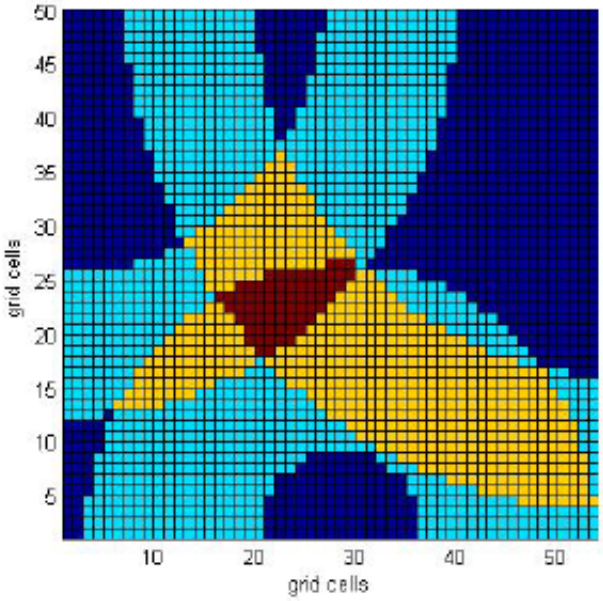


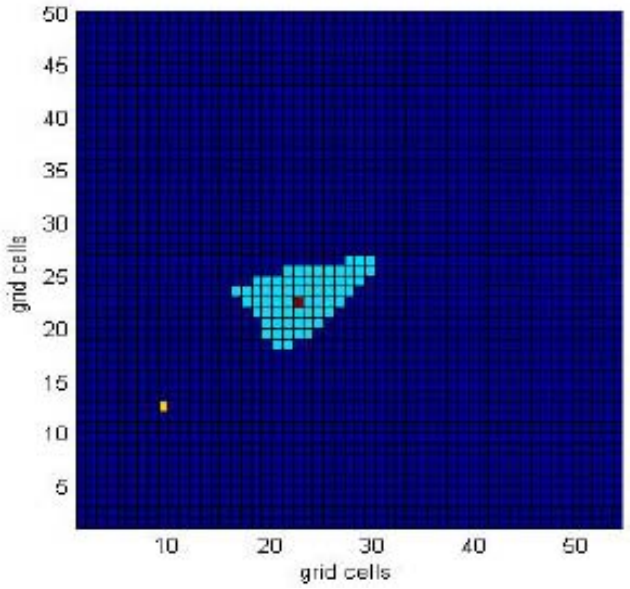
Test case 1: Dependent Algorithm



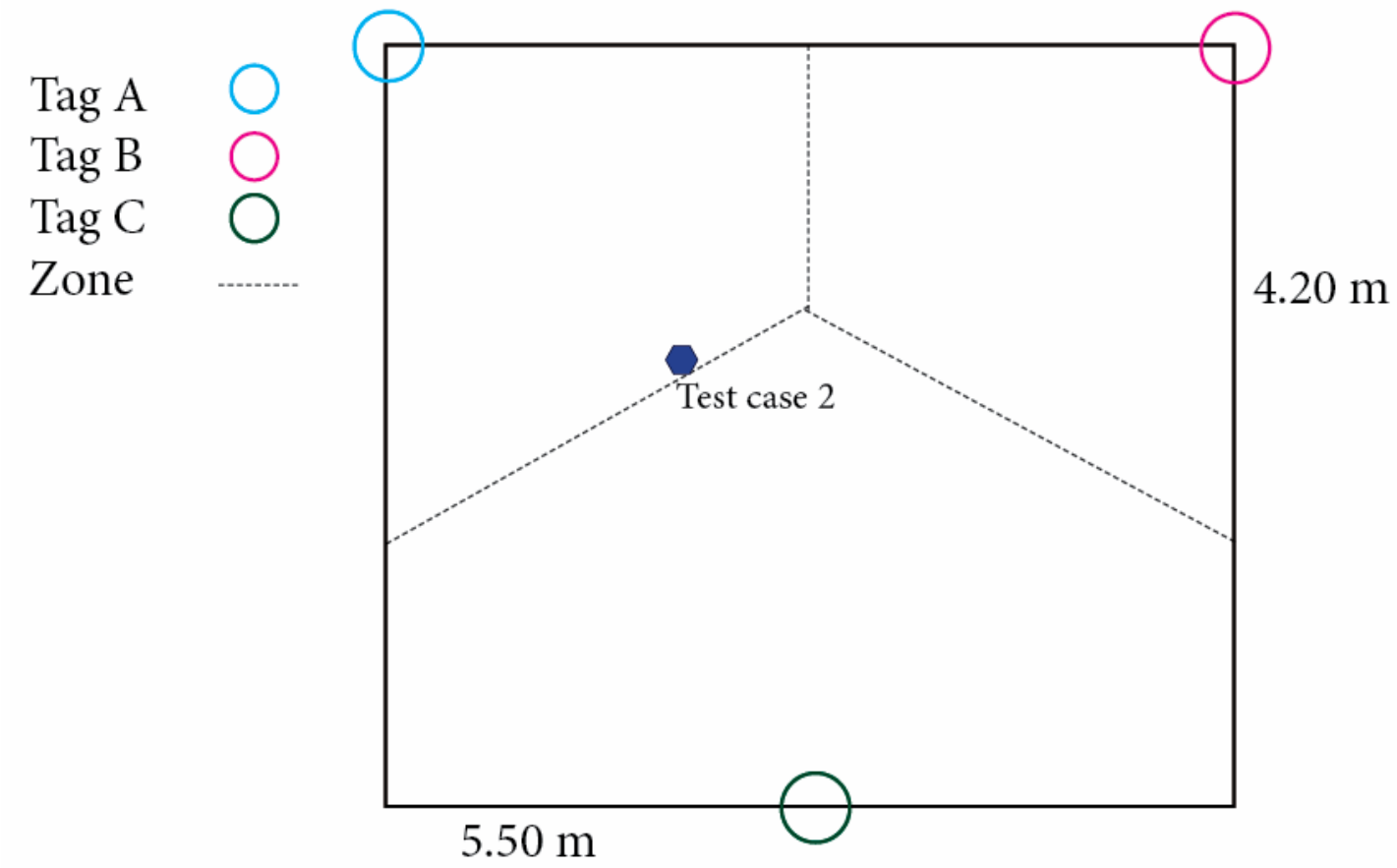


Test case 1: PML

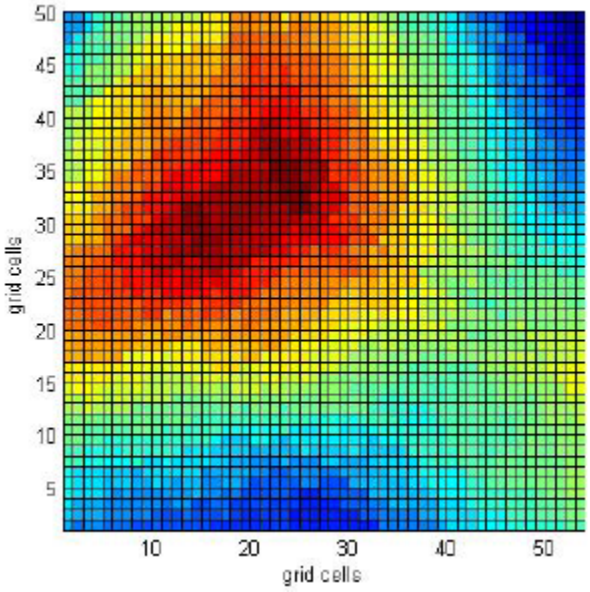


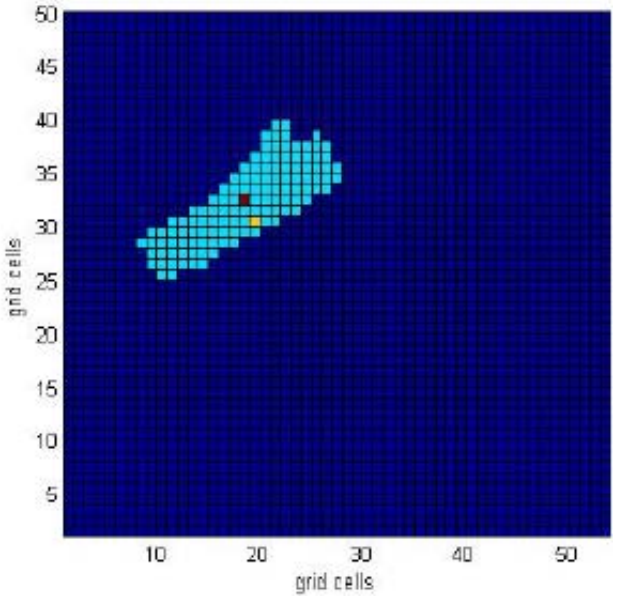


Test case 2

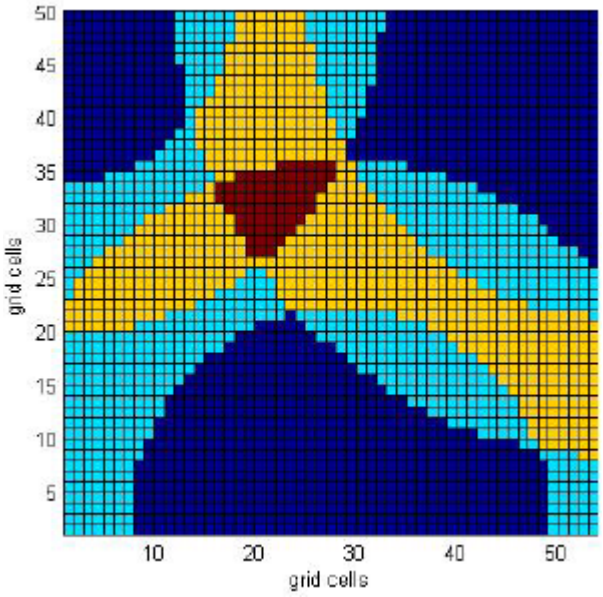


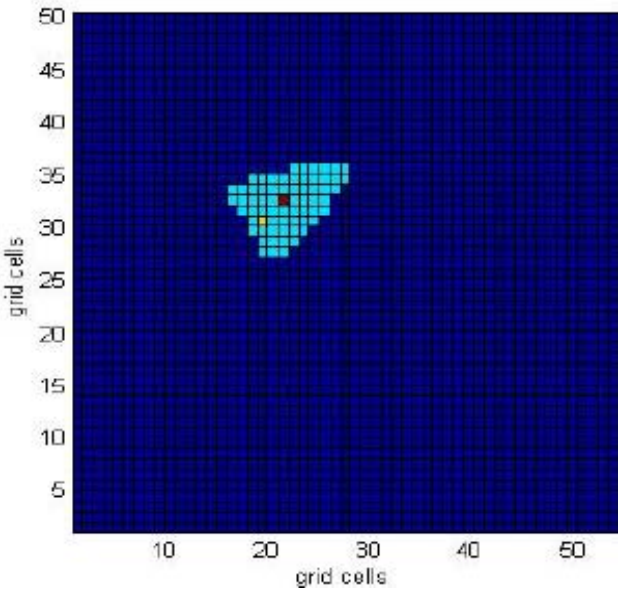
Test case 2: Dependent Algorithm



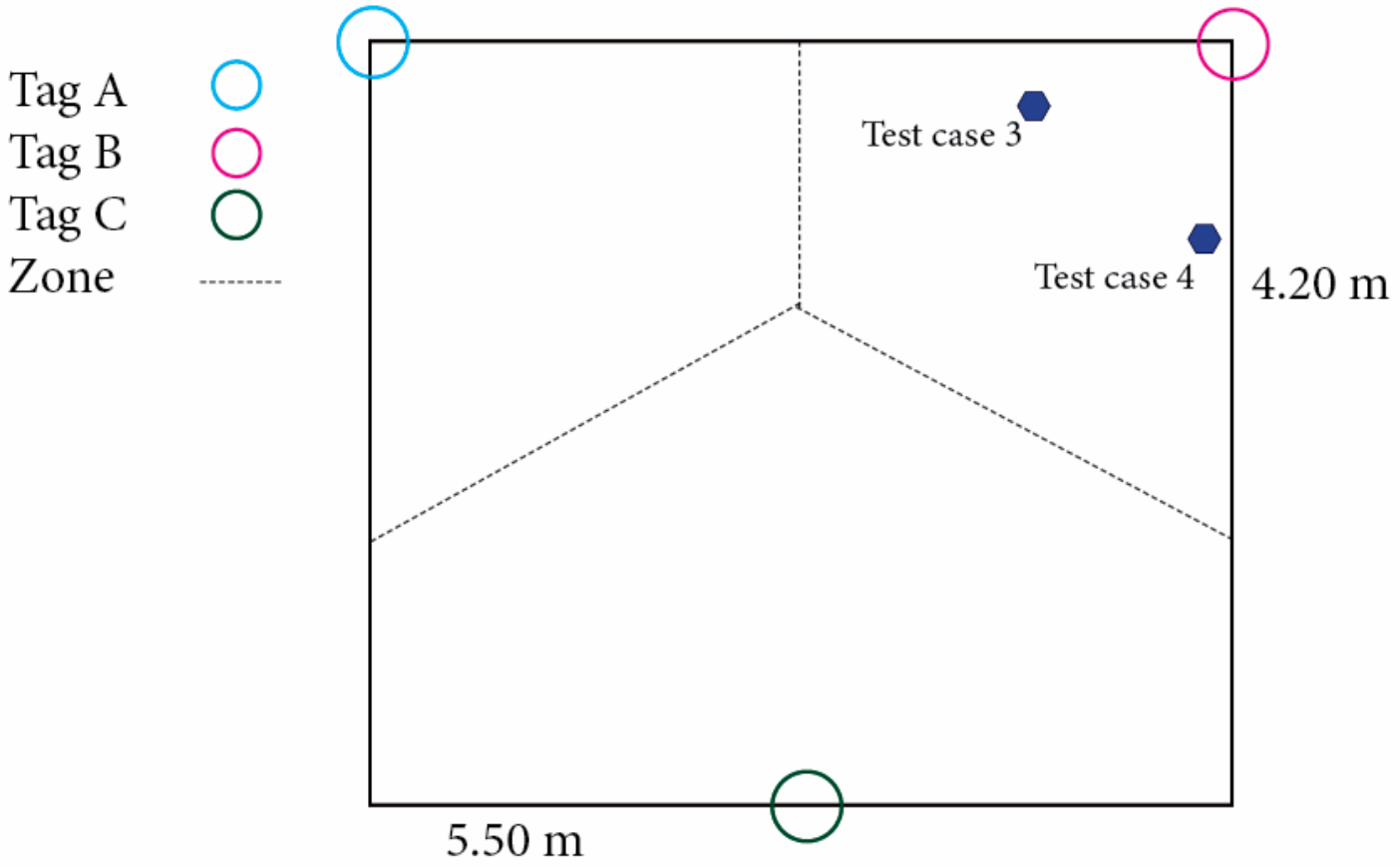


Test case 2: PML

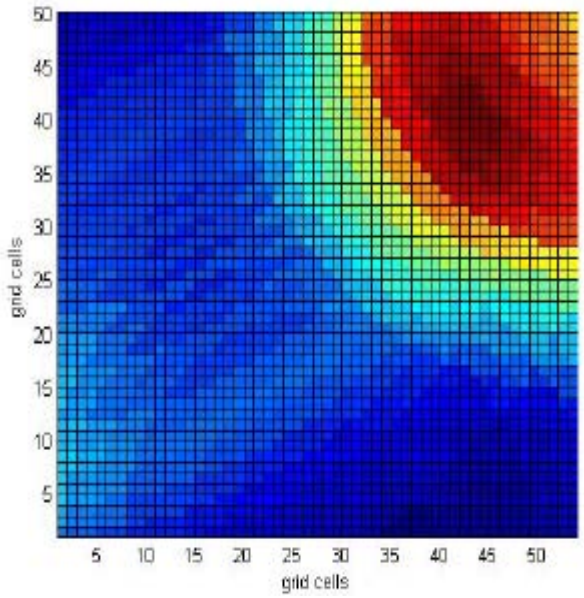


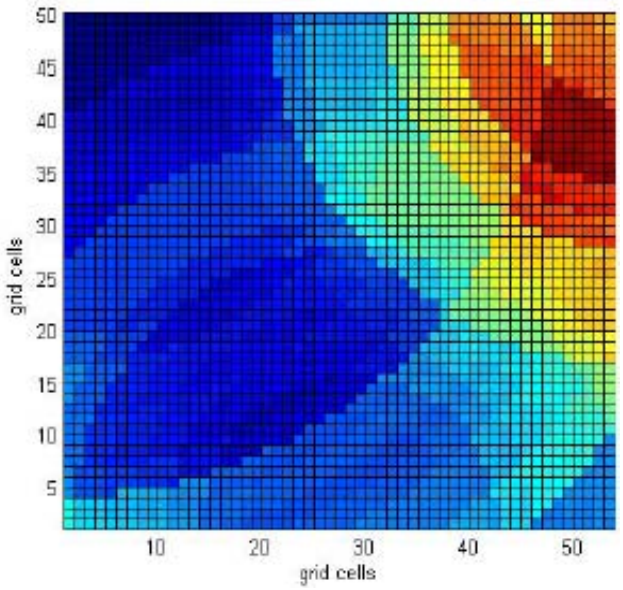


Test case 3 & 4

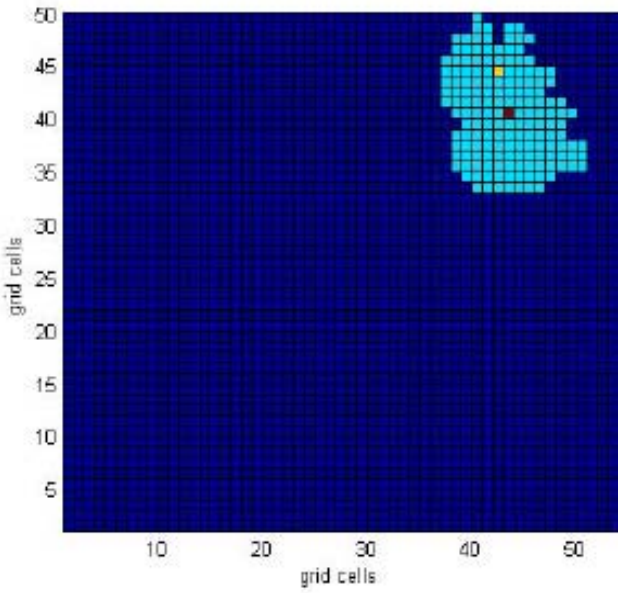


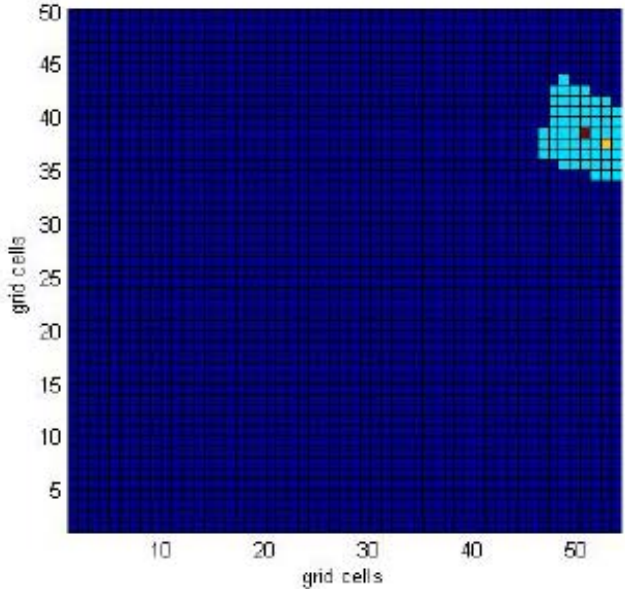
Test case 3 & 4: Dependent Algorithm



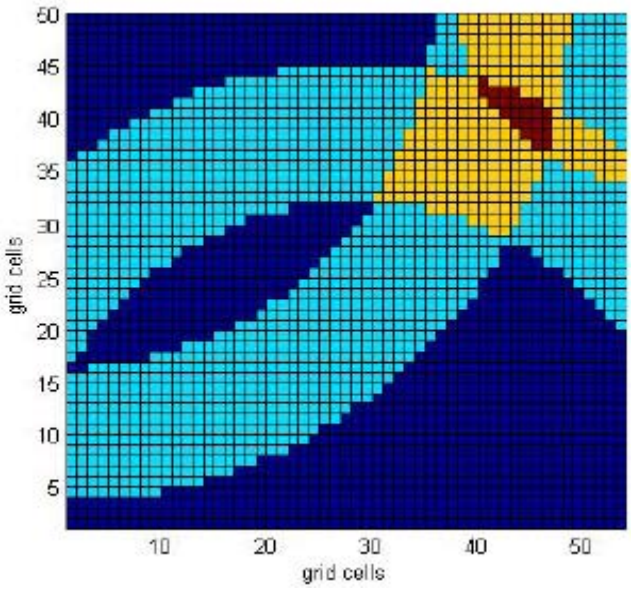


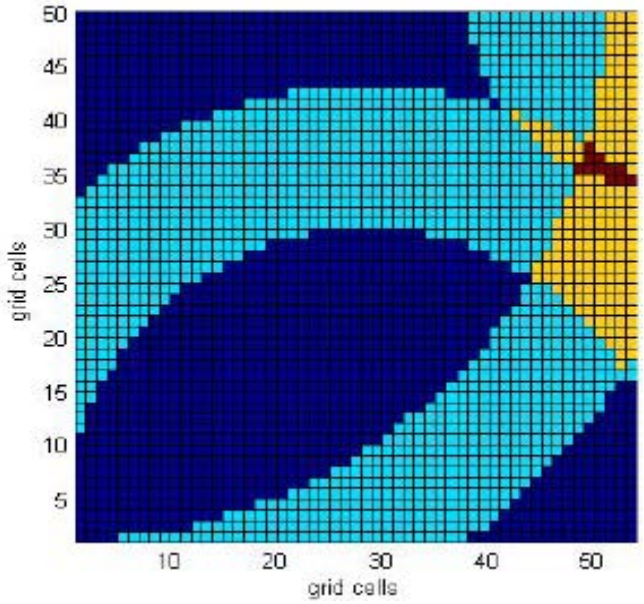
Test case 3 & 4: Dependent Algorithm



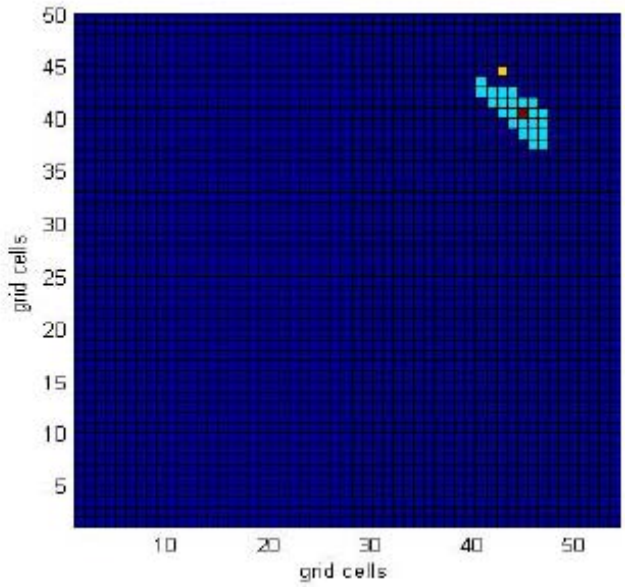


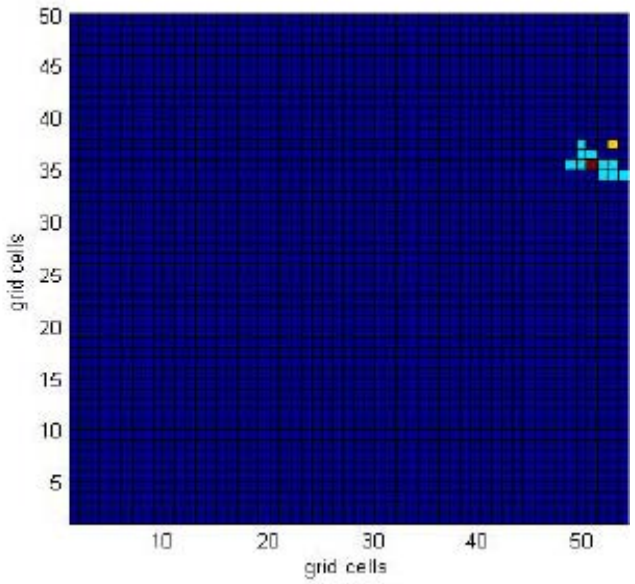
Test case 3 & 4: PML





Test case 3 & 4: PML





Test and results

Zone selection is correct in all cases.

The dependent algorithm shows a differentiated result and localizes in most cases within half a meter of the centroid.
Distances between the centroid of the computed area and the actual location are slightly larger for the PML.

Although it is difficult to draw hard conclusions on the capabilities of the algorithms from merely four tests, the results look promising.

Distance (cm) between centroid computed area and actual location sensor	Test case 1	Test case 2	Test case 3	Test case 4
Dependent algorithm	38	12	51	19
PML	173	19	53	24

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  - Distance approach
- Tests and results
  - Test case 1: clear difference in distance from each tag
  - Test case 2: the boundary of two zones
  - Test case 3 and 4: distinction comparable locations
- Future work and conclusions

Future work and Oppertunities

- Expand tests in more complex and larger environments.
- Applying and testing of the zone selection combined with constrained triangulation.
- Hardware improvements with solar cell.
- Expand to tracking algorithm with particle filter.
- Possibility of combining object localization with localization sensor.

Conclusions

- UHF RFID is sensitive to environmental influence which leads to inconsistent proximity indication.
- The linear correlation between RSSI and distances between 1 and 6 meters makes BLE suitable for indoor localization.
- Although the dependent algorithm generally returns a better result than the PML algorithm, the PML method is preferable since PML functions without pre-knowledge of the type of sensors.

Conclusions

The hardware is scalable in price and can become scalable in maintenance-costs if the hardware is provided with a small solar cell. The characteristics of BLE make it adaptive to different shapes and forms of buildings.

The influence of environmental factor on BLE seems to be limited and it can be considered a robust technique. Combining this with the proposed localization method (PML), which can be applied in a variety of rooms and irregular spaces with any type of sensor, makes the combination extremely flexible, scalable and widely applicable.

Thank you

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