Impact of Channel Access on Localization in Cooperative UWB Sensor Network: a Case Study

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Outline

- Introduction
- System Description
- Experimental Results
- Conclusions

Introduction

Introduction

Localization in WSNs is needed in many applications:

- Fire detection
- Object Tracking
- ... and more...

Standard algorithms rely on having enough range informations from fixed-position nodes to perform localization, but:

- Not always enough Anchors are reachable
- Channel can be noisy
- Some node can be faulty

<u>Localization accuracy can be degraded!</u>

Cooperation

To cope with these problems, cooperation between radios can be exploited:

- Each radio can work as Anchor or Agent, depending on the request received
- Information about positions and ranges are exchanged between all the radios
- Data packet can also be forwarded through all the radios

Pros:

- Increase of localization accuracy
- Better network coverage
- Energy saving

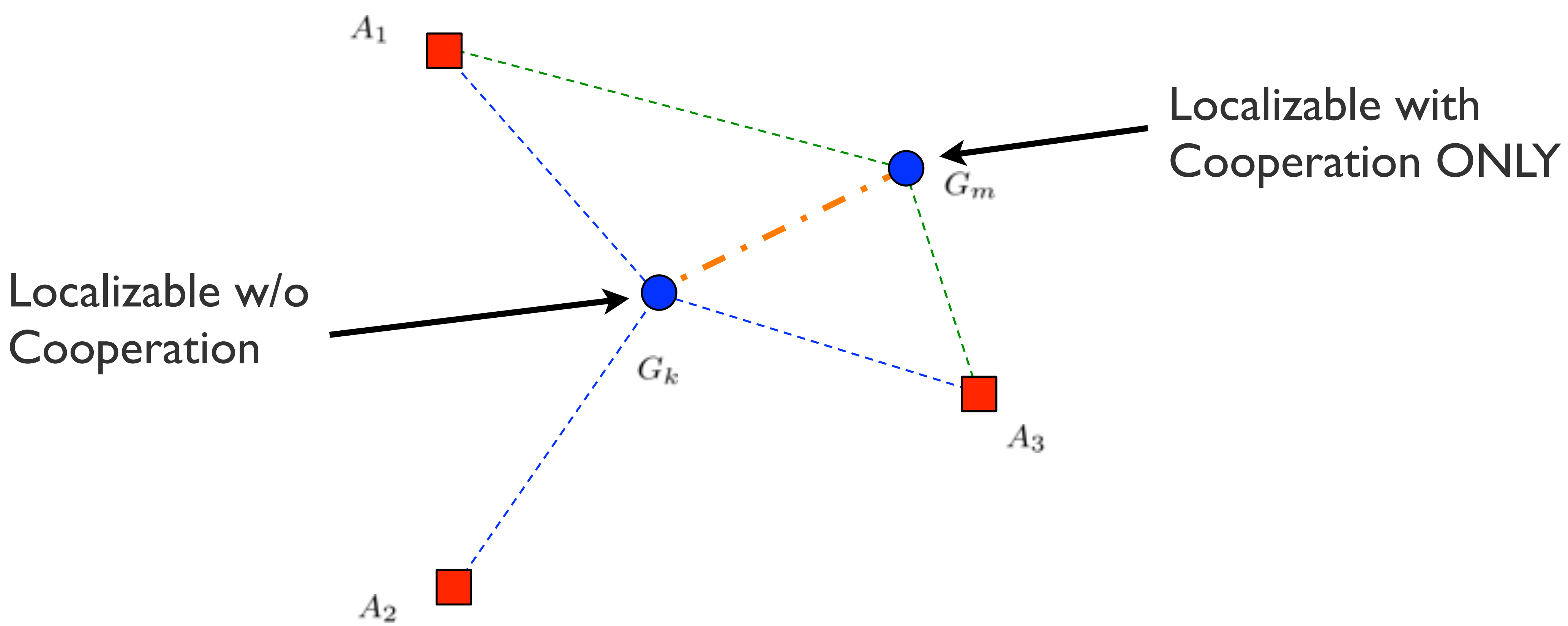
Cons:

- Network complexity increased
- Collisions may occur

Channel access control needed!

Cooperation

- In standard localization networks agents exchange information with anchors only: this can limit the performances and the feasibility of the localization
- In cooperative networks each agent exchange information with all the others (anchors and agents too): in this way it's possible to increase the amount of position information and improve localization accuracy.



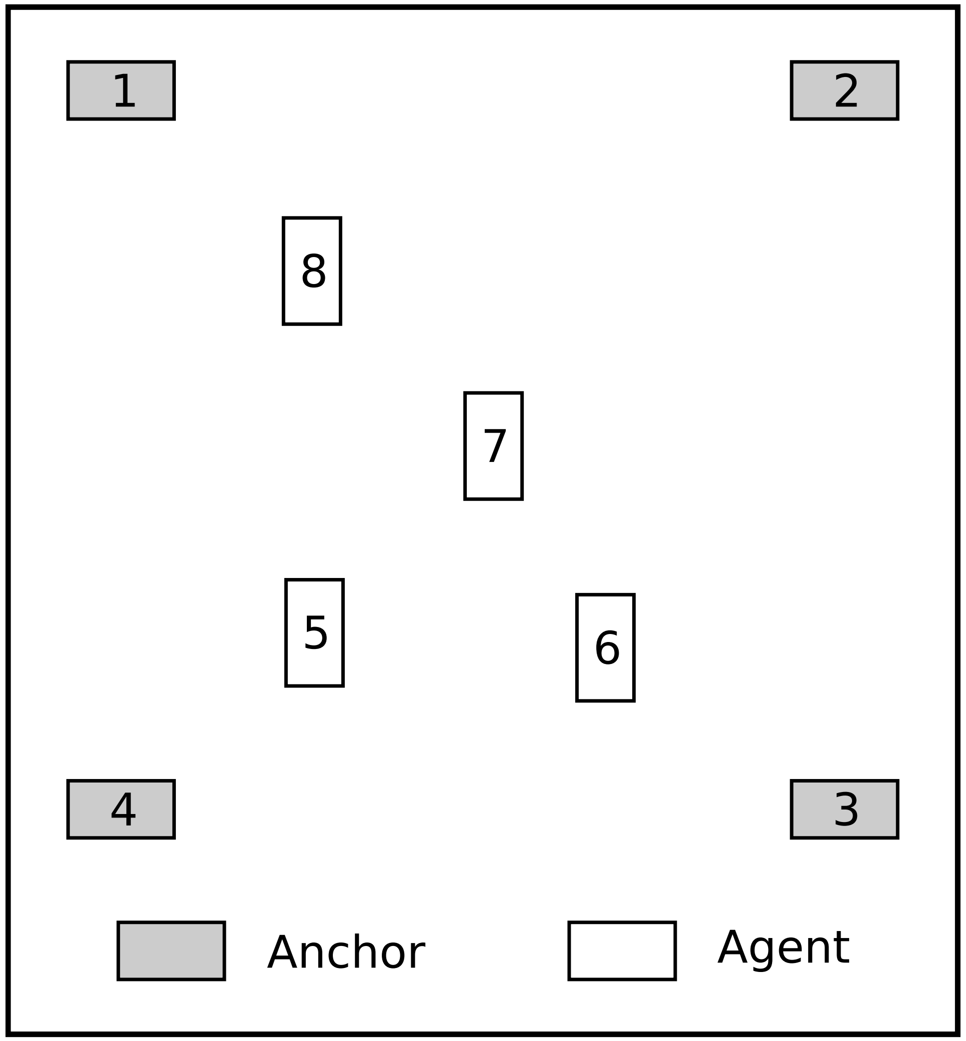
System Description

Network Topology

A cooperative network has been deployed in a 6 x 6 meters room, using PulsOn P220 UWB radios, able to reach an accuracy of 10cm in LOS:

- 4 Agents, 4 Anchors
- All antennas were in LOS
- Static scenario (no motion)
- The position of all nodes is kown (for data analysis purpose)

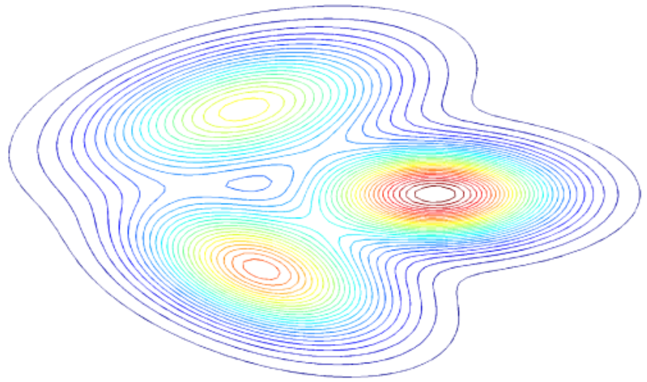
All nodes share the same radio channel, and they can exchange range or data packet, depending on the instruction received.



Cooperative Localization Algorithm

To estimate nodes' positions a Loopy Belief Propagation (LBP) algorithm has been implemented:

- Each node knows his position with probability distribution (Belief)
- For each localization algorithm step, this probability is updated with the one coming from the other node (Belief Update)



This algorithm runs over the on-board radio processor, so no external HW is needed to perform localization.

Data about position informations, time and packets exchanged between radios are logged on a remote PC for the off-line data analysis.

Cooperative Localization Algorithm

Localization Algorithm Steps:

1. A node (Requester) asks for a range measurement to another one, regardless if it is an Agent or an Achor
2. The recipient (Responder) will perform a range measurement with a TOF technique and sends the distance and its belief back to the requester
3. The requester will update its belief with the information received

Range measurements are obtained evaluating the Time of Flight of a specific signal sent between two radios.

Problem:

Collisions between packets might lead to a loss of information and localization accuracy may be affected.

Collision Avoidance Implementation

Usually, a sensing of the channel before transmitting is done to check if the medium is used or not from another radio. Out of luck, UWB Radios don't have a Sensing hardware, so we are not able to know anything from the channel.

Thus, we developed an ALOHA-like scheduling algorithm able to overcome this lack using some Library Calls:

1. Use the *Listen* function to listen for an incoming packet (since all the transmissions are broadcasted all the packets on the medium can be received)
2. If no pakets are received the channel should be free, so transmit the packet
3. If something is received then the channel should be busy; so, wait for a random exponential time and repeat the steps from the beginning

Test Design

Three sets of tests had been done:

- Each Agent talks with Anchors only (no Cooperation)
- Each Agent talks with Anchors and Agents
- Each Agent talks with all Agents and with two Anchors only

For each test, two sub-tests were made:

- With Access Control
- Without Access Control

Max iterations allowed: 30

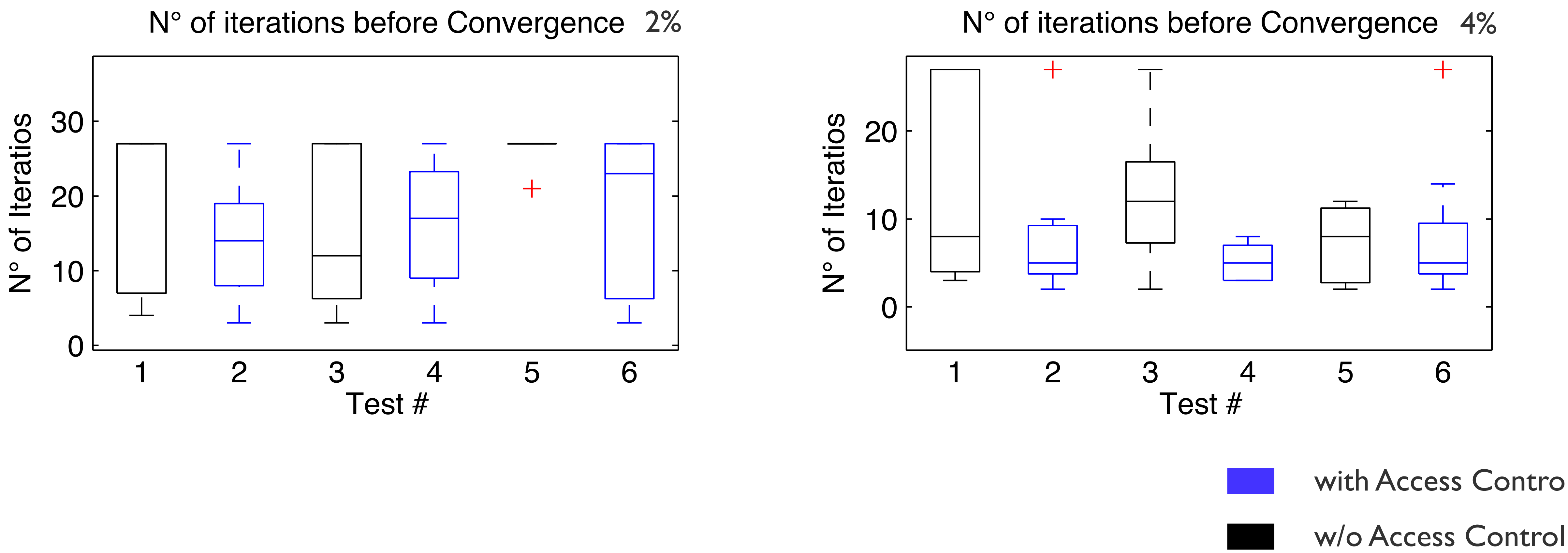
Test #	Test Description	Access Control
1	Each agent talks with anchors only	No
2	Each agent talks with anchors only	Yes
3	Each agent talks with anchors and other agents	No
4	Each agent talks with anchors and other agents	Yes
5	Each agent talks with two anchors only and with other agents	No
6	Each agent talks with two anchors only and with other agents	Yes

Test Design

- We repeated each test many times to have a statistical distributions of resulting values
- We consider the algorithm converged if the estimated position does not change for more than a certain percentage - a threshold - from a number of previous measurement
- Two threshold were used: 2% and 4%

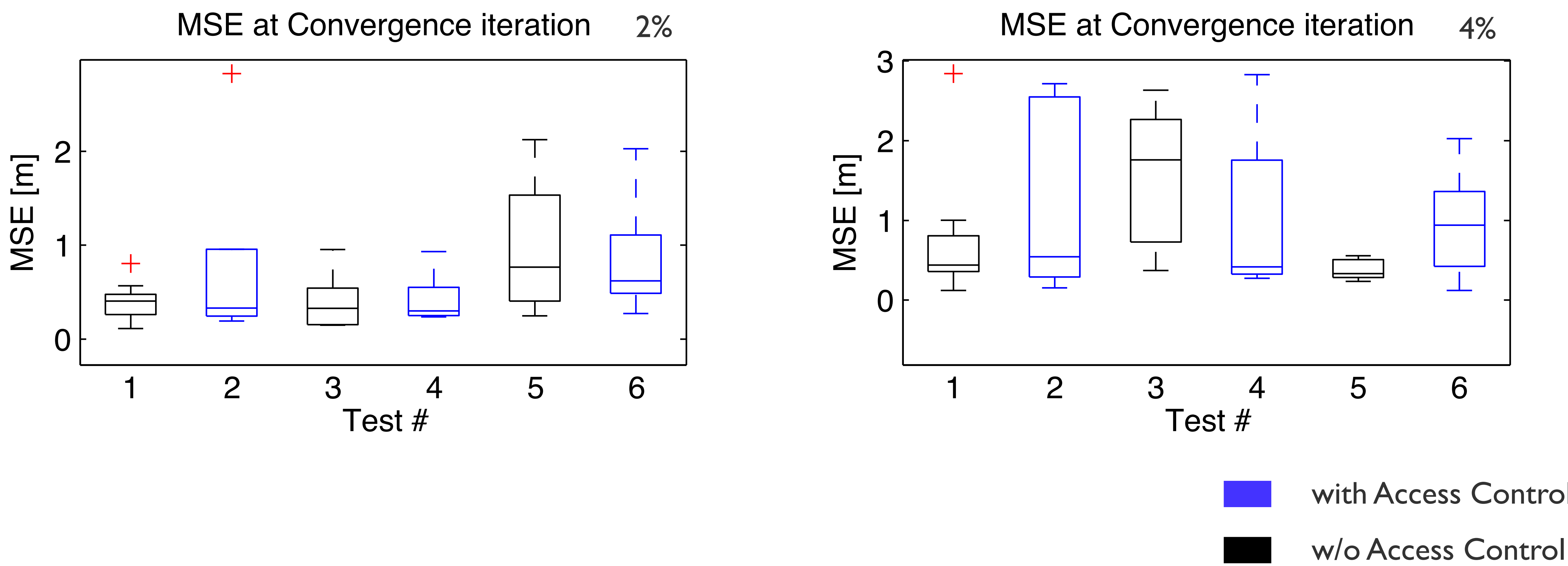
Experimental Results

Number of Iterations



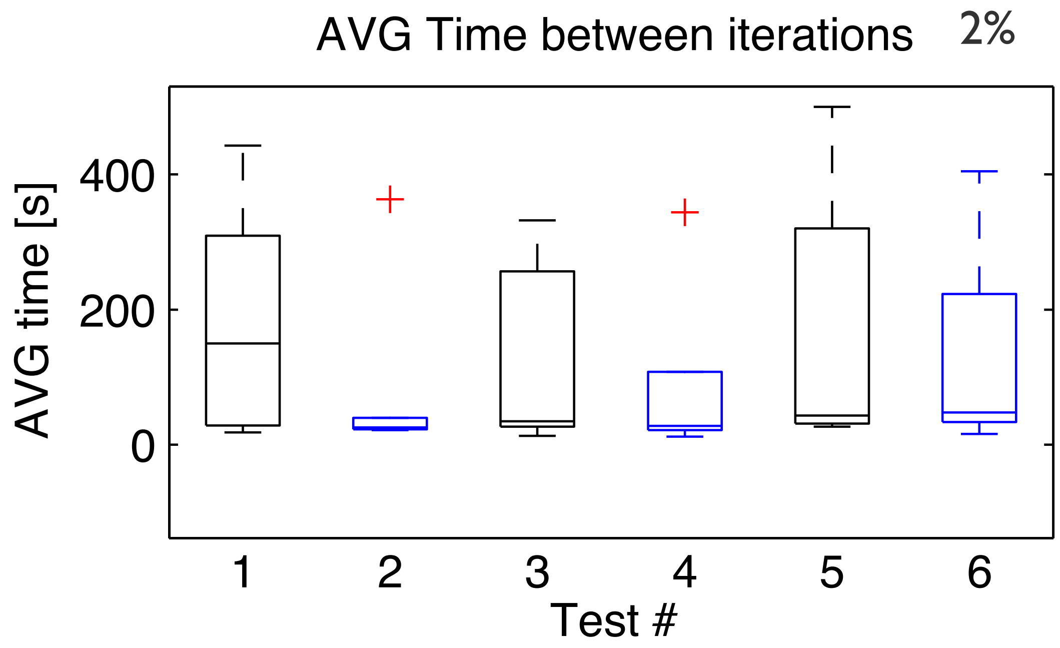
- Less iterations needed to reach convergence with active Access Control
- The Collision avoidance speeds up the convergence, expecially in the 4% threshold case

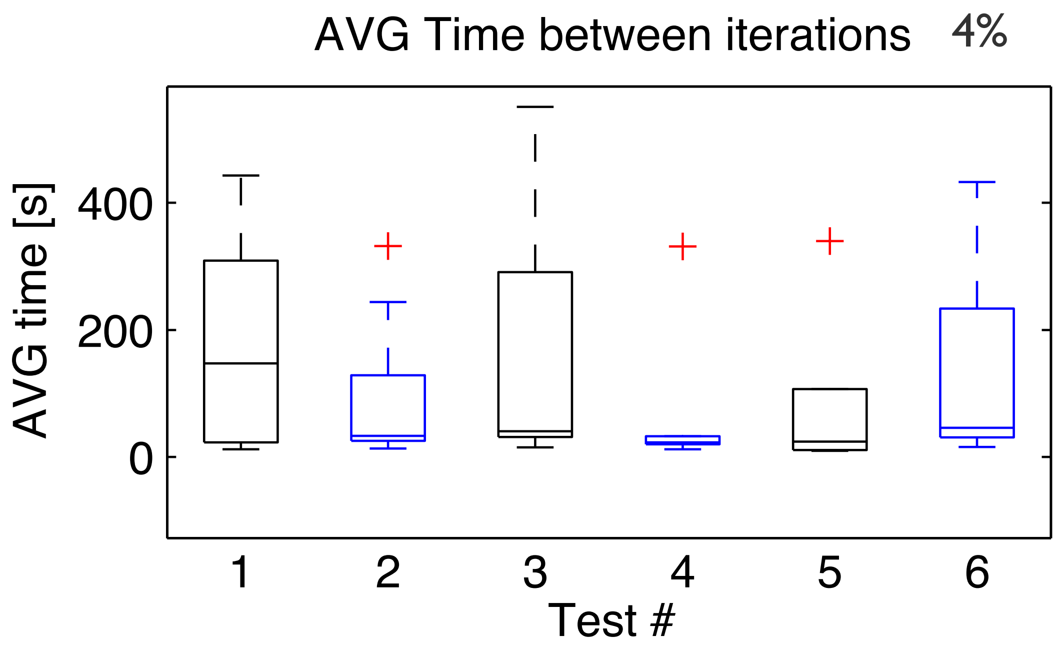
MSE at Convergence Iteration



- Access Control speeds up the convergence, but doesn’t improve the localization accuracy (if ranges are corrupted by reflections or non-LOS conditions, nothing can be done)

AVG time between iterations



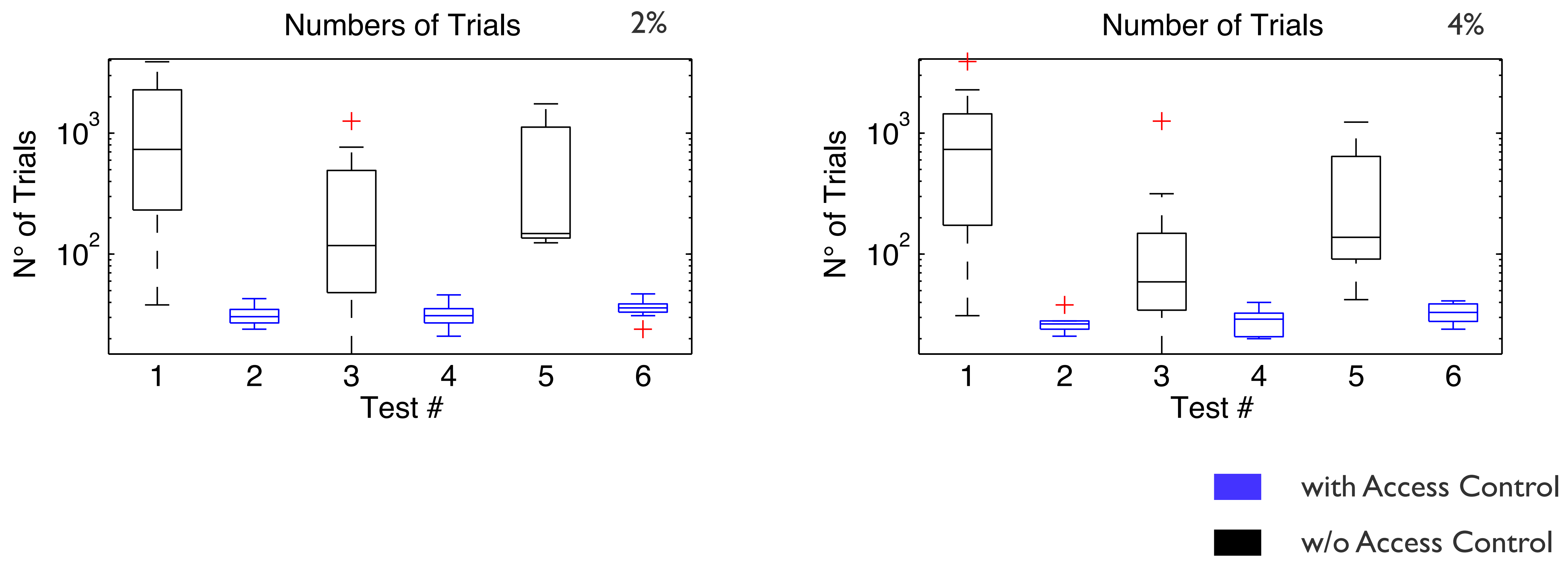


with Access Control

w/o Access Control

- Access Control reduces the time between iterations in both cases
- Even if A. C. introduces delays, the reduction of collisions limit the retransmissions, and so the interval between two succesfully delivered packets

Number of Trials



- The number of tries is greatly reduced using the Access Control mechanism
- Less tries means less transmission, hence less energy needed to perform localization

Conclusions

Conclusions

- We presented an experimental analysis on the effects of channel access on Localization performances in Cooperative networks
- We deployed a real test WSN based on UWB devices
- We implemented a cooperative localization system using LBP algorithm
- An ad-hoc Access Control algorithm has been implemented
- The Access Control algorithm improve the performance of the network increasing the localization convergence speed
- The number of transmissions has been reduced
- The energetic efficency of the network has been increased

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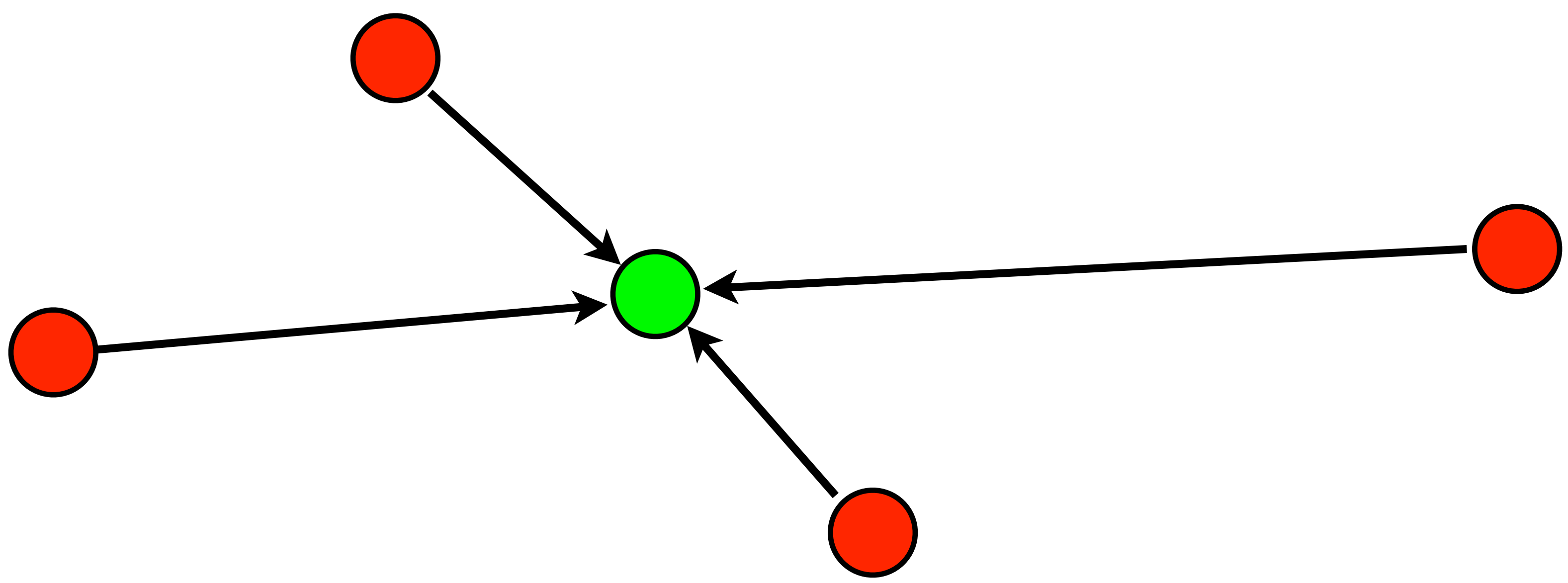
BKP Slides

Localization Basics

The purpose of any localization system is to find the position of an unknown node, giving some measurements



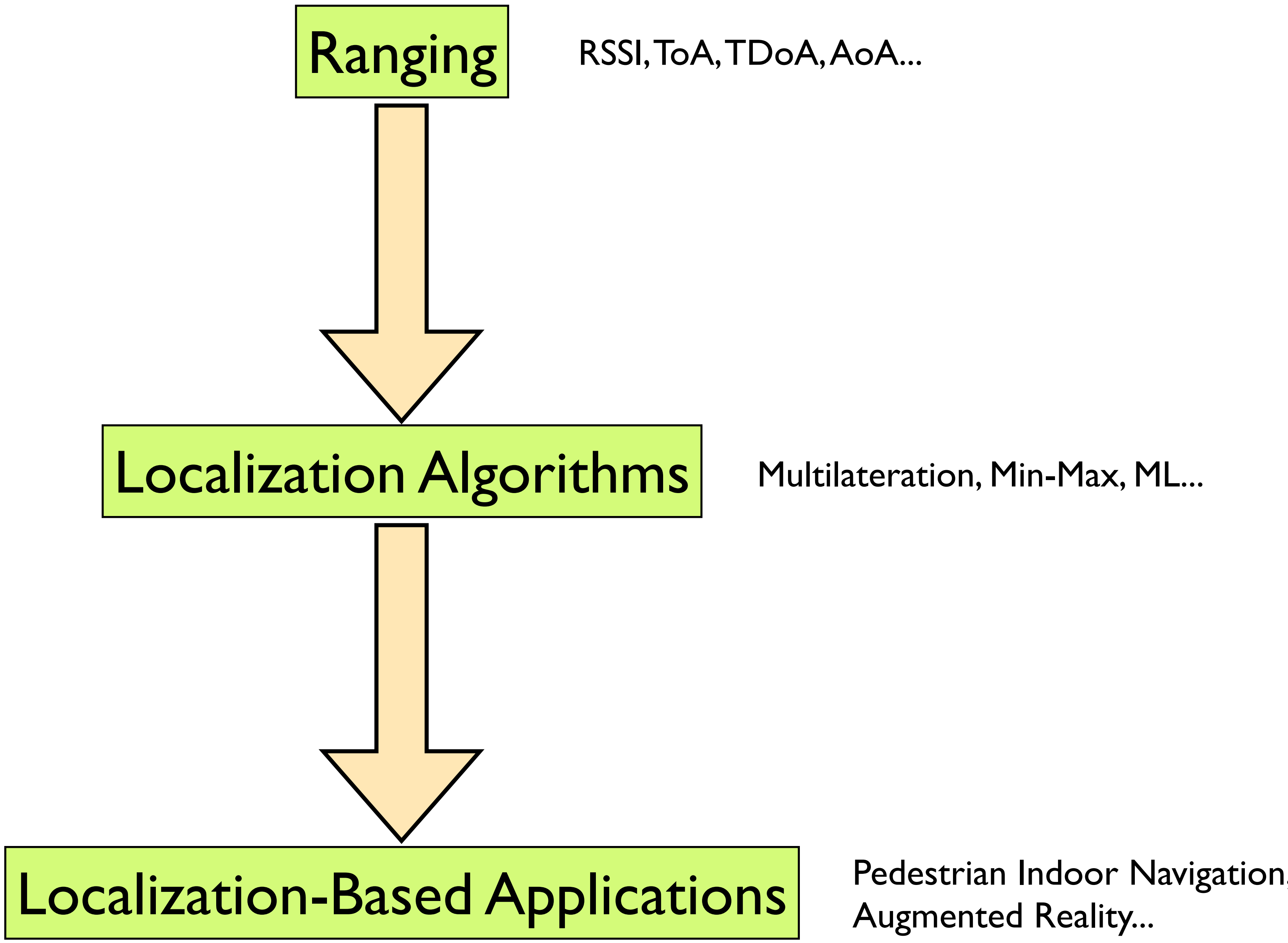
Anchor Nodes
(Known Position, GPS or Map)

Target Node
(Unknown Position)

Two main steps are needed in order to localize a node:

- Perform some measurements between nodes (ranging)
- Join measurements through a proper Localization Algorithm

Localization Basics



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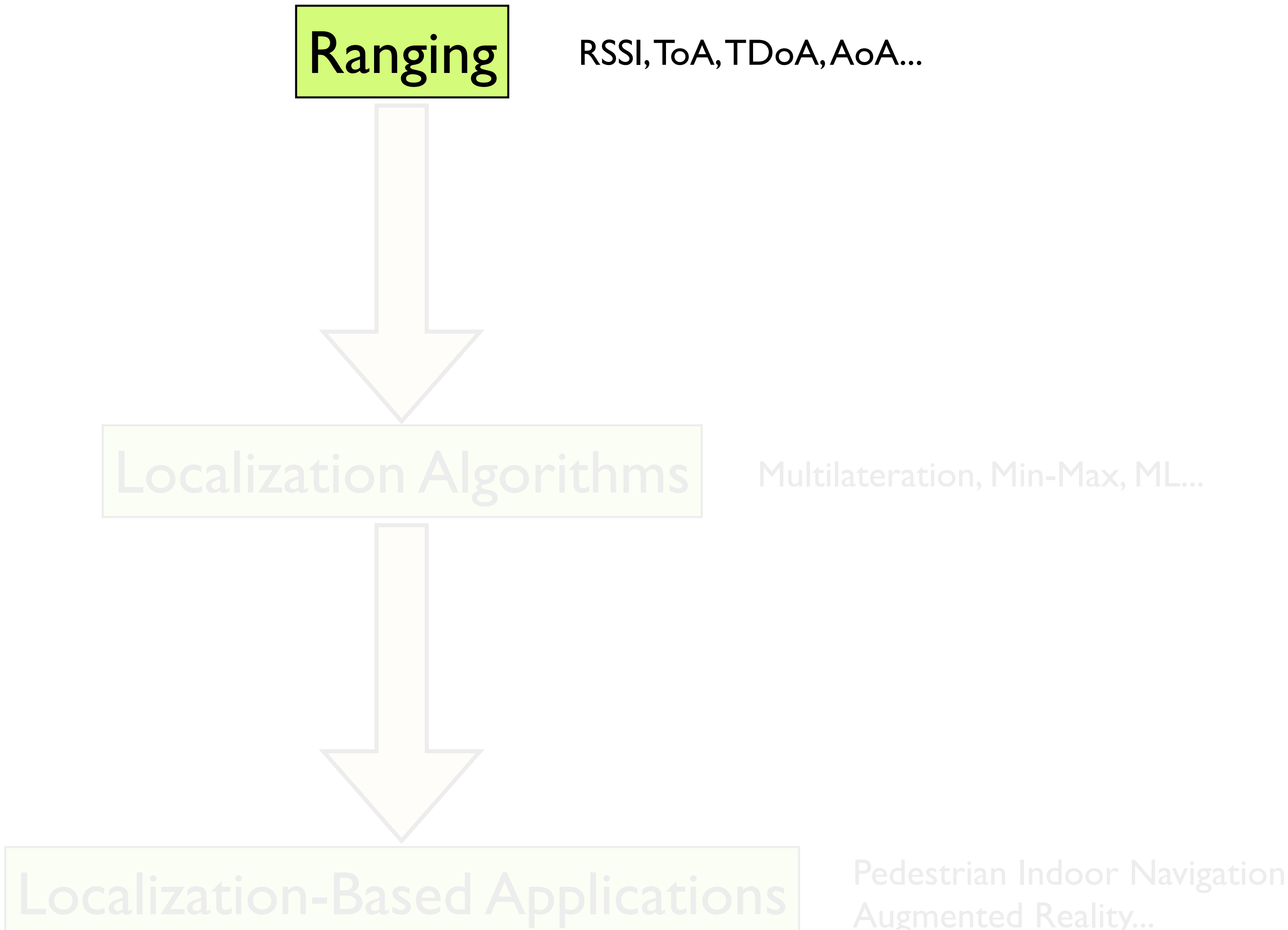
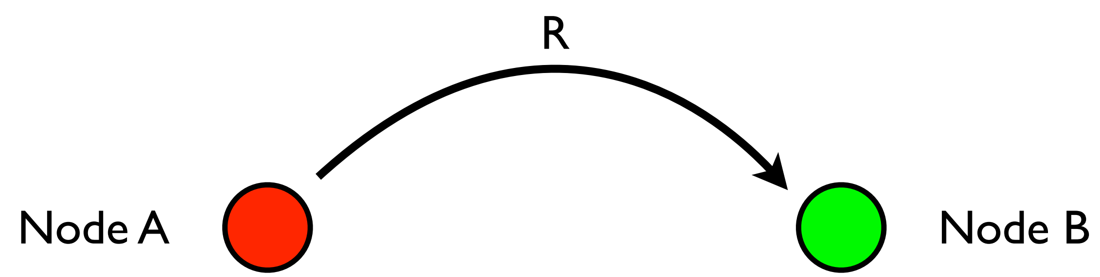


Distance estimation: Ranging

Ranging between two nodes is the technique employed by two nodes in the network to determine the physical distance between them.



Main ranging technologies:

- Received Signal Strength (RSSI):
  - Distance vs RSSI
  - Used in 802.15.4 narrowband radios
- Time-Based:
  - ToA of E.M. waves
  - Used in 802.15.4a Ultra WideBand (UWB) radios

RSSI Ranging

RSSI ranging is the simplest way to obtain range measurements:

- No additional HW needed
- RSS value is stored in a default register of 802.15.4 compliant transceivers

BUT

Range estimates are afflicted by Propagation Effects (like multipath, fading, reflection...)

Measure are easily affected by errors

RSSI Ranging

Signal strength is related to distance between nodes by Friis' law:

$$P_R = P_T \frac{G_T G_R \lambda^2}{(4\pi)^2 d^n}$$

Where:

- Pr = Power of received signal
- Pt = Power of transmitted signal
- Gr = Receiver's antenna gain
- Gt = Transmitter's antenna gain
- d = distance between nodes
- n = propagation coeff.

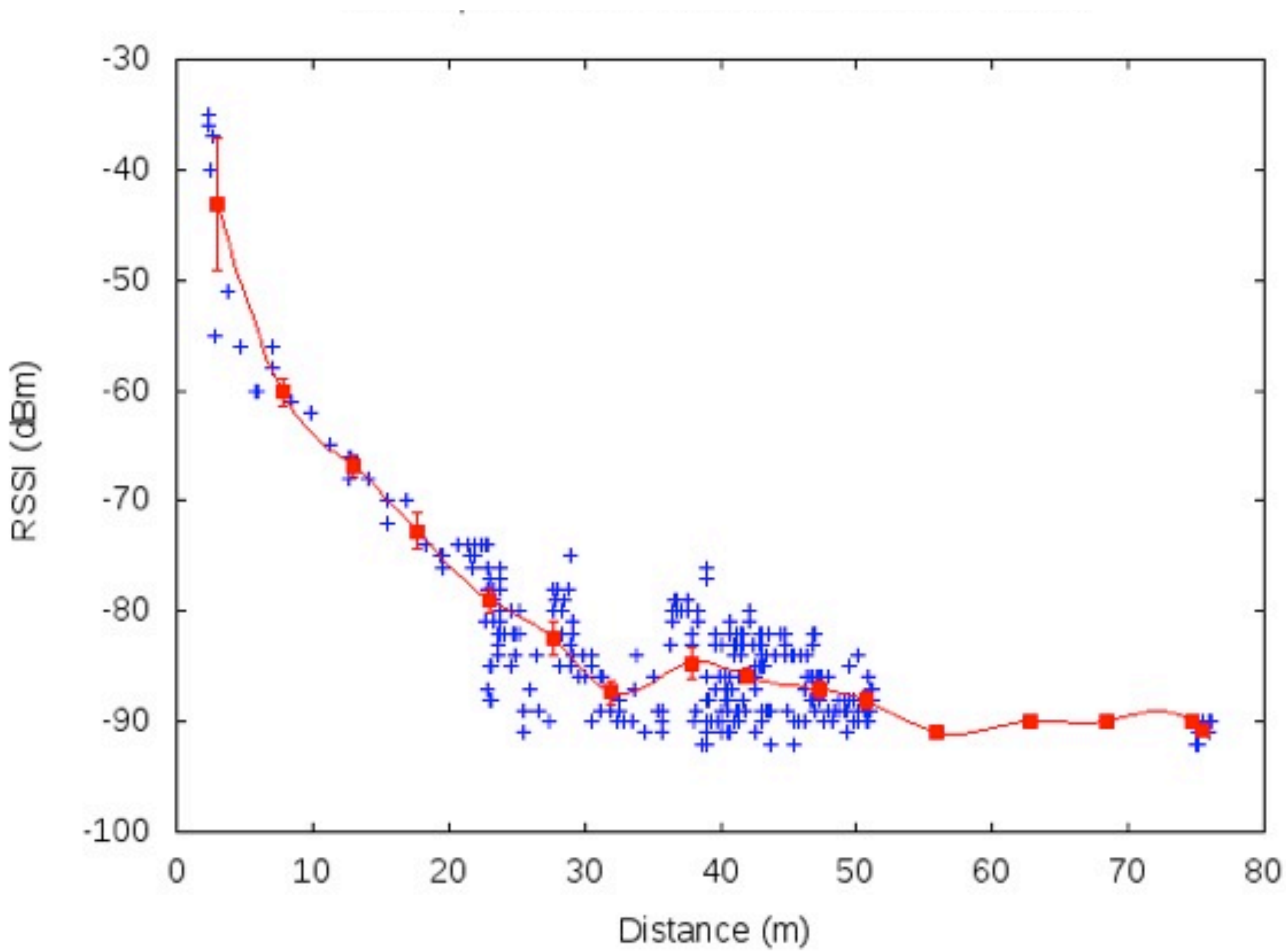
RSSI Ranging

Given RSSI value, distance (in meters) can be estimated by:

$$d = 10^{\left(\frac{A - RSSI}{10 \cdot n}\right)}$$

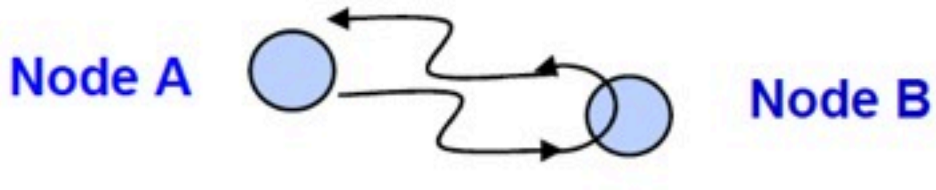
Where:

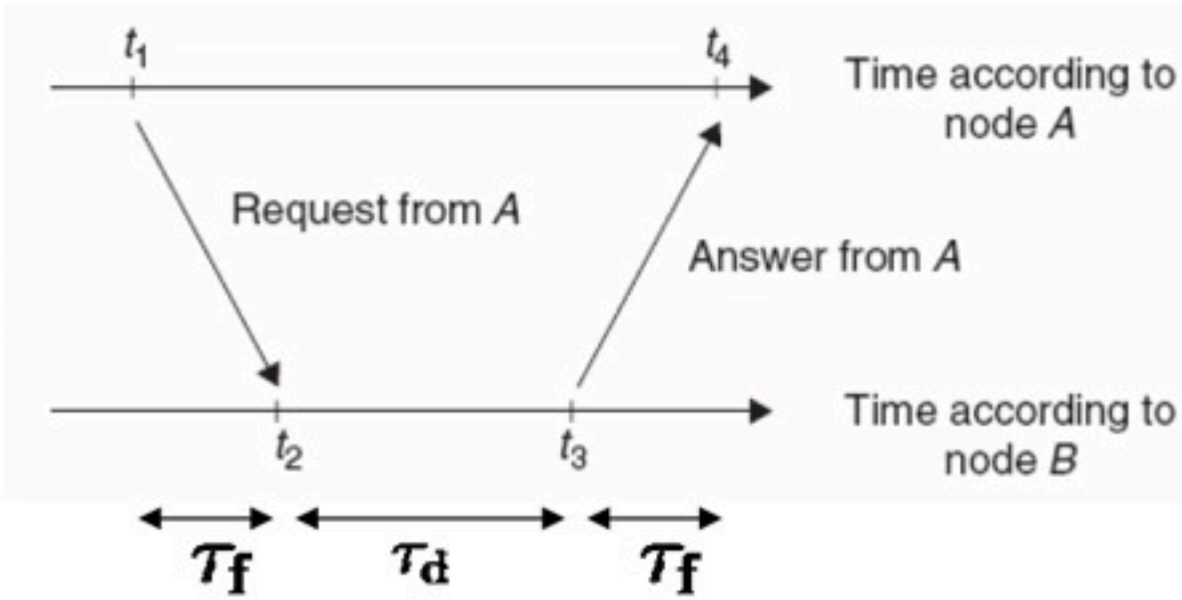
- A = nominal received power @ 1 meter
- n = propagation coeff.



Time-Based Ranging

Time-based ranging is mostly used in UWB systems, where the large bandwidth allow to send very short pulses: these pulses can be use for triggering a stop watch to get the Time of Flight of an EM wave.





$$\hat{\tau}_f = \frac{(t_2 - t_1) + (t_4 - t_3)}{2}$$

ToF:

- 30cm accuracy with a bandwidth of 1GHz
- Close synchronization between nodes is needed (specific HW must be used)

Main Issues During Ranging

Ranging process is usually performed in real-life scenarios, so many sources of error can degrade ranging accuracy:

- Multipath, due to secondary waves that arrive to receiver's antenna
- Reflection of the waves against walls and ceilings
- Shadowing, due to destructive interference between reflected waves
- Non Line-of-Sight (NLOS) conditions: different propagation Speed of the EM wave through different materials can alter the measured distance (usually it's over-estimated)
- In general, interference caused from other devices (Microwaves, WiFi, Cellphones...)

Ranging accuracy is degraded

Localization Algorithms

Ranging

RSSI, ToA, TDoA, AoA...

Localization Algorithms

Multilateration, Min-Max, ML...

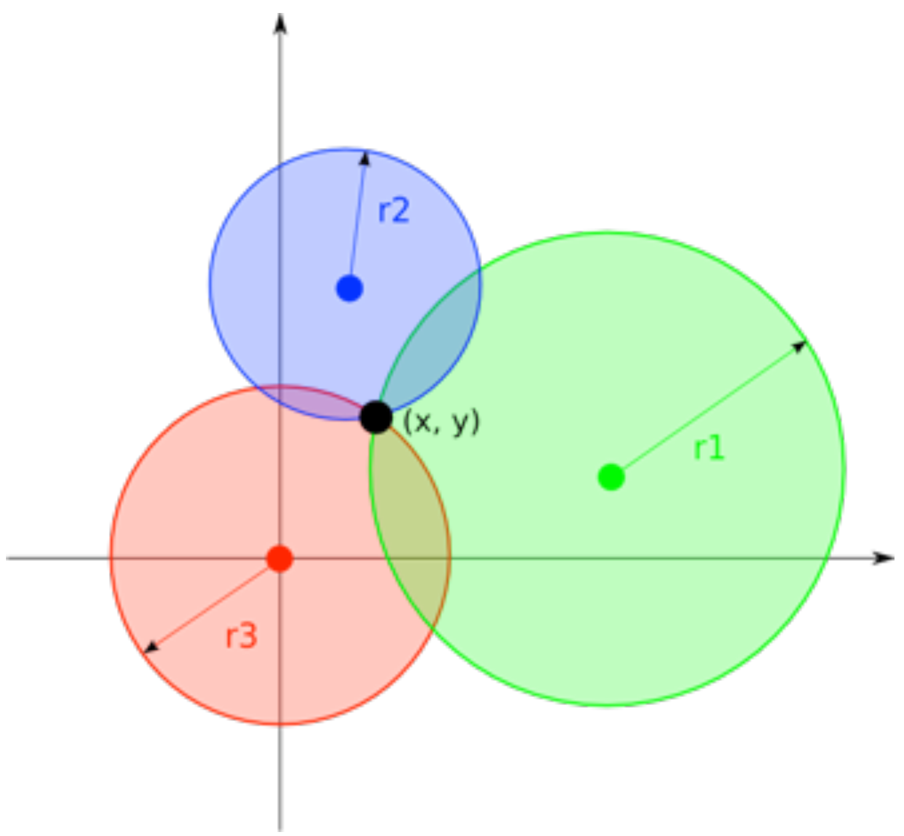
Localization-Based Applications

Pedestrian Indoor Navigation,
Augmented Reality...

Multilateration

- Based on geometrical considerations
- Adaptive

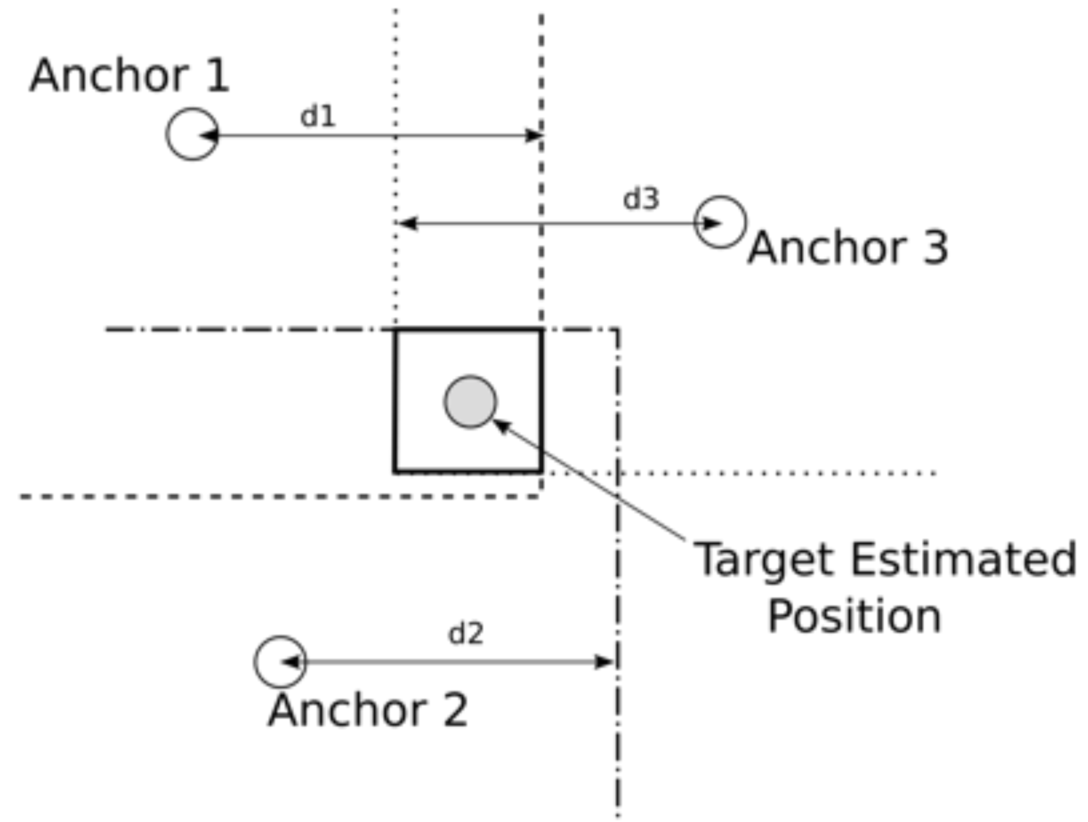
$$\begin{cases} (x - x_1)^2 + (y - y_1)^2 = r_1^2 \\ (x - x_2)^2 + (y - y_2)^2 = r_2^2 \\ (x - x_3)^2 + (y - y_3)^2 = r_3^2 \end{cases}$$



The target node build circles around each anchor node, and the intersection between nodes is its estimated position.

Min-Max

- Based on simple geometrical considerations
- Easy to implement
- Low computational cost



The target node can estimate its position iterating this function:

$$[\max(x_i - d_i), \max(y_i - d_i)] \times [\min(x_i + d_i), \min(y_i + d_i)]$$

Maximum Likelihood

- Based on statistical considerations
- Heavy computational demanding
- Needs many RSSI measures to obtain good performances

Not usually implemented in WSNs

Maximum Likelihood

Given a pool of i distance measurements between target and anchor nodes, the estimated coordinates of target node (x_0, y_0) could be found with the following equation:

$$b = (X^T X)^{-1} X^T y$$

Where:

$$X = \begin{bmatrix} 2(x_k - x_1) & 2(y_k - y_1) \\ \vdots & \vdots \\ 2(x_k - x_{k-1}) & 2(y_k - y_{k-1}) \end{bmatrix}$$

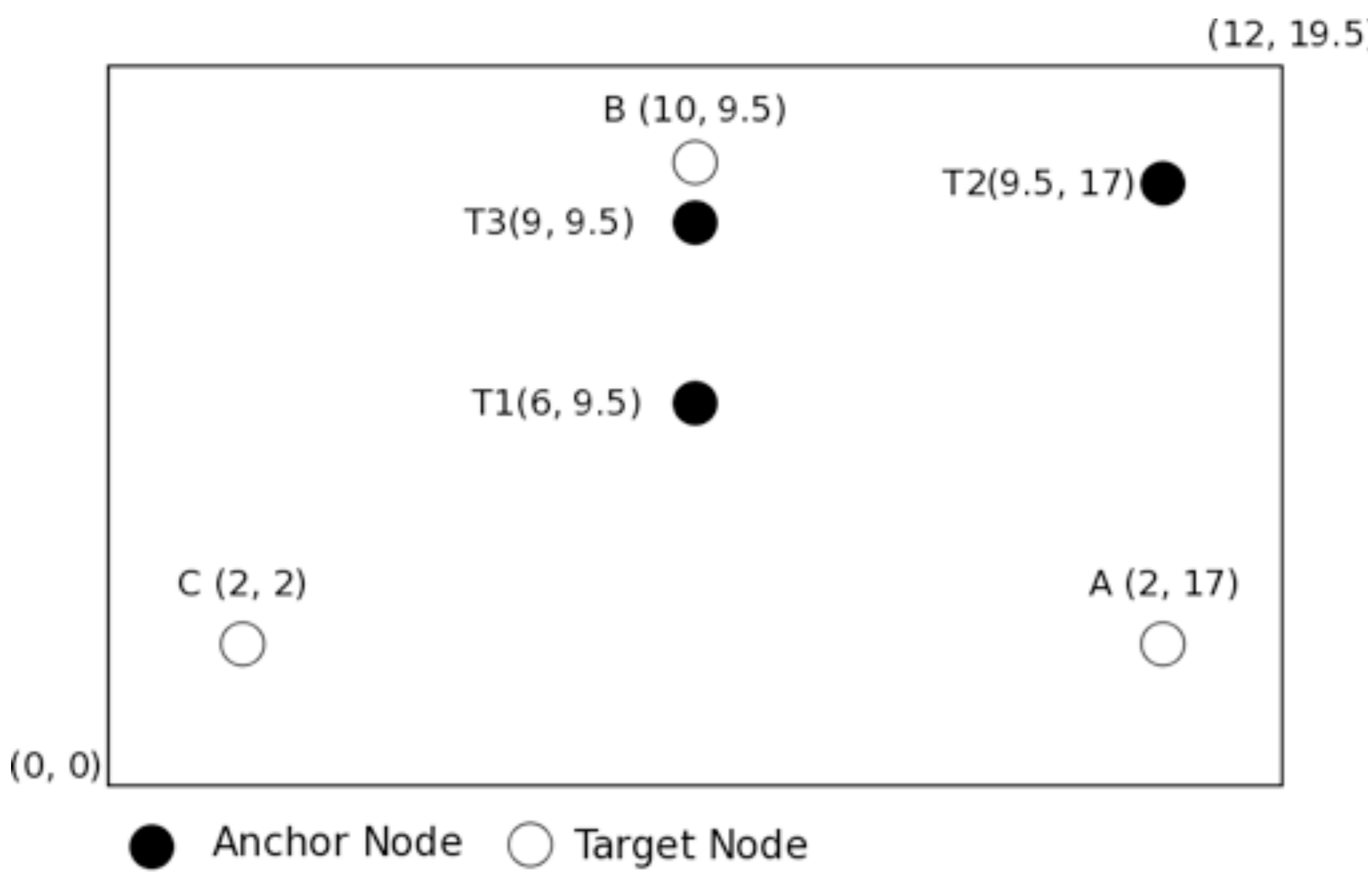
$$y = \begin{bmatrix} -x_1^2 - y_1^2 + d_1^2 - (-x_k^2 - y_k^2 + d_k^2) \\ \vdots \\ -x_{k-1}^2 - y_{k-1}^2 + d_{k-1}^2 - (-x_k^2 - y_k^2 + d_k^2) \end{bmatrix}$$

$$b = \begin{bmatrix} x_0 \\ y_0 \end{bmatrix}$$

Case Study: Localization through RSSI

We tested the performances of the localization algorithms in an testbed deployed indoor:

- 12m by 19.5m room
- Minimum number of anchor nodes
- A target node has been deployed in different positions



Case Study: Localization through RSSI

We wanted to evaluate the performances of the different localization algorithms in localize a target node in a WSN. To perform this comparison an extensive set of tests have been made:

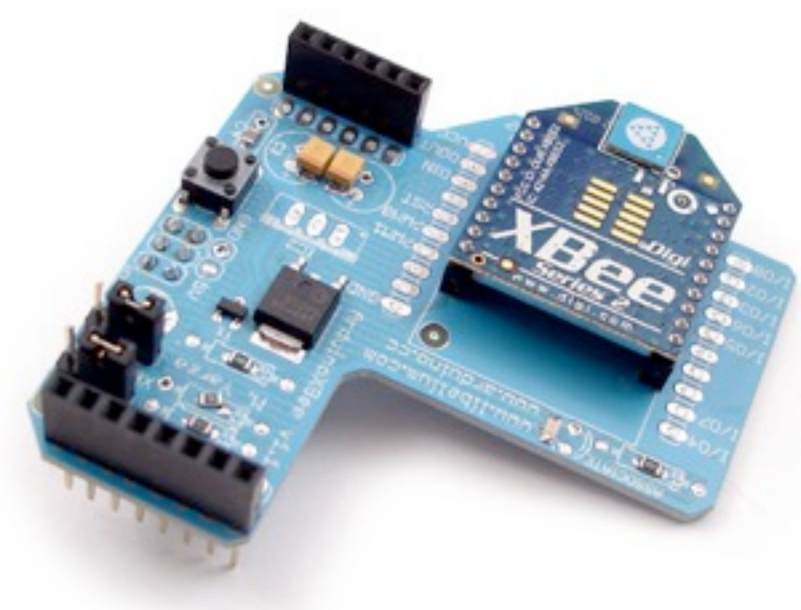
- For each algorithm three different tests have been made, changing the position of the target node
- We gathered 25 times RSSI value in every position of the target node
- Using the red RSSI values, target node estimates its position through the localization algorithm selected

Case Study: Localization through RSSI

All the nodes of the WSN deployed are based on Arduino development board:

- 8-bit microcontroller @ 16MHz
- 16 Kbytes flash memory
- 6 channel 10 bit ADC
- Low power demanding
- Programmable in C language

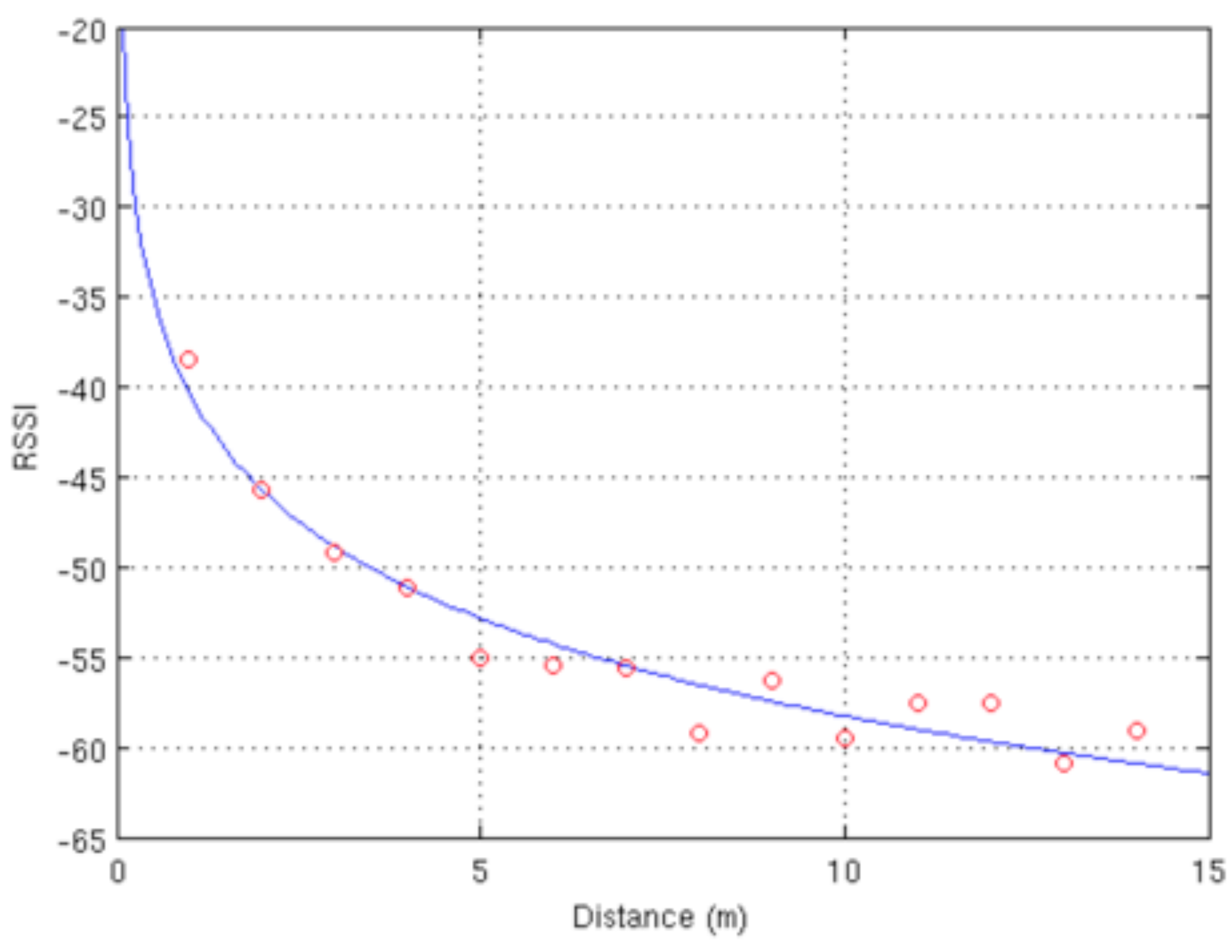
On the radio side we used the Digi's Xbee IEEE 802.15.4 compliant tranceivers



Case Study: Localization through RSSI

We performed an accurate channel characterization for our specific environment:

- We moved target node from 0 to 15m at steps of 1m and we acquired 25 RSSI values for each configuration
- We discarded RSSI data outside 1 st.dev.
- We performed a logarithmic interpolation of cleaned data to obtain A and n values (parameters depending on the specific hardware and the environment)



A = -40,295

n = 1,7981

Case Study: Localization through RSSI

Performances of the compared localization algorithms (in m):

Algorithm	Err. T1	Err. T2	Err. T3
Min-Max	1.72	8.75	0.94
ML	6.34	17.02	13.21
Trilateration	1.44	9.12	3.83

Average Mean Errors and Standard Deviations (in m):

Algorithm	Mean Error	Std. Deviation
Min-Max	3.80	2.94
ML	12.21	6.45
Trilateration	4.79	2.41

The best algorithm in our case is Min-Max (also the simplest one!)