Localization in ZigBee sensors networks

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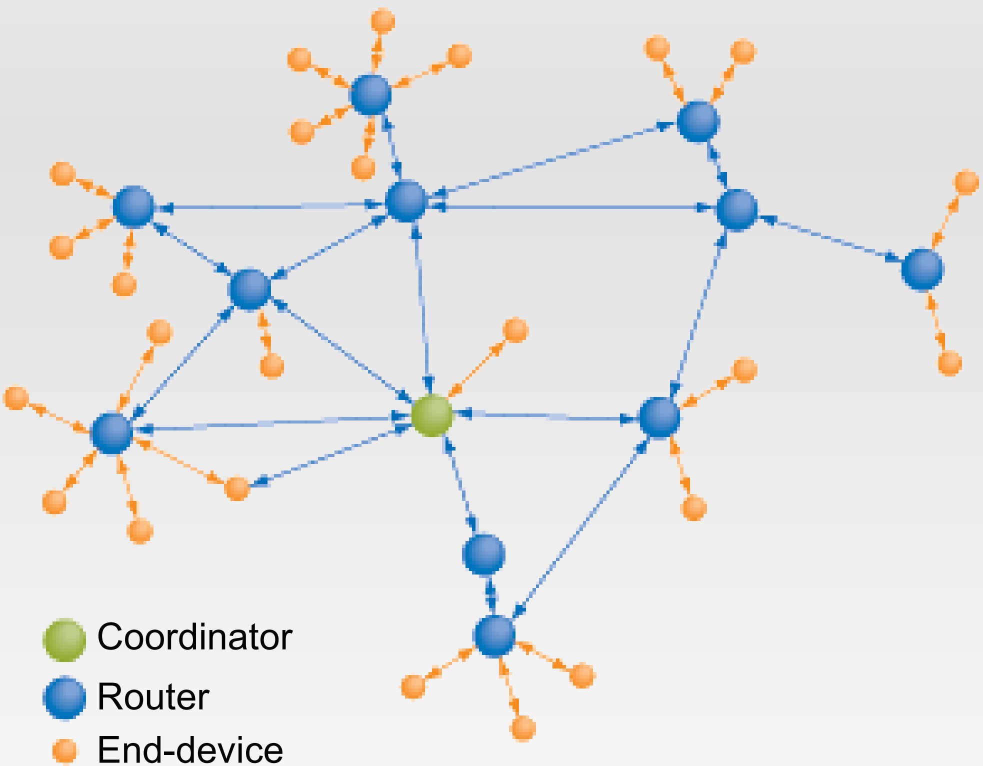
Context and possible applications

- **Project's targets**
  - Development of a localization prototype for ZigBee networks, based on the Received Signal Strength Indicator (RSSI)
  - Verify experimentally the accuracy of the system
- **Examples of possible contexts and applications**
  - **Hospital environment**
    - Localization of items (e.g. oxygen cylinders, defibrillators)
    - Monitoring their state (e.g. Are they full or empty?)
    - Indoor environment
  - **Harbour environment**
    - Localization of goods on a harbour's square
    - Outdoor environment

ZigBee

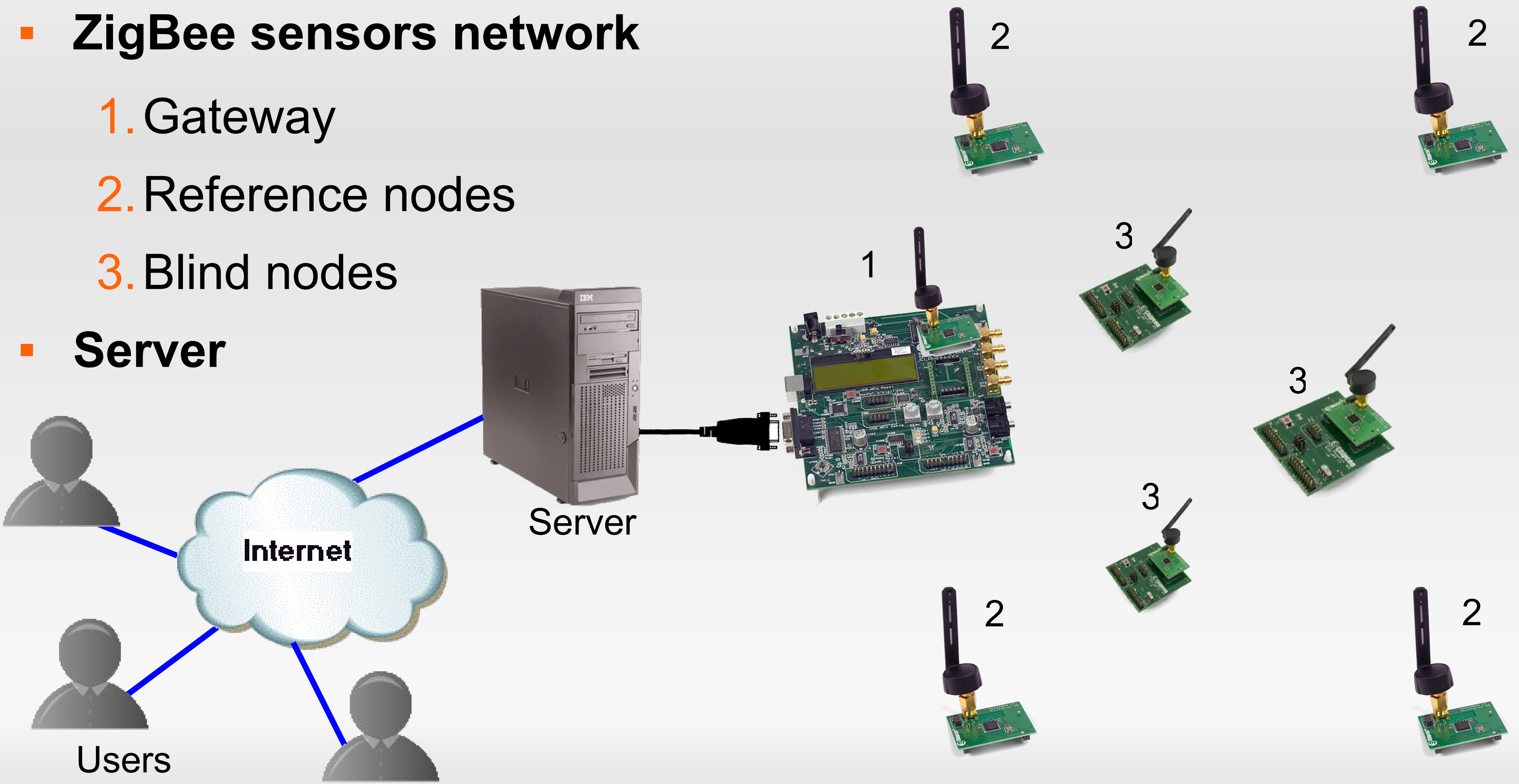
Why ZigBee?

- Actually ZigBee is the leading standard for the wireless sensors networks
- Low cost of devices
- Low power consumption
- Devices can measure physical quantities using various sensors

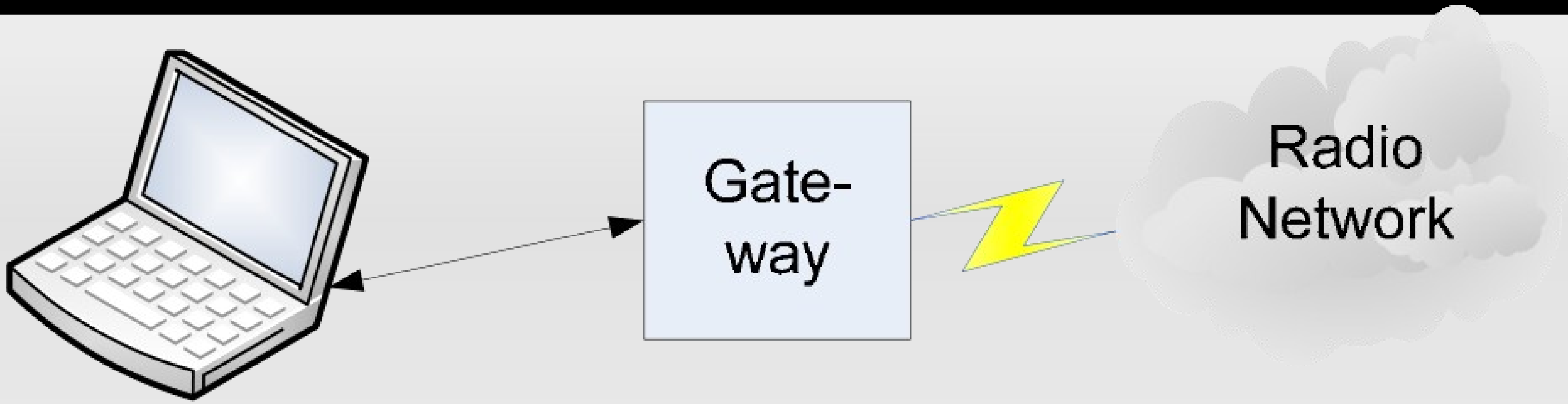


System architecture

- **ZigBee sensors network**
  1. Gateway
  2. Reference nodes
  3. Blind nodes
- **Server**



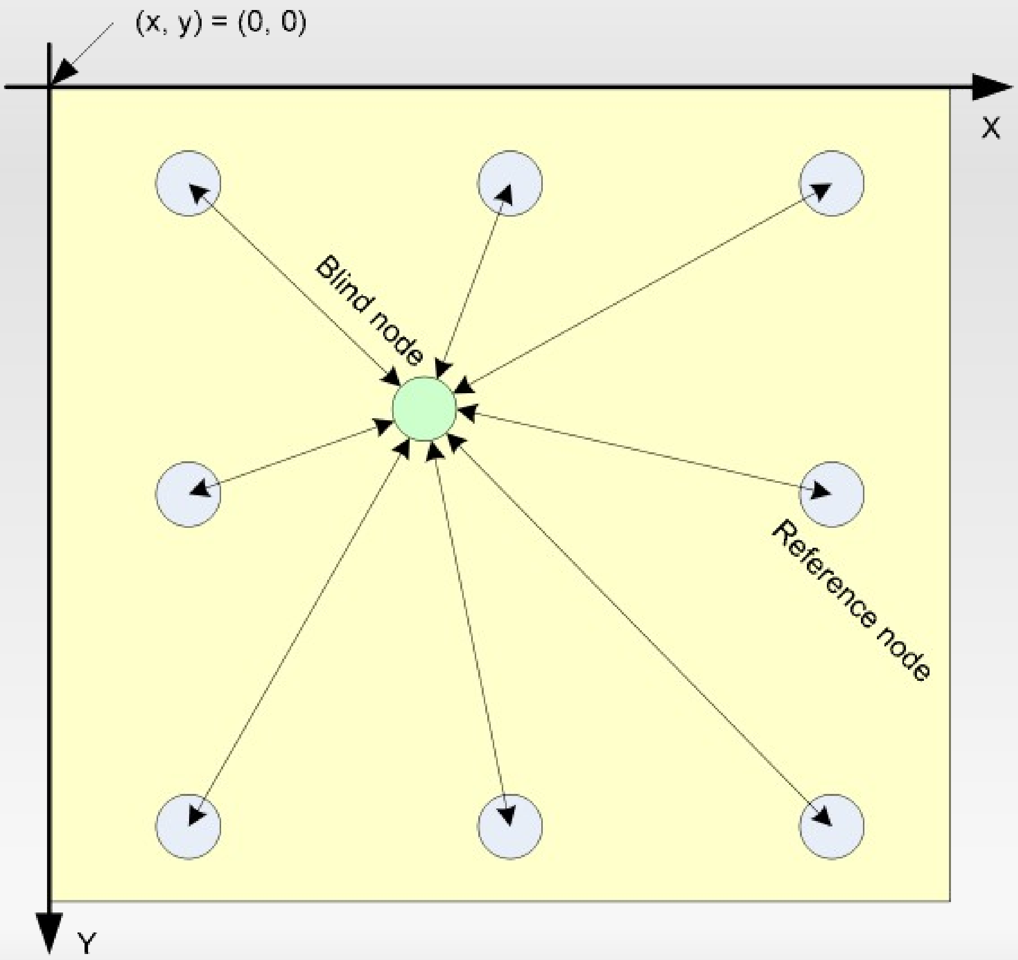
Gateway



- It is unique in the whole sensors network
- It plays also the role of ZigBee coordinator
- It communicates with the server through a serial interface
- It needs a permanent power source
- Always active
- His job is to forward data from ZigBee network to the server and vice-versa

Reference nodes

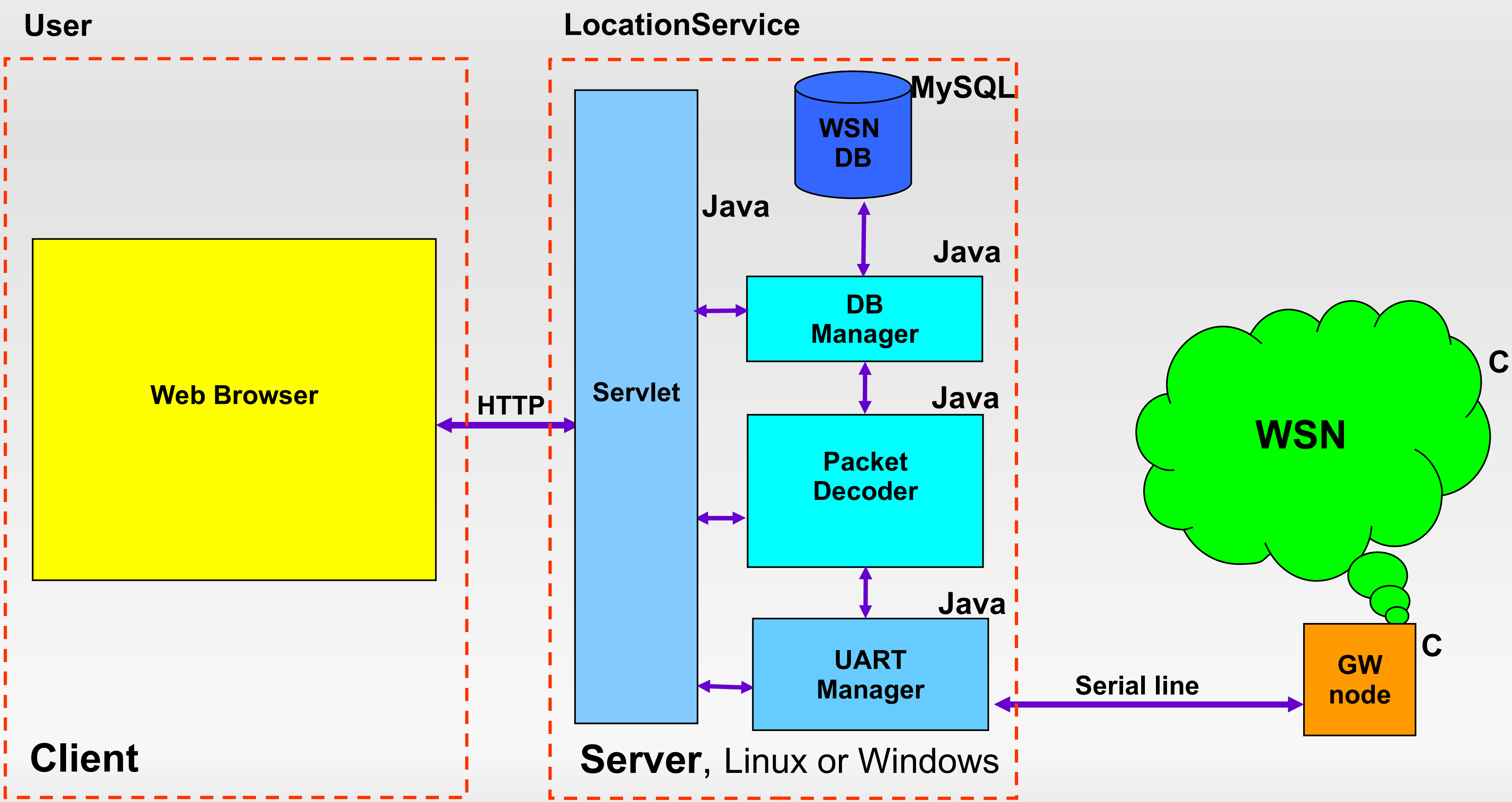
- They have static positions
- They act also as ZigBee routers
- As reference nodes are static, they can be fed by power line
- Always active
- Used by blind nodes to estimate distances
- They can monitor environmental parameters (e.g. temperature, humidity, light) related to the specific environment where they are installed



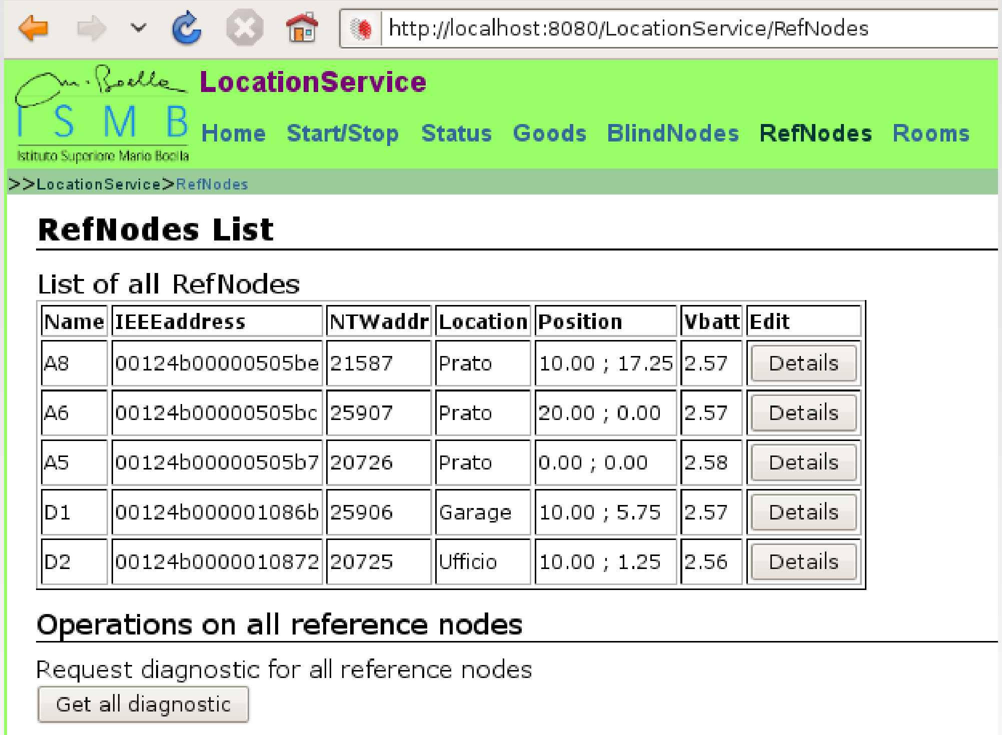
Blind nodes

- They can move freely
- Paired to the goods to monitor
- Configured as end-device
- Powered by battery
- They spend most of the time in sleep state
- They periodically collect the RSSI value measured by nearby reference nodes and send it to the gateway
- They can also monitor the status of the paired good by using the available sensors (e.g. temperature and pressure sensors applied to a gas cylinder)

Application and DB server



Web Application



http://localhost:8080/LocationService/RefNodes

LocationService

Home Start/Stop Status Goods BlindNodes RefNodes Rooms

>>LocationService>RefNodes

RefNodes List

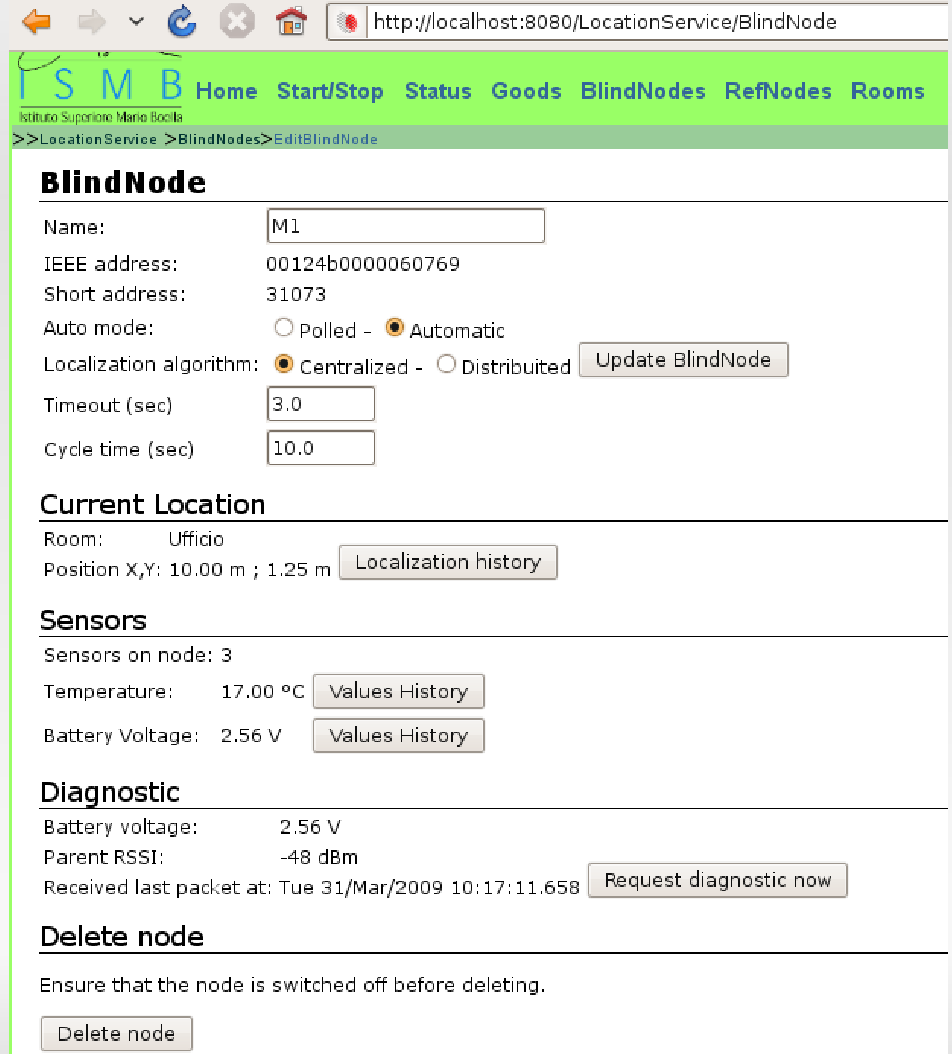
List of all RefNodes

Name	IEEEAddress	NTWaddr	Location	Position	Vbatt	Edit
A8	00124b00000505be	21587	Prato	10.00 ; 17.25	2.57	Details
A6	00124b00000505bc	25907	Prato	20.00 ; 0.00	2.57	Details
A5	00124b00000505b7	20726	Prato	0.00 ; 0.00	2.58	Details
D1	00124b000001086b	25906	Garage	10.00 ; 5.75	2.57	Details
D2	00124b0000010872	20725	Ufficio	10.00 ; 1.25	2.56	Details

Operations on all reference nodes

Request diagnostic for all reference nodes

Get all diagnostic



http://localhost:8080/LocationService/BlindNode

Home Start/Stop Status Goods BlindNodes RefNodes Rooms

>>LocationService >BlindNodes>EditBlindNode

BlindNode

Name: M1

IEEE address: 00124b0000060769

Short address: 31073

Auto mode: Polled - Automatic

Localization algorithm: Centralized - Distribuited | Update BlindNode

Timeout (sec) 3.0

Cycle time (sec) 10.0

Current Location

Room: Ufficio

Position X,Y: 10.00 m ; 1.25 m | Localization history

Sensors

Sensors on node: 3

Temperature: 17.00 °C | Values History

Battery Voltage: 2.56 V | Values History

Diagnostic

Battery voltage: 2.56 V

Parent RSSI: -48 dBm

Received last packet at: Tue 31/Mar/2009 10:17:11.658 | Request diagnostic now

Delete node

Ensure that the node is switched off before deleting.

Delete node

The RSSI index

RSSI: *Received Signal Strength Indicator*

- It is the power of the radio signal measured by the receiving station
- ZigBee stack makes available RSSI measurement for every received packet
- With CC2430 modules it goes from -20 dBm to -90 dBm
- Strongly influenced by multipath (reflections) and interferences
- His original purpose is to determine the link quality

Relationship between RSSI and distance

The relationship between the power of a received radio signal and distance is expressed by *Friis* equation:

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

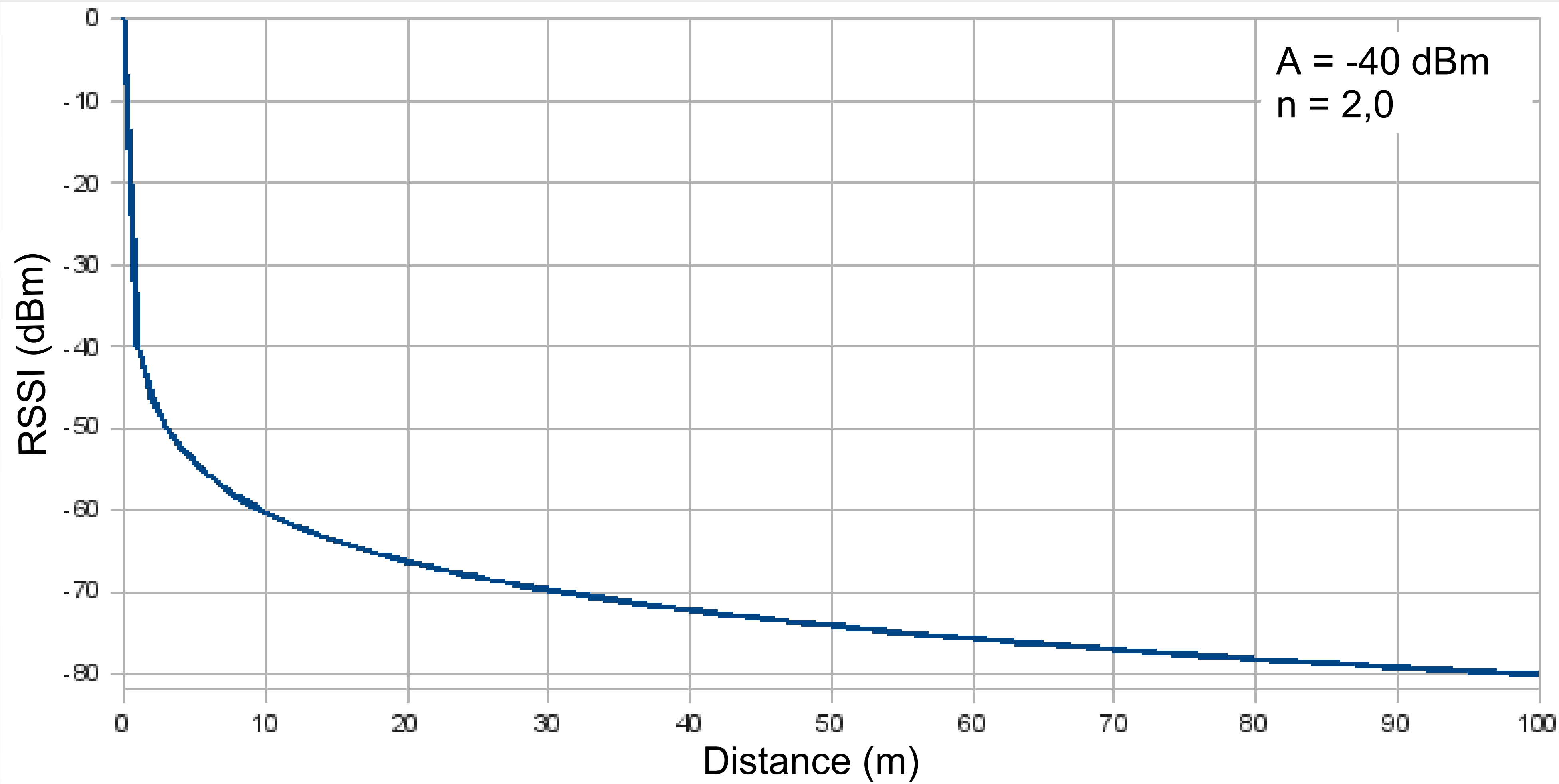
Substituting the characteristics of CC2430 (Pt = 1mW, f = 2.441 GHz) and converting it in dBm:

$$RSSI = -(10 \cdot n \cdot \log_{10}(d) - A)$$

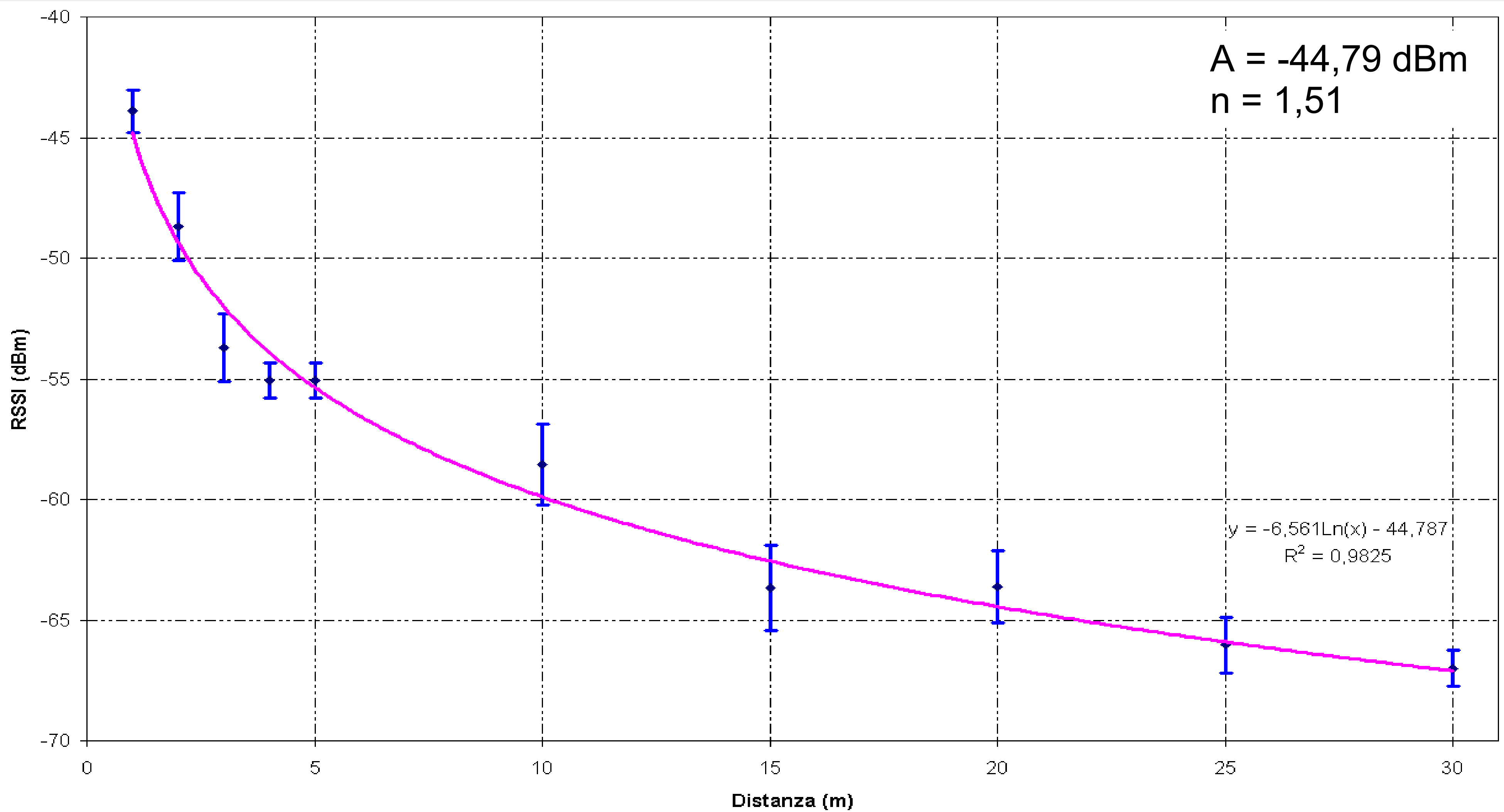
where:

- **n** is a constant, called path loss exponent, it depends on the environment (in the free space it is equals to 2)
- **A** is the received power at one meter of distance expressed in dBm. For the CC2430 modules the value of A is about -40 dBm

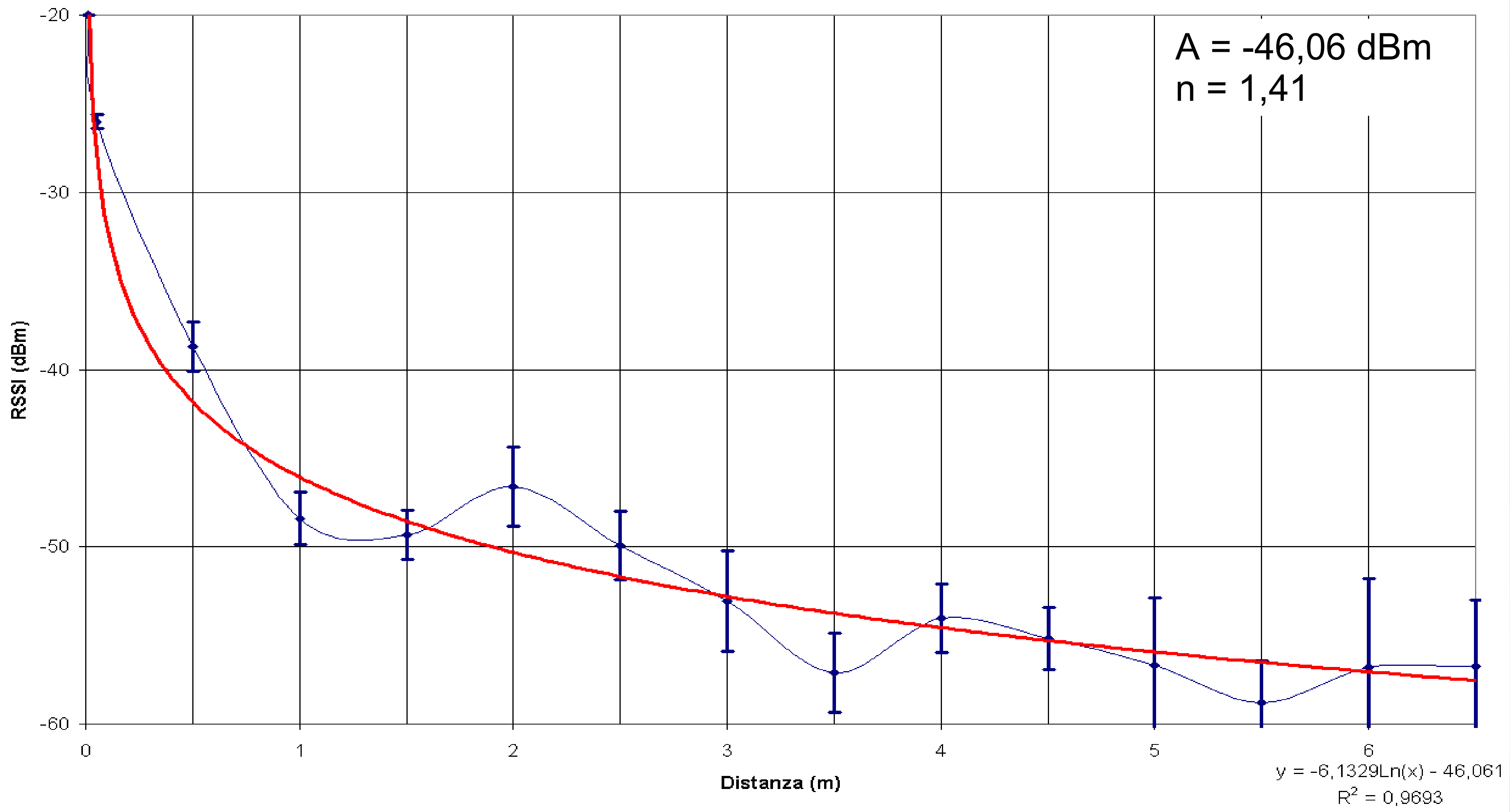
The ideal case



The reality: outdoor measurements



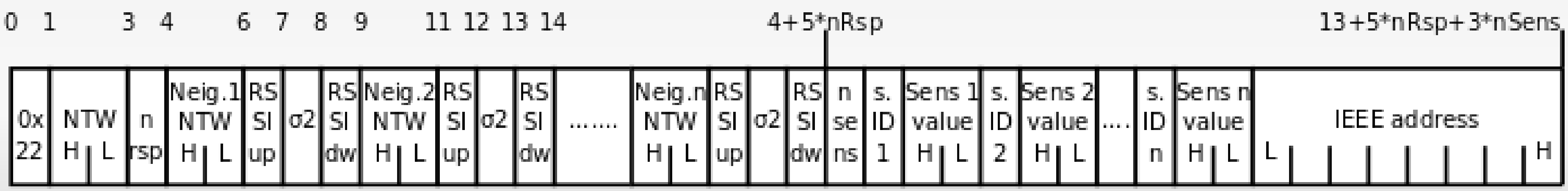
The reality: indoor measurements



Position algorithm steps 1/3

First step: collecting RSSI measures

1. The blind node periodically broadcasts series of *blasts* messages
2. The neighbour reference nodes reply with the average RSSI and standard deviation related to the series of *blasts*
3. The blind node collects the replies from neighbours reference nodes
4. The blind node sends all collected replies to the gateway, then it returns in sleep state
5. The gateway receives all the data and forwards it to the server trough the serial line



Position algorithm steps 2/3

Second step: selecting the best measures

6. The server receives a collection of RSSI from one blind node with respect to some reference nodes
7. All RSSI measures with $\sigma^2 > 10$ are ignored
8. We assume that the blind node is located in the same room of the reference node that has measured the strongest RSSI
9. If in that room there are at least three reference nodes the positioning algorithm can try to estimate the blind node's coordinates. Firstly, the RSSI measures are translated in distances using the reverse of the previous formula:

$$d = 10^{\frac{A - RSSI}{10 \cdot n}}$$

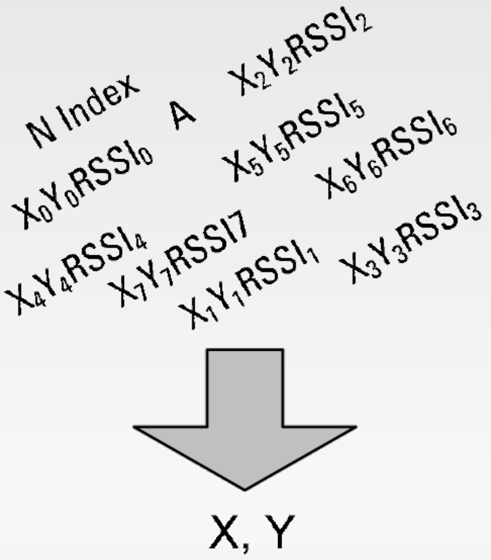
10. All the resultant distances greater than the maximum possible for that room are ignored

Position algorithm steps

Third step: calculating the position

11. The coordinates are estimated in a first step with the multilateration algorithm

12. The previous estimated coordinates are corrected with one iteration of the indirect observations method



Multilateration

The *n* measures of distance respect to *n* reference points become a system of equations: *x* and *y* are the coordinates of reference points, and *d* are the measured distances.

$$A=\begin{bmatrix} 2(x_1-x_n) & 2(y_1-y_n) \\ 2(x_2-x_n) & 2(y_2-y_n) \\ \vdots & \vdots \\ 2(x_{n-1}-x_n) & 2(y_{n-1}-y_n) \end{bmatrix}$$

$$b=\begin{bmatrix} x_1^2-x_n^2+y_1^2-y_n^2+d_n^2-d_1^2 \\ x_2^2-x_n^2+y_2^2-y_n^2+d_n^2-d_2^2 \\ \vdots \\ x_{n-1}^2-x_n^2+y_{n-1}^2-y_n^2+d_n^2-d_{n-1}^2 \end{bmatrix}$$

$$\begin{bmatrix} x_0 \\ y_0 \end{bmatrix}=(A^T\cdot A)^{-1}\cdot A^T\cdot b$$

$$residue=\frac{\sum_{i=1}^{n}\sqrt{(x_i-x_0)^2+(y_i-y_0)^2}-d_i}{n}$$

x_0 and y_0 are the coordinates of the blind node estimated using the least squares approach, the *residue* can be used to evaluate the accuracy of this result

Method of indirect observations

Here we calculate the differences to be added at the previous coordinates from the multilateration. W is the weights matrix, weights are calculated using σ values and distances.

$$A_1 = \begin{bmatrix} 2(x_0 - x_1) & 2(y_0 - y_1) \\ 2(x_0 - x_2) & 2(y_0 - y_2) \\ \vdots & \vdots \\ 2(x_0 - x_n) & 2(y_0 - y_n) \end{bmatrix}$$

$$l = \begin{bmatrix} (x_1 - x_0)^2 + (y_1 - y_0)^2 - d_1^2 \\ (x_2 - x_0)^2 + (y_2 - y_0)^2 - d_2^2 \\ \vdots \\ (x_n - x_0)^2 + (y_n - y_0)^2 - d_n^2 \end{bmatrix}$$

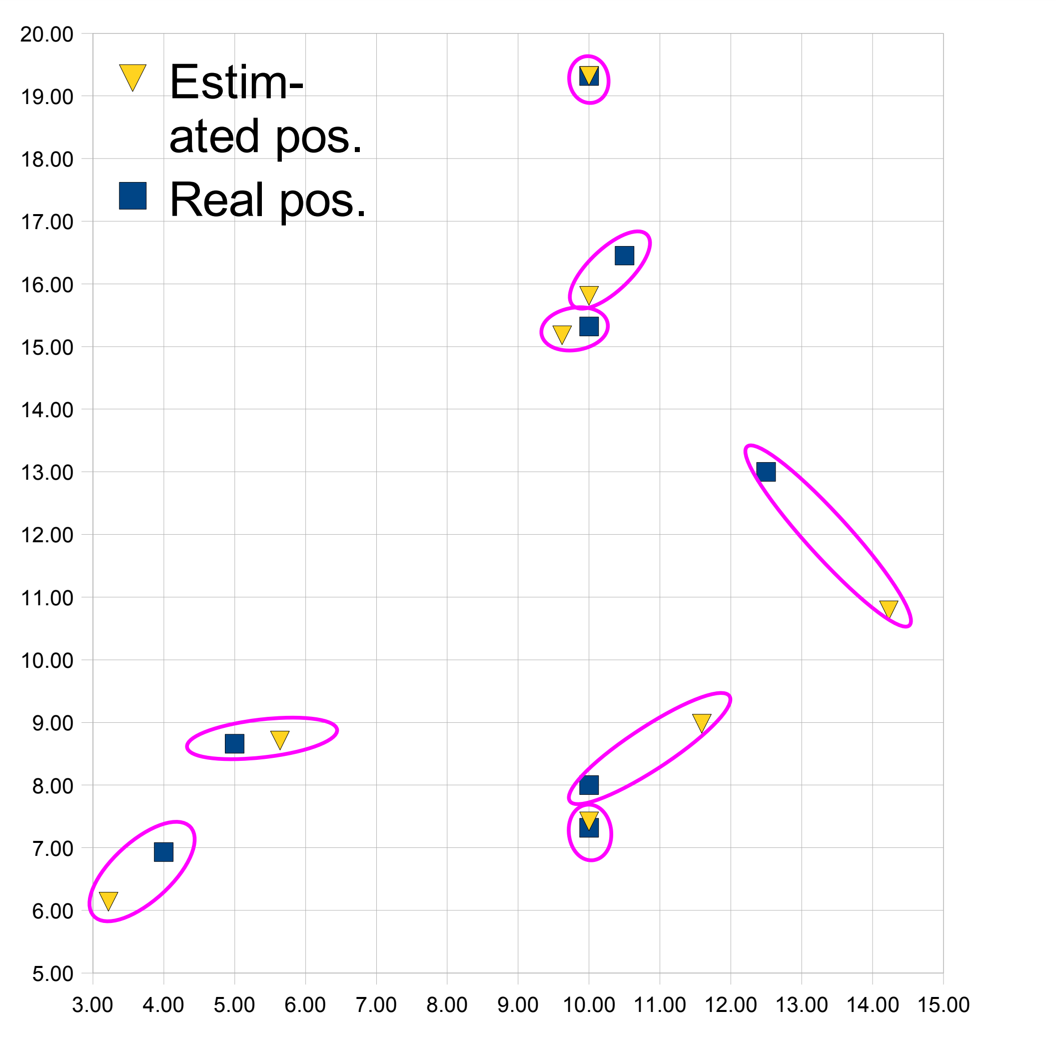
$$\sigma_{il} = -2\mathrm{d}_i \cdot \sigma_i$$

$$W = \begin{bmatrix} \frac{1}{\sigma_{l1}^2} & 0 & \cdots & 0 \\ 0 & \frac{1}{\sigma_{l2}^2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \frac{1}{\sigma_{\mathrm{ln}}^2} \end{bmatrix}$$

$$\begin{bmatrix} \delta x \\ \delta y \end{bmatrix} = -(A_1^T \cdot P \cdot A_1)^{-1} \cdot A_1^T \cdot W \cdot l$$

$$x = x_0 + \delta x$$
$$y = y_0 + \delta y$$

Results



Test conditions

- Open field: a meadow
- Modules at 40 cm of height from the ground
- 3 reference nodes, forming a equilateral triangle with 20 m sides
- a blind node moved in known positions

Results: details

Real position		Estimated pos.		Error	Position corrected		Error
X (m)	Y (m)	X (m)	Y (m)	est. (m)	X (m)	Y (m)	corr. (m)
10.00	8.00	11.60	7.97	1.60	11.59	8.98	1.87
10.00	15.32	10.00	15.79	0.47	10.00	15.81	0.49
10.50	16.45	7.71	14.51	3.40	9.62	15.18	1.55
12.50	13.00	7.71	14.41	4.99	14.23	10.79	2.81
10.00	7.32	10.00	6.73	0.59	10.00	7.42	0.10
5.00	8.66	-0.44	12.52	6.67	5.64	8.71	0.64
4.00	6.93	1.83	9.91	3.69	3.22	6.14	1.11
10.00	19.32	10.00	19.40	0.08	10.00	19.32	0.00

Conclusions

- Indoor environment: it is convenient to localize just by room
- Outdoor environment: it is possible localize by coordinates with an average error of about 2.5 m
- Advantages in terms of low power consumption and low cost
- No extra hardware is needed for the localization
- The system can be used to localize a car in a parking area but not to localize a book on a shelf between other books

Future developments

- Knowing the importance of environmental parameters **A** and **n**, it should be very useful to implement an automatic calibrating procedure to call every time is necessary to add a new room into the system and estimate his A and n parameters
- To improve the accuracy of distance estimation we can send the blasts at different transmission powers and calculate the RSSI with a weighted average accounting the power each blast has been sent

End

Thanks for your attention