Sensor Fusion for UWB and Wifi Indoor Positioning Systems

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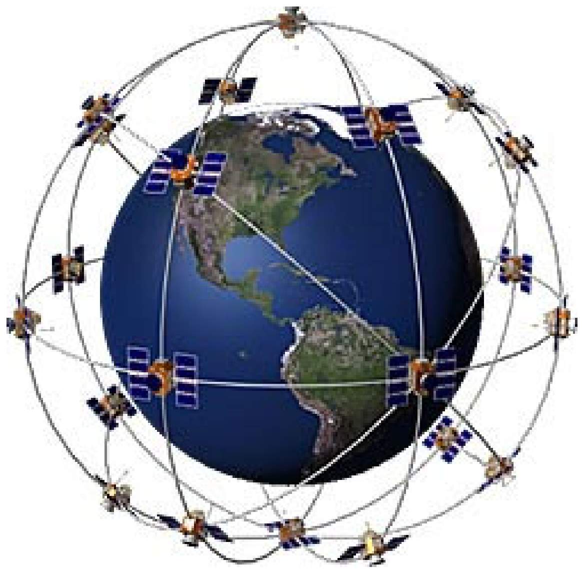
Frédéric EVENNOU

France Telecom
Research & Development

What positioning is used for ?

- **Many applications require positioning information**
  - In city driving
  - Emergencies (E911, E112)
  - Finding your friends (buddy finder applications)
  - Visiting an area or a museum
- **Many solutions exist**
  - GPS
  - GSM network (Cell-ID, TDOA, AOA)
  - Video
  - Ultra-sound and infra-red
- **Some weaknesses remain**
  - Poor accuracy
  - Dependant of the environment

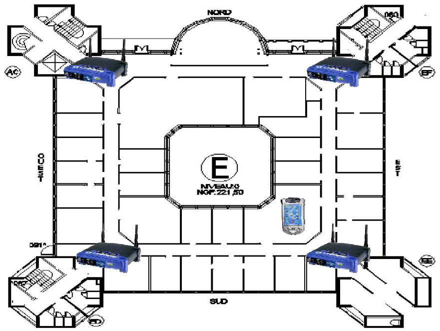


Contents of this presentation

- **Indoor positioning with WiFi**
  - Basic WiFi positioning
  - Improving WiFi positioning
    - The Kalman filter
    - The particle filter
    - Particle filter on a Voronoi diagram
- **Indoor positioning with UWB technology**
- **Accuracy augmentation with sensor fusion**

Basic indoor positioning with WiFi (1)

- **WiFi access points are present in more and more public area**
- **Time information is not available in standard commercial WiFi products**
- **The available information is the signal strength from the different acces points**
  - Use of a popagation model $P_{received}(d) = P_{received}(d_0) - 10 \cdot \alpha \cdot \log\left(\frac{d}{d_0}\right)$
    - Triangulation
  - Use of the fingerprinting method
- **Simple propagation model does not match the indoor complex propagation**

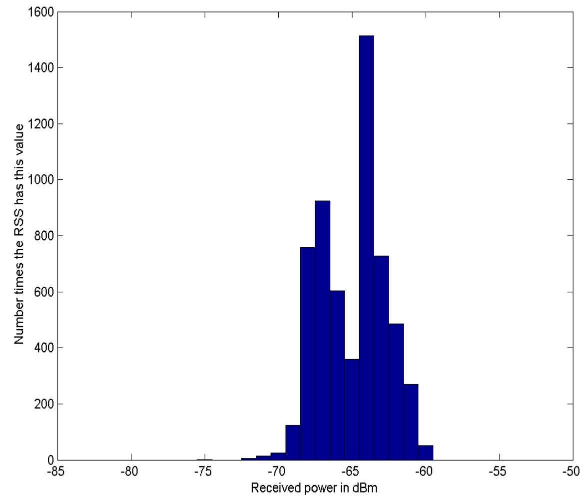


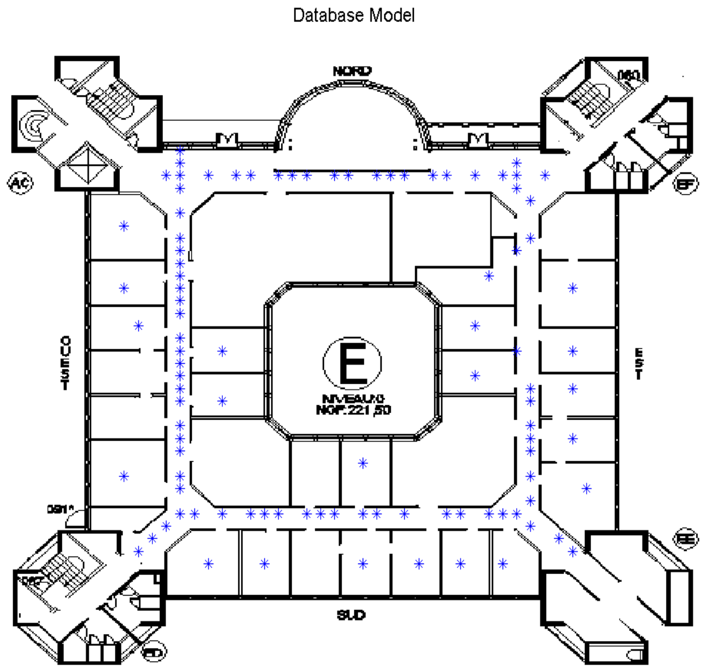
Basic indoor positioning with WiFi (2)

- **Use of a database containing the signal strength footprints**
- **Constraint**
  - Building the database
- **Closest neighbor algorithm:**
  - Search in the database

$$X = \underset{x_k, y_k}{\arg\min} \left(\sum_{l=1}^{N} \left(P_{r_l}(x, y) - P_{r_l}(x_k, y_k) \right)^2 \right)$$

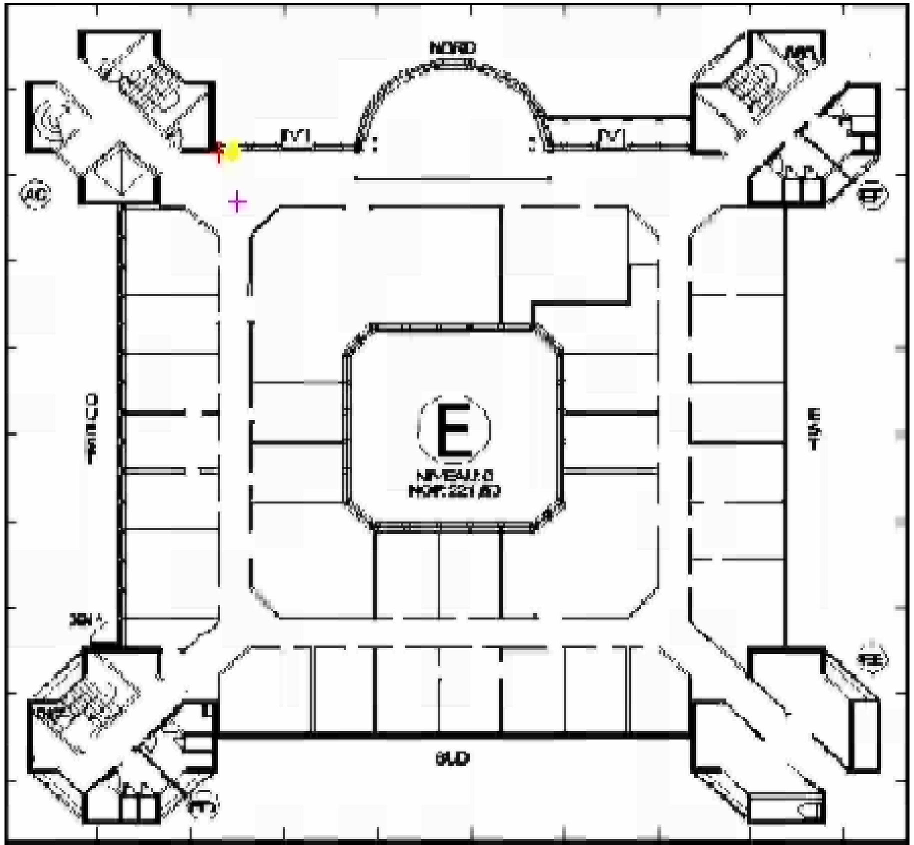
- **Problem:**
  - Signal strength fluctuations over the time
    - Position extracted from the database fluctuates all the time





The Kalman filter

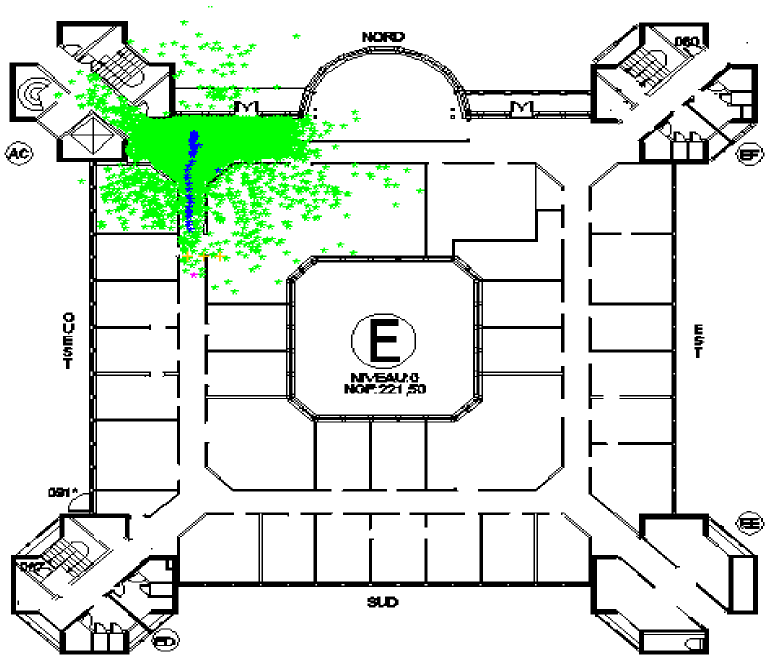
- **Estimates the state of a system**
  - Pediction of the next state
  - Correction by a new measurement
- **Minimization of the covariance of the posterior error**
- **Appliance conditions: linear laws**
  - Hard to model all the situations
- **Advantages:**
  - Gives a linear trajectory
  - Can be run on handheld devices
- **Drawbacks**
  - Some wall crossings remain
  - Signal strength fluctuations remain



Kalman_parcours_couloir_2-56.avi

The particle filter (1)

- **Filter based on a set of "particles" exploring the space of possibilities**
- **Each particle has a weight.**
  - The weight is the probability to find the particle at a given position
- **The weight includes:**
  - The history of the particle
  - The structure of the building
  - The signal strength measurements
  - Other information (ex: INS)
- **Leads to the distribution law associated to the mobile's presence probability density**



The particle filter (2)

- **The weight of a particle is defined as follows**

$$w_k^i \propto w_{k-1}^i \cdot \Pr\left[Z_k \middle| X_k^i\right] \cdot \Pr\left[X_k^i \middle| X_{k-1}^i\right]$$

- **The prior law is the movement law:**
  - Use of gaussian noises to model the acceleration
- **Taking into account the structure of the building**
  - If a particle crossed a wall : $\Pr\left[x_k | x_{k-1}\right] = P_m$
  - If a particle did not cross a wall : $\Pr\left[x_k | x_{k-1}\right] = 1 - P_m$
- **The posterior law:** $\Pr\left[z_k | x_k\right] = N\left(z_k, d_c\right)$
  - Gaussian law

FT Group Restricted

The particle filter (3)

- **Problem**
  - Degeneracy of the filter
    - Particles with a too low weight need to be re-introduced in the interesting area
- **Solution**
  - Triggering a resampling step

$$N_{eff} = \frac{1}{\sum_{i=1}^{N} \left(w_k^i\right)^2} \leq \frac{N}{100}$$

- **Consequence**
  - Loss of a part of the diversity of the filter
  - The filter can collapse (if all the particles remain trapped in a room)
- **Criterion**
  - Search of the particles having the highest weights
  - Add a noise to get locally some diversity (Epanechnikov, Gaussian kernels)

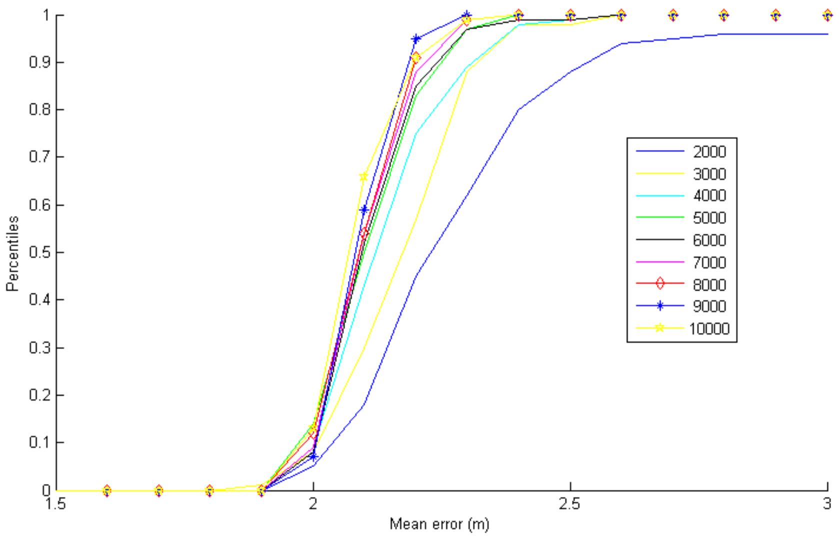
The particle filter (4)

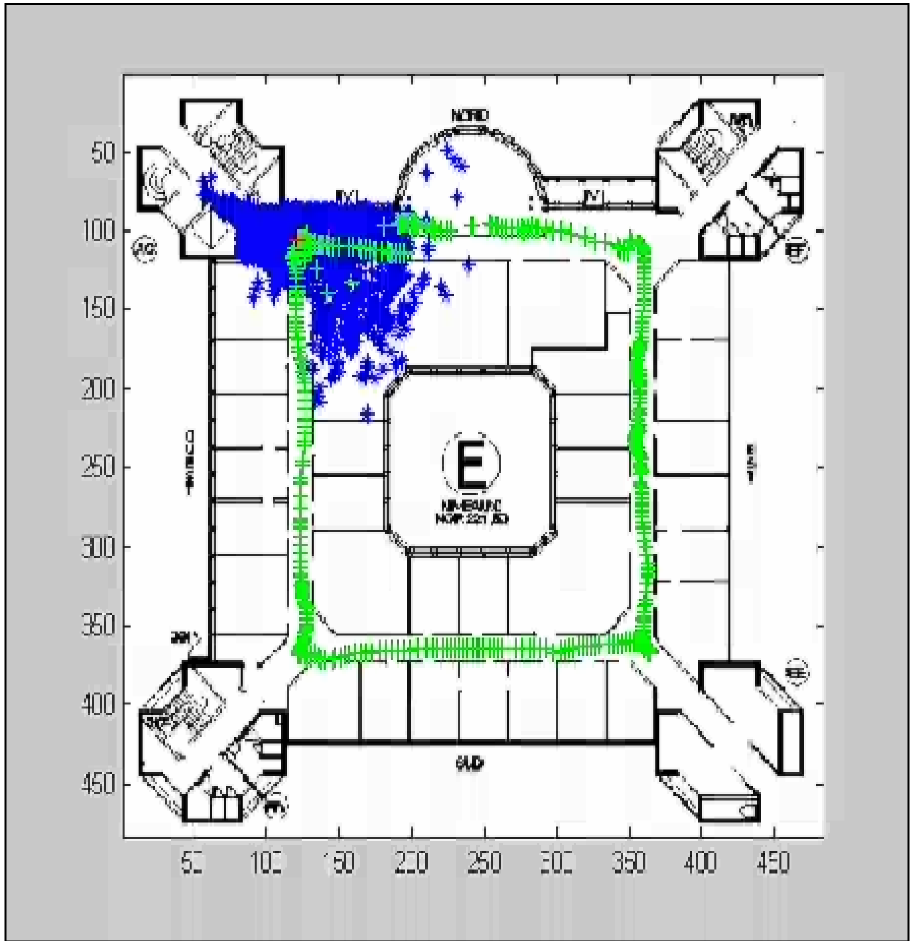
Some interesting results

- Accuracy improvements
- fewer wall crossings

Inconvenient

- Requires a large number of particles
  - High processing work load
  - Cannot be implemented on limited processing devices





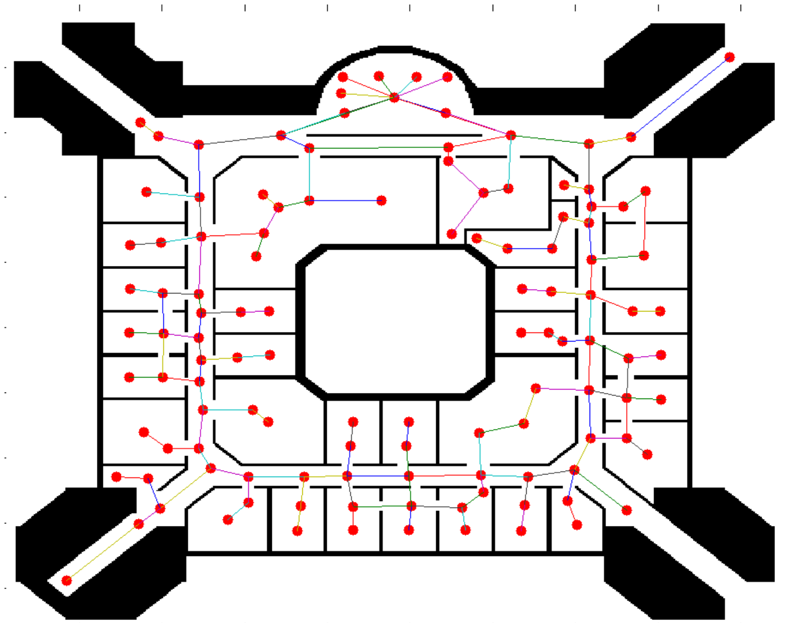
particle_filter_corridor.avi

FT Group Restricted

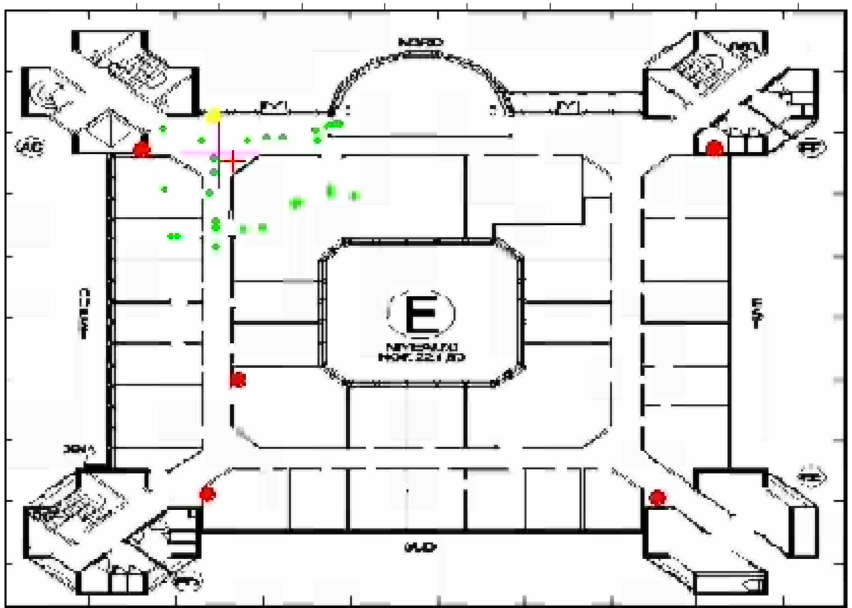
Complexity reduction

Reduction of the number of particles

- Reduction of the space to explore
  - The Voronoi diagram could be a solution
- Automatic building of this diagram
- Avoid the particles be trapped
- No checking for the wall crossings



	Database	Kalman filter	Particle filter	Voronoi filter
Elapsed time per Measurement (ms)	1	1.2	175	44
Run on a laptop	√	√	√	√
Run on a PDA	√	√		√



Voronoi_parcours_couloir_1-77.avi

Principle & overview of our UWB system

Objectives

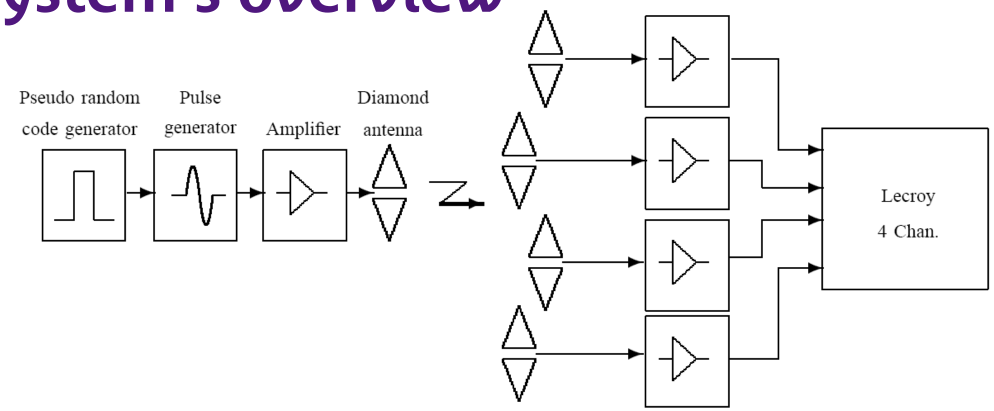
- Comparison of timming position vs. Signal strength fingerprinting
- Study of the capabilities of UWB radio impulse for device positioning

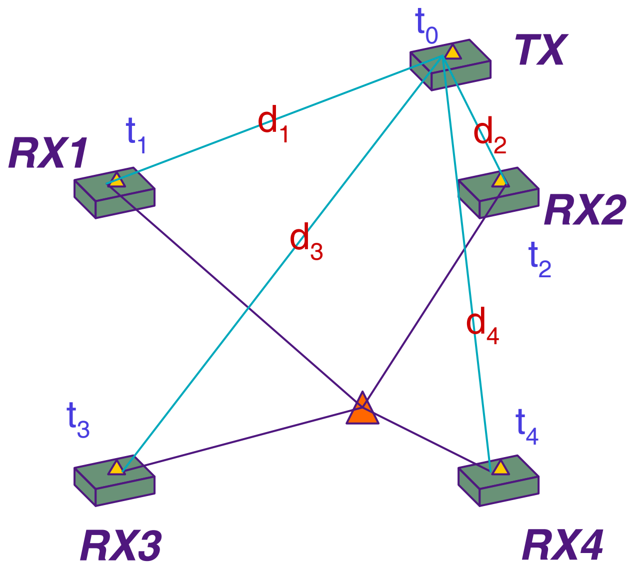
Technique : Time Difference Of Arrival

- Computation of way differences

$$[(t_i-t_0) - (t_{ref}-t_0)]*c = (t_i - t_{ref})*c$$

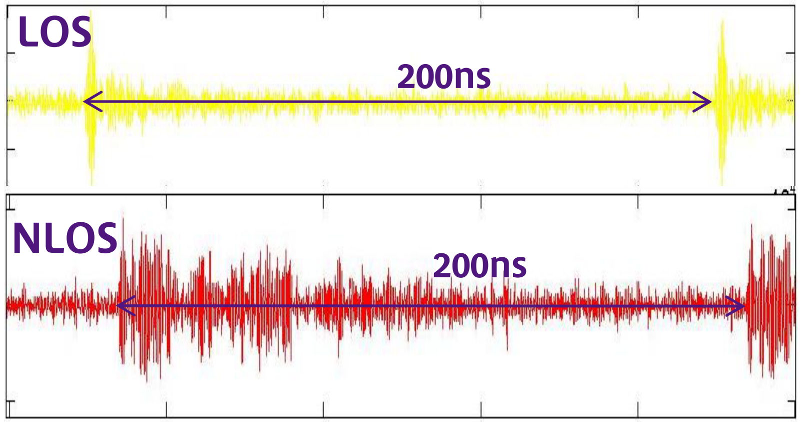
System's overview

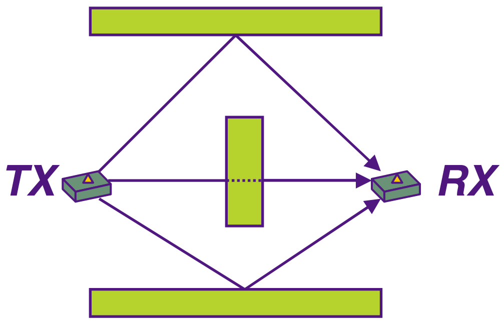


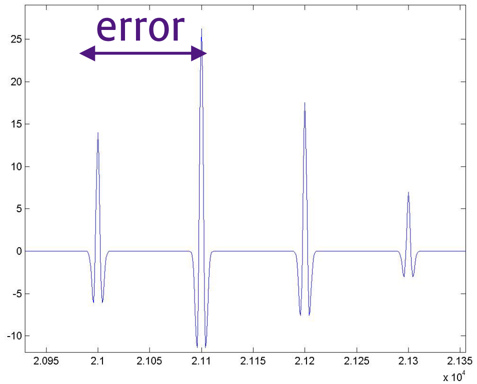


The challenge

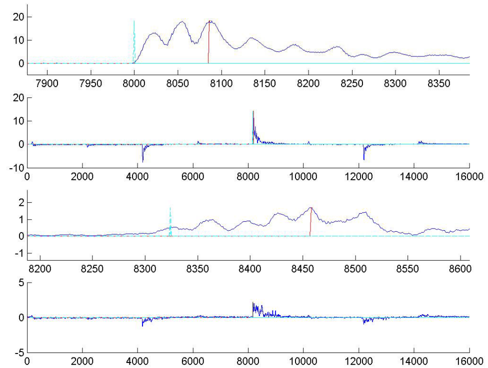
- **Fighting the multipath (indoor environment)**
  - Delay spread > 100 ns
  - ISI is possible: chip duration = 200 ns
- **Finding the direct path**
  - Better accuracy







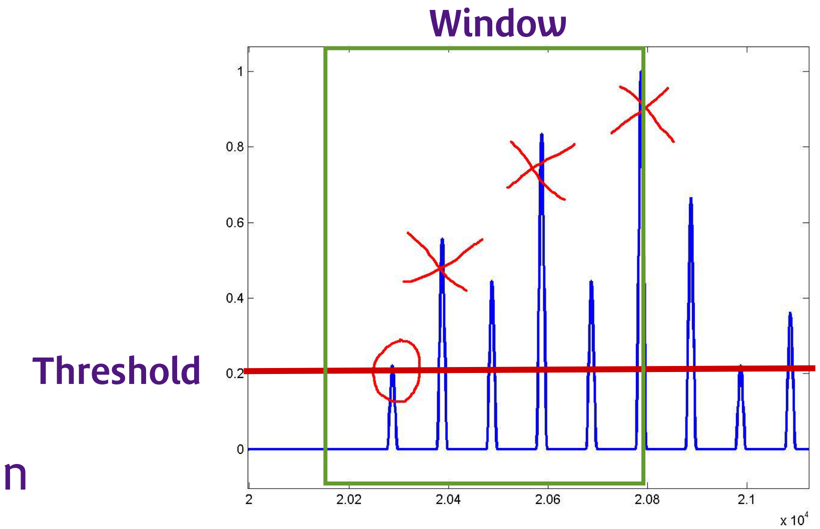
Correlation result



Signal processings (1)

Use of the CLEAN algorithm to detect that path

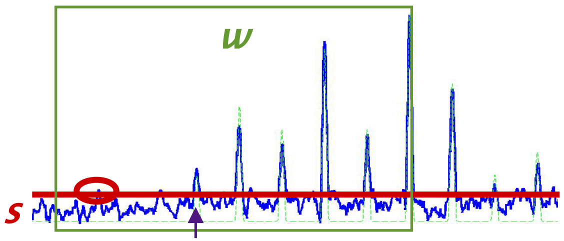
- Based on the Generalised Maximum Likelihood algorithm (iterative algorithm)
- Hypothesis : $$r(t)=\sum_i c_i w(t-\tau_i)$$
- Stop criterion : $$\operatorname{argmin}\left[\left\| r(t)-\hat{r}(t)\right\|^2\right]$$



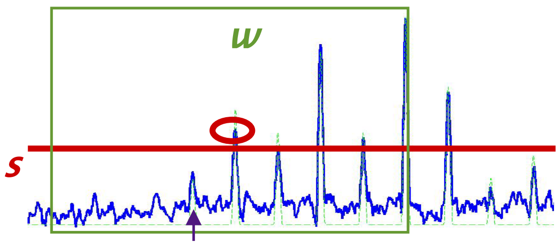
Code Correlation

Limitation:

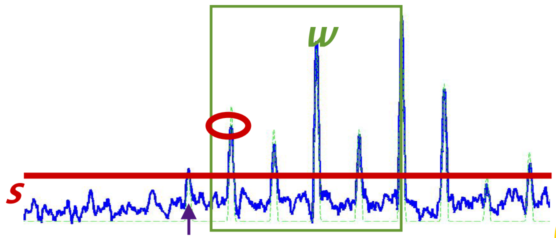
- Ignorance of the pulse shape at reception
- Use of the energy detection
- Minimization of the False Alarm (P_{FA}) and the Missed path detection (P_{MP})



Threshold too low



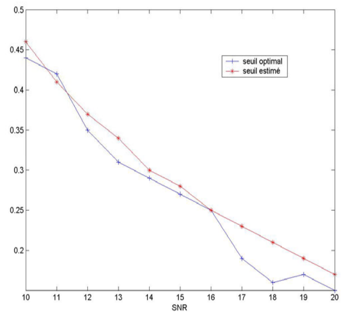
Threshold too high



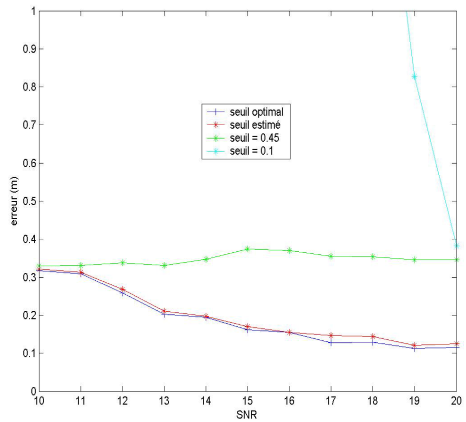
Window too short

Signal processings (2)

- P_{MP} depends on the channel's statistics
  - $\tau_{direct} - \tau_{max}$
  - $\dfrac{\alpha_{direct}}{\alpha_{max}}$
- P_{FA} : probability that the noise be over s during the window w
  - Depends on the processing at reception
- Criterion: choose w such as the direct path be not missed and s minimizing P_{FA} and P_{ND}
- Simulations with the 802.15.3 channel models
- Limitations:
  - P_{FA} : requires the maximum correlation peak value for normalization
  - P_{MP} : channel's statistics; measurement campaign



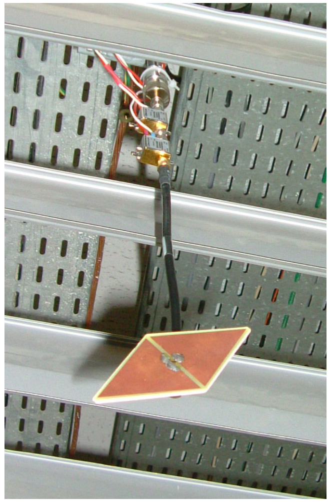
Optimal threshold

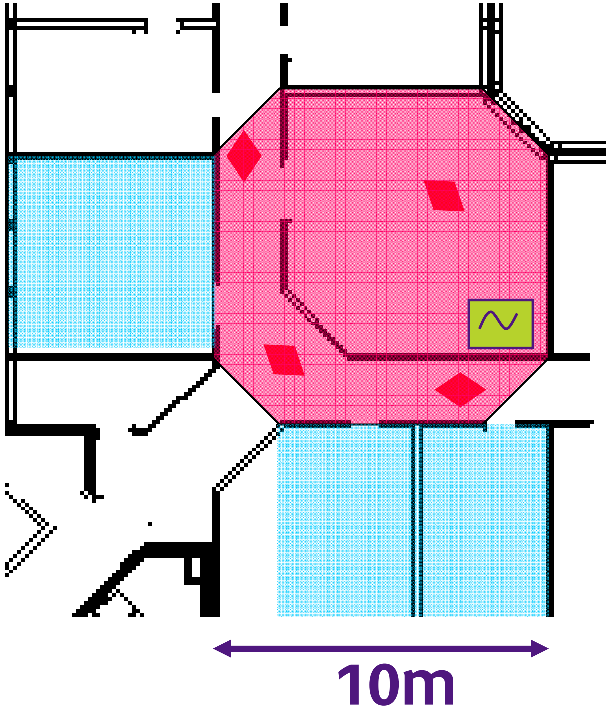


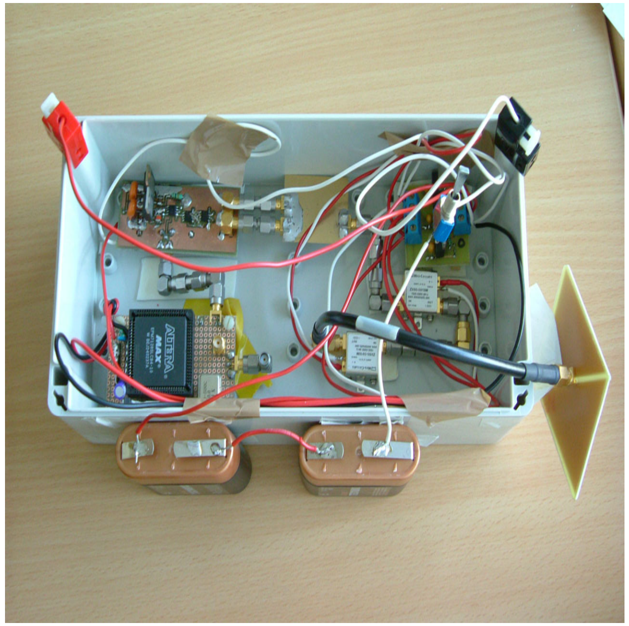
Error ranging estimation

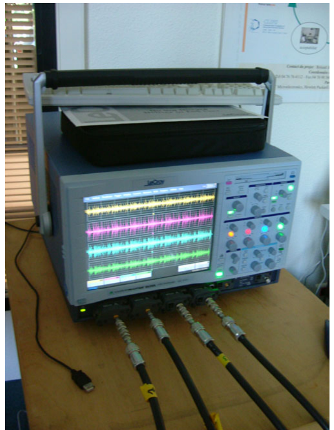
Positioning system

- Always an NLOS situation
- Covered area 20*20 m
  - Two kinds of positioning areas







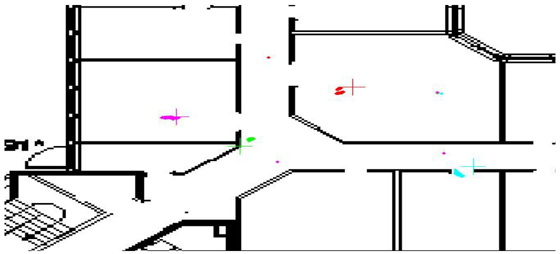


Comparison of different strategies

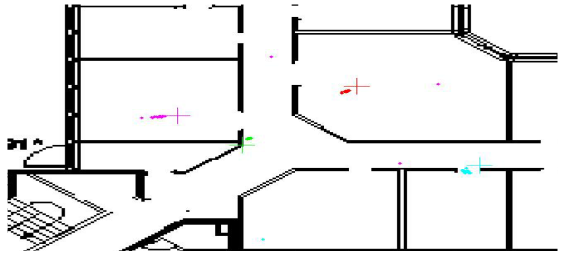
Strategies

- Adaptive threshold
- Fixed thesholds
- Maximum peak detection

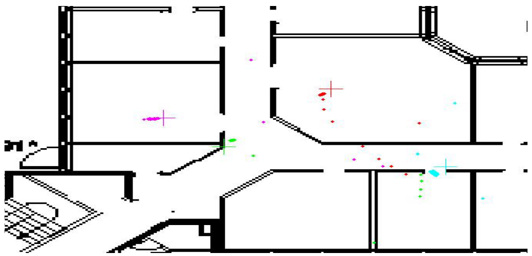
Adaptive threshold



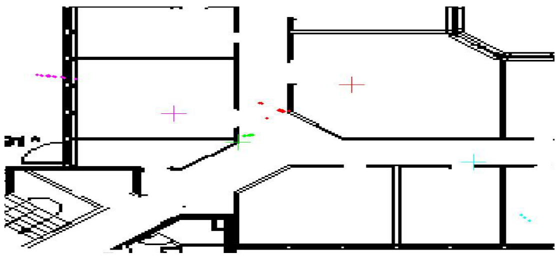
Fixed threshold [0.5 0.5 0.5 0.5]

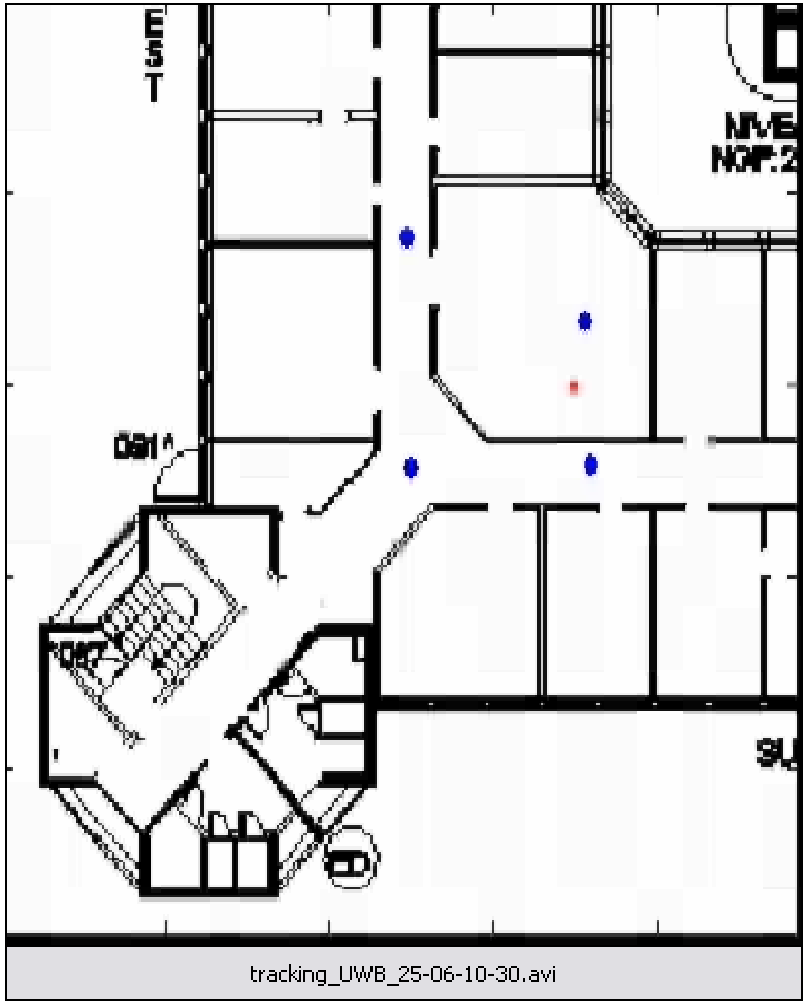


Fixed threshold [0.2 0.3 0.5 0.3]



Maximum peak detection





Sensor fusion (1)

- **The particle filter is a convenient tool:**
  - Calculate $\Pr\left[z_k \middle| x_k\right] = \Pr\left[z_k^{Wifi}, z_k^{UWB} \middle| x_k\right]$
    - Hypothesis
      - *Assume the WiFi and UWB measurements are uncorrelated*

$$\Pr\left[z_k \middle| x_k\right] = \Pr\left[z_k^{Wifi} \middle| x_k\right] * \Pr\left[z_k^{UWB} \middle| x_k\right]$$

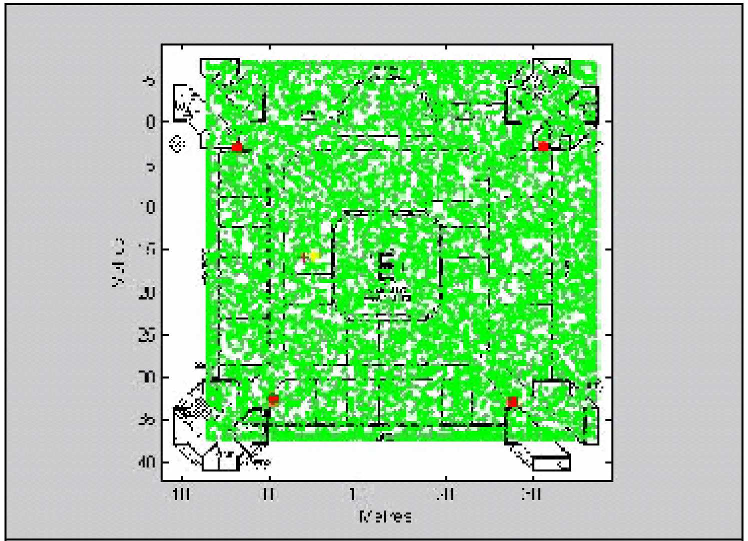
      - *Each probability density is assumed to be gaussian*
  - The best of each sensor must be kept
    - WiFi: 2 m accuracy
    - UWB: 50 cm accuracy
- **Constraint:**
  - Area availability of each technology
    - WiFi: coverage over the building
    - UWB: coverage over a 20*20 m area

Sensor fusion (2)

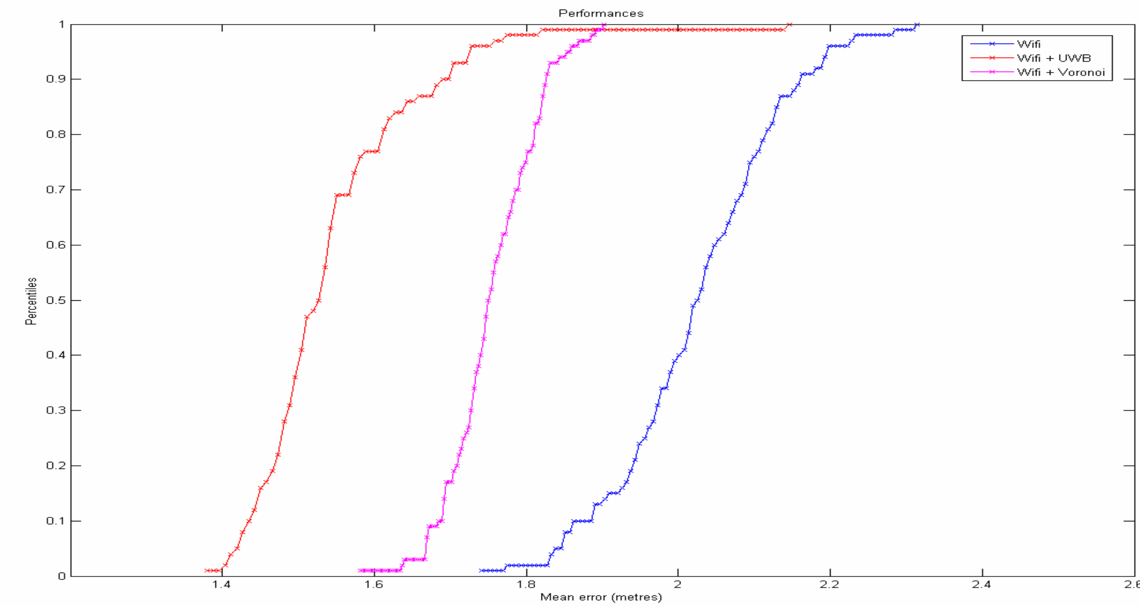
- **No special criterion for the WiFi measurement**
  - Accuracy is estimated to be about 2m
- **Need a special criterion for the UWB measurement**
  - Accuracy depends on the signal to noise ratio
    - The lower it is, the harder the first path detection will be
      - *Poor accuracy*
- **Confidence index will be introduced by the variance of each gaussian law**

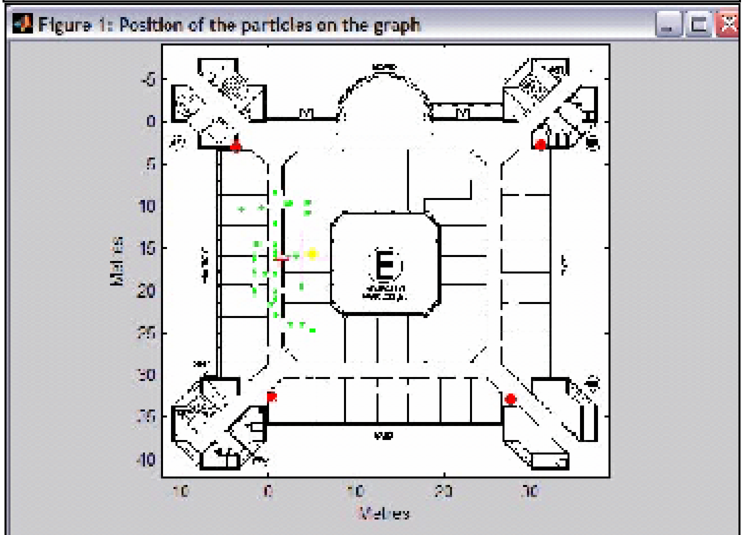
$$\sigma_{UWB} = \begin{cases} \infty & if \quad \min\left[SNR_i\right] \leq SNR_{low} \\ \sigma_{WiFi} & if \quad SNR_{low} < \min\left[SNR_i\right] \leq SNR_{high} \\ \dfrac{\sigma_{WiFi}}{4} & if \quad \min\left[SNR_i\right] > SNR_{high} \end{cases}$$

Performances of sensor fusion

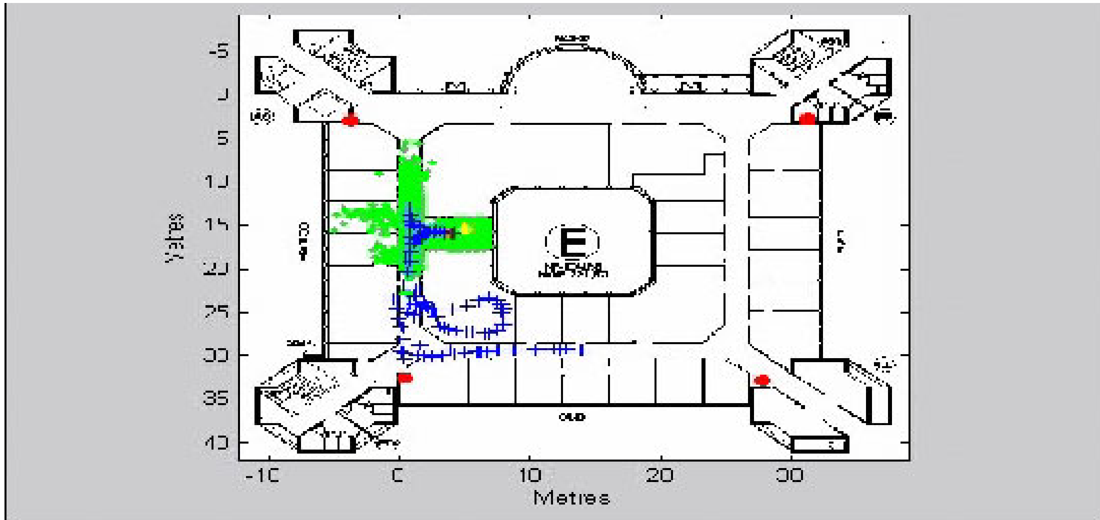


particle_filter_1.87m.avi





voronoi_1.71m.avi



wifi_uwb_1.56m.avi

Summary

- **Indoor positioning is promising in comparison with actual outdoor techniques**
  - Better accuracy (2 m)
  - Infrastructure are most of the time installed
    - Low cost (network + interface on the mobile device)
- **UWB leads to encouraging positioning results**
  - Accuracy (50 cm)
  - But short coverage area (20*20 m area)
- **Combination of positioning technologies is necessary**
  - To know the position of the mobile in a room
  - Resynchronize the poorest technology
  - UWB + WiFi positioning require a network-based solution
    - Higher processing capabilities