Positioning and localization of mobiles in rich multipath scenarios

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Joint Seminar WIBEC // COST-IRACON on Radio Frequency Localization Techniques
29/05/2018 – Room P1.6
Outline

1. Overview of localization and positioning techniques

2. Multidimensional radio channel measurements for Parametric estimation techniques

2. Dedicated localization techniques in rich multipath scenarios
   1. Outdoor scenario
   2. Indoor scenario

3. Conclusion
OVERVIEW OF LOCALIZATION AND POSITIONING TECHNIQUES
Context - 1

Positioning (DL) & Localization (UL)

Computed by MS

Computed by dedicated BS network
GNSS satellite systems

- limitations: obstructing in urban scenarios (NLOS)

Positioning

⇒ APPLICATIONS:
Service called by the user
  • Route, carpooling, …

- GNSS satellite systems
  ➢ Hybrid satellite/mobile systems in dense urban environments

Localization

⇒ APPLICATIONS:
Search & Rescue Services (civil security)
  • injured civilians, lost, buried
  • surveillance of dangerous people

Robot guiding
  • in inaccessible or dangerous spots for humans (nuclear plants)

- Mobile, WiFi, Bluetooth
- Dedicated networks (UWB, Beacon, Zigbee, RFID, local network)
Localization w/ cooperative/non-cooperative mode

Cooperative mode
Mobile (MS) & Base Stations (BS) in service network can all contribute to the localization

Non-cooperative mode
Deployment of dedicated receiving stations (RS) which only contribute to the localization
Localization Constraints

Goal: On the spot demand  
⇒ non-cooperative mode

Challenges: Localization < ~ m
- few APs or BSs
- urban environment  
  ⇒ NLOS, multipath components diffusion, depolarization
- No MS-RS synchronization
- Unknown emitting polarization
- Limited bandwidth

200 kHz = GSM channel
# 20 MHz = Aggregated GSM or LTE band

No existing article in the literature with such specifications…
Localization techniques overview - 1

Radio Localization

Geometrical techniques
- Multilateration
- Triangulation

Non-geometrical techniques
- Fingerprinting
- Multi-hop
Localization techniques overview - 2

Geometrical techniques

TOA, RSS

- TOA [JAN13]: RMSE 25 m. w/ 3 RS

AOA

- AOA [HUA14]: RMSE 1 m w/ 10 RS

TDOA

- LTE-TDOA [ZHAN12]: 92.88% ≤ 50 m w/ 4 RS

Literature: Only simulation results!
Weak performances for NLOS scenarios w/ few RS
Localization techniques overview - 3

**Non-geometrical techniques**

**Fingerprinting**

- **Aerial view of urban environment**

- **Comparison of fingerprints extracted from data with database**

- **Experimental results in urban scenarios**:
  - Cooperative mode + database built from measurements!

- **FP-RSS**:
  - Cooperative GSM+WiFi [CUJI12]
  - Mean error 30 m
  - (large # of BS or WiFi access points)

- **Multi-hop (ad hoc)**

- **TOA [SHI14]**:
  - RMSE 16m
  - w/ 14 RS + 3 to 11 cooperative MS

- **Only simulation results!**
# Localization techniques overview - 4

<table>
<thead>
<tr>
<th>Technology</th>
<th>Dependence to scenario</th>
<th>Calibration</th>
<th>Accuracy</th>
<th>Robustness</th>
<th>Complexity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>UWB</td>
<td>High</td>
<td>Several times</td>
<td>&lt;0.3m (50%&lt;0.3 m)</td>
<td>Average</td>
<td>Good</td>
<td>High</td>
</tr>
<tr>
<td>RFID</td>
<td>Low</td>
<td>-</td>
<td>&lt;2m (50%&lt;1m)</td>
<td>High</td>
<td>Good</td>
<td>Low</td>
</tr>
<tr>
<td>BLE (beacon)</td>
<td>High</td>
<td>Several times</td>
<td>&lt;2m (95%&lt;2m)</td>
<td>Average</td>
<td>High</td>
<td>Average</td>
</tr>
<tr>
<td>WiFi</td>
<td>High</td>
<td>Several times</td>
<td>&lt;2m (50%&lt;2m)</td>
<td>Average</td>
<td>Good</td>
<td>High</td>
</tr>
<tr>
<td>WiFi Symbolic</td>
<td>Low</td>
<td>-</td>
<td>~ 10 m</td>
<td>Very High</td>
<td>Low</td>
<td>Average</td>
</tr>
<tr>
<td>LTE</td>
<td>High</td>
<td>Several times</td>
<td>50m – 250 m</td>
<td>Average</td>
<td>High</td>
<td>Average</td>
</tr>
</tbody>
</table>
Localization with WiFi Positioning System (WiPS)

• Signal strength-based
  – RSSI (Trilateration + propagation models)
  – Fingerprinting (Reference Database)
    • Deterministic or probabilistic

• Geometrical-based
  – AOA (Triangulation)
  – Time of Flight (Trilateration using timestamps)
    • Sensitive to clock synchronization issues, noise, sampling artifacts and multipath channel effects
Observed Time Difference of Arrival (OTDOA) for Positioning in LTE

- DL multilateration technique introduced in Release 9 with ~50 m accuracy
- The UE measures the TOA from Positioning Reference Signals (PRS) sent by the eNBs
  - TDOA computed from reference eNB
- Approach rather similar to GNSS
  - Solves « navigation equations » from Reference Signals Time Difference (RSTD) computed between 2 eNBs equations
  - Very sensitive to geometric dilution and multipath fading

\[
RSTD_{i,1} = \sqrt{(x_t - x_i)^2 + (y_t - y_i)^2/c} - \sqrt{(x_t - x_1)^2 + (y_t - y_1)^2/c} + (n_i - n_1)
\]
• Pseudo-random QPSK sequence mapped with shift in frequency and time to avoid collision with signaling reference signals (PSS/SSS) or control channel (Physical DL CCH - PDCCH)

<table>
<thead>
<tr>
<th>PRS BW [MHz]</th>
<th>(N_{\text{PRS}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0438</td>
</tr>
<tr>
<td>2</td>
<td>0.0875</td>
</tr>
<tr>
<td>4</td>
<td>0.1750</td>
</tr>
<tr>
<td>6</td>
<td>0.2625</td>
</tr>
<tr>
<td>1.4</td>
<td>0.0938</td>
</tr>
<tr>
<td>3</td>
<td>0.1875</td>
</tr>
<tr>
<td>5</td>
<td>0.3125</td>
</tr>
<tr>
<td>10</td>
<td>0.3125</td>
</tr>
<tr>
<td>15</td>
<td>0.4688</td>
</tr>
<tr>
<td>20</td>
<td>0.6250</td>
</tr>
</tbody>
</table>

\(F_{\text{sc}} = 15\ \text{kHz}\)

\(T = 66.67\ \mu\text{s}\)
RADIO CHANNEL MODELS AND MULTIDIMENSIONAL MEASUREMENT
Time-varying
MIMO radio channel MODEL

\[ H(f, t) = G_{R_f}(f) \cdot G_{T_f}(f) \cdot \sum_{p=1}^{P} \left\{ B_R(\varphi_{R,p}, g_{R,p}) \cdot \Gamma_p \cdot B_T(\varphi_{T,p}, g_{T,p})^T \cdot e^{-j2\pi f \cdot \tau_p} \cdot e^{-j2\pi \frac{\Delta f}{f_c} \cdot \tau_p} \right\} \]

Antenna Gain
Rx/Tx

Far field beam
pattern Rx

Far field beam
pattern Tx

Path Time Delay

Doppler Shift

\[ \Gamma_p = \begin{bmatrix} \gamma_{HH,p} & \gamma_{VH,p} \\ \gamma_{HV,p} & \gamma_{VV,p} \end{bmatrix} \in \mathbb{C}^{2 \times 2} \]

\[ B_R(\varphi_R, g_R) = \begin{bmatrix} b_{R,1}(\varphi_R, g_R) \\ \vdots \\ b_{R,M_R}(\varphi_R, g_R) \end{bmatrix} \]

\[ B_T(\varphi_T, g_T) = \begin{bmatrix} b_{T,1}(\varphi_T, g_T) \\ \vdots \\ b_{T,M_T}(\varphi_T, g_T) \end{bmatrix} \]
Multidimensional Radio Channel Analysis

- Model order -> How many MPCs?
  - Complex weight for each MPC
- ToA – Time of Arrival $\tau_p(t)$ [$d_p(t) = c.\tau_p(t) = \lambda/f.\tau_p(t)$]
  - Wideband or UWB radio channel measurement within coherence time
- DoA – Direction of Arrival: Azimuth $\vartheta_p(t)$ & elevation $\varphi_p(t)$
  - Antenna array at receiving side
- DoD – Direction of Departure: Azimuth $\vartheta_T(t)$ & elevation $\varphi_T(t)$
  - Antenna array at transmitting side
- Doppler frequency $f_d(t)$
  - Time-varying radio channel

1 fast linear parameter $\gamma(t)$
6 slow non-linear parameters $\tau(t), \vartheta_p(t), \varphi_p(t), \theta_T(t), \varphi_T(t), f_d(t)$

6D Estimation problem!
And distributed scattering

- \( \lambda \sim \) diffusing element

- Highly frequency dependent phenomena but contribution decreases dramatically with frequency
  - From 25 to 80% at mobile frequencies to few % at 60 GHz
PARAMETRIC ESTIMATION TECHNIQUES
# Parametric Estimators Overview

<table>
<thead>
<tr>
<th>Algorithms</th>
<th>Fonction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beamforming (BF)</td>
<td>$P_{BF}(\theta) = \frac{a^H(\theta)Ra(\theta)}{M^2}$</td>
<td>Classical beamformer with low resolution</td>
</tr>
<tr>
<td>MUSIC</td>
<td>$P_M(\theta) = \frac{1}{a^H(\theta)E_NE_N^Ha(\theta)}$</td>
<td>HR technique but computationally slow with MD matrices</td>
</tr>
<tr>
<td>ESPRIT</td>
<td>$\theta_i = \cos^{-1}\left(\frac{\arg(\lambda_i)}{2\pi d}\right)$</td>
<td>HR technique but sub-arrays decrease resolution</td>
</tr>
<tr>
<td>SAGE</td>
<td>$\theta_i = \arg\max_{\theta_i \in \Theta} \left(a^H_i R_i a_i \right)$</td>
<td>HR ML technique</td>
</tr>
<tr>
<td>RIMAX</td>
<td>$\hat{\theta}<em>{sp} = \arg\min</em>{\theta_{sp}} \left(x - s(\theta_{sp})\right)^H R(\theta_{dan})^{-1} \left(x - s(\theta_{sp})\right)$</td>
<td>SMC ($\theta_{sp}$) + DMC ($\theta_{dan}$) Computationally efficient</td>
</tr>
</tbody>
</table>
RiMAX Data Model

\[ h \sim \mathcal{N}_C \left( s(\theta_{sp}), R(\theta_{dmc}) \right) \in \mathbb{C}^{M \times 1} \]

Sampled Radio Channel

Mean

Covariance Matrix

Covariance Matrix Kronecker Factorization

\[ R(\theta_{dmc}) = R_R(\theta_{dmc}) \otimes R_T(\theta_{dmc}) \otimes R_f(\theta_{dmc}) \otimes R_t(\theta_{dmc}) \]

\[ R(\theta_{dmc}) = I_{M_R} \otimes I_{M_T} \otimes R_f(\theta_{dmc}) \otimes I_{M_t} \]

Simpler models consider AWGN channel

\[ R_t(\theta_{dmc}) = \sigma^2 I \]

\[ R_{mm} = \alpha_0 I + R(\theta_{dmc}) \]
Dense Multipaths Components

\[ \kappa(\theta_{dan}) = \frac{\alpha_1}{M_f} \left[ \frac{1}{\beta_d} \left( \frac{e^{-j2\pi \tau_d}}{\beta_d + j2\pi \frac{1}{M_f}} \right) \right]^T + \alpha_0 e_0 \]

Concentrated propagation paths

\[ h = s(\theta_{sp}) + d_{dmc} \]

Dense Multipath components

\[ R_f(\theta_{dmc}) = \text{toep}(\kappa(\theta_{dmc}), \kappa(\theta_{dmc})^H) \]

Figure 2-4: Dense multipath distribution model in the time delay domain \( \psi_{\text{max}}(\tau, \tau) \).
Complete Polarimetric MIMO System Model

\[ H_S(\theta_{sp}) = G_R \cdot H(\theta_{sp}) \cdot G_T^T \]

\[ H(\theta) = \begin{bmatrix} H_{HH} & H_{VH} \\ H_{HV} & H_{VV} \end{bmatrix} \]

\[ G_T = \begin{bmatrix} G_{T_{fH}} & G_{T_{fV}} \end{bmatrix} \in \mathbb{C}^{(M_f \cdot M_T) \times (2 \cdot N_f \times N_T)} \]

\[ G_R = \begin{bmatrix} G_{R_{fH}} & G_{R_{fV}} \end{bmatrix} \in \mathbb{C}^{(M_f \cdot M_R) \times (2 \cdot N_f \times N_R)} \]
PDF of Sampled radio Channel

\[ p(x|\theta, R_{mm}) = \frac{1}{\pi^M \det(R_{mm}(\theta))} e^{-((x-s(\theta))^H R_{mm}(\theta)^{-1}(x-s(\theta)))} \]

<table>
<thead>
<tr>
<th></th>
<th>Aperture / Data Domain</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal samples</td>
<td>Time ( t )</td>
<td>Doppler-shift ( \alpha )</td>
</tr>
<tr>
<td>Frequency samples</td>
<td>Frequency ( f )</td>
<td>Time delay of arrival ( \tau )</td>
</tr>
<tr>
<td>Tx antenna ports</td>
<td>Space at Tx</td>
<td>Azimuth of Departure ( \varphi_T )</td>
</tr>
<tr>
<td>Rx antenna ports</td>
<td>Space at Rx</td>
<td>Elevation of Departure ( \varphi_D )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Azimuth of Arrival ( \varphi_R )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Elevation of Arrival ( \varphi_E )</td>
</tr>
</tbody>
</table>

| \( B_d \)            | - coherence bandwidth of the diffuse components |
| \( r_d \)            | - base TDoA of the diffuse components |
| \( \beta_d = \frac{B_d}{B_s} = \frac{B_d}{M_f f_0} \) | - coherence bandwidth of the diffuse components normalised to the measurement bandwidth |
| \( M_f \)            | - number of frequency points measured within the measurement bandwidth |
| \( r_d = \frac{r_d}{\tau} \) | - base TDoA of the diffuse components normalised to the total length of the observed impulse-response |
| \( \alpha_1 \)       | - power of the diffuse components at \( r = r_d \) |
| \( B_2 = \frac{B_3}{B_0} \) | - 3dB coherence bandwidth of the diffuse components |
Estimation of Parameters

\[ p(x|\theta, R_{nn}) = \frac{1}{\pi^M \det(R_{nn}(\theta))} e^{- (x-s(\theta))^H R_{nn}(\theta)^{-1} (x-s(\theta))} \]

\[ x = s(\theta) + n_{dan} \]

Deterministic Maximum Likelihood (DML)

Stochastic Maximum Likelihood (SML)

Joint Maximum Likelihood Estimation Problem

Cramer-Rao Lower Bound

\[ C_\theta = E\left\{ (\hat{\theta} - \theta) \cdot (\hat{\theta} - \theta)^T \right\} \geq CRB_\theta \]
Experimental Analysis of Dense Multipath Components in an Industrial Environment

Emmeric Taughe, Davy P. Caillot, Martine Liénard, Luc Martens, Member, IEEE, and Wout Joseph, Senior Member, IEEE
RIMAX Example 2

Polarization Properties of Specular and Dense Multipath Components in a Large Industrial Hall

Davy P. Gaillot, Emmeric Taughe, Wout Joseph, Senior Member, IEEE, Pierre Laly, Viet-Chi Tran, Marine Liènard, and Luc Martens, Member, IEEE
DEDICATED LOCALIZATION TECHNIQUES

Outdoor Scenarios
**Proposed Localization Technique - 1**

### FINGERPRINTING CHOICE

### CONSTRAINTS

<table>
<thead>
<tr>
<th>Immediate and on the spot need</th>
<th>Database built from deterministic radio channel models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited bandwidth</td>
<td>Antenna Array for BS and high-resolution estimator to estimate fingerprints AOA (spatial) et TOA (frequency)</td>
</tr>
<tr>
<td>RS discretion</td>
<td></td>
</tr>
<tr>
<td>Unknown MS polarization</td>
<td>Dual-polarized antennas for BS (Polarization diversity)</td>
</tr>
</tbody>
</table>

→ Multidimensional diversity
Proposed Localization Technique - 1

→ 1st STEP (beyond current work)

- IMSI catcher

**MS Identification**

**MS communication forcing mode**

**IMSI (International Mobile Subscriber Identity) Catcher principle**
Proposed Localization Technique - 2

Channel reciprocity
Fingerprinting

FINGERPRINTING

Database

Correlation ?

Amplitude

TOA

Delay

Deterministic Model

BS Meas.

Δt = résolution temporelle

Amplitude
Deterministic Radio Channel

- Database construction
- Synthesis of radio channels for simulations

<table>
<thead>
<tr>
<th>Polarization Tx</th>
<th>Polarization Rx</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>V</td>
</tr>
<tr>
<td>V</td>
<td>H</td>
</tr>
<tr>
<td>H</td>
<td>V</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

Cross-polarization mode not available
Parametric Estimation Performance

Three strongest paths – 12-element patch UCA – 20 dB SNR

TOA Mean Error (ns)

AOA Mean Error (°)
NLOS Example RL vs. Exp.

Most Energetic Paths (10 dB threshold)
RS design: depends on RIMAX performance

⇒ Simulated perf. as a function:
- Bandwidth, SNR
- Antenna array (Circular, rectangular)
- Type and # of antennas

**Simulation environment:** Lille 1 Campus

<table>
<thead>
<tr>
<th>K Factor ($\frac{P_{LOS}}{P_{NLOS}}$)</th>
<th>Channel %</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; -25 dB</td>
<td>98.3 %</td>
</tr>
<tr>
<td>-25 &lt; K &lt; 6.7 dB</td>
<td>1.7 %</td>
</tr>
</tbody>
</table>

- $\tau_{rms}$ : [23 ns - 164 ns] (median: 60 ns)
- $\phi_{rms}$ : [15° - 94°] (median 56°)
Localization Results (Simulations)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Channel Characteristics</th>
<th>Estimation</th>
<th>LOCALIZATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>90% error (ns/°)</td>
<td>Correct Localization (%)</td>
<td>90% error (m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 RS</td>
<td>2 RS</td>
</tr>
<tr>
<td>Bw=5 MHz, UCA12 patch</td>
<td>&lt;30 ns/&lt;11°</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Bw=22 MHz, UCA12 patch</td>
<td>&lt;2.7 ns/&lt;3.8°</td>
<td>11</td>
<td>24.7</td>
</tr>
<tr>
<td>Bw=100 MHz, UCA12 patch</td>
<td>&lt;0.4 ns/&lt;1.4°</td>
<td>25</td>
<td>60</td>
</tr>
</tbody>
</table>

- Localization error:
  - RIMAX estimation errors
  - COST function artifacts
- Large errors w/ 1 RS: 90% accuracy > 44 m
Experimental Campaign - 1

- Numerous buildings → reflections, diffractions, Mostly NLOS
- Presence of vegetation

Lille 1 Aerial View

Orientation of Tx antenna for polarization diversity meas.

Virtual UCA Rx
Experimental Campaign - 2

**Depolarization phenomena**

Metric: \[ XPD_u = \frac{P_{\text{mo}u}}{P_{\text{mo}v}} \exp(v 
eq u) \]

- Tx-Rx height difference
- Depolarizing objects

**Weak XPD channels (0 à 8 dB)**
- Dense vegetation (around Tx)
- Metallic objects

**Strong XPD channels (10 à 17 dB)**
- => LOS or first order interactions
Localization Results (Experimental)

Mean SNR impact

<table>
<thead>
<tr>
<th>Polarization</th>
<th>Success %</th>
<th>Error % ≤10m</th>
<th>50% accuracy (m)</th>
<th>90% accuracy (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>w/o polarization diversity – 2 RS</td>
<td>uV</td>
<td>18</td>
<td>&lt; 11.2 m</td>
<td>&lt; 51.5 m</td>
</tr>
<tr>
<td></td>
<td>uH</td>
<td>23</td>
<td>&lt; 9 m</td>
<td>&lt; 47.8 m</td>
</tr>
<tr>
<td>w/ polarization diversity – 2 RS</td>
<td>u</td>
<td>16.5</td>
<td>&lt; 9 m</td>
<td>&lt; 34 m</td>
</tr>
<tr>
<td></td>
<td>VV (theo.)</td>
<td>24.7</td>
<td>&lt; 2.5 m</td>
<td>&lt; 15 m</td>
</tr>
<tr>
<td>w/ polarization diversity – 3 RS</td>
<td>u</td>
<td>17</td>
<td>&lt; 7.5 m</td>
<td>&lt; 18 m</td>
</tr>
</tbody>
</table>

SNR > 50 dB
3 dB < SNR < 16 dB

Good robustness to weak SNRs
Summary

• Developed complete localization algorithm framework for LOS/NLOS urban scenarios
  – Non-cooperative mode
  – Fingerprinting database

• Numerical database constructed w./ RL software

• Exploits frequency, spatial, and polarization diversity
  – High-resolution parametric estimator

• Experimental results:
  – \(59\% \leq 10\, m\), \(CDF_{90\%} = 34\, m\)
DEDICATED LOCALIZATION TECHNIQUES

Indoor Scenarios
Indoor localisation technique

\[ \tau_1, \theta_1, \phi_1: \text{delay, DOA, DOD} \]

\[ \tau_2, \theta_2, \phi_2 \]

\[ \tau_3, \theta_3, \phi_3 \]

\[ \tau_4, \theta_4, \phi_4 \]
Localisation indoors - principe

- 2 synchronized receivers $Rx_1$ et $Rx_2$
- $Rx$ & $Tx$ equipped with antenna arrays
- At least two paths between $Rx$ & $Tx$
  - 1 LOS + 1 NLOS
  - 2 1st order NLOS
- Parametric estimation
  - Delay, DOA, DOD
Equations

- **Cosinus DOA (4 Equations \(\theta_1, \theta_2, \theta_3, \theta_4\))**
  \[
  \tan(\theta_1) = \frac{y_A - y_{R_1}}{x_A - x_{R_1}}
  \]

- **TDOA (6 Equations)**
  \[
  c(\tau_A - \tau_B) = \left[ d(R_A A) + d(AT_x) \right] - \left[ d(R_B B) + d(BT_x) \right]
  \]

- **Scalar product Tx (6 Equations)**
  \[
  R_A \cdot R_B = |R_A| |R_B| \cos(\theta_1 - \theta_2)
  = (x_A - x_{R_1})(x_B - x_{R_1}) + (y_A - y_{R_1})(y_B - y_{R_1})
  \]

- **Vectorial products Tx (6 Equations)**

- **Scalar products Rx (2 Equations)**
  \[
  T_x \cdot A \cdot T_x B = |T_x A| |T_x B| \cos(\varphi_1 - \varphi_2)
  = (x_A - x_{T_x})(x_B - x_{T_x}) + (y_A - y_{T_x})(y_B - y_{T_x})
  \]

- **Vectorial products Rx (2 Equations)**
Ambiguities
Solutions

• « Smart » initial solution
• Tx and impact points
• Tracking of mobile
• Use more receivers!
Ideal Case Simulation

![Graph showing position estimation error](image)

- LOS 2 Rx
- NLOS 2 Rx
- LOS 3 Rx
- NLOS 3 Rx

P(E≥ Localization error) vs Position estimation error (metres)
LOS Path tracking

- 3 Rx, 100 points
- RIMAX estimation
  - RX & TX: URA 4x4
  - Bandwidth 40 MHz/20 MHz
  - SNR: 20 dB
- Mobile trajectory selection
  - 4 possible solutions (Rx$_1$ & Rx$_2$), (Rx$_1$ & Rx$_3$), (Rx$_2$ & Rx$_3$), (Rx$_1$ & Rx$_2$ & Rx$_3$)
  - Most likely initial point
  - Point on track via convergence & distance between two points
## Results

<table>
<thead>
<tr>
<th>Erreur localisation (mètres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Rx}_{123}$</td>
</tr>
<tr>
<td>0,462</td>
</tr>
<tr>
<td>0,102</td>
</tr>
<tr>
<td>4,873</td>
</tr>
<tr>
<td>0,078</td>
</tr>
<tr>
<td>22,06</td>
</tr>
<tr>
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<table>
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<th>Pourcentage (%)</th>
<th>$\text{Pr}_{123}$</th>
<th>$\text{Pr}_{12}$</th>
<th>$\text{Pr}_{13}$</th>
<th>$\text{Pr}_{23}$</th>
<th>$\text{Pr}_\emptyset$</th>
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<tbody>
<tr>
<td>55,44</td>
<td>70,29</td>
<td>62,37</td>
<td>71,28</td>
<td>6,93</td>
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**LOS/NLOS Track**

- 3 Rx, 177 points

<table>
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<tr>
<th></th>
<th>Rx₁ &amp; Rx₂ &amp; Rx₃</th>
<th>Rx₁ &amp; Rx₂</th>
<th>Rx₁ &amp; Rx₃</th>
<th>Rx₂ &amp; Rx₃</th>
<th>Aucun couple</th>
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<tbody>
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<td>Pourcentage (%)</td>
<td>50,9</td>
<td>54,2</td>
<td>63,8</td>
<td>81,4</td>
<td>2,3</td>
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Localisation sur un parcours LOS/NLOS avec les paramètres idéaux (Ray Tracing)
Real Environment – Sports Hall
Summary

• Overview of multidimensional radio channel measurements and parametric estimation
  – Data deluge with latest systems!

• Broad range of localization/positioning techniques and technology becomes rapidly mature
  – Accuracy not the key metric
  – Technological, processing, and cost constraints
  – Strongly depends on the application and scenarios
Thank you for your attention!

Questions??