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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

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Outline

1. Overview of localization and positioning techniques

1. Multidimensional radio channel measurements for Parametric estimation techniques

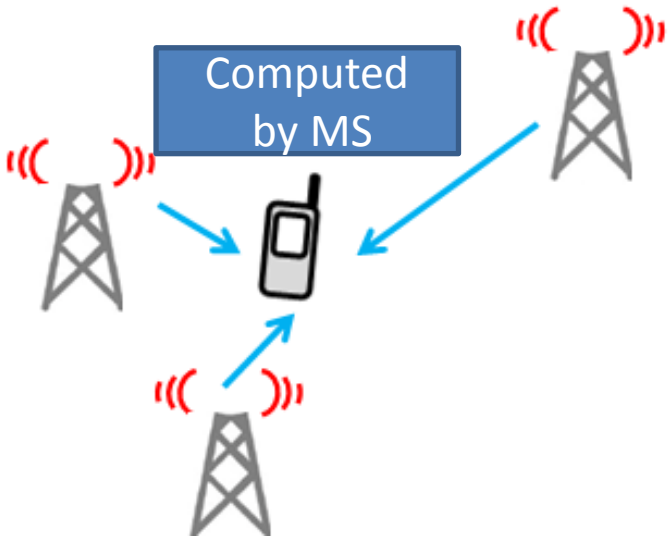
2. Dedicated localization techniques in rich multipath scenarios
   1. Outdoor scenario
   2. Indoor scenario

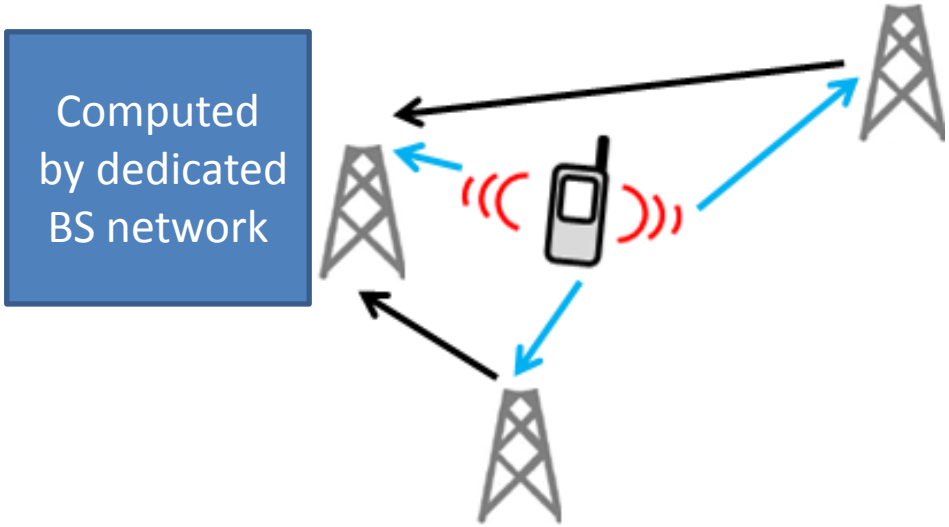
3. Conclusion

OVERVIEW OF LOCALIZATION AND POSITIONING TECHNIQUES

Context - 1

Positioning (DL) & **Localization (UL)**





Context - 2

Positioning

⇒ **APPLICATIONS** :

Service called by the user

- Route, carpooling, …

•**GNSS satellite systems**

➢ limitations : obstructing in urban scenarios (NLOS)

• **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)**

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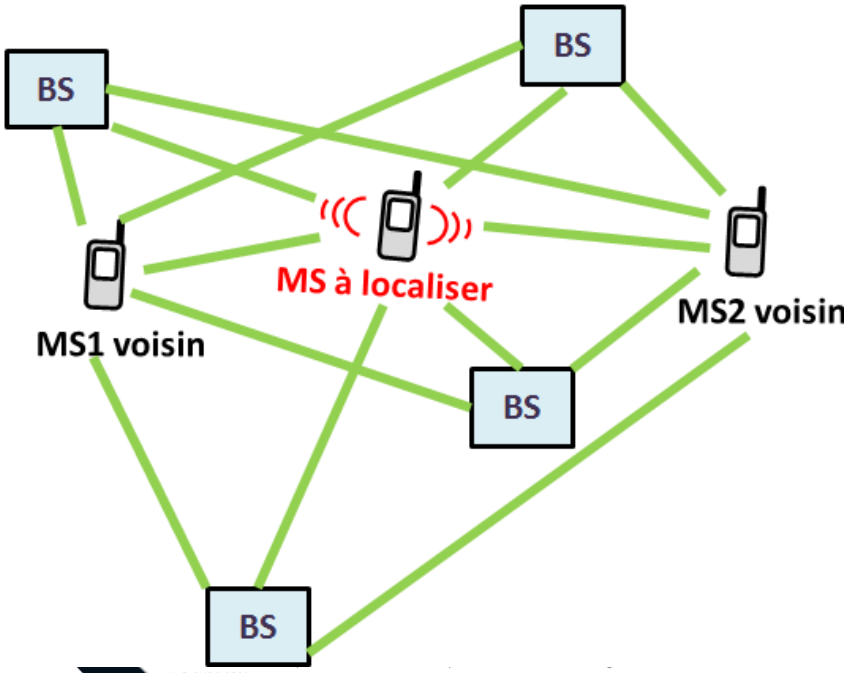
Context - 3

Localization w/ cooperative/non-cooperative mode

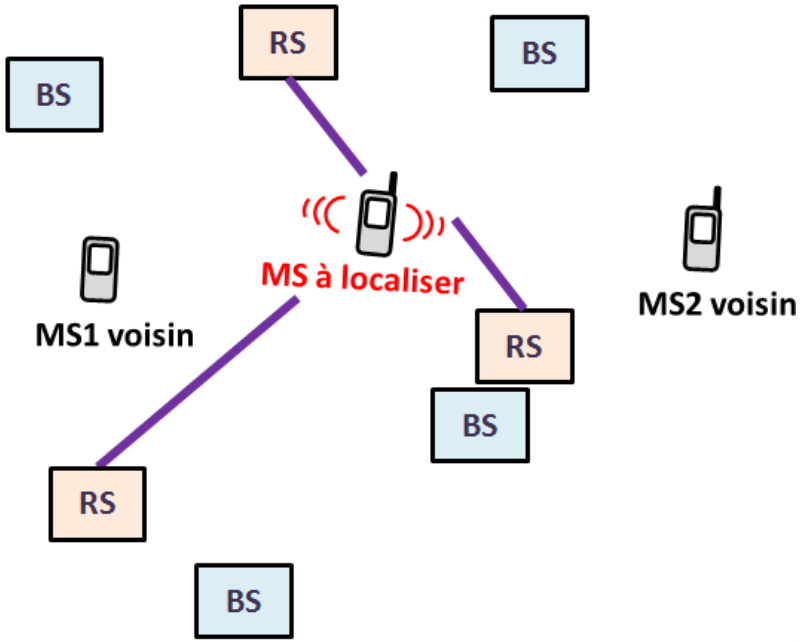
Cooperative mode

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…

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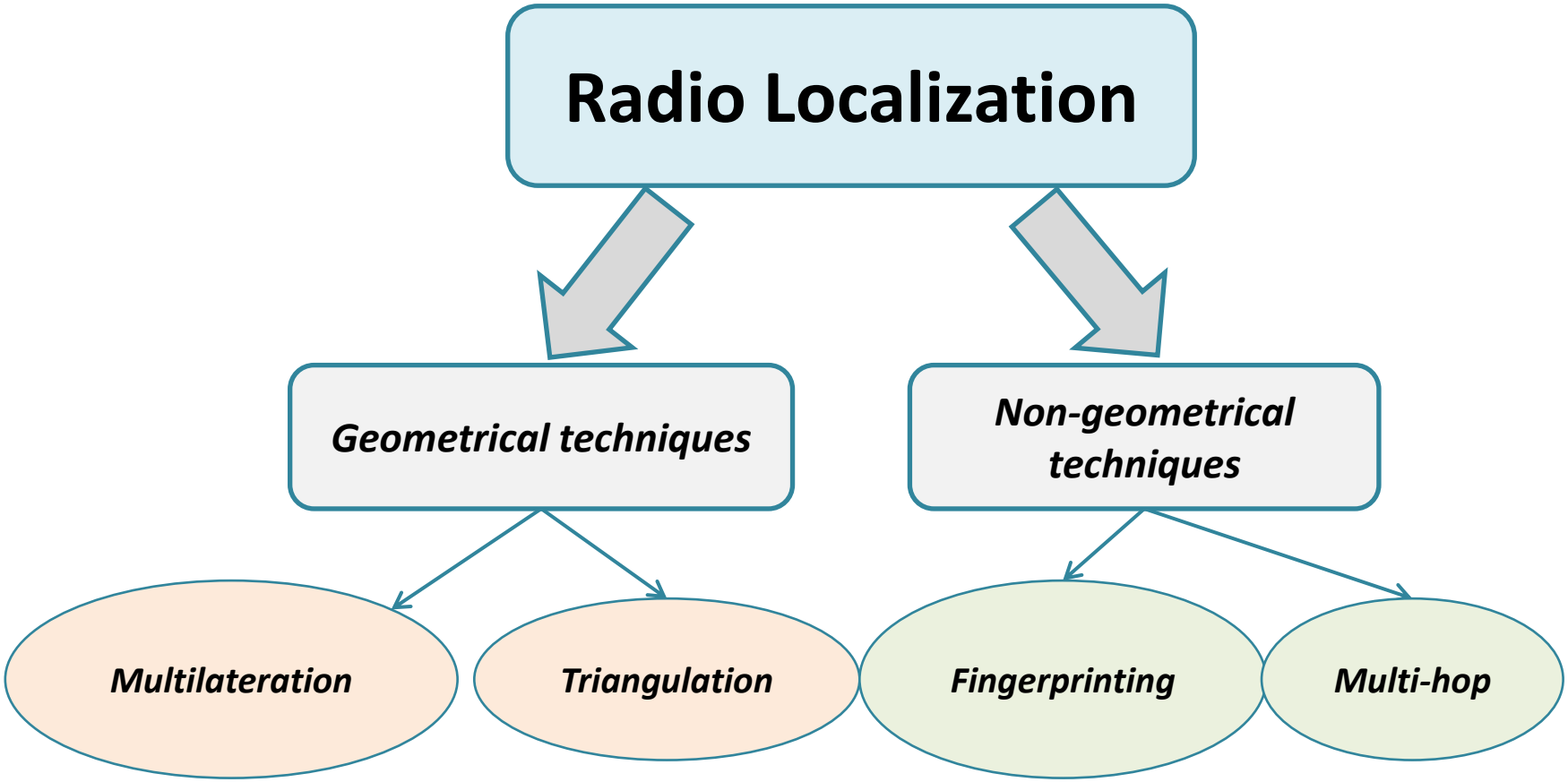
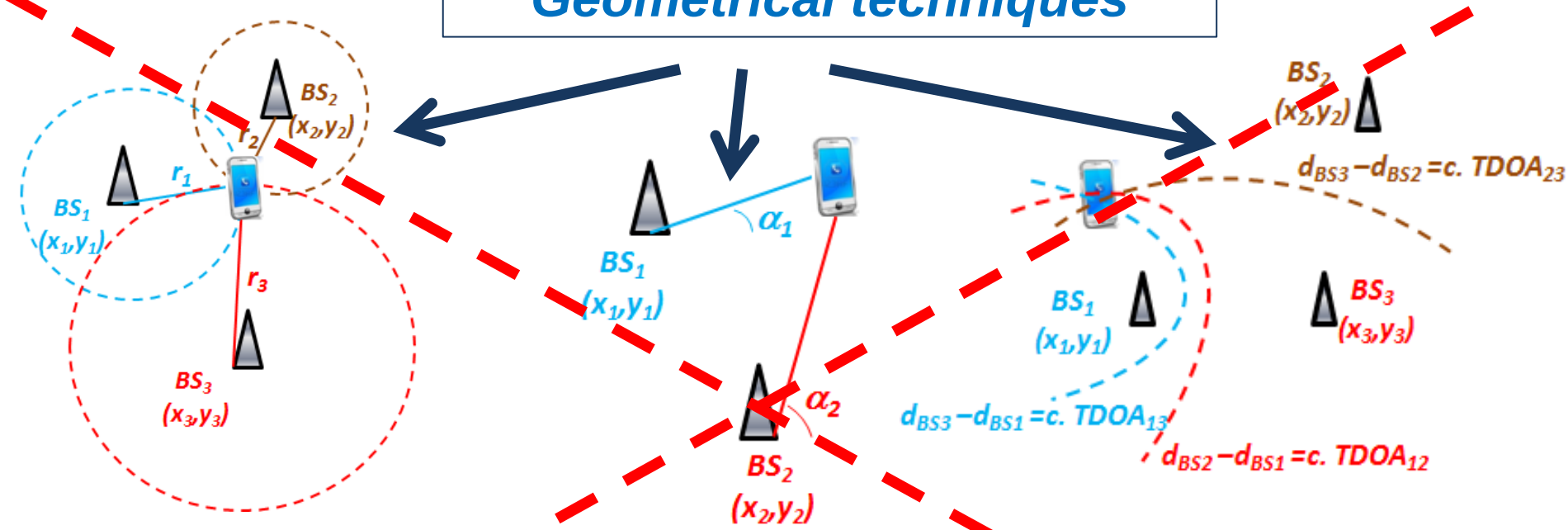
Localization techniques overview - 1



Localization techniques overview - 2

Geometrical techniques



TOA, RSS	AOA	TDOA
TOA [JAN13]: RMSE 25 m. w/ 3 RS	AOA [HUA14]: RMSE 1 m w/ 10 RS	LTE-TDOA [ZHAN12]: 92.88 % ≤ 50 m w/ 4 RS

Literature : Only simulation results !

Weak performances for NLOS scenarios w/ few RS

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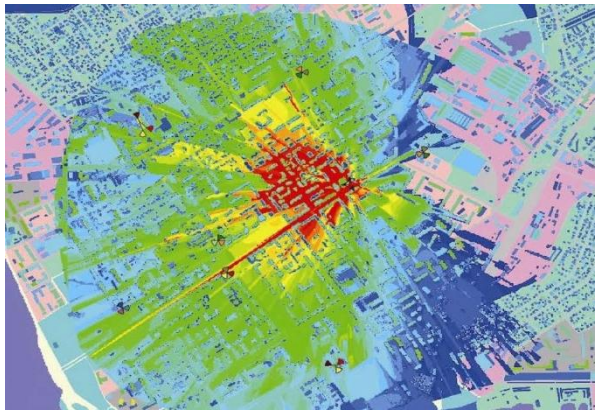
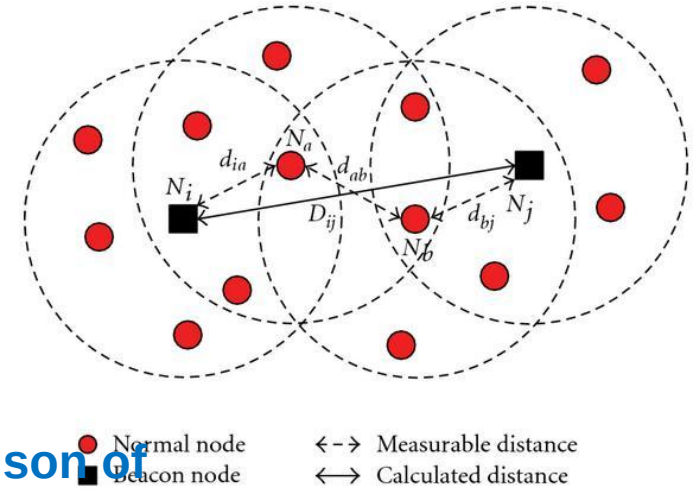
Localization techniques overview - 3

Non-geometrical techniques

Aerial vue of urban environment



Fingerprinting



Multi-hop (ad hoc)

→ Comparison of fingerprints extracted from data with database

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

Only simulation results!

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

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

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Localization techniques overview - 4

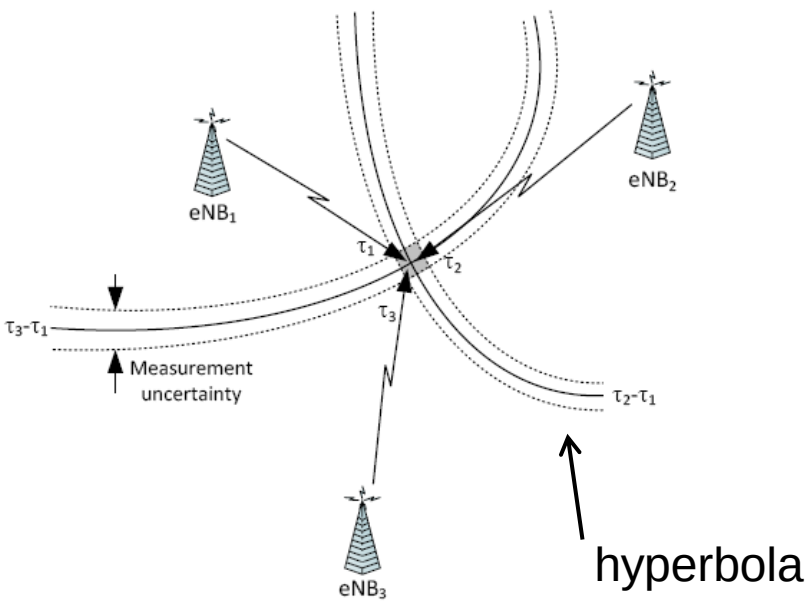
Technology	Dependence to scenario	Calibration	Accuracy	Robustness	Complexity	Cost
UWB	High	Several times	<0.3m (50%<0.3 m)	Average	Good	High
RFID	Low	-	<2m (50%<1m)	High	Good	Low
BLE (beacon)	High	Several times	<2m (95%<2m)	Average	High	Average
WiFi	High	Several times	<2m (50%<2m)	Average	Good	High
WiFi Symbolic	Low	-	~ 10 m	Very High	Low	Average
LTE	High	Several times	50m – 250 m	Average	High	Average

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

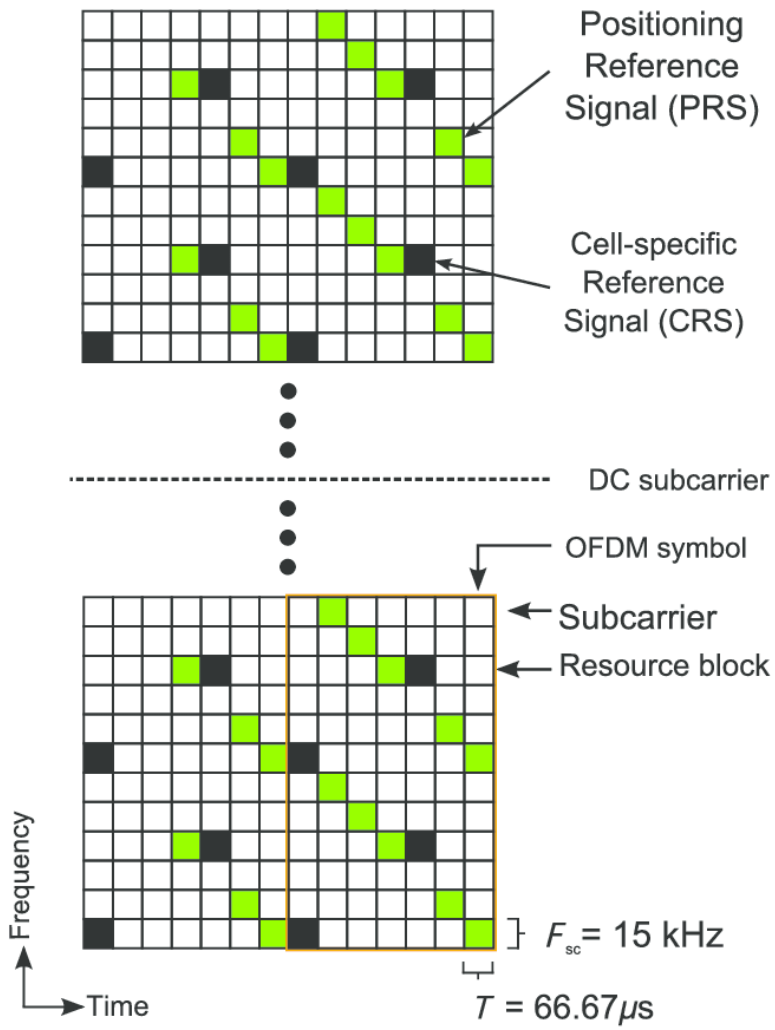
Observed Time Difference of Arrival (OTDOA) for Positioning in LTE

- 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 sentitive to geometric dilution and multipath fading



$$RSTD_{i,1} = \sqrt{(x_t - x_i)^2 + (y_t - y_i)^2}/c - \sqrt{(x_t - x_1)^2 + (y_t - y_1)^2}/c + (T_i - T_1) + (n_i - n_1)$$

PRS

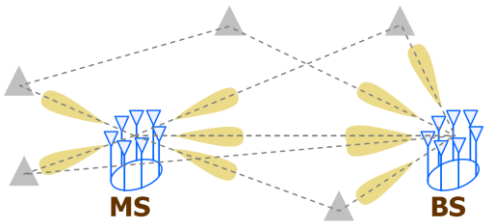


- Pseudo-random QPSK sequence mapped with shift in frequency and time to avoid collision with signaling reference signals (PSS/SSS) or control channel (Physical DL CCH - PDCCH)

PRS overhead percentage (LTE System BW 20 MHz)				
PRS BW [MHz]	N_{PRS}			
	1	2	4	6
1.4	0.0438	0.0875	0.1750	0.2625
3	0.0938	0.1875	0.3750	0.5625
5	0.1563	0.3125	0.6250	0.9375
10	0.3125	0.6250	1.2500	1.8750
15	0.4688	0.9375	1.8750	2.8125
20	0.6250	1.2500	2.5000	3.7500

RADIO CHANNEL MODELS AND MULTIDIMENSIONAL MEASUREMENT

Time-varying MIMO radio channel MODEL



$M_T \times M_R$ SISO channels

Path Time Delay

$$\mathbf{H}(f,t) = \underbrace{G_{R_f}(f)\cdot G_{T_f}(f)}_{\text{Antenna Gain Rx/Tx}}\cdot \sum_{p=1}^{P}\left\{\underbrace{\mathbf{B}_R(\varphi_{R,p},\vartheta_{R,p})}_{\text{Far field beam pattern Rx}}\cdot \mathbf{\Gamma}_p \cdot \underbrace{\mathbf{B}_T(\varphi_{T,p},\vartheta_{T,p})}_{\text{Far field beam pattern Tx}}{}^{\mathrm{T}}\cdot \mathrm{e}^{-\mathrm{j}2\pi\cdot f\cdot \tau_p}\cdot \mathrm{e}^{-\mathrm{j}2\pi\cdot \alpha_p\cdot t}\right\}$$

Doppler Shift

p paths

Polarimetric transmission coefficients

$$\mathbf{\Gamma}_p = \begin{bmatrix} \gamma_{HH,p} & \gamma_{VH,p} \\ \gamma_{HV,p} & \gamma_{VV,p} \end{bmatrix} \in \mathbb{C}^{2\times 2}$$

$$\mathbf{B}_R(\varphi_R,\vartheta_R) = \begin{bmatrix} \mathbf{b}_{R,1}(\varphi_R,\vartheta_R) \\ \vdots \\ \mathbf{b}_{R,M_R}(\varphi_R,\vartheta_R) \end{bmatrix}$$

$$\mathbf{B}_T(\varphi_T,\vartheta_T) = \begin{bmatrix} \mathbf{b}_{T,1}(\varphi_T,\vartheta_T) \\ \vdots \\ \mathbf{b}_{T,M_T}(\varphi_T,\vartheta_T) \end{bmatrix}$$

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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 $\vartheta p_R(t)$ & elevation $\varphi p_R(t)$
  - Antenna array at receiving side
- DoD – Direction of Departure: Azimuth $\vartheta p_T(t)$ & elevation $\varphi p_T(t)$
  - Antenna array at transmitting side
- Doppler frequency $f_d(t)$
  - Time-varying radio channel

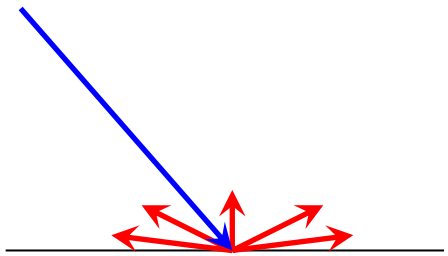
1 fast linear parameter $\gamma(t)$

6 slow non-linear parameters $\tau(t)$, $\theta p_R(t)$, $\varphi p_R(t)$, $\theta_{pT(t)}$, $\varphi p_R(t)$, $f_d(t)$

$\Rightarrow$ 6D Estimation problem!

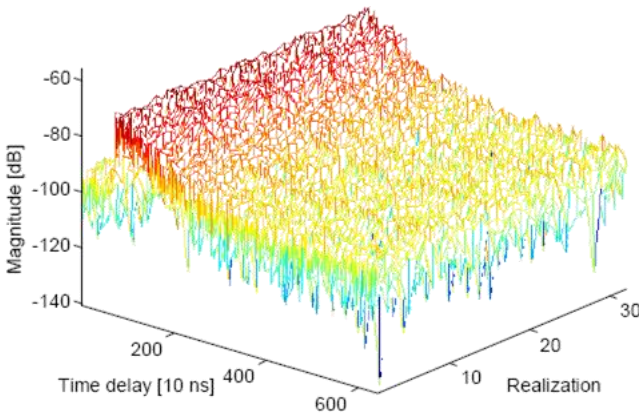
And distributed scattering

– λ ~ diffusing element

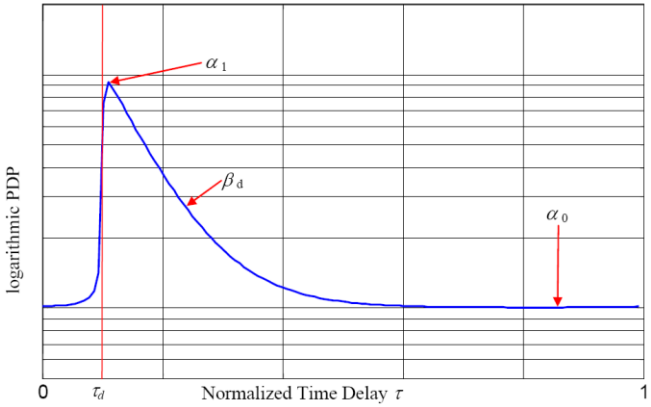


Diffuse surface

The moon!



– 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

Algorithms	Fonction	Description
Beamforming (BF)	$\mathrm{P}_{\mathrm{BF}}(\theta)=\dfrac{\mathbf{a}^{\mathrm{H}}(\theta)\mathbf{R}\mathbf{a}(\theta)}{M^2}$	Classical beamformer with low resolution
MUSIC	$\mathrm{P}_{\mathrm{M}}(\theta)=\dfrac{1}{\mathbf{a}^{\mathrm{H}}(\theta)\mathbf{E}_{\mathrm{N}}\mathbf{E}_{\mathrm{N}}^{\mathrm{H}}\mathbf{a}(\theta)}$	HR technique but computationally slow with MD matrices
ESPRIT	$\theta_i=\cos^{-1}\left(\dfrac{\arg(\lambda_i)}{2\pi d}\right)$	HR technique but sub-arrays decrease resolution
SAGE	$\theta_i=\arg\max\limits_{\theta_i\in\Theta}\left(\mathbf{a}_i^{\mathrm{H}}\mathbf{R}_i\mathbf{a}_i\right)$	HR ML technique
RIMAX	$\hat{\boldsymbol{\theta}}_{\mathrm{sp}}=\arg\min\limits_{\boldsymbol{\theta}_{\mathrm{sp}}}\left(\mathbf{x}-\mathbf{s}(\boldsymbol{\theta}_{\mathrm{sp}})\right)^{\mathrm{H}}\mathbf{R}(\boldsymbol{\theta}_{\mathrm{dan}})^{-1}\left(\mathbf{x}-\mathbf{s}(\boldsymbol{\theta}_{\mathrm{sp}})\right)$ $\hat{\boldsymbol{\theta}}_{\mathrm{dan}}=\arg\max\limits_{\boldsymbol{\theta}_{\mathrm{dan}}}\left(-\ln\left(\det\left(\mathbf{R}(\boldsymbol{\theta}_{\mathrm{dan}})\right)\right)-\hat{\mathbf{x}}_{\mathrm{dan}}^{\mathrm{H}}\mathbf{R}(\boldsymbol{\theta}_{\mathrm{dan}})^{-1}\hat{\mathbf{x}}_{\mathrm{dan}}\right)$	SMC (θ_{sp}) + DMC (θ_{dan}) Computationally efficient

RiMAX Data Model

$$\mathbf{h} \sim \mathcal{N}_C\left(\mathbf{s}(\boldsymbol{\theta}_{sp}), \mathbf{R}(\boldsymbol{\theta}_{dmc})\right) \in \mathbb{C}^{M\times 1}$$

Sampled Radio Channel

Mean

Covariance Matrix

Covariance MatrixKronecker Factorization

$$\mathbf{R}(\boldsymbol{\theta}_{dmc}) = \mathbf{R}_R(\boldsymbol{\theta}_{dmc}) \otimes \mathbf{R}_T(\boldsymbol{\theta}_{dmc}) \otimes \mathbf{R}_f(\boldsymbol{\theta}_{dmc}) \otimes \mathbf{R}_t(\boldsymbol{\theta}_{dmc})$$

$$\mathbf{R}(\boldsymbol{\theta}_{dmc}) = \mathbf{I}_{M_R} \otimes \mathbf{I}_{M_T} \otimes \mathbf{R}_f(\boldsymbol{\theta}_{dmc}) \otimes \mathbf{I}_{M_t}$$

Simpler models consider AWGN channel → $\mathbf{R}_t(\boldsymbol{\theta}_{dmc}) = \sigma^2 I$

$$\mathbf{R}_{nn} = \alpha_0 \mathbf{I} + \mathbf{R}(\boldsymbol{\theta}_{dmc})$$

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Dense Multipaths Components

$$\boldsymbol{\kappa}(\boldsymbol{\theta}_{dan}) = \frac{\alpha_1}{M_f}\left[\frac{1}{\beta_d} \quad \frac{e^{-j2\pi\tau_d}}{\beta_d + j2\pi\frac{1}{M_f}} \quad \cdots \quad \frac{e^{-j2\pi(M_f-1)\tau_d}}{\beta_d + j2\pi\frac{M_f-1}{M_f}}\right]^T + \alpha_0 \mathbf{e}_0$$

Concentrated propagation paths

$$\mathbf{h} = \mathbf{s}(\boldsymbol{\theta}_{sp}) + \mathbf{d}_{dmc}$$

Dense Multipath components

$$\mathbf{R}_f(\boldsymbol{\theta}_{dmc}) = \mathrm{toep}\left(\boldsymbol{\kappa}(\boldsymbol{\theta}_{dmc}), \boldsymbol{\kappa}(\boldsymbol{\theta}_{dmc})^H\right)$$

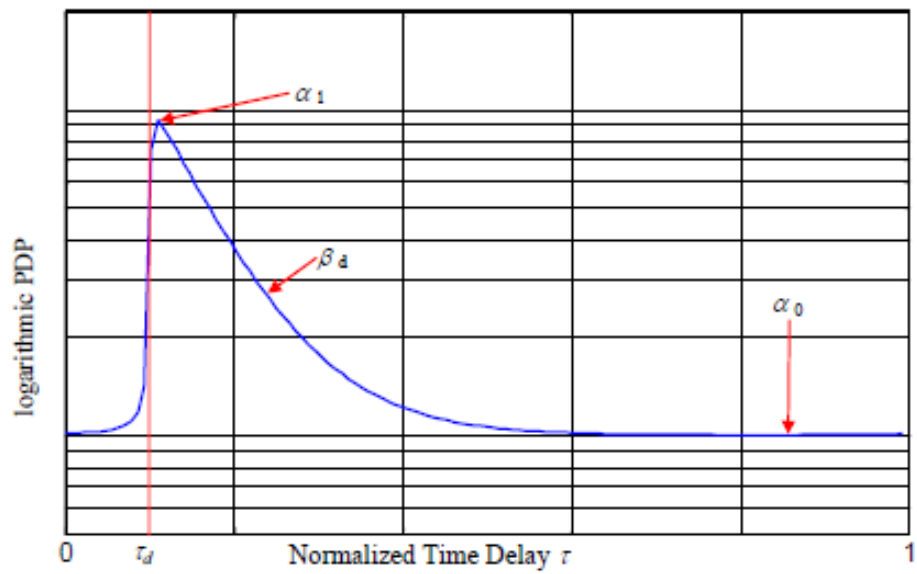

Figure 2-4: Dense multipath distribution model in the time delay domain $\psi_{mpc}(\tau,\tau)$.

Complete Polarimetric MIMO System Model

$$\mathbf{H}_S(\boldsymbol{\theta}_{sp}) = \mathbf{G}_R \cdot \mathbf{H}(\boldsymbol{\theta}_{sp}) \cdot \mathbf{G}_T^{\mathrm{T}}$$

$$\mathbf{H}(\boldsymbol{\theta}) = \begin{bmatrix} \mathbf{H}_{HH} & \mathbf{H}_{VH} \\ \mathbf{H}_{HV} & \mathbf{H}_{VV} \end{bmatrix}$$

$$\mathbf{G}_T = \begin{bmatrix} \mathbf{G}_{T_{fH}} & \mathbf{G}_{T_{fV}} \end{bmatrix} \in \mathbb{C}^{(M_f \cdot M_T) \times (2 \cdot N_f \times N_T)}$$

$$\mathbf{G}_R = \begin{bmatrix} \mathbf{G}_{R_{fH}} & \mathbf{G}_{R_{fV}} \end{bmatrix} \in \mathbb{C}^{(M_f \cdot M_R) \times (2 \cdot N_f \times N_R)}$$

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PDF of Sampled radio Channel

$$p(\mathbf{x}|\boldsymbol{\theta}, \mathbf{R}_{nn}) = \frac{1}{\pi^M \det(\mathbf{R}_{nn}(\boldsymbol{\theta}))} e^{-(\mathbf{x}-\mathbf{s}(\boldsymbol{\theta}))^H \cdot \mathbf{R}_{nn}(\boldsymbol{\theta})^{-1} \cdot (\mathbf{x}-\mathbf{s}(\boldsymbol{\theta}))}$$

$$\boldsymbol{\theta}_{chn} = \begin{bmatrix} \boldsymbol{\theta}_{sp} \\ \boldsymbol{\theta}_{dmc} \end{bmatrix}$$

	Aperture / Data Domain	Parameters	
		Physical	Normalised
Temporal samples	Time t	Doppler-shift α	$\mu^{(\alpha)}$
Frequency samples	Frequency f	Time delay of arrival τ	$\mu^{(\tau)}$
Tx antenna ports	Space at Tx	Azimuth of Departure φ_T Elevation of Departure ϑ_T	$\mu^{(\varphi_T)}$ $\mu^{(\vartheta_T)}$
Rx antenna ports	Space at Rx	Azimuth of Arrival φ_R Elevation of Arrival ϑ_R	$\mu^{(\varphi_R)}$ $\mu^{(\vartheta_R)}$

B_d	-	coherence bandwidth of the diffuse components
τ'_d	-	base TDoA of the diffuse components
$\beta_d = \frac{B_d}{B_m} = \frac{B_d}{M_f \cdot f_0}$	-	coherence bandwidth of the diffuse components normalised to the measurement bandwidth
M_f	-	number of frequency points measured within the measurement bandwidth
$\tau_d = \frac{\tau_d}{t_m}$	-	base TDoA of the diffuse components normalised to the total length of the observed impulse-response
α_1	-	power of the diffuse components at $\tau = \tau_d$
$B_3 = \frac{\sqrt{3}}{\pi} B_d$	-	3dB coherence bandwidth of the diffuse components

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Estimation of Parameters

$$p(\mathbf{x}|\boldsymbol{\theta},\mathbf{R}_{nn}) = \frac{1}{\pi^M \det(\mathbf{R}_{nn}(\boldsymbol{\theta}))} e^{-(\mathbf{x}-\mathbf{s}(\boldsymbol{\theta}))^H \cdot \mathbf{R}_{nn}(\boldsymbol{\theta})^{-1} \cdot (\mathbf{x}-\mathbf{s}(\boldsymbol{\theta}))}$$

$$\mathbf{x} = \mathbf{s}(\boldsymbol{\theta}_{sp}) + \mathbf{n}_{dan}$$

Deterministic Maximum Likelihood (DML)

Stochastic Maximum Likelihood (SML)

$$E\{\hat{\boldsymbol{\theta}} - \boldsymbol{\theta}\} = \mathbf{0}$$

$$\mathcal{L}(\mathbf{x}|\boldsymbol{\theta},\mathbf{R}_{nn}) = \ln(p(\mathbf{x}|\boldsymbol{\theta},\mathbf{R}_{nn})) = -M \cdot \ln(\pi) - \ln(\det(\mathbf{R}_{nn})) - (\mathbf{x}-\mathbf{s}(\boldsymbol{\theta}))^H \mathbf{R}_{nn}^{-1} (\mathbf{x}-\mathbf{s}(\boldsymbol{\theta}))$$

Joint Maximum Likelihood Estimation Problem

Cramer-Rao Lower Bound

$$\mathbf{C}_{\hat{\boldsymbol{\theta}}} = E\{(\hat{\boldsymbol{\theta}} - \boldsymbol{\theta}) \cdot (\hat{\boldsymbol{\theta}} - \boldsymbol{\theta})^T\} \geq \mathbf{CRB}_{\hat{\boldsymbol{\theta}}}$$

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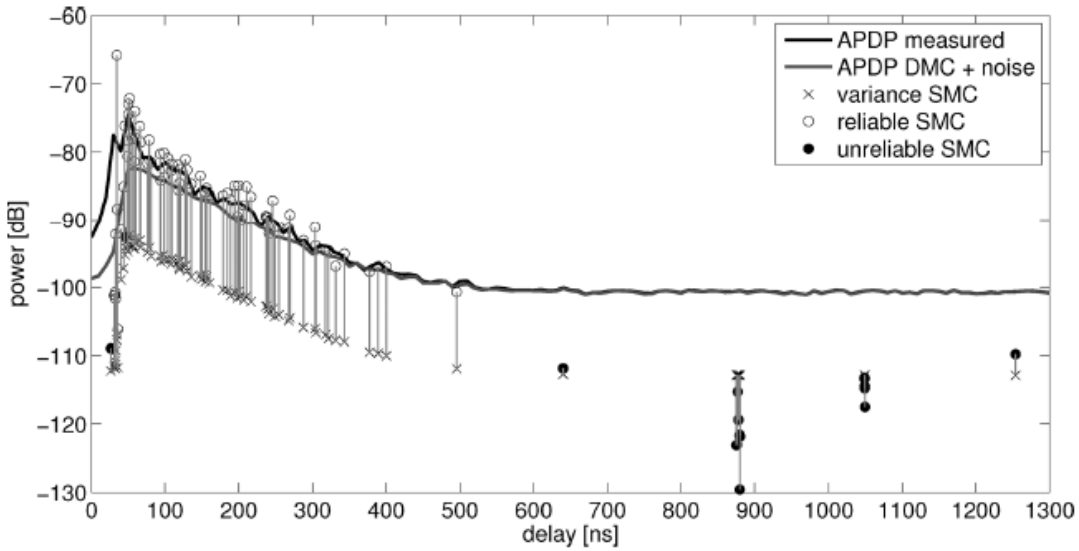
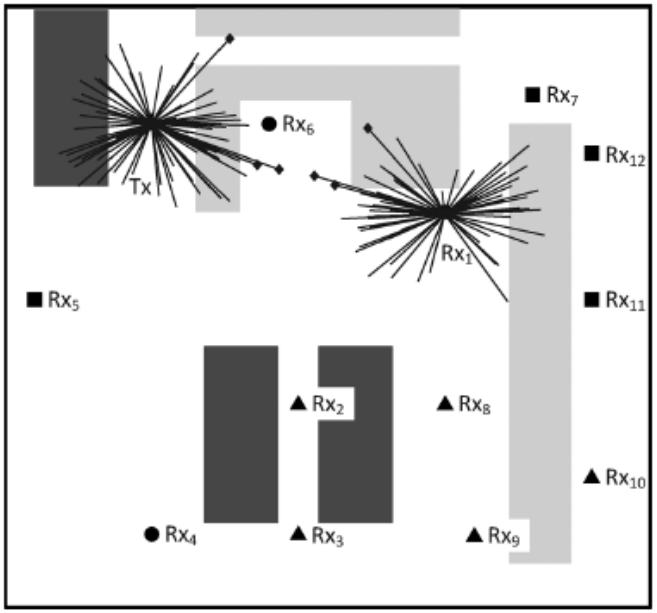
RIMAX Example 1





Experimental Analysis of Dense Multipath Components in an Industrial Environment

Emmeric Tanghe, Davy P. Gaillot, Martine Liénard, Luc Martens, *Member, IEEE*, and Wout Joseph, *Senior Member, IEEE*

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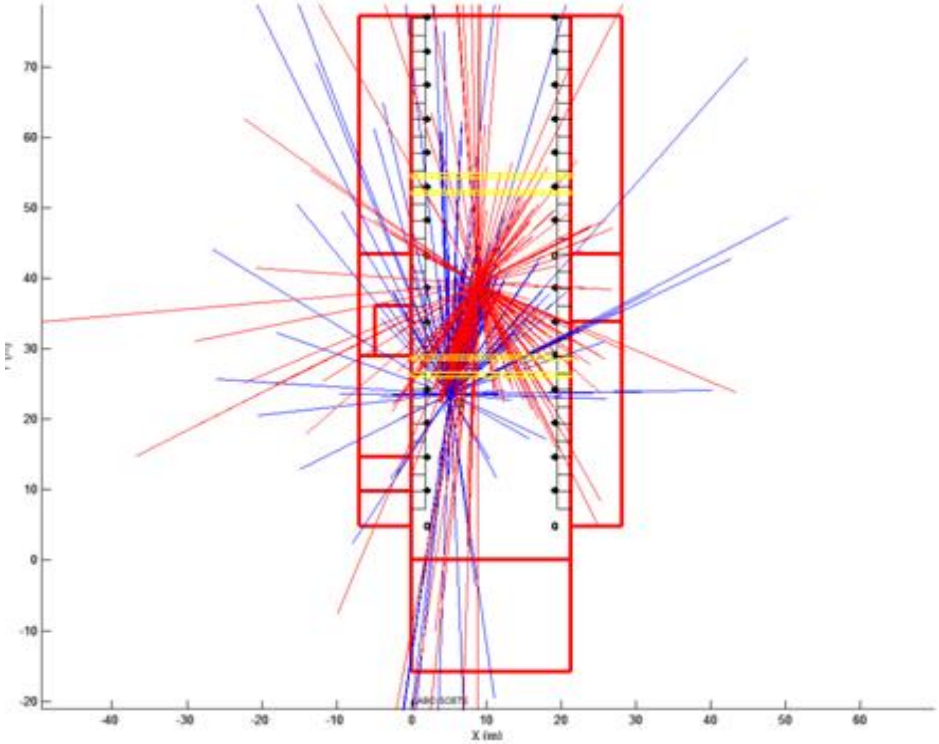
RIMAX Example 2

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

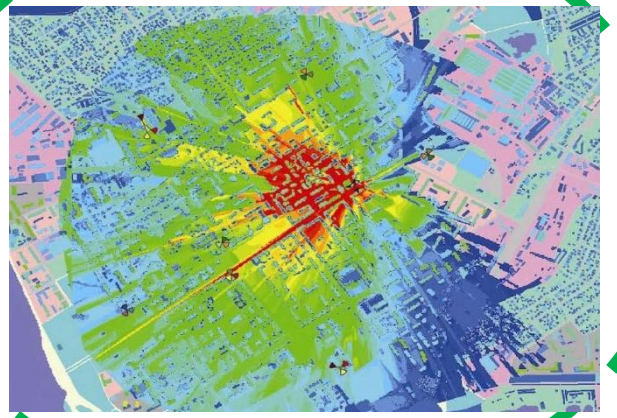
Davy P. Gaillot, Emmeric Tanghe, Wout Joseph, *Senior Member, IEEE,* Pierre Laly, Viet-Chi Tran, Martine Liénard, and Luc Martens, *Member, IEEE*



DEDICATED LOCALIZATION TECHNIQUES
Outdoor Scenarios

Proposed Localization Technique - 1

FINGERPRINTING CHOICE



CONSTRAINTS	SOLUTIONS → Multidimensional diversity
Immediate and on the spot need	Database built from deterministic radio channel models
Limited bandwidth	Antenna Array for BS and high-resolution estimator to estimate fingerprints AOA (spatial) et TOA (frequency)
RS discretion	
Unknown MS polarization	Dual-polarized antennas for BS (Polarization diversity)

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Proposed Localization Technique - 1

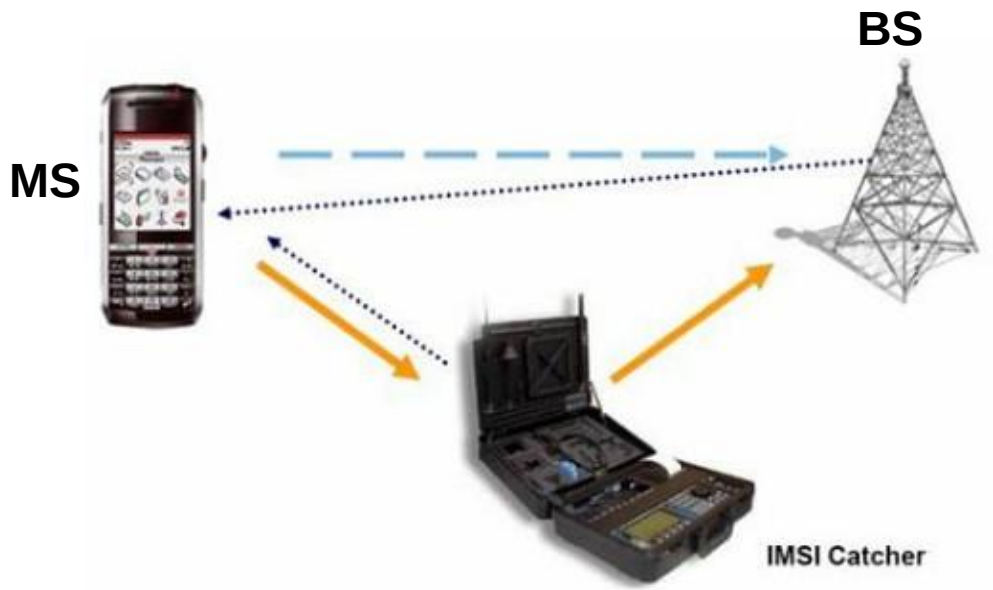
→ 1st STEP (beyond current work)

MS Identification

IMSI catcher

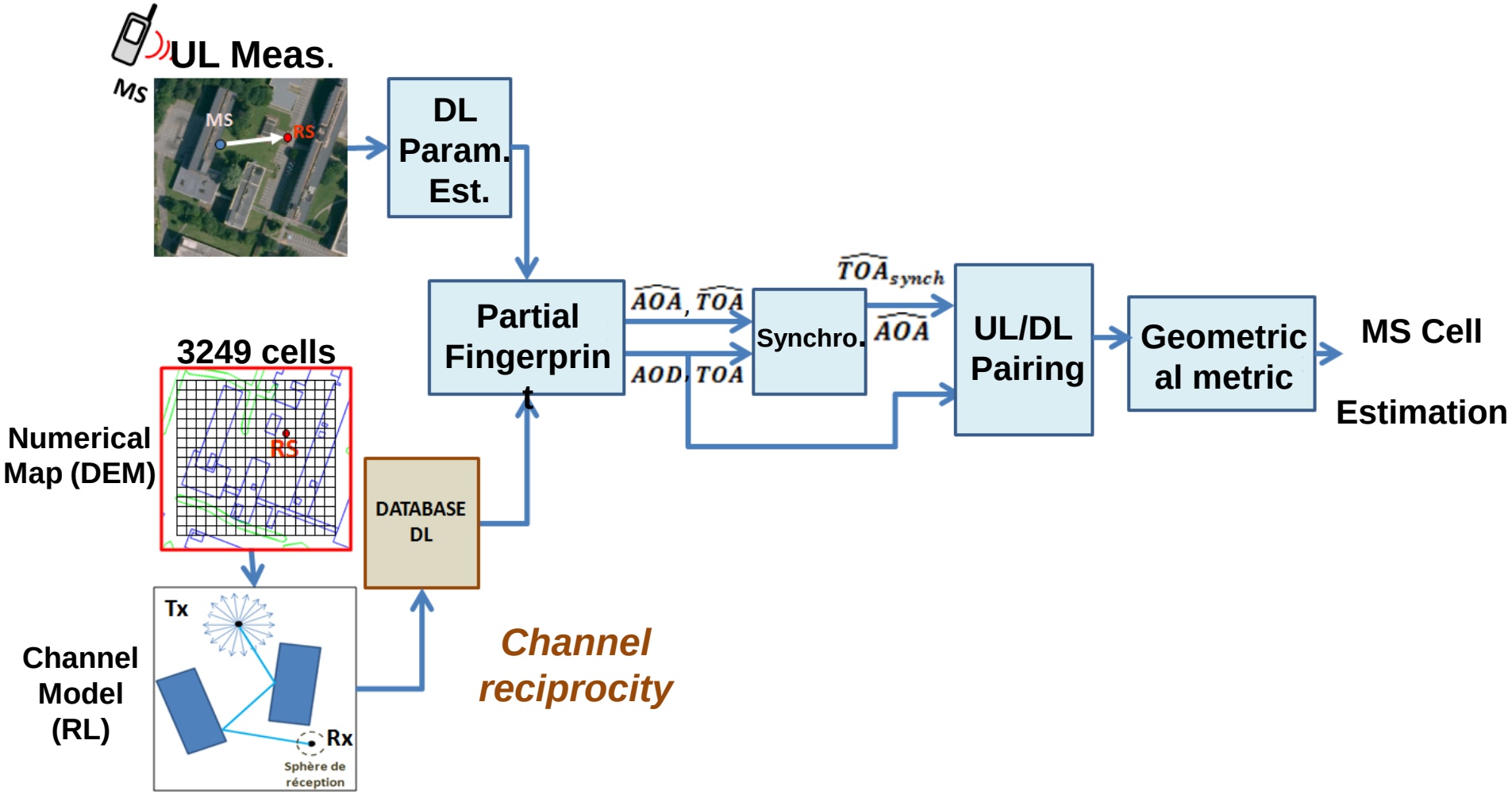
→

MS communication forcing mode

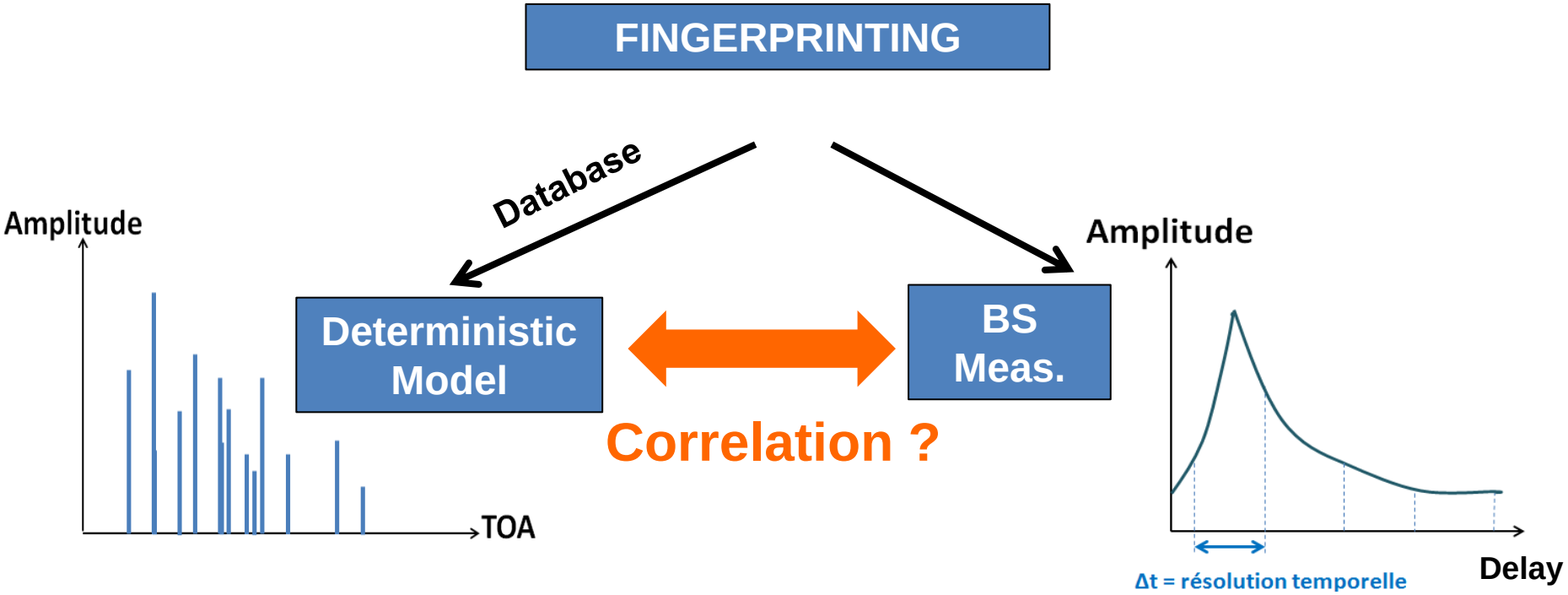


IMSI (International Mobile Subscriber Identity) Catcher principle

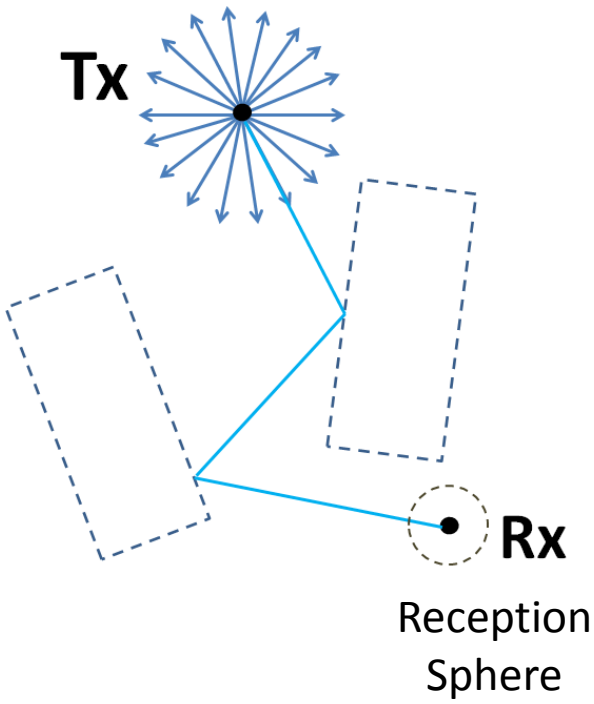
Proposed Localization Technique - 2



Fingerprinting



Deterministic Radio Channel



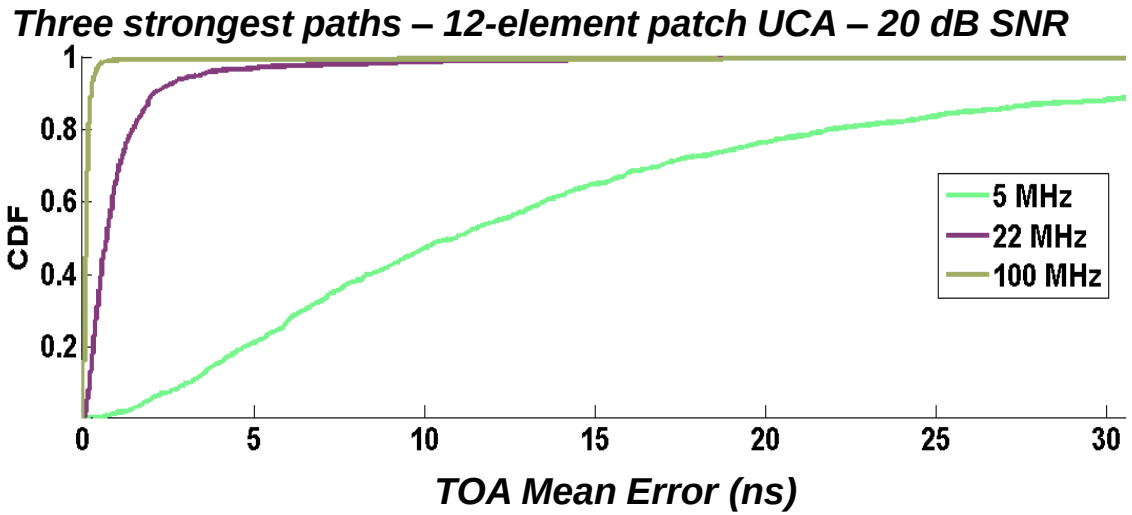
Ray-Launching

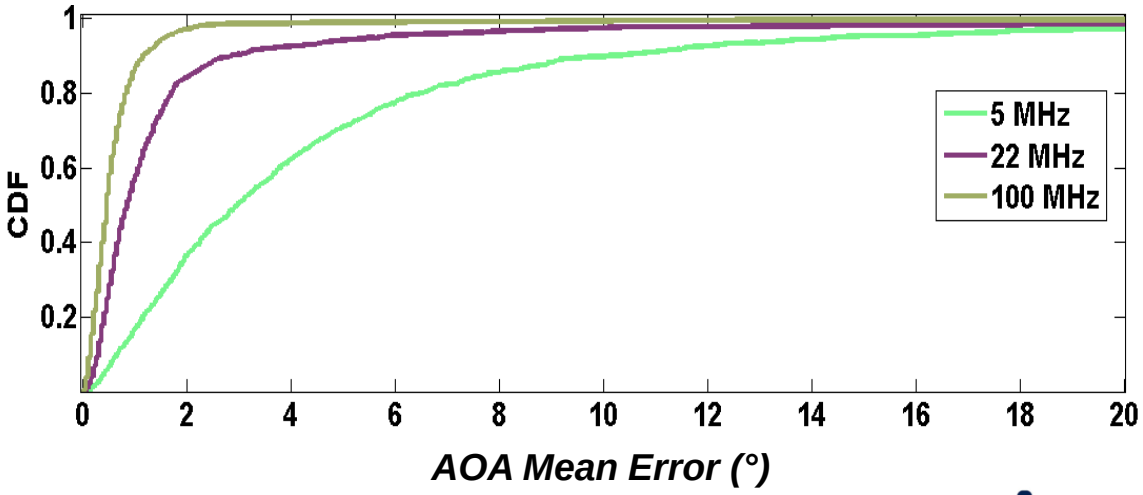
→ **Database construction**
→ **Synthesis of radio channels for simulations**

Polarization Tx	Polarization Rx
V	V
~~V~~	~~H~~
~~H~~	~~V~~
H	H

Cross-polarization mode not available

Parametric Estimation Performance





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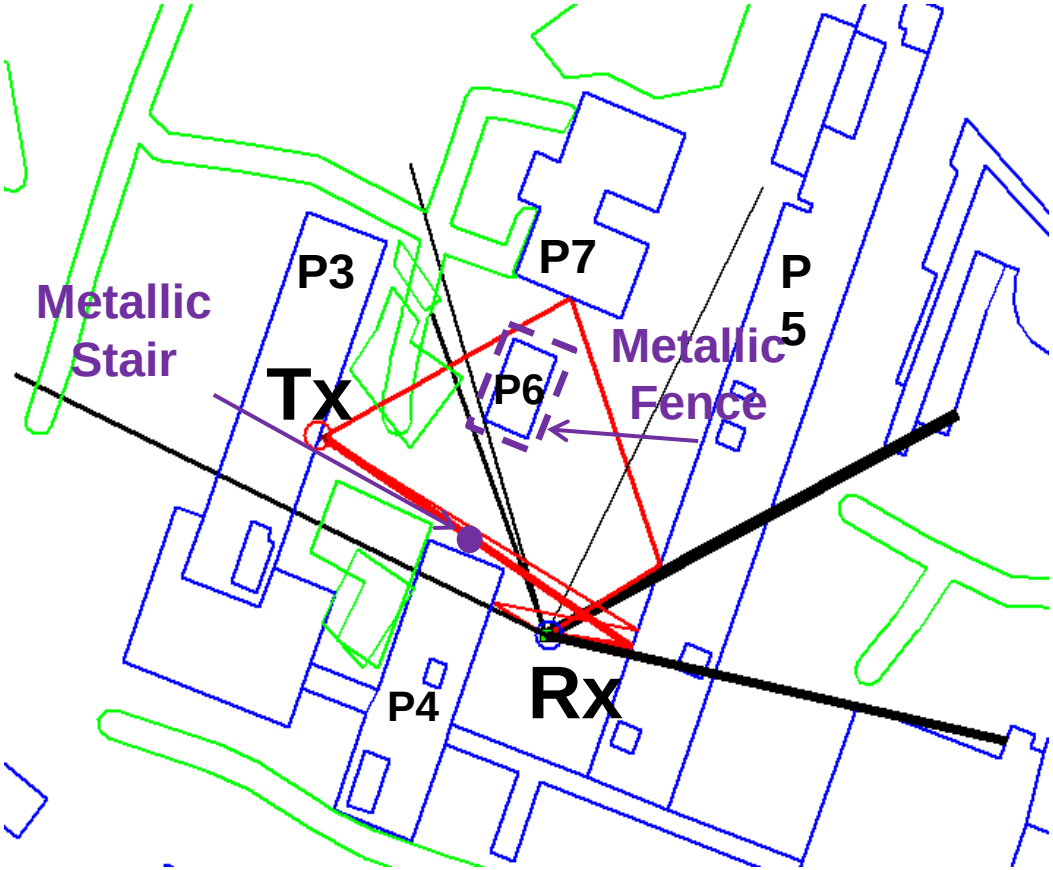
NLOS Example RL vs. Exp.



Most Energetic Paths (10 dB threshold)

Simulated Scenario

RS design: depends on RIMAX performance

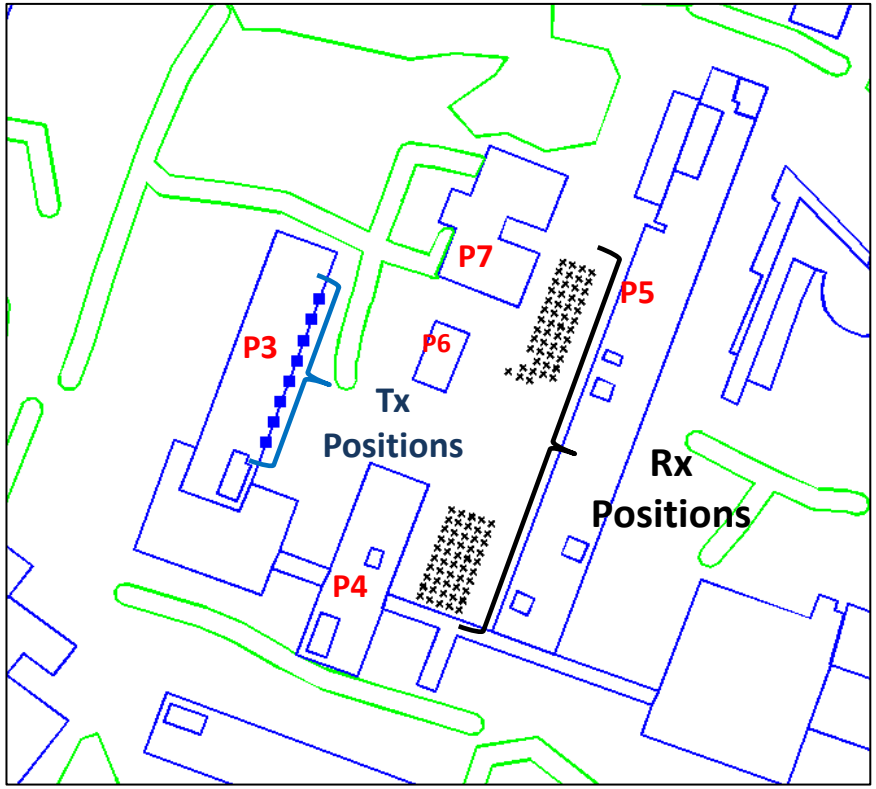
⇒ Simulated perf. as a function :

- **Bandwidth, SNR**
- **Antenna array (Circular, rectangular)**
- **Type and # of antennas**

Simulation environment: Lille 1 Campus

K Factor ($\frac{P_{LOS}}{P_{NLOS}}$)	Channel %
< -25 dB	98.3 %
-25 < K < 6.7 dB	1.7 %

- τ_{rms} : [23 ns - 164 ns] (median: 60 ns)
- ϕ_{rms} : [15° - 94°] (median 56°)



Lille 1 Aerial view

Localization Results (Simulations)

Configuration	Channel Characteristics Estimation	LOCALIZATION			
	90% error (ns/°)	Correct Localization (%)		90% error (m)	
		1 RS	2 RS	1 RS	2 RS
Bw=5 MHz, UCA12 patch	<30 ns/<11°	1	3	< 72	< 60.9
Bw=22 MHz, UCA12 patch	<2.7 ns/<3.8°	11	24.7	< 68	< 15
Bw=100 MHz, UCA12 patch	<0.4 ns/<1.4°	25	60	< 44.3	< 5.6

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

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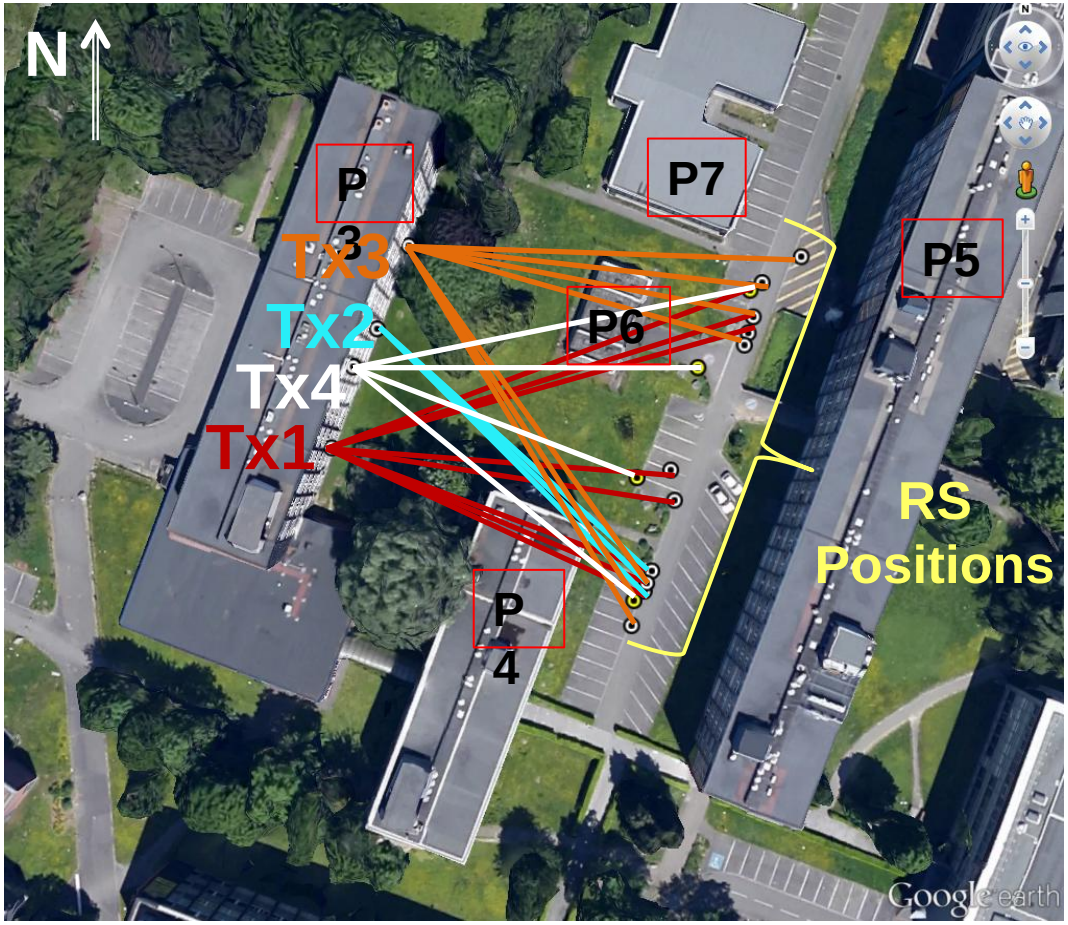
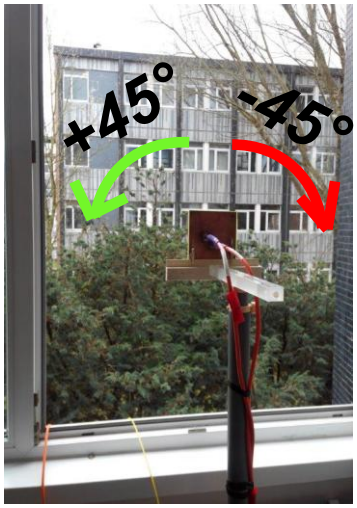
Experimental Campaign - 1



Lille 1 Aerial View

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



Orientation of Tx antenna for polarization diversity meas.

Virtual UCA Rx

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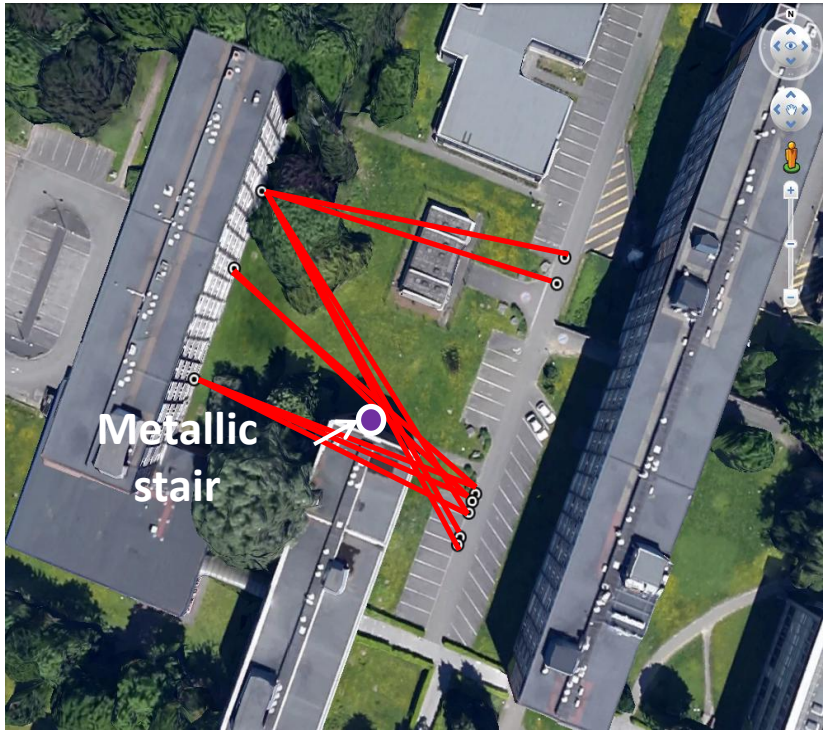
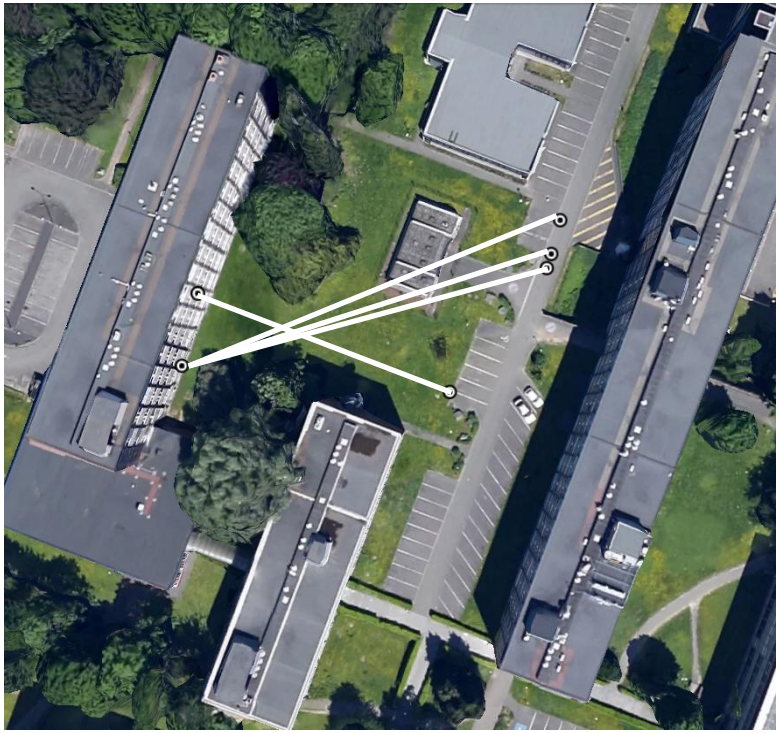
Experimental Campaign - 2

Depolarization phenomena

Metric : $XPD_u = \frac{P_{moy,uu}^{exp}}{P_{moy,uv}^{exp}}, \quad v \neq u$

- 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

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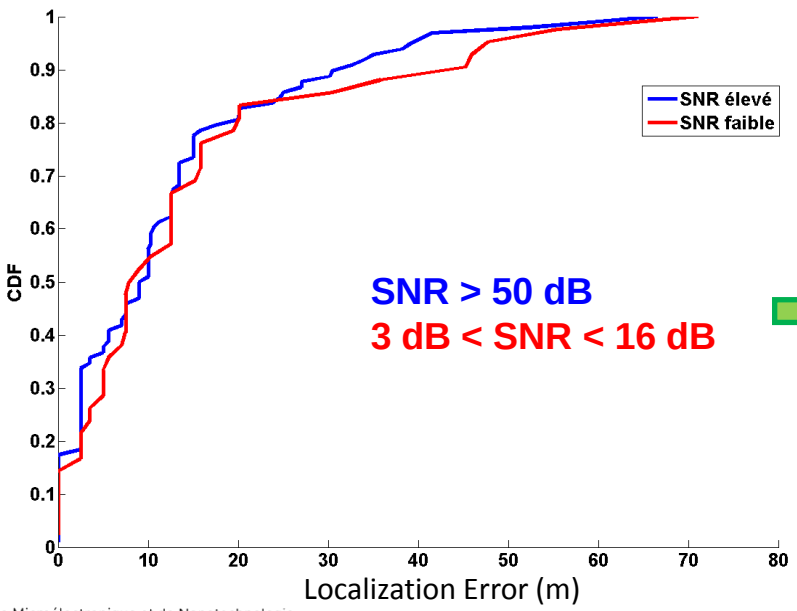
Localization Results (Experimental)

	Polarization	Success %	Error % ≤10m	50% accuracy (m)	90% accuracy (m)
w/o polarization diversity – 2 RS	uV	18	48	< 11.2 m	< 51.5 m
	uH	23	59	< 9 m	< 47.8 m
w/ polarization diversity – 2 RS	u	16.5	59	< 9 m	< 34 m
	VV (theo.)	24.7	88	< 2.5 m	< 15 m
w/ polarization diversity – 3 RS	u	17	71	< 7.5 m	< 18 m

Mean SNR impact



SNR > 50 dB
3 dB < SNR < 16 dB

Good robustness to weak SNRs

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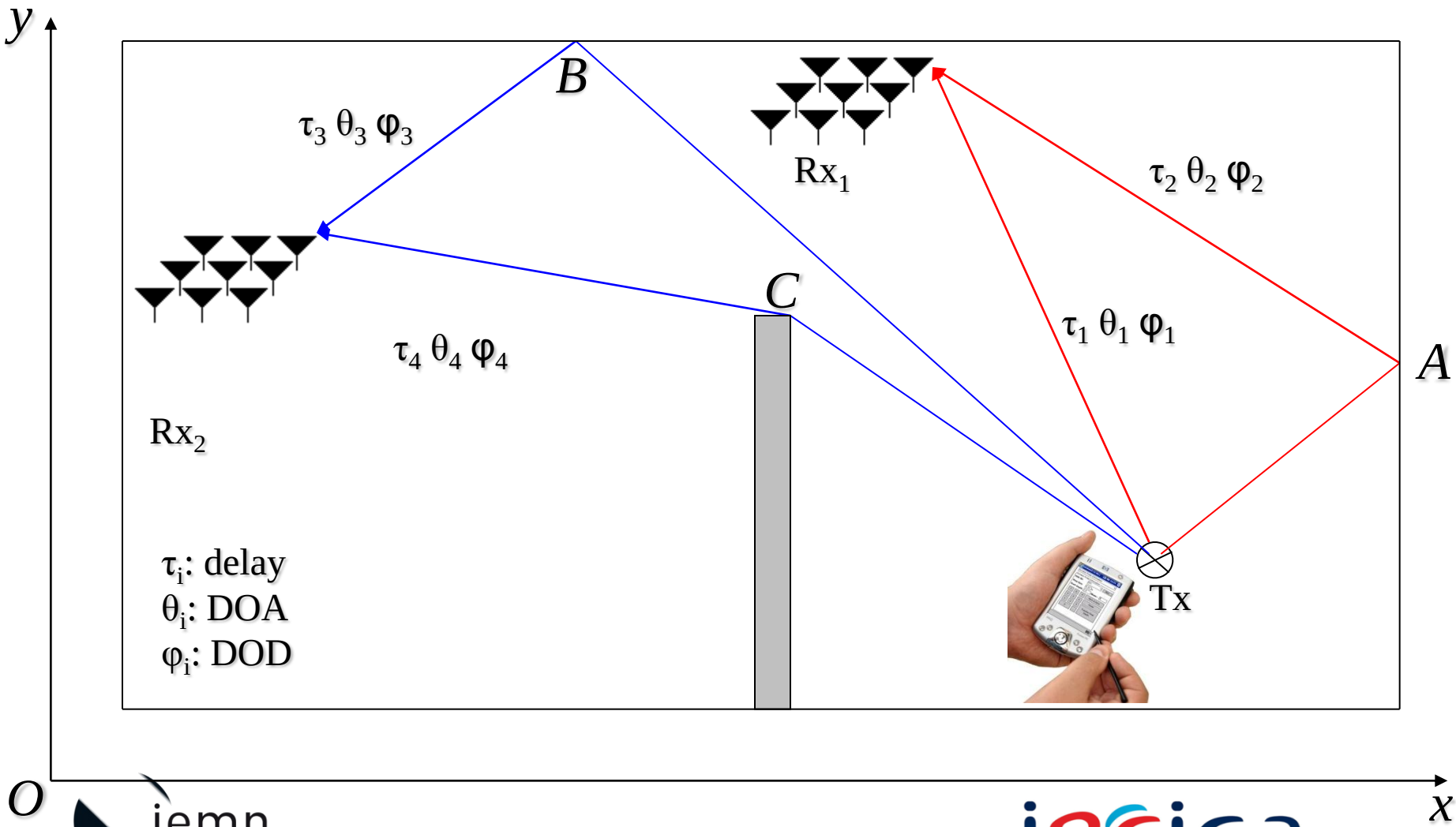
Summary

- Developed complete localization algorithm framework for LOS/NLOS urban scenarios
  - Non-cooperative mode
  - Fingerprinting dabase
- Numerical database constructed w./ RL software
- Exploits frequency, spatial, and polarization diversity
  - High-resolution parametric estimator
- Experimental results:
  - **59 % ≤ 10 m, $CDF_{90\%}$ = 34 m**

DEDICATED LOCALIZATION TECHNIQUES
Indoor Scenarios

Indoor localisation technique



Localisation indoors - principe

- 2 syncronized receivers Rx_1 et Rx_2
- Rx & Tx equiped with antenna arrays
- At teast two paths between Rx & Tx
  - 1 LOS + 1 NLOS
  - 2 1st order NLOS
- Parametric estimation
  - Delay, DOA, DOD

Equations

- **Cosinus DOA (4 Equations θ_1, θ_2, θ_3, θ_4)**

$$tg(\theta_1) = \frac{y_A - y_{Rx_1}}{x_A - x_{Rx_1}}$$

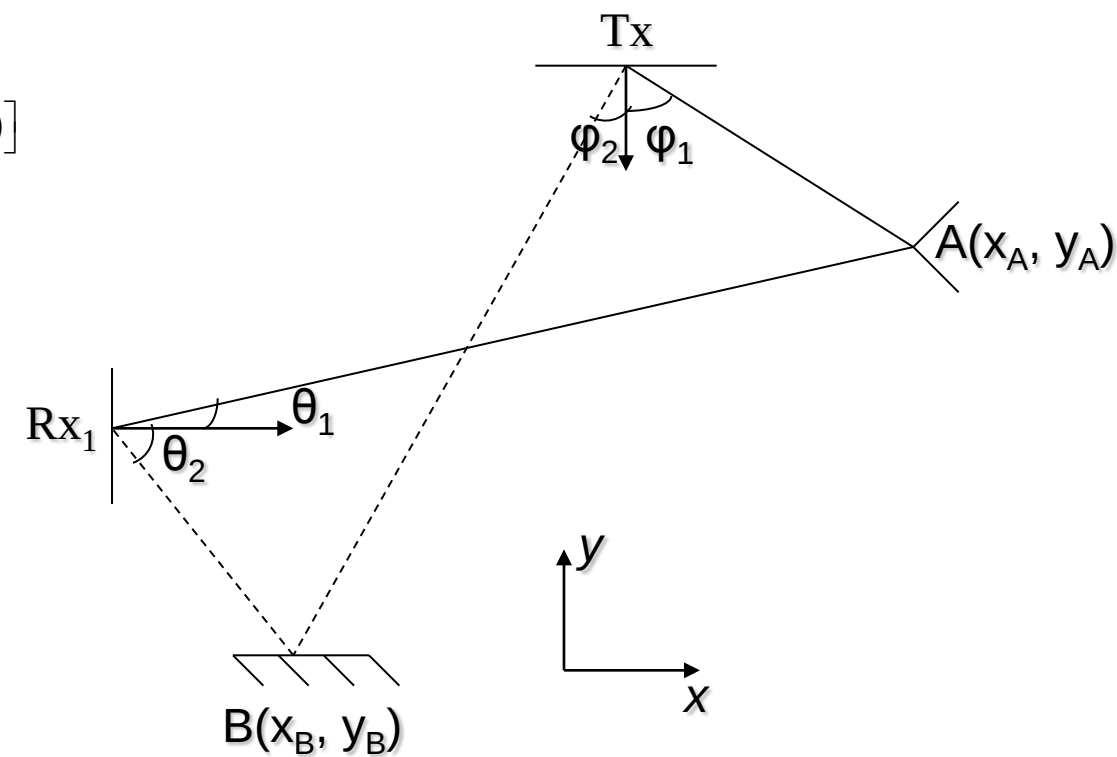
- **TDOA (6 Equations)**

$$c(\tau_A - \tau_B) = \left[d(R_{x_1}A) + d(AT_x)\right] - \left[d(R_{x_1}B) + d(BT_x)\right]$$

- **Scalar product Tx (6 Equations)**

$$\overrightarrow{R_{x_1}A}.\overrightarrow{R_{x_1}B} = \left|\overrightarrow{R_{x_1}A}\right|.\left|\overrightarrow{R_{x_1}B}\right|.\cos(\theta_1 - \theta_2)$$
$$= (x_A - x_{Rx_1})(x_B - x_{Rx_1}) + (y_A - y_{Rx_1})(y_B - y_{Rx_1})$$

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



- **Scalar products Rx (2 Equations)**

$$\overrightarrow{T_xA}.\overrightarrow{T_xB} = \left|\overrightarrow{T_xA}\right|.\left|\overrightarrow{T_xB}\right|.\cos(\varphi_1 - \varphi_2)$$
$$= (x_A - x_{Tx})(x_B - x_{Tx}) + (y_A - y_{Tx})(y_B - y_{Tx})$$

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

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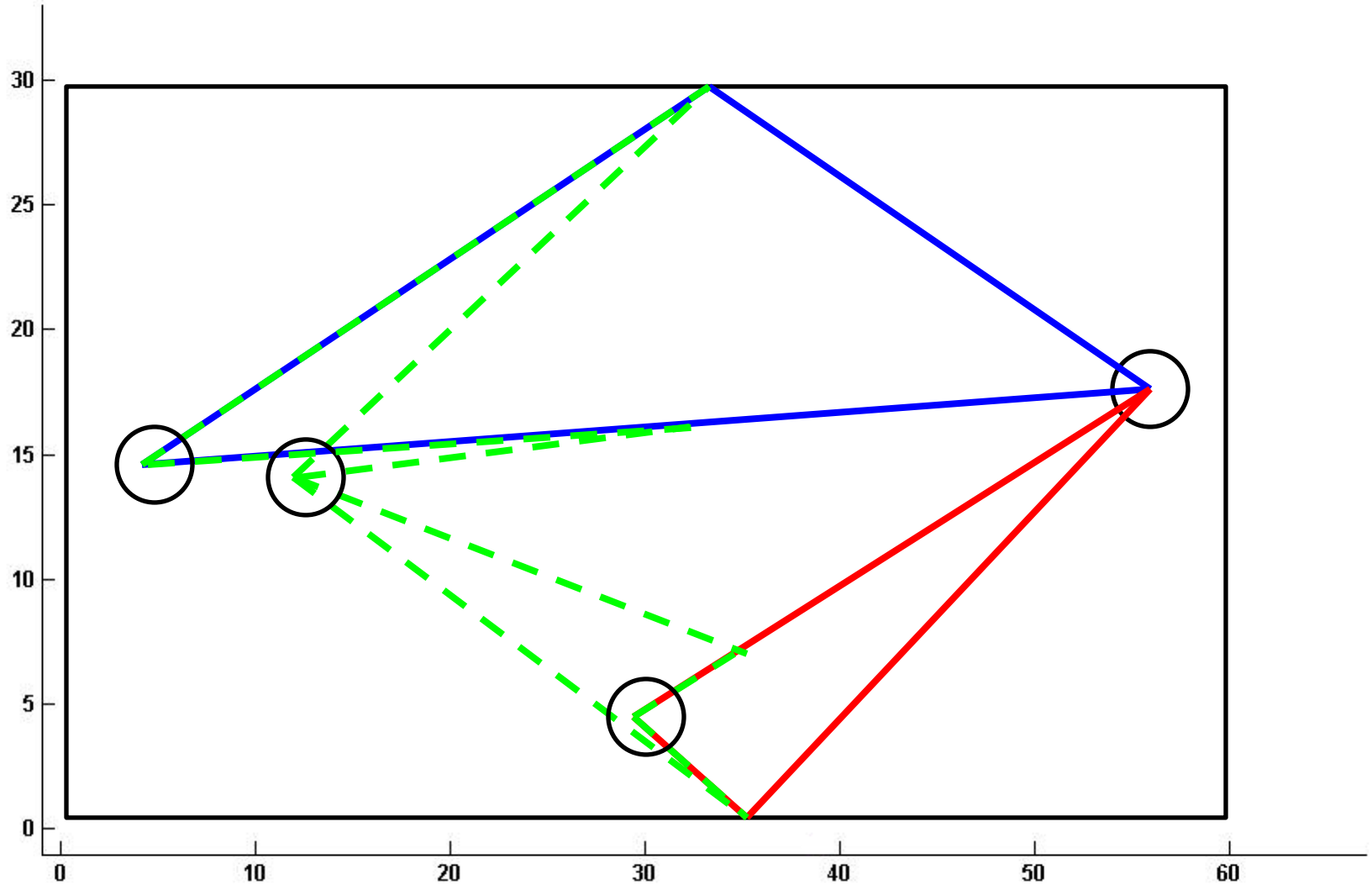
Ambiguities



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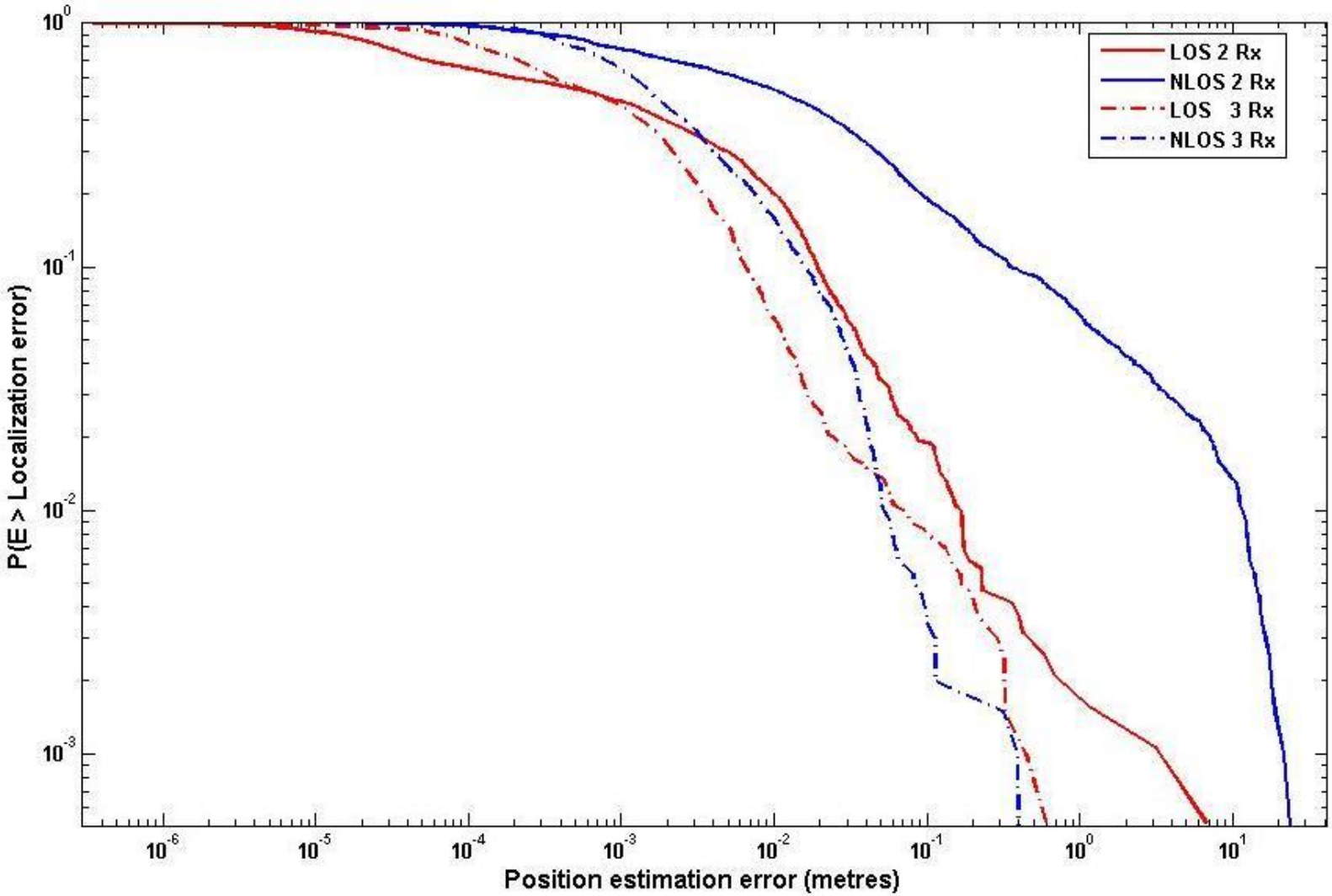
Solutions

- « Smart » initial solution
  - Tx and impact points
- Tracking of mobile
- Use more receivers!

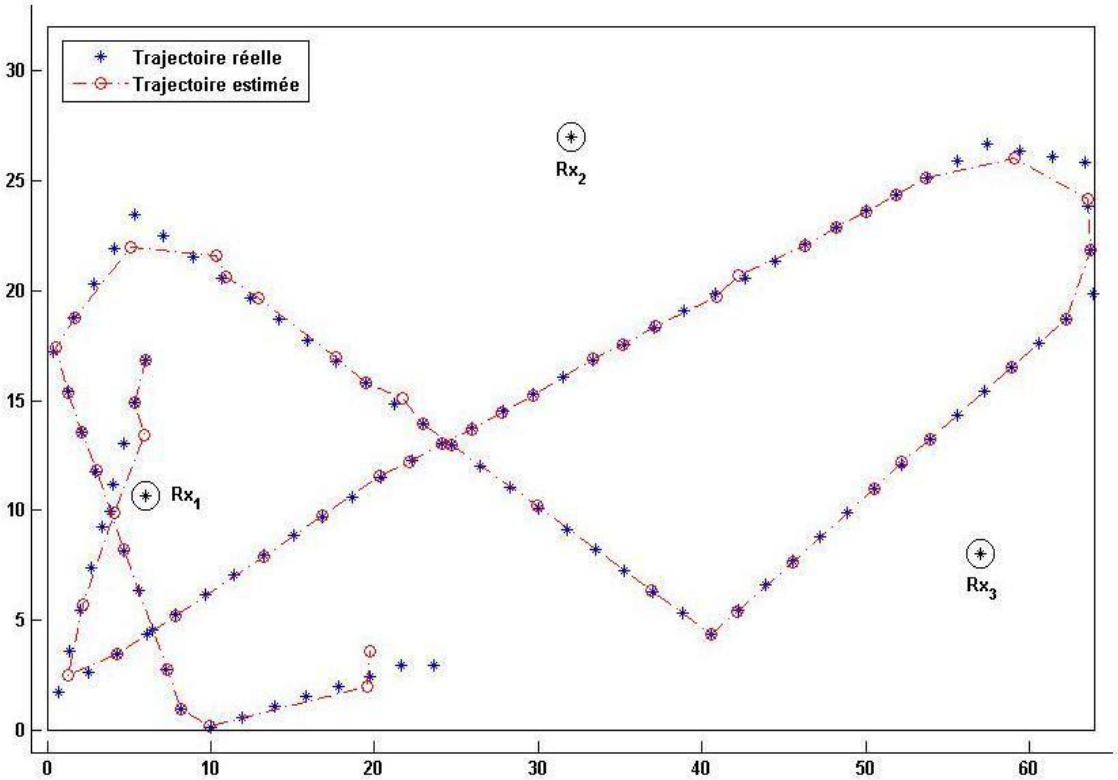
Ideal Case Simulation



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



Erreur localisation (mètres)			
Rx_{123}	Rx_{12}	Rx_{13}	Rx_{23}
0,462	0,049	0,881	0,515
0,102	0,023	0,143	0,019
4,873	0,105	5,404	18,375
0,078	0,011	0,308	0,768
22,06	**9,961**	**7,513**	**39,107**
6,444	8,648	0,144	34,086
10,02	0,354	10,113	42,209
0,021	0,017	0,025	0,023
0,022	0,022	0,036	0,094
0,545	0,014	0,109	0,685

	Pr_{123}	Pr_{12}	Pr_{13}	Pr_{23}	$Pr_{\varnothing}$
Pourcentage (%)	55,44	70,29	62,37	71,28	6,93

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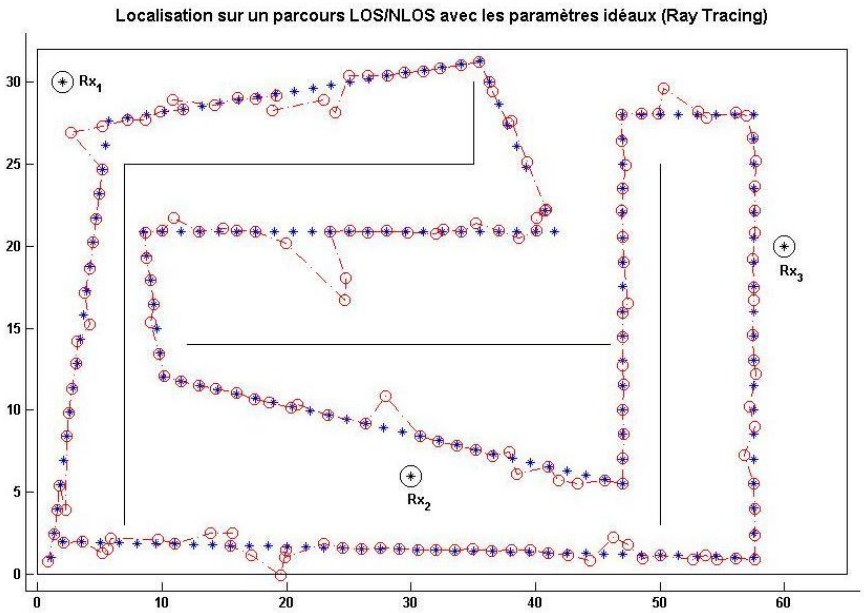
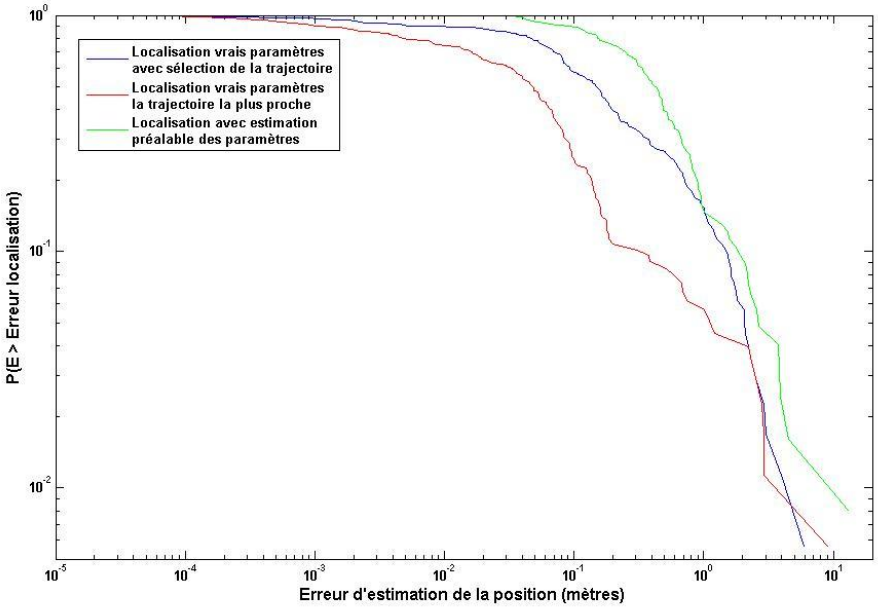
LOS/NLOS Track

- 3 Rx, 177 points

	Rx_1 & Rx_2 & Rx_3	Rx_1 & Rx_2	Rx_1 & Rx_3	Rx_2 & Rx_3	Aucun couple
Pourcentage (%)	50,9	54,2	63,8	81,4	2,3





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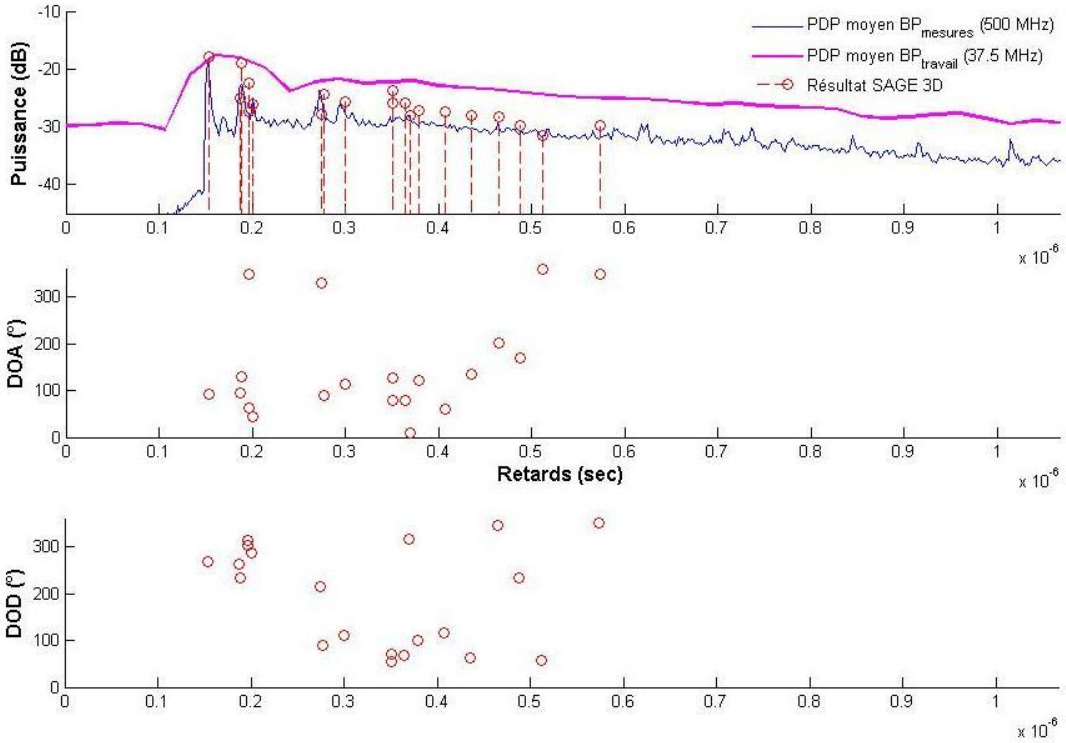
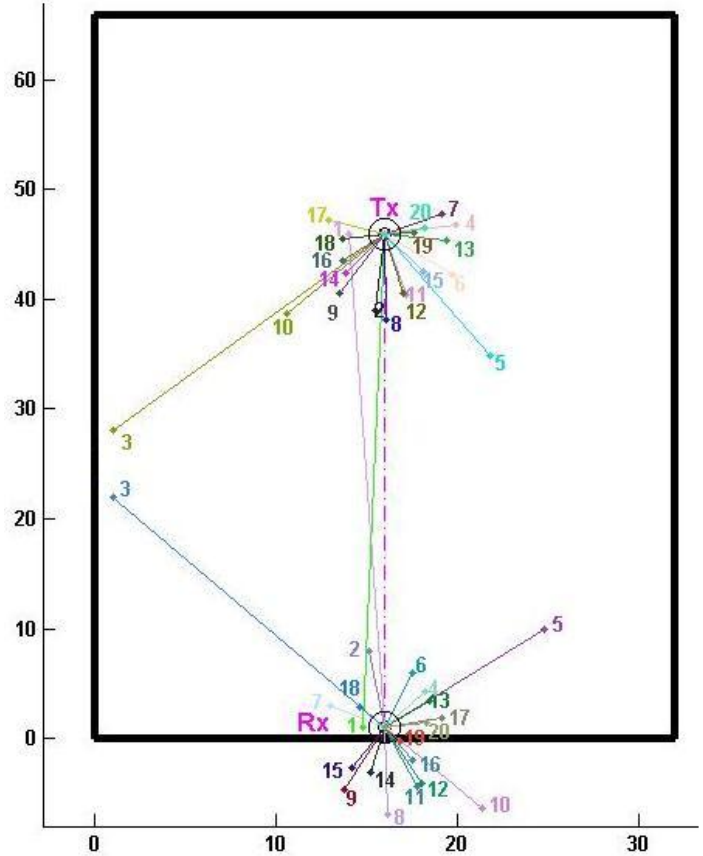
Real Environment – Sports Hall





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??