Cooperative Multipath-assisted Navigation and Tracking: A Low-Complexity Approach

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September 24, 2015

Outline

Cooperative indoor localization

Implementation

Evaluation

Conclusion

Cooperative indoor localization

Idea:

- Several mobiles locate their position
- No anchor nodes
- Floor plan is provided

Measurement: UWB channel

- Mono-static measurement: local non-cooperative
- Bi-static measurement: cooperative

Literature

- Cooperative mobiles with one anchor[1]
- Cooperative mobiles without anchor[2]

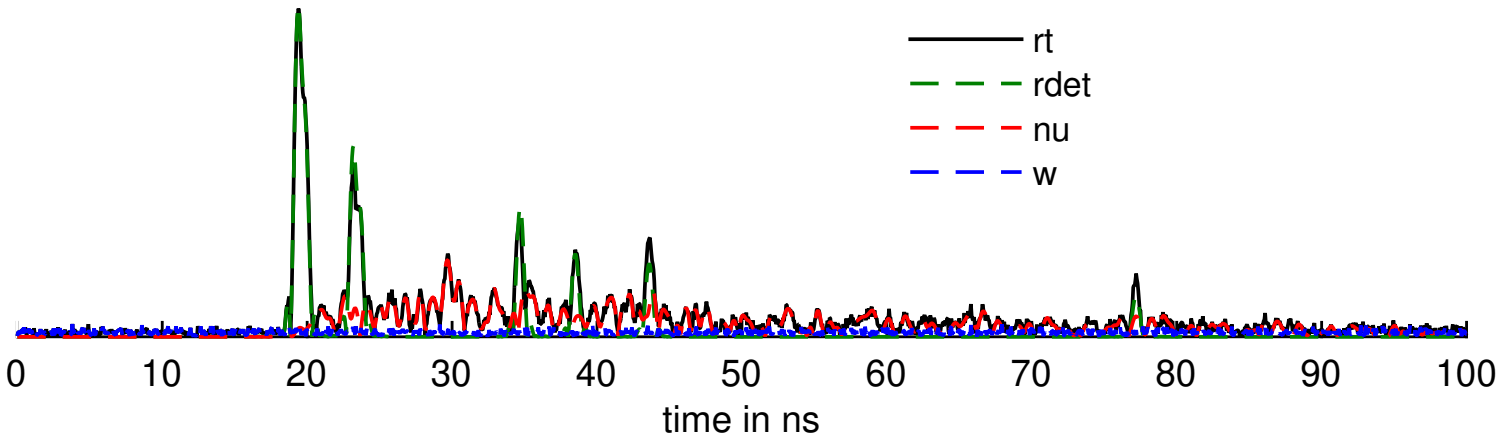
[1] S. Van de Velde et al.: **"Cooperative Multipath-Aided Indoor Localization,"** IEEE Wireless Communications and Networking Conference: Mobile and Wireless Networks, 2012.

[2] M. Froehle et al.: **"Cooperative Multipath-Assisted Indoor Navigation and Tracking (Co-MINT) Using UWB Signals,"** IEEE International Conference on Communications (ICC), 2013.

Signal & Channel Model

Received signal[3]:

- $r(t) = \sum_{k=1}^{K} \alpha_k \underbrace{s(t-\tau_k)}_{\text{TX pulse}} + \underbrace{\nu(t)}_{\text{diffuse}} * s(t) + \underbrace{w(t)}_{\text{noise}}$

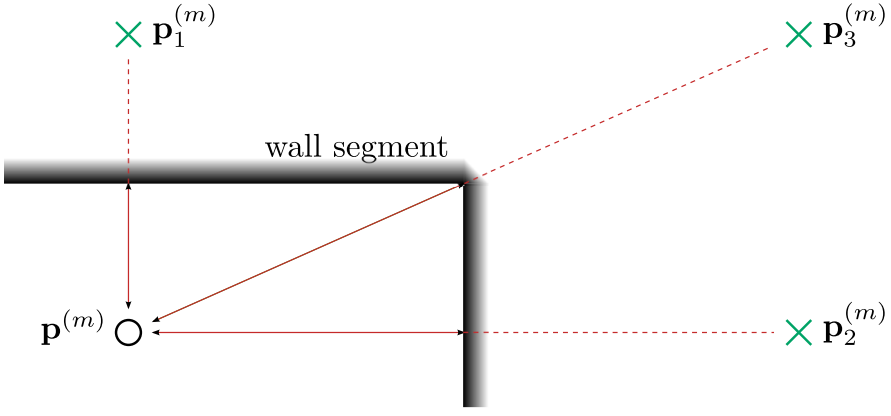


[3] K. Witrisal, P. Meissner: **"Performance Bounds for Multipath-assisted Indoor Navigation and Tracking (MINT),"** IEEE International Conference on Communications (ICC), 2012.

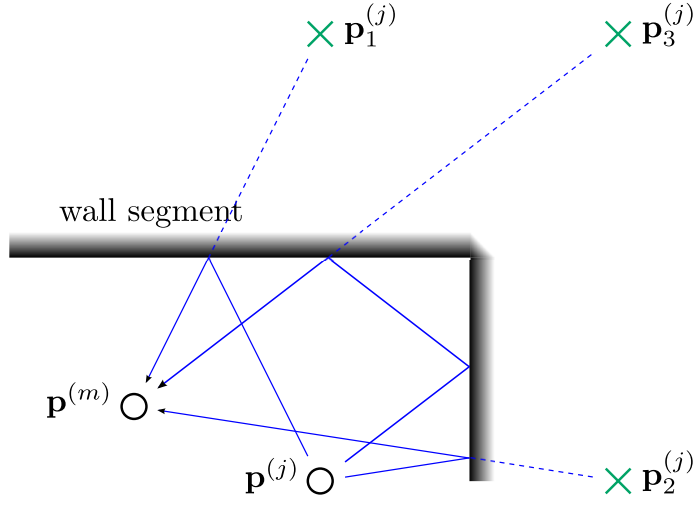
Signal & Channel Model

Multipath propagation

- Multipath propagation of mobile $\mathbf{p}^{(m)}$ by modeling Virtual Anchors (VA) $\mathbf{p}_k^{(m)}$



Mono-static measurement

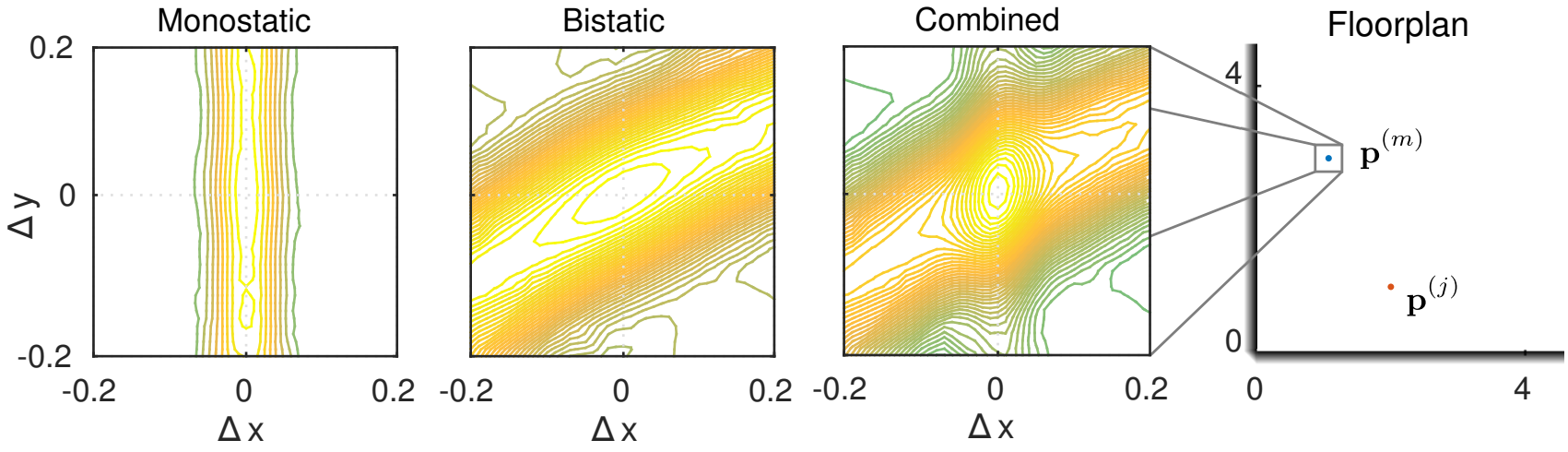


Bi-static measurement

- Mono-static measurement (red): local non-cooperative
- Bi-static measurement (blue): cooperative

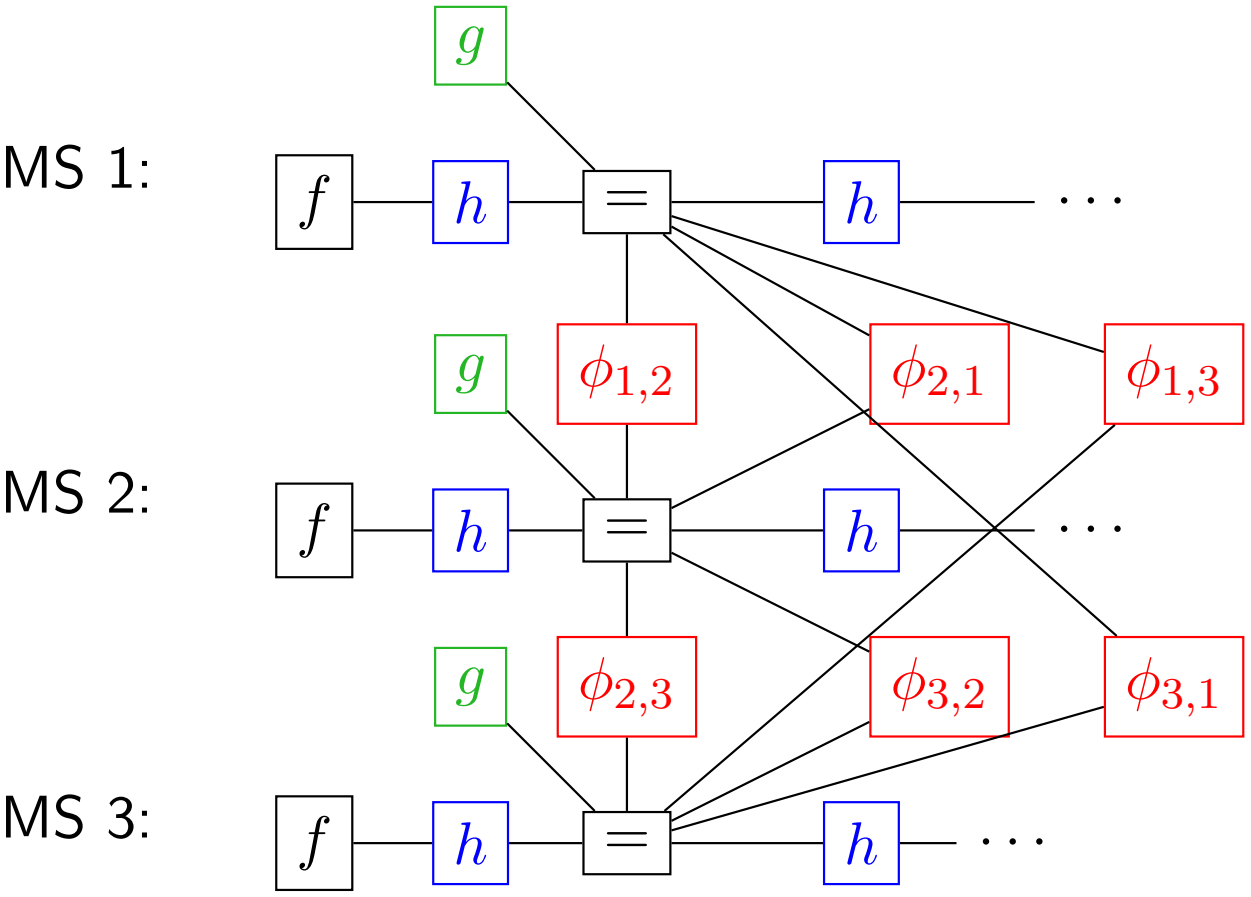
Likelihood function

- Mono-static measurement
- Bi-static measurement



Factor Graph – For 3 Mobile Nodes

Time: $k = 0$ $k = 1$ $\dots$



- State: $\mathbf{x}_k^i$
- Prior:
  $f(\mathbf{x}_0^i) = p(\mathbf{x}_0^i)$
- Motion model:
  $h(\mathbf{x}_{k-1}^i, \mathbf{x}_k^i) = p(\mathbf{x}_k^i | \mathbf{x}_{k-1}^i)$
- Mono-static:
  $g(\mathbf{x}_k^i) = p(\mathbf{z}_{\text{self},k}^i | \mathbf{x}_k^i)$
- Bi-static:
  $\phi_{i,j}(\mathbf{x}_k^i, \mathbf{x}_k^j) = p(\mathbf{z}_{\text{rel},k}^i | \mathbf{x}_k^i, \mathbf{x}_k^j)$

Co-MINT Implementation

Challenges

- Nonlinear relation of distance measurements and position
- Non-Gaussian distribution of the position error
- Particle Filters: high complexity $\mathcal{O}(N^2)$ for N particles
- Remedy: approximate neighbors by their sample mean[4]

Proposed method

- Estimate positions of mobiles with Extended Kalman Filter
- Joint state of mobile position and corresponding VAs
- Combine Mono-static and Bi-static measurements

[4] M. Froehle et al.: **"Cooperative Multipath-Assisted Indoor Navigation and Tracking (Co-MINT) Using UWB Signals,"** IEEE International Conference on Communications (ICC), 2013.

Co-MINT Implementation

Initialization

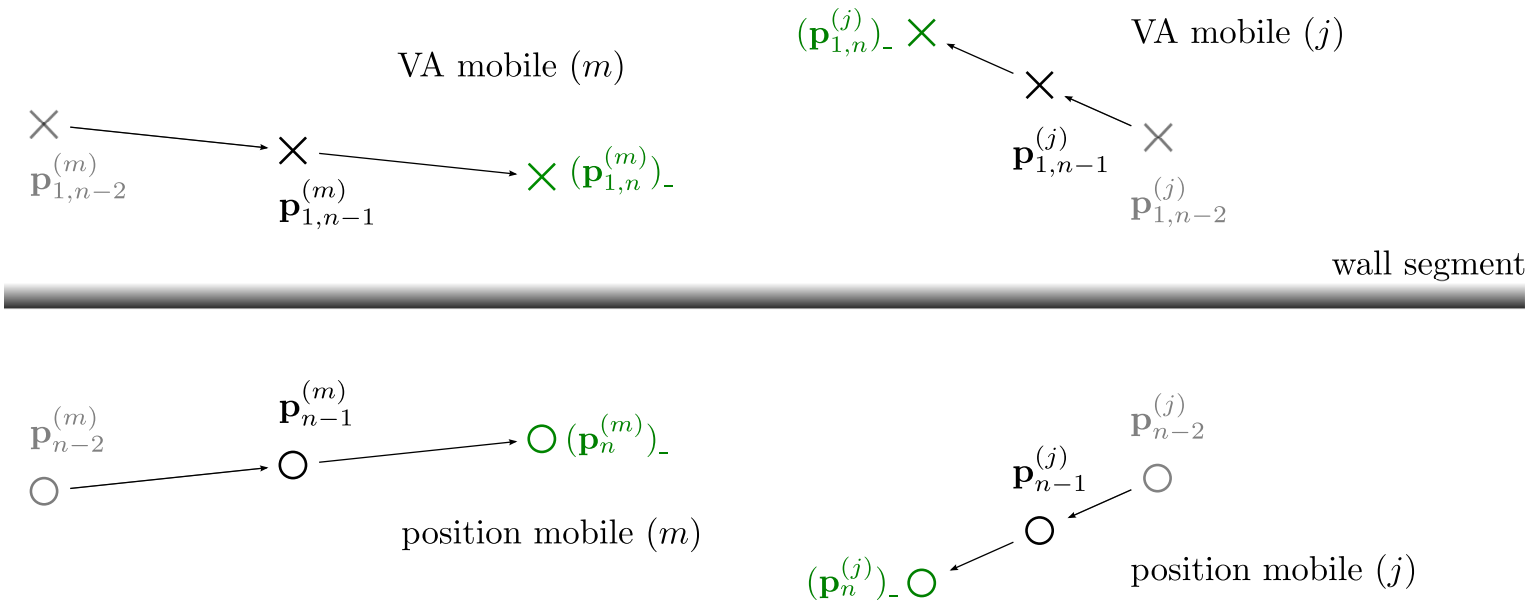
- Compute VA set for each mobile dependent on floor plan
- Initialize Kalman state
  - Stack positions of mobiles and corresponding VAs

Extended Kalman Filter EKF

- Prediction step
- Update step

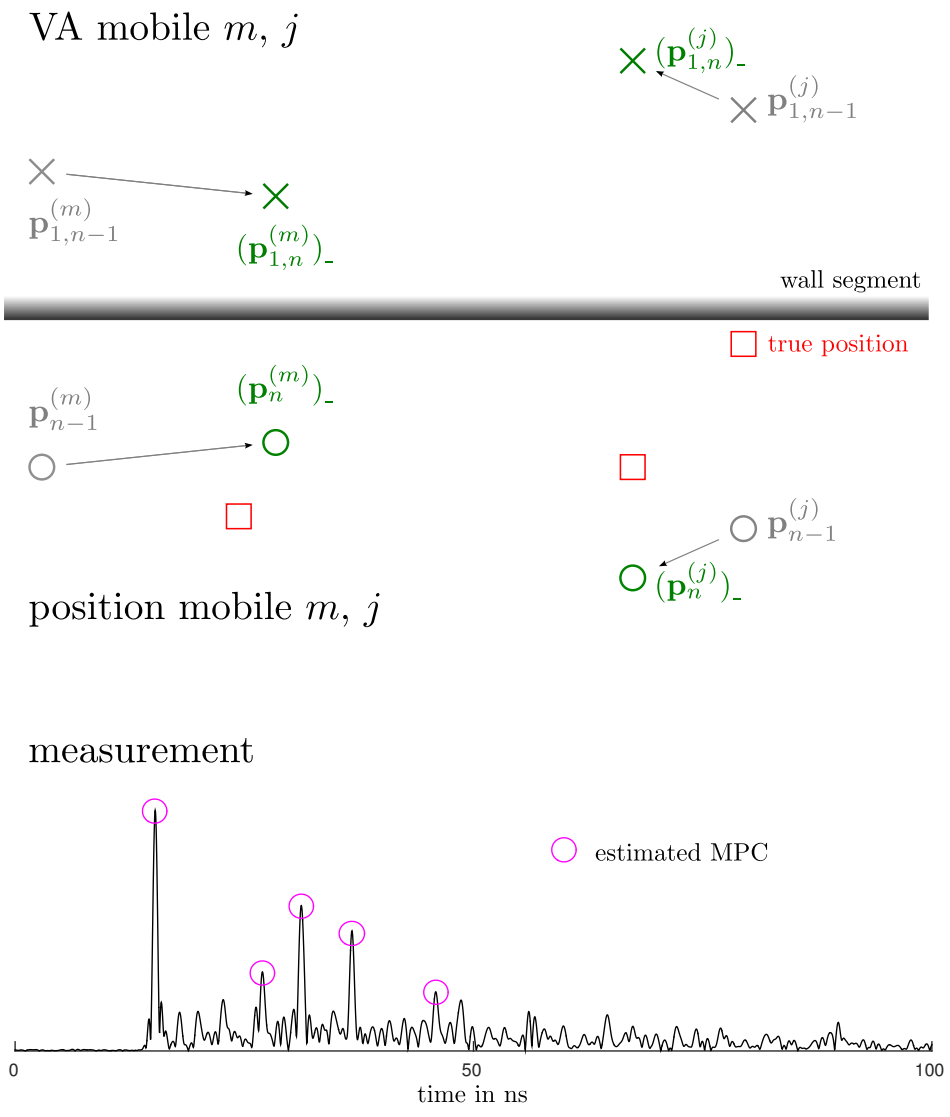
Co-MINT Implementation

- Prediction step
  - Constant velocity motion model
  - VA movement dependent on the floor plan



Implementation

- Update Step
  - Perform measurements of each mobile
  - Estimate arrival time of multipath components
  - Compute expected delays given the virtual anchors
  - Data Association of estimated and expected set of MPCs
  - Perform EKF update step



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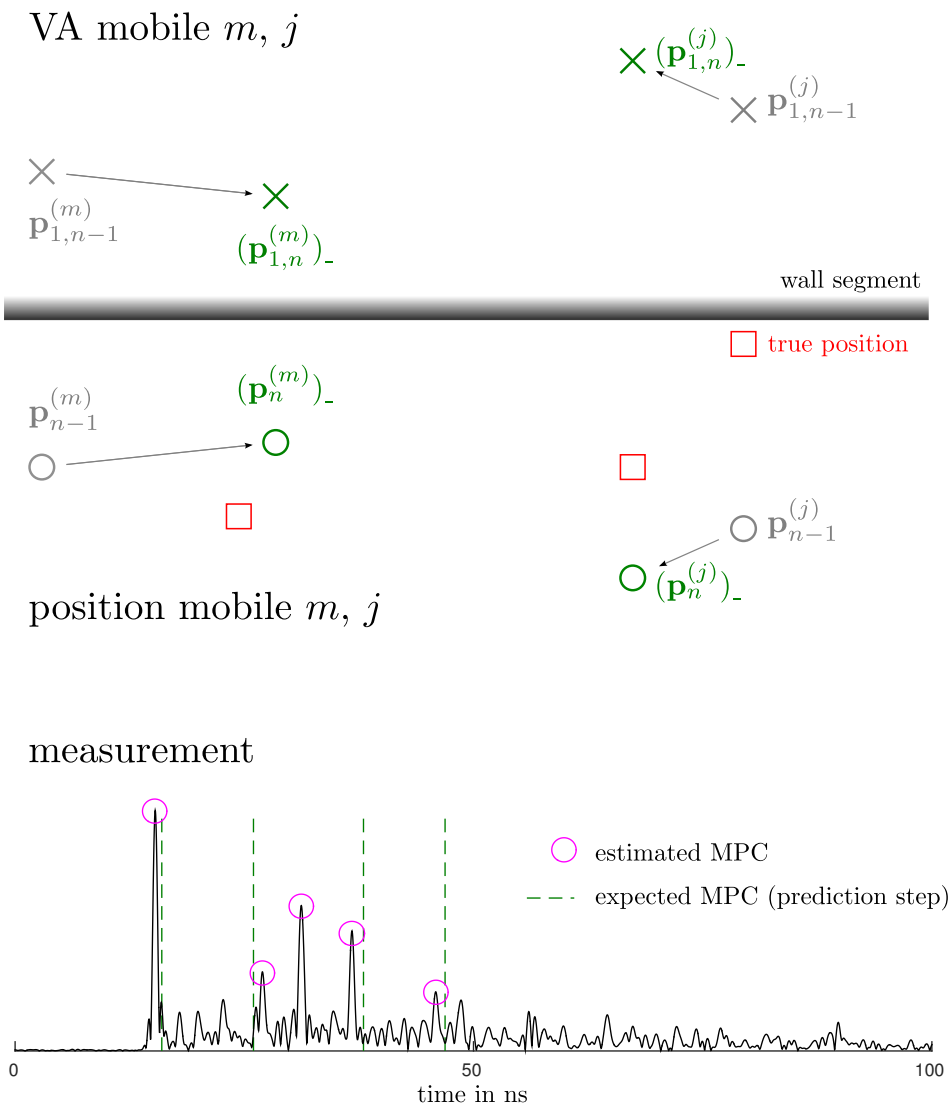

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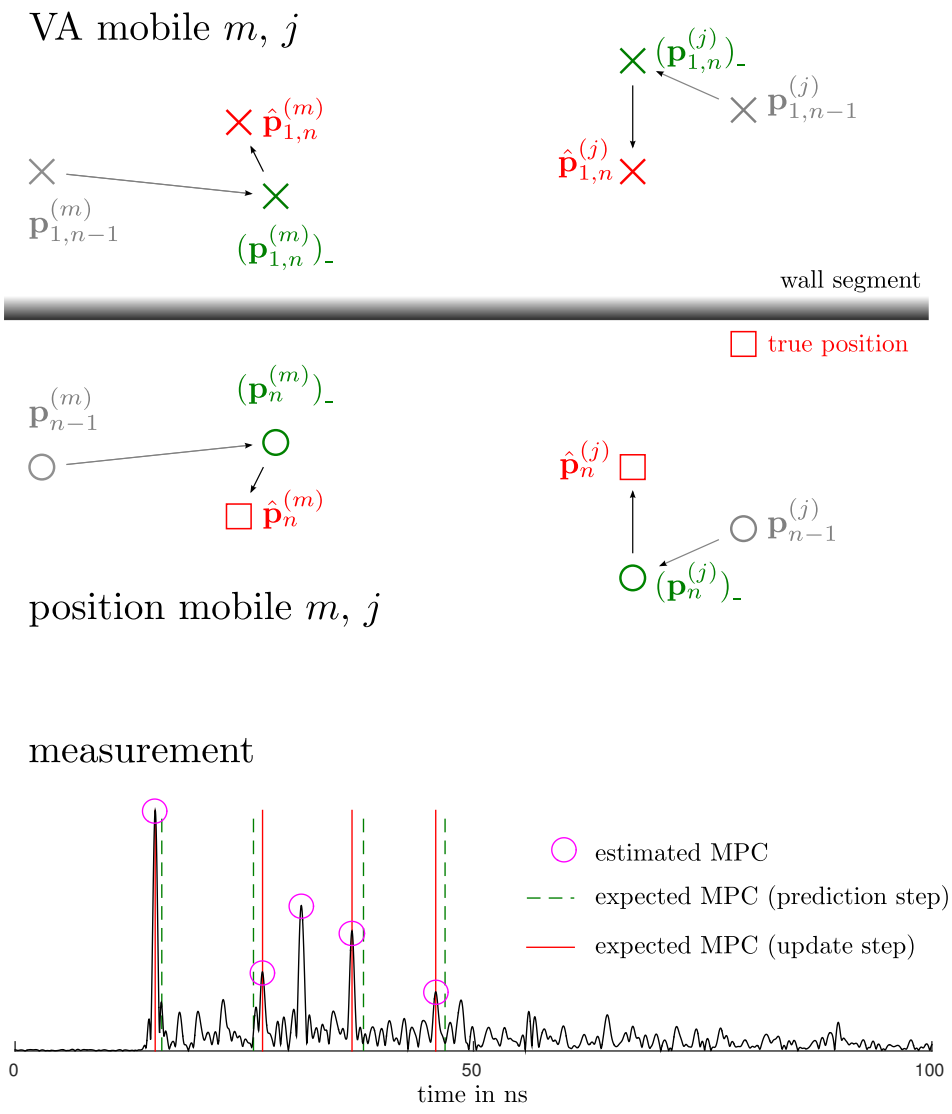


Extended Kalman Filter EKF

Benefits

- Low Complexity
  - Data Association $\mathcal{O}(M^2K^3)$
    - $M \sim 2$ (#mobiles), $K \sim 10$ (#assigned measurements)
  - PF: $\mathcal{O}(MN^2)$
    - $N \sim 500$ (#particles)

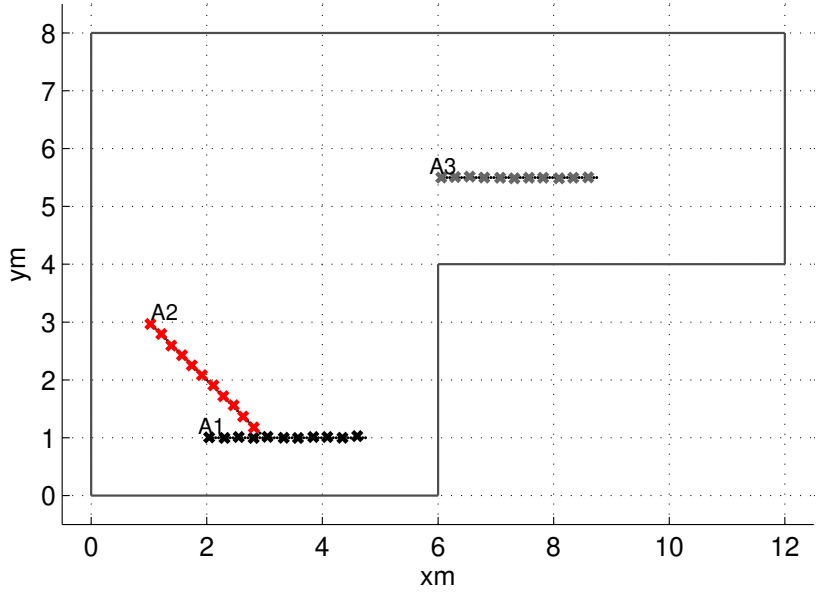
Drawbacks

- Reduced positioning performance
  - Linearization of measurement equations
  - Non-Gaussian positioning error

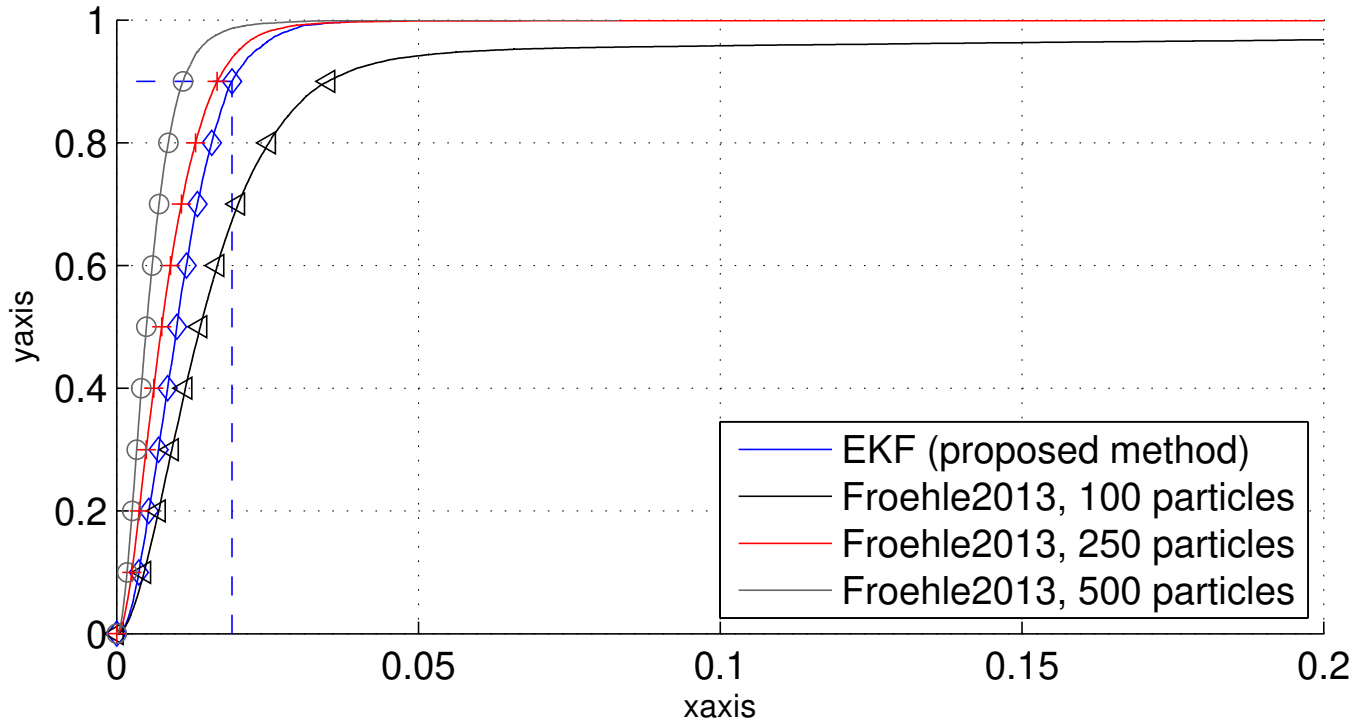
Evaluation

Setup

- L-shaped room with non line of sight conditions
- Three mobiles
- Pulse bandwith 2 GHz (15 cm)
- VAs up to 2nd order
- Perfect initialization



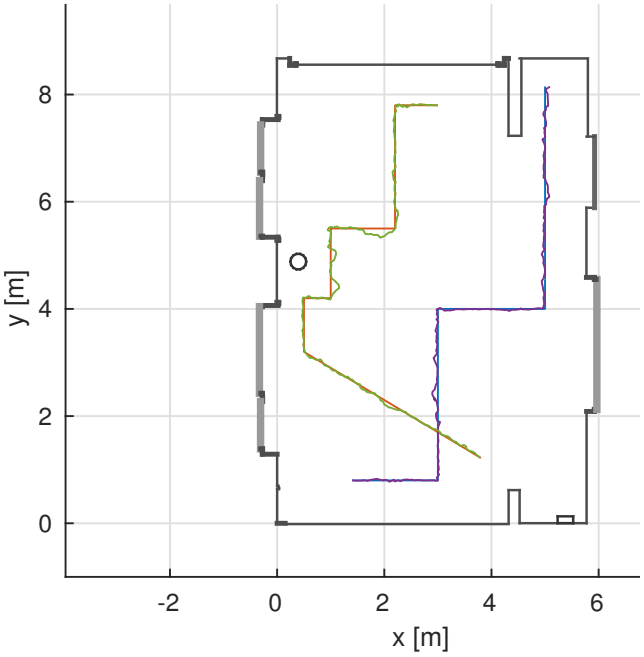
Evaluation

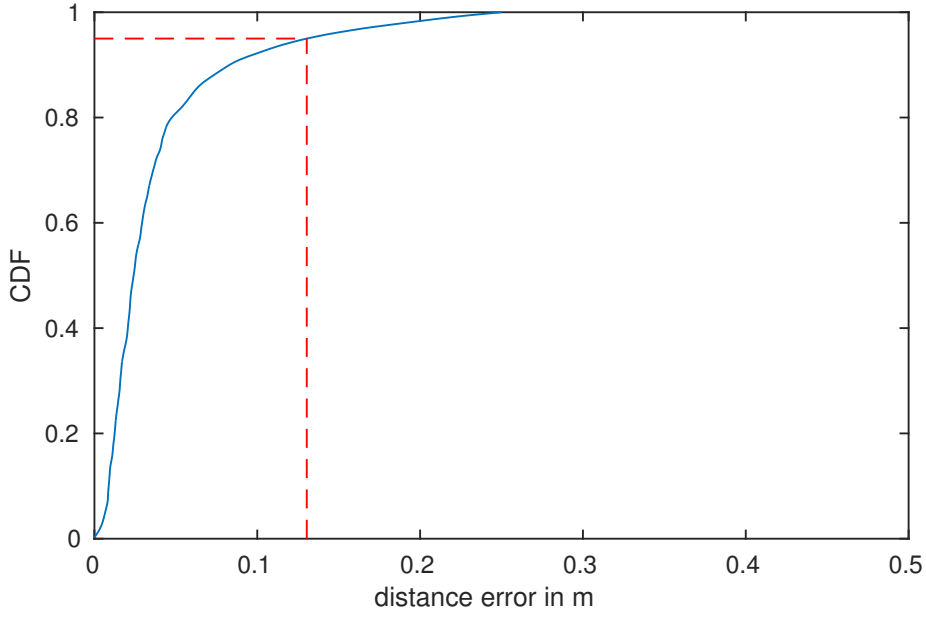


Execution time - real time factor

- PF100 / EKF: 200
- PF250 / EKF: 750
- PF500 / EKF: 2300

Preliminary results





Two mobiles, UWB 2 GHz, transmitted pulse: raised cosine

Conclusion and Future Work

Conclusion

- Cooperative Localization using multipath components
- Reduced complexity
- Preserved robustness

Future work

- Consider uncertainty of floor plan
- Distributed localization
- Further discussion on Mono- and Bi-static measurements