A Neural-enhanced Factor Graph-based Algorithm for Robust Positioning in Obstructed LOS Situations

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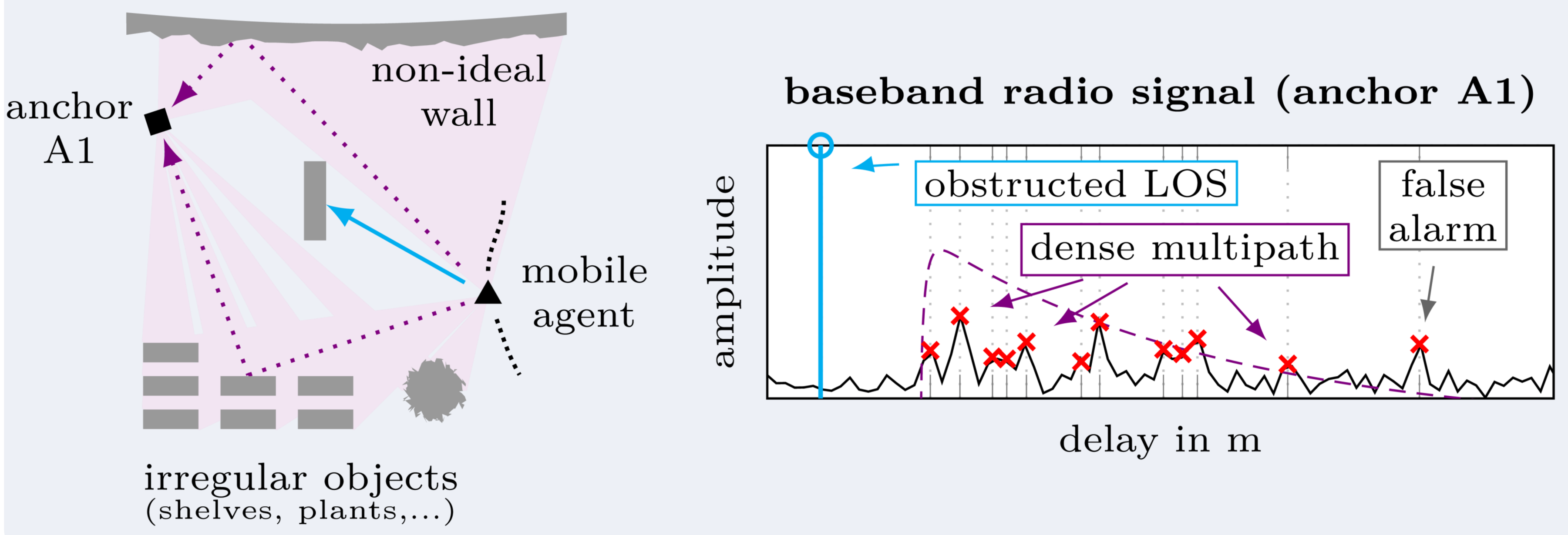
Abstract

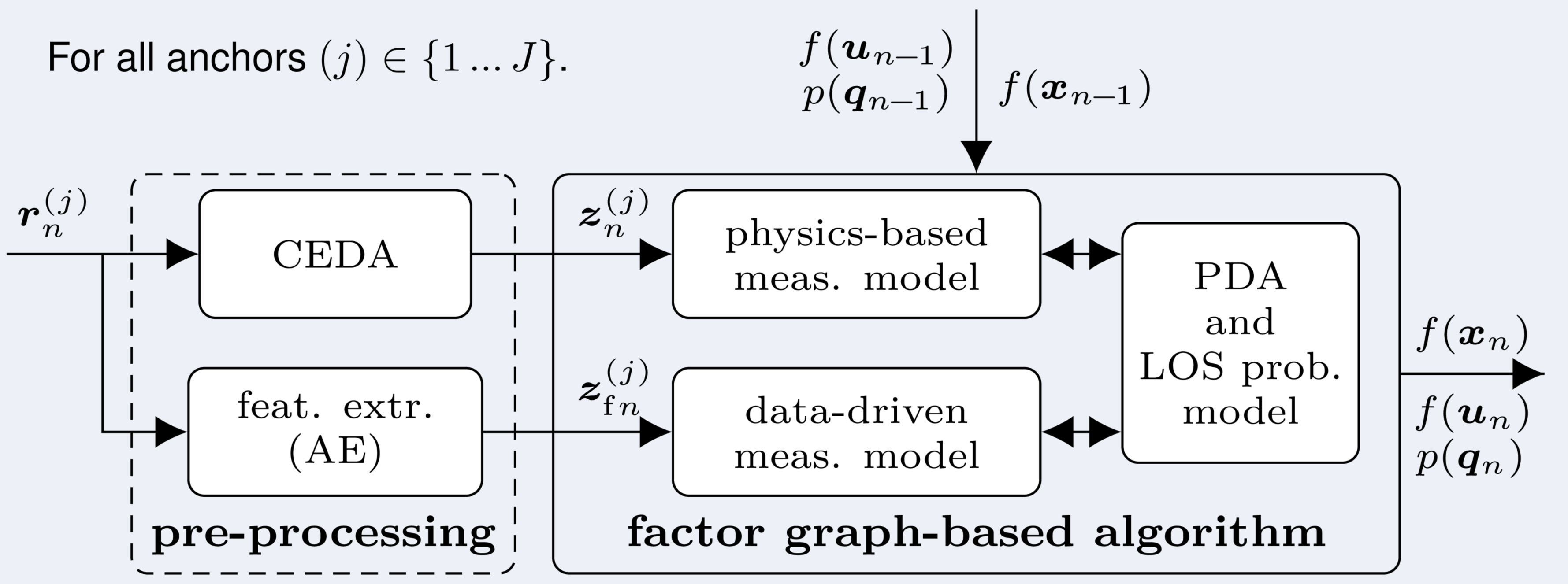
- **Neural-enhanced joint Bayesian probabilistic model** and corresponding **factor graph-based algorithm** for robust radio signal-based localization and tracking in multipath environments with fully obstructed LOS situations.
- Proposed method only requires sparse training data, works **in arbitrary multipath channels**, and significantly outperforms state-of-the-art methods.

Problem Statement

Robustly estimate the mobile agent state PDF in scenarios with arbitrary multipath propagation (specular or dense/diffuse) **even in obstructed LOS situations.**



Algorithm Concept

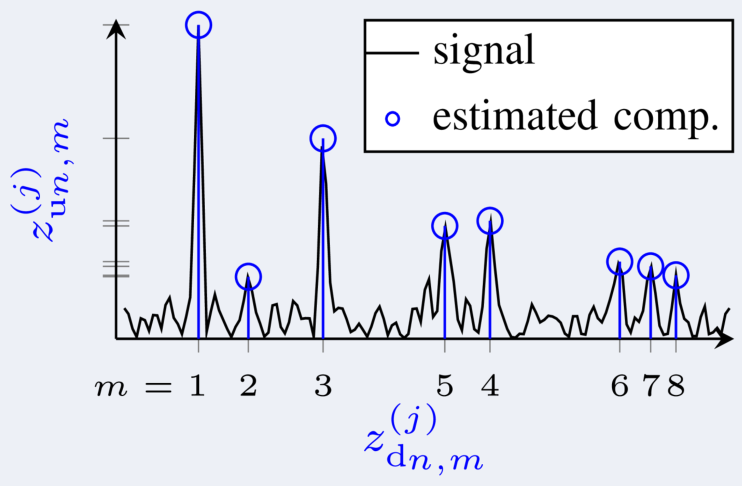


Pre-processing

For each anchor j ...

1) a Channel Estimation and Detection Algorithm (CEDA) estimates $m_n^{(j)}$ **signal component measurements** $\boldsymbol{z}_{n,m}^{(j)} = [z_{\mathrm{d}n,m}^{(j)}, z_{\mathrm{u}n,m}^{(j)}]^{\mathsf{T}}$.

2) a pre-trained Auto Encoder Deep Neural Network (AE-DNN) extracts F **feature measurements** denoted by $z_{\mathrm{f}\,i,n}^{(j)}$ (latent space).



Advantages: compression of signal, unsupervised training, may capture details.

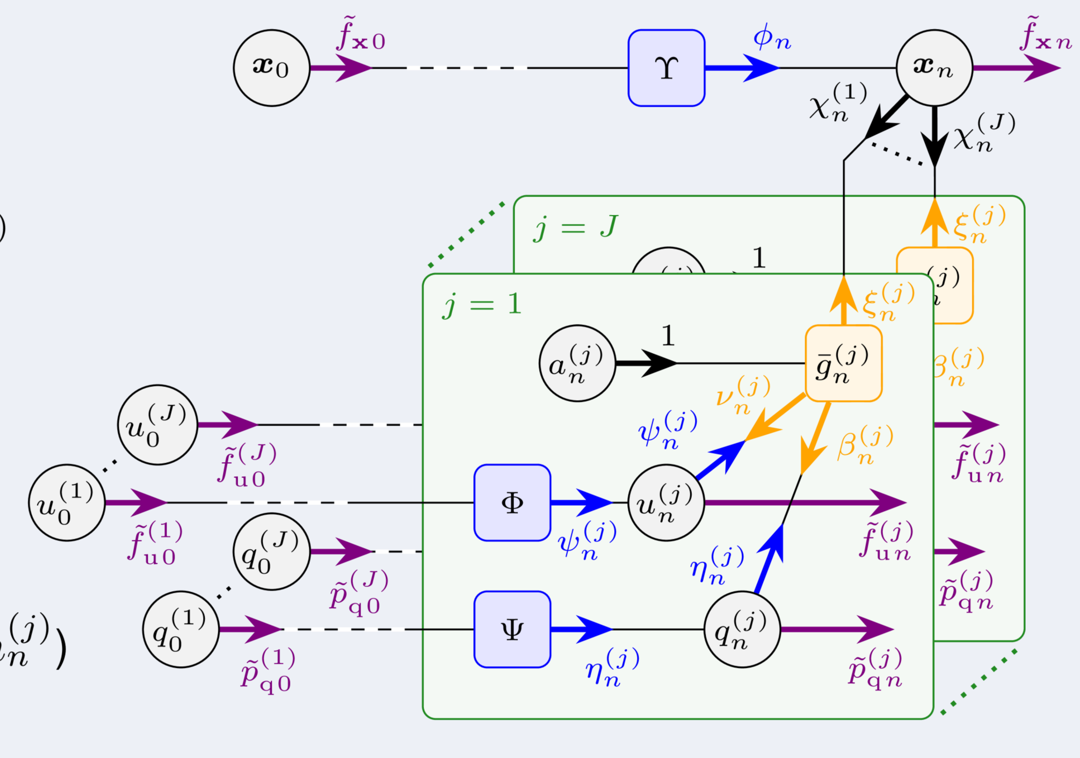
Factor Graph-based Algorithm

Hidden random variables

- agent state $\boldsymbol{x}_n$
- for all J anchors:
  - data association variable $a_n^{(j)}$
  - normalized amplitude $u_n^{(j)}$
  - LOS probability $q_n^{(j)}$

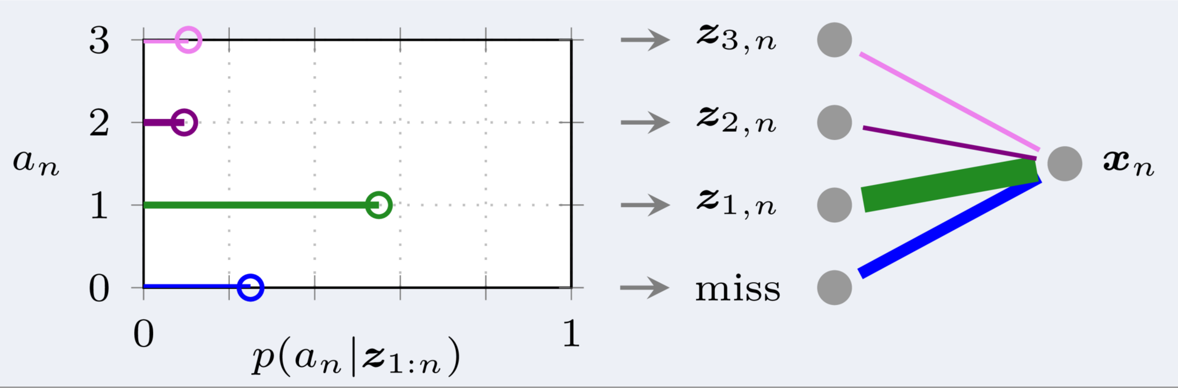
Observed random variables

- CEDA measurements $\boldsymbol{z}_{n,m}^{(j)}$ (with random num. of meas. $m_n^{(j)}$)
- AE-DNN measurements $z_{\mathrm{f}\,1,n}^{(j)}$

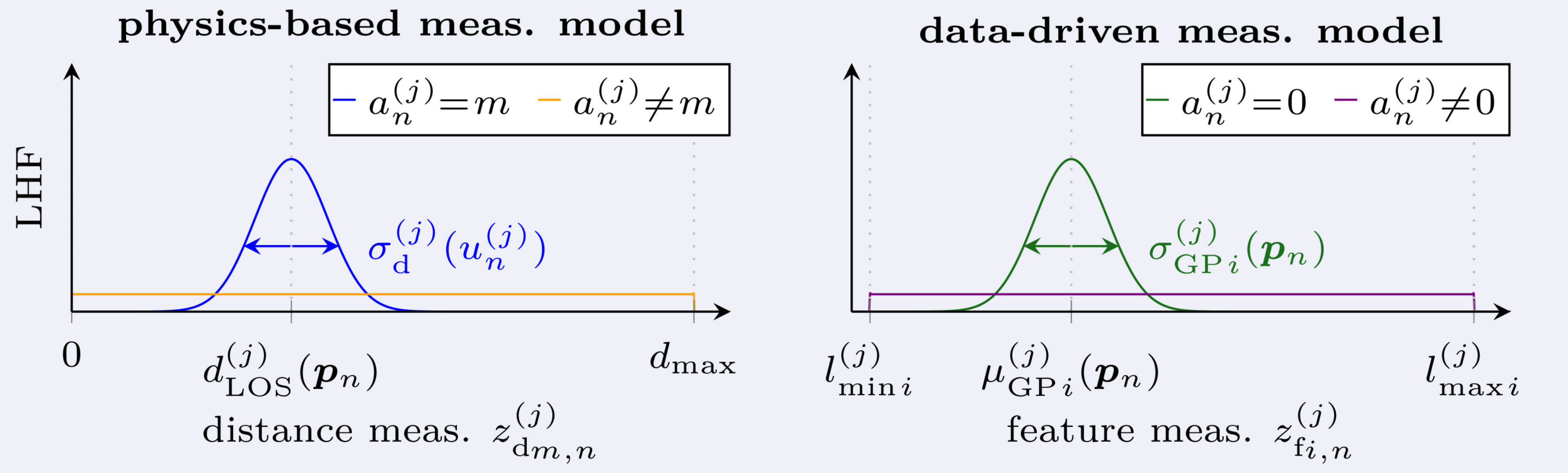


Probabilistic Data Association (PDA)

Differentiate between a **single** possible **LOS** measurement and **many** possible **NLOS** measurements (MPCs or false alarms).



Measurement Model



$d_{\mathrm{LOS}}^{(j)}(\boldsymbol{p}_n)$: euclid. dististance , $\sigma_{\mathrm{d}}(u_n^{(j)})$: Fisher information (CRLB)

$\mu_{\mathrm{GPi}}^{(j)}(\boldsymbol{p}_n)$, $\sigma_{\mathrm{GPi}}^{(j)}(\boldsymbol{p}_n)$: Gaussian Process Regression (GPR) mean value and std. dev.

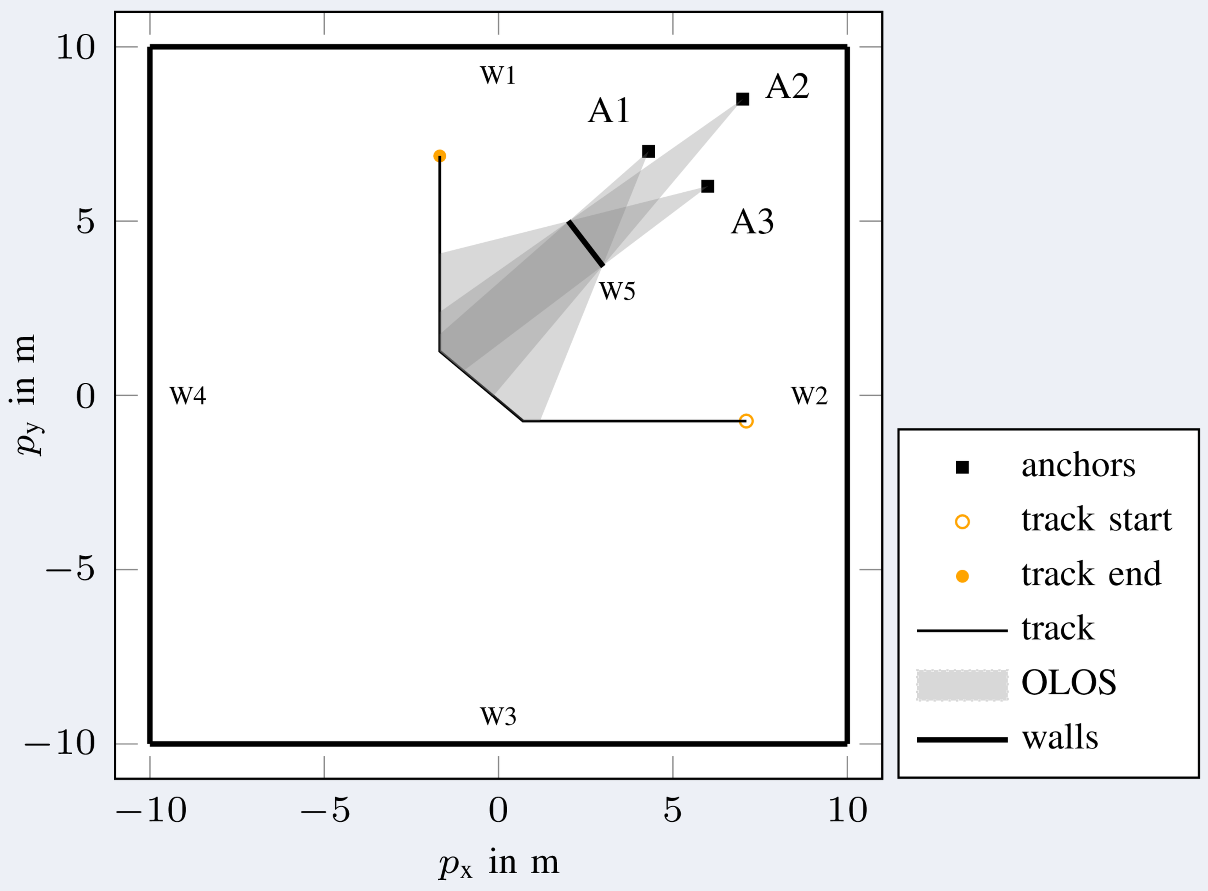
Numerical Simulation

Challenging Scenario

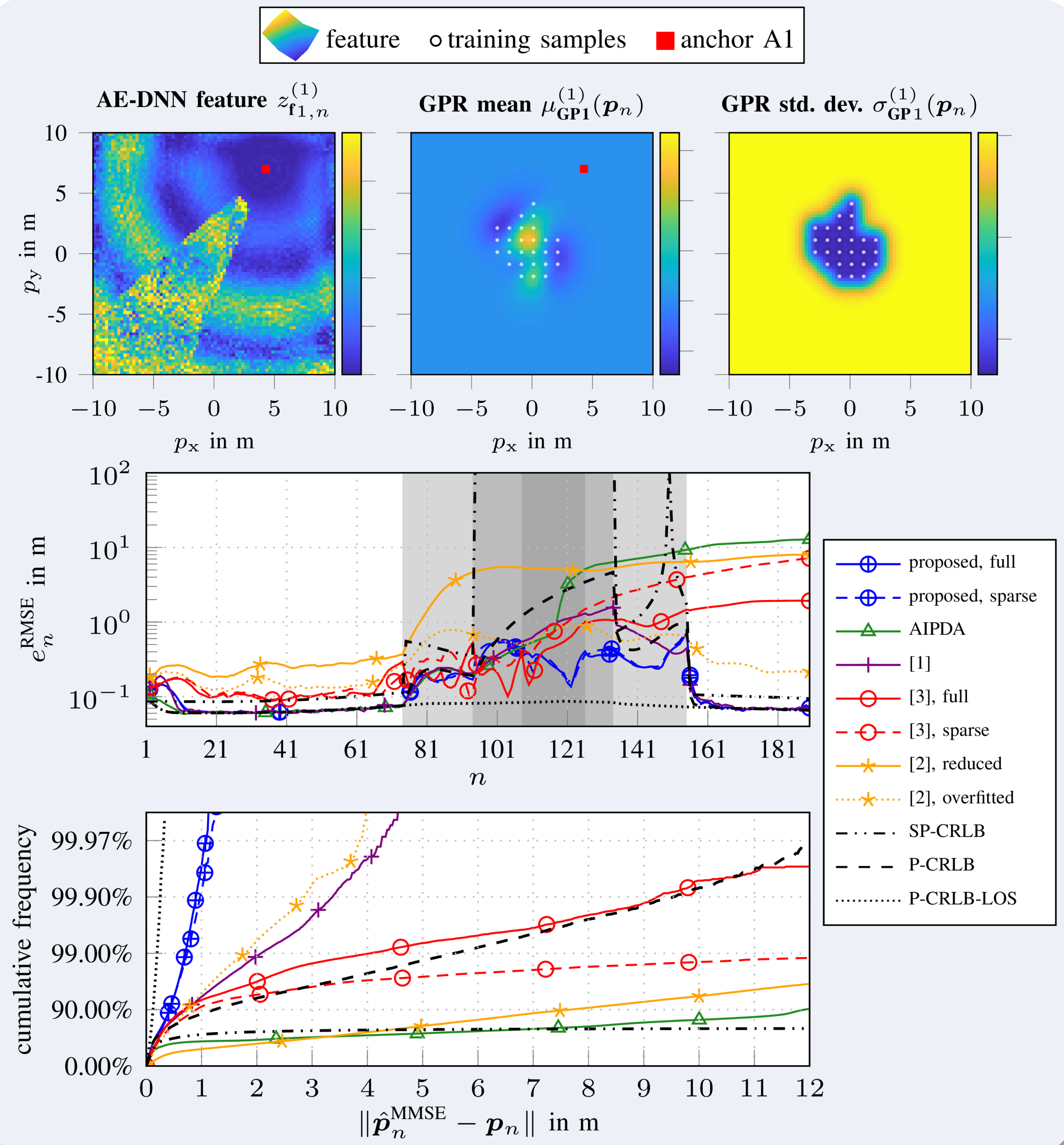
- fully obstructed LOS
- anchors in close vicinity (poor GDOP)

Parameters

- MPCs based on image source model
- free-space path loss
- 30 dB SNR at 1m + 3dB per reflection
- RRC signal with 500 MHz bandwidth



Exemplary Results



Conclusion

- Demonstrated the applicability of the presented algorithm in the context of **fully obstructed LOS mitigation**.
- The presented algorithm **significantly outperforms** all compared algorithms and constantly attained the **posterior CRLB** (P-CRLB).

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[1] A. Venus, E. Leitinger, S. Tertinek and K. Witrisal, ``A Graph-based Algorithm for Robust Sequential Localization Exploiting Multipath for Obstructed-LOS-Bias Mitigation,'' in IEEE Trans. Wireless Commun., 2023.

[2] H. Wymeersch, S. Marano, W. M. Gifford, and M. Z. Win, ``A machine learning approach to ranging error mitigation for UWB localization,'' IEEE Trans. Wireless Commun., 2012.

[3] S. Kram, C. Kraus, T. Feigl, M. Stahlke, J. Robert, and C. Mutschler, ``Position tracking using likelihood modeling of channel features with Gaussian processes,'' ArXiv e-prints, vol. abs/2203.13110, 2022.