中国科学技术大学
University of Science and Technology of China

Intelligent
Perception Lab

RLoc: Towards Robust Indoor Localization by Quantifying Uncertainty

Tianyu Zhang, Dongheng Zhang, Guanzhong Wang, Yadong Li, Yang Hu,
Qibin Sun and Yan Chen*

University of Science and Technology of China

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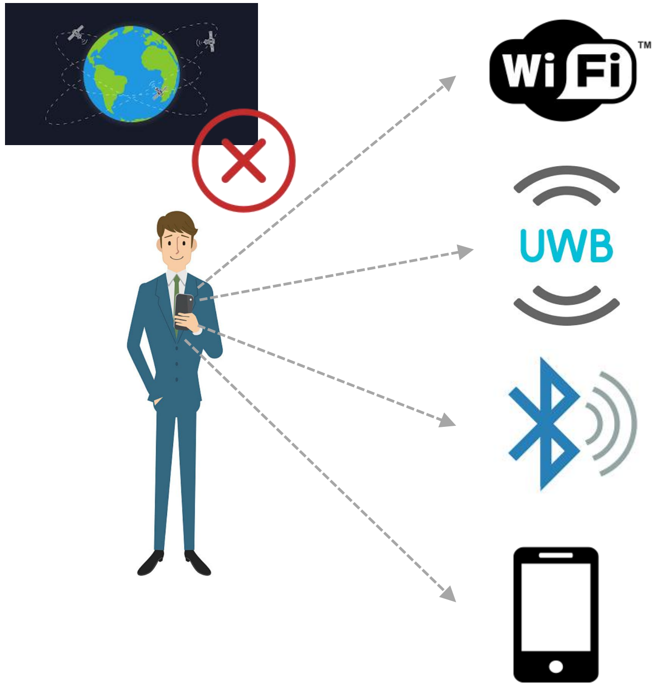
Indoor & Wi-Fi Localization

https://www.geotab.com/blog/what-is-gps/

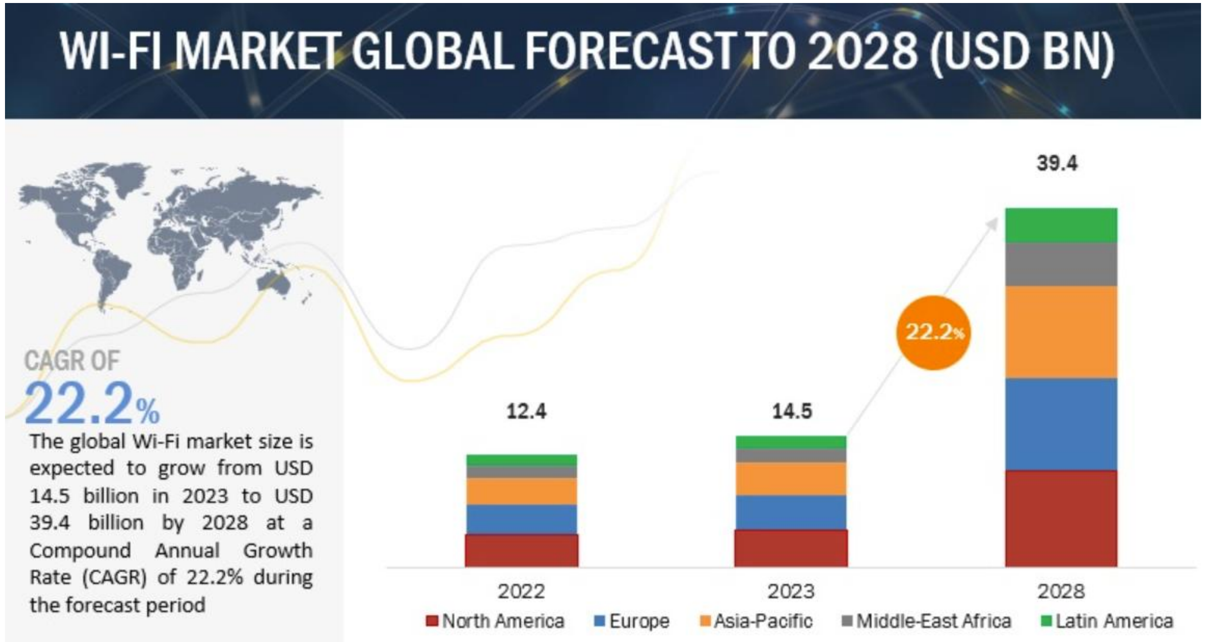


Wi-Fi

UWB

BLE

Smartphone Sensors



https://www.marketsandmarkets.com/Market-Reports/global-wi-fi-market-994.html

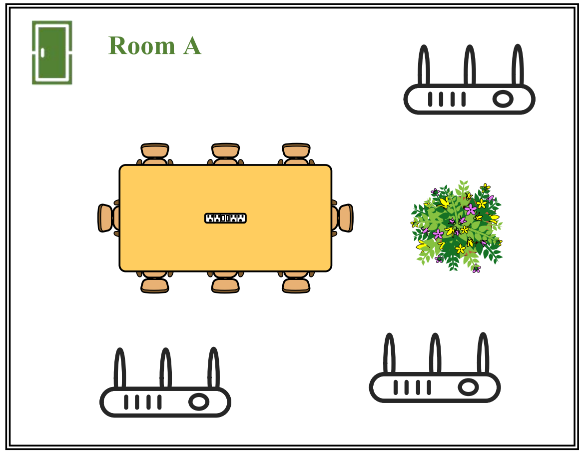
Related Work

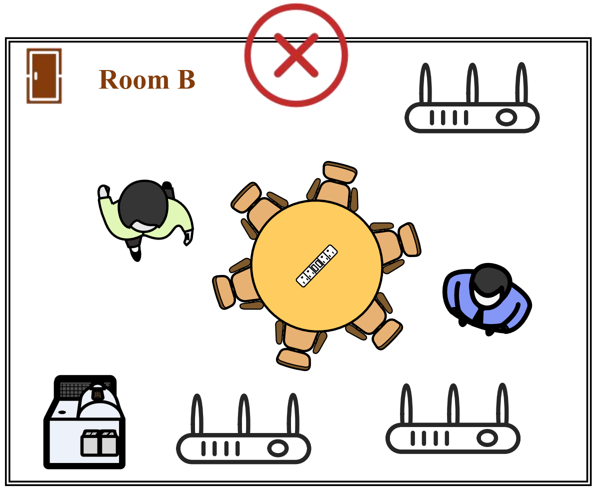
Fingerprint-based methods

- High accuracy but requires intensive data collection and recalibration.

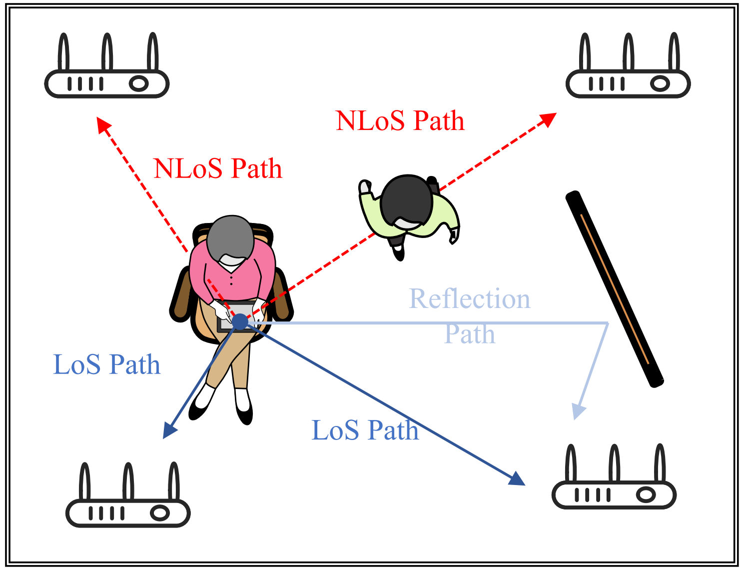
Angle-based methods

- Effective but sensitive to multipath effects and Non-Line-of-Sight (NLoS) condition.

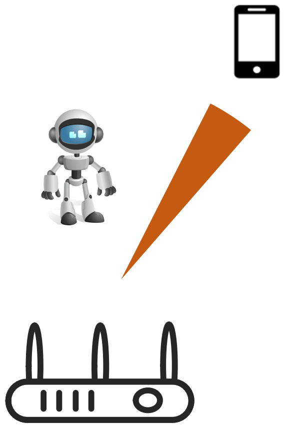




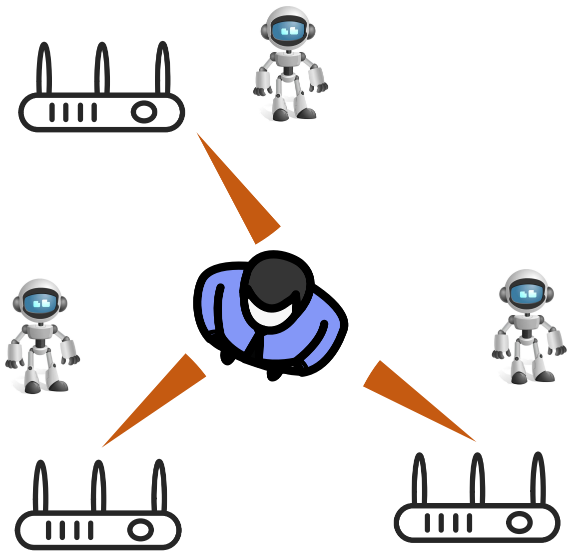
When collecting fingerprint…



How About Leveraging the Strengths of Both?

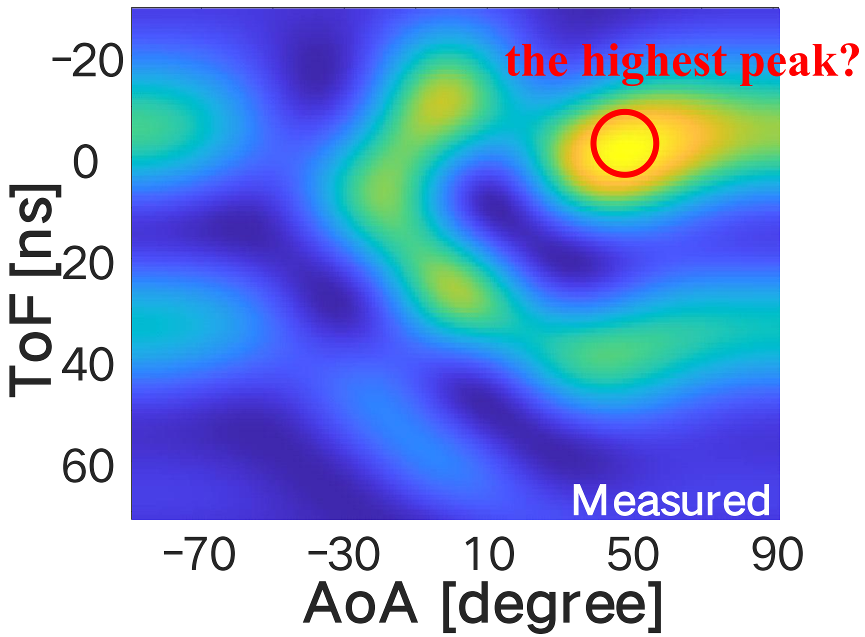


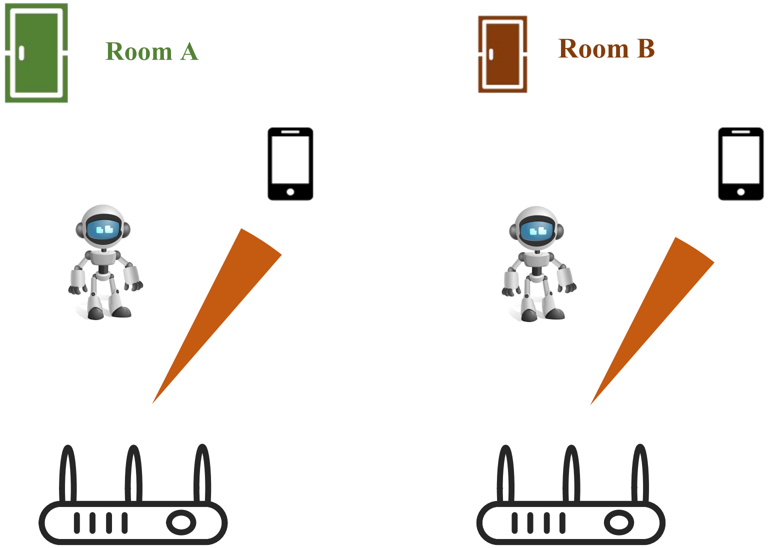
Model the relationship between Wi-Fi signal and Angle of Arrival (AoA) using a neural network.



Then, perform triangulation for localization.

Benefits with Both Approaches





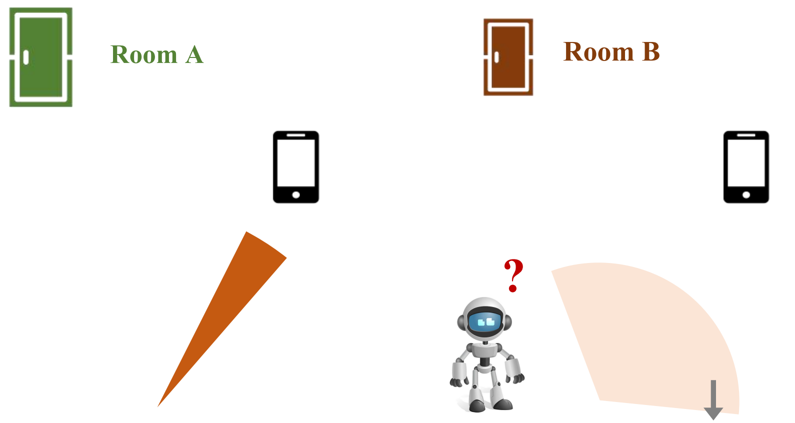
Train in **Room A**, apply in **Room B**

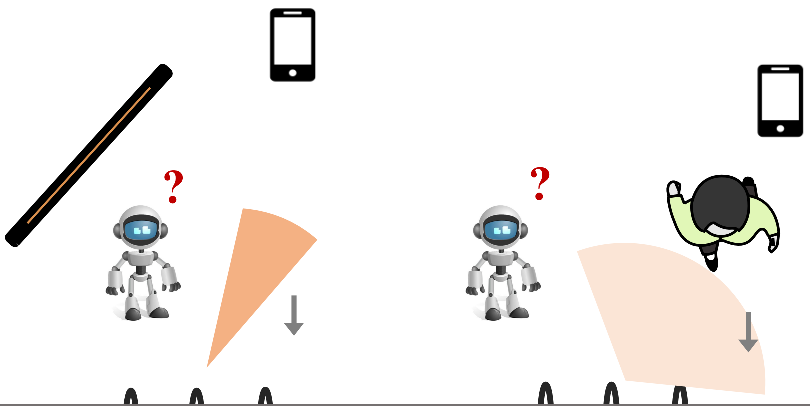
Opportunity Ⅰ: Use neural networks to extract more comprehensive information from 2D-FFT maps.

Opportunity Ⅱ: Leverage AoA's cross-domain potential to reduce the cost of fingerprinting in different environments.

Challenges with Both Approaches

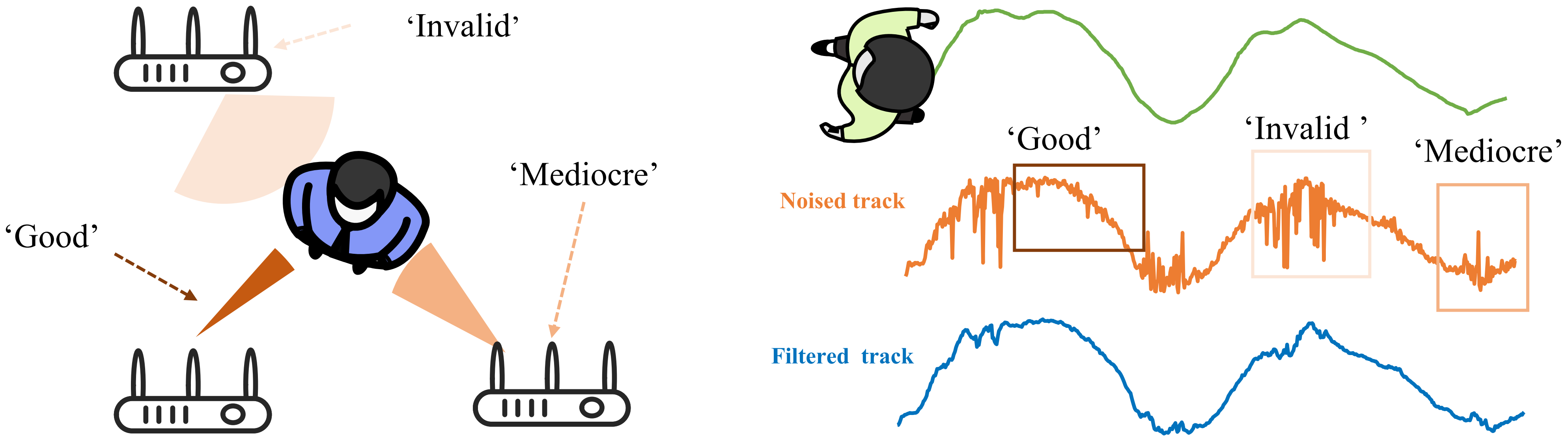
- Experiences from deployments have shown learning-based wireless localization methods to be sensitive to environmental changes.
- Complex and dynamic interferences, as well as NLoS conditions, can still lead to unreliable AoA estimations.





How can we maximize the benefits while overcoming the challenges?

RLoc: Quantify Uncertainty !



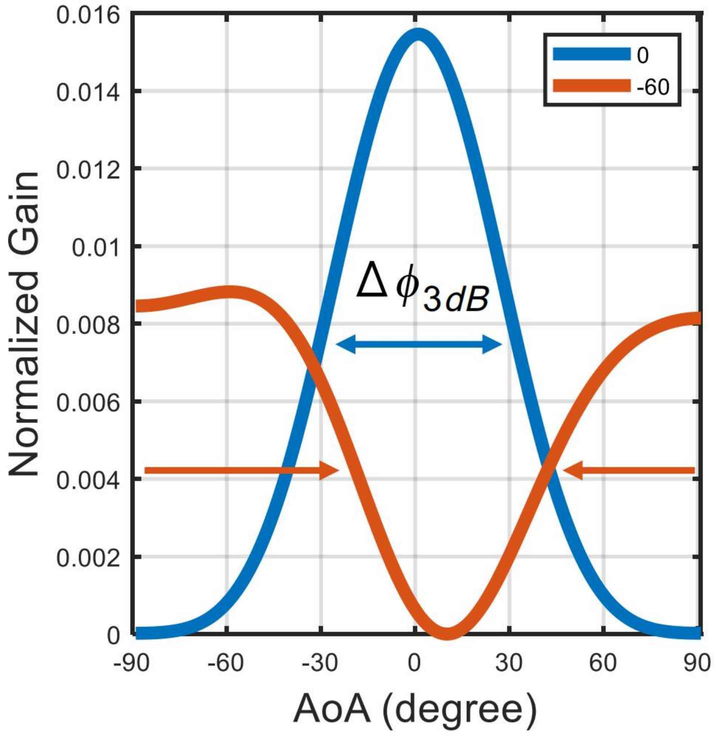
How can we achieve this?

1. Incorporating Wireless Localization Knowledge for Input Representation

Beamwidth ($\Delta\phi_{3dB}$) represents the angle between the half-power points of the main lobe.

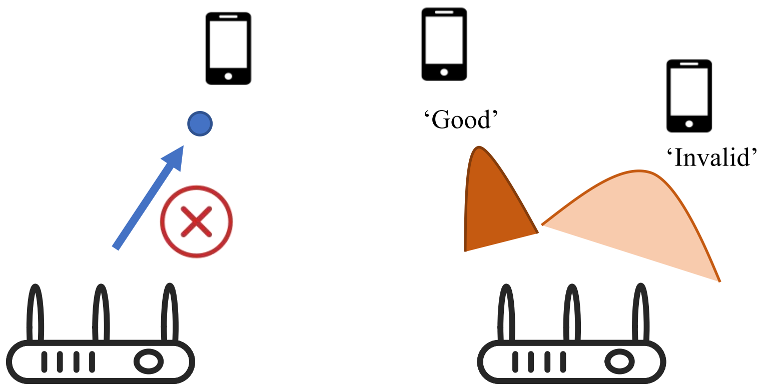
Table 1. Comparison of Pearson correlation coefficient [20] (PPC) between two variables. The PPC ranges between −1 and 1, with a value closer to 1 indicating a stronger positive linear correlation.

PPC	S1	S2	S3	S4	S5	S6
$\theta_{max} - \theta_{label}$	0.70	0.47	0.55	0.62	0.27	0.59
$\theta_{beam} - \theta_{label}$	**0.71**	**0.49**	**0.58**	**0.64**	**0.30**	**0.61**
$\theta_{max} - \theta_{error}$	−0.06	−0.37	0.04	0.05	0.23	0.25
$\Delta\phi_{3dB} - \theta_{error}$	**0.41**	**0.40**	**0.29**	**0.26**	**0.35**	**0.28**



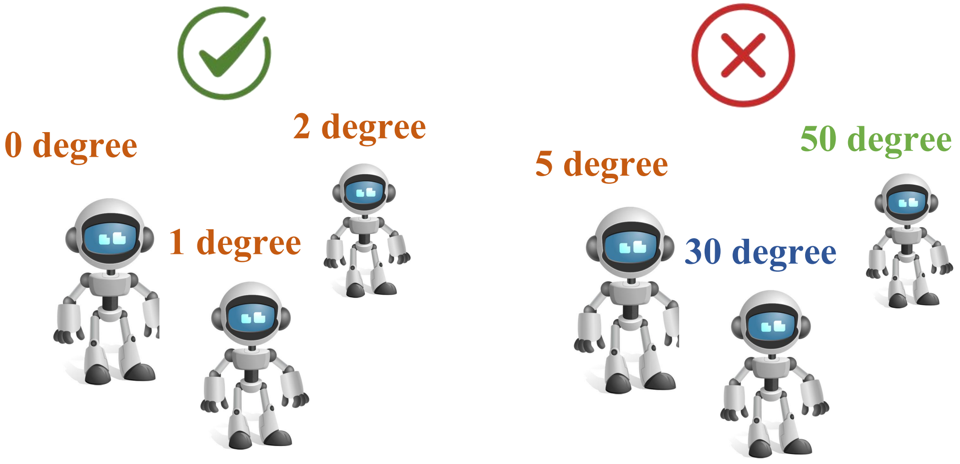
2. Incorporating Uncertainty in Neural Network

2.1 Utilize the Kullback-Leibler (KL) divergence loss function to predict the distribution.



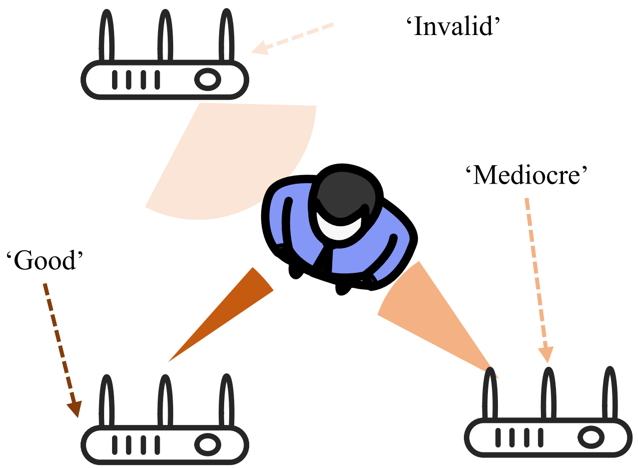
$$L_{KL} = D_{KL}(\mathcal{N}(\mu, \sigma)||\delta_f(y)) \propto \frac{\log(\sigma^2)}{2} + \frac{(y-\mu)^2}{2\sigma^2}$$

2.2 Use the technique of deep ensemble to capture the uncertainty.



$$\hat{\sigma} = \sqrt{\sum_{z=1}^{Z} (\hat{\theta} - \mu_z)^2/Z} + \sum_{z=1}^{Z} \sigma_z/Z$$

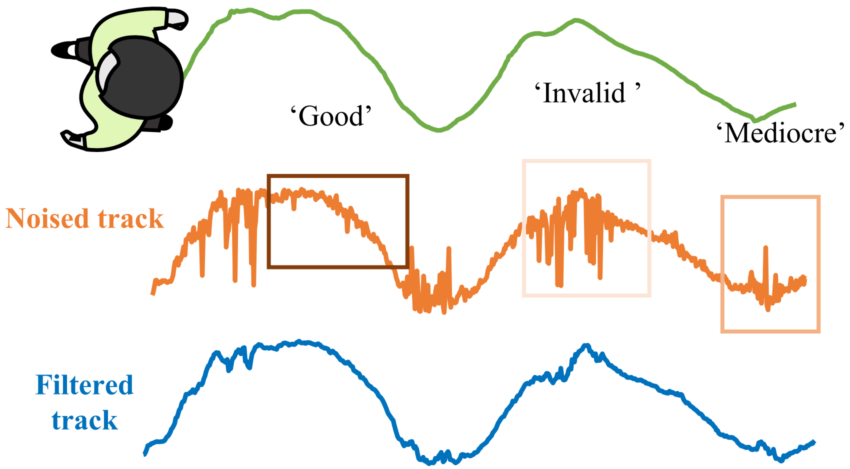
3. Uncertainty-assisted Localization and Tracking



$$L(\chi) = \prod_{i=1}^{I} \frac{1}{\hat{\sigma}_i\sqrt{2\pi}} e^{-\frac{(\theta_i - \hat{\theta}_i)^2}{2\hat{\sigma}_i^2}},$$

$$\chi^* = argmaxL(\chi).$$

Given AoA estimates with their uncertainties from multiple APs, we perform weighted averaging.



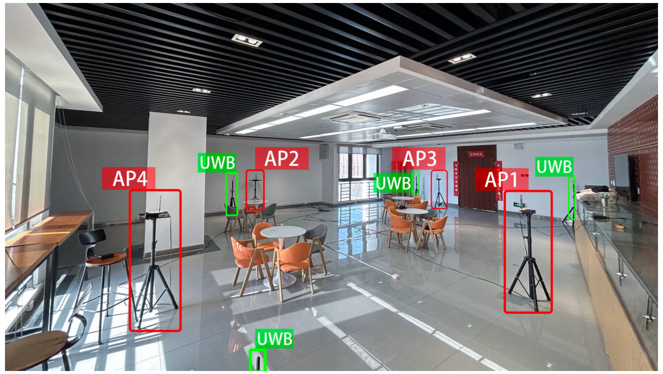
$$x_t = x_{t-1} + W_p$$

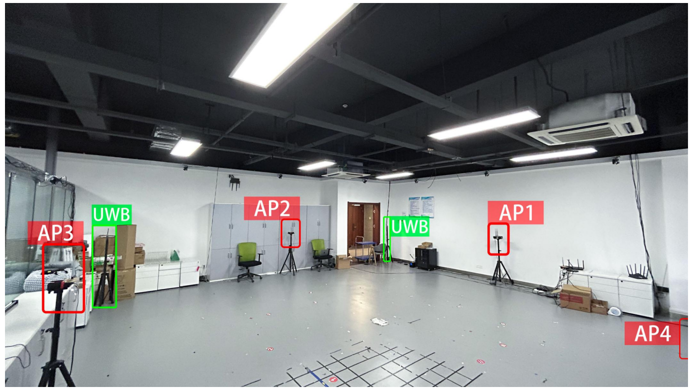
$$z_t = x_t + W_o$$

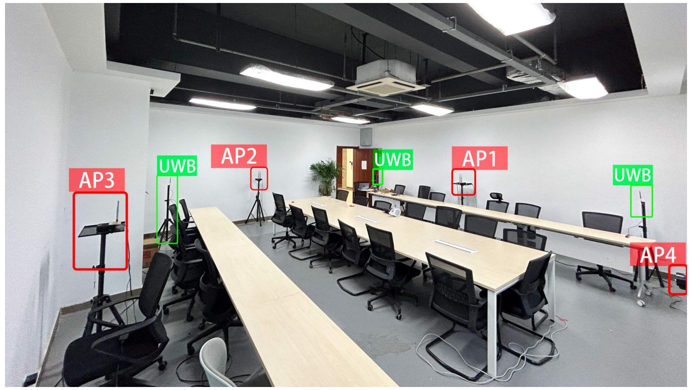
Using Kalman filtering to smooth AoA estimates by incorporating quantified uncertainty.

Human-held device Wi-Fi indoor localization dataset (H-WILD)

We construct a **human-held device** Wi-Fi indoor localization dataset (H-WILD), consisting of approximately 120k data points collected from ten volunteers across four classic indoor scenarios.







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Train in scenario A, Test in scenario B/C/..

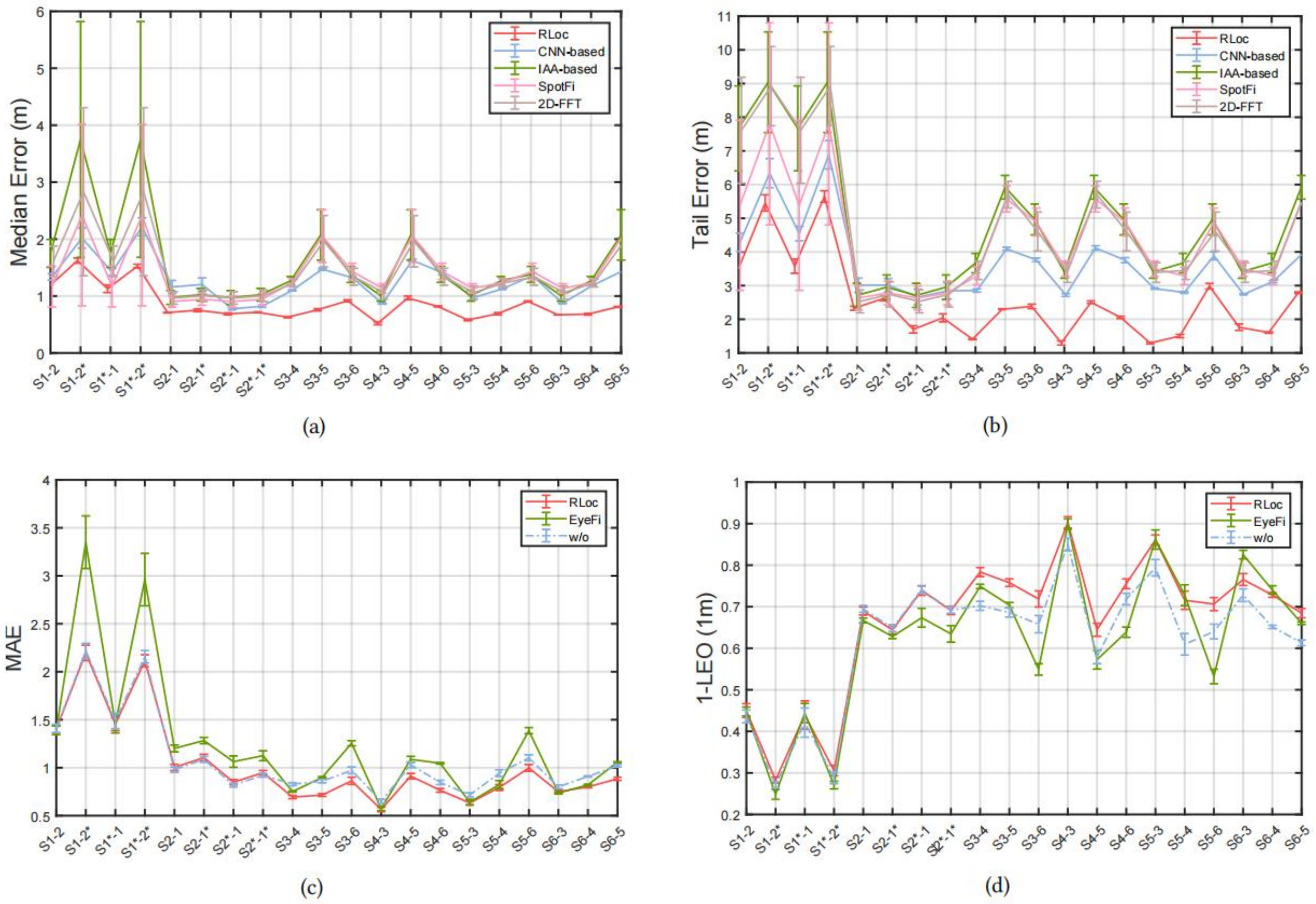

Fig. 14. Cross-scenario evaluation of localization and tracking results. "SA-B" denotes training on Scenario A and testing on Scenario B.

(a) Comparison of median errors in localization.
(b) Comparison of tail errors in localization.
(c) Comparison of MAE in tracking.
(d) Comparison of LEO in tracking.

Evaluation of quantified uncertainty in cross-scenario.

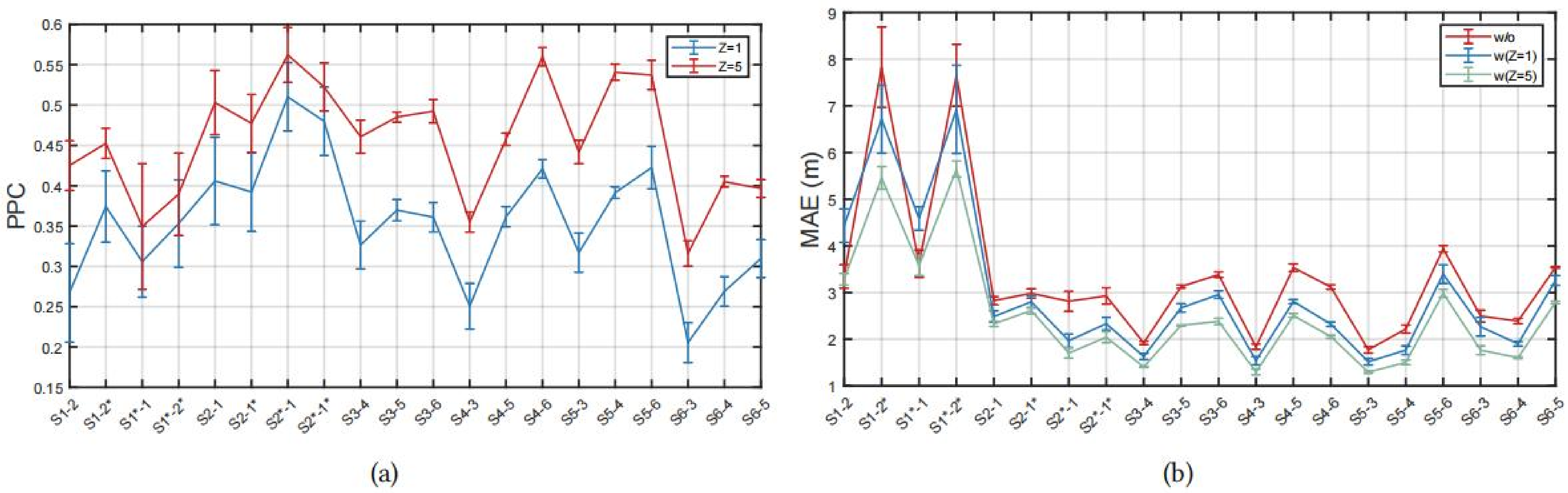

Fig. 15. Evaluation of quantified uncertainty in cross-scenario. **(a)** Evaluation of PPC between AoA error and quantization uncertainty in different scenarios. **(b)** Comparative analysis of the localization system's performance with and without the incorporation of uncertainty.

CONCLUSION

- Exploiting underutilized spatial spectrum information.
- Exploring uncertainty in angle estimation tasks using deep learning.
- Utilizing uncertainty feedback to enhance localization and tracking.
- The first human-held device Wi-Fi localization and tracking dataset.

Thanks！

Q&A

- Tianyu Zhang
- Email: tianyuzhang@ustc.edu.cn
- Homepage: https://ray-ui.github.io/

IP Lab Homepage

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H-WILD Dataset

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