MLoc: Practical Indoor Localization for Malls

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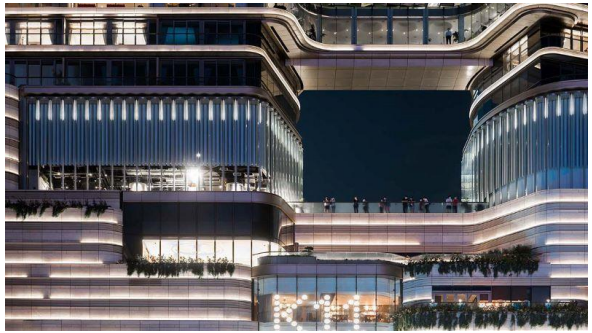
Background

Large shopping centers have complex internal layouts.

- Indoor localization is important

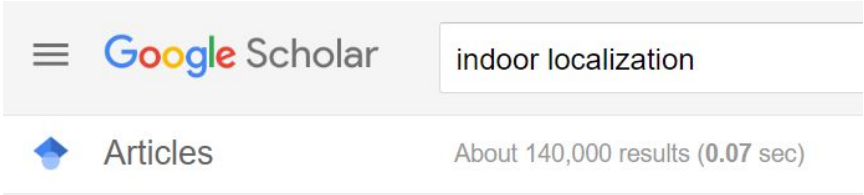


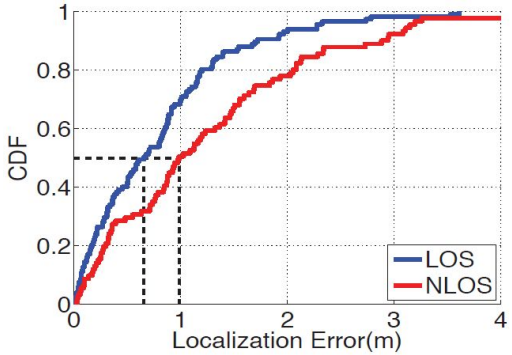
Background

State-of-the-art solutions can reach submeter-level accuracy.

- E.g., Chronos (NSDI'16), MonoLoco (MobiSys'18)

The large-scale deployment is far lagging behind.





Challenge

Many solutions are impractical in shopping malls.

- Do not work on off-the-shelf smartphones.
- WiFi scanning frequency is limited on smartphones.
- Require excessive infrastructure deployment.
- Aesthetic considerations of shopping malls.

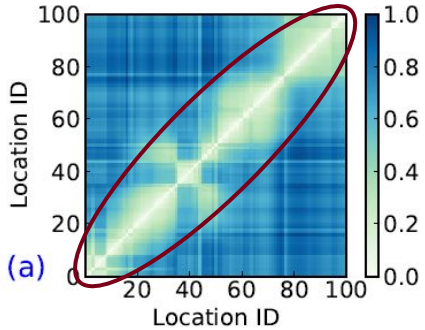
Overview

MLoc: Fingerprinting-based Indoor Localization

- BLE signals & Geomagnetic fields (GMF).
- Deployed in 35 Malls across 7 cities in China.
- More than 1 million monthly active users.

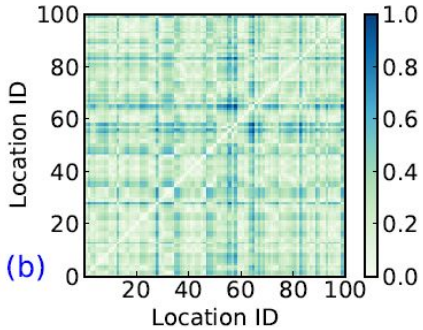
Fingerprints

BLE and GMF fingerprints are complementary.



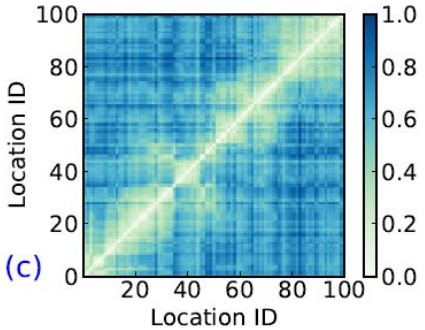
BLE fingerprint:

- Low resolution
- Slow to collect



GMF fingerprint:

- High resolution
- But noisy



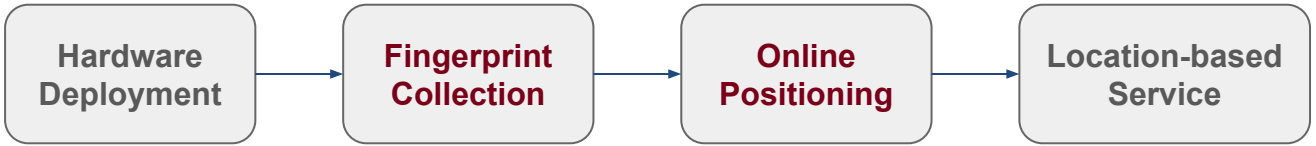
Combine BLE & GMF

Outline

- System Design
- Evaluation
- User Behaviors

MLoc System

Basic components



MLoc System -- Hardware

Small-size and low-cost hardware

- Battery-powered BLE beacon
- Density: 5-15m

No additional power or networking cables.

Bluetooth scanning

MLoc System -- Fingerprint Collection

Large-scale Fingerprint Collection (1,100 km walking distance)

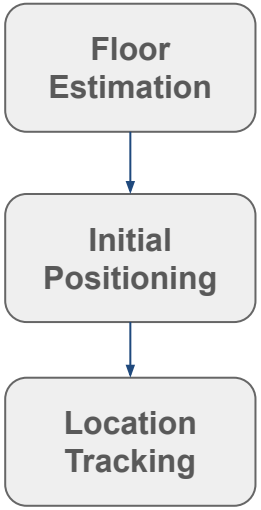
- Challenge 1: A lack of groundtruth location.
- Challenge 2: Inefficient walking path of surveyors.

Solutions

- Use landmarks to locate themselves.
- Generate suggested paths for the surveyors.

MLoc System -- Online Positioning

- Floor estimation: BLE
  - Floor change detection: IMU
- Initial positioning: BLE
- Location tracking: BLE & GMF & IMU



MLoc System -- Online Positioning

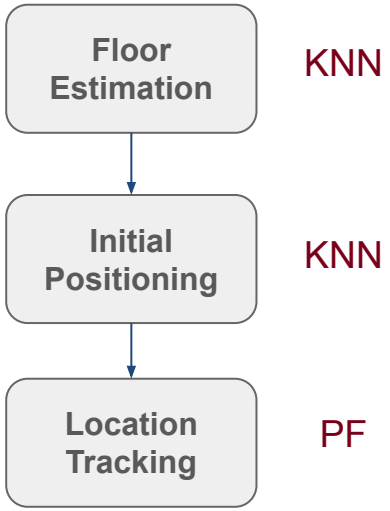
Traditional algorithms

- KNN & Particle Filtering (PF)

Problem: Coarse positioning

Solution:

- Fine tuning on a per-site/floor basis.
- Normalized fingerprints for device heterogeneity.



MLoc System -- Corner Cases

Large floor error in corner cases

- Atrium areas.

Atrium area

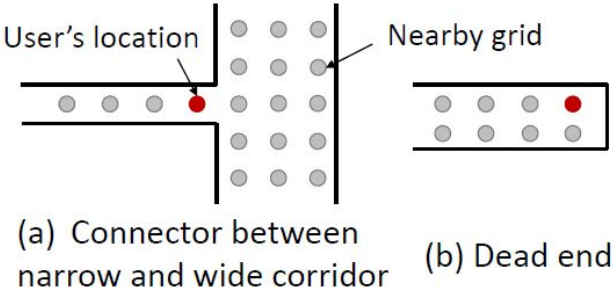
Solution

- Lightweight DNN-based floor detection method.

MLoc System -- Corner Cases

Large positioning error:

- Connector area and dead ends.



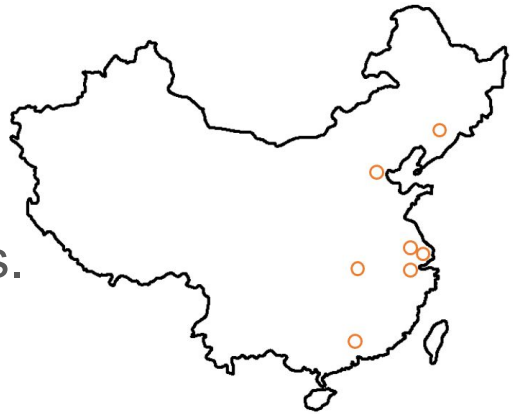
Solution

- Adjust fingerprints' weights based on layout.

MLoc System -- Deployment

Large-scale deployment since 2018

- In most cases, MLoc is provided as an SDK.
- Deployed in shopping malls and their garages.
- 35+ malls across 7 cities.
- More than 1 million active users.



Outline

- System Design
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- User Behaviors

Evaluation

Large-scale Evaluation

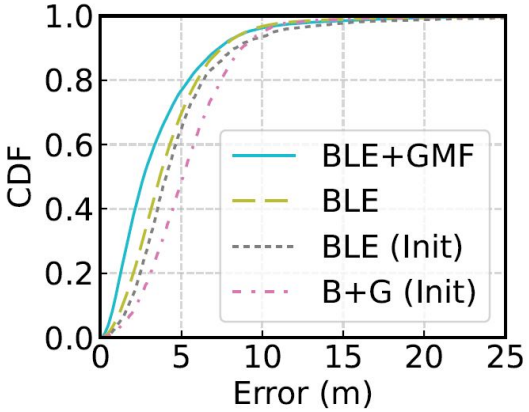
- Based on the data collected by surveyors.
- > 200km of test paths in 35 malls.
- Containing the ground truth of the target location.

Evaluation

Localization and tracking accuracy

- An initial localization accuracy of 4.1m with per-site tuning.
- MLoc achieves a tracking accuracy of 2.4m.

- With fine tuning, lightweight algorithms can achieve satisfactory localization accuracy.

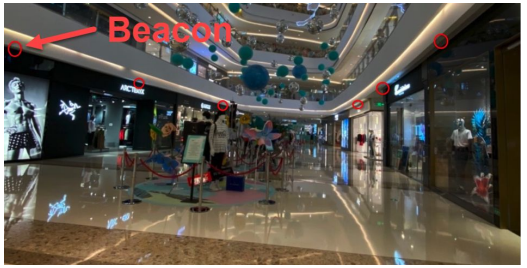


Evaluation

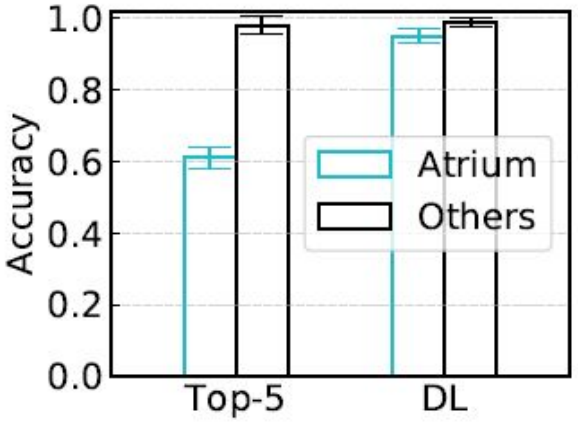
Floor error in atrium areas

- KNN has a large error (~40%).
- Lightweight DNN yields 96% accuracy.

- A lightweight DNN model can yield good accuracy in challenging atrium areas.



Atrium area

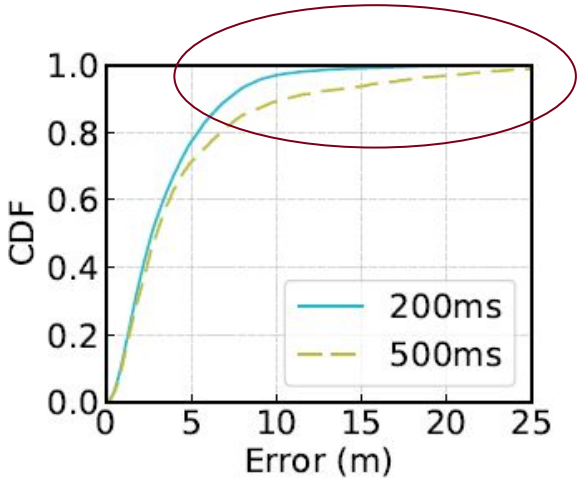


KNN, K=5 Deep Learning

Evaluation

Beacon Broadcast Interval (BBI)

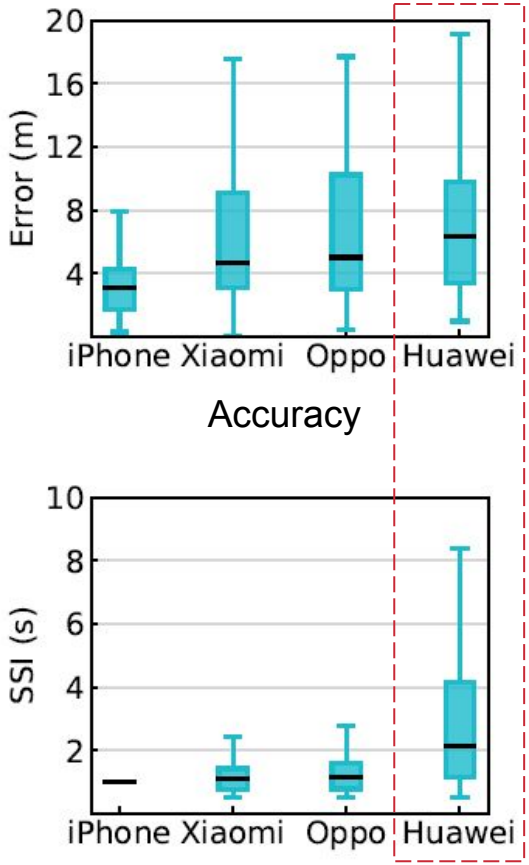
- Increasing BBI brings small improvements in most cases.
- Significantly improves the accuracy for the long tail.
- Benefit the devices with long BLE scanning intervals.



Evaluation

Smartphone Brands/Models

- Different smartphones exhibit considerable differences in localization accuracy.
- Some vendors throttle the BLE scanning frequency to save energy.

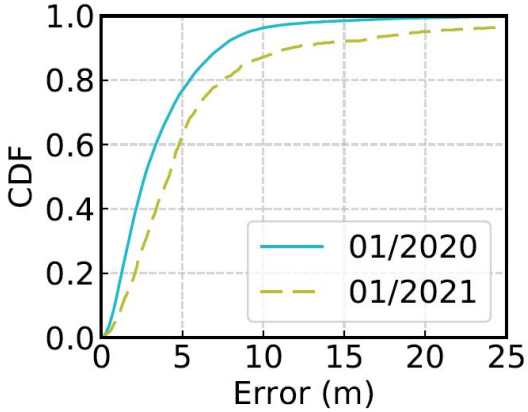


Successful Scanning Interval (SSI)

Evaluation

After one-year usage:

- Localization error remains at an acceptable level (4.6m).
- Without replacing failed beacons or updating training data.



Outline

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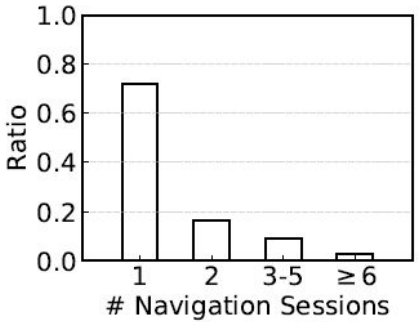
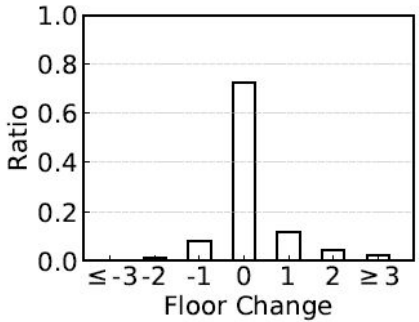
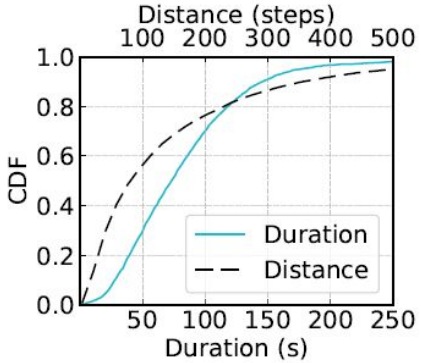
User Behaviors

- 28% customers use MLoc more than once within a day.
- 73% navigation sessions have no floor change.
- Users prefer locating themselves and finding the right directions to tracking them.



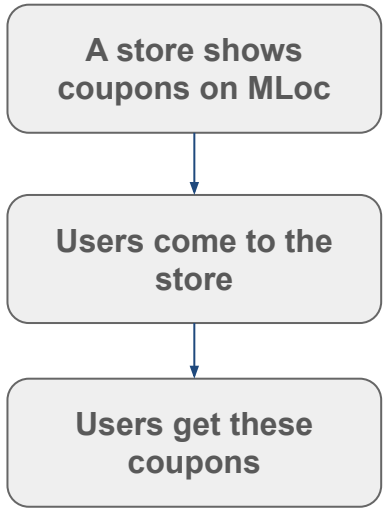




User Behaviors

Location-based service

- Marketing Platform.
- Coupon-finding activity.



Summary

- Robust online algorithms for indoor localization in complex malls.
- Deployment in 7 cities in China, and more than 1 million customers.
- Our experience in developing and deploying MLoc.

Data Release

Our 40GB data is available at: https://mloc.umn.edu

- BLE, GMF, & IMU data
- Floor Map
- Groundtruth Location

To our knowledge the largest indoor localization dataset with groundtruth.

Discussion

Outsourcing v.s. Crowdsourcing.

Discussion

Accurate localization services are not always preferred.

- Underground garage: high accuracy.
- Shopping malls: medium accuracy.

Adjust localization accuracy in different areas/time.

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