Walkie-Markie

Walkie-Markie:
Indoor Pathway Mapping Made Easy

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The context of this work …

- Location, location, location, …
- Primarily focused on location inference algorithms
- Largely neglected the fundamental "enabler" – Maps!
  - "… assume the radio map is established offline in advance …"
- Such assumptions are not easy to fulfill, in practice.

Internal pathway map is of practical interest

- Maps = { floor plan, radio map, … }
- Localizing users w.r.t pathways is of practical importance
  - Users move along pathways
  - Indoor locations (POIs) are connected via pathways

Problem & high-level approach

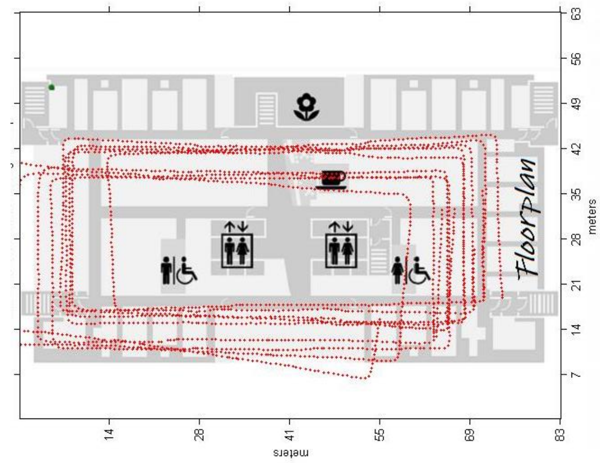
- How to build internal pathway maps for millions of buildings?
  - Professional onsite survey? – *Expensive and not scalable*
  - Request floor plans? – *Impractical*
    - Different owners, often proprietary, legacy buildings, frequent redecoration, etc.
    - Still missing *hooks* for localization

- Pathway mapping via user tracking and crowdsourcing!
  - User trajectory consists of portions of pathways
  - Possible to infer pathway maps from enough user trajectories
  - Dead Reckoning is possible with phone IMU-sensors

Goal and challenges

- Build a crowdsourcing system that can construct indoor pathway maps by ordinary pedestrians w/ mobile phones.

- Challenges:
  - Noisy IMU-based tracking results, and significant drift over time
  - Difficult to fuse data from different users
    - Start/stop anywhere, cover only a subset
  - Must handle user diversity and device diversity
  - Automatic, no special user attention, no change to user behavior



Core concept: phone perceivable landmark

- Motivating observation: landmarks
  - Real life UX – people give directions w.r.t landmarks
    - Landmark: easily discoverable, stable, and at known location
  - Landmark can *stop error propagation* and *merge different paths*

- *Phone perceivable pathway mark*
  - A *stable* location on the pathway that can be *automatically discovered* and *unambiguously identified* by mobile phones with its on-device *sensors*
    - Visual landmarks: good for human, but not easily discoverable by devices!

Leverage WiFi Infrastructure for landmarks

- Wide deployment of WiFi infrastructure
  - Using AP? – *Coverage overly large, unknown position*
  - Using WiFi fingerprints?
    - Good association between WiFi fingerprints and locations
    - Basis for state-of-the-art WiFi-based localization methods

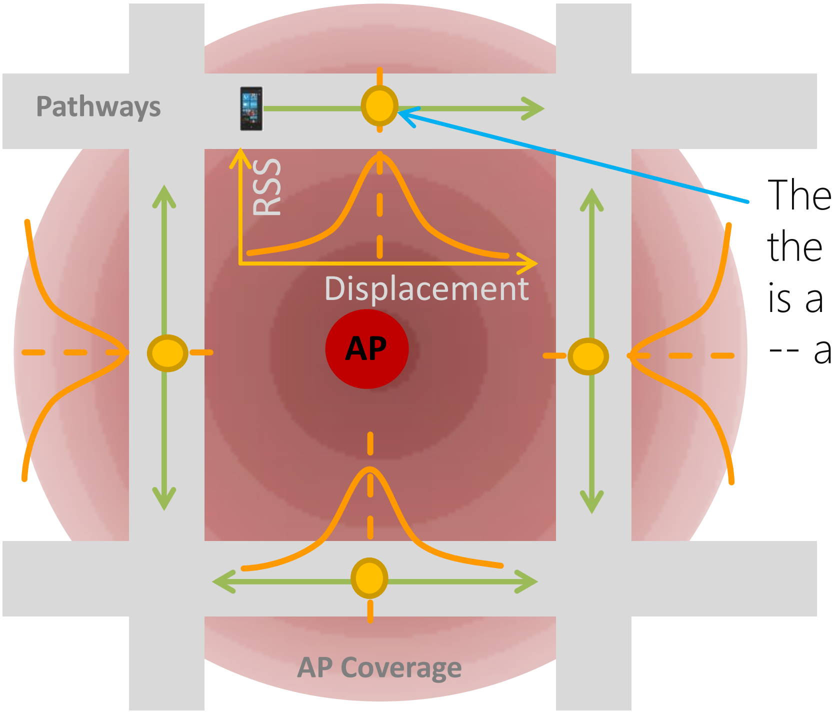
- Challenges:
  - Difficult to model WiFi signal accurately
    - WiFi signal fluctuates over time, affected by multipath effects
  - Difficult to deal with device diversity
    - Different readings for the same WiFi signal on different devices

WiFi-defined landmark (WiFi-Mark)

- Key idea: don't look for AP, look for its '*shadow*' on pathways

The mobile phone constantly measures received WiFi signal strength (RSS) while walking along a pathway

RSS increases or decreases when approaching or leaving an Access Point (AP).
-- law of radio propagation

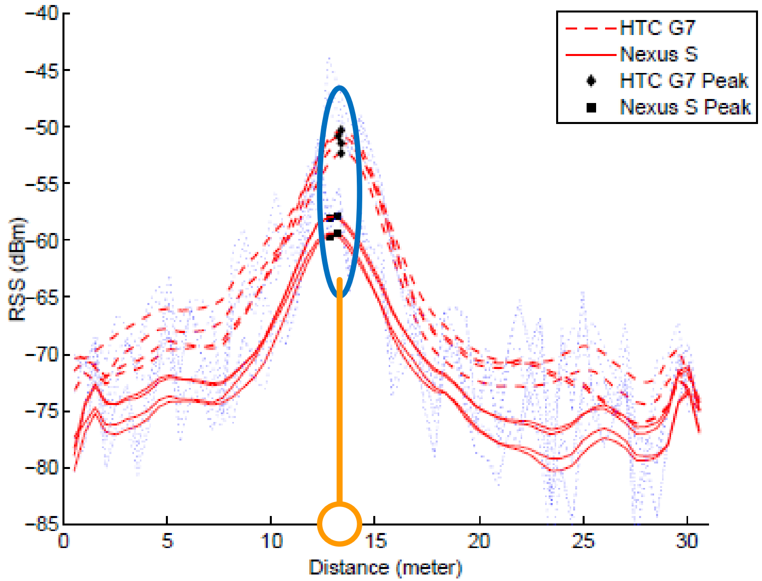


The location corresponding to the tipping point of RSS trend is a WiFi-defined landmark.
-- a novel way to leverage WiFi

Many such landmark opportunities exist.

Feasibility of WiFi-Mark

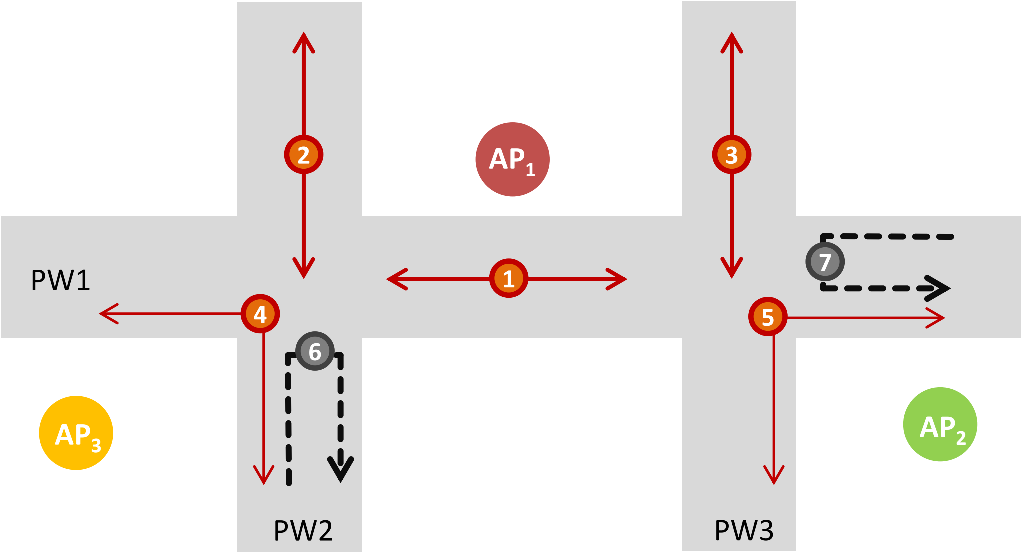
- Measurement study
  - Straight corridor 35m in length, two devices, very slow motion
  - Different time of day (morning, afternoon, evening, midnight)
  - Filtering with triangle window



- ➢ Invariant location, over ToD → stable and consistent
- ➢ Obvious trend → easily discoverable by device
- ➢ Using trend, not value → insensitive to device type, device attitude

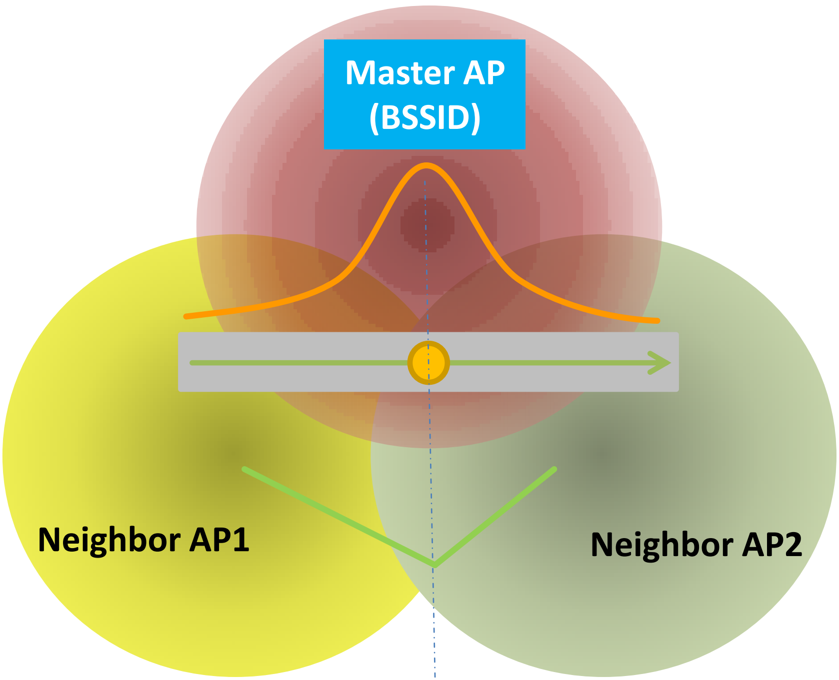
How to uniquely identify each WiFi-Mark?

- Large number of potential WiFi-Marks: O(#AP x #Pathways)
- Using AP identification (BSSID) is not enough
  - One AP can lead to multiple WiFi-Marks
  - Some good, some indistinguishable, and some false case



WiFi-Mark qualification and identification in effect

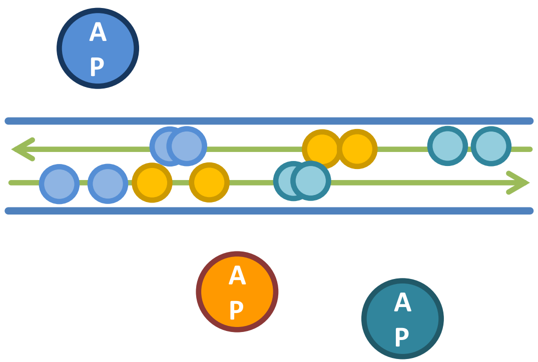
- Three-element tuple
  - BSSID of the master AP
  - Orientations, before and after the RSS tipping point
  - Neighborhood APs

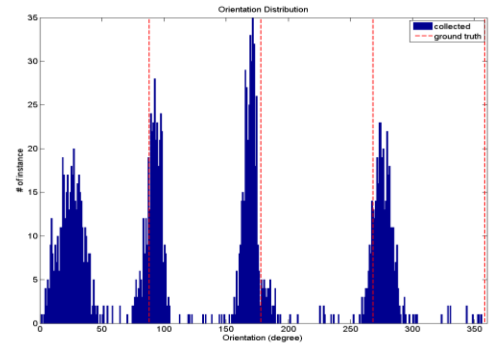


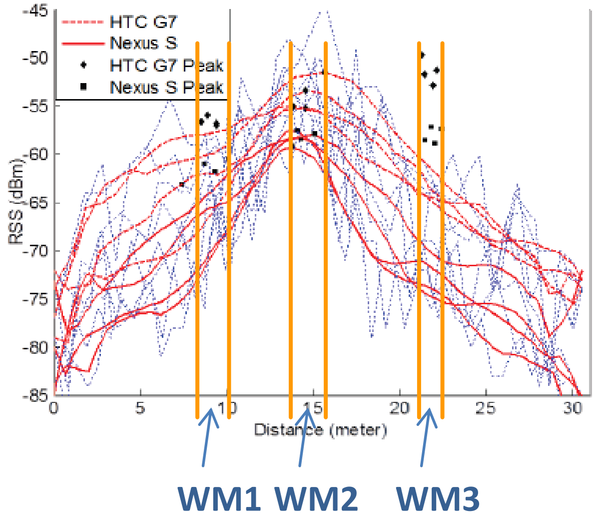
WiFi-Mark: [BSSID, Orientation<before, after>**, Neighboring APs**<(BSSID, ΔRSSI)>**]**

Possible WiFi-Mark variations

- Multiple possible observations for the same WiFi-Mark
  - Long scanning time & user motion
  - Magnetic sensor noise
  - Radio environment variation

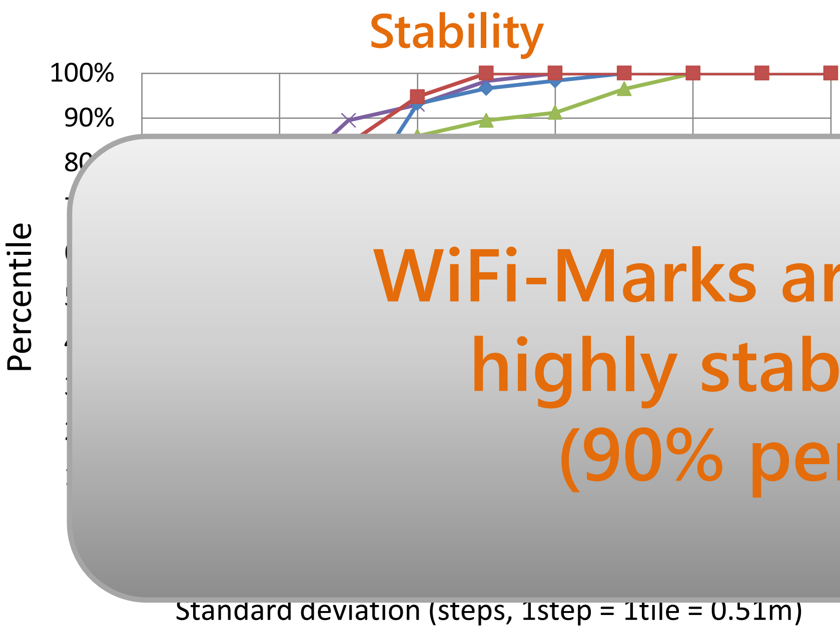


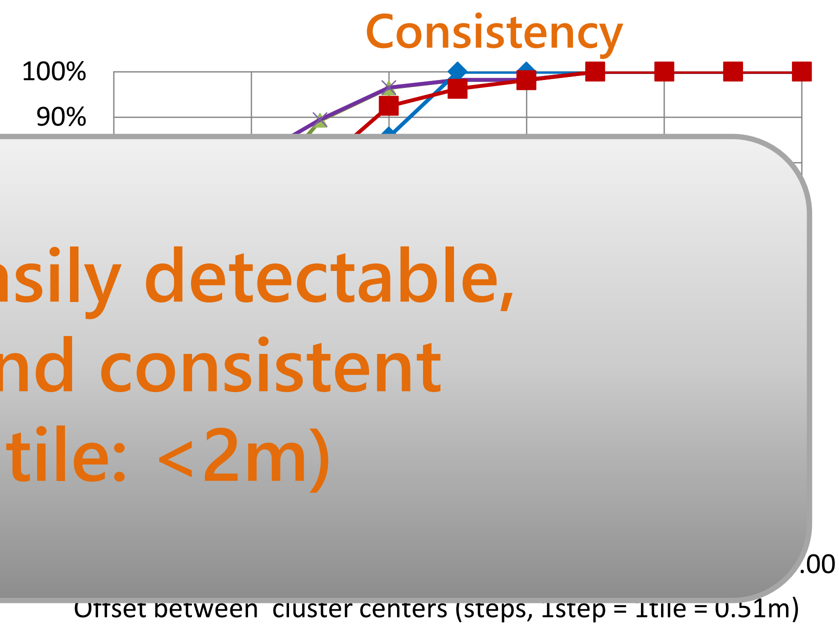




WiFi-Mark stability in practice

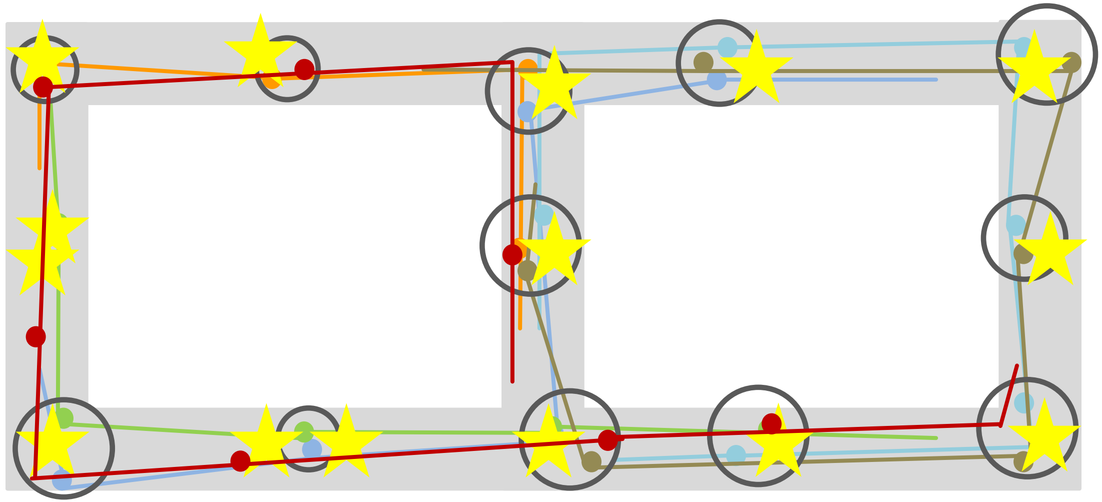
- Stability and consistency among different settings





WiFi-Marks are easily detectable, highly stable and consistent (90% percentile: <2m)

Building total pathway map from crowdsources



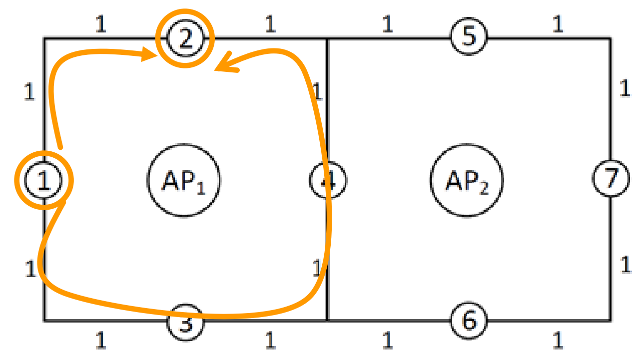
- Users record WMs and also the trajectory in between
  - With some sorts of IMU-based tracking method (e.g., step counting)
- System fuses pathways from different users together
- Where are these WMs' real locations?
  - Challenges: errors in WM positions and IMU measurements

Optimal coordinate assignment: Arturia algorithm

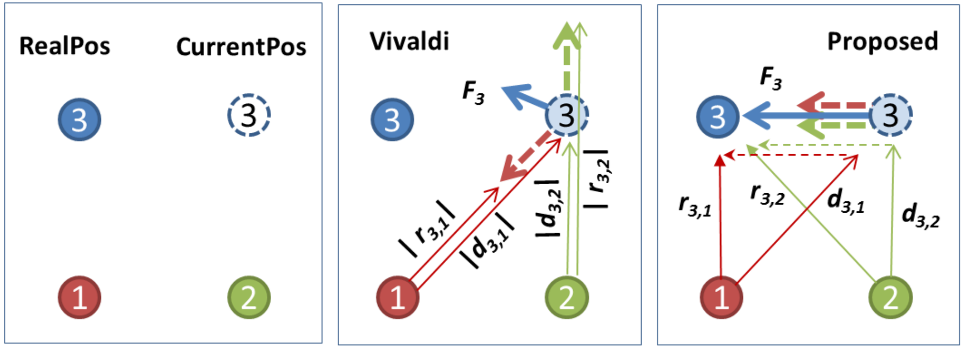
- A classical graph embedding problem
- Arturia uses additional info – walking direction
- Based on spring relaxation concept
  - Treat WiFi-Mark clusters as nodes
  - Treat edges (measurements) as springs
  - Minimize the overall potential energy via iterations, move nodes according to the net force of all neighboring nodes.

Arturia algorithm

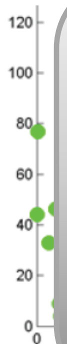
- Using displacement, makes it more localizable, as compared with using distance



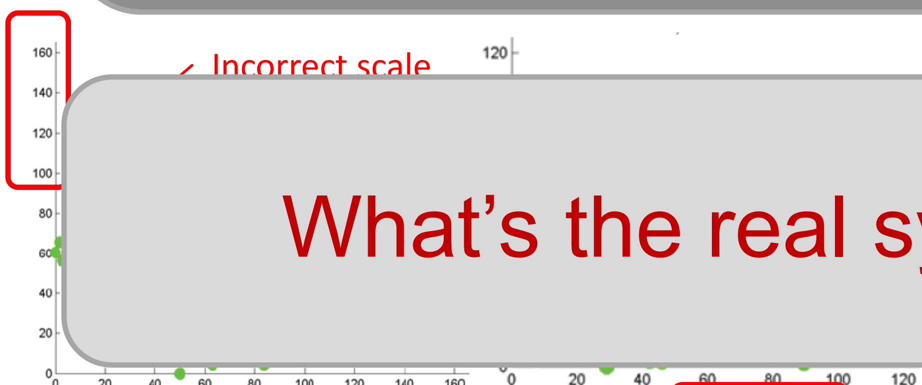
- Using displacement leads to more effective update in each iteration



Algorithm comparison: Arturia vs Villaldi vs AFL



WiFi-Marks are stable (90% percentile: <2m),
and can be efficiently located.



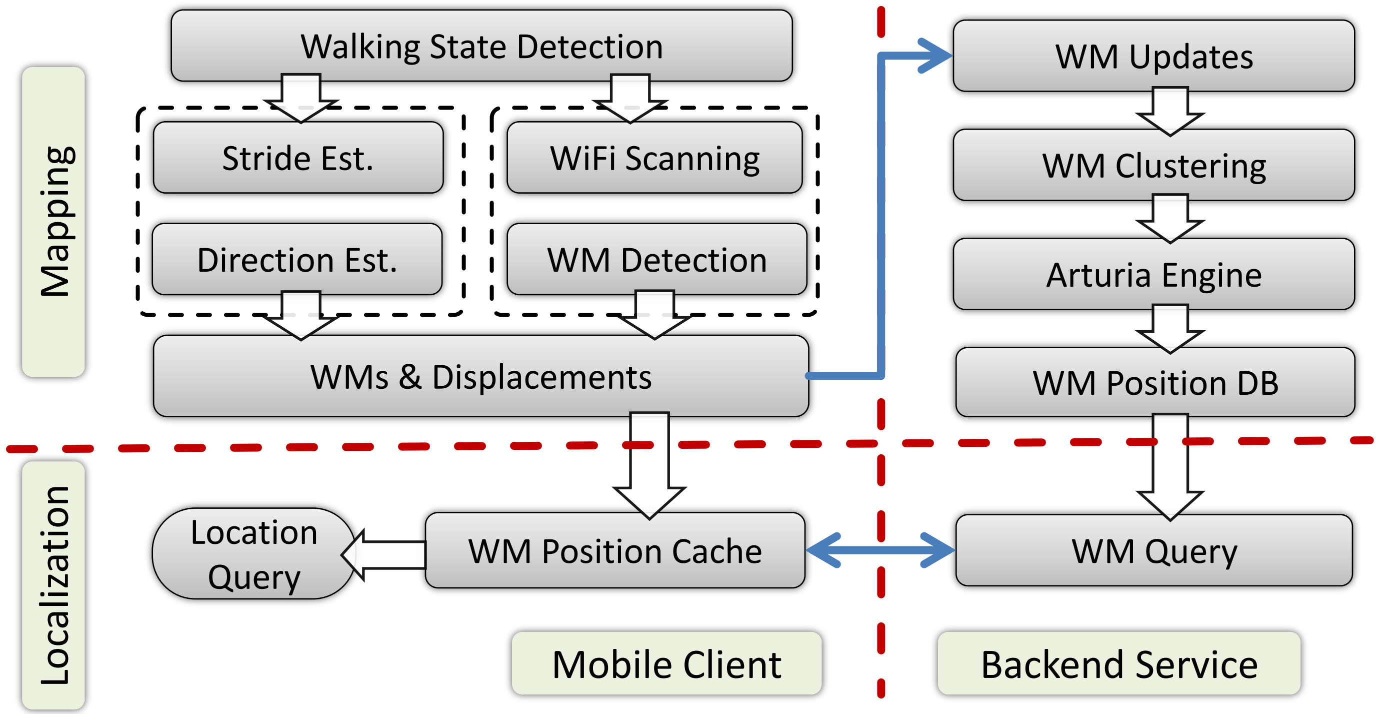
100	6	38967	27327	450	0.6604	0.106	0.0072

What’s the real system performance?

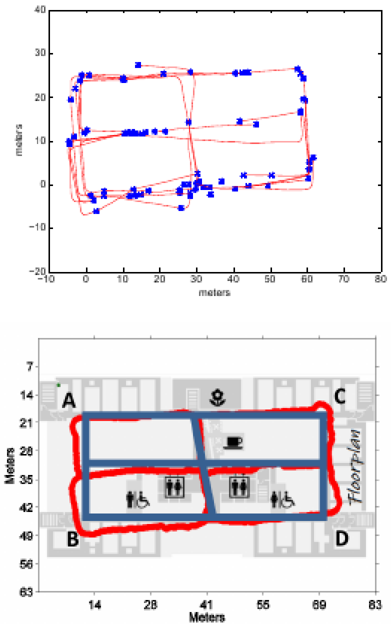
AFL, $K = 100$ Arturia, $K = 30$

Walkie-Markie system implementation

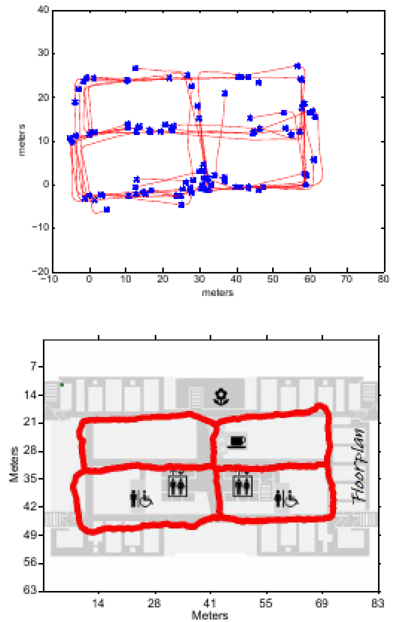
- Architecture: mobile clients + backend service



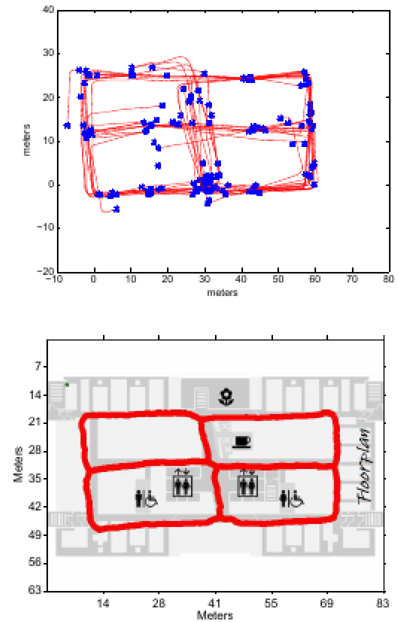
Visual results



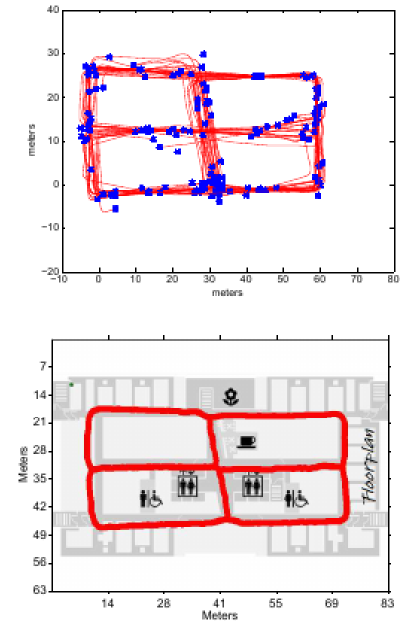
(a) after 20min walk.



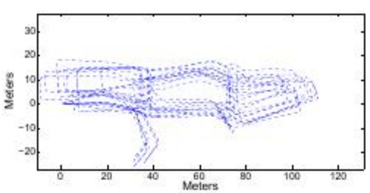
(b) after 30min walk.



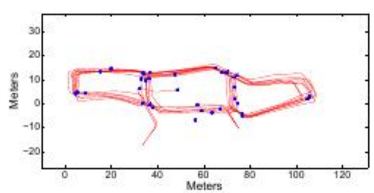
(c) after 50min walk.



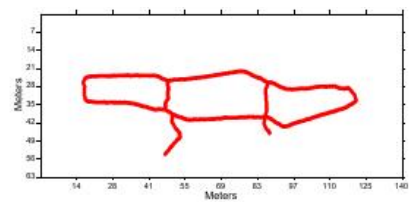
(d) after 100min walk.



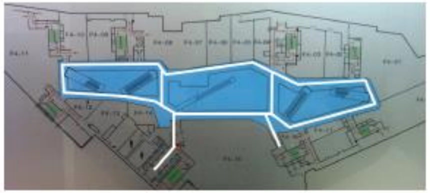
(a) normal IMU-tracking



(b) with WM alignment



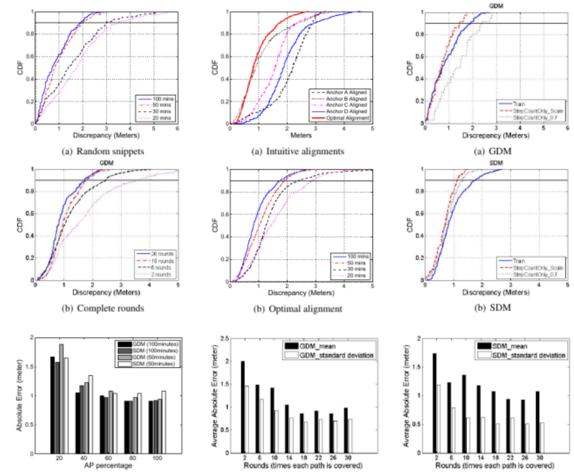
(c) Inferred pathway map



(d) Picture from flyer.

Some quantitative results

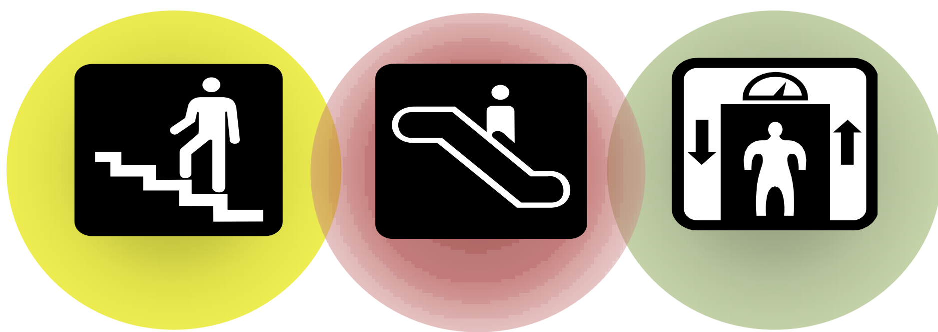
- Node (singular locations) discrepancy:
  - Max: 3m, 90%: 2m.
- Shape discrepancy:
  - Max: 2.8m, 90%: 1.8m.
- System agility:
  - Well converged at 5-6 visits per path segment
- When applied to localization:
  - 1.65m/2.9m for 50/90 percentile accuracy
  - Better than Radar (2.3m/5.2m)



Conclusion & Future work

Walkie-Markie == *user* Walkin', *device* Markin'

- Future work: other types of phone perceivable landmarks



We're hiring: interns and FTEs. ☺