Zee: Zero-Effort Crowdsourcing for Indoor Localization

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Overview

- Method for indoor localization using crowd sourced data acquisition
- Uses sensors on average smartphone to collect data
- Helps locate a user in an indoor location
- “Zero effort” solution

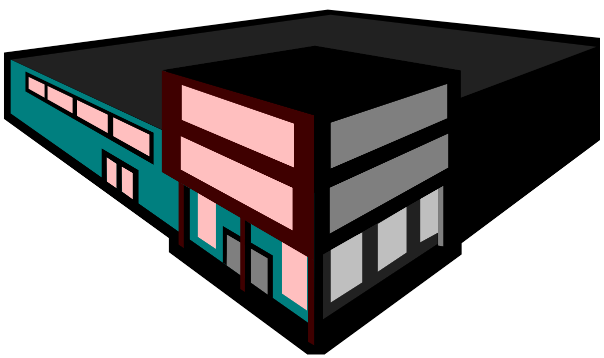


Image from Clipart

Obstacles

- GPS not available indoors for localization
- Current RF fingerprinting requires training data
- Training data is time consuming to obtain and requires specific effort
- Training data needs to be updated when changes occur in the environment

What Zee Offers

- Zero effort indoor localization
- Crowd sourced localization that adapts as more data is inputted
- No effort required from those involved in crowd sourcing
- No extra infrastructure necessary
- Similar accuracy to other methods (ex. Horus and EZ)
- Small requirements
    - Map of indoor location outlining walls and other impassable area
    - Zee software installed and running on users' phones

Components

- Augmented Particle Filter (APF)
  - Discriminates between valid and invalid location points
- Backward Belief Propagation
  - Further refines location data after path has been determined
- Placement-Independent Motion Estimation
  - Uses common sensor data to estimate step count and approximate orientation which is filtered by the APF

Background & Related Work

- Infrastructure-Based Localization
- RF Fingerprinting based Localization
- Modeling instead of Calibration
- Alternatives to RSS-based Localization
- Inertial Sensing

Background & Related Work

- Robotic Navigation
  - Simultaneous Localization and Mapping (SLAM) problem provides ideas on finding a robot's position relative to landmarks (localization) and landmark's positions relative to other landmarks (mapping).
  - Markov localization models the robot's position as a multi-modal and non-Gaussian probability density function
  - Monte Carlo Localization (MCL) uses particle filtering to describe robot's location as weighted random samples

Background & Related Work

- Particle Filtering
  - Approximates a probability distribution by a collection of weighted particles.
  - Particles are updated and reweighted every step to reflect the probability of a certain position.
  - Particles are later resampled to avoid low weighted samples being of no use.
  - Particles with large weight represent coordinates that would most likely describe a certain position.

Zee: Putting it all together

- Robotic Navigation
  - Uses probabilistic location representation paired with augmented particle filter
- Inertial Sensing
  - Uses placement independent sensing
- RF Fingerprinting
  - Uses existing techniques in conjunction with crowd sourced calibration

Zee Example Scenario

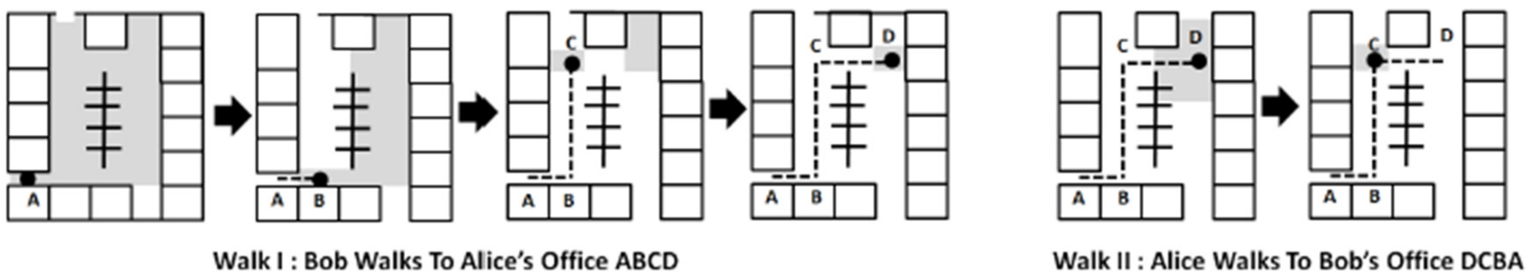


Figure 1: Example Scenario

Zee Architecture

- Placement Independent Motion Estimator (PIME)
  - Accelerometer, Gyroscope and Compass are used for three key functions
    - 1. Determining whether the user is walking or not
    - 2. Recognizing when a step is taken
    - 3. Providing a rough estimate of direction in which the step was taken
  - Independent of device placement

Zee Architecture

- Augmented Particle Filter
  - Tracks the probability distribution of a user's location as he/she walks
  - Estimates stride length and direction of walking
  - Maintains a 4 dimensional joint probability function comprising 2D location, stride length, and heading offset

Zee Architecture

- Wi-Fi Localization
  - Creates a database of time-indexed location data paired with its RSS data
  - Corrects data by using belief back propagation to determine a more precise location for previously ambiguous positions
  - Wi-Fi RSS data from previous path can be fed into the APF to create a more localized starting point
  - Each subsequent trip further refines the database of Wi-Fi localization data.

Zee Architecture

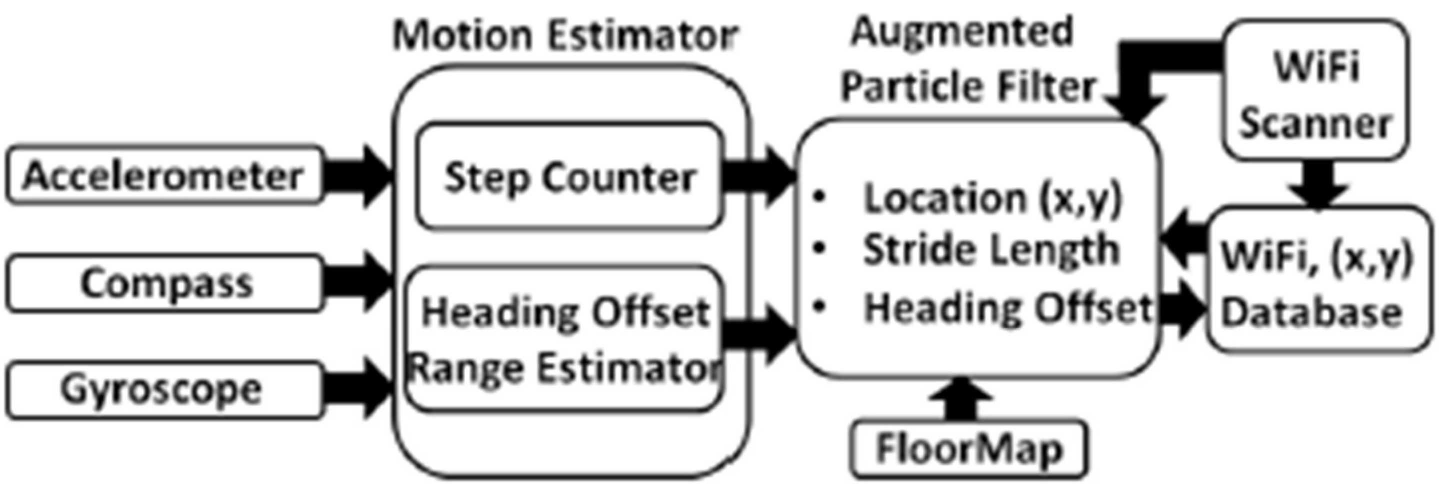


Figure 2: Zee Architecture

Zee Mechanics

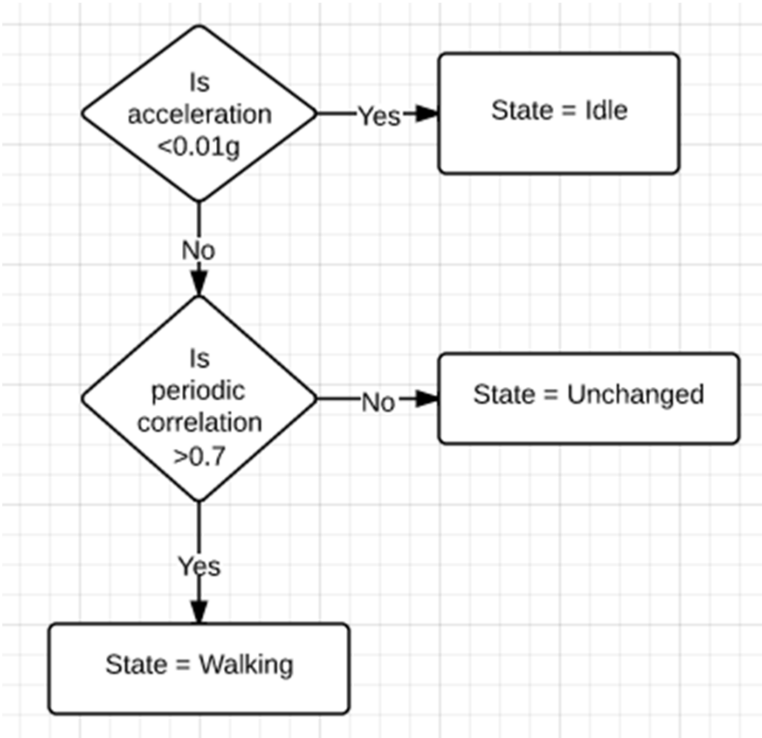
- Counting Steps
  - Acceleration <0.01g is considered being idle
  - Relies upon the periodic nature of walking
  - Using a normalized correlation function Zee determines if user is walking
  - Estimates the period of each step cycle (left, then right)

$$\chi(m,\tau) = \frac{\sum_{k=0}^{k=\tau-1}\left[\begin{array}{c}(a(m+k)-\mu(m,\tau))\\(a(m+k+\tau)-\mu(m+\tau,\tau))\end{array}\right]}{\tau\sigma(m,\tau)\sigma(m+\tau,\tau)}$$

$$\psi(m) = max_{\tau=\tau_{min}}^{\tau=\tau_{max}}\left(\chi(m,\tau)\right).$$

Zee Mechanics

- Counting Steps (cont.)



Zee Mechanics

- Estimating Heading Offset
  - Recorded heading and actual heading differ due to two main factors: magnetic offset and placement offset
  - Magnetic offset (γ)
    - Caused by presence of magnetic materials that might distort the original magnetic field
    - Characteristic of a given location
    - Within $\pm 15\%$ in 90% of locations
  - Placement offset (α)
    - Caused by difference in orientation of phone and direction of motion of the user
    - Typically $\pm 45\%$

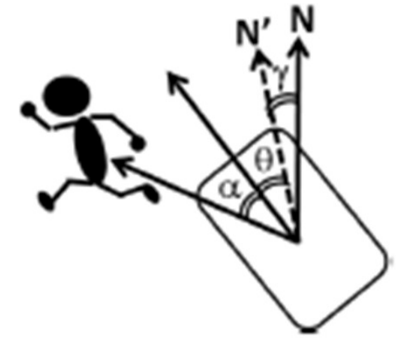


Figure 6: Heading Offset

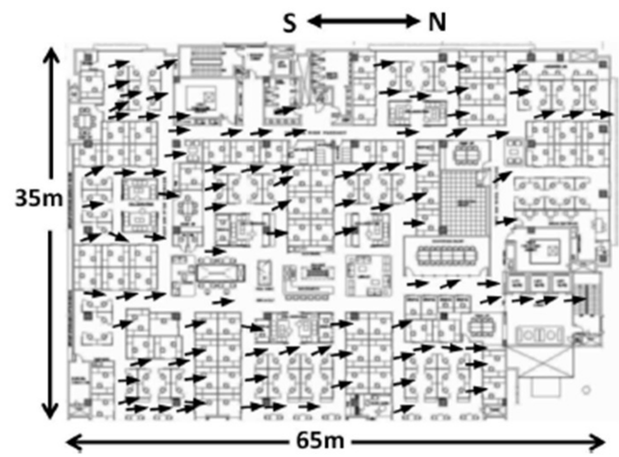


Figure 7: Direction of North as shown by the compass across the floor of a large office

Zee Mechanics

- Estimating Heading Offset (cont.)
  - Determine Heading Offset (HO) through 2 step approach
    - Step 1: Estimate HO in broad range based on acceleration
      - Second fundamental frequency of a user step period is more pronounced when the user is walking in the same direction as the phone orientation.
      - $\propto + \gamma = \arctan\left(\frac{F_x}{F_y}\right) - \theta$ where F_x *and* F_y are magnitudes of the second harmonics in the x and y direction
      - Can fairly accurately determine which two 90° direction quadrants the user is not walking into.
    - Step 2: Refine HO as the user walks by using the APF

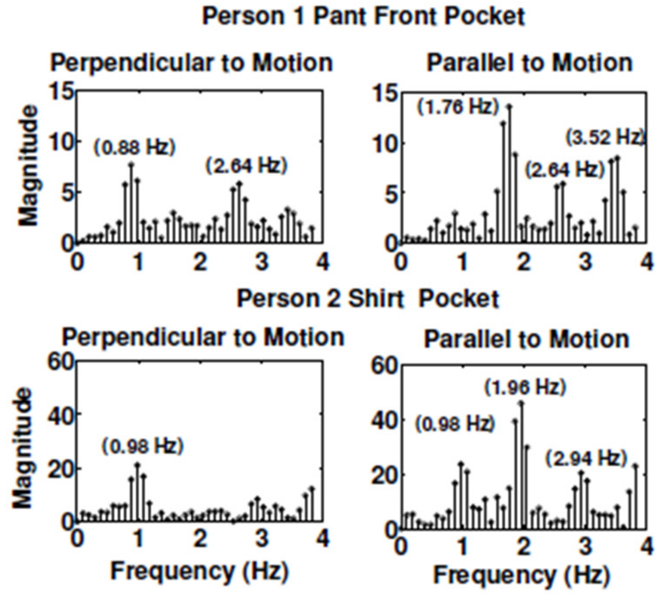


Figure 9: Spectrum of walking

Zee Mechanics

- Estimating Heading Offset (cont.)
  - Can fairly accurately determine which two 90° direction quadrants the user is not walking into.

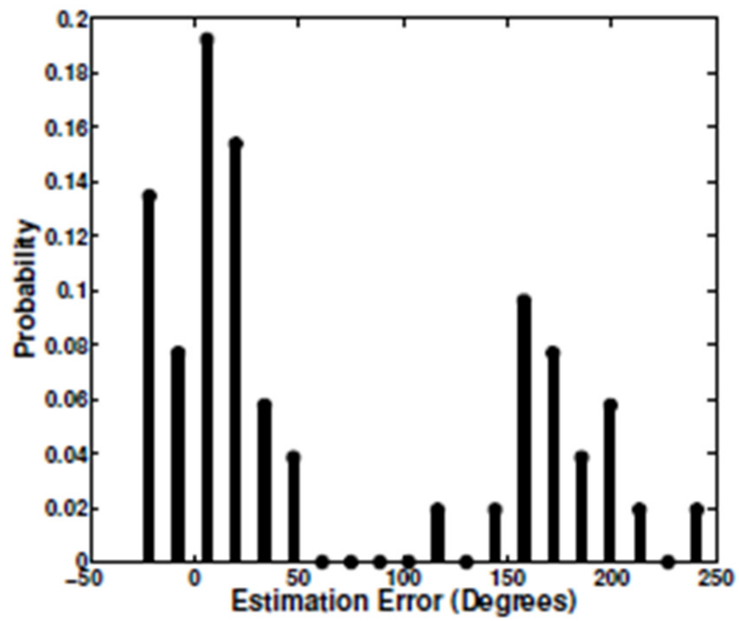


Figure 10: Error distribution of HO estimation

Zee Mechanics

- Tracking using Augmented Particle Filter (APF)
  - Location is described as a probability of where the user could be
  - The APF narrows these probabilities down as more input data is provided
  - 4 variable probability distribution including: 2D location, stride length and heading offset
  - Provides successively better estimates for variables as more input data is received
  - The particle filter is modeled as:

$$
\begin{aligned}
x_i^k &= x_i^{k-1} + (s_i + \delta_i)\cos(\alpha_i + \theta + \beta_i) \\
y_i^k &= y_i^{k-1} + (s_i + \delta_i)\sin(\alpha_i + \theta + \beta_i)
\end{aligned}
$$

Zee Mechanics

- Tracking using Augmented Particle Filter (cont.)
  - Once particles are narrowed down to a single location the APF uses backward belief propagation to narrow down the exact location of user in previous steps

Another Zee Example

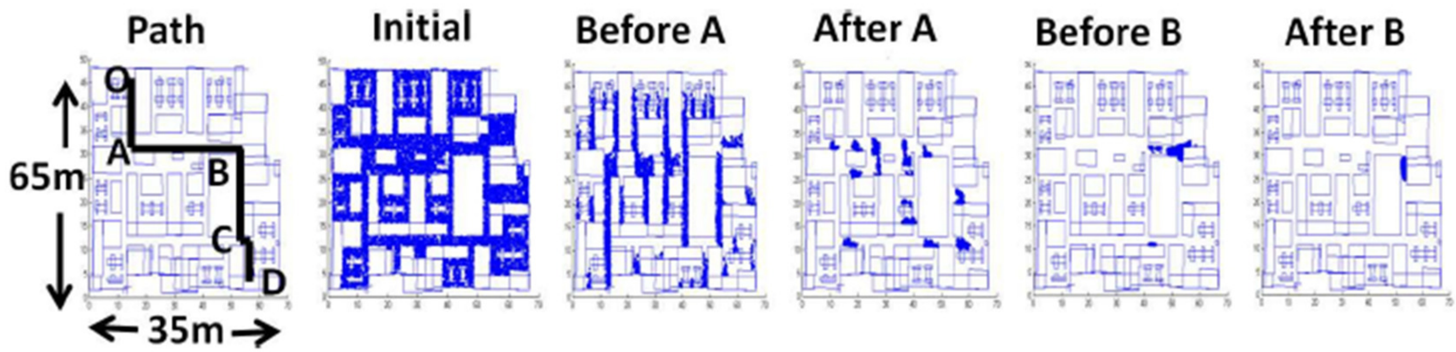


Figure 11: An example run of Zee

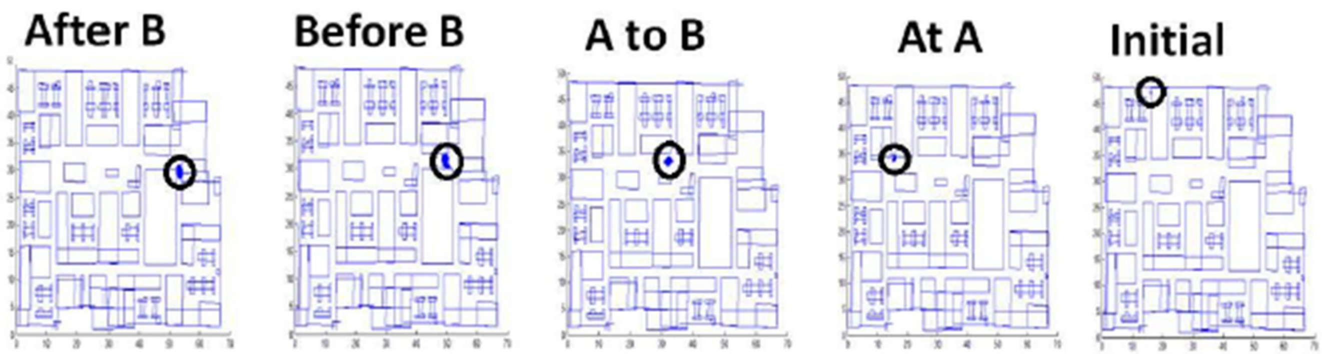


Figure 12: Backward belief propagation in Zee

Zee Mechanics

- Incorporating RF fingerprinting
  - Data from APF is tagged with RSS data so that future paths can narrow down the initial position using RF fingerprinting
  - Two Wi-Fi localization schemes used:
    1. Horus
       - RSS measurements construct a probability distribution where the location is estimated as the location of maximum likelihood for the given RSS data
    2. EZ
       - Uses Log Distance Path Loss model to estimate the distance between the user and each AP
       - Uses triangulation of multiple distances from AP to determine location

Zee Evaluation

- Experimental Testing
  - Tested in an office environment with multiple trips being taken of varying lengths at different times to simulate multiple users
  - Results graphs are as follows:

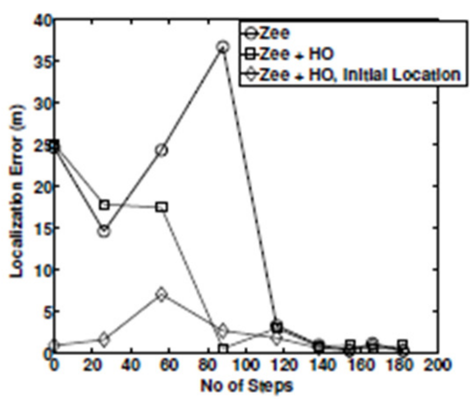


Figure 15: Location errors seen by Zee during walk 1.

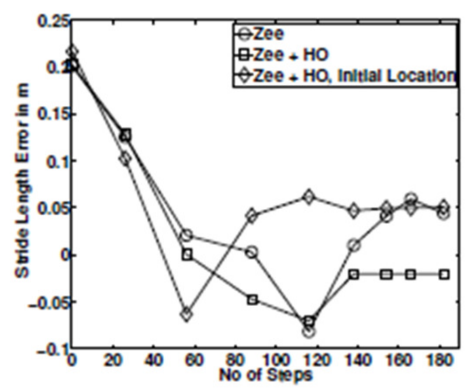


Figure 16: Stride length errors seen by Zee during walk 1.

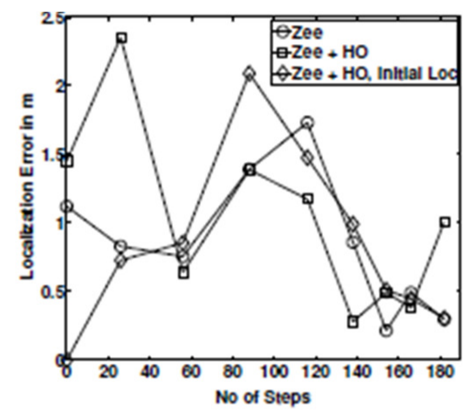


Figure 17: Location errors seen after backward belief propagation by Zee during walk 1

Zee Evaluation

- Experimental Testing (cont.)
  - Results Graphs (cont.)

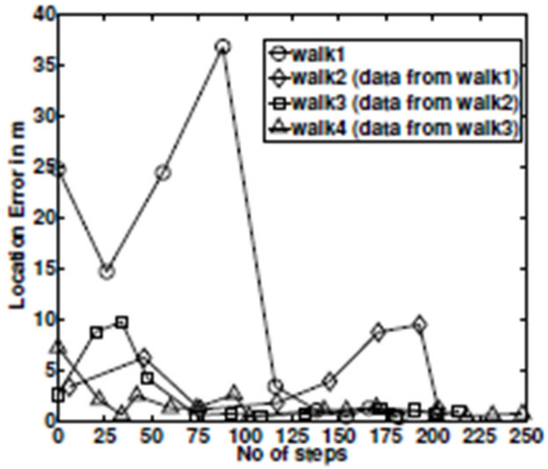


Figure 18: Using WiFi measurements from previous walks to start subsequent walks

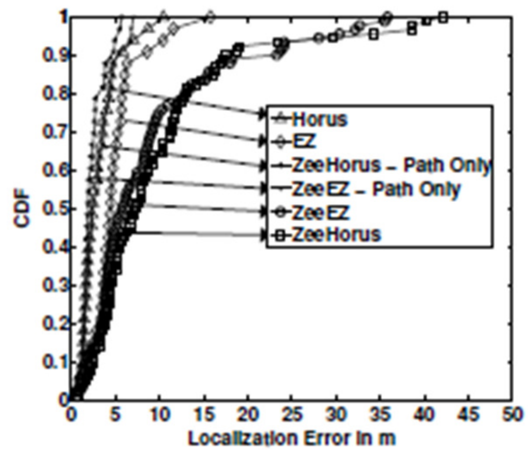


Figure 19: Performance of WiFi localization on Zee data

Reflection

- The Good
  - Infrastructure-less
  - Accuracy is as good as other methods when data has been collected
  - Adaptive
  - Initial location and stride length not needed
- The Bad
  - Relies heavily on crowd behaviour
  - Needs significant data to become accurate
  - Database needed
  - Significant processing power

Conclusions

- Requires no additional infrastructure
- Crowd sourced data acquisition
- “Zero-effort” user interaction
- Data acquired can be used for other Wi-Fi localization techniques
- Performs with accuracy consistent of current RF fingerprinting approaches

References

All images from Anshul Rai, Krishna K. Chintalapudi, Venkata N. Padmanabhan and Rijurekha Sen, “Zee: Zero-Effort Crowdsourcing for Indoor Localization,” in Mobicom (2012)