VOR Base Stations for Indoor 802.11 Positioning

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indoor positioning

- no GPS indoors!
- classifications of existing systems
  - infrastructure
    - existing 802.11 base stations
    - specialized beacons
  - measurement medium
    - RF (radio frequency)
    - infrared
    - ultrasound
  - actual positioning method
    - triangulation
    - trilateration
    - signal strength map

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positioning basics

1. range based - trilateration
2. angle based - triangulation
3. signal strength map - nearest neighbor, Bayes
trilateration

\[ (x_M - x_A)^2 + (y_M - y_A)^2 = MA^2 \]
\[ (x_M - x_B)^2 + (y_M - y_B)^2 = MB^2 \]
\[ (x_M - x_C)^2 + (y_M - y_C)^2 = MC^2 \]

solve for \( (x_M, y_M) \)

- \( MA, MB, MC \) are affected by errors
- several methods available
example: Cricket (MIT)

○ mobile
  - measures ranges to ceiling beacons
    • TDOA between RF and ultrasound
  - triangulates

○ pros:
  - good accuracy 1.3m

○ cons:
  - extensive infrastructure
  - line of sight to the beacons
triangulation

\[ (x_M - x_A) \sin \alpha = (y_M - y_A) \cos \alpha \]
\[ (x_M - x_B) \sin \beta = (y_M - y_B) \cos \beta \]
\[ (x_M - x_C) \sin \gamma = (y_M - y_C) \cos \gamma \]

solve for \((x_M, y_M)\)

- \(\alpha, \beta, \gamma\) -affected by errors (Gaussian)
- several methods available
build SS map:
  - for each point, measure SS to all 5 BS
query:
  - measure SS to 5 BS $\Rightarrow$ best match in the map
example: RADAR (Microsoft)

- use nearest neighbor to decide for the best match

- **pros:**
  - no additional infrastructure

- **cons:**
  - requires high resolution sampling
  - people, furniture, BS position affect the SS map

- median position error 3m
example: LANDMARC (MSU)

- replaces
  - training points with RFID tags
  - BS with RFID readers

- mobile uses an RFID tag → nearest neighbor, etc.

- pros:
  - **no remapping** → updates map on the fly

- cons:
  - additional infrastructure (RFID)
  - many readers, tags
goals:

- no signal strength map
- less infrastructure
- move complexity to the 802.11 base station

use:

- angles
- ranges
- angles and ranges
VORBA prototype

IR receiver → IR sender
antenna
802.11 card

prototype
directional antenna pattern
basic measurements

- mean SS

signal strength [dBm]

- discrete angles
- angle distribution
- range

$SS(\alpha)$
experiments

- 32 measurement points
- 5 + 2 base stations
- N/E/S/W measurements of 3-4 revolutions each
best peak distribution

- 4.5 peaks on average
- best peak is first/second 90% of the time
other peak distribution

- other peaks point away from true direction

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discrete angle positioning

○ 3.5m median position error
○ 3m if we knew the best peak
triangulation analysis

\[ Var[x] > \frac{\sigma^2_a}{\lambda \pi \ln \frac{R}{R_m}} \]

- \( Var[x] \) - standard dev. of positioning error
- \( \lambda \) - density of base stations / \( m^2 \)
- to improve positioning:
  1. decrease measurement error \( \sigma_a \)
  2. use more base stations
quantized angles

- measurements rounded to the nearest 45°
- simulation
little degradation for

- 16 directions (22.5°)
- 8 directions (45°)
angle distribution
range inference

- **open space attenuation:**
  
  \[ SS[\text{dBm}] = SS_0[\text{dBm}] - \log_{10}(\frac{d}{d_0})^n \]

- **\(d(\text{SS})\)**
  - obtained through fitting
  - known to be unreliable

- we obtain it from integration of \(SS(\alpha)\)

- **5-fold cross validation**
  - corridor base stations - waveguide effect
  - median range error 2.8m
positioning w. ranges

- trilateration 5 base stations
- median position error 4.5m


ranges and angles

\[
\begin{align*}
    x_M &= x_A + MA \cos \alpha = x_B + MB \cos \beta = x_C + MC \cos \gamma \\
    y_M &= y_A + MA \sin \alpha = y_B + MB \sin \beta = y_C + MC \sin \gamma
\end{align*}
\]

- one base station is theoretically enough
- \( \alpha, \beta, \gamma, MA, MB, MC \) - affected by errors
position uncertainty

- approximate uncertainty as an ellipse
- error ellipse increases with distance
- $\sigma_a = 0.4$ radians $\simeq 21^\circ$
- $\sigma_r = 0.2r$
how to combine several readings? Kalman filter.
- More base stations ⇒ better positions
- 2.1m median position error (all 7 BS)
discussion

- triangulation with large outliers
- use more than two angles?
- no correlation between
  - angle error and distance
  - angle error and SS
- corridors $\Rightarrow$ waveguides
- revolving signal at the mobile?
- data performance?
VORBA = VOR base station

- complexity into the base station
  - less infrastructure
  - no SS map

- revolving base station measures $SS(\alpha)$ to derive
  - discrete angles
  - angle distributions
  - ranges

- works with quantized angles as well

- can achieve 2.1m - 4m median error
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