VOR Base Stations for Indoor 802.11 Positioning

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existing systems require either:

- **extra infrastructure**
  + good accuracy
  - instrumentation
  - specialized beacons, badges
  - LOS

- **signal strength (SS) map**
  + existing 802.11 base stations
  - map depends on people, furniture, ...
  - centralized database
1. **build SS map:**
   - for each point, measure SS to all 5 BS

2. **query:**
   - measure SS to 5 BS $\Rightarrow$ best match in the map
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 base station
directional antenna pattern

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basic idea

signal strength variation = $SS(\alpha)$

1. $SS(\alpha)$  
2. \begin{align*} &\text{peak} \rightarrow \text{angle} \\
&\text{mean} \rightarrow \text{range} \end{align*}  
3. \begin{align*} &\text{angle and/or} \\
&\text{range} \rightarrow \text{position} \end{align*}
experiments

- 32 measurement points
- 5 + 2 base stations
- N/E/S/W measurements of 3-4 revolutions each
angles **only** positioning

- **3.5m** median position error
- **3m** if we knew the best peak
quantized angles

- measurements rounded to the nearest $45^\circ$
- simulation
- little degradation for $45^\circ$ and $22.5^\circ$ quantizations
○ **angle error** $\sigma_a = 0.4 \text{ radians} \approx 21^\circ$

○ **range error** $\sigma_r = 0.2r$

○ **approximate uncertainty as an ellipse**

○ **error ellipse increases with distance**
how to combine several readings? Kalman filter.
angles & ranges positioning

- **more base stations** ⇒ better positions
- 2.1m median position error (all 7 BS)
summary

- 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
index

○ indoor positioning
  - angulation/lateration
  - SS map example

○ VOR BAse station
  - prototype
  - basic idea
  - experiment setup

○ angles only positioning
  - discrete angles
  - quantized angles

○ angles and ranges
  - uncertainty
  - performance

○ summary
trilateration

\[ (x_M - x_A)^2 + (y_M - y_A)^2 = M A^2 \]
\[ (x_M - x_B)^2 + (y_M - y_B)^2 = M B^2 \]
\[ (x_M - x_C)^2 + (y_M - y_C)^2 = M C^2 \]

- \( MA, MB, MC \) are affected by errors
- several methods available

solve for \((x_M, y_M)\)
(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
ranges and angles

\[ x_M = x_A + MA \cos \alpha = x_B + MB \cos \beta = x_C + MC \cos \gamma \]
\[ y_M = y_A + MA \sin \alpha = y_B + MB \sin \beta = y_C + MC \sin \gamma \]

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

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

- \( \text{Var}[x] \) - standard dev. of positioning error
- \( \lambda \) - density of basestations / \( m^2 \)
- to improve positioning:
  1. decrease measurement error \( \sigma_a \)
  2. use more basestations
angle distribution
quantized angles

![Graph showing cumulative probability vs error in meters for different quantization levels: best angle (non quantized), quantization 45, quantization 22.5, quantization 90.]

- little degradation for
  - 16 directions (22.5°)
  - 8 directions (45°)
range inference

○ open space attenuation:

\[ SS[dBm] = SS_0[dBm] - \log_{10}(\frac{d}{d_0})^n \]

○ \( d(SS) \)
  - obtained through fitting
  - known to be unreliable

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

○ 5-fold cross validation
  - corridor basestations - waveguide effect
  - median range error 2.8m
trilateration 5 base stations

median position error 4.5m
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?