VOR Base Stations for Indoor 802.11 Positioning

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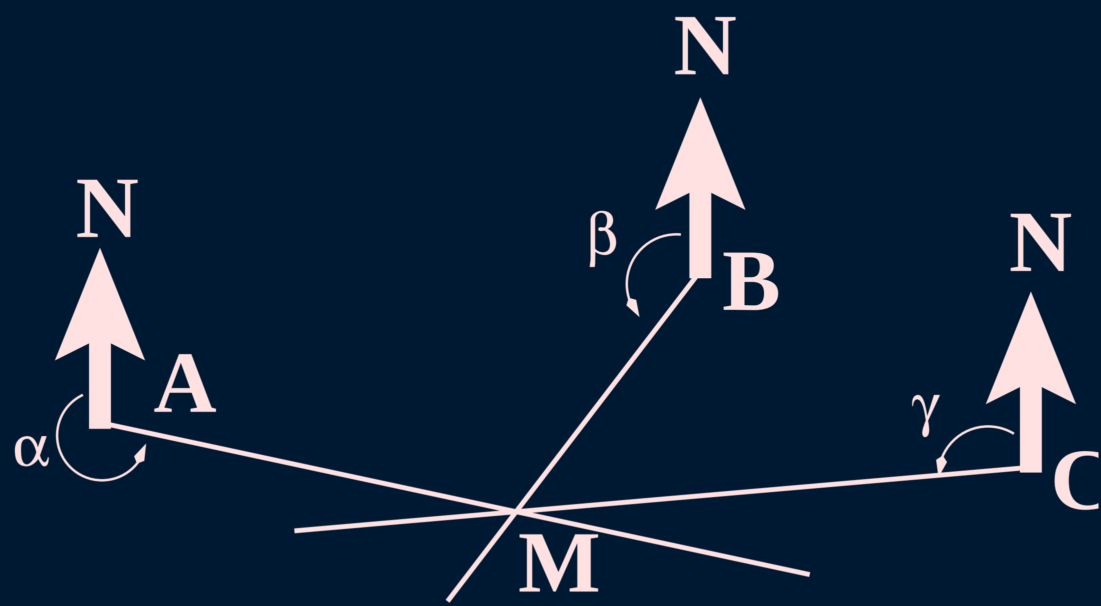
indoor positioning

- **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

positioning basics

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

trilateration



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

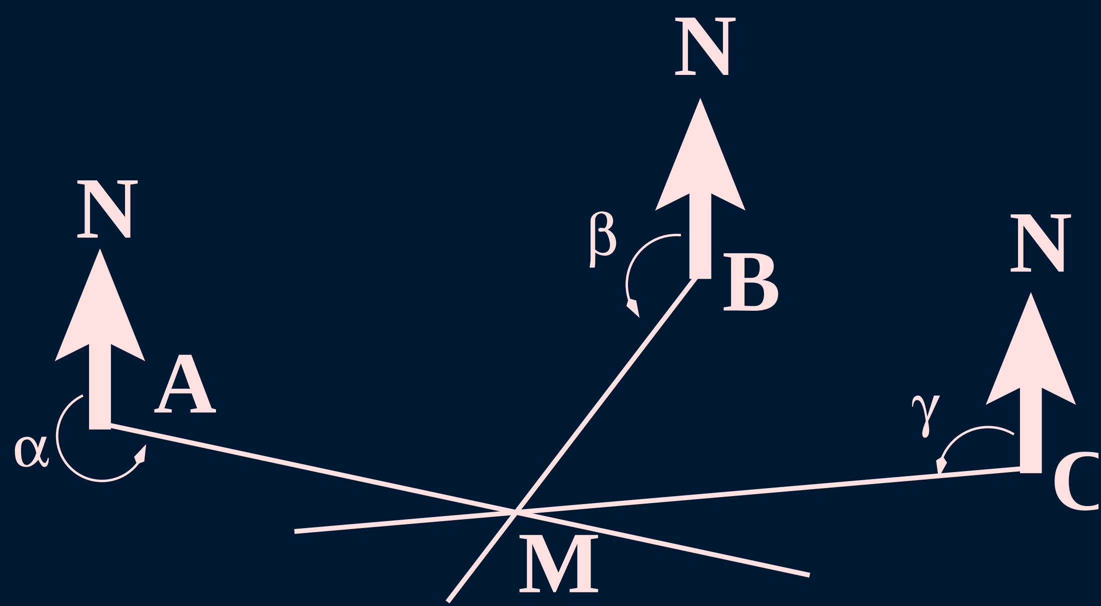
solve for (x_M, y_M)

- 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

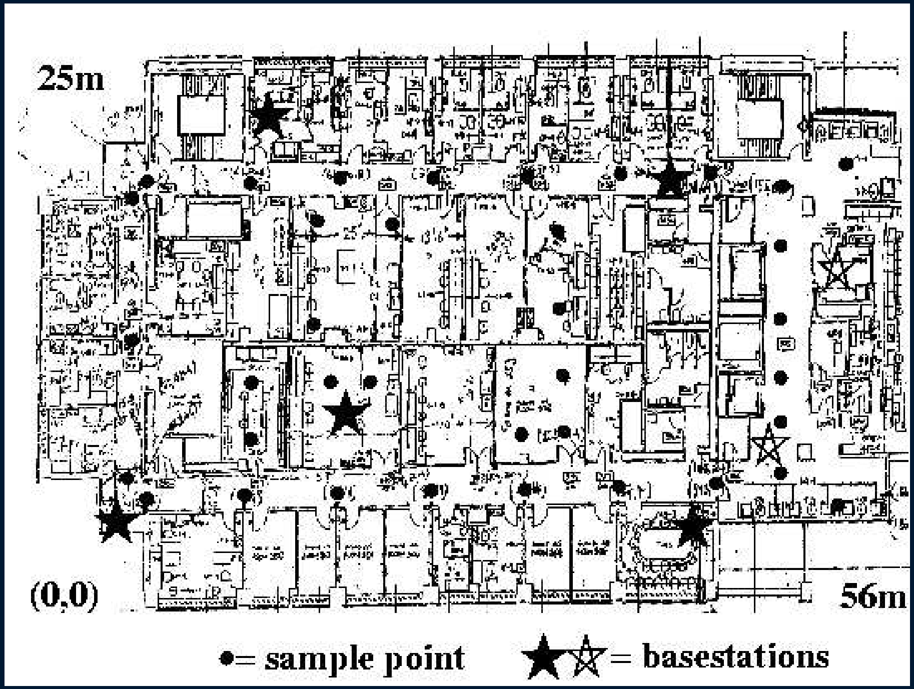


$$(x_M - x_A)\sin\alpha = (y_M - y_A)\cos\alpha$$
$$(x_M - x_B)\sin\beta = (y_M - y_B)\cos\beta$$
$$(x_M - x_C)\sin\gamma = (y_M - y_C)\cos\gamma$$

solve for (x_M, y_M)

- α, β, γ **-affected by errors (Gaussian)**
- **several methods available**

signal strength map



- build SS map:
  - for each point, measure SS to all 5 BS
- query:
  - measure SS to 5 BS⇒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

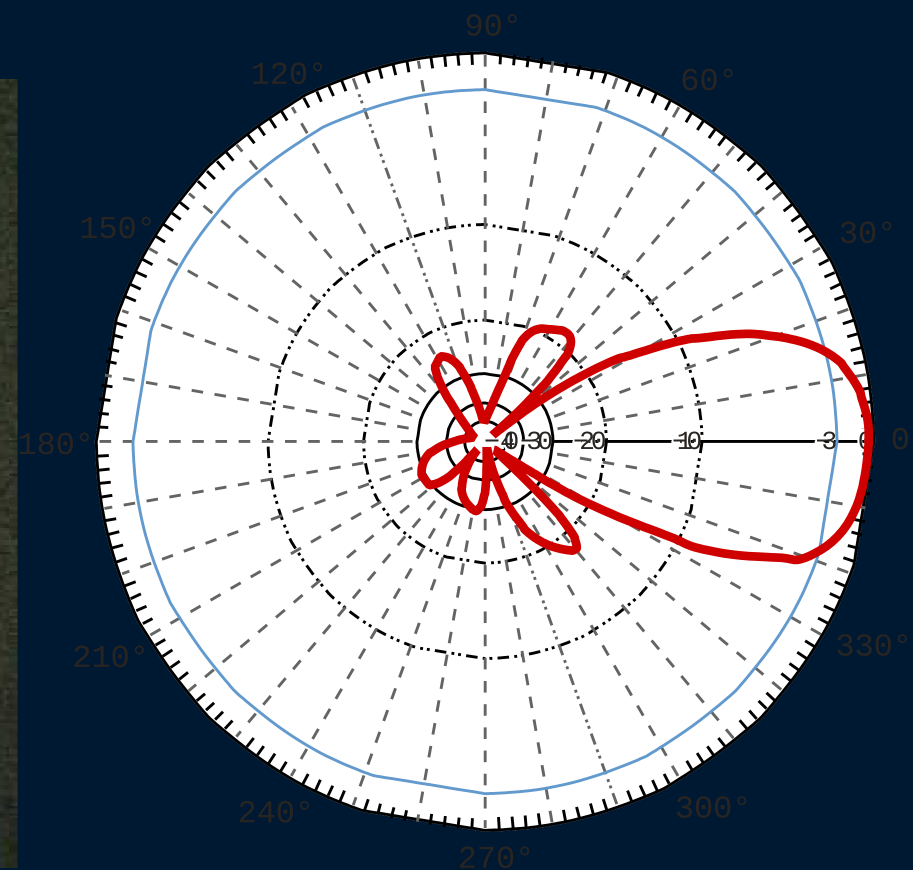
VORBA - VOR BAse stations

goals:

- no signal strength map
- less infrastructure
- move complexity to the 802.11 base station
- use:
  - angles
  - ranges
  - angles and ranges

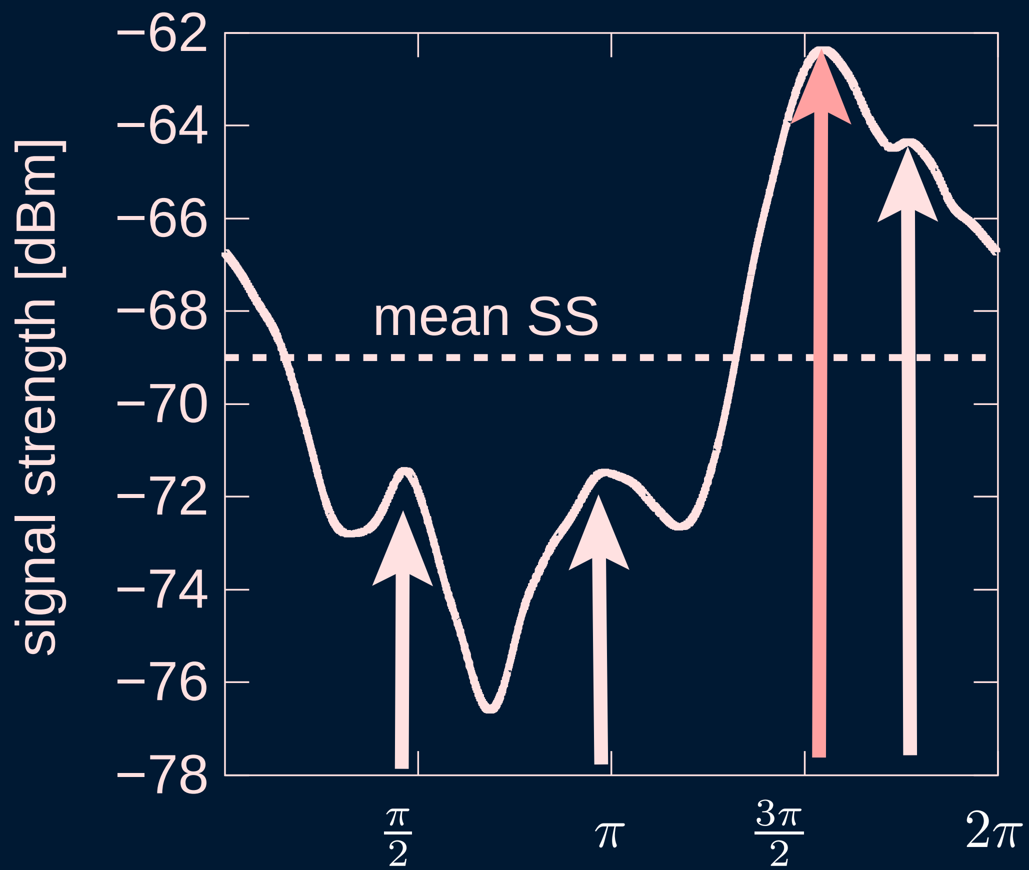
VORBA prototype

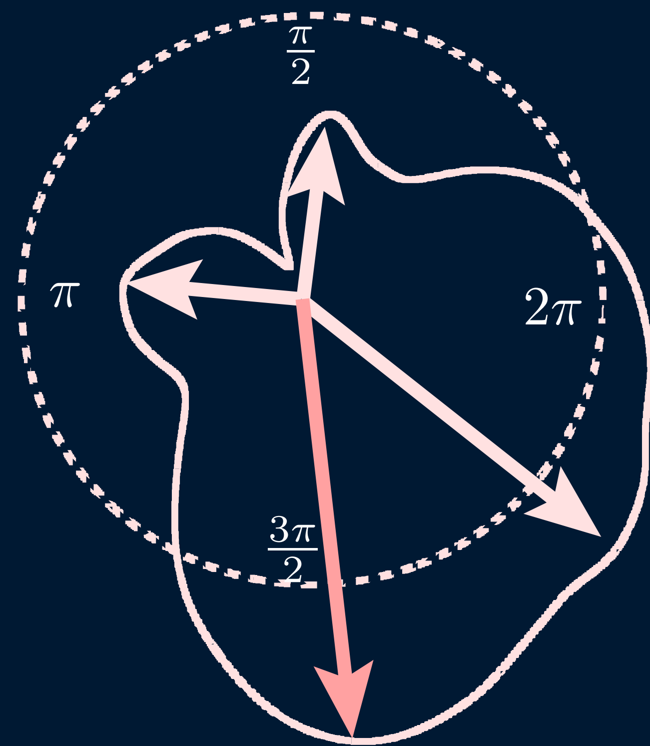
prototype



directional antenna pattern

basic measurements

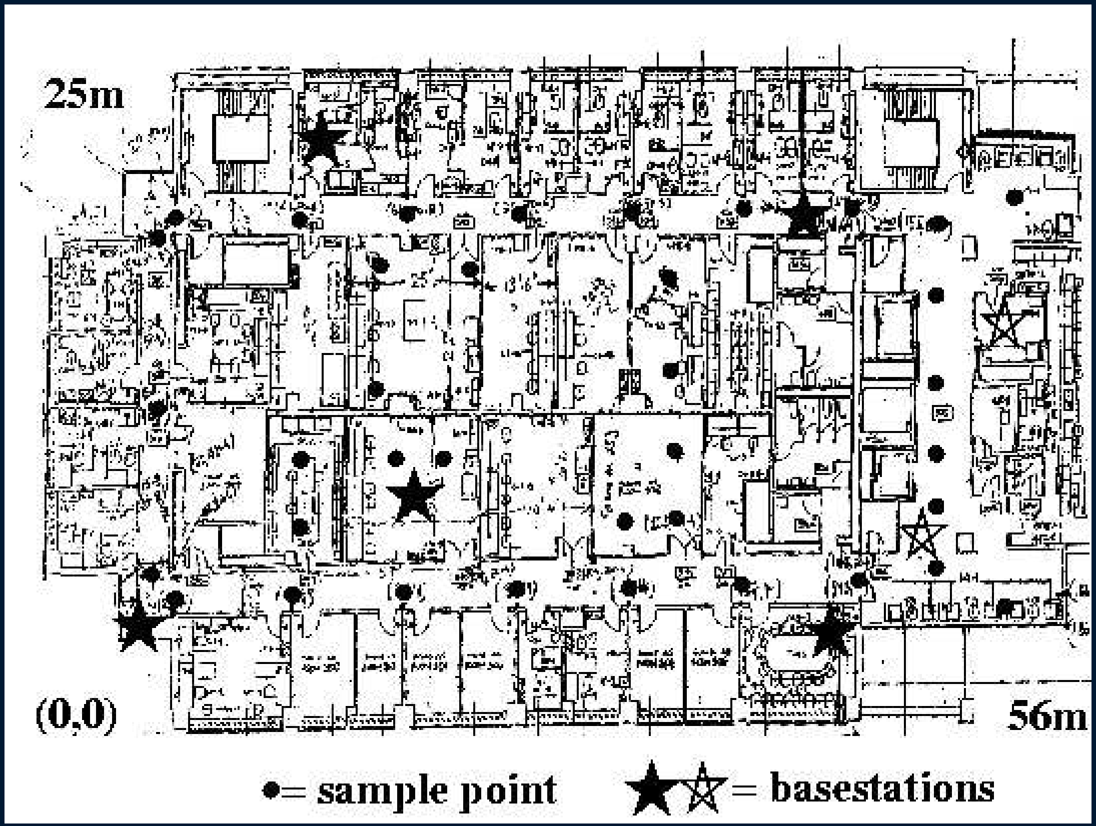




- **discrete angles**
- **angle distribution**
- **range**

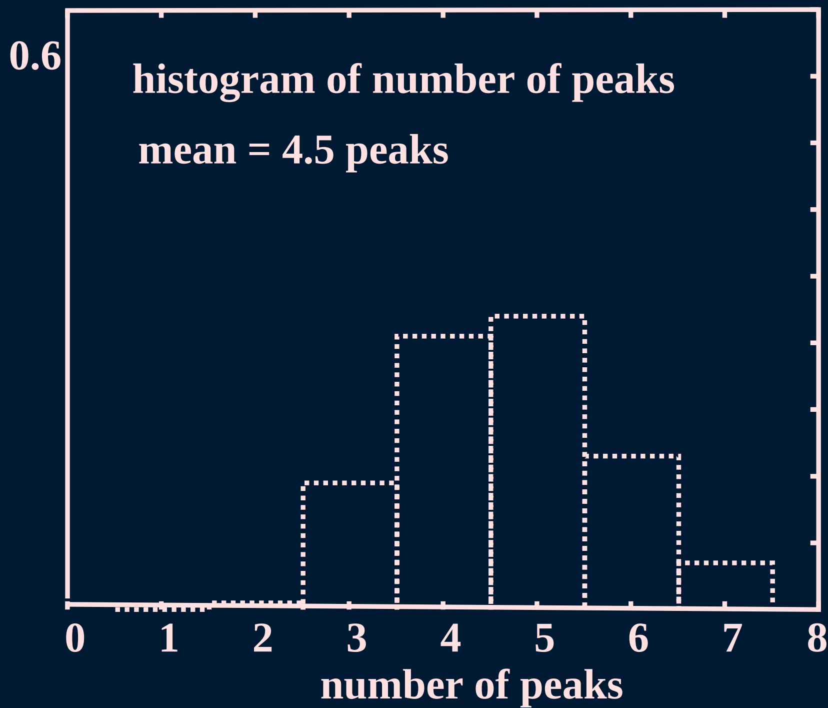
$SS(\alpha)$

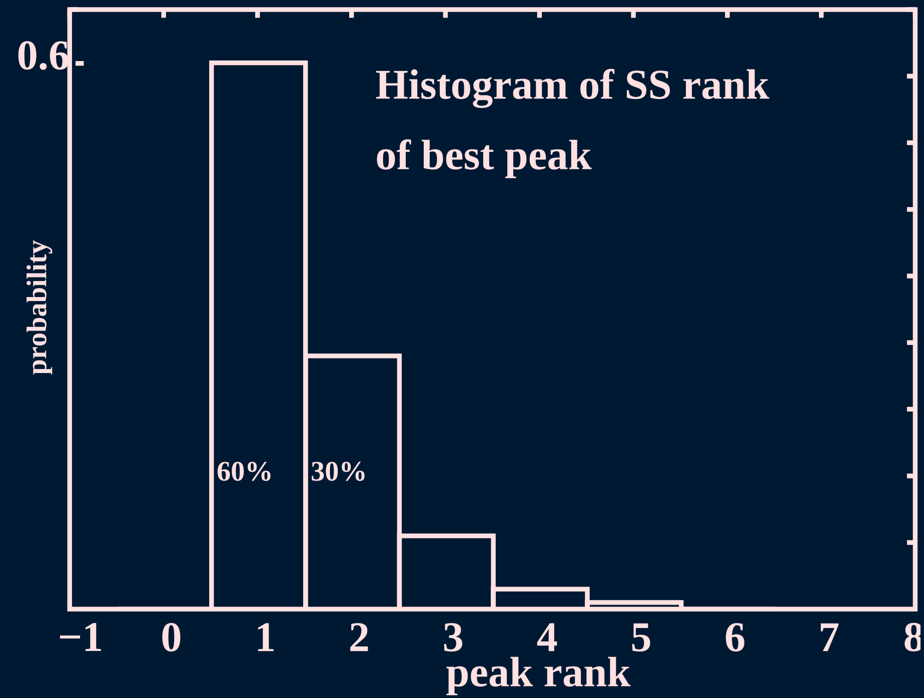
experiments



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

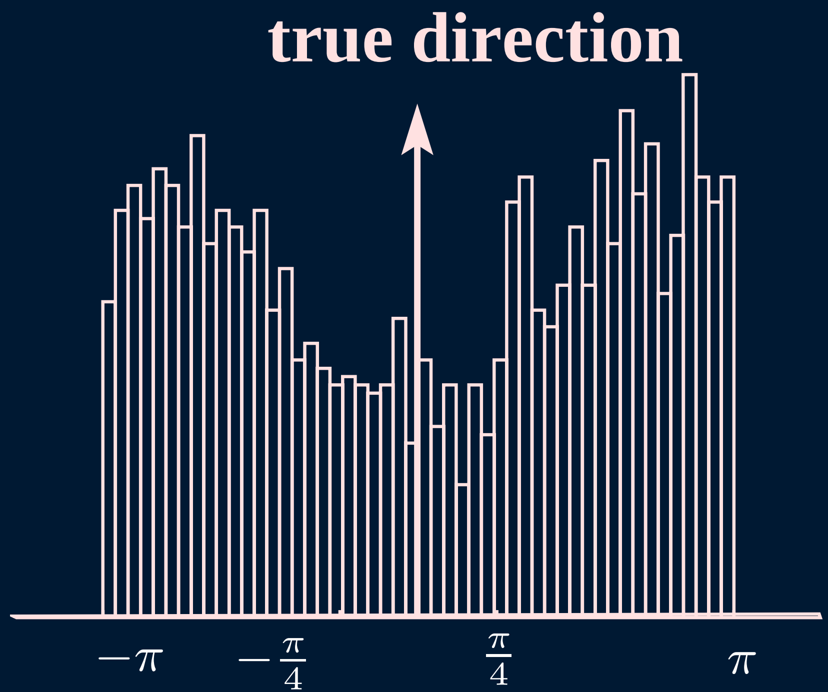
best peak distribution

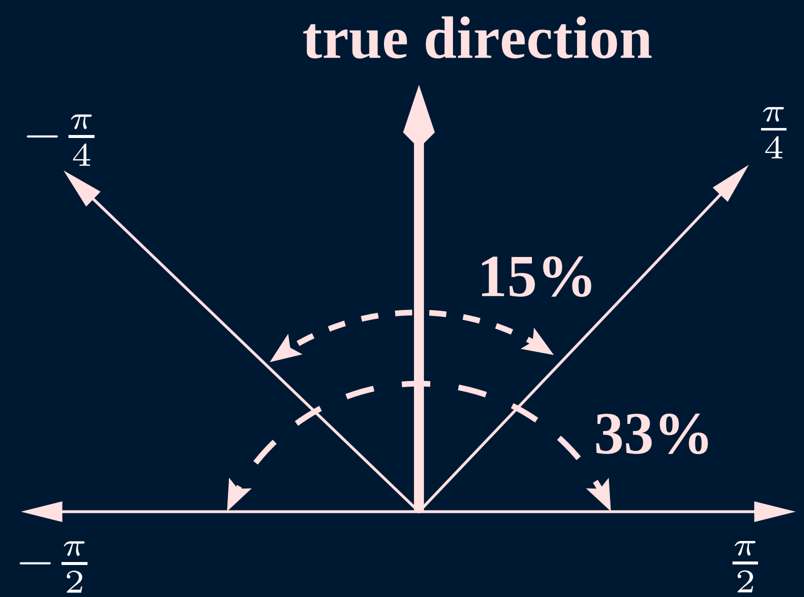




- 4.5 peaks on average
- best peak is first/second 90% of the time

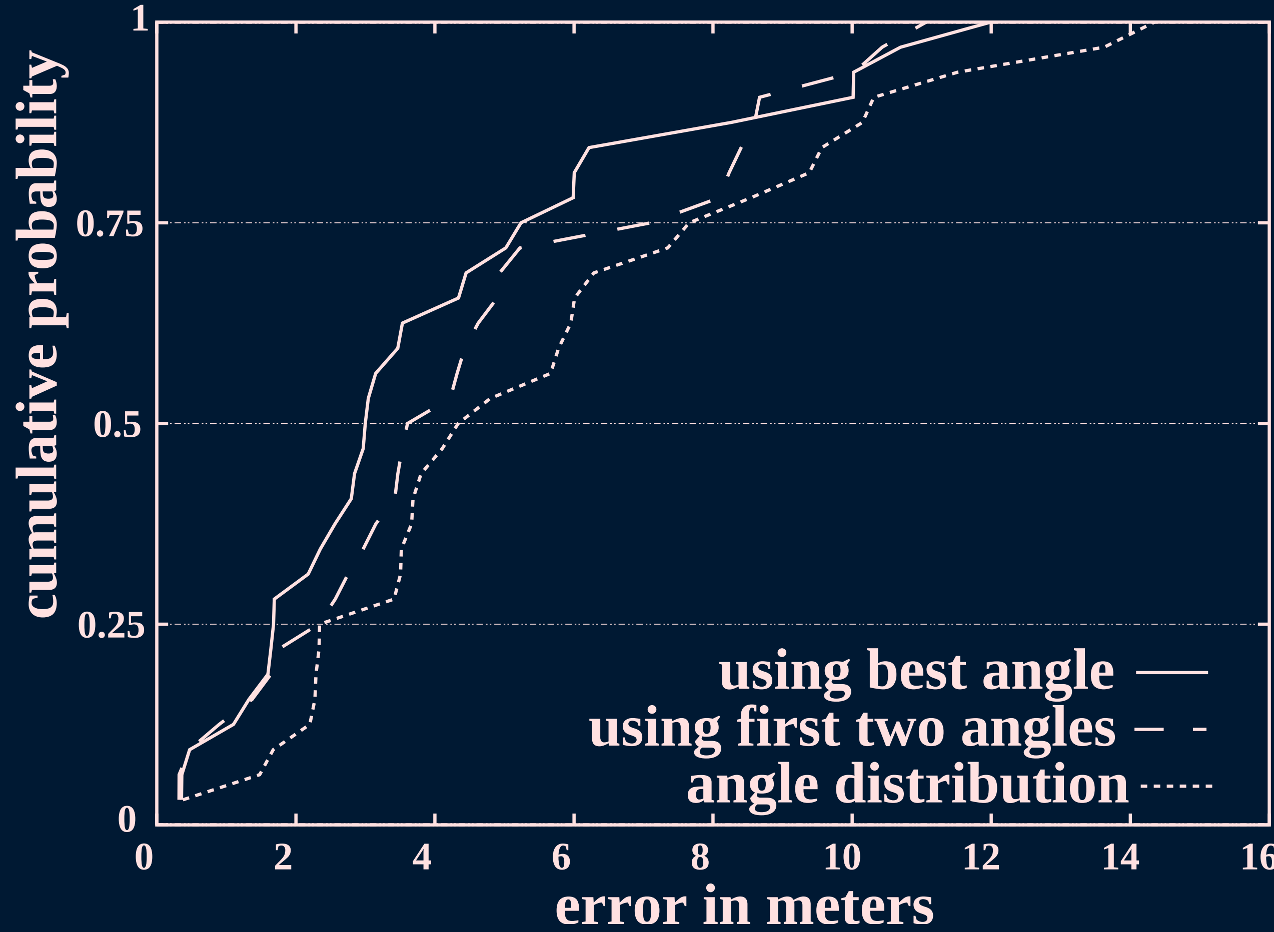
other peak distribution





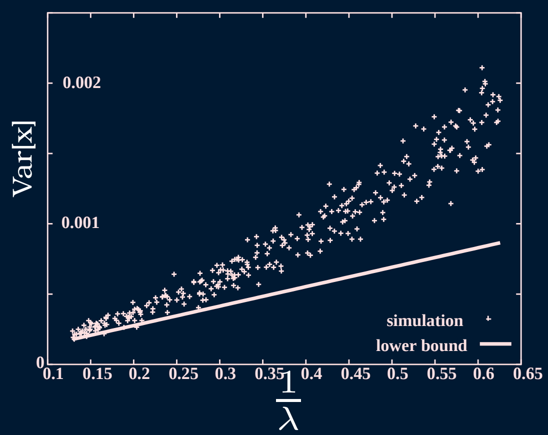
- other peaks point away from true direction

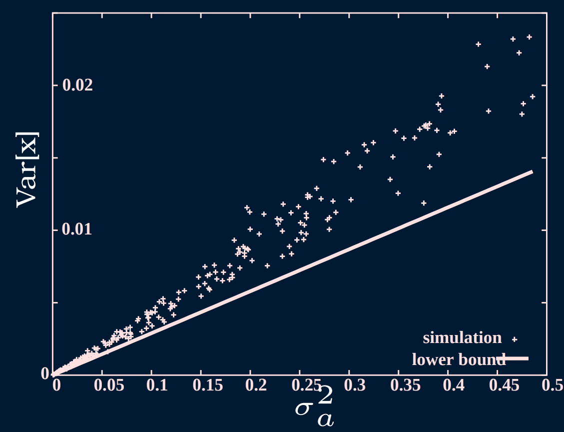
discrete angle positioning

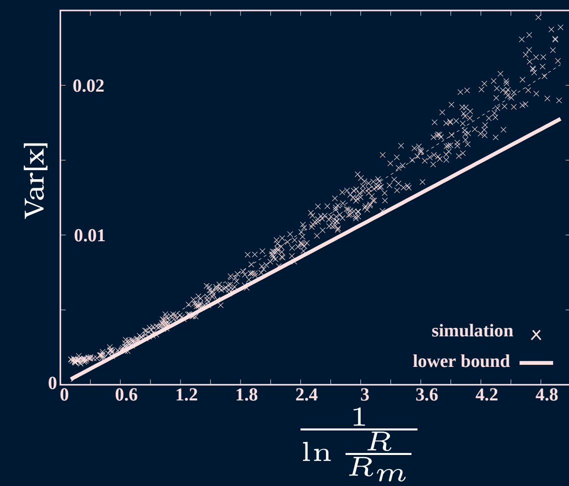


- 3.5m median position error
- 3m if we knew the best peak

triangulation analysis



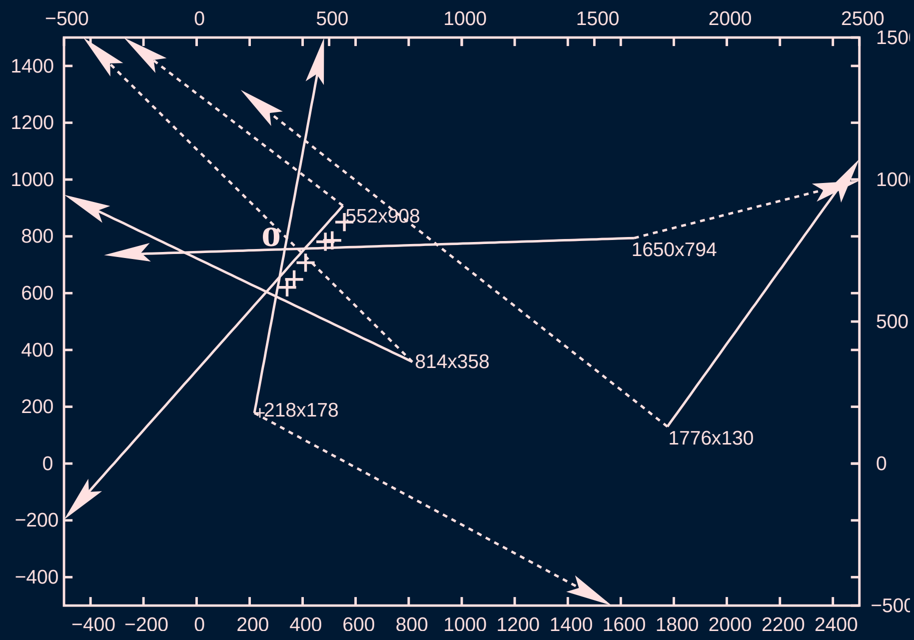


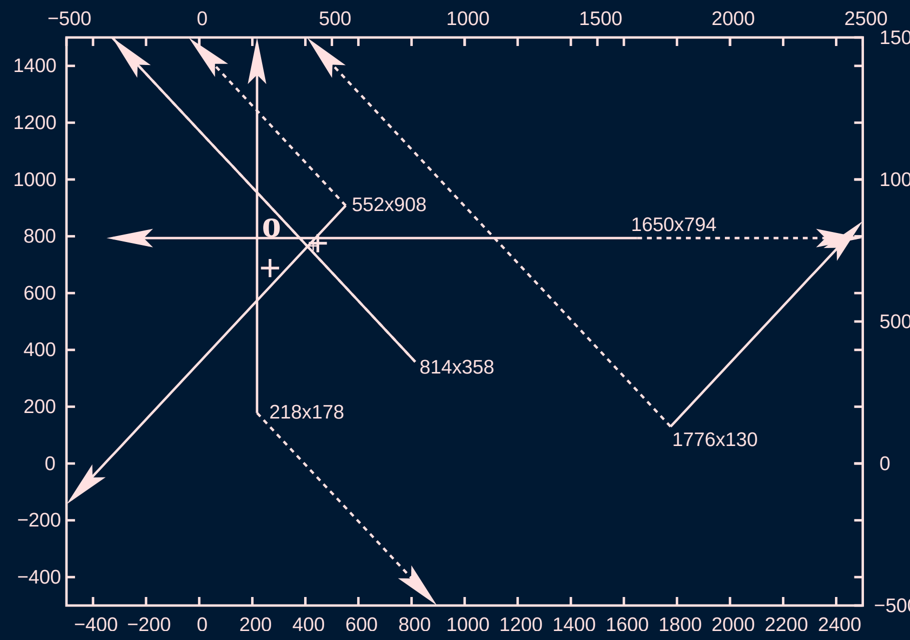


$$Var[x] > \frac{\sigma_a^2}{\lambda\pi \ln \frac{R}{R_m}}$$

- $Var[x]$ - **standard dev. of positioning error**
- λ - **density of basestations /** m^2
- **to improve positioning:**
  1. **decrease measurement error** σ_a
  2. **use more basestations**

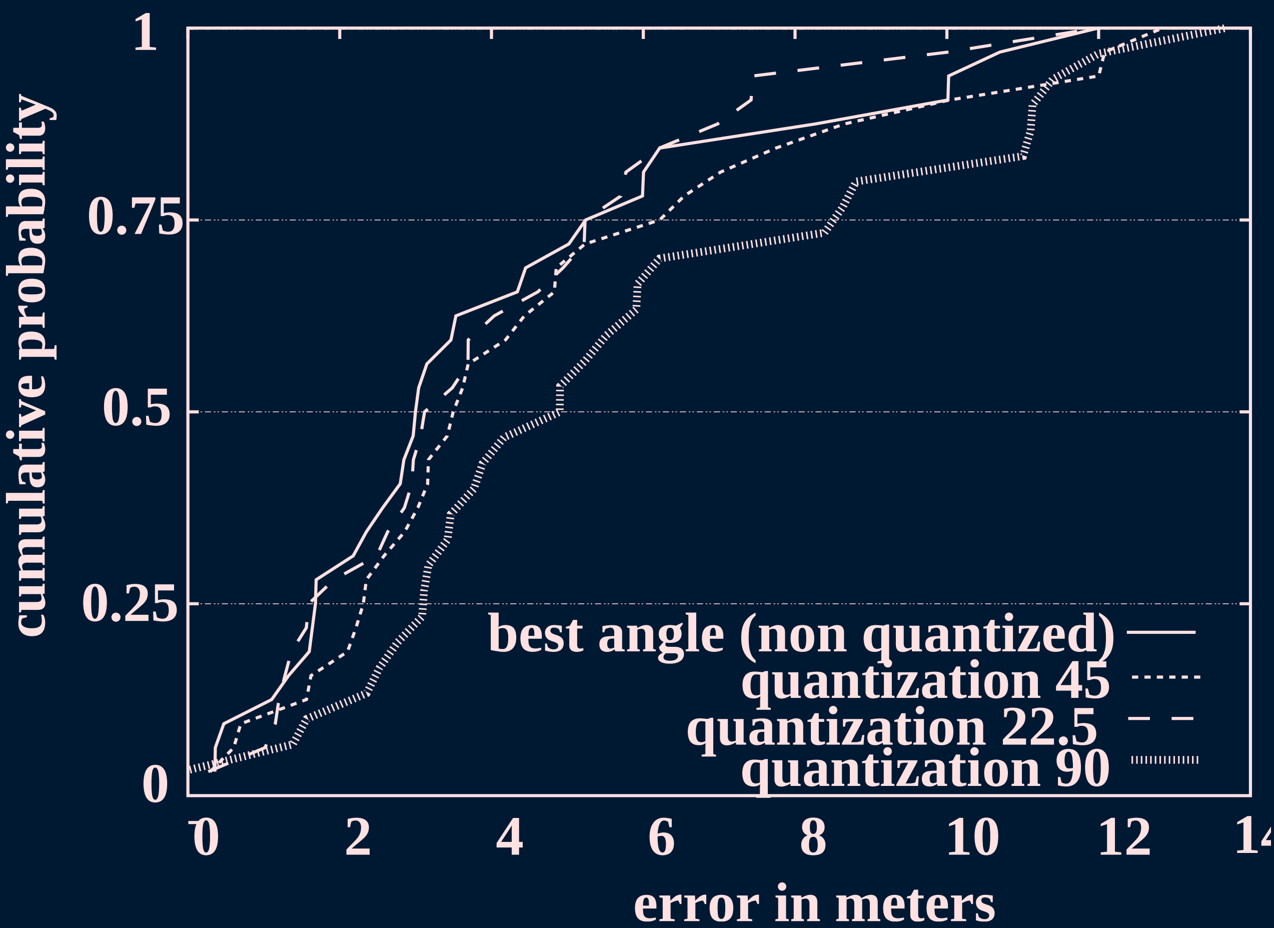
quantized angles





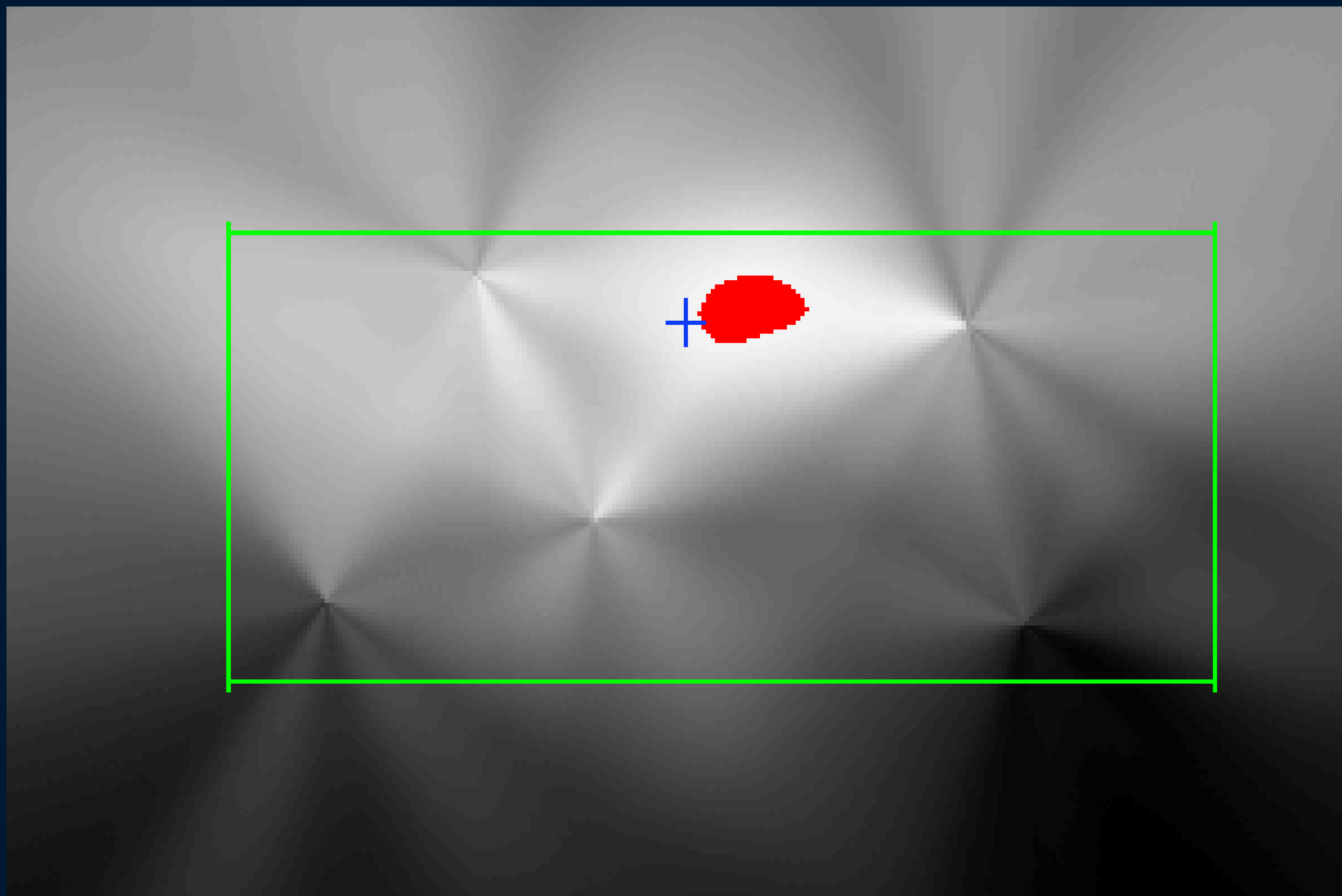
- **measurements rounded to the nearest** 45°
- **simulation**

quantized angles



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

angle distribution



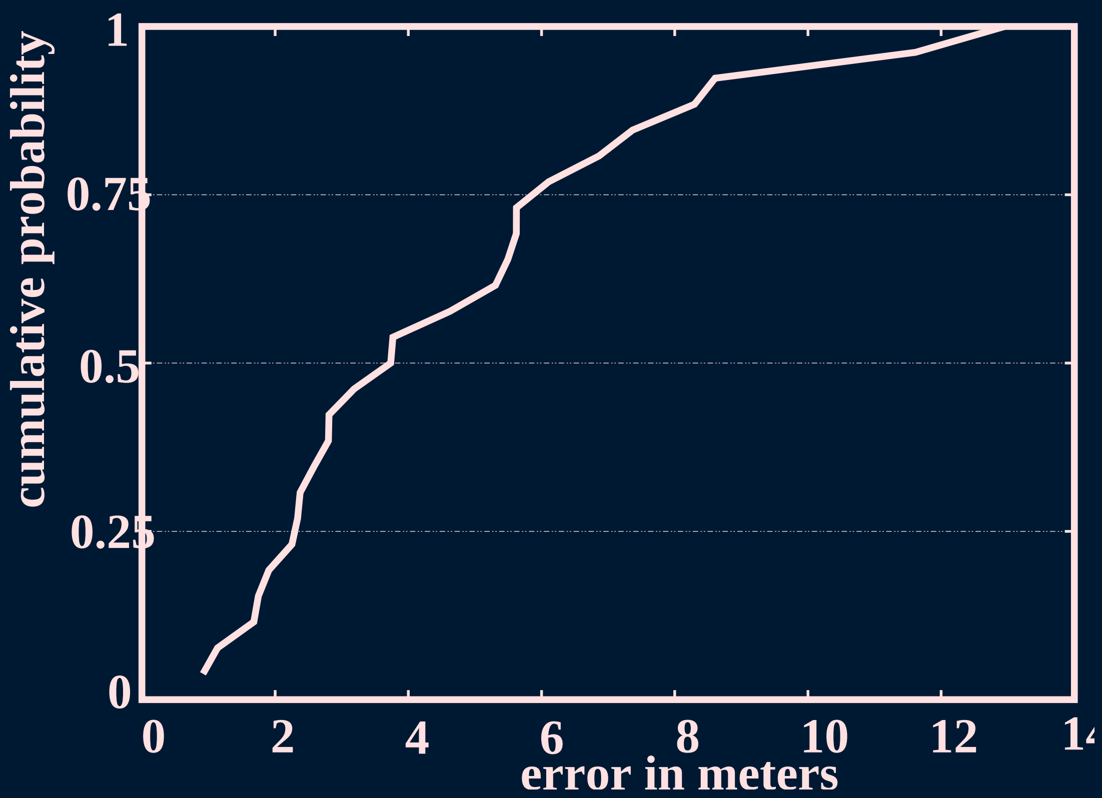
range inference

- **open space attenuation:**

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

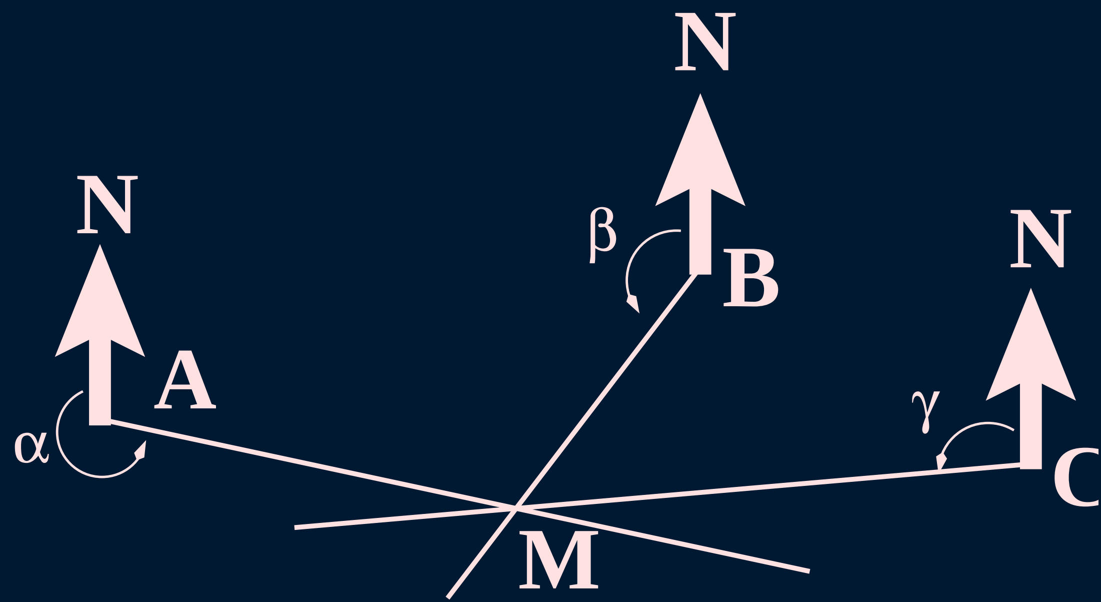
- $d(SS)$
  - **obtained through fitting**
  - **known to be unreliable**
- **we obtain it from integration of** $SS(\alpha)$
- **5-fold cross validation**
  - **corridor basestations - waveguide effect**
  - **median range error 2.8m**

positioning w. ranges



- trilateration 5 base stations
- median position error 4.5m

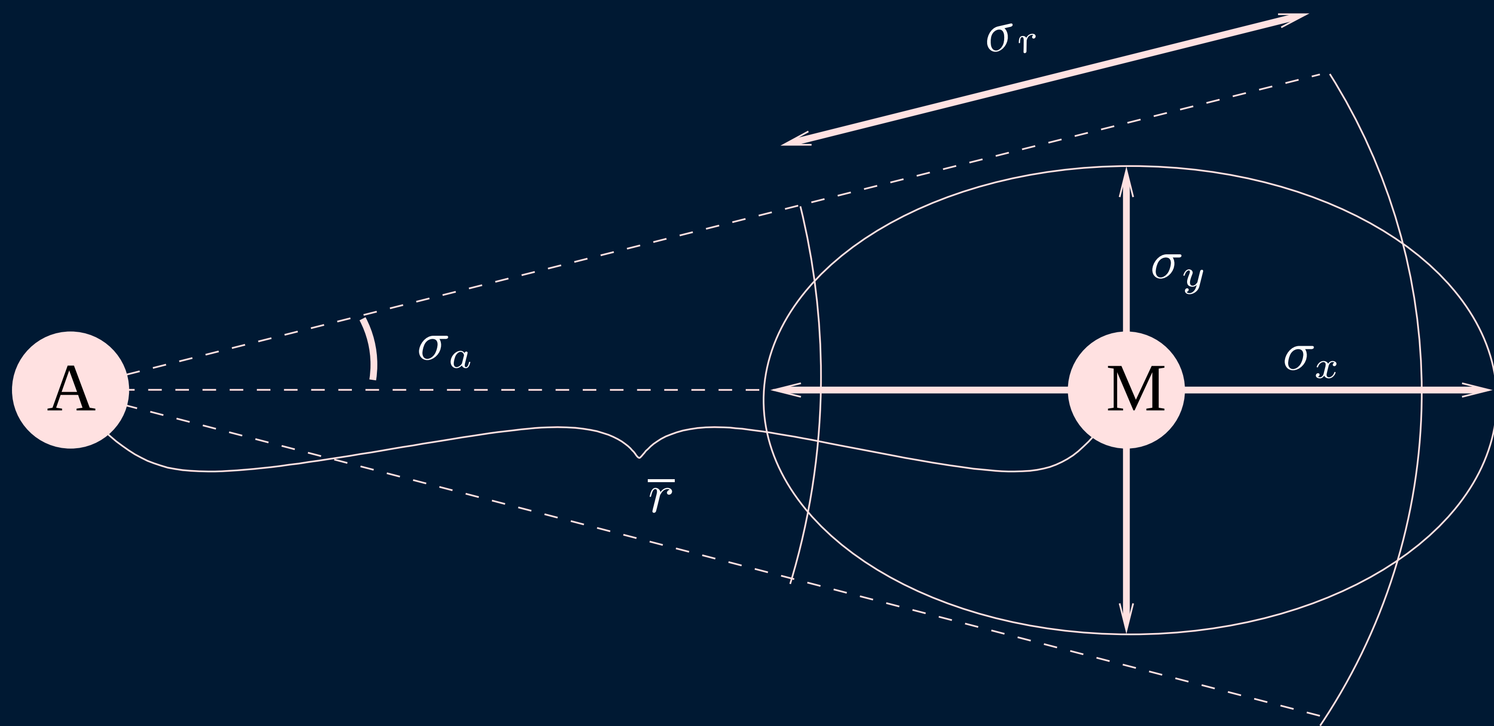
ranges and angles



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

- **one base station is theoretically enough**
- $\alpha, \beta, \gamma, MA, MB, MC$ - **affected by errors**

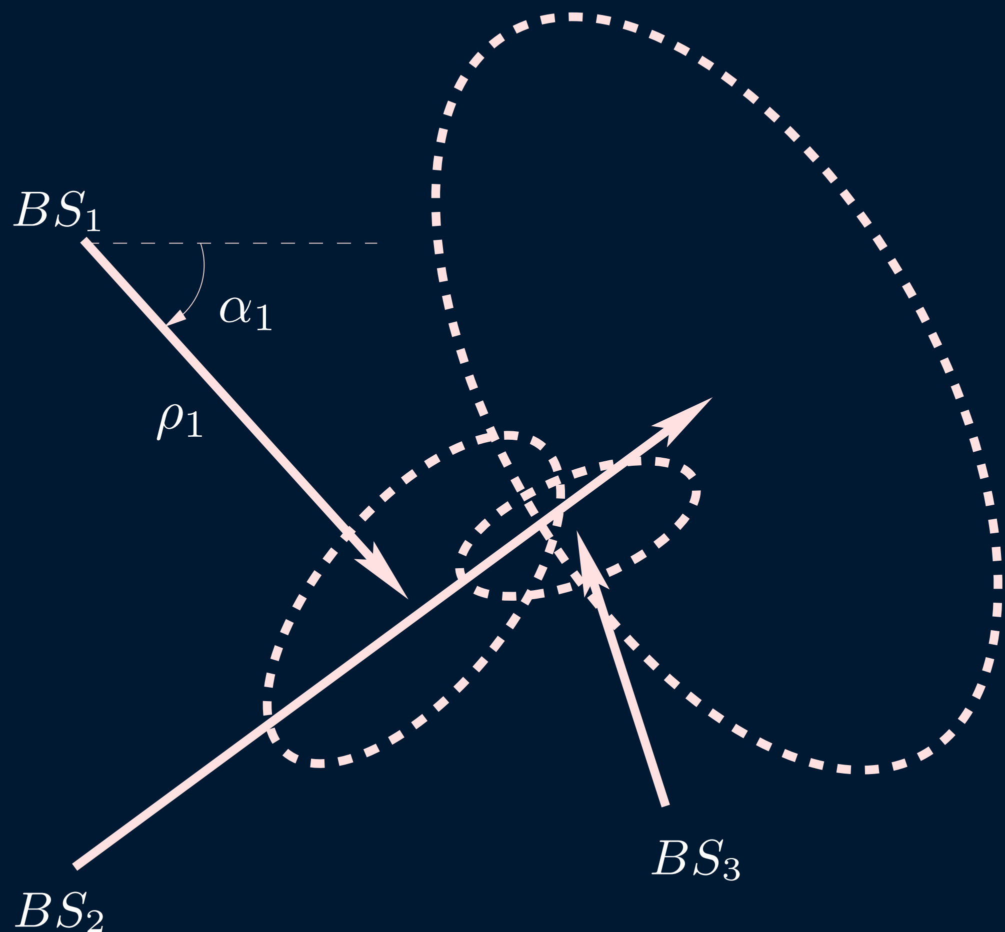
position uncertainty



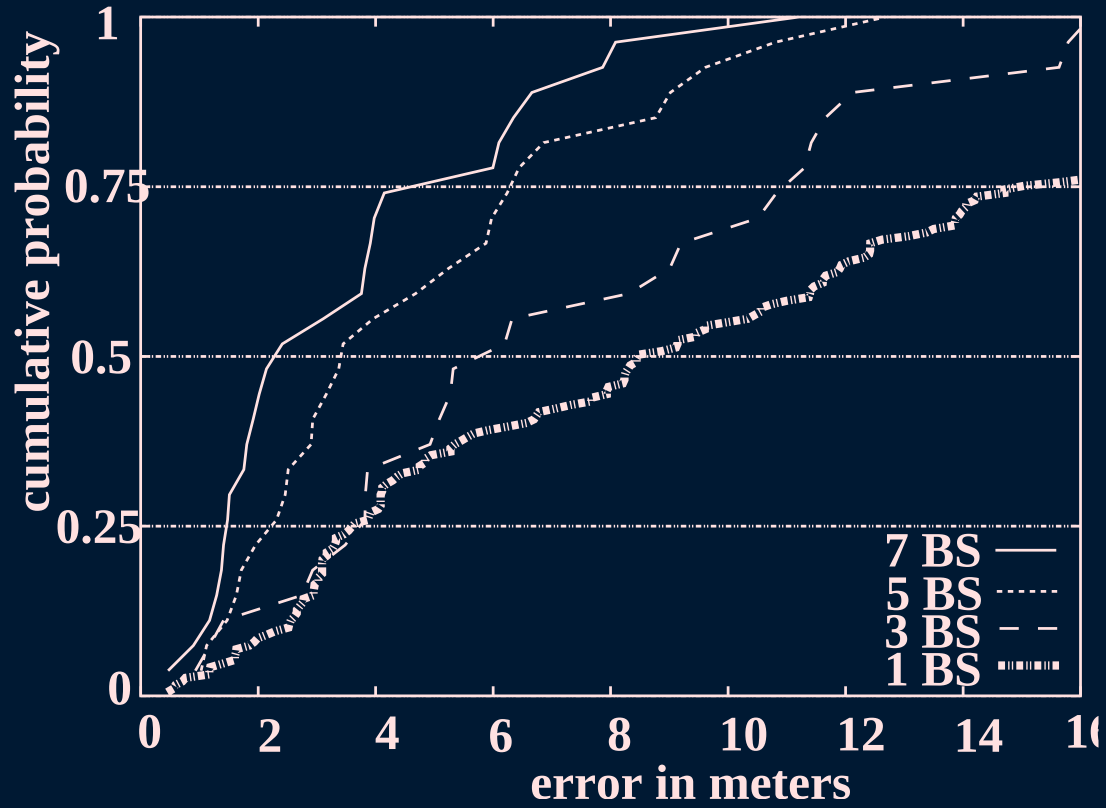
- **approximate uncertainty as an ellipse**
- **error ellipse increases with distance**
- $\sigma_a = 0.4$ **radians** $\simeq 21°$
- $\sigma_r = 0.2r$

uncertainty w. ranges & angles

how to combine several readings? Kalman filter.



positioning w. ranges & angles



- 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?

summary

- VORBA = VOR base station
- complexity into the base station
  - less infrastructure
  - no SS map
- revolving basestation 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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