Wireless Sensor Networks

16th Lecture

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CoNe Freiburg

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Goals of this chapter

- **Means for a node to determine its physical position (with respect to some coordinate system) or symbolic location**
- **Using the help of**
  - Anchor nodes that know their position
  - Directly adjacent
  - Over multiple hops
- **Using different means to determine distances/angles locally**

Overview

- *Basic approaches*
- **Trilateration**
- **Multihop schemes**

Localization & positioning

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- **Determine** *physical position* **or** *logical location*
  - Coordinate system or symbolic reference
  - Absolute or relative coordinates
- **Options**
  - Centralized or distributed computation
  - Scale (indoors, outdoors, global, …)
  - Sources of information
- **Metrics**
  - Accuracy (how close is an estimated position to the real position?)
  - Precision (for repeated position determinations, how often is a given accuracy achieved?)
  - Costs, energy consumption, …

Main approaches (information sources)

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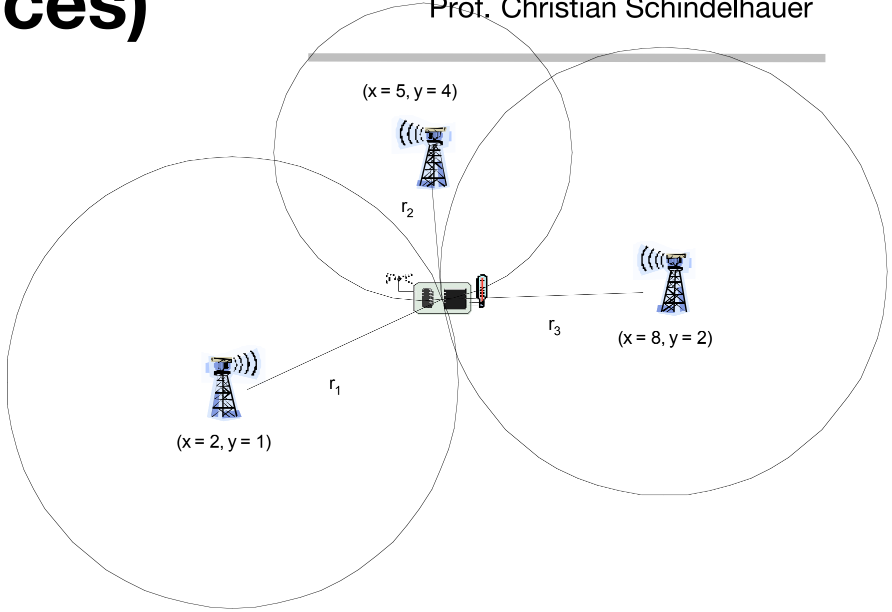
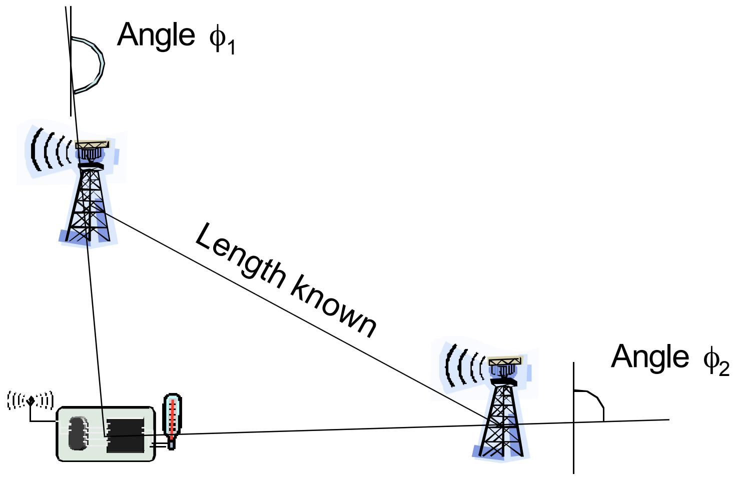
- **Proximity**
  - Exploit finite range of wireless communication
  - E.g.: easy to determine location in a room with infrared room number announcements
- **(Tri-/Multi-)***lateration* **and** *angulation*
  - Use distance or angle estimates, simple geometry to compute position estimates
- **Scene analysis**
  - Radio environment has characteristic "signatures"
  - Can be measured beforehand, stored, compared with current situation





Estimating distances – RSSI

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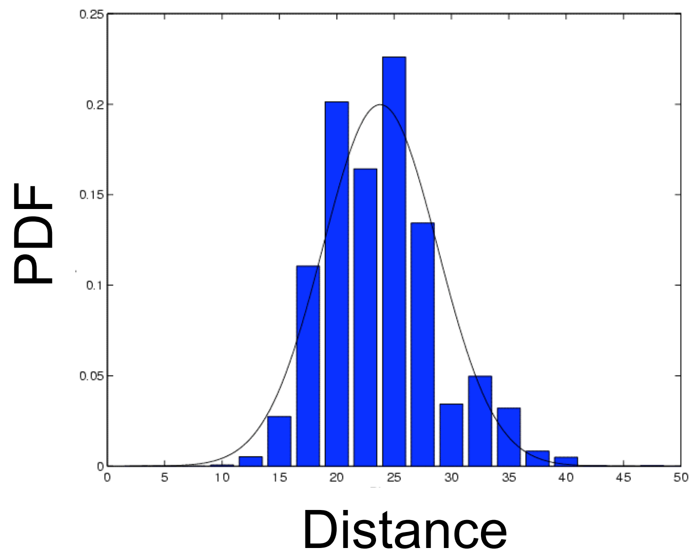
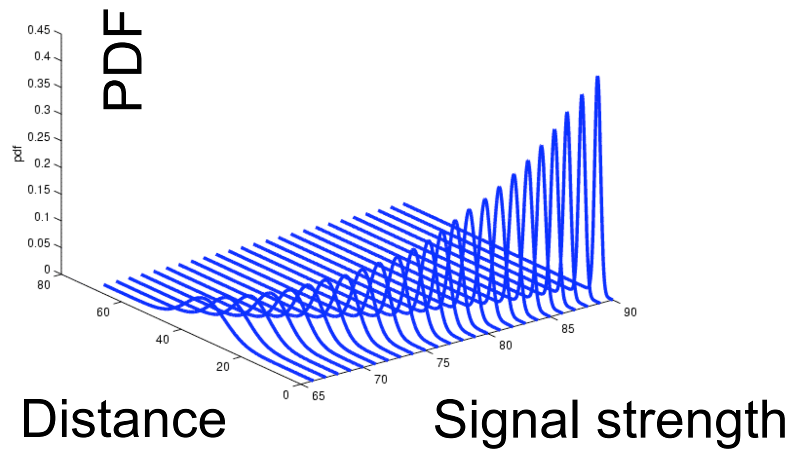
- **Received Signal Strength Indicator**
  - Send out signal of known strength, use received signal strength and path loss coefficient to estimate distance

$$P_{\text{recv}} = c\frac{P_{\text{tx}}}{d^{\alpha}} \Leftrightarrow d = \sqrt[\alpha]{\frac{cP_{\text{tx}}}{P_{\text{recv}}}}$$

  - Problem: Highly error-prone process – Shown: PDF for a fixed RSSI





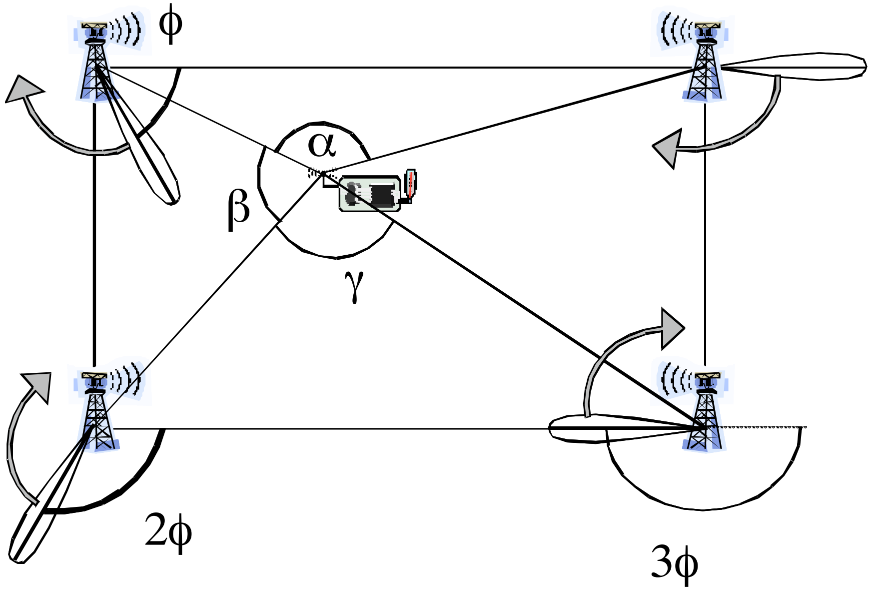
Estimating distances – other means

- **Time of arrival (ToA)**
  - Use time of transmission, propagation speed, time of arrival to compute distance
  - Problem: Exact time synchronization

- **Time Difference of Arrival (TDoA)**
  - Use two different signals with different propagation speeds
  - Example: ultrasound and radio signal
    - Propagation time of radio negligible compared to ultrasound
  - Compute difference between arrival times to compute distance
  - Problem: Calibration, expensive/energy-intensive hardware

Determining angles

- **Directional antennas**
  - On the node
  - Mechanically rotating or electrically "steerable"
  - On several access points
    - Rotating at different offsets
    - Time between beacons allows to compute angles



Some range-free, single-hop localization techniques

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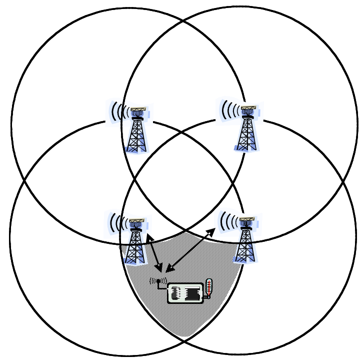
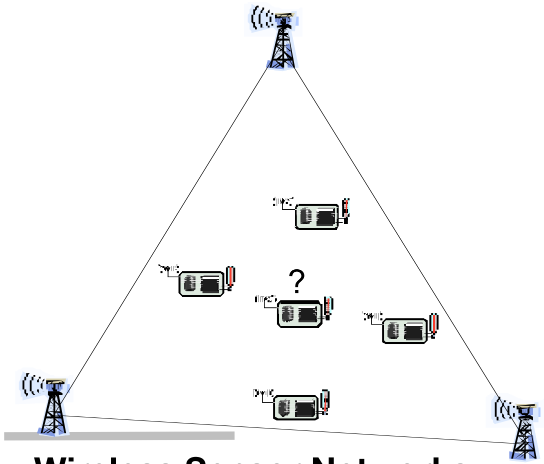
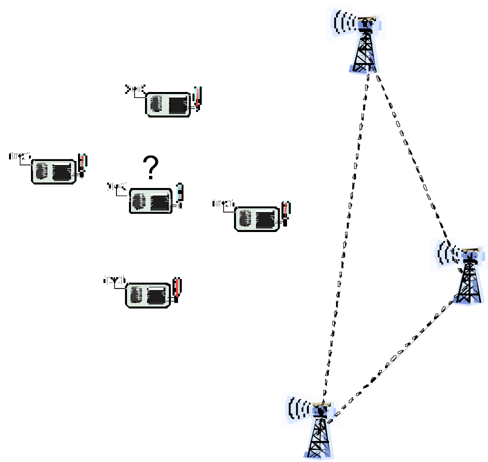
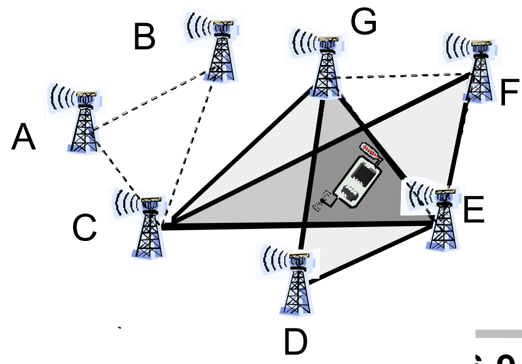
- *Overlapping connectivity*: **Position is estimated in the center of area where circles from which signal is heard/not heard overlap**



- *Approximate point in triangle*
  - Determine triangles of anchor nodes where node is inside, overlap them
  - Check whether inside a given triangle – move node or simulate movement by asking neighbors
  - Only approximately correct







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Overview

- **Basic approaches**
- *Trilateration*
- **Multihop schemes**

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Trilateration

- **Assuming distances to three points with known location are exactly given**
- **Solve system of equations (Pythagoras!)**
  - (x_i, y_i) : coordinates of ***anchor point*** i, r_i distance to anchor i
  - (x_u, y_u) : unknown coordinates of node

$$(x_i - x_u)^2 + (y_i - y_u)^2 = r_i^2 \text{ for } i = 1, \ldots, 3$$

  - Subtracting eq. 3 from 1 & 2:

$$(x_1 - x_u)^2 - (x_3 - x_u)^2 + (y_1 - y_u)^2 - (y_3 - y_u)^2 = r_1^2 - r_3^2$$
$$(x_2 - x_u)^2 - (x_2 - x_u)^2 + (y_2 - y_u)^2 - (y_2 - y_u)^2 = r_2^2 - r_3^2.$$

  - Rearranging terms gives a linear equation in (x_u, y_u)!

$$2(x_3 - x_1)x_u + 2(y_3 - y_1)y_u = (r_1^2 - r_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2)$$
$$2(x_3 - x_2)x_u + 2(y_3 - y_2)y_u = (r_2^2 - r_2^2) - (x_2^2 - x_3^2) - (y_2^2 - y_3^2)$$

Trilateration as matrix equation

- **Rewriting as a matrix equation:**

$$2\begin{bmatrix} x_3 - x_1 & y_3 - y_1 \\ x_3 - x_2 & y_3 - y_2 \end{bmatrix} \begin{bmatrix} x_u \\ y_u \end{bmatrix} = \begin{bmatrix} (r_1^2 - r_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) \\ (r_2^2 - r_2^2) - (x_2^2 - x_3^2) - (y_2^2 - y_3^2) \end{bmatrix}$$

- **Example:** **$(x_1, y_1) = (2,1)$, $(x_2, y_2) = (5,4)$, $(x_3, y_3) = (8,2)$, $r_1 = 10^{0.5}$, $r_2 = 2$, $r_3 = 3$**

$$2\begin{bmatrix} 6 & 1 \\ 3 & -2 \end{bmatrix} \begin{bmatrix} x_u \\ y_u \end{bmatrix} = \begin{bmatrix} 64 \\ 22 \end{bmatrix}$$

$\rightarrow (x_u,y_u) = (5,2)$

Thank you

*(and thanks go also to **Holger Karl** for providing slides)*

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