Algorithms for Radio Networks

Localization

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Localization

- Determine the physical position or logical location
  - coordinate system
  - reference points
  - Absolute or relative coordinates

- Parameter
  - Centralized or distributed computing
  - Application
    - Indoors, outdoors, global
  - sources of information

- Metrics
  - accuracy
  - precision
  - other costs
Sources of Information

- **Neighborhood information**
  - Range provides coarse location information
    - e.g. GSM / UMTS cell, wireless IDs
- **Triangulation and trilateration**
  - Angle differences
  - distance measurement
- **Analysis of the environment**
  - Characteristic "signature" by radio conditions in the environment
RSSI

- Received Signal Strength Indicator
  - Using the path loss at a known transmission power
  - Measurement of the received signal

\[ P_{\text{recv}} = c \frac{P_{\text{tx}}}{d^\alpha} \iff d = \left( \frac{c P_{\text{tx}}}{P_{\text{recv}}} \right)^{\frac{1}{\alpha}} \]

  - Problem: High error rate
- Problem: high error rate
  - Probability distribution for RSSI and given transmission power

RSSI

- Problem: high error rate
  - Probability distribution for RSSI and given transmission

Algorithm
Prof. Chri
Sonntag, 11. Dezember 11
Time of Arrival

- Time of arrival (TOA)
  - Transmission time is measured
  - Results from the quotient:
    - Transmission time = distance / speed signal

- Problem
  - Positions of measurement points (anchors) must be known
  - Accurate time measurement
  - Clock synchronization
  - Relative timing requires further anchors
Time Difference of Arrival (ToA)

- Two different signals with different transmission speeds
  - E.g. ultrasound and radio signal
  - Main component of the speed of sound
  - Calculate the different arrival times is distance

- Problems:
  - calibration
  - special hardware is required
Determination of Angles

- Optical angle measurement
  - done manually
- Laser beams
  - maximum accuracy
  - Controlled by rotating mirrors
- Directional antennas
  - free joint-directional or parabolic antennas
- Smart Antennae (antenna array)
  - (still) low precision (up to 1-2 degrees)
Coarse Localization Techniques

- **Hop-distance**
  - in dense ad hoc networks or wireless sensor networks
  - approximate position by the number of hops to anchor points

- **Overlapping connections**
  - position at the intersection of the received transmission circuits

- **Localization point in the triangle**
  - determination of triangles of anchor points
    - in which the node lies
  - overlap provides approximate position
Trilateration

- Assuming the distance to three points is given
- System of equations
  - \((x_i, y_i)\): coordinates of an anchor point \(i\),
  - \(r\) distance from the anchor point \(i\)
  - \((x_u, y_u)\): unknown coordinates of a node

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

- Problem: Quadratic equations
  - Transformations lead to a linear system of equations
Trilateration

- System of equations

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

- Transformation

\[
\begin{align*}
(x_1 - x_u)^2 - (x_u - x_3)^2 + (y_1 - y_u)^2 - (y_u - y_3)^2 &= r_1^2 - r_3^2 \\
(x_2 - x_u)^2 - (x_2 - x_u)^2 + (y_2 - y_u)^2 - (y_u - y_2)^2 &= r_2^2 - r_3^2.
\end{align*}
\]

- results in:

\[
\begin{align*}
2(x_3 - x_1)x_u + 2(y_3 - y_1)y_u &= (r_1^2 - r_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) \\
2(x_3 - x_2)x_u + 2(y_3 - y_2)y_u &= (r_2^2 - r_3^2) - (x_2^2 - x_3^2) - (y_2^2 - y_3^2)
\end{align*}
\]
Trilateration as a Linear System of Equations

- Forming a system of equations

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

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

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

\[\rightarrow (x_u, y_u) = (5,2)\]
Some Available Localization Systems

- **Satellite-based**
  - NAVSTAR-GPS
  - GLONASS
  - Galileo

- **Land stations**
  - LORAN-C
  - Mobile cells
  - WLAN identification
Possible Improvements

- Combination of different methods
  - magnetic field
  - air pressure
  - sonar
- Kalman filter
  - Extension of Markov filters
- Motion sensors
  - gyroscopes
  - acceleration sensors
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