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Internet of Things

IV. Localization

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Internet of Things: Localization

Table of Contents

1. Classification of Localization Mechanisms

- Coordinate Systems
  - Absolute
    - Global coherence
  - Relative
    - Positions are relative to a local system.
    - Network-wide coherence
  - Local
    - Only communicating parties position themselves to each other.
    - Local coherence
- Algorithms
  - Centralized
    - Central node might use global information.
  - Distributed
    - Usage of distributed computing and communication
  - Localized
    - Usage of local data and communication in limited area
- Measurement parameters
  - Distances (lateration)
  - Angles (angulation)
- Range-free and Range-based
  - Range-based
    - range-measurements, e.g., received signal strength, for distance estimation
  - Range-free
    - estimation of relative positions using connectivity information: lower hardware requirements, but less accurate

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2. Determining Distances

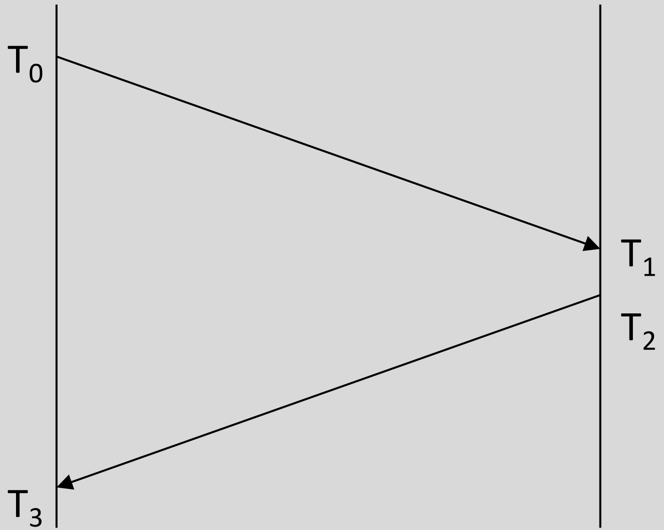
Estimation of distances to anchor nodes based on

- Time of Arrival
- Time Difference of Arrival
- Received Signal Strength Indicator
- Lighthouse location system

2. Determining Distances

1.1 Time of Arrival

- Distance $d = ((T_3 - T_0) - (T_2 - T_1)) * v / 2$
- v: velocity of signal
- Example: ultrasound
- Problems:
  - Signal processing
  - Receiver delay



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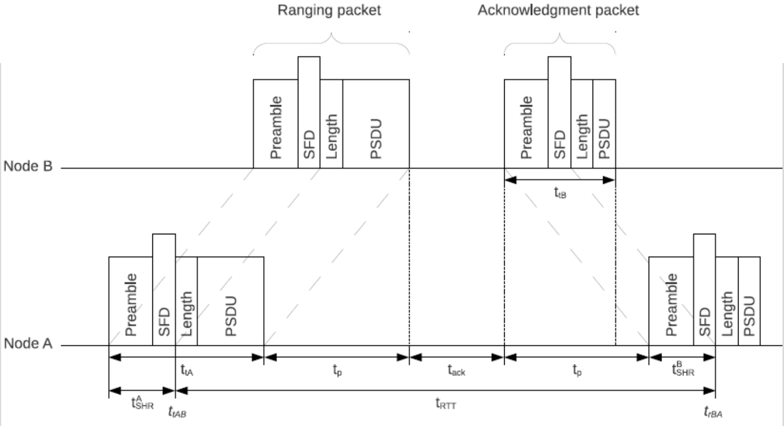
2. Determining Distances

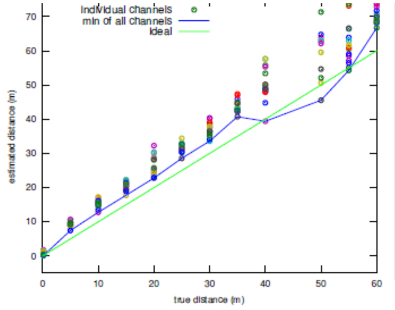
1.2 Example: Two-Way Time of Flight Sensor Network Ranging

– No time synchronization needed

– Implementation on Zolertia Z1 with MSP 430 processor with digitally clocked oscillator (DCO) and 0.32 kHz uncertainty on clock frequency
  – Transmission in case of clear channel
  – Use of CC2420's automatic (hardware) acknowledgement feature to avoid variable processing delay

– Multipath effects may depend on different frequencies: use several frequencies and take lowest delays.

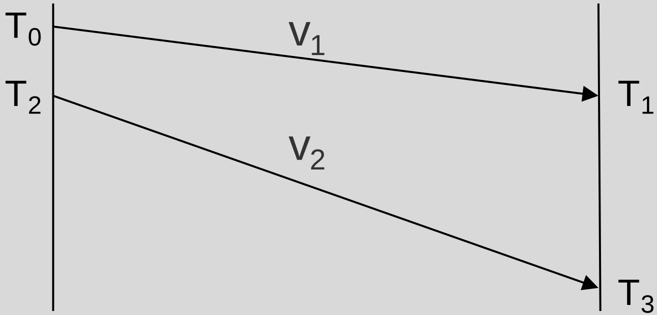




2. Determining Distances

2.1 Time Difference of Arrival I

- Transmission of two different signals (e.g., radio, ultrasound) from a single point
- Distance d
- $T_1 – T_0$ = offset + d/v_1
- $T_3 – T_2$ = offset + d/v_2
- $d = ((T_3 – T_1) – (T_2 – T_0)) * (v_1 * v_2) / (v_1 – v_2)$



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2. Determining Distances

2.2 Time Difference of Arrival II

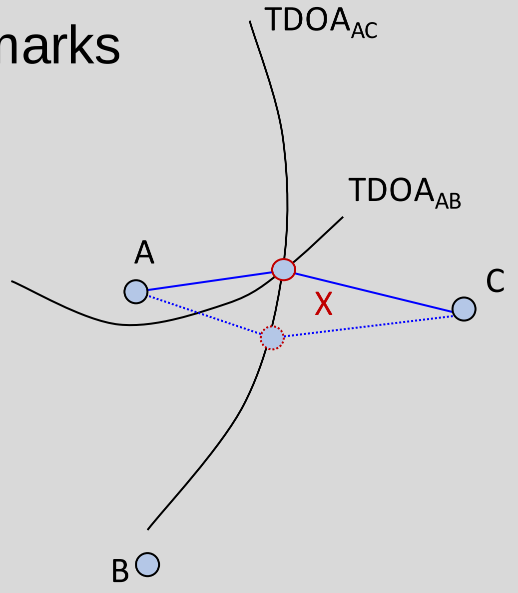
– Measurement of difference in distances to two landmarks

– Time of signal transmission need not be known.

– Each TDOA measurement defines line-of-position as a hyperbola.

– Hyperbola is a curve of constant difference in distance from two fixed points.

– Location of node is at the intersection of the hyperbolas

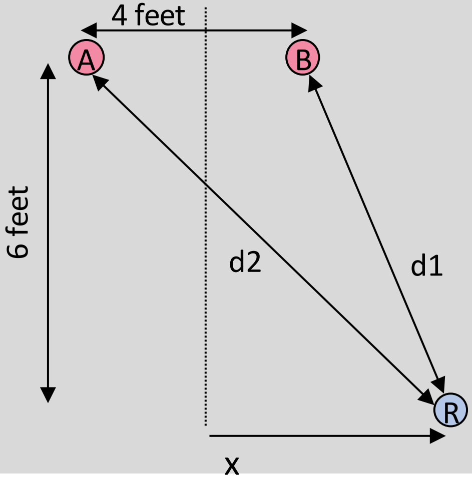


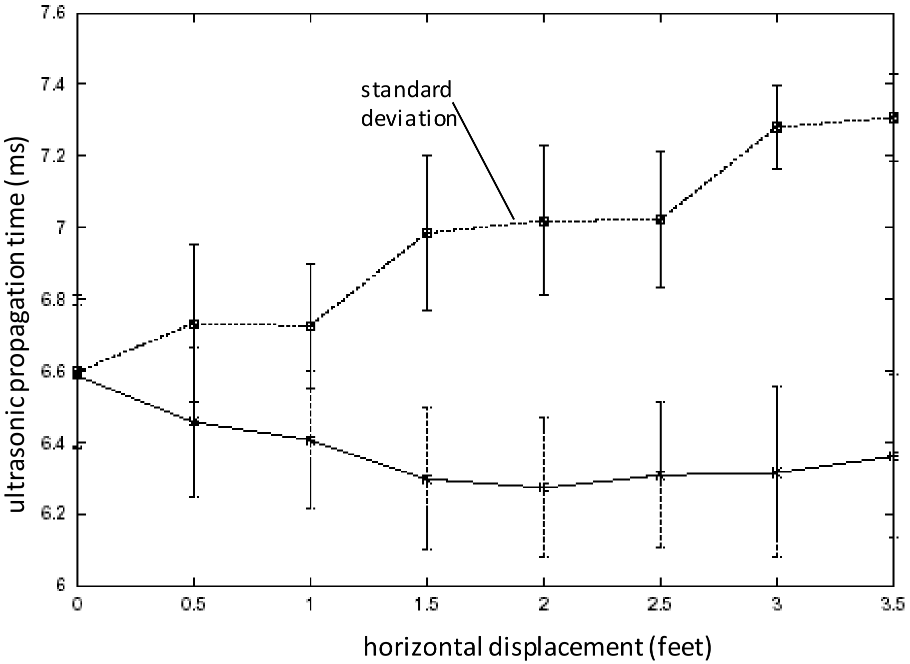
2. Determining Distances

2.3 Example: Cricket

– Usage of radio and ultrasound beacons

– Radio signal is used by the receiver to start ultrasound device.



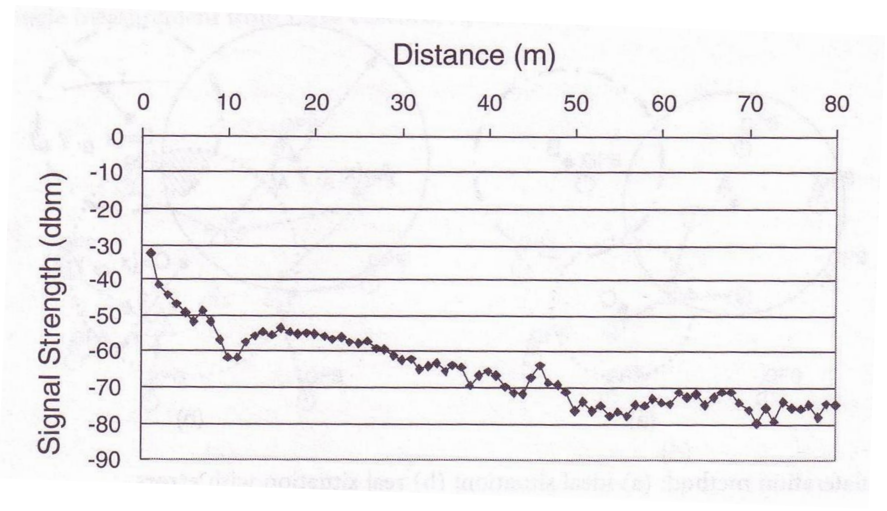


2. Determining Distances

3.1 Received Signal Strength Indicator

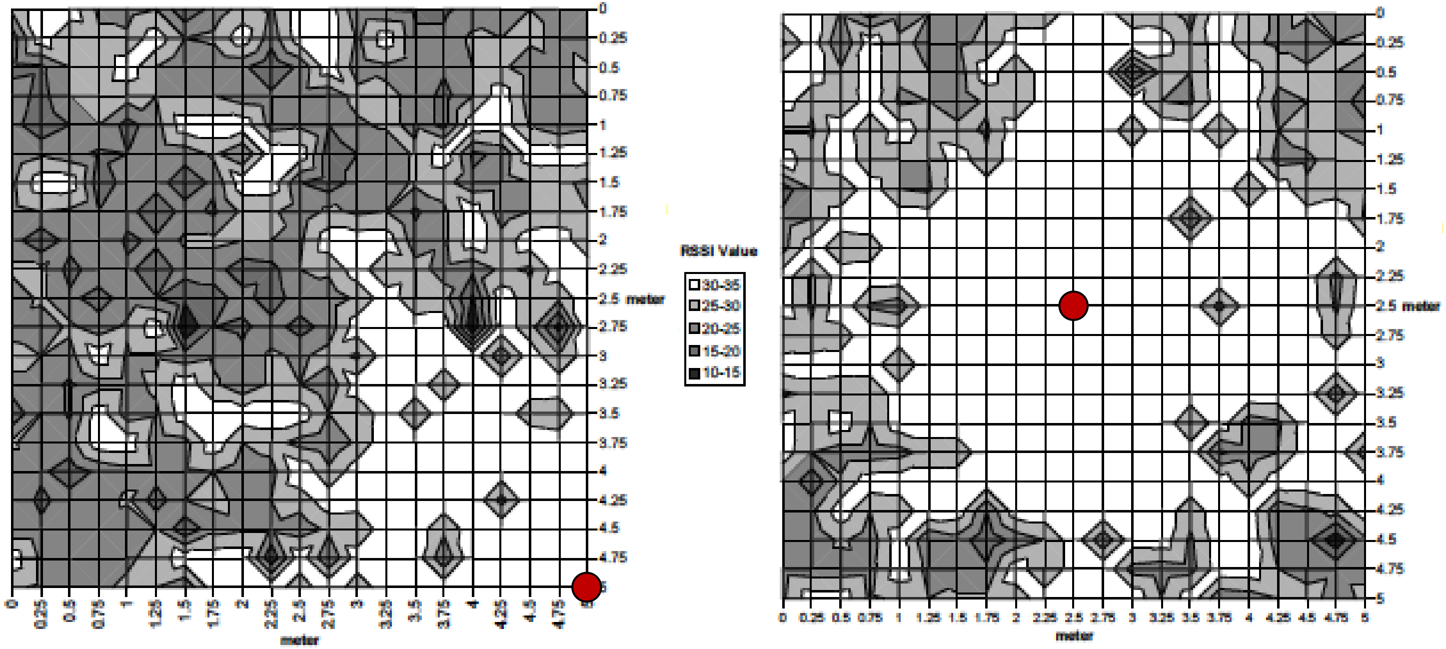
$$PL(d) = PL(d_0) + 10n\log\left(\frac{d}{d_0}\right)$$

- PL: path loss
- d_0: reference point close to transmitter
- n: loss coefficient
- Problems: unstable curve due to environmental factors
- Example: IEEE 802.11 WLAN



2. Determining Distances

3.2 Example: RSSI with MSB Nodes



2. Determining Distances

4. Lighthouse Location System

– Assumption: Parallel beam is transmitted from a lighthouse.

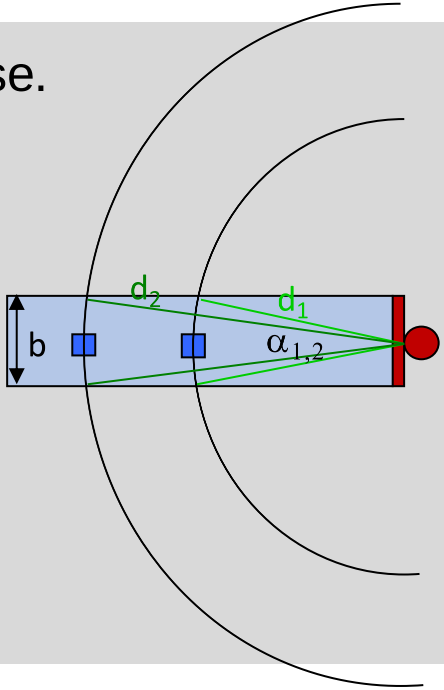
– Each node measures the time t_{beam} it sees the beam.

– t_{turn}: time for one beam rotation

$$\alpha = 2\pi \frac{t_{beam}}{t_{turn}} \wedge d = \frac{b}{2\sin(\frac{\alpha}{2})} \Rightarrow d = \frac{b}{2\sin(\pi \frac{t_{beam}}{t_{turn}})}$$

– Problem:
  – Parallel beam might be difficult to realize.

– Results:
  – Errors < 2 % with 2 lighthouses (2D)



3. Determining Angles

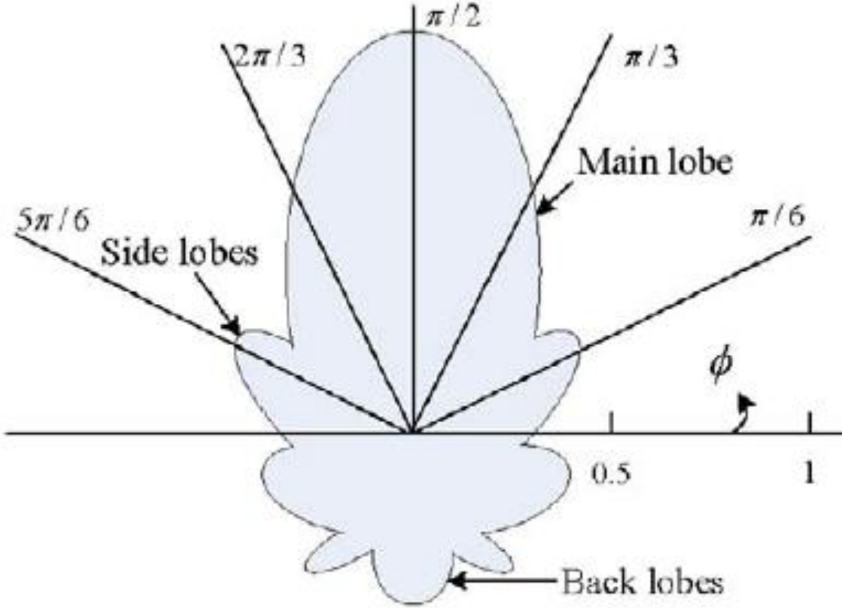
Estimation of angles using

- Directional antennas (transmitting / receiving from certain directions only), e.g.
  - Beamforming
  - Lighthouses: VHS Omni-Directional Ranging
  - Estimating RSS Ratios Between Directional Antennas
- Measuring phase or time difference of signal arrival at / from multiple antennas, e.g. : Compass

3. Determining Angles

1. Beamforming

- Based on anisotropic reception pattern of antennas
- Electronic or mechanical rotation of antenna



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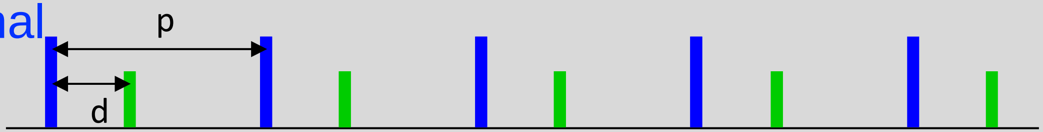
3. Determining Angles

2. VHS Omni-Directional Ranging

– Landmark sends two signals
  1. Periodic and omni-directional
  2. Directional and rotating



– Node measures time difference between first and second signal.

– $\alpha = d / p * 2\pi$

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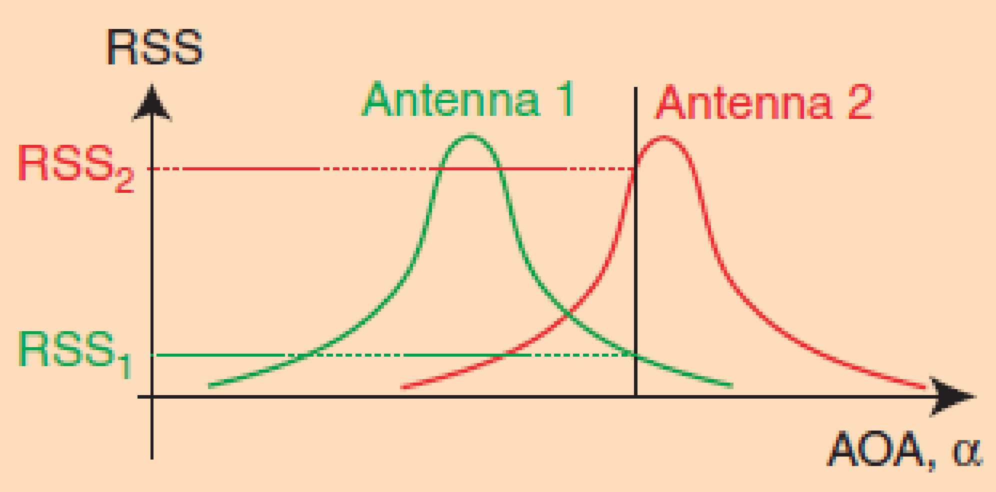
3. Determining Angles

3. Estimating RSS Ratios Between Directional Antennas

Ratio of RSS between two different directional antennas depends on angle of the signal.



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3. Determining Angles

4. Compass

$$(x+\frac{L}{2}\sin\alpha)^2+(\frac{L}{2}\cos\alpha)^2=x_2^2$$

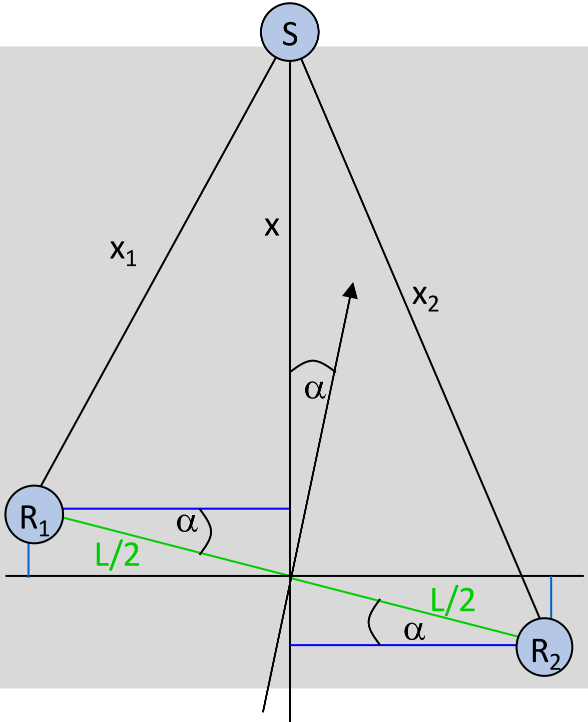
$$(x-\frac{L}{2}\sin\alpha)^2+(\frac{L}{2}\cos\alpha)^2=x_1^2$$

$$\Rightarrow x_2^2-x_1^2=2Lx\sin\alpha$$

$$for\, x>>L: x=\frac{x_1+x_2}{2}$$

$$\Rightarrow x_2^2-x_1^2=L(x_1+x_2)\sin\alpha$$

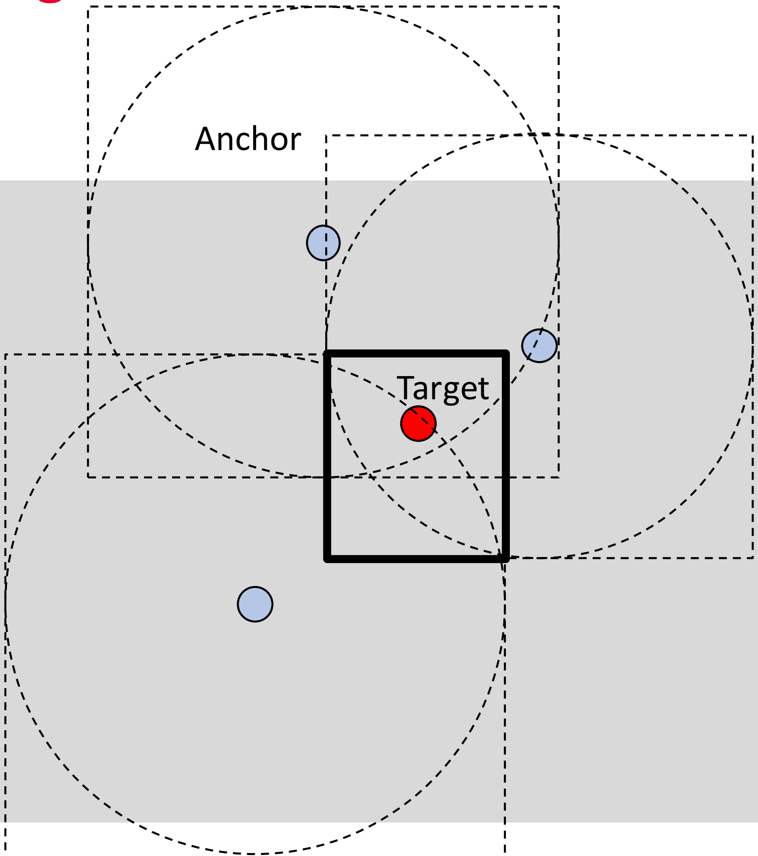
$$\Leftrightarrow \alpha=\arcsin(\frac{x_2-x_1}{L})$$



4. Range-Based Localization Algorithms

1. Bounding Box

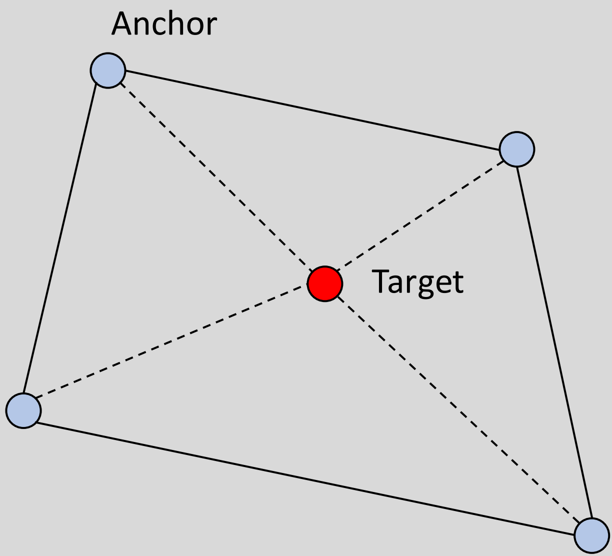
- Construct boxes around anchor nodes with side length equal to estimated distance.
- Construct intersection of bounding boxes
- Simple and fast implementation



4. Range-Based Localization Algorithms

2. Weighted Centroid

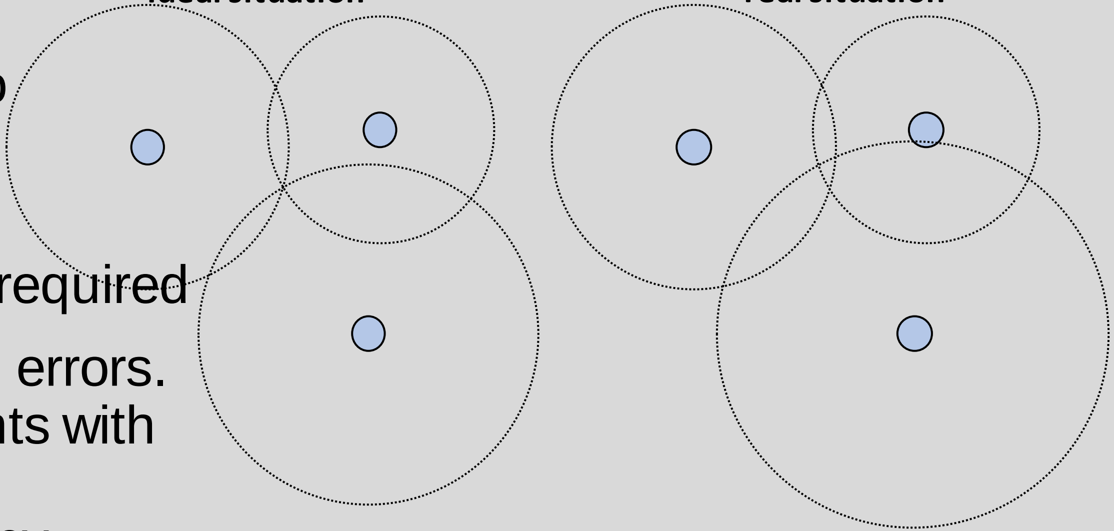
- Set of anchor nodes with known position vectors x_i
- Weights ω_i, e.g., dependent on number of received beacons, relative RSSI, etc.
- Target position: $x = \frac{\sum_{i=1}^{N} \omega_i x_i}{\sum_{i=1}^{N} \omega_i}$



4. Range-Based Localization Algorithms

3. Trilateration

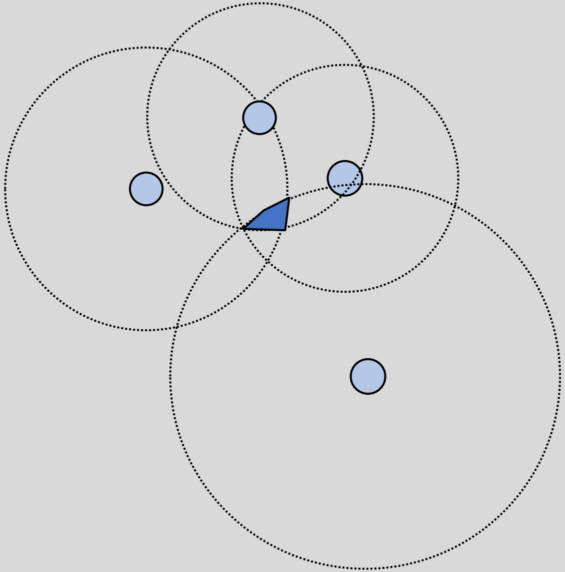
- Distance measurements to landmark nodes
- Curves have intersections
  → 3 landmarks for planes required
- Measurements might have errors.
  → redundant measurements with least-square techniques to improve estimation accuracy



4. Range-Based Localization Algorithms

4.1 Multilateration

- Consideration of multiple (> 3) landmark nodes
- Minimization of errors



4. Range-Based Localization Algorithms

4.2 Multilateration

Given: distances d_i of a node (x, y) to nodes with known positions (x_i, y_i)

$$(x_1 - x)^2 + (y_1 - y)^2 = d_1^2$$

$$\dots$$

$$(x_n - x)^2 + (y_n - y)^2 = d_n^2$$

Linearization by subtracting last line from first n-1 equations

$$x_1^2 - x_n^2 - 2(x_1 - x_n)x + y_1^2 - y_n^2 - 2(y_1 - y_n)y = d_1^2 - d_n^2$$

$$\dots$$

$$x_{n-1}^2 - x_n^2 - 2(x_{n-1} - x_n)x + y_{n-1}^2 - y_n^2 - 2(y_{n-1} - y_n)y = d_{n-1}^2 - d_n^2$$

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4. Range-Based Localization Algorithms

4.3 Multilateration

$$A\hat{x}=b$$

$$A=\begin{bmatrix} 2(x_1-x_n) & 2(y_1-y_n) \\ \dots & \dots \\ 2(x_{n-1}-x_n) & 2(y_{n-1}-y_n) \end{bmatrix}$$

$$b=\begin{bmatrix} x_1^2-x_n^2+y_1^2-y_n^2+d_n^2-d_1^2 \\ \dots \\ x_{n-1}^2-x_n^2+y_{n-1}^2-y_n^2+d_n^2-d_{n-1}^2 \end{bmatrix}$$

Overdetermined system can be solved by standard least squares approach:

$$\hat{x}=(A^TA)^{-1}A^Tb,\ \hat{x}: location\,estimate$$

$\hat{x}$=(x,y)

4. Range-Based Localization Algorithms

4.4 Multilateration

- For any vector: $||v||_2^2 = v^T \cdot v$
  - $||v||_2$: 2-norm of v, i.e. square root of sum of squares of vector elements
- $||Ax - b||_2^2 = (Ax-b)^T \cdot (Ax-b)$
  $= (Ax)^T (Ax) - b^T Ax - (Ax)^T b + b^T b$
  $= x^T A^T Ax - 2x^T A^T b + b^T b$

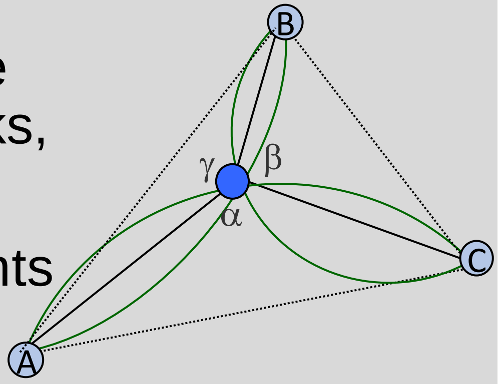
- Minimum is found at 0 of derivative with respect to x

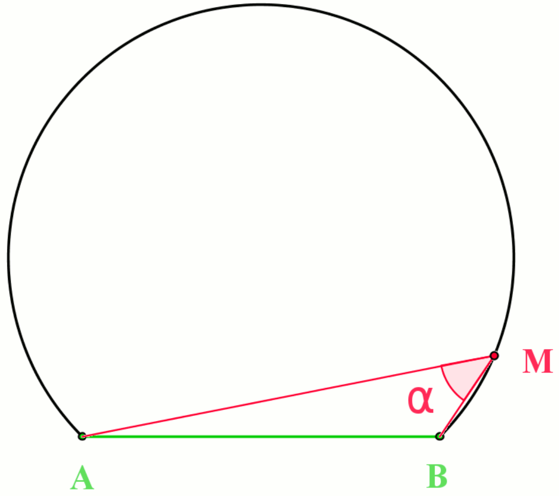
$\Rightarrow 2\, A^T A\, x - 2A^T b = 0 \Leftrightarrow A^T A\, x = A^T b \Leftrightarrow \; x = (A^T A)^{-1} A^T b$

4. Range-Based Localization Algorithms

5. Triangulation

- Node can measure angles to landmarks, e.g. α, β, γ.
- Circles denote points with the same angle to two given points.
- Node must lie on circle intersections.





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4. Range-Based Localization Algorithms

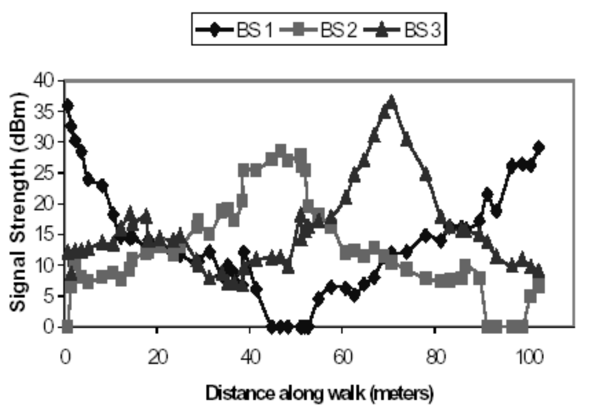
6.1 Fingerprinting

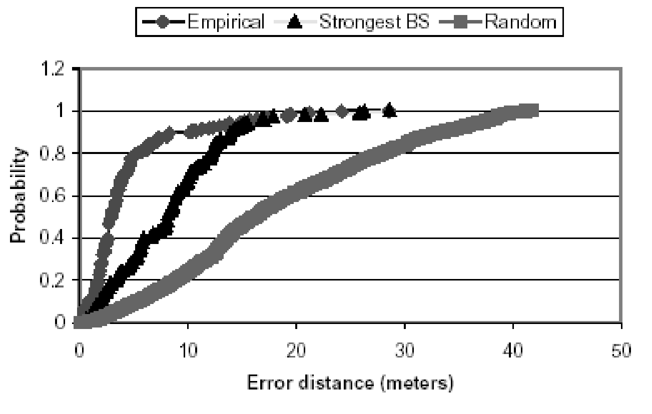
- Comparison of received signal pattern with database
- Phases
  - Off-line
    - Collection of signals from all base stations at each training location
    - Database entry: (x, y, (ss1, ss2, …, ssn))
  - Real-time
    - Estimation of location by comparing current received signal strengths with database
    - Algorithm: Nearest Neighbor Signal Space (NNSS)
      - Computation of Euclidean distance (square root of summation of squares of differences) in signal space to each database entry
      - Training location with minimum Euclidean distance is chosen.
      - Variant: select k closest locations and compute average coordinates
- Example: RADAR

4. Range-Based Localization Algorithms

6.2. Example: RADAR

- Experiments with 3 base stations
- NNSS Algorithm
- (ss1, ss2, ss3) → (x, y, d), d: direction
- Averaging makes only sense for a few nodes (k = 2, …, 4).





5. Range-Free Localization

1. Overview

Techniques based on information about

- Area
  - Division of network into areas, e.g., overlapping transmission ranges, and estimation of area in which the node lies
- Hop count
  - Estimation of distance between nodes A and B: $R * h_{min}$
    - R: transmission range
    - h_{min}: minimum number of hops between A and B
- Neighbourhood
  - Estimation of location based on received beacons, e.g., centroid algorithm

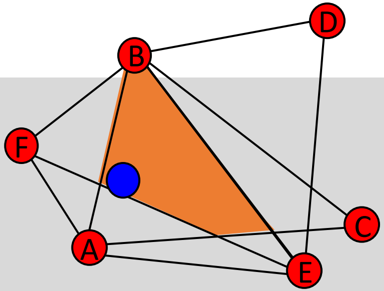
Examples

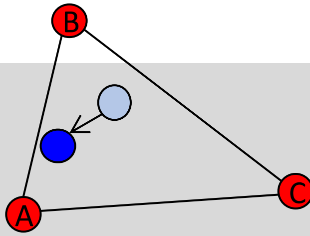
- Approximate Point in Triangle
- Ad Hoc Positioning System
- Centroid (centre of estimated area, no weights)

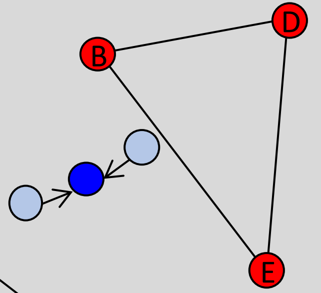
5. Range-Free Localization

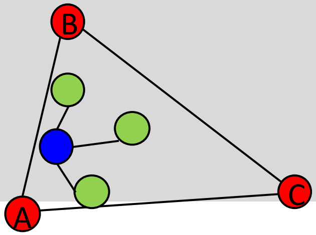
2. Approximate Point in Triangle

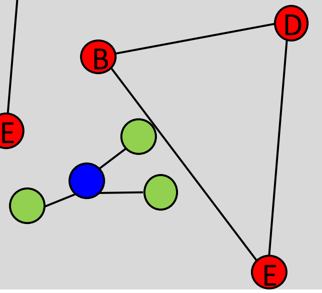
- Node detects whether itself is inside or outside of triangle.; Example 1: Node is inside ACB and BFE, but outside BED.
- Target node is located at intersection of triangles, e.g., in center of gravity.
- Perfect Point-In-Triangulation Test
  - Node is inside the triangle: Node must be closer to (further from) at least one corner than before; Example 2: Node moves closer to A.
  - For a node outside a triangle, there must exist a direction, in which the position becomes further from or closer to all three corners; Example 3: Node moves away from B, D, and E.
- Approximate Point-In-Triangulation Test
  - Approximation by enquiring distances from neighbors, e.g., using RSSI values
  - If no neighbor is further from/closer to all three corners simultaneously, the node assumes that it is inside triangle (Example 4), otherwise it assumes to be outside of the triangle (Example 5).





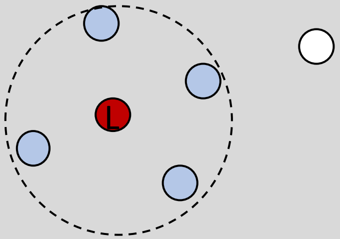






6. Localization in Multi-Hop Environments

Most localization schemes assume connectivity of a node to a certain number (e.g., 3) of landmark nodes.

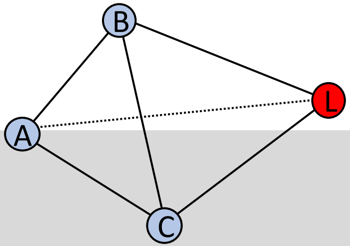


Approaches

- Multi-hop range estimation
  - Use indirect range estimation between node and distant landmark supported by multi-hop communication
  - Example: Ad Hoc Positioning System
- Iterative/collaborative multilateration
  - Nodes adjacent to landmarks estimate their position. Their neighbors use the nodes with known positions as landmarks.
  - Example: Ad Hoc Localization System

6. Localization in Multi-Hop Environments

1. Ad Hoc Positioning System



- Nodes directly connected to a landmark learn distance to it.
- Nodes with neighbors knowing their positions relative to a landmark compute distance/orientation to that landmark, too.
- Example:
  - A has distances to B and C.
  - B and C have distances to each other and also to landmark L.
  - A can calculate distance to L.

Variants

- DV-hop
  - Calculation of average hop length by landmark
  - Estimation of distance to landmarks based on hop count to landmark
- DV-Euclidean
  - Nodes can use distance information to other nodes with known position to estimate destination to landmark, e.g., lengths AB, AC, BC and positions B, C are known.
- DV-position
  - Usage of orientation information

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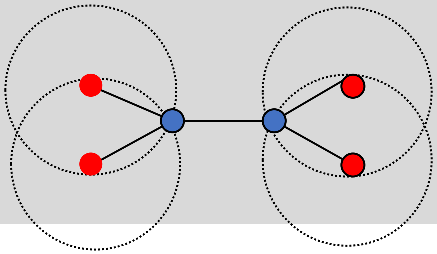
6. Localization in Multi-Hop Environments

2. Ad hoc Localization System

- Nodes learning their position via landmarks can act as landmarks for other nodes.
- Problem:
  - A node might never be adjacent to more than 2 landmarks.



- Approach: Collaborative multi-lateration
  - Identification of a group of nodes that can form a non-linear system with sufficient equations to resolve the unknown coordinates

Thanks

for Your Attention

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