10. Localization

Node localization in WSN

Wireless sensor networks

Martin Úbl
`ublm@kiv.zcu.cz`

2023/24

<DCSE> DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

Localization

- node localization is an important problem
- having "precise" location allows for:
  - effective routing
  - effective energy saving
  - data affinity
  - meaningful aggregation

Localization

- types of localization:
  - absolute localization (2D, 3D)
  - relative localization (2D, 3D)
  - directional localization
- relative localization can localize by:
  - distance (obviously)
  - signal strength
  - signal to noise ratio
  - other spatial and signal attributes

Localization

Parameters

- parameters
  - extra hardware? price?
  - can we use fixed beacons?
  - accuracy
  - indoors/outdoors
  - direct visibility
  - effective – how many messages to transmit?
  - duration
  - clock precision
  - robustness and fault-tolerance

Localization

- types of localization procedures
- pair-wise localization
  - two nodes localize each other
  - relative – determines a single parameter
    - e.g., determine distance, signal strength
  - never an absolute information – not enough data
- global localization
  - localization of node within a network
  - information from multiple nodes (multiple locations)

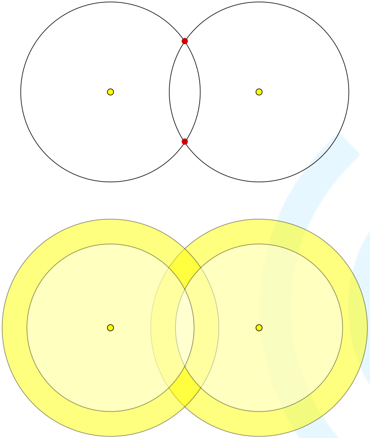
Localization

Algorithms

- Range- or angle-based
  - often very energy consuming
  - Time of Arrival (ToA)
  - Time Difference of Arrival (TDoA)
  - Angle of Arrival (AoA)
- range independent
  - relative localization, often based on logical metric
  - in fact, some of them are determining the network topology
  - Centroid Localization Algorithm (CLA)
  - Approximate Point In Triangulation (APIT)
  - Distance Vector-Hop (DV-Hop)

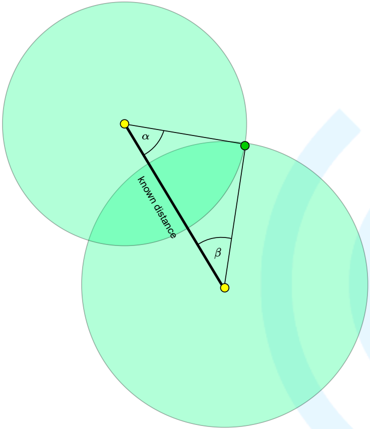
Localization

- distance-based localization
- ideal case (top), real-world (bottom)



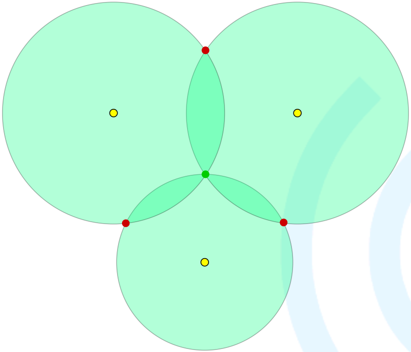
Localization

- triangulation
- localize third node based on known distance between 2 stationary points and angles



Localization

- trilateration
- localize fourth node based on distances from 3 stationary points



Localization

GPS

- *Global Positioning System* (GPS)
- uses trilateration
- 76 satellites orbiting Earth (as of 2023)
- at least 7 satellites at a single moment in time should be visible
- theoretically, we need only 4 (3D localization)
  - practically, at least 5-6 to obtain reasonable accuracy
- can synchronize time
- alternatives:
  - GLONASS (Russia)
  - Galileo (Europe)
  - BeiDou (China)

Localization

GPS

- unsuitable for WSN
  - highly energy consuming
  - long initialization procedure (up to minutes)
  - relatively high cost
- can be used for e.g., beacon nodes to determine precise location
- beacon nodes then use a different protocol to localize the rest of WSN
- presumed accuracy: 10m, sometimes 2-3m
  - this might not be accurate enough for WSN nodes

Localization

TOA

- **Time of Arrival** (ToA)
- trilateration-based, e.g., GPS
- or measuring a distance by considering the time delay and transmission speed
- may be relatively good for longer distances
- practically not very usable for WSN

Localization

TDOA

- **Time Difference of Arrival** (TDoA)
- difference between two signals sent in parallel
- needs additional hardware
  - for example, we send one ultrasound signal and one radio signal
- we quantify the difference between time of arrivals
- we then calculate the distance based on signal properties
- many factors influence the speed:
  - temperature
  - humidity
  - spatial obstacles
  - etc.
- fairly complex for WSN

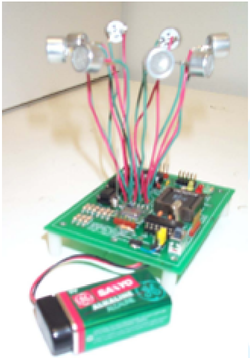
Localization

AoA

- **Angle of Arrival** (AoA)
- specialized receivers
  - multiple antennas
  - or rotating antennas with timed sampling
- ultrasound-based localization, or RSSI based localization without use of ultrasound
- more options:
  - sensor node has multiple antennas and measures angle
  - set of base stations have multiple antennas and triangulate

Localization
AoA

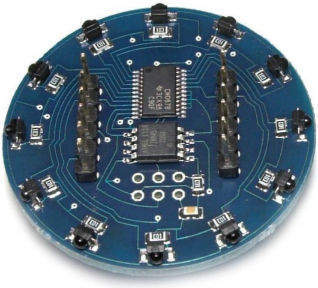
- Medusa node
- ultrasound AoA-based localization



Localization

AoA

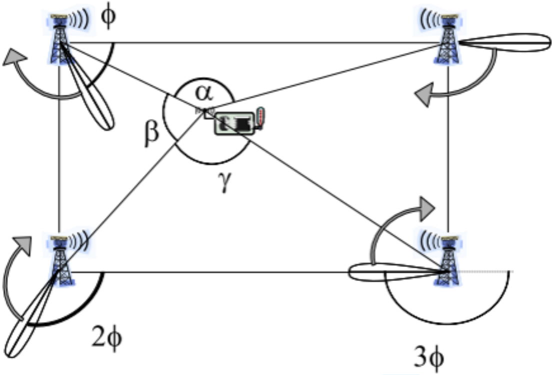
- Ir-AoA node
- infrared light AoA-based localization



Localization

AoA

- base stations with AoA localization
- known base station locations, we can triangulate



Localization

RSSI

- **Received Signal Strength Indicator** (RSSI)
- intensity of signal arriving to the receiver
- if the transmit power is known, we can calculate the approximate distance
- intensity diminishes approximately with the square of distance
- very rough estimation of distance
  - practically not very usable
  - large errors
  - reflections, refractions
  - uneven radio emission diagram

Localization

DV-Hop

- **Distance Vector-Hop** (DV-Hop)
- requires multiple *anchor nodes* (ideally at least 3 or 4)
- anchor nodes know their location
- anchor nodes flood the network with localization packets
- first phase propagates hop count
- second phase calculates the approximate location from all received localization packets

Localization

DV-Hop

- algorithm
  1. each anchor node i broadcasts localization packet containing the node location and hop count h_{ij} from anchor node initialized to 0
     - $[i, x_i, y_i, h_{ij}]$
  2. each node maintains a table of DV vectors; node receives localization packet
     - if it already has the i-th node, it checks, if the received h_{ij} is lower than the stored one
     - if yes, replace the one in table and forward the packet further with $h_{ij} + 1$
     - if no, ignore it
  3. each node eventually obtains a table of $[i, x_i, y_i, h_{ij}]$ records
  4. each anchor node calculates average distance per hop using the following formula:
     - $S_i = \frac{\sum_{i \neq j}^{N} (\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2})}{\sum_{i \neq j}^{N} h_{ij}}$

Localization

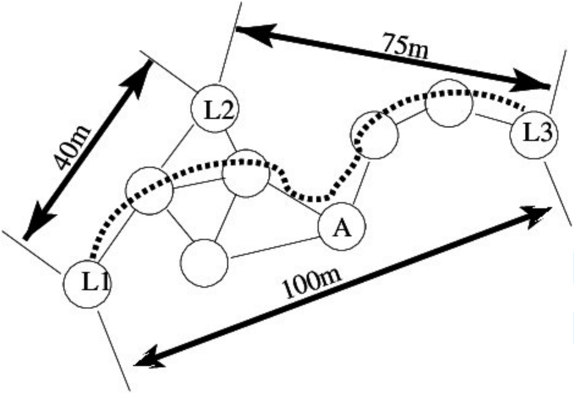
DV-Hop

- algorithm (part 2)
  5. anchor nodes floods their average hop size S_i to the network
     - $[i, S_i]$
  6. each node knows the average hop size towards all anchors
  7. each node can now calculate its approximate location, based on the knowledge:
     - $[i, x_i, y_i, h_{ij}, S_i]$
     - non-trivial calculation
     - `https://doi.org/10.1023/A:1023403323460`

Localization

DV-Hop

- example of DV-Hop location correction



Localization

CLA

- **Centroid Localization Algorithm** (CLA)
- anchor nodes periodically broadcast their location
- assumes, that anchor nodes have much larger radio reach than an ordinary node
- each node receives broadcasts of multiple anchor nodes
- each node estimates the distance of all anchor nodes
    - using RSSI, ToA, ...
- location of a node is the weighted centroid of obtained coordinates and distance estimations

Localization

PIT

- Point In Triangulation (PIT)
- criterion for localization
- assumes:
  - 1 to 2 % of nodes are anchors
  - anchors have at least 10 times the reach than regular nodes
  - each node must recognize, if it’s closer to the anchor, than its immediate neighbors
    - in other words – there exist local distance ordering of nodes

Localization

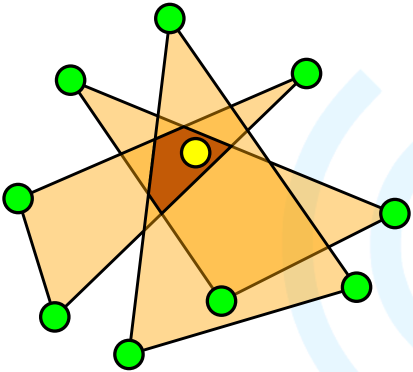
APIT

- **Approximate Point In Triangulation** (APIT)
- assumption:
  - network is enclosed by heterogeneous anchor nodes
  - anchor nodes have exact location (fixed)
- node localization based on trianges constructed from anchor nodes
- construct trianges between all anchor nodes
- determine, if the node is inside (PIT) or outside the triangle
- calculate the intersecting polygon of triangles containing the nodeV

Localization

APIT

- APIT example
- brown polygon is the estimated position of the localizated node



Localization

Algorithms, protocols

- lots of extensions were propiosed for DV-Hop and APIT protocols
- both of them may be the most widely used in current WSNs
- we may adjust them to fit our use case
  - e.g., if we know the physical topology beforehand, we may pre-configure lots of things
  - e.g., another strong assumption is the spacing of anchors – if it’s even, lots of algorithms work better

Localization

Final remarks

- localization is important for a lot of use cases
- there's no point in localization if we don't need it explicitly
- we must also consider the desired accuracy
- always consider relative localization before absolute localization