Sensor networks and applications

Routing (location based). Localization.

Localization in WSNs

- Most WSN applications require **location-aware operation**
  - E.g., environmental monitoring, vehicle tracking, etc.

- **Energy can be spared** as well with location-aware operation
  - E.g., location-based routing
    - There is no need for route discovery

- Using the GPS is far more expensive and complex in sensor networks!

Location based routing

- Nodes can be **addressed based on their location**.
- The position (location) of the nodes must be known.
  - GPS (expensive!)
  - Distance can be measured (based on signal strength or other quantities, e.g., acoustic signals)
  - Triangulation.

Localization

Taxonomy, methods.

Content

- Locatilazion (taxonomy)

- Localization solutions

Localization – taxonomy

- Localization information can be…
  - **physical**
    - E.g., location of a building: 47°39’17”N 122 °18’23”W 20.5m
  - **symbolic**
    - E.g., „in the kitchen”, „on a train towards Berlin”, ...

- Information systems providing physical localization information can be extended to provide symbolic localization.
  - E.g., **database**, where other infrormation/services can be provided with localization.
  - Many times we use it just for this!

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Localization – taxonomy

- Different information systems can be combined for localization.
  - E.g., GPS on a train + ticketing database + personal calendar entries → localization of a person

Localization – taxonomy (cont'd.)

- Absolute vs. relative position
  - **Absolute:** common reference grid is needed
    (e.g., GPS – geolocation coordinates)
  - **Relative:** reference frame can be different from object to object.
    (e.g., relative compared to itself)
- The absolute position can be easily converted into relative information (relative to some other object), and vice verse
  - E.g., triangulation in geography using reference heights
- Exception: The absolute <-> relative conversion is not possible if the reference point is moving and its (absolute) position is unknown.

Localization – taxonomy (cont'd.)

- „**Local localization**": The object to be localized is able to locate itself, and no one else can do it.
  - It can be advantageous from privacy point of view.
  - E.g., GPS
- In other cases the object itself has to provide some (telemetric or other) data to an external infrastructure.
  - E.g., active badges, RFID tags
- In many cases the localization information is private and <u>personal</u> information, that <u>must be protected</u>!

Localization – taxonomy (cont'd.)

- **Accuracy** vs. **precision**
  - E.g., A GPS receiver is able to position with 10m accuracy in 95% of the cases.
- The required accuracy is highly application specific!
  - E.g., „*Which paths whales choose during their jurney?*"
  - or: „*In which room was I at noon?*"
  - or: „*In which cubic centimeter of space was the tip of my finger at 12:01:59.412?*"
- Typically, higher precision can be obtained when accuracy is lower.

Localization – taxonomy (cont'd.)

- **Cost** – important in WSNs!
  - „time": time for deployment+ administration during operation
  - „space": infrastructure + hardware cost per node
- E.g., As for GPS the cost of satellites + their management (US Air Force) + GPS receiver/node + optional terrestial auxiliary devices
- **Limitations**: Some systems can not be used in certain circumstances.
  - E.g., GPS can not be used indoor.

Localization solutions

Localization…

- Localization can be done using…
  1. **reference points**, and
  2. **telemetry**.

- <u>Would be desirable, if</u> no special hardwer would be needed, with only a few reference points, in uneven node distribution, and with possible moving sensors…

Localization techniques

- **Centralized**:
  - Based on collected (global) information, the positions are calculated in a central location.
- **Distributed**:
  - All node calculates its own position by communicating with (some of) its neighbors..
- Distributed solutions
  - **Range-based**
  - **No range-based**

Localization techniques

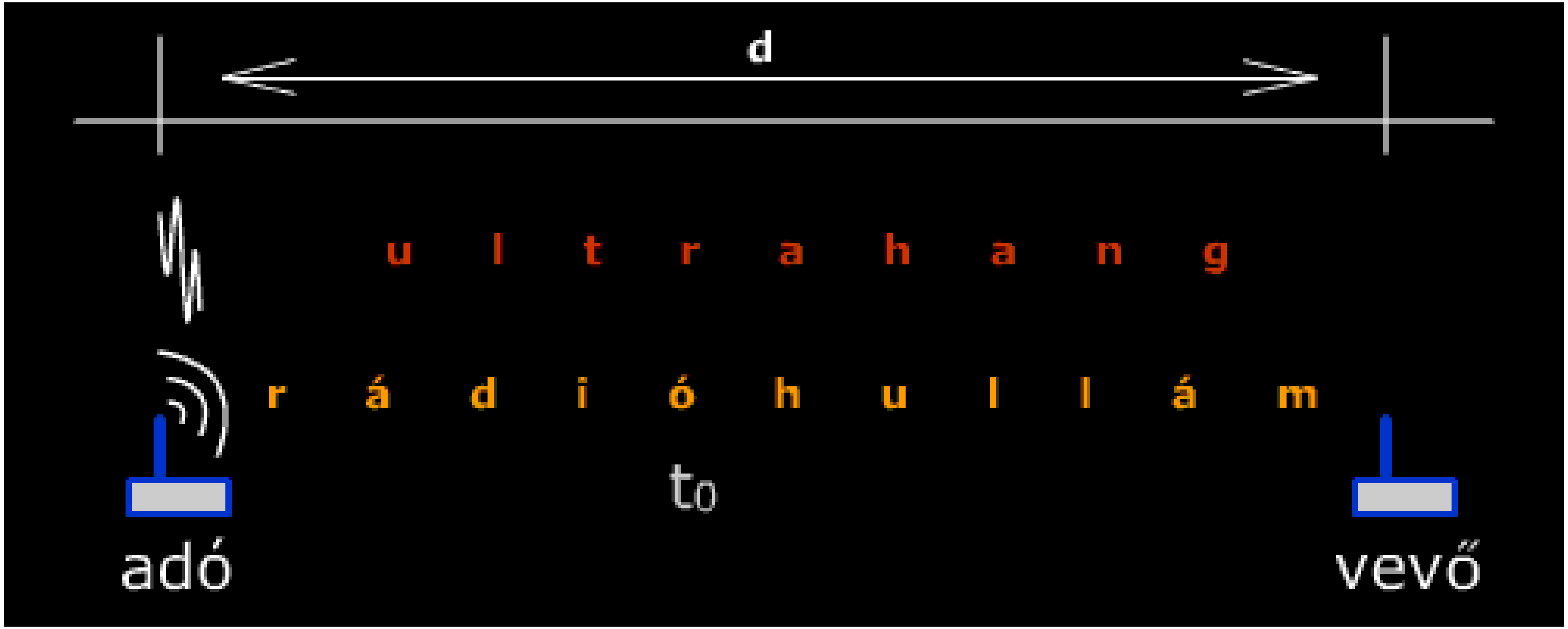
- Range-based solutions:
  - based on **arrival times**;
  - based on **received signal strength**;
  - based on **inter-arrival times** of two signals;
  - using **direction of arrival**.
- No range-based solutions
  - Local solution with the help of (many) **reference points**
  - based on „**Hop counts”**

*: If the radio range of a reference point is large then many points are within distance.

Range-based solutions

acoustic:

- ultrasonic sensors, sending ultrasonic and radio packet at the same time
- the inter-arrival times of the two signals are measured, and
- the distance is calculated



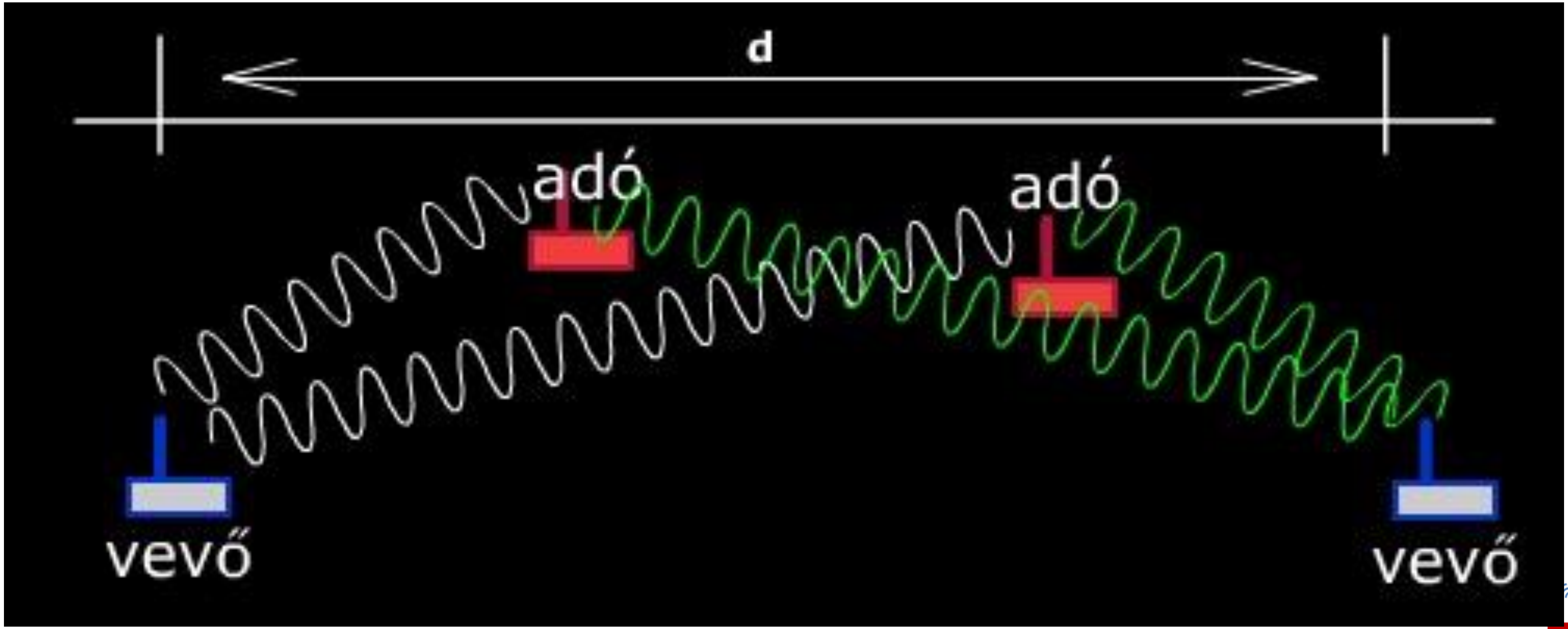
Range-based solutions

radio wave interference:

• two transmitters, two receivers;

• By changing the frequency of the two carriers, the interference pattern at the receiver is monitored.

• distance can be calculated from the phase shifts



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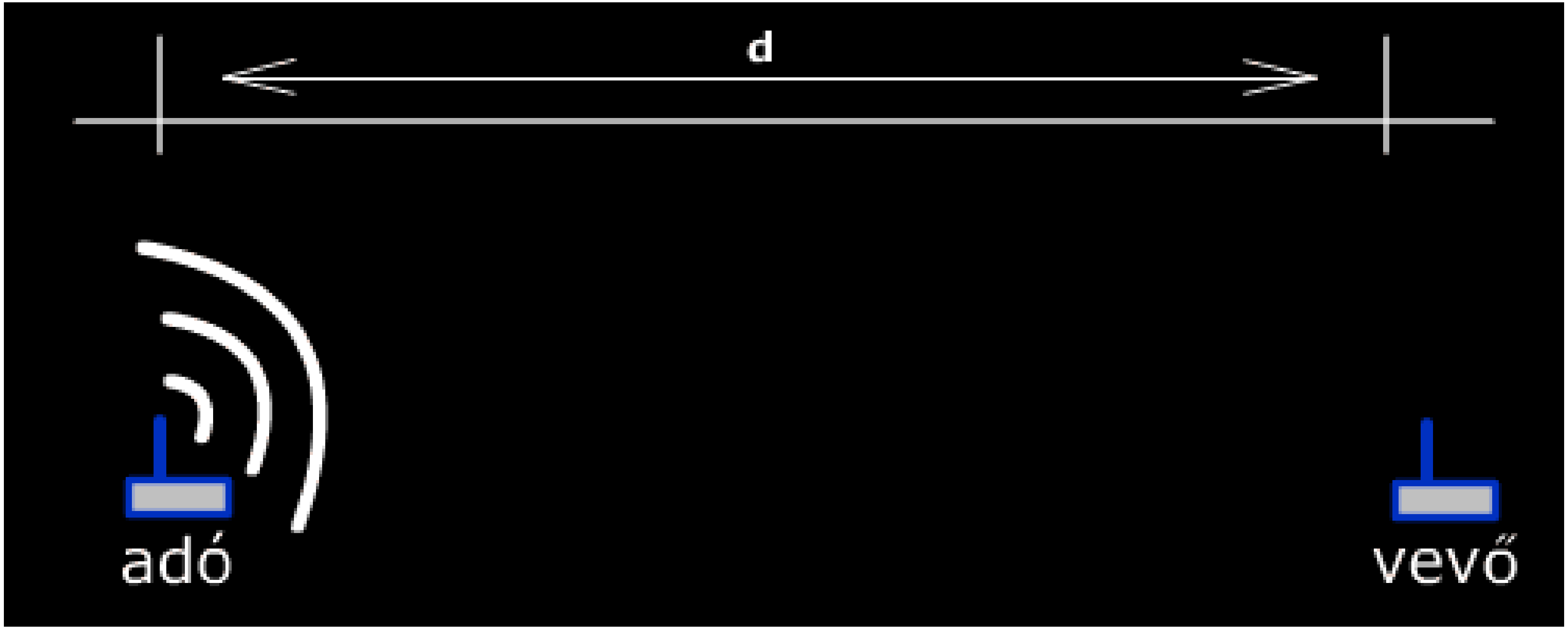
Range-based solutions

based on received signal strength:

- distance is estimated from the signal strength

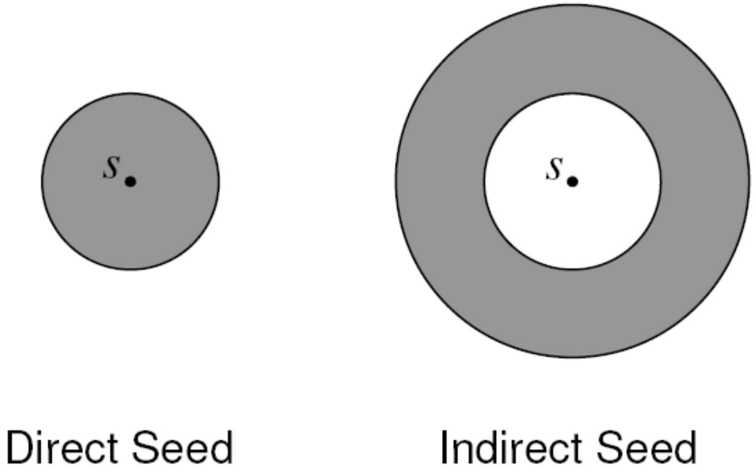


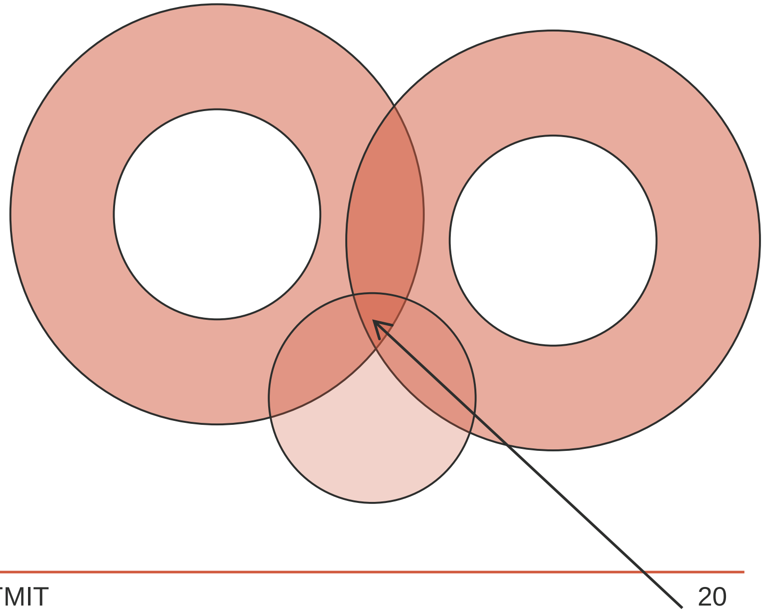
No range-based solutions

- **Centroid method**:
  - Local solution using reference points.
  - All nodes position themselves into the **center of all reference points that can be „heard”**.
  - The method is only effective if there are many and evenly distributed reference points.
- **DV-HOP**:
  - „Distance-vector routing” based solution.
  - All nodes store the length (hop-count) of the routes to all known reference points.
  - The broadcasting of route lengths are necessary within the network.
    - Initiated by the reference points by flooding.
  - The method is effective also with a fewer reference points.

Other solutions for localization

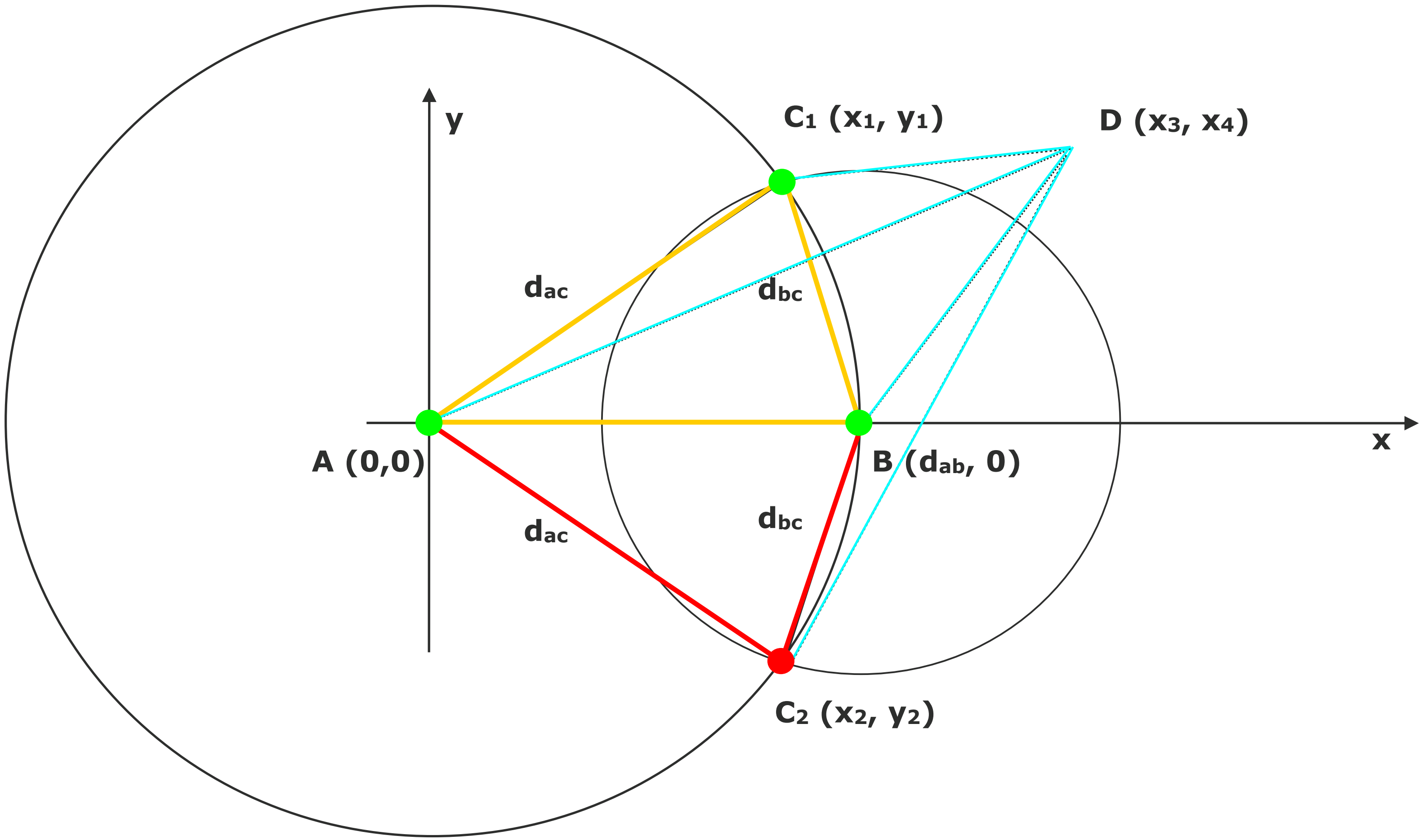
- **„Noise map”-based** solutions
  - Can be used in static environment. (E.g., RF signal strength map)
  - Nodes monitor the RF signal strengths of reference points that are mapped *a priori* onto a noise map.
- **„Hear – can’t hear”**
  - If a reference point is out of reach, that is also information!





Triangulation…

- distance measurements → positioning

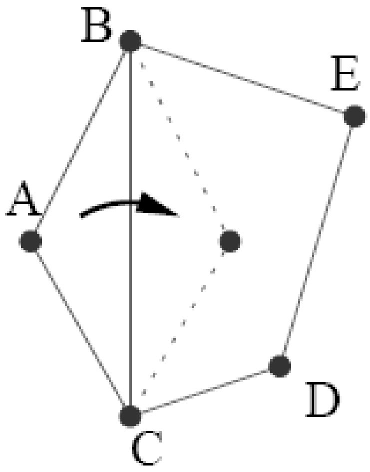


Graph realization

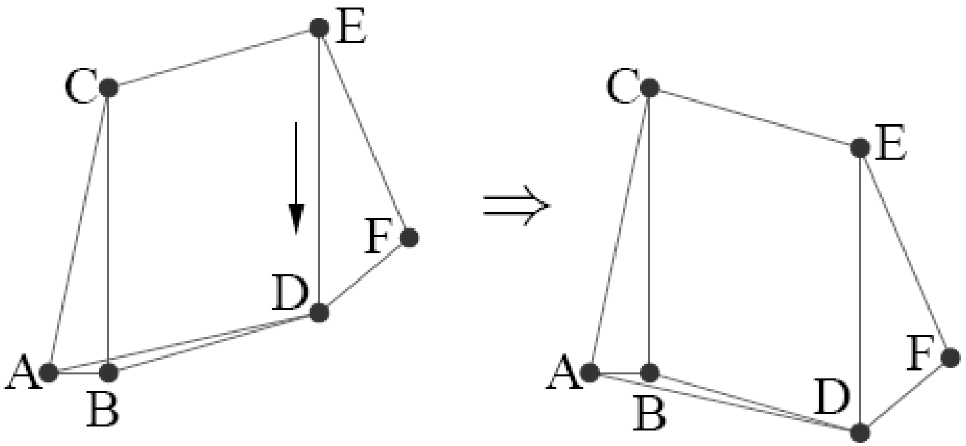
- **The problem of graph realization**: Calculating the geometric (Euclidean) position of the vertices.
  - The problem is NP-hard even in 2D!

- Knowing the edge length of a graph is not always enough for a unique reprezentation.
  - **Non-rigid graphs** can be continuosly deformed to get infinite number of realizations.
  - **In rigid graphs** there can be two kinds of deformations, that prevents unique realization: „**mirroring**” and „**bending**”

Problems in graph realization



Mirroring



bending

In practice, the length measurements are with errors!

Illustrative examples…

- Existing solutions for localizations (examples)
  - Active Badge
  - Active Bat
  - Cricket
  - (RADAR)
  - …

Active badge

- Olivetti and AT&T
- Uses infrared (IR) transmitters, indoor, cell-based (proximity) system.
- The transmitter sends it unique ID periodically (e.g., in every 10 secs).
- The signals collected by the IR sensors are analyzed by a central unit.
- It provides absolute localization information (rooms)
- Sunlight or neon light sources can cause problems because of IR.

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Active Bat

- AT&T solution
- Ultrasonic transmitters instead of IR
- The transmitter is carried by the user, the controller asks it to send an ultrasonic signal.
- The receivers are mounted on the ceiling in a grid structure.
- The controller can reset the timers in the receivers and the transmitter synchronously. The receiver can calculate the distances based on inter-arrival time differences.
- High accuracy! (~9 cm, 95%)

Cricket

- In contrast to Active Bat, the receiver is now at the user, the transmitters are deployed and fixed.
- It is the receiver that does the calculations based on triangulation.
- There is no need for a deployed grid (but is comes with less accurcy).

RADAR

- Microsoft, IEEE 802.11 WLAN-based solution
- All WLAN base stations can measure the received signal strength
- The position within a building can then be calculated
- Advantage:
  - „WLAN is everywhere”
- Drawback:
  - IEEE 802.11 equipment is too expensive in complexity and energy thus is not appropriate for WSNs.

Mobility in sensor networks

Mobility in sensor networks

- Typically, the nodes in a sensor network are static, but...
  - in certain cases mobility can be useful, or
  - the movement of the nodes cannot be avoided.

- In a WSN, can move...
  - the base station (BS), and/or
  - the sensors, and/or
  - the „events”, tracked objects.

Mobility in sensor networks

- The aim of mobility can be..
  - energy efficiency,
  - provide coverage,
  - topology-control,
  - quality improvement of monitoring.

- A mobile sensor network can react physically to its environment of changing surroundings.

Mobility in sensor networks

- The movement of a base station/sensor node can be…
  - controlled (e.g., controlled (micro-)robots)
  - uncontrolled (e.g., sensors floating on water surface)

- The (active) movement of sensors is energy consuming, and special hardware is needed..

Base station mobility

- The aim/cause of base station mobility can be…
  - The <u>user is moving</u> within the area of WSN
    - E.g., military staff of vehicles on the field
  - The <u>sink (randomly) roaming</u> within the area
    - E.g., data collector units mounted on animals or tourists
  - The sink nodes are <u>controlled by the network/user</u>
    - E.g., energy-efficient operation,
    - assuring connectivity (topology control).

Base station mobility

- Question arise when the BS is moving:
  1. „How can the BS announce its new position to the nodes?”
  2. „How can the nodes set their new paths towards the BS?”
  3. „How BS mobility affects the other energy-efficiency solutions (e.g., clustering, data aggregation)?”

Base station mobility

- Altough it is not typical for sensor nodes, for the BS we can assume that it is no problem to provide mobility.
- The primary task for the BS (sink) is to collect sensory data.

- Idea: *The BS can „go for the data" and collect them locally where the sensors measure them!*
- Advantage:
  - Long-distance data transmission can be avoided, either using direct or multi-hop communication.
  - There is no need to construct routes towards the BS BS-hez, if it comes for the data to fetch it.
    - (E.g., semi-smart metering)

Base station mobility

- BS mobility can be…
  - random,
  - predictable,
  - controlled,
  - adaptive.

- The BS can move…
  - on its own, or
  - with the help of some carrier.

BS random mobility

- In case of **random mobility**, it is not possible to follow an optimal routes and routing strategy.
  - E.g., „**data-mule**”: Environmental monitoring in a wild reserve, where the BSs are mounted on animals within the monitored habitat.
  - By the random roaming of the animals, the BSs sooner or later reach every part of the monitored area.
- The sensors either…
  - detect, if the BS comes close, and hand over all of their collected data, or…
  - the BS sends pilot signals to wake-up and query the sensors for the data.
- Typically, the transfer delay is very large, random, and data delivery is not always guaranteed.

BS predictable mobility

- In case of **predictable BS mobility**, data collection can be planned in advance.
  - E.g., the BS follows a given trajectory, going around periodically, covering the whole area.
- Advantages:
  - Sensor nodes do not have to communicate with a far away BS.
  - Delay can be big, but can be controlled, quality guarantee can be given (e.g., max D < lap time)
  - Few (~1) BS is enough to cover the whole network.

BS adaptive mobility

- The best network operation can be achieved by using **adaptive BS mobility** if possible.
  - E.g., The BS goes to the area where and when it is most needed.
- Advantage:
  - Energy efficient operation can be assured.
  - Load sharing can be achieved by using network resources evenly.
    - IMPORTANT: *In many cases the BS must be relocated just because its neighboring nodes start to deplete their battery (in multi hop communication)!*
  - Can follow up the changing network topology can be adaptively.
  - The BS can collect additional data when reaching the area of interes.

BS controlled mobility

- Using **controlled BS mobility**, the trajectory and timing can be planned using a preferred strategy.
  - E.g., the BS is moved to the area that is interesting for us.
- Advantage:
  - total control → more options to choose from
  - More BSs can be controlled together.
  - Data quality can be guaranteed (QoS).
- Note: The cost of BS mobility must be taken into account!

Sensor mobility

- In contrast to BS mobility, moving sensor nodes can be critical from energy and cost point of view!

- Sensors can move randomly, or in a controlled way.

- **Random mobility** for the sensors is typical, when they move along with the environment or medium, in a passive way.
  - E.g., Sensors in rivers, on the surface of water, underwater, in air, on glaciers, etc.
  - E.g., Sensors mounted on animals or vehicles…

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Sensor mobility

- Using **controlled mobility** for sensors, it is possible to …
  - increase coverage,
  - provide connectivity,
  - ensure energy efficiency.
- In many cases the sensor can be moved only once, just after deployment to reach the desired topology.
  - E.g., uncovered areas, uneven node density, communication „holes” (=topology control).
- Sometimes only a small subset of the sensor nodes are mobile.

Sensor mobility

- In event-driven networks, sensors can **move adaptively** towards more „interesting” areas.
- The strategy for sensor mobility can be…
  - **reactive**: sensors move by reacting to events
    - E.g., they move closer to the events
  - **proactive**: sensors try to spread out optimally (evenly).
- A possible group of algorithms for sensor mobility is based on **potential fields**.
  - E.g., electrostatic field emulation, where same charges push themselves apart.

„Virtual” mobility in sensor networks

- **Mobile agents**: Agents are code segments, that can move within the network and executed on some network nodes.

- It can be useful to process the data within the network right where the data was collected.

- The network can be reconfigured by **virtually move (relocate) the BS(s)**.

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