Sensor networks and applications

Routing (hierarchical). Localization.

Routing paradigms

- Network topology-based solutions
  - Flat
  - **Hierarchical**
    - LEACH, **TEEN, APTEEN**
  - Location based
  - other...

TEEN

- TEEN = Threshold-sensitive Energy Efficient sensor Network protocol
- Cluster-based solution.
- Reactive.
- Suitable for time-critical applications.

- Idea: Sensors monitor the environment continuously, but only send data when the measured value is above a certain threshold.

TEEN

- Protocol operation:
  - The cluster head sends a hard and soft threshold value to all of its sensor nodes.
  - When a monitored value is above the hard threshold, the node turns on its radio and sends the data to the cluster head. It also stores the data for itself.
  - Next, the node only sends new data if...
    1. the measured value is still above the hard threshold, and
    2. the difference between the old and new data is larger than the soft threshold.
- When the cluster head is changed, the new CH sends new thresholds values within its cluster.

TEEN

- Advantages:
  - Energy efficient solution.
  - Only relevant data is measured because of the hard threshold.
  - Using the soft threshold, a trade-off between accuracy and data volume can be set.

- Modification: APTEEN – Adaptive Periodic TEEN

APTEEN

- Hybrid protocol: thresholds + periodicity
- Parameters sent by the cluster head:
  - Attribute (physical quantity)
  - Thresholds: hard and soft
  - TDMA scheduling information
  - Max period length
- The use of thresholds is the same as in TEEN.
- All nodes can send data only in their dedicated TDMA slot.
- All nodes must send data at least once in every period (proactive operation)

APTEEN

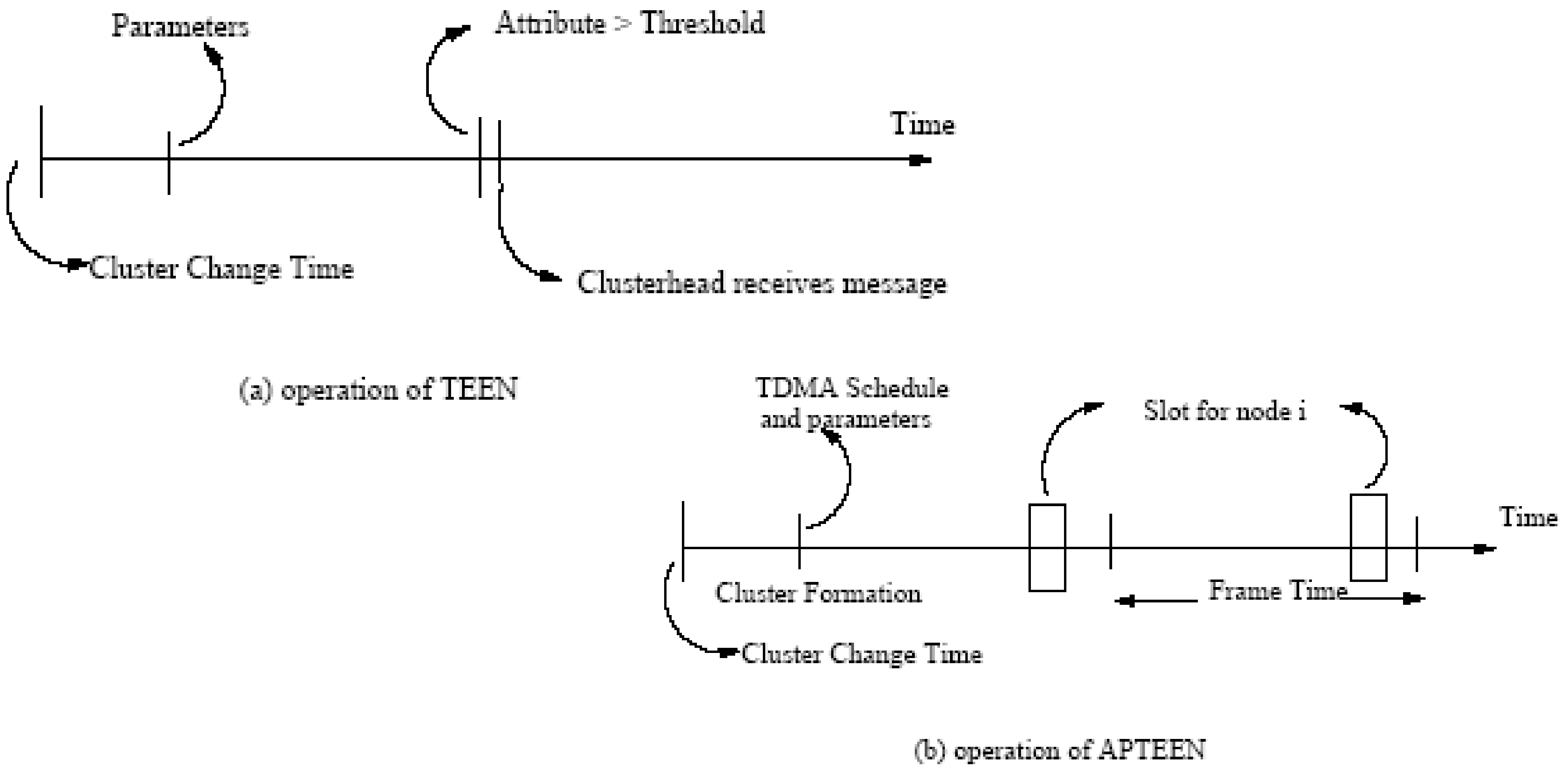
Advantages:

- Flexibility by parametrization.
- Reactive and proactive operation.

Drawbacks:

- Complexity (thresholds and periods)
- Clustering and cluster head election.

TEEN and APTEEN



Routing paradigms

- Network topology-based solutions
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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 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!

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!

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
- <u>Exception</u>: 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 personal information, that must be protected!

Localization – taxonomy (cont'd.)

- **Accuracy** vs. **precision**
  - E.g., A GPS receiver is able to position with <u>10m accuracy </u>in <u>95% of the cases</u>.
- 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**.

- Would be desirable, if 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

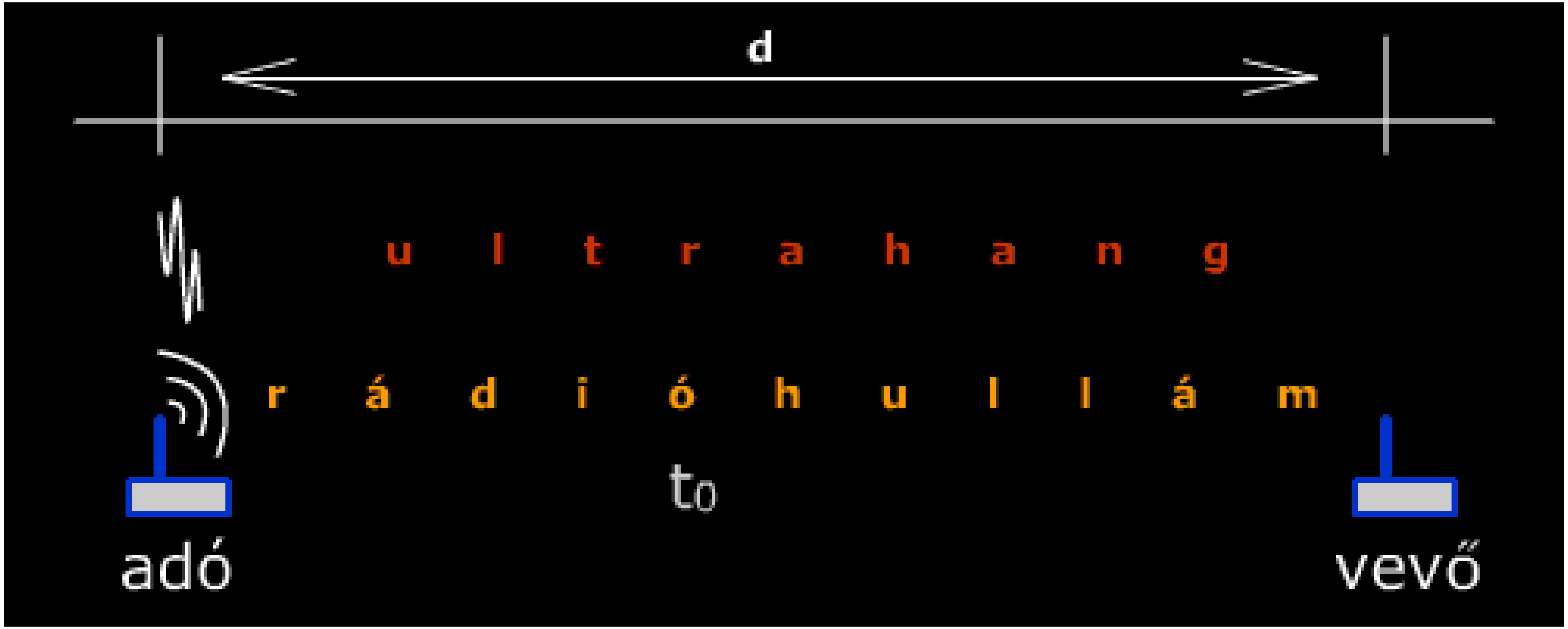
- Range-based solutions:
  - based on **arrival times**;
  - based on **received signal strength**;
  - based on **inter-arrival times** of two signals;
  - using **direction of arrival**.
- No range-based solutions
  - Local solution with the help of (many) **reference points**
  - based on „**Hop counts”**

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

Range-based solutions

acoustic:

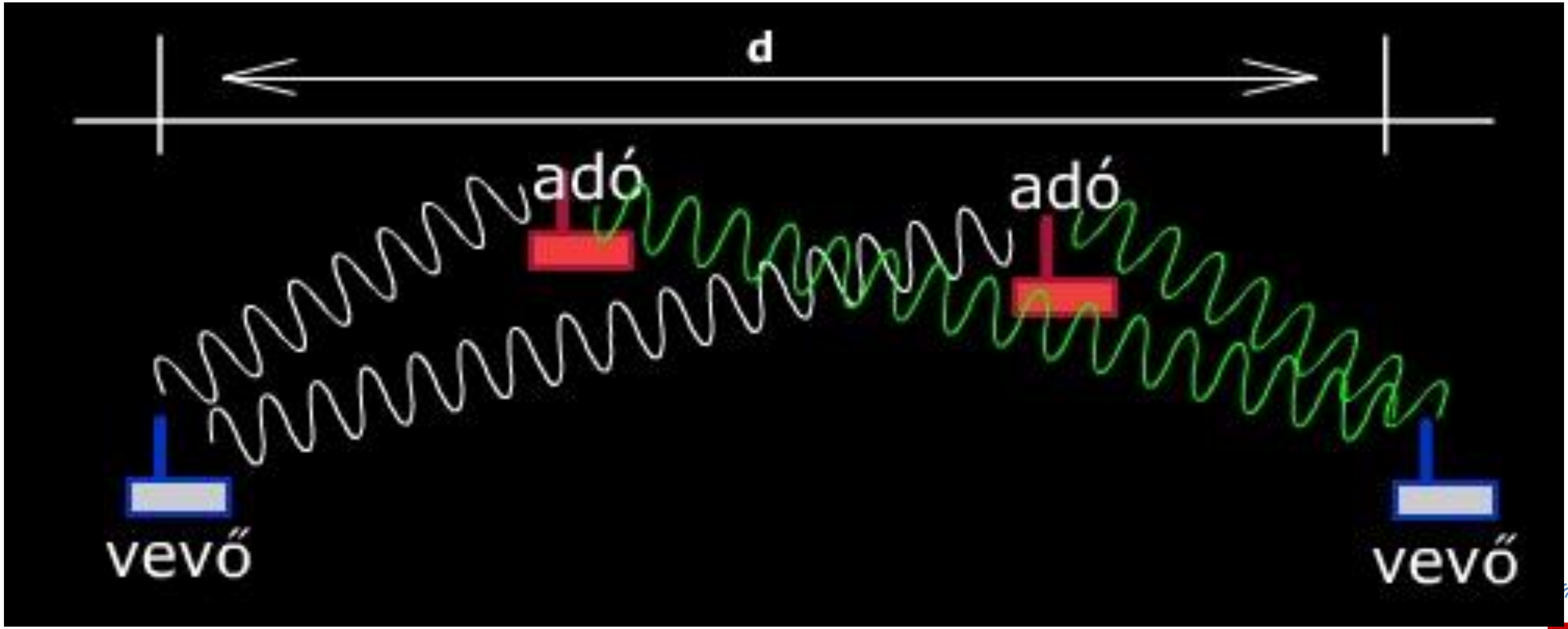
- ultrasonic sensors, sending ultrasonic and radio packet at the same time
- the inter-arrival times of the two signals are measured, and
- the distance is calculated



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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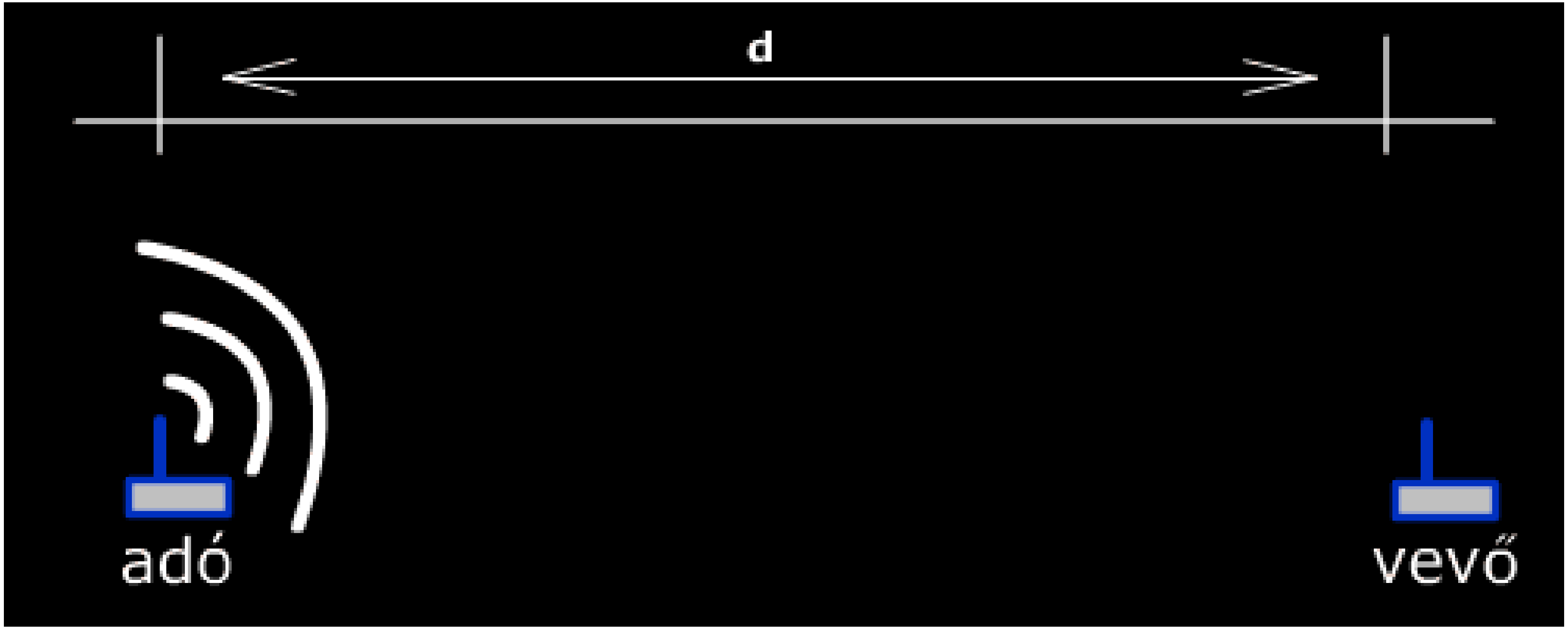
Range-based solutions

based on received signal strength:

- distance is estimated from the signal strength

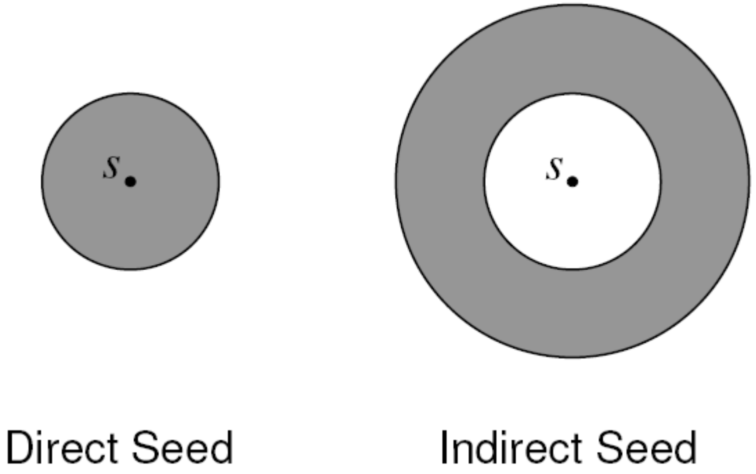


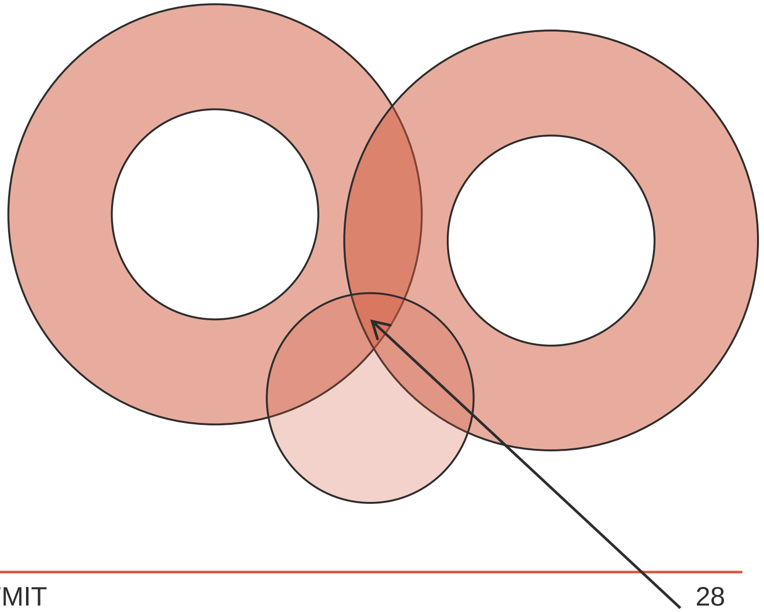
No range-based solutions

- **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 <u>many</u> and <u>evenly distributed reference points</u>.
- **DV-HOP**:
  - „Distance-vector routing” based solution.
  - All nodes store the <u>length</u> (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

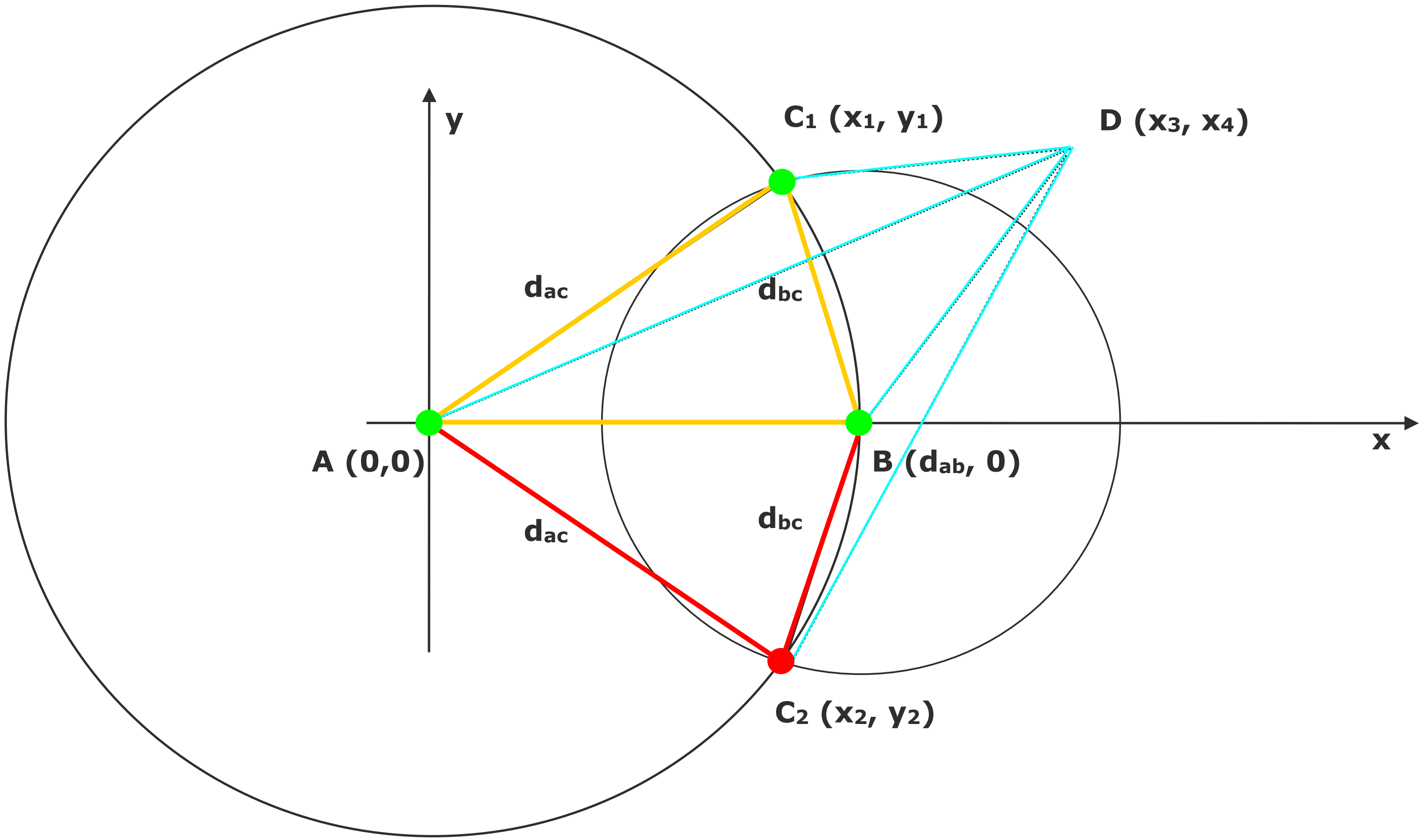
- **„Noise map”-based** solutions
  - Can be used in static environment. (E.g., RF signal strength map)
  - Nodes monitor the RF signal strengths of reference points that are mapped *a priori* onto a noise map.
- **„Hear – can’t hear”**
  - If a reference point is out of reach, that is also information!





Triangulation…

- distance measurements → positioning

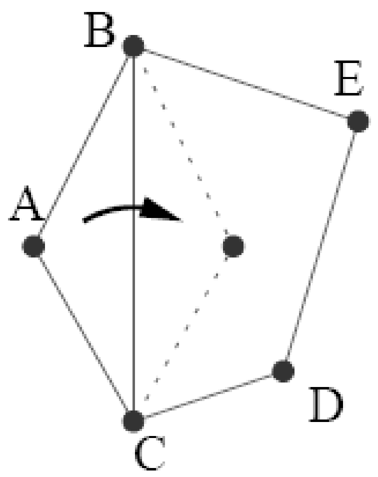


Graph realization

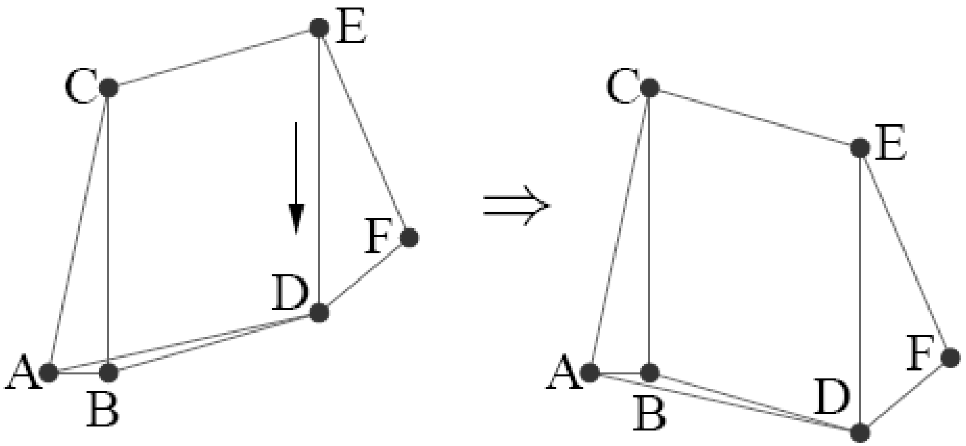
- **The problem of graph realization**: Calculating the geometric (Euclidean) position of the vertices.
  - The problem is NP-hard even in 2D!

- 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.

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 <u>not appropriate for WSNs</u>.