CIS373 - Pervasive Computing Wireless Sensor Networks (pt 2)

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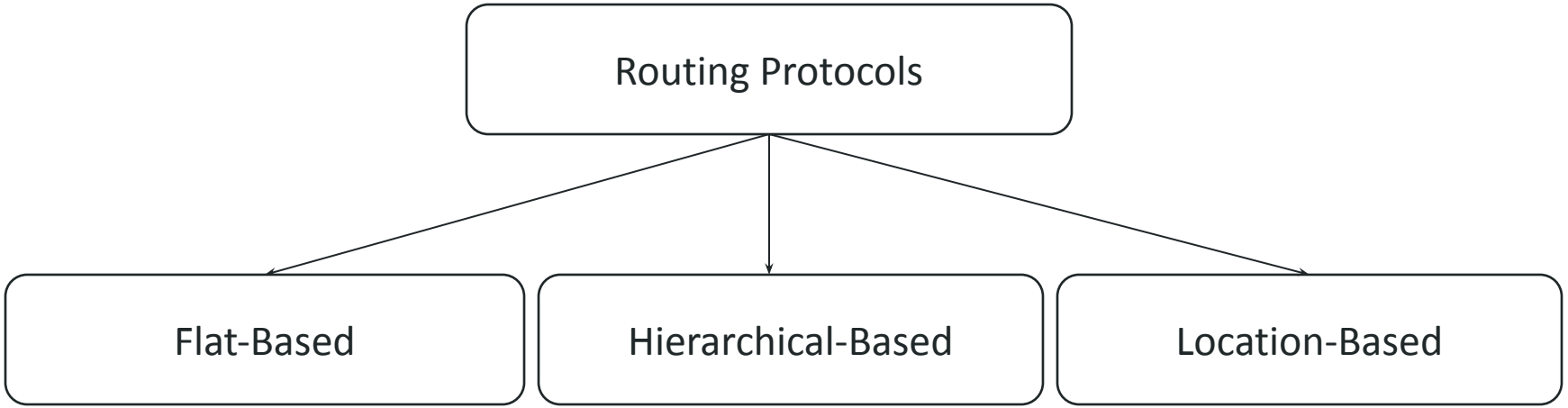
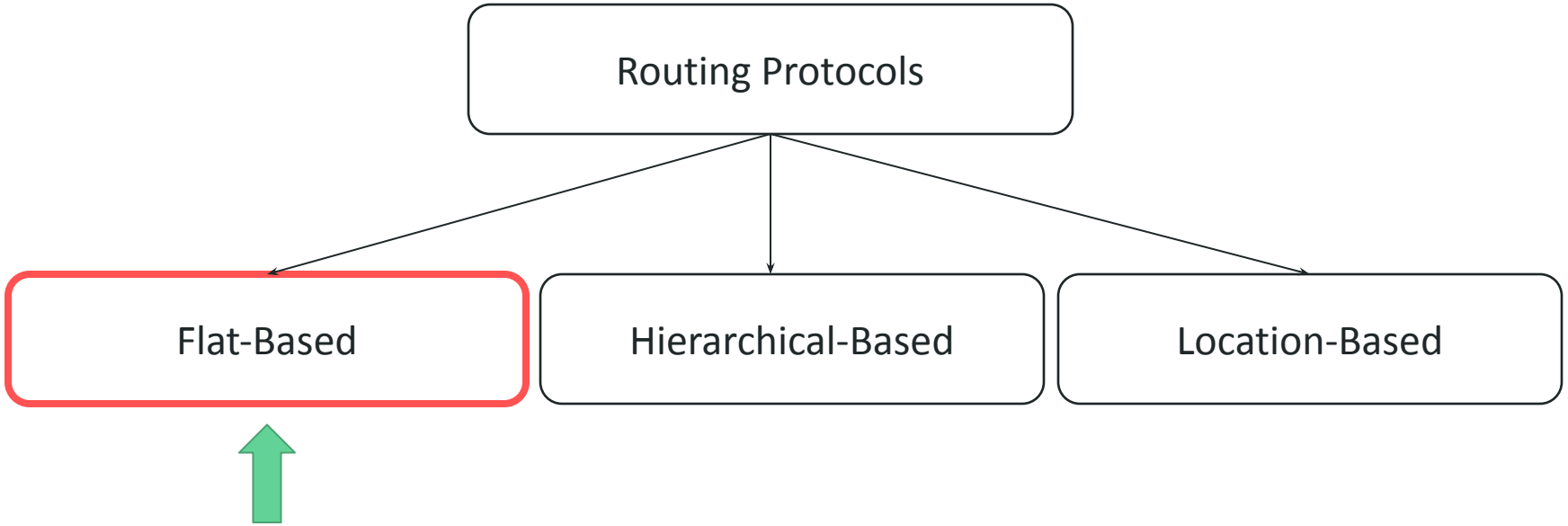
Adapted from materials provided by Xiang Cao

Routing

Network structure categorization



Network structure categorization



All the nodes are treated equally and have the same functionality

Flat-based routing protocols

1. **Flooding** (straightforward):
   - Source node sends data to all neighbors
   - Receiving node stores and sends data to all its neighbors
   - Disseminate data quickly
2. **Sensor Protocol for Information Negotiation (SPIN)**:
   - Send meta-data to neighboring nodes, instead of data
   - Request for the desired data
   - Avoid redundant data transmission
   - Adaptation to remaining energy ➜ increase network lifetime

Flat-based routing protocols

3. **Directed Diffusion**:

- Base Station (BS) continuously sends query to the neighboring nodes
- Node with the desired data transmit all the way back to BS
- Saving energy by selecting the optimal return path
- Not practical for continuous data demand cases

Flooding

Dissemination is the process of distributing individual sensor observations to the whole network, treating all sensors as sink nodes

- Replicate complete view of the environment
- Enhance fault tolerance
- Broadcast critical piece of information

Flooding is the **classic approach** for dissemination

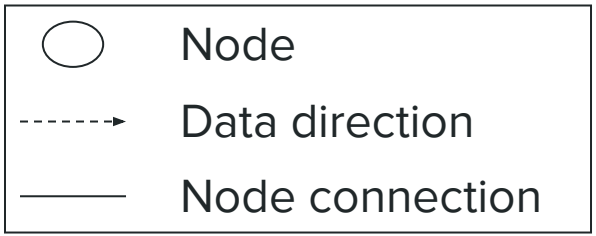
What are some deficiencies???

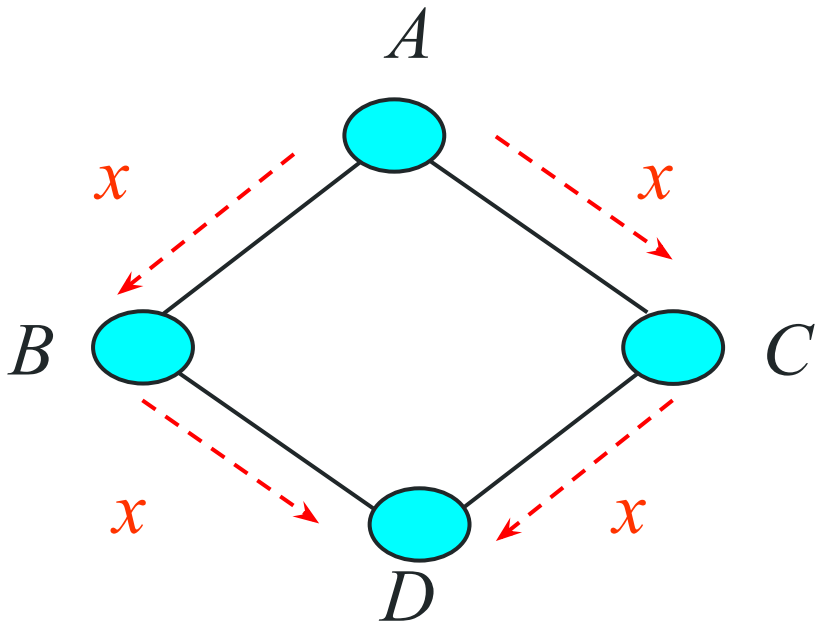
Flooding

What are some deficiencies???

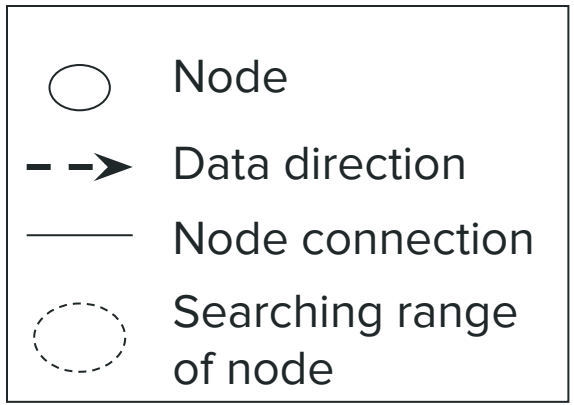
- Redundancy
- Overlap
- Resource blindness

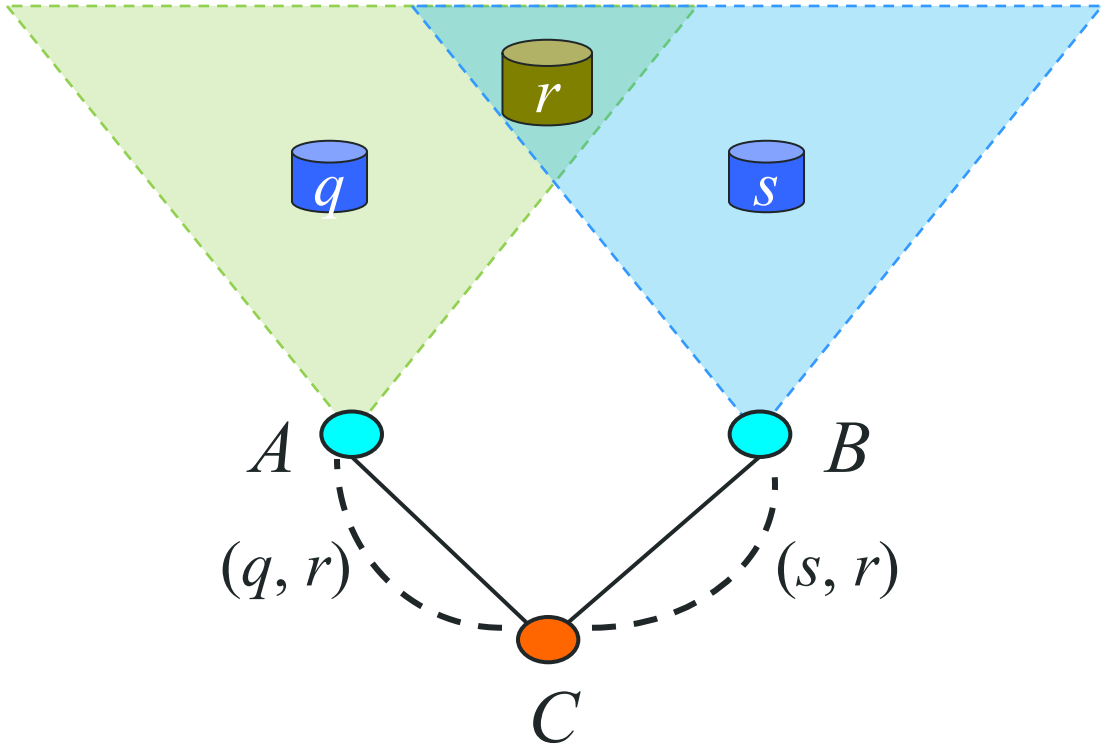
Flooding - redundancy





Flooding - overlap





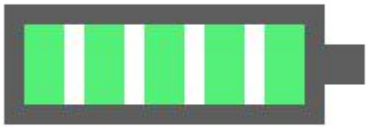
Flooding - resource blindness

Nodes **typically** do not modify their activities based on the amount of energy available to them!

- Run until we're dead :thumbsup:

However....

- A network of embedded sensors can be resource-aware
- Adapt its communication and computation to the state of its energy resource



Sensor Protocols for Information via Negotiation (SPIN)

Negotiation-based protocol for disseminating information in WSNs

Negotiation

- Before transmitting data, nodes negotiate with each other to overcome redundancy and overlap
- Only useful information will be transferred
- Observed data must be described by meta-data

Resource adaptation

- Each sensor node has resource manager
- Applications probe manager before transmitting or processing data
- Sensors may reduce certain activities when energy is low

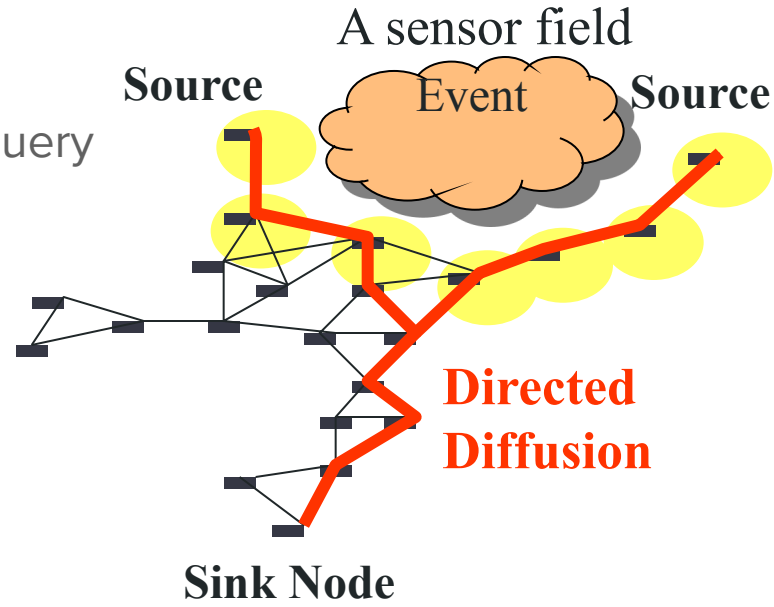
Directed diffusion

Data-centric communication

- Data is named by attribute-value pairs
  - e.g., How many pedestrians do you observe in the geographical region X
- Base Station's query (task) is diffused
- Sensors begin collecting information about query
- Information returns along the reverse path
- Intermediate nodes aggregate the data
  - Combining reports from sensors

Directed diffusion consists of:

- **Interest** - Query which specifies what a user wants
- **Data** - Collected information



Directed diffusion - pros and cons

Different from SPIN in terms of **on-demand data querying mechanism**

- Sink floods interests only if necessary (lots of energy savings)
- In SPIN, sensors advertise the availability of data

Pros

- Each node can do aggregation & caching

Cons

- On-demand, query-driven
  - Inappropriate for applications requiring continuous data delivery

QUESTIONS

We have the following applications/scenarios, which routing approach should be adopted respectively?

Flooding, SPIN, or directed diffusion?

- **Farmland monitoring** (to avoid duplicate data reporting, sensors can negotiate and take turn to send data), non-critical
- **Car accident** (base station actively sends query to those sensors in that area to get latest information)
- **Emergent message dissemination** (e.g., fire, crash)

QUESTIONS

Flooding

- Emergent message dissemination (e.g., fire, crash)

Sensor Protocols for Information via Negotiation (SPIN)

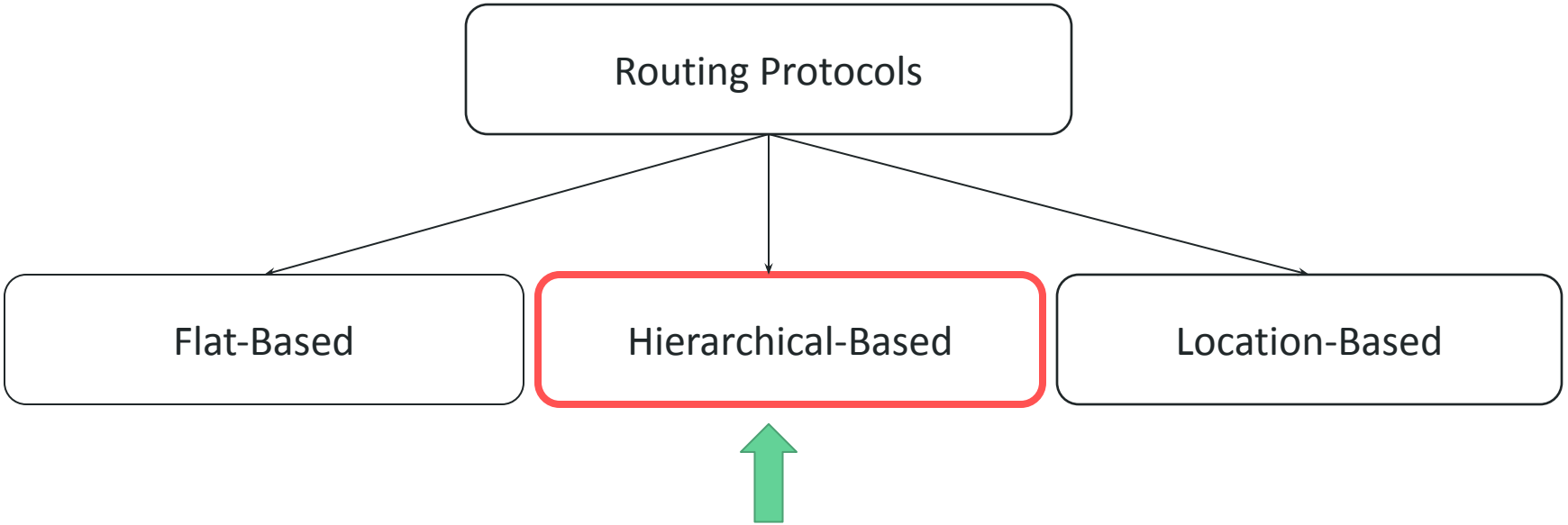
- Farmland monitoring (to avoid duplicate data reporting, sensors can negotiate and take turn to send data), non-critical

Directed Diffusion

- Car accident (base station actively sends query to those sensors in that area to get latest information)

```
Type = vehicle
Interval = 20 s                    // send events every 20s
Duration = 1200 s                  // Send for next 1200 s
coordinate = [-100, 100, 200, 400]   // sensors in this area
```

Network structure categorization



- Different sensors have different roles in the network
- Increasing lifetime

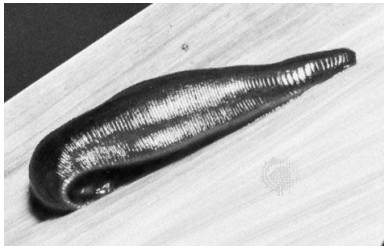
Hierarchical routing

1. Low Energy Adaptive Clustering Hierarchy (LEACH):

- Random and variation Cluster Head (CH) selection
- Compression and transmission of arriving data at CHs
- Constant monitoring applications
- Good for small networks
- Extra overhead because of clustering

2. Self Organizing Protocol (SOP):

- Mobile sensors to probe the environment
- Stationary nodes as the routers



LEACH

Clustering-based protocol that **minimizes energy dissipation** in sensor networks.

- Outperforms classical clustering algorithms by using adaptive clusters and rotating cluster-heads
  - Network overlay changes over time
- Energy requirements of the system are distributed among all the sensors

LEACH is able to perform **local computation in each cluster** to reduce the amount of data that must be transmitted to the base station.

LEACH

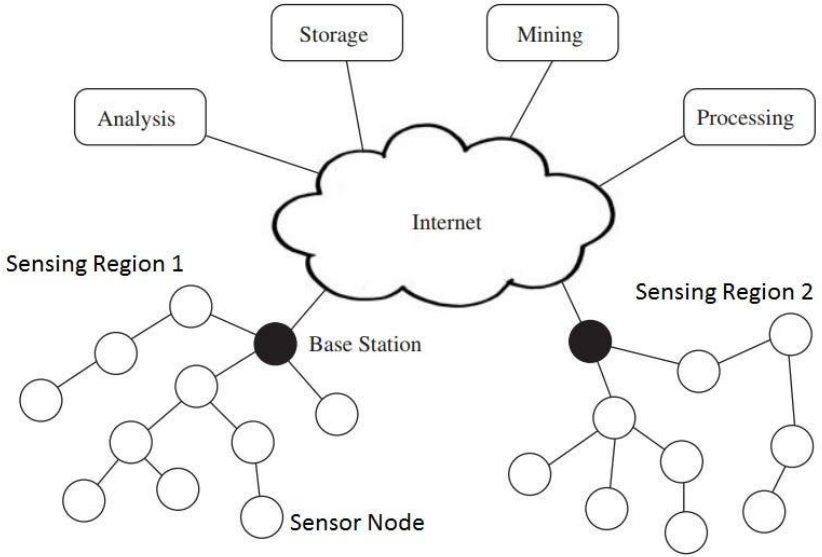
Sensors **elect themselves** to be local cluster-heads at any given time with a certain probability.

- Each sensor node joins a cluster-head that **requires the minimum communication energy.**

Once all the nodes are organized into clusters, each cluster-head creates a **transmission schedule** for the nodes in its cluster.

In order to balance the energy consumption, the cluster-head nodes are not fixed

- Position is self-elected at different time intervals

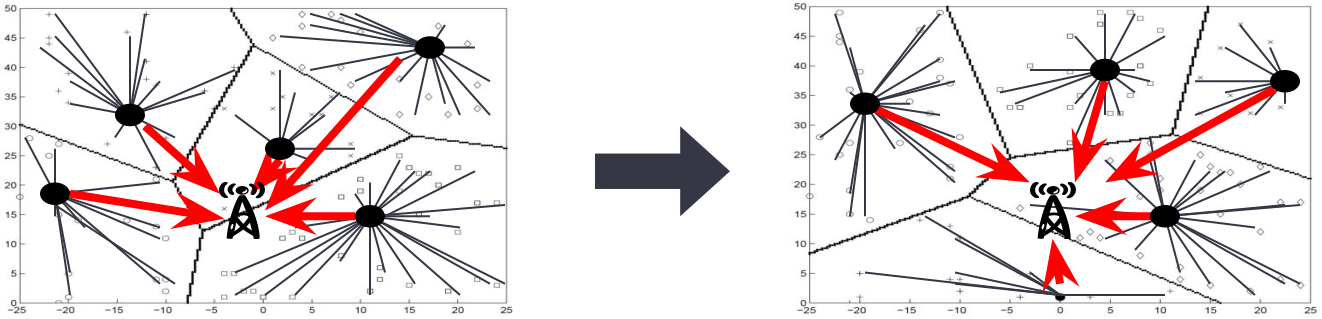


LEACH - Adaptive clustering

Periodic independent self-election

- Probabilistic

Nodes select advertisement with **strongest signal strength**



All nodes marked with a given symbol belong to the same cluster, and the cluster head nodes are marked with a ●.

LEACH algorithm

Periodic process

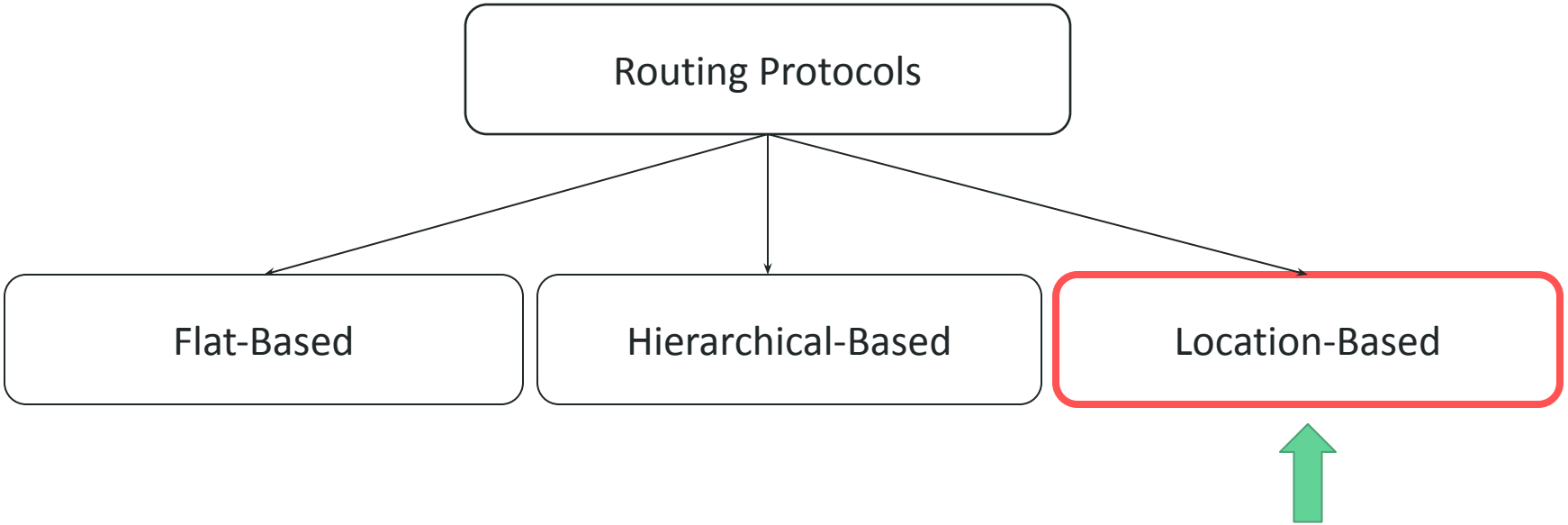
Two phases per round:

- Setup phase
  - Advertisement: Execute election algorithm
  - Members join cluster
  - Cluster-head broadcasts schedule

network communication protocol

- Steady-State phase
  - Data transmission to cluster-head using TDMA
  - Cluster-head transfers data to BS (Base Station)

Network structure categorization



- Sensor nodes are addressed based on their location
- Location are acquired by GPS or via coordination among nodes

Location-based routing

1. Geographic Adaptive Fidelity (GAF):

- Network divided into zones
- Only one node is awake in each zone, the rest sleep
- Conserves energy by turning off unnecessary nodes
- Increases the network lifetime

2. An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Networks (SPAN):

- Some nodes are selected as coordinators based on their positions
- Enough coordinators such that network is three-hop reachable

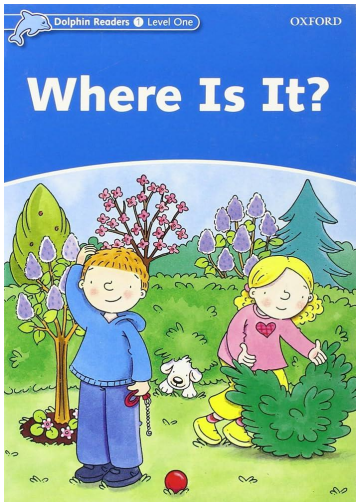
Localization

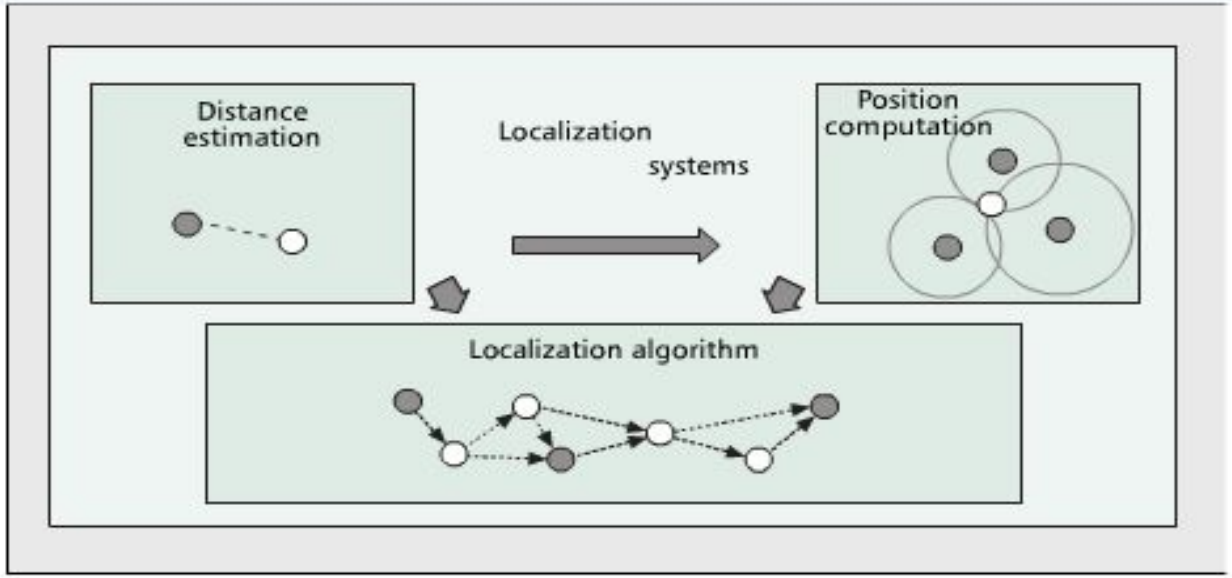
Localization

Localization is a process to **compute the locations** of wireless devices in a network

- WSN comprising a large number of inexpensive nodes that are densely deployed in a region of interests to measure certain phenomenon

- Primary objective is to determine the location of the target





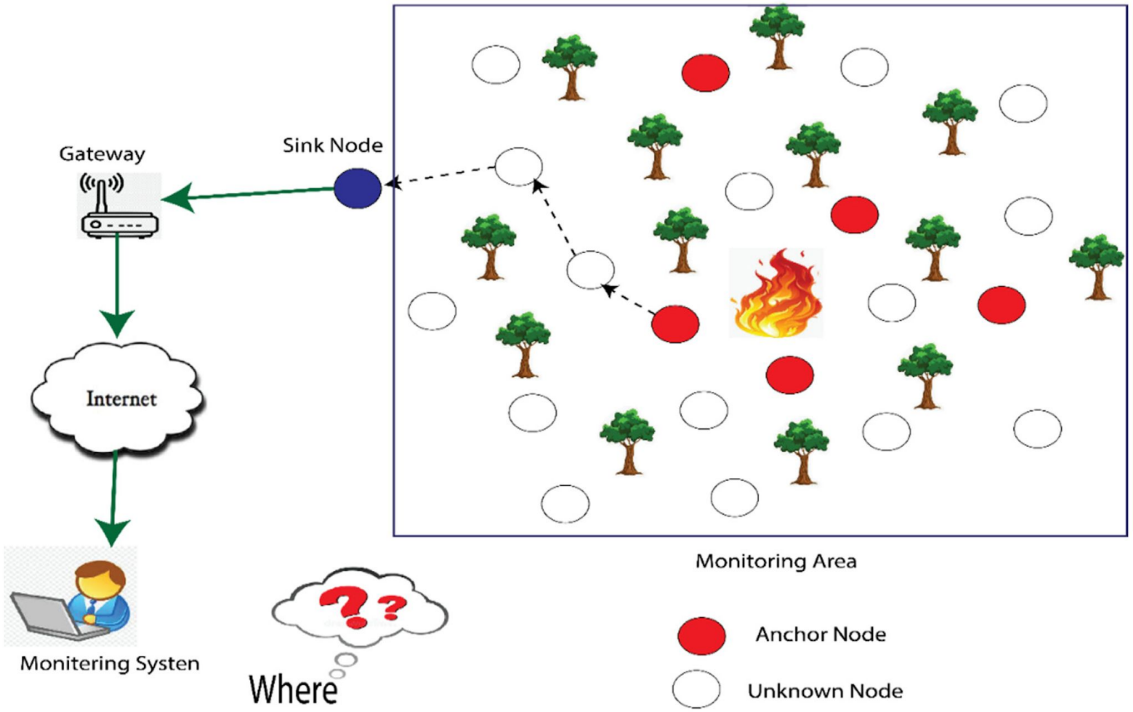
Distance/angle estimation: Estimating position related parameters between two nodes.

Position computation: Computing a node's position based on available information and anchor nodes positions.

Localization algorithm: Manipulating available information in order to localize other nodes in a WSN.

Usage

- Coverage
- Deployment
- Routing
- Location service
- Target tracking
- Rescue



GPS?!??!?!?!

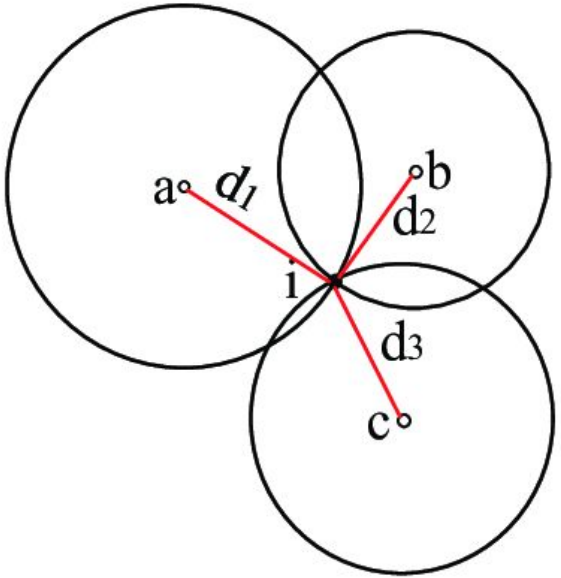
Need to determine the physical coordinates of a group of sensor nodes

- Due to application context and massive scale, use of GPS is **unrealistic**, therefore, sensors need to self-organize a coordinate system
- **Expensive**
- GPS satellite signals are **weak**, so it doesn't work well indoors, underwater, under trees, etc.
- Highest accuracy requires **line-of-sight** from the receiver to the satellite (this is why GPS doesn't work very well in an urban environment)
- The US DoD (dept of defense) can, at any given time, **deny users** use of the system (i.e., they degrade/shut down the satellites)

1. Target/Source localization

Most of the source localization methods are focused on the **measured signal strength**

To obtain the measurements, the node needs a complex calculating process



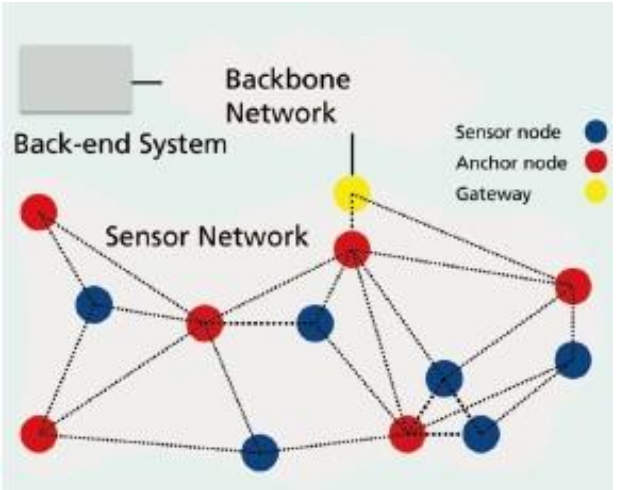
2- Node Self-localization

Range-based localization

- Uses the measured distance/angle to estimate the indoor location using geometric principles.

Range-free localization

- Uses the connectivity or pattern matching method to estimate the location.
- Distances are not measured directly but hop counts are used.
- Once hop counts are determined, distances between nodes are estimated using an average distance per hop and then geometric principles are used to compute location.



Range-based localization

- Time of arrival (TOA)

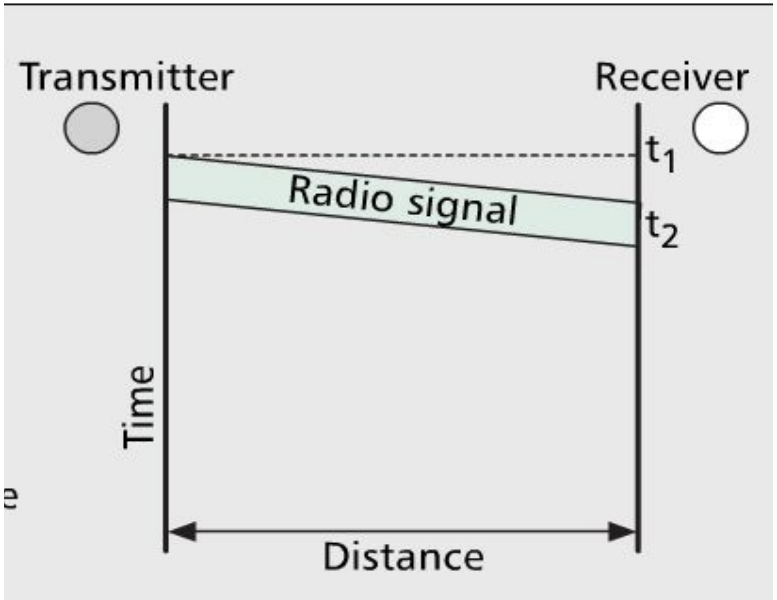
- Time difference of arrival (TDOA)

- Received signal strength indicator (RSSI)

Time of arrival: (TOA)

Estimates distance between 2 nodes using time based measures.

Accurate, but needs **synchronization**

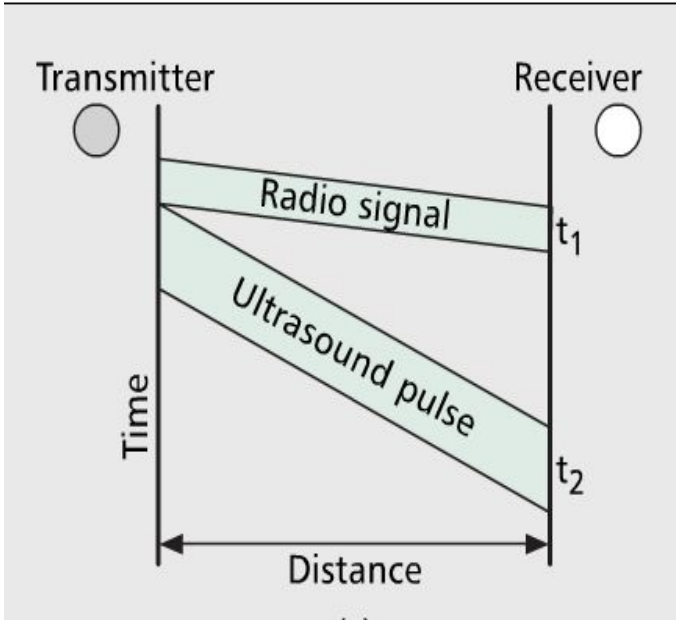


Time Difference Of Arrival: (TDOA)

Determine the distance between a mobile station and a nearby synchronized base station.

- AT&T uses it to locate a caller when they dial 911 from their mobile phone.
- TDOA calculates the location of a mobile phone by using the difference in the time of arrival of signals at different cell sites.

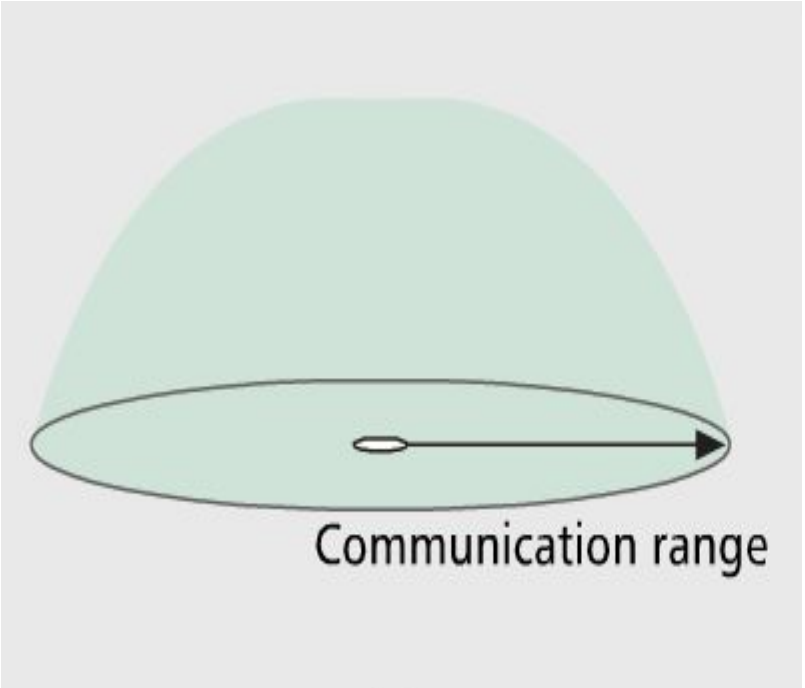
No synchronization needed but **costly**.



Received Signal Strength Indicator: (RSSI)

Translate signal strength into distance

- Low cost but very sensitive to noise



Range-free localization

DV-Hop is the typical representation

- DV: Distance Vector
  - Doesn’t need to measure the absolute distance between the beacon node and unknown node.
  - Average hop distance to approximate the actual distances
  - Reduces the hardware requirements.

Range-free localization

Pro:

- Easy to implement and applicable to large network

Con:

- The positioning error is correspondingly increased!
    - i.e., we're "estimating"

DV-Hop

Divided into 3 stages:

- Information broadcast
- Distance calculation
- Position estimation

DV-Hop: Information Broadcast

Beacon nodes broadcast their location information package
- Includes hop count and is initialized to zero for their neighbors

Receiver records the minimal hop of each beacon nodes
- Ignores the larger hop for the same beacon nodes

Receiver increases the hop count by 1 and transmits it to neighbor nodes

All the nodes in a network can record the minimal hop counts of each beacon nodes.

DV-Hop: Distance Calculation

According to the position of the beacon node and hop count, each beacon node estimates the actual distance of every hop

$$\text{HopSize}_i = \frac{\sum_{j \neq i} \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}}{\sum_{j \neq i} h_j}$$

- (x_i, y_i) and (x_j, y_j) are the coordinates of beacon nodes i an j.
- h_j is the hop count between them.

DV-Hop: Position Estimation

Beacon node will calculate the average distance
- Broadcast the information to network

Unknown nodes records the average distance
- Transmit it to neighbor nodes

Unknown node calculates its location

DV-Hop

Anchors: A
- flood network with own position
- flood network with avg hop distance

Nodes: B
- count number of hops to anchors
- multiply with avg hop distance