# ROUTING PROTOCOL
# WIRELESS SENSOR NETWORKS

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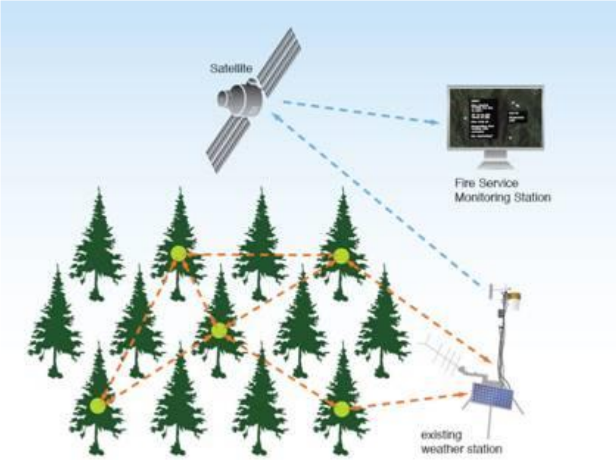
# Routing Techniques in Wireless Sensor Networks

- Structure and applications of WSNs
- WSN vs. Ad hoc and cellular networks
- Routing challenges and design issues
- Classification of routing protocols
- Flat network routing
- Hierarchical routing
- Location based routing
- Comparison of different protocols
- Route Discovery Protocols
- Conclusion and future directions

# Wireless Sensor Networks (WSN)

- Small nodes with sensing, computation, and wireless communications capabilities.

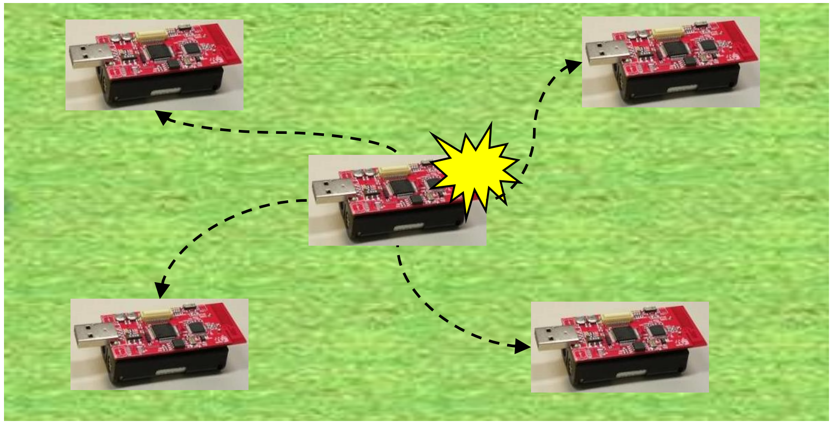



- Applications:
  - ✓ Security and tactical surveillance
  - ✓ Weather monitoring
  - ✓ Disaster management....

# WSN vs. Ad hoc and cellular networks

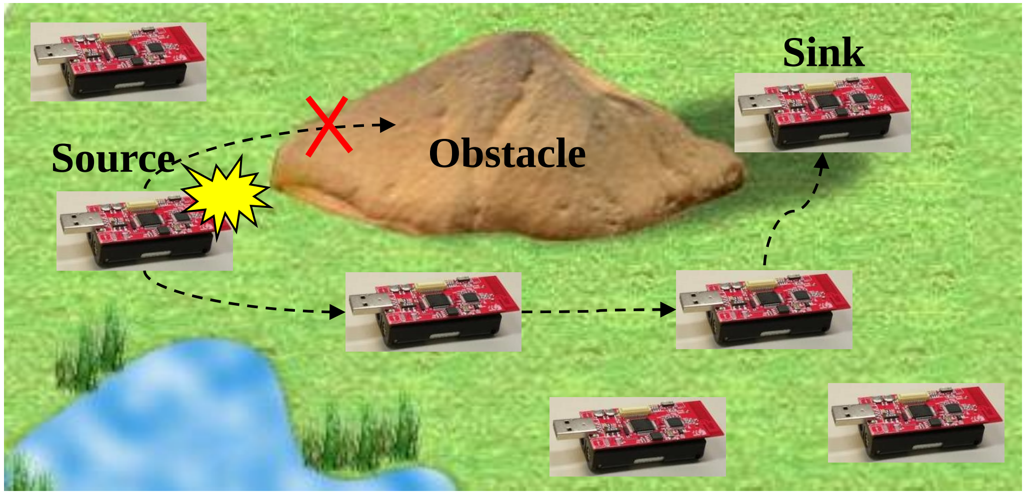
- Very large number of sensor nodes
- Data flow from multiple sources to particular BS
- Constraint of energy, processing  and storage capabilities
- Nodes are generally stationary after deployment
- WSN are application-specific
- Position awareness of sensor nodes is important
- High probability of redundancy

# Single-hop vs. Multi-hop Networks



Single-hop networks

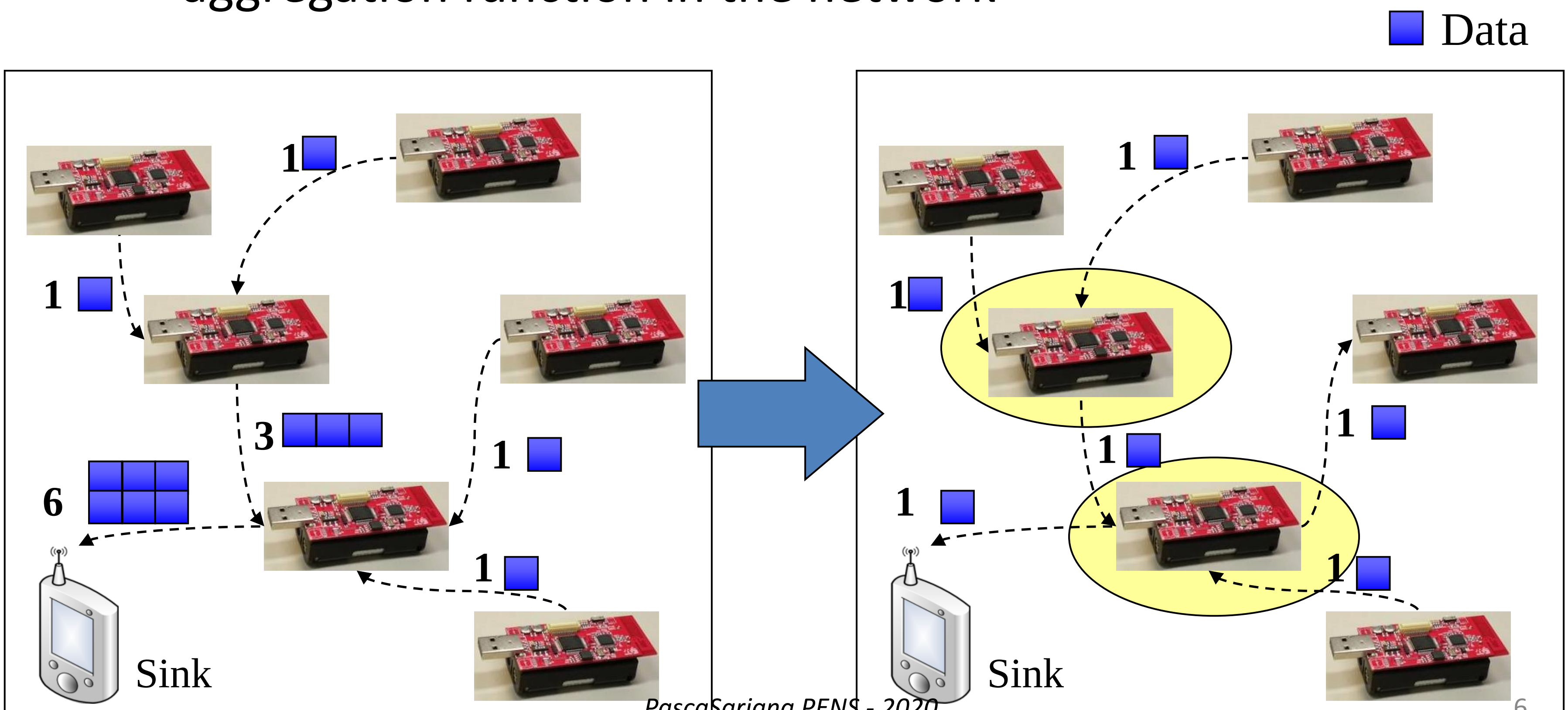
Multi-hop networks




- Multi-hop networks: sensors cooperate in propagating sensor data towards the sink
- Routing protocol is responsible for finding and maintaining path from sensor to sink

# In-network Processing

- Processing Aggregation example
  - The simplest in-network processing technique
  - Reduce number of transmitted bits/packets by applying an aggregation function in the network



# Routing challenges and design issues

- Node deployment: deterministic, randomized
- Energy consumption: without losing accuracy
- Data reporting method: time-driven, event-driven, query-driven, hybrid
- Fault Tolerance: lack of power, physical damage or environmental interferences
- Node/link heterogeneity
- Network Dynamics: fixed and mobile nodes
- Scalability: hundreds or thousands of nodes
- Data aggregation: aggregation from multiple nodes
- Quality of service: related with energy dissipation

# Routing Protocols in WSNs: A taxonomy

## Routing protocols in WSNs

### Network Structure

Flat routing
- SPIN
- Directed Diffusion(DD)

Hierarchical routing
- LEACH
- PEGASIS
- TTDD

Location based routing
- GEAR
- GPSR

### Route Discovery

Reactive
- AODV
- DSR

Proactive
- DSDV
- OLSR

Hybrid
- ZRP

### Protocol Operation

Negotiation based routing
- SPIN

Multi-path network routing
- DD

Query based routing
- DD, Data centric routing

QoS based routing
- TBP, SPEED

Coherent based routing
- DD

Aggregation
- Data Mules, CTCCAP

# Classification of Routing Protocols

- Network structure
  - Flat: all nodes are "equal"
  - Hierarchical: different "roles" for different nodes
  - Location-based: nodes rely on location information
- Route Discovery
  - Reactive (on-demand): find route only when needed
  - Proactive (table-driven): establish routes before they are needed
  - Hybrid: protocols with reactive and proactive characteristics
- Protocol operation
  - Negotiation-based: negotiate data transfer before they occur
  - Multi-path: use multiple routes simultaneously
  - Query-based: receiver-initiated
  - QoS-based: satisfy certain QoS (Quality-of-Service) constraints
  - Coherent-based: perform only minimum amount of in-network processing

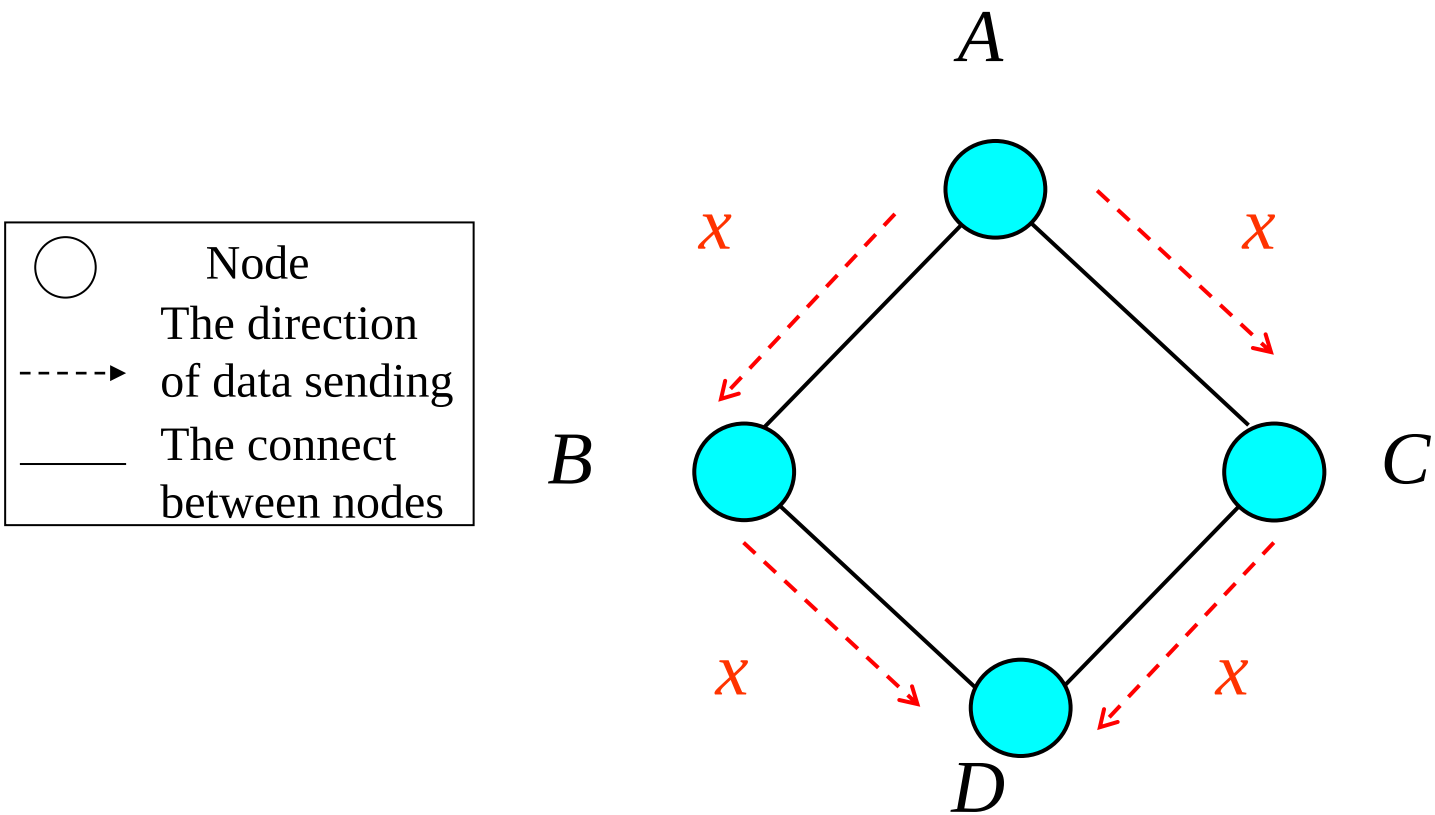
# Routing Metrics

- Minimum hop (shortest hop)
- Energy
  - Minimum energy consumed per packet
  - Maximum time to network partition
  - Minimize variance in node power levels
  - Maximum (average) energy capacity
- Quality-of-service
  - Latency (delay), throughput, jitter, packet loss, error rate
- Robustness
  - Link quality, link stability

# Flat Routing

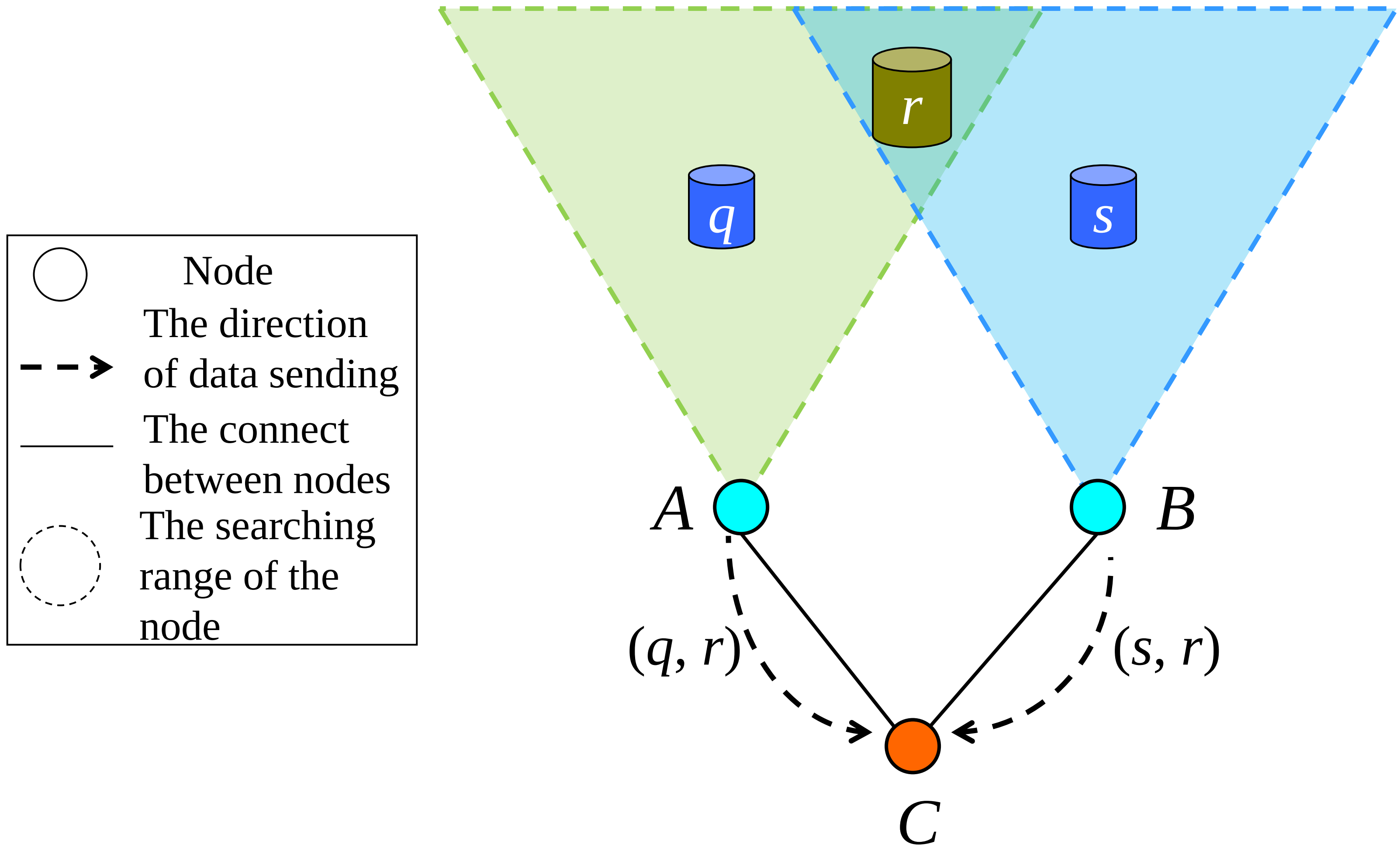
- In flat network, each node typically plays the same role and sensor nodes collaborate together to perform the sensing task.
- Every sensor node (re-)broadcasts sensor data to all of its neighbors => flooding
- Problem in flooding:
  - Implosion: nodes will re-broadcast even when neighbors already have a copy
  - Overlap: sensor data contains redundant information
- To overcome the problems: uses negotiations (data-centric routing)
- Prior works on data centric routing, e.g., SPIN and Directed Diffusion, were shown to save energy through data negotiation and elimination of redundant.

# Problem in Flat: Implosion




https://www3.nd.edu/~cpoellab/teaching/cse40815/Chapter7.pdf

# Problem in Flat: Overlap

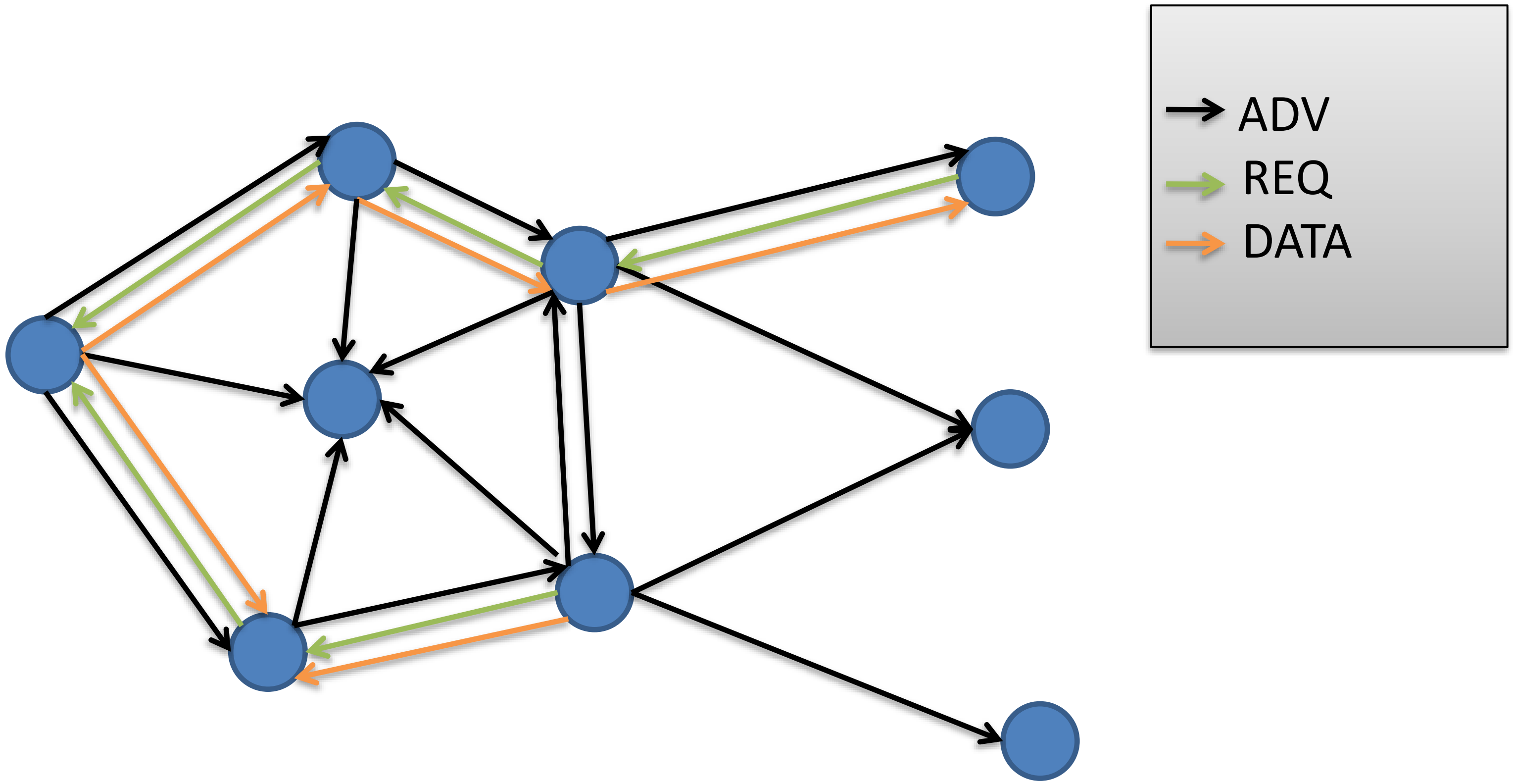


# Flat network routing

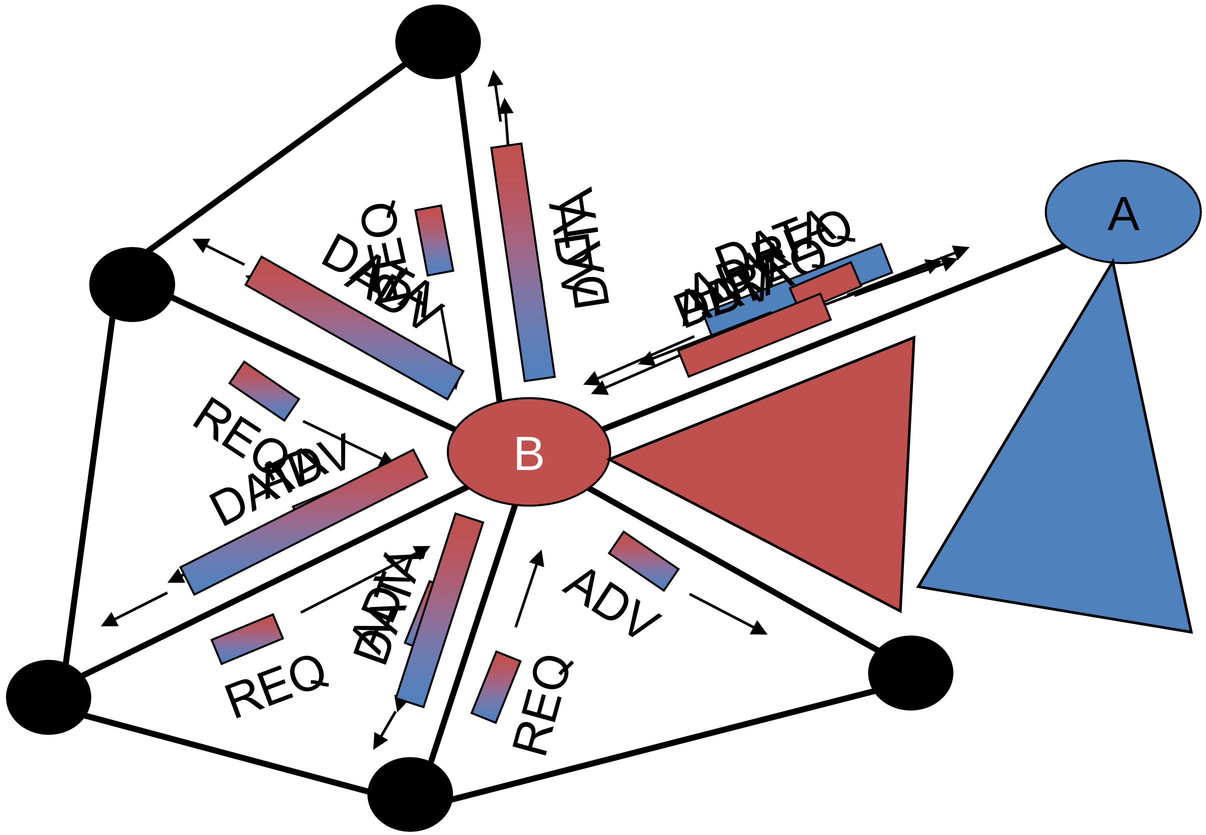
**Sensor Protocol for Information via negotiation (SPIN)**

- Each node is considered as a potential BS
- Sending data that describe the sensor data instead of sending all the data
- Solves the problem of flooding and saves energy by negotiating the transmitted data
- Three-stage protocol: ADV, REQ, DATA

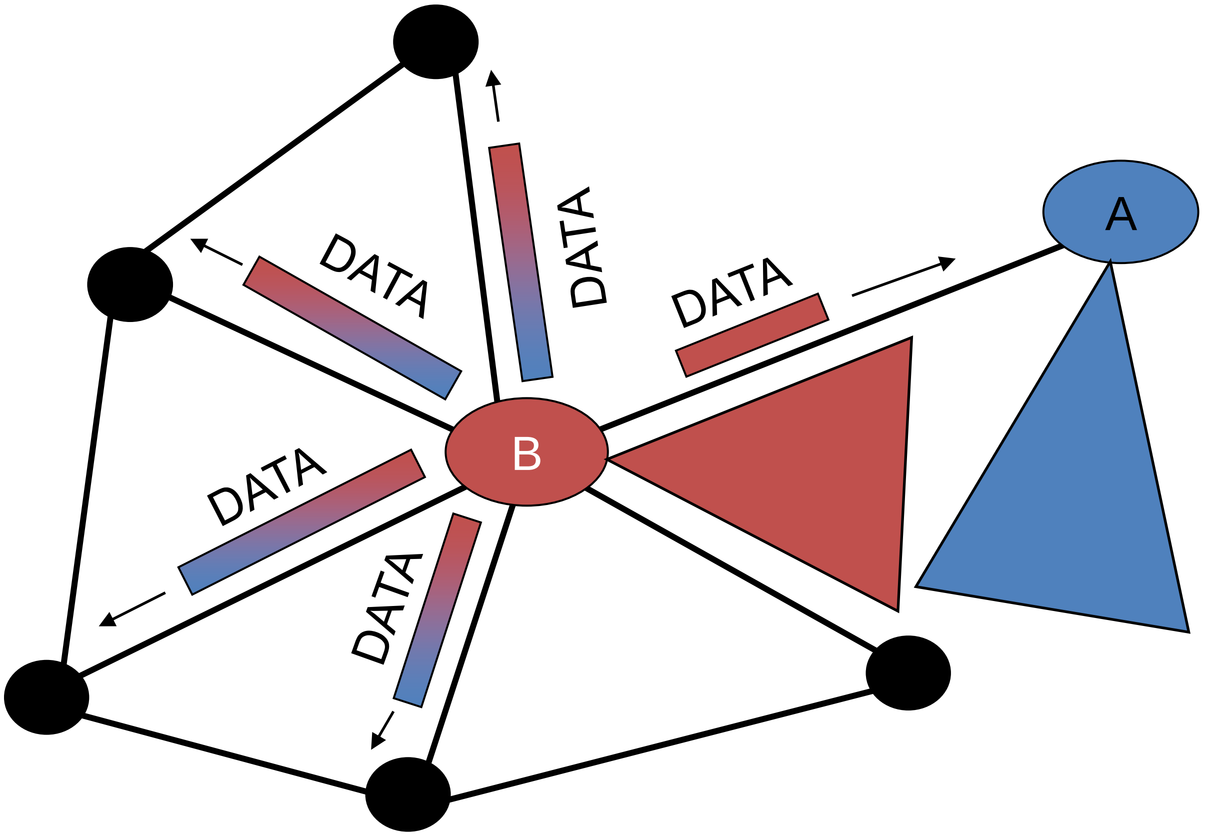
# Sensor Protocol for Information via negotiation (SPIN)



# SPIN (3-Step Protocol)

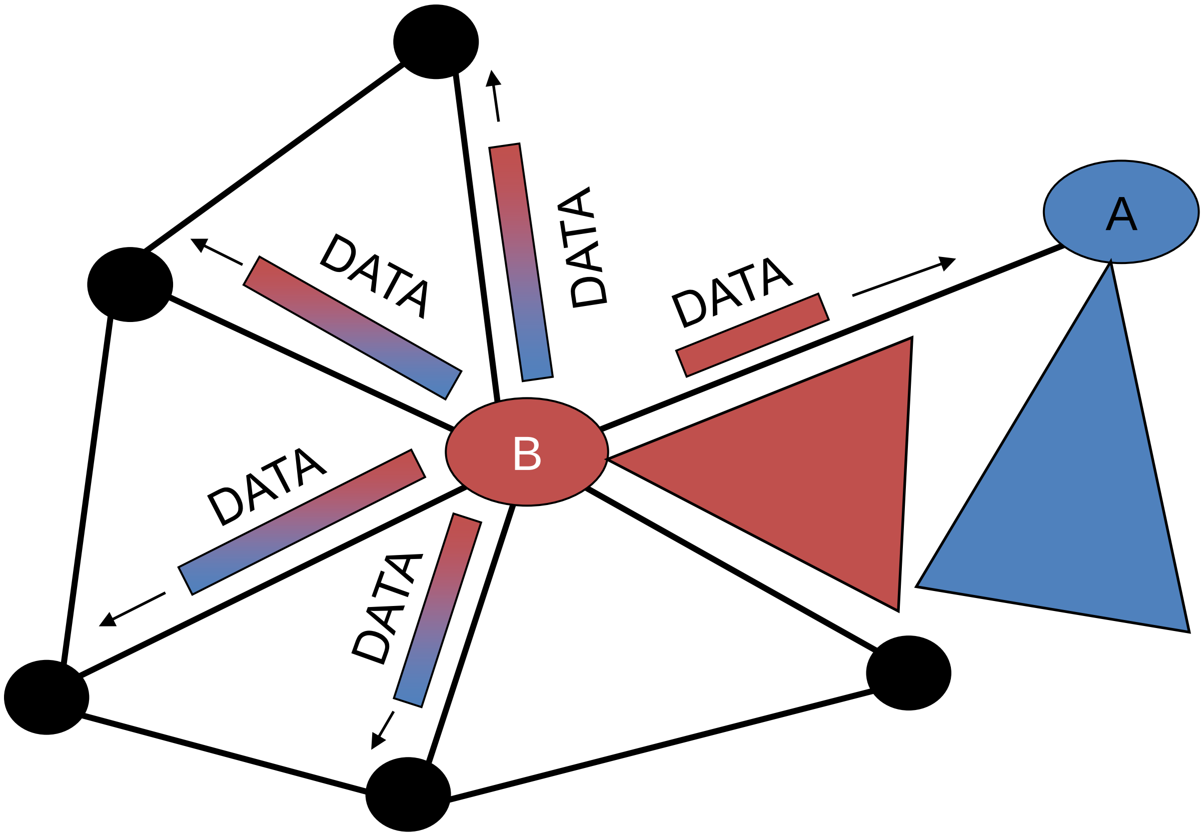


# SPIN (3-Step Protocol)




Notice the color of the data packets sent by node B

# SPIN (3-Step Protocol)




**SPIN effective when DATA sizes are large : REQ, ADV overhead gets amortized**

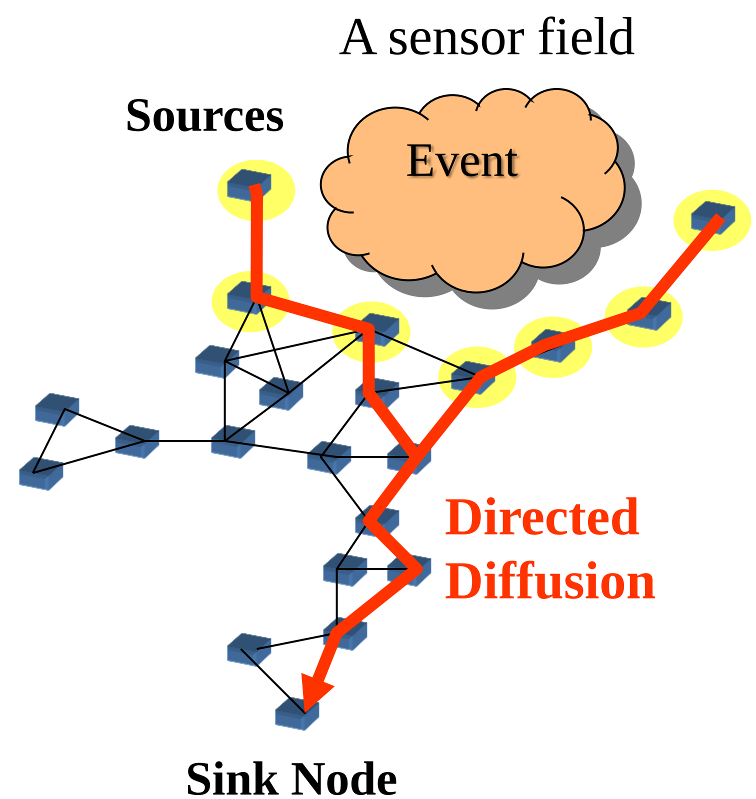
# Flat network routing

## Directed diffusion

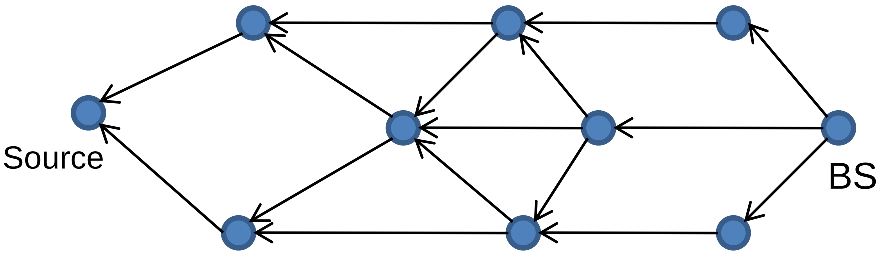
- Data-centric protocol
- Finds an optimal tree that gets the data from multiple source nodes to the BS
- The BS requests data by broadcasting interests
- Gradients are set up to draw requested data toward the requesting node
- Best paths are elected and reinforced to prevent further flooding
- The BS periodically refreshes and resends the interest when it starts to receive data from the source

# Directed Diffusion

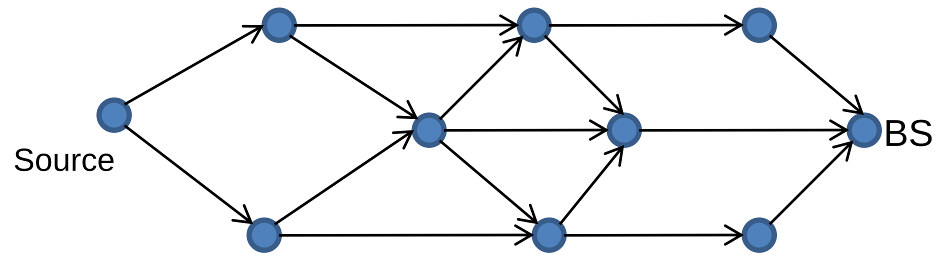
- Data-centric communication
  - Data is named by attribute-value pairs
  - Different form IP-style communication
    - End-to-end delivery service
  - e.g.
    - How many pedestrians do you observe in the geographical region X?



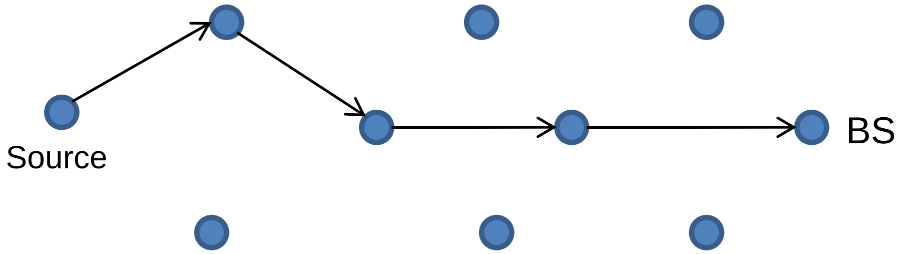
# Directed diffusion




(a) Propagate interest




(b) Set up gradients




(c) Send data and path reinforcemennt

# Hierarchical network routing

**Low Energy Adaptive Clustering Hierarchy protocol (LEACH)**

- Cluster based
- Cluster Heads randomly selected
- CH's role is rotated → uniform energy dissipation
- Uses TDMA as MAC protocol → avoid collision

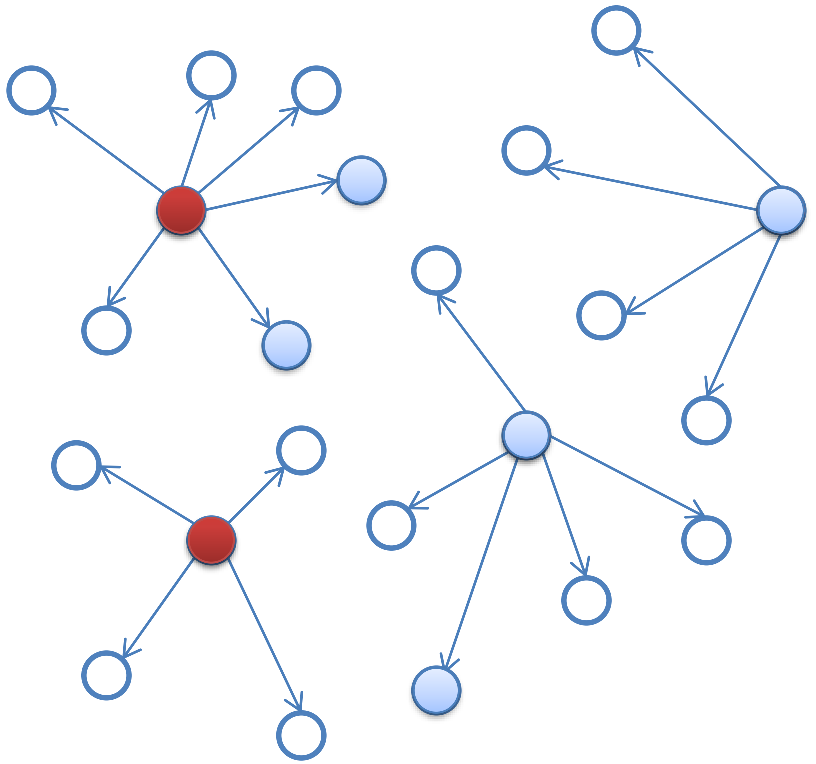
✓ Two phases:

- **Setup phase**: *Clusters organization and CHs selection*
- **Steady state phase** : *Data transfer*

# Low Energy Adaptive Clustering Hierarchy protocol (LEACH)

## Setup phase:

- **Predetermined fraction of nodes elect themselves:**
  1. *A sensor node chooses a random number r*
  2. *If r > threshold t**h**en the node becomes a CH*
  3. *No CHs nodes select to witch cluster to belong after receiving CHs advertisement*
  4. *Each CH creates a TDMA schedule and broadcasts it to all nodes within the cluster*



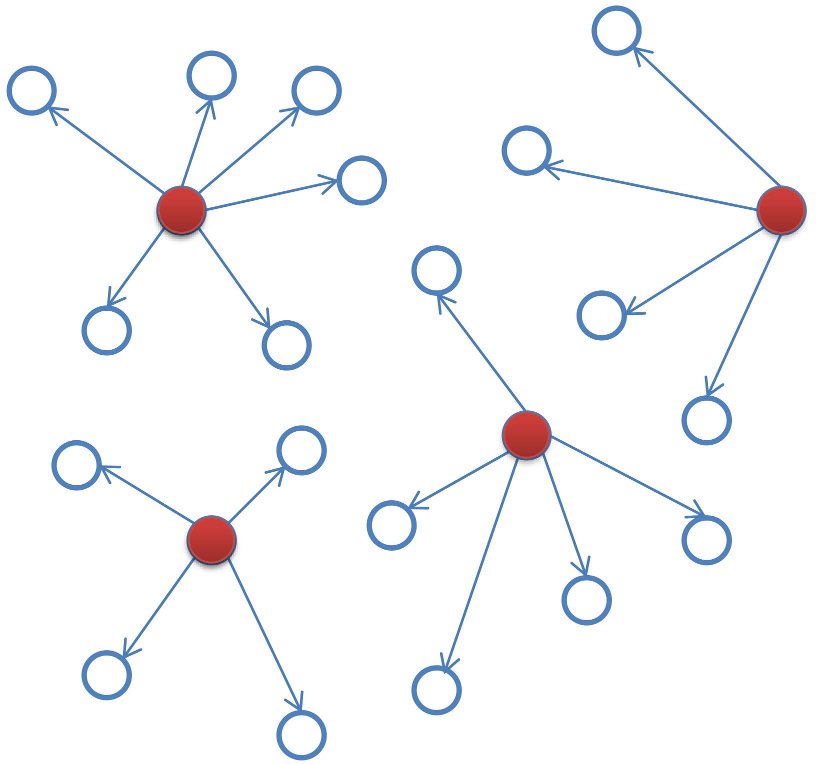
# Low Energy Adaptive Clustering Hierarchy protocol (LEACH)

- ***Threshold:***
  - Each node computes its own threshold
  - Depends on:
    - the Remaining energy of the node
    - Number of the nodes already elected as CH
    - Equal to 0 if the node is already elected within last 1/P rounds where P is a given fraction (between 0 and 1)

# Low Energy Adaptive Clustering Hierarchy protocol (LEACH)

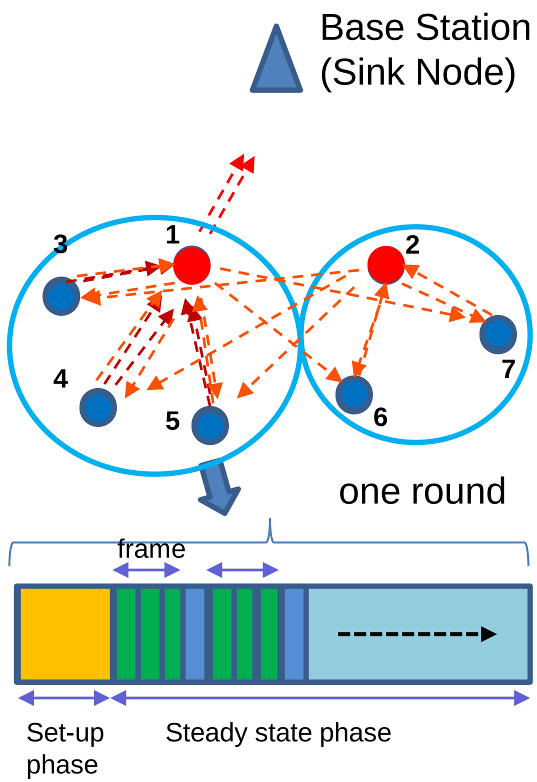
## *Steady phase:*

- *Sensor nodes start sensing and transmitting data to CHs*
- *CHs aggregate data and send it to BS*
- *After a predetermined time the network goes back to the setup phase*



# Low Energy Adaptive Clustering Hierarchy protocol (LEACH)

Basic Clustering: LEACH (Low-Energy Adaptive Clustering Hierarchy) - Decentralized




- It is divided into round.
- Each round has:

a. Set-up phase

- Elected CH (Cluster Head) based on the probability.
- Broadcast ADV (Advertisement) message to non-CH
- Each non-CH chooses CH based on RSSI (signal strength) and send join-request message
- CH sets up transmission schedule (TDMA)

b. Steady State phase

- Cluster members (CM) send data to CH once per frame during the allocated time slot.

# Low Energy Adaptive Clustering Hierarchy protocol (LEACH)

- Drawbacks:
  - Assumes that all nodes have enough power to transmit to the BS

  ➔ *Not applicable in large regions*

  - Random election

  ➔ Possibility that all CHs will be concentrated in same area

  - Dynamic clustering

  ➔ extra overhead (CH role rotating, advertisement)

# Location based protocols

**Geographic and Energy Aware Routing**

- *Routing based on a cost function depending on the <u>distance</u> to the target and the remaining <u>energy</u>.*

- *A node N receive from a neighbor Ni its cost function and then updates its own cost function:*

  $$H(N,T) = H(Ni, T) + C(N, Ni)$$

- *If no cost function received from the node, then compute a default cost function:* $C(N,T) = \alpha d(N,T) + (1-\alpha) Er$

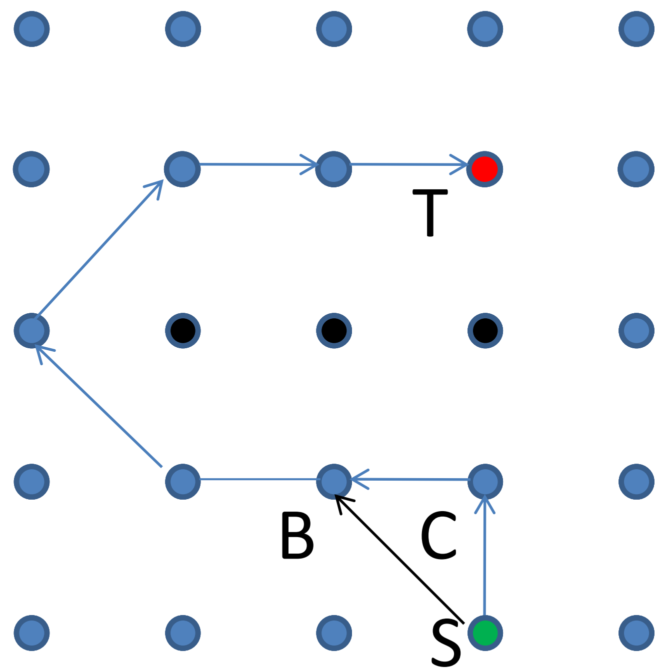
# Geographic and Energy Aware Routing

- Suppose α = 1
- S is sending a packet to T
- C is the closer neighbor to T

➔S Sends the packet through C

- S receive new learned cost function from C.
- Now, B's cost function is less than C

➔ Next packet will be sent through B



# Comparison of routing protocols

| | Classification | Negotiation based | Data aggregation | Localization | QoS | Multipath | Query based |
|---|---|---|---|---|---|---|---|
| SPIN | Flat | Yes | Yes | No | No | Yes | Yes |
| Directed diffusion | Flat | Yes | Yes | Yes | No | Yes | Yes |
| LEACH | Hierarchical | No | Yes | Yes | No | No | No |
| GEAR | Location | No | No | No | No | No | No |

# Challenges to be solved

- Tight coupling between sensor nodes and the physical space.
  - Unattended environment
- Energy consumption while packet transmission:
  - Sending 1 bit over 100m ⇔ millions of processing tasks
- No guaranteed QoS:
  - Need of guaranteed bandwidth and delay, especially for real time applications
- Nodes mobility:
  - Most existing protocols assume that sensor nodes and BS are stationary

# Future directions

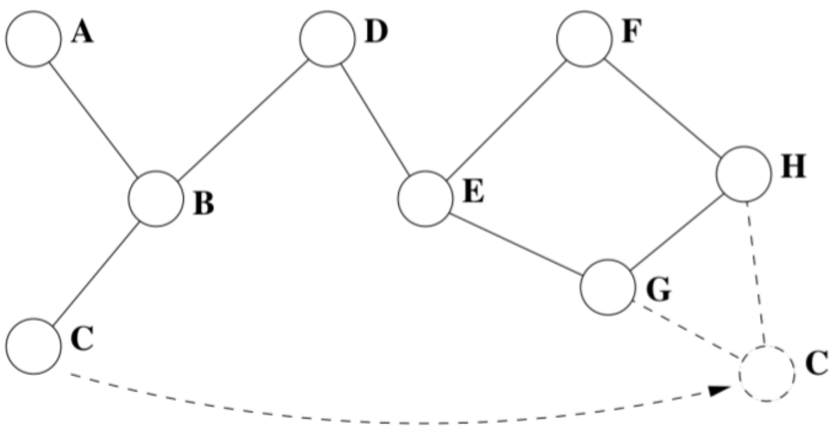
- Exploit redundancy:
  - Fault tolerance techniques
- Processing and computation of data locally
  - → High need to create efficient processing points in the network
  - How to efficiently choose those points ?
- Localization:
  - Means of establishing a coordinate system
  - GPS usage is not conceivable
  - Existing techniques doesn’t offer enough accuracy

# ROUTE DISCOVERY

# Proactive Routing

- Routes are established before they are actually needed => table-driven routing
- Example: DSDV (Destination-sequenced distance vector) and OLSR (Optimized link state routing)
- Main advantage: routes can be used immediately when needed (table look up for next-hop neighbor)
- Main disadvantages:
  - Establishing and maintaining routes that are infrequently (or never) needed
  - Routing tables can become very large
  - Stale information in tables can lead to routing errors

# DSDV: Example




| | | |
|---|---|---|
| C | B | Data |

| | | |
|---|---|---|
| C | E | Data |

| Destination | NextHop | Distance |
|---|---|---|
| A | B | 2 |
| B | B | 1 |
| C | B | 2 |
| D | D | 0 |
| E | E | 1 |
| F | E | 2 |
| G | E | 2 |
| H | E | 3 |

Node D's Table Before C's Move

| Destination | NextHop | Distance |
|---|---|---|
| A | B | 2 |
| B | B | 1 |
| C | E | 3 |
| D | D | 0 |
| E | E | 1 |
| F | E | 2 |
| G | E | 2 |
| H | E | 3 |

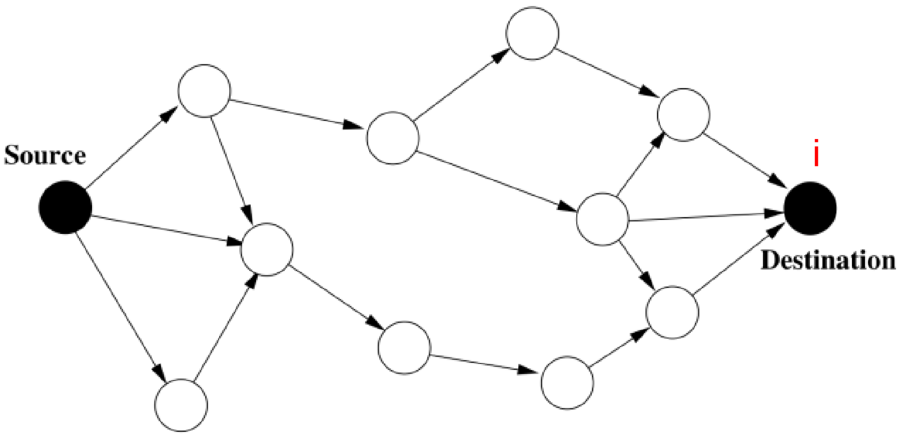
Node D's Table After C's Move

- DSDV: nodes broadcast their routing tables to their neighbors periodically and whenever significant information is available

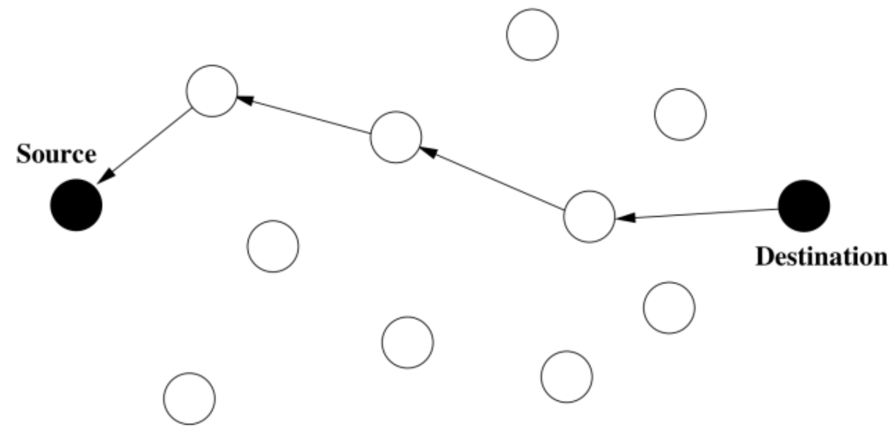
# On-Demand (Reactive) Routing

- Routes are not established until actually needed
- Instead, a source node (knowing the identity / address of a destination node) initiates a route discovery process which completes when at least one route has been found or all possible paths have been examined
- A newly discovered route is then maintained until it either breaks or is no longer needed by the source
- Example: AODV (Ad Hoc On-Demand Distance Vector), DSR (Dynamic Source Routing)
- AODV relies on broadcast route discovery mechanism, which is used to dynamically establish route table entries at intermediate nodes
- Path discovery process of AODV: route request (RREQ) and route reply (RREP)

# AODV VECTOR



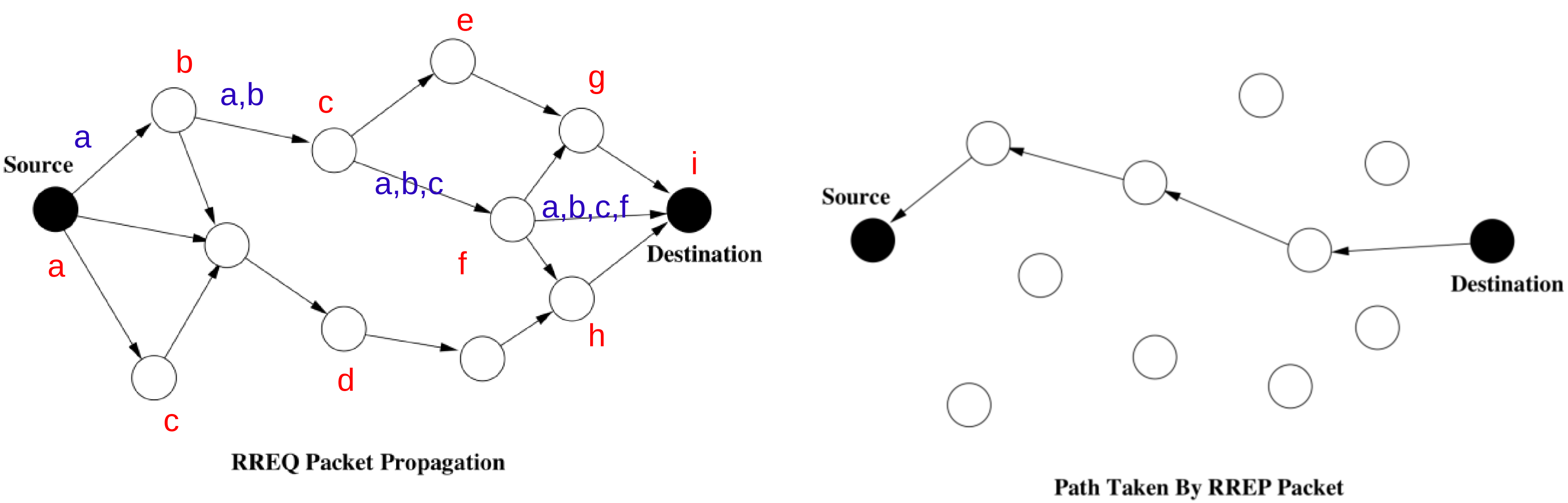

RREQ Packet Propagation




Path Taken By RREP Packet

- Routes are established only when needed
- No need for route table updates and exchanges for unused routes
- Periodic HELLO messages
- RREP uses reverse path of RREQ

# DSR (Dynamic Source Routing)




- Each data packet sent by the source has to contain complete source route information

# Zone Routing Protocol (ZRP)

- Hybrid approach – proactive (intra-zone) and on-demand (inter-zone)
- Border nodes (via bordercast) perform on-demand route discovery