ROUTING PROTOCOL
WIRELESS SENSOR NETWORKS

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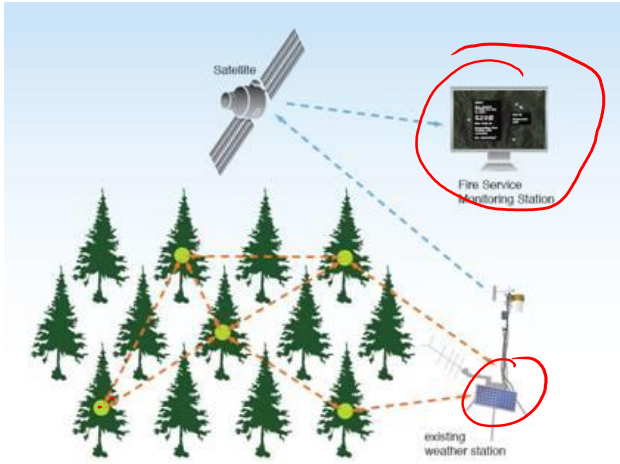
Routing Techniques in Wireless Sensor Networks

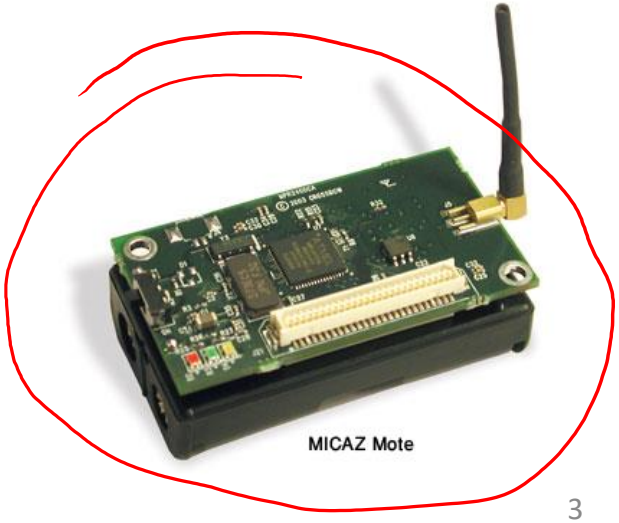
- Structure and applications of WSNs
- WSN vs. Ad hoc and cellular networks
- Routing challenges and design issues
- Classification of routing protocols
- Flat network routing
- Hierarchical routing
- Location based routing
- Comparison of different protocols
- Conclusion and future directions

Wireless Sensor Networks (WSN)

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



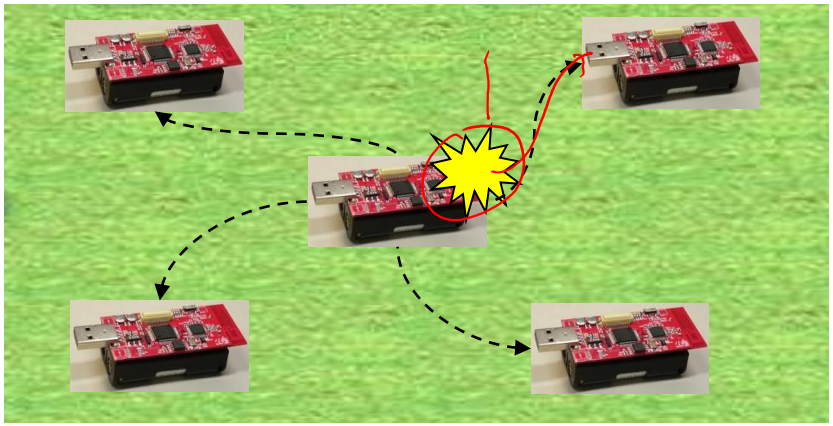
- Applications:
  - ✓ Security and tactical surveillance
  - ✓ Weather monitoring
  - ✓ Disaster management....



WSN vs. Ad hoc and cellular networks

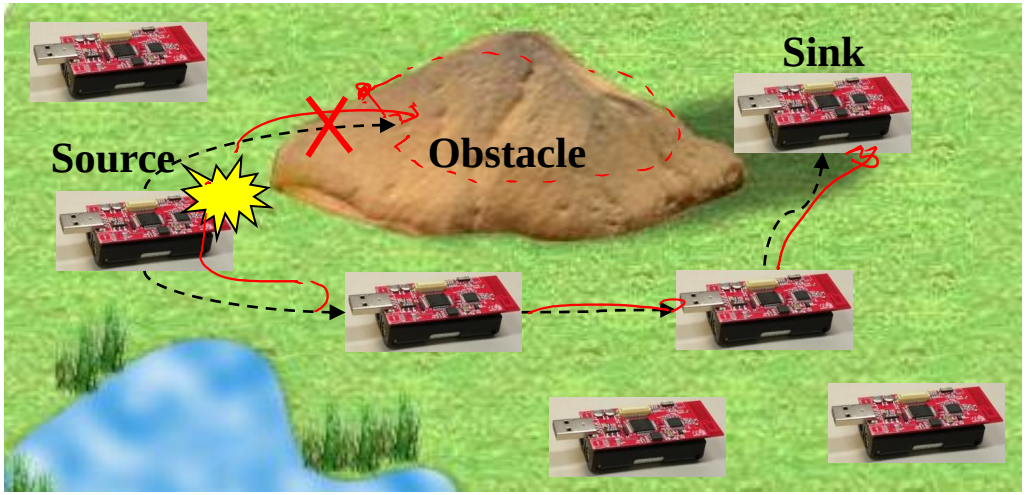
- Very large number of sensor nodes
- Data flow from multiple sources to particular BS
- Constraint of energy, processing and storage capabilities
- Nodes are generally stationary after deployment
- WSN are application-specific
- Position awareness of sensor nodes is important
- High probability of redundancy

Single-hop vs. Multi-hop Networks



Single-hop networks

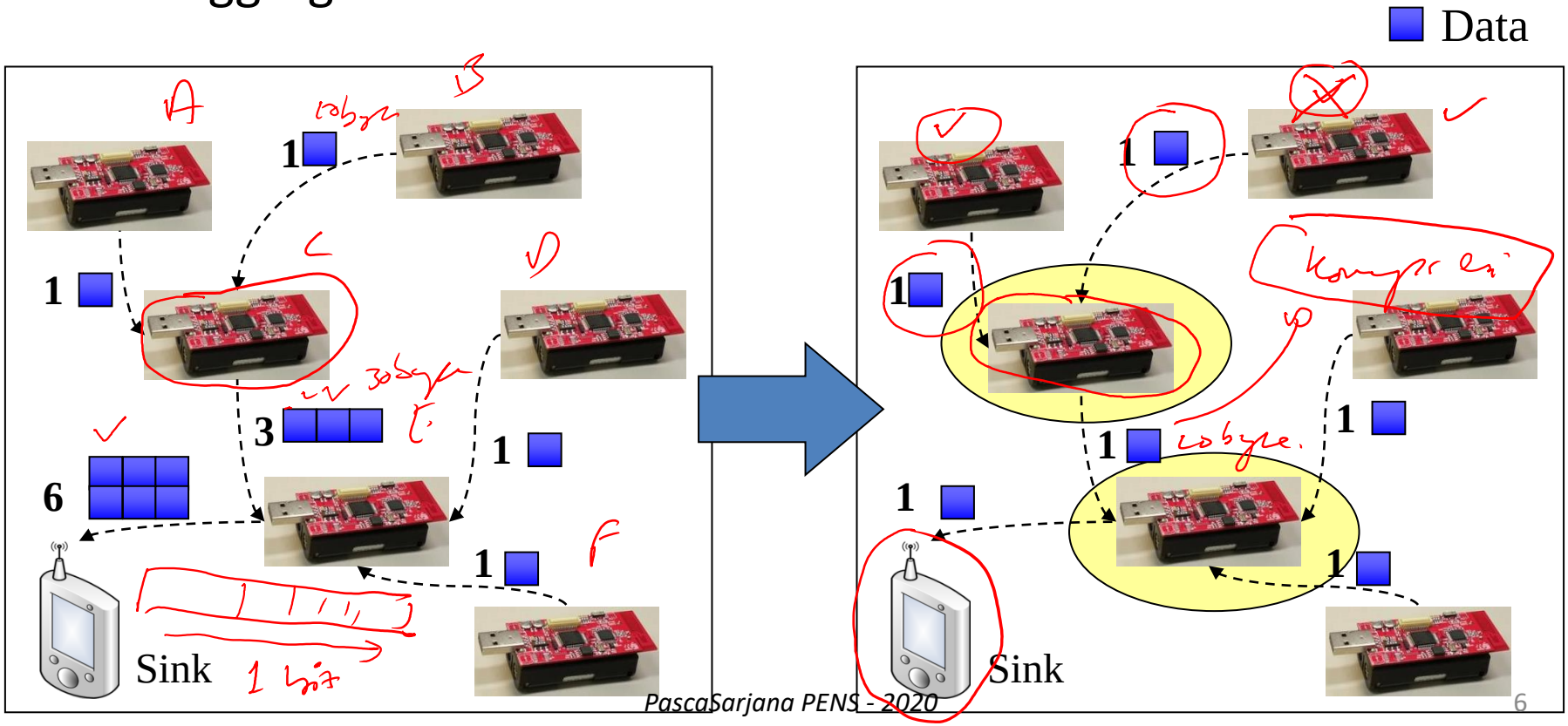
Multi-hop networks



- 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

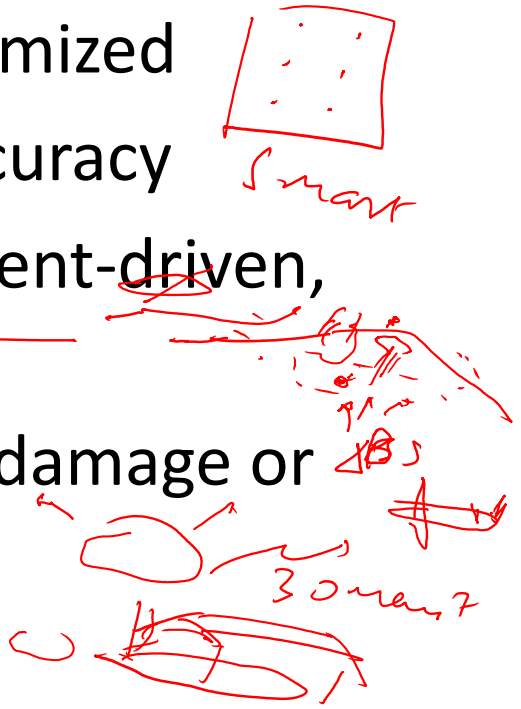
In-network Processing

- 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



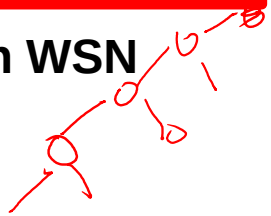
Routing Protocols : A taxonomy

Routing protocols

Network Structure

- Flat routing
  - SPIN
  - Directed Diffusion(DD)
- Hierarchical routing
  - LEACH
  - PEGASIS
  - TTDD
- Location based routing
  - GEAR
  - GPSR

Applicable in WSN

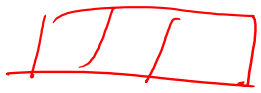


Route Discovery

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

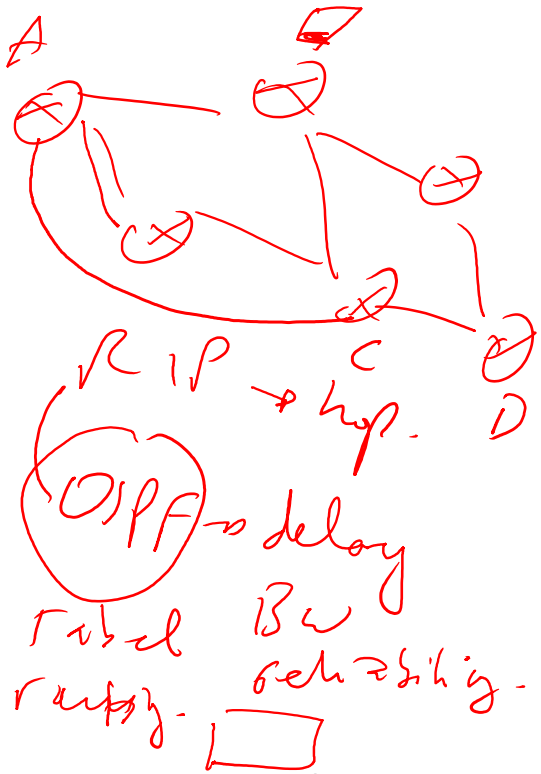
Coherent based routing
- DD

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



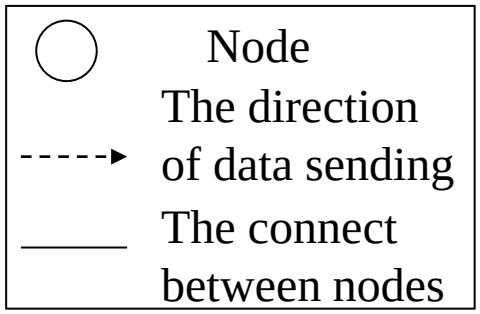
- Minimum hop (shortest hop)
- Energy
  - Minimum energy consumed per packet
  - Maximum time to network partition
  - Minimize variance in node power levels
  - Maximum (average) energy capacity
- Quality-of-service
  - Latency (delay), throughput, jitter, packet loss, error rate
- Robustness
  - Link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

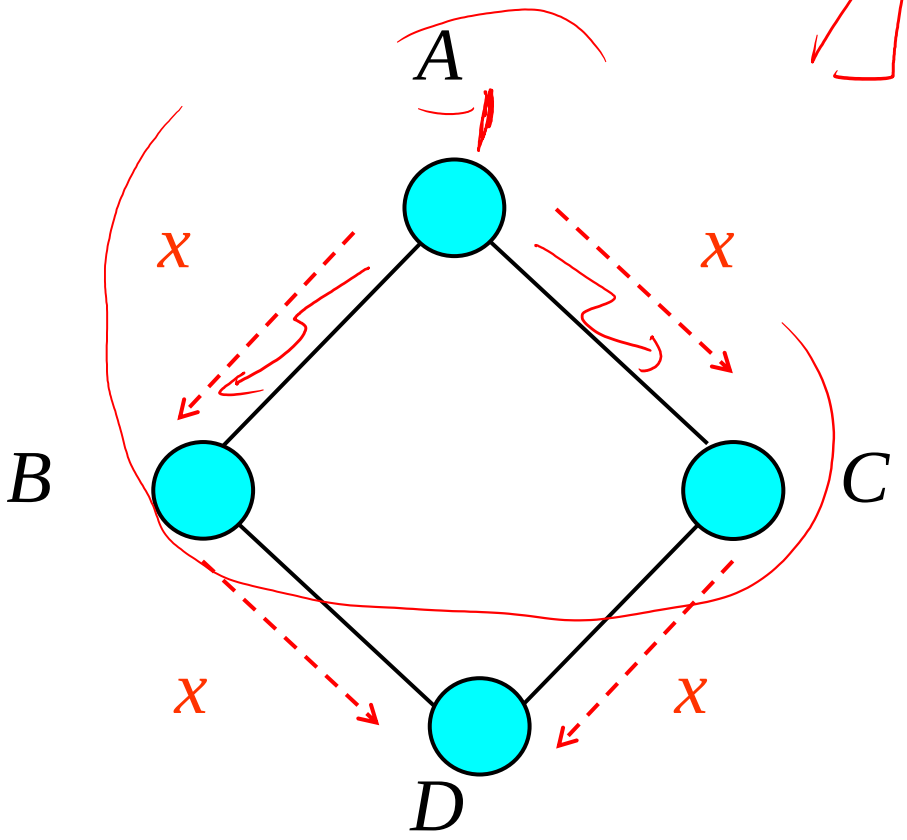
protocol overhead.

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.

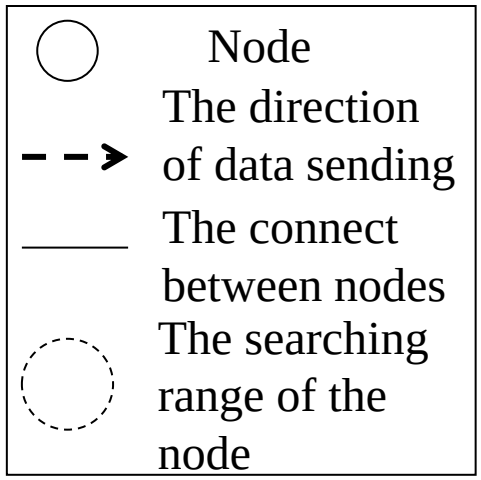
Problem in Flat: Implosion

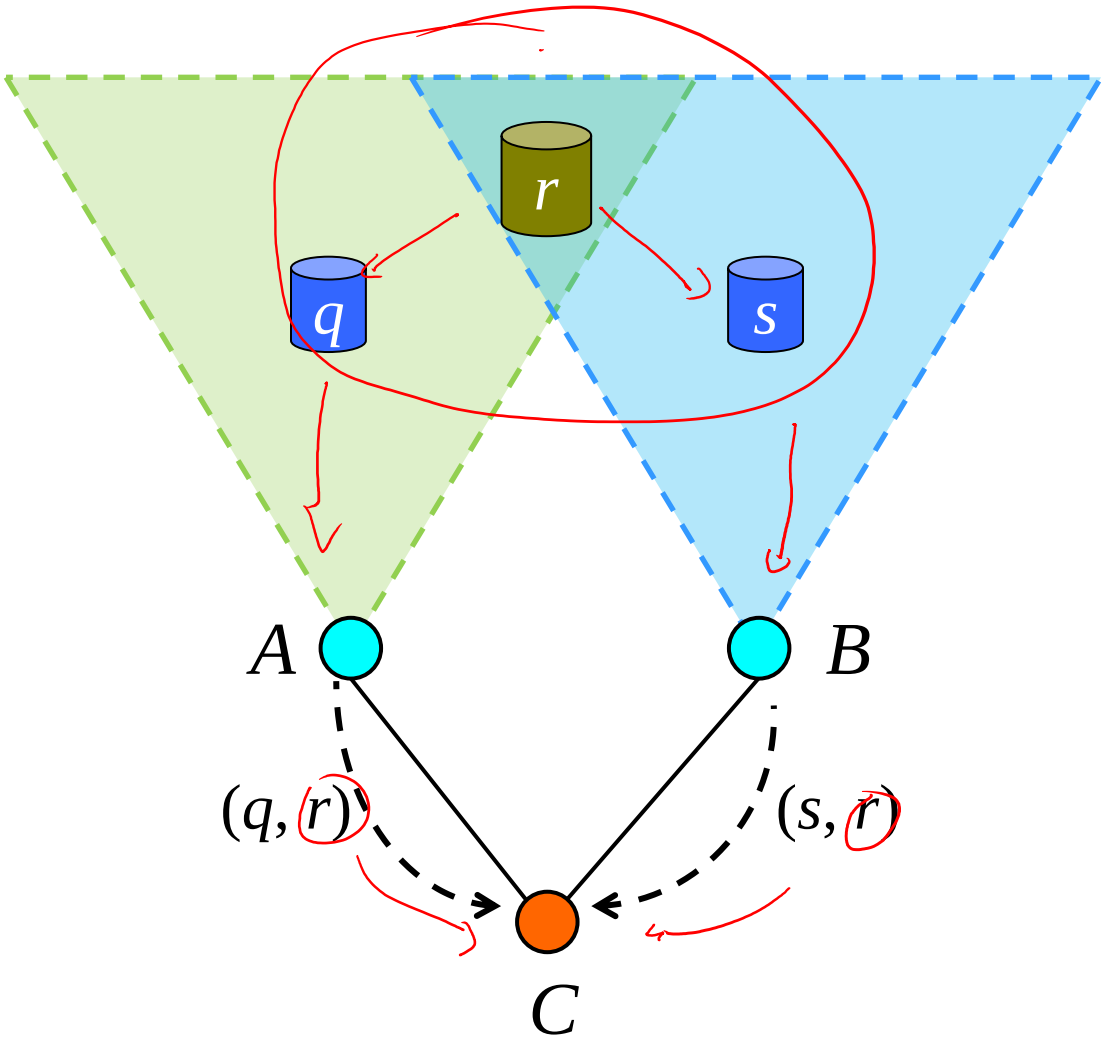




https://www3.nd.edu/~cpoellab/teaching/cse40815/Chapter7.pdf

Problem in Flat: Overlap



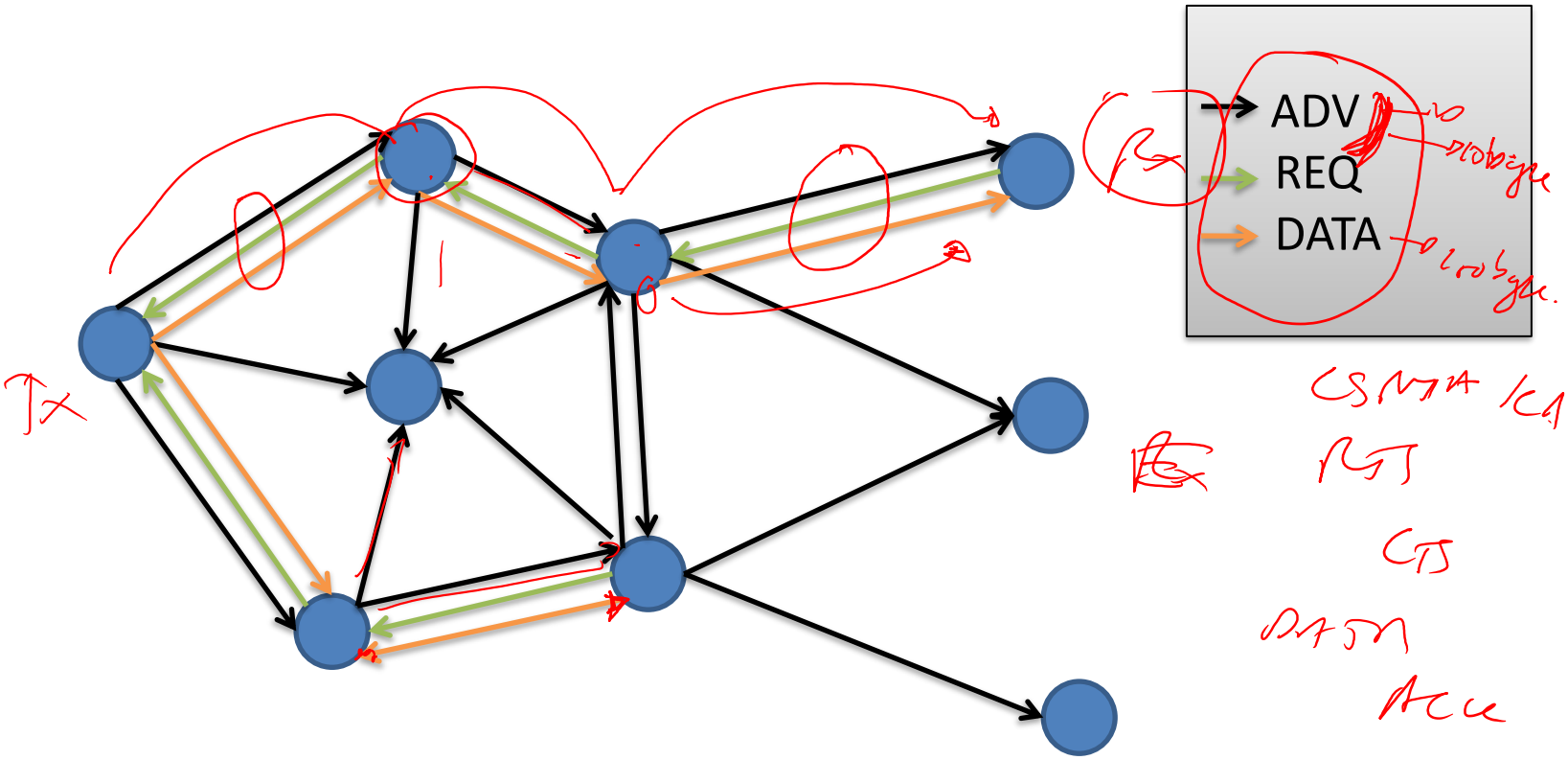


Flat network routing

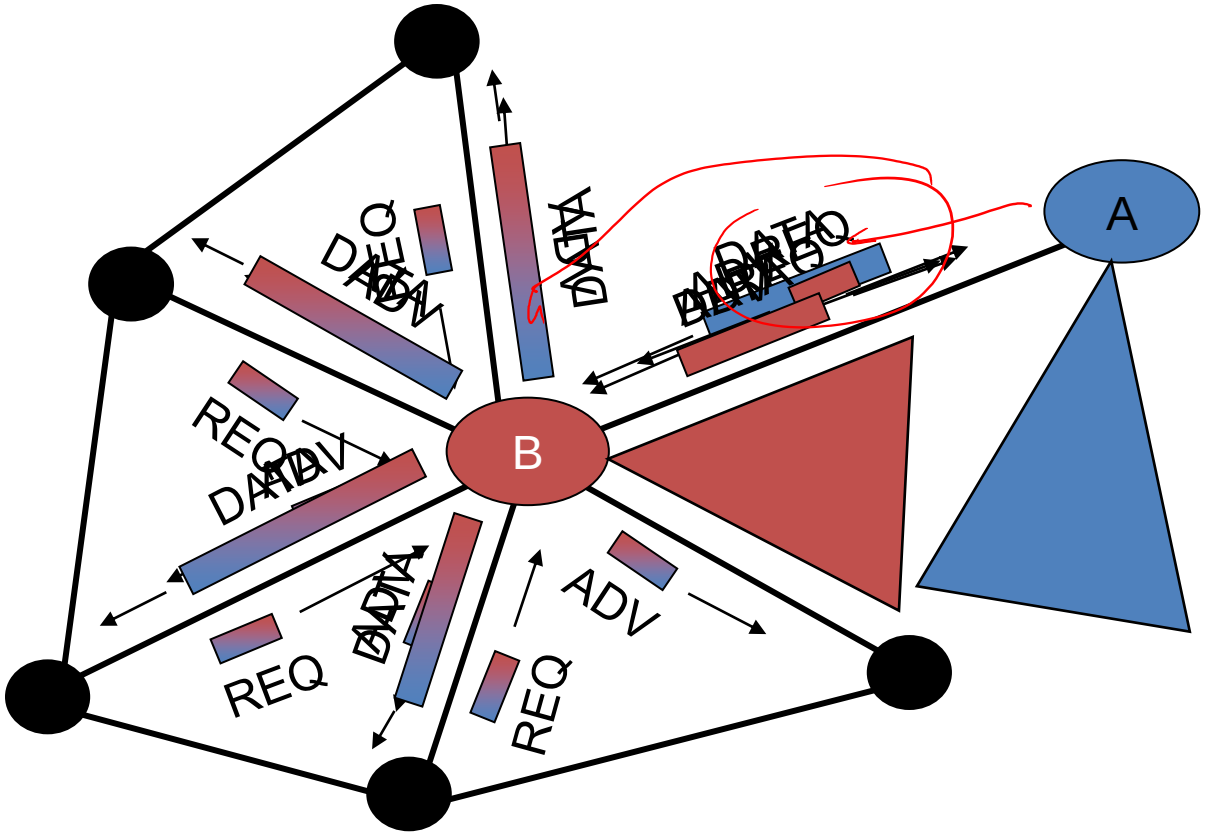
Sensor Protocol for Information via negotiation (SPIN)

- 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

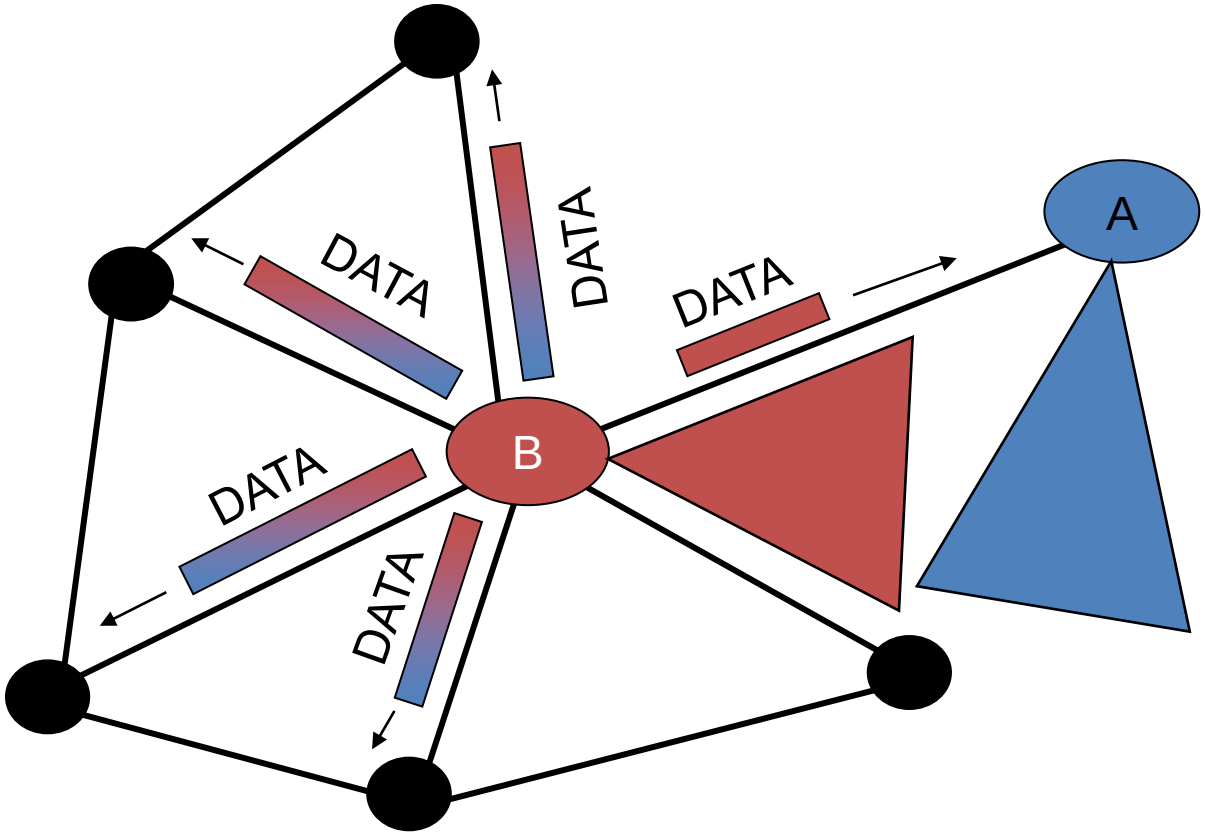
Sensor Protocol for Information via negotiation (SPIN)



SPIN (3-Step Protocol)

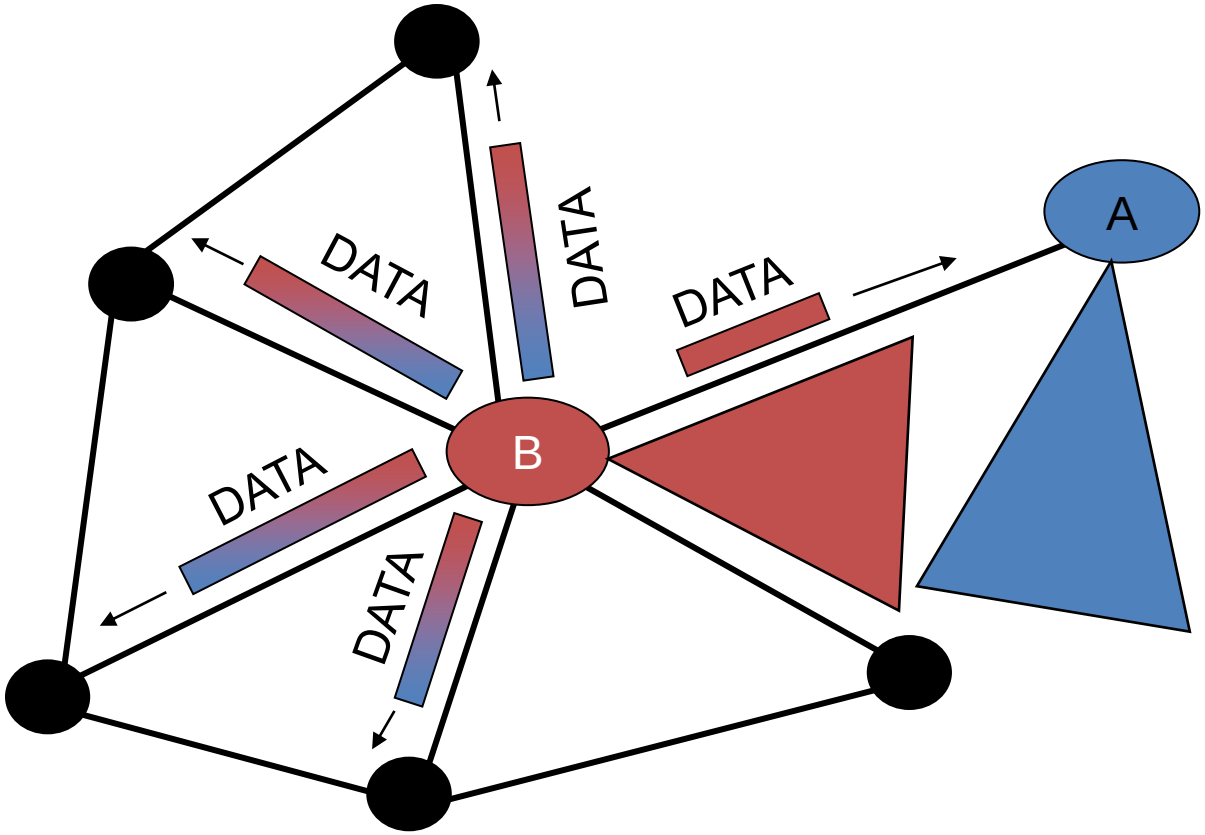


SPIN (3-Step Protocol)



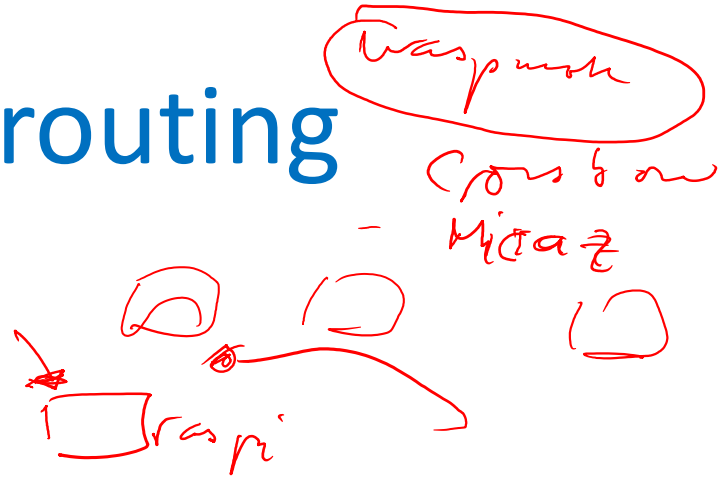
Notice the color of the data packets sent by node B

SPIN (3-Step Protocol)



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

Flat network routing

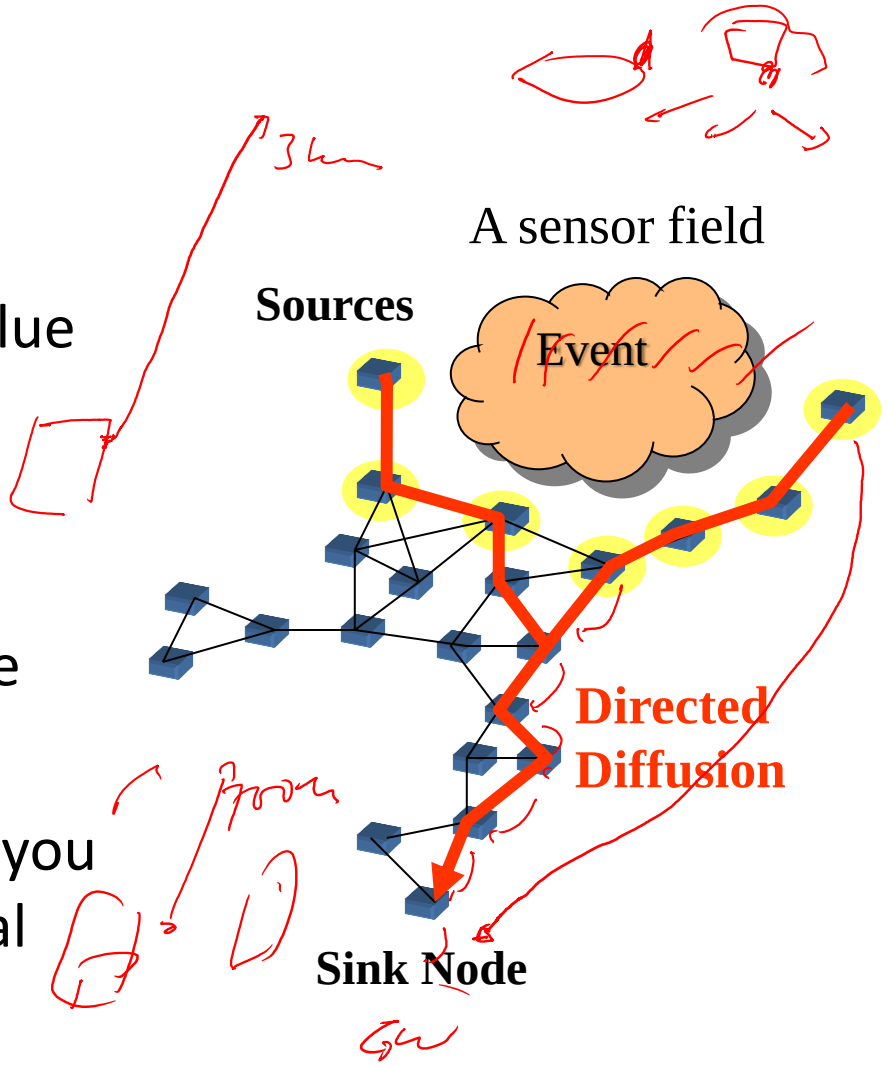


Directed diffusion

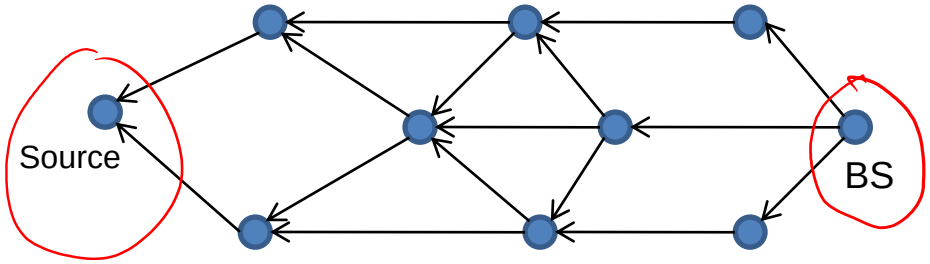
- Data-centric protocol
- Finds an optimal tree that gets the data from multiple source nodes to the BS
- The BS requests data by broadcasting interests
- Gradients are set up to draw requested data toward the requesting node
- Best paths are elected and reinforced to prevent further flooding
- The BS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

Directed Diffusion

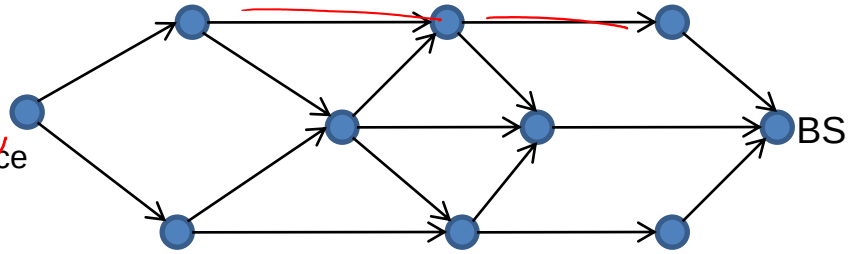
- Data-centric communication
  - Data is named by attribute-value pairs
  - Different form IP-style communication
    - End-to-end delivery service
  - e.g.
    - How many pedestrians do you observe in the geographical region X?



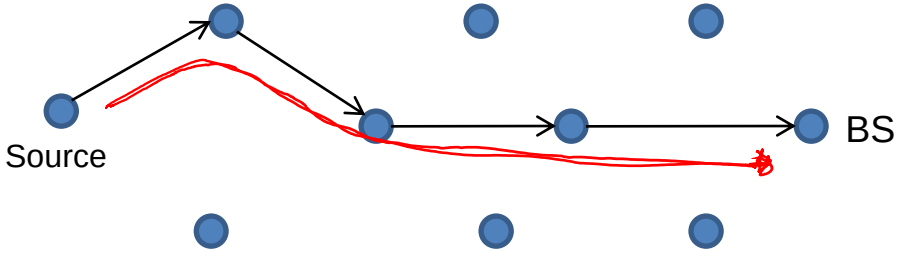
Directed diffusion



(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

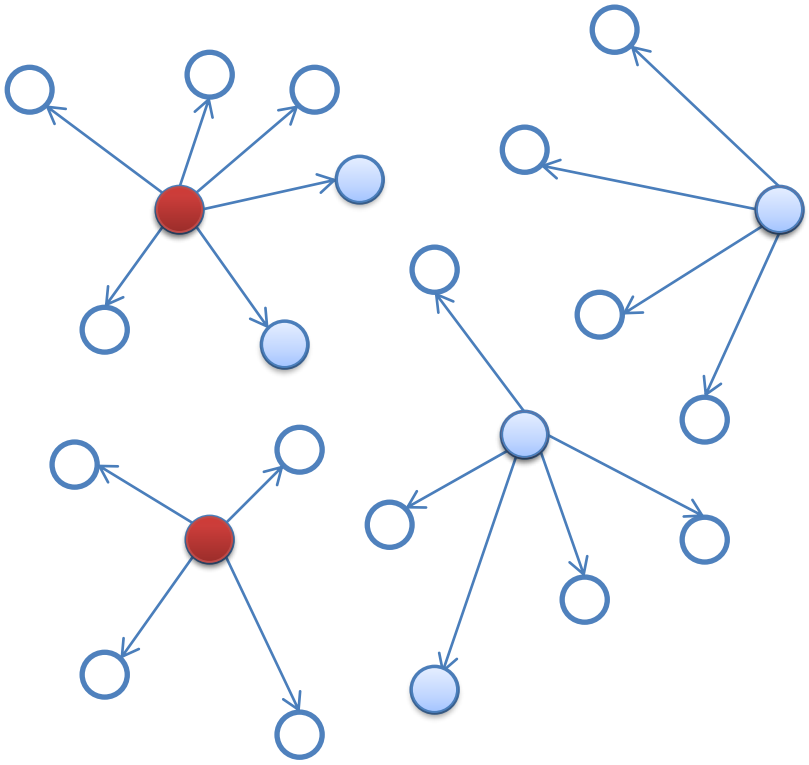
✓ Two phases:

- **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 then 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*



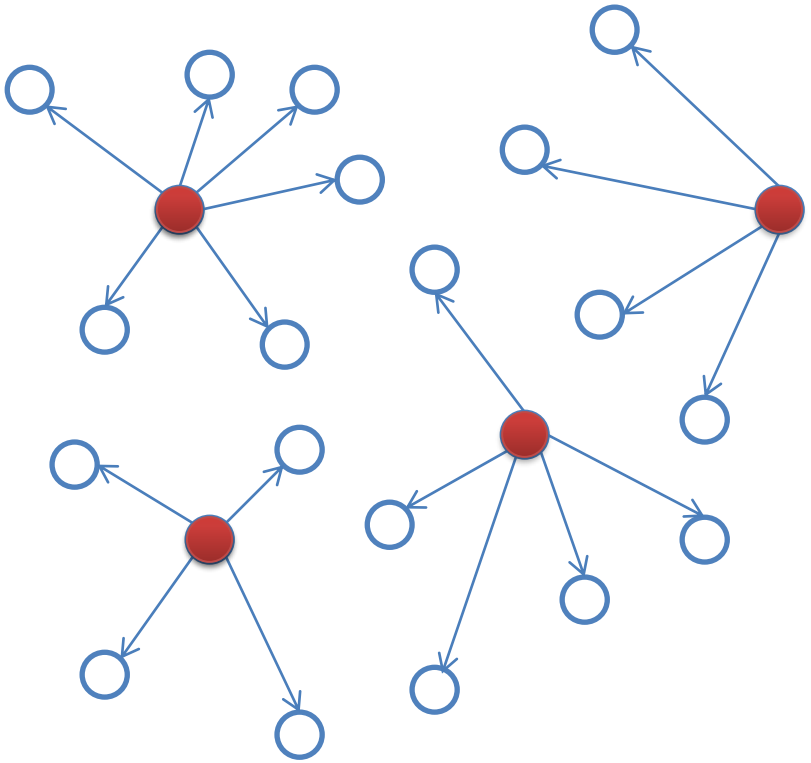
Low Energy Adaptive Clustering Hierarchy protocol (LEACH)

- ***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)

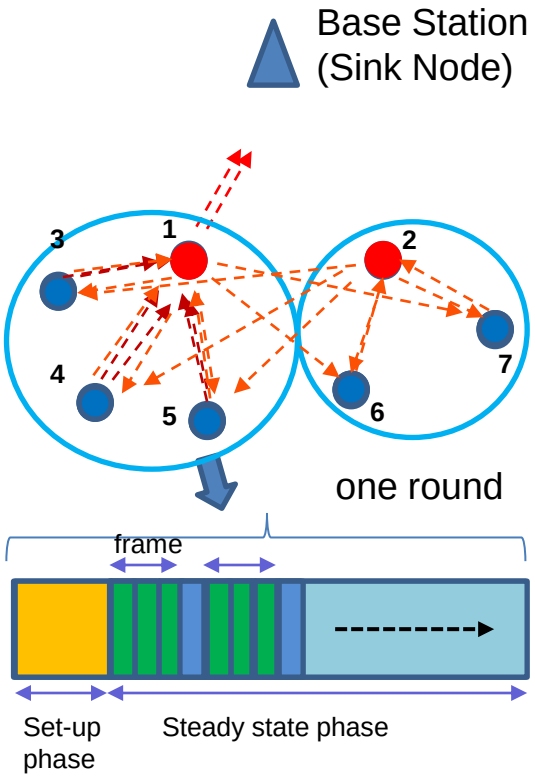
Steady phase:

- *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 distance to the target and the remaining energy.*

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

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

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

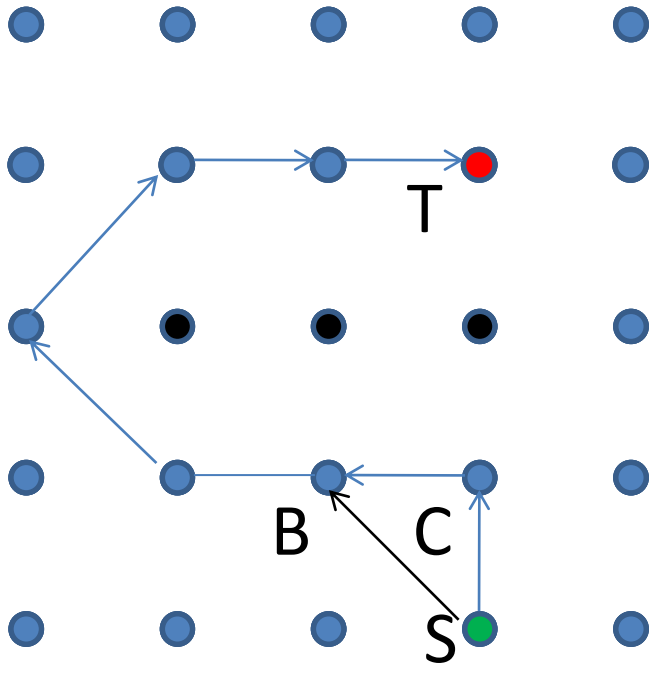
Geographic and Energy Aware Routing

- 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