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# ROUTING ALGORITHMS

## Part 1: Data centric and hierarchical protocols

# Why can't we use conventional routing algorithms here??

- A sensor node does not have an identity (address)
  - **Content** based and **data** centric
    - * Where are nodes whose temperatures will exceed more than 10 degrees for next 10 minutes?
    - * Tell me the location of the object ( with interest specification) every 100ms for 2 minutes.

# Why can't we use conventional routing algorithms here?

- Users interested in collective information from multiple sensors regarding a physical phenomenon
- Intermediate nodes can perform data aggregation and caching in addition to routing.
  * Where, When, How?

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# Why can't we use conventional routing algorithms here?

- Not node-to-node packet switching, but node-to-node data propagation.
- High level tasks are needed:
  - * At what speed and in what direction was that elephant traveling?
  - * Is it the time to order more inventory?

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# Challenges

- Energy-limited nodes
- Computation
  - Aggregate data
  - Suppress redundant routing information
- Communication
  - Bandwidth-limited
  - Energy-intensive

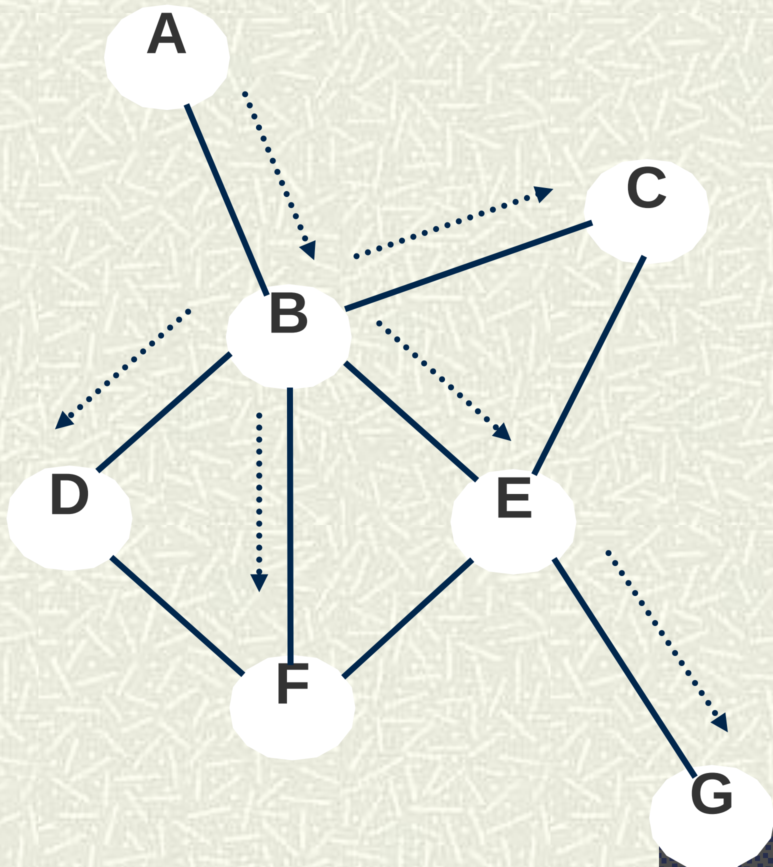
**Goal: Minimize Energy Dissipation**

# Challenges

- Robustness: unexpected sensor node failures
- Dynamic Changes: no *a-priori* knowledge
  - Sink Mobility
  - Target Moving
- Scalability: ad-hoc deployment in large scale
  - Fully distributed without global knowledge
  - Large numbers of sources and sinks

# What should be the Optimum “Ideal” Routing Protocol for WSNs

Shortest-path routes
Avoids overlap
Minimum energy consumption
Needs global topology information



# Taxonomy of Routing Protocols for Wireless Sensor Networks
# K. Akkaya and M. Younis, "A Survey on Routing Protocols for Wireless Sensor Networks," AdHoc Networks (Elsevier) Journal, 2005

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## 1. DATA CENTRIC PROTOCOLS

Flooding, Gossiping, SPIN, Directed Diffusion, Rumor Routing, Cougar, Acquire

## 2. HIERARCHICAL PROTOCOLS

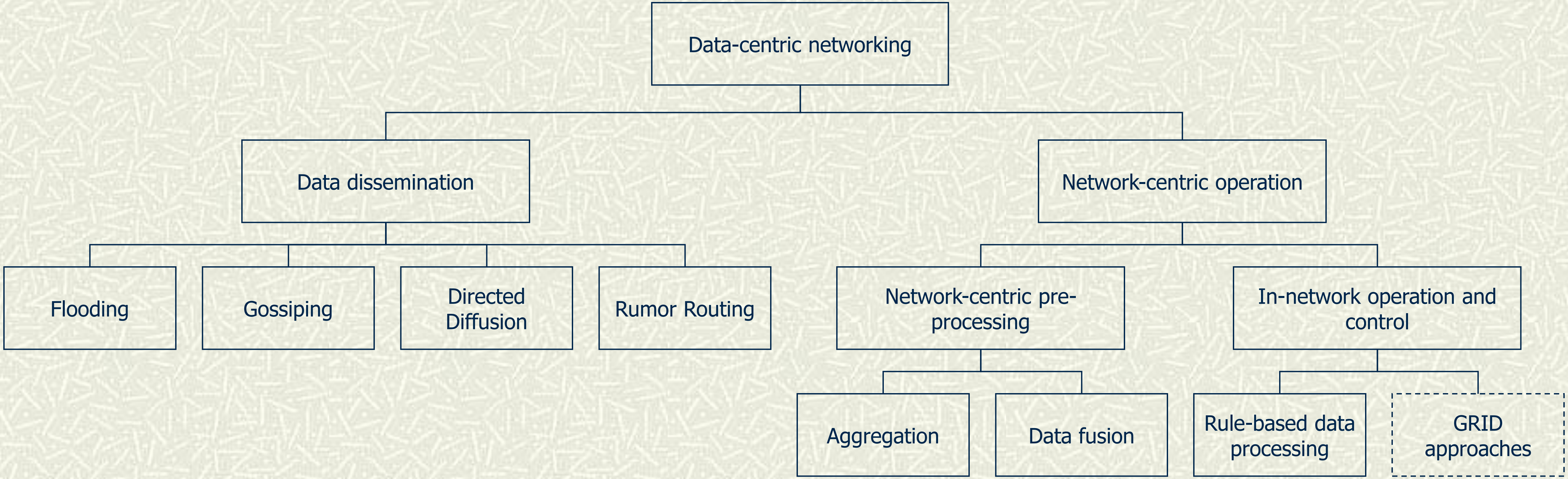
LEACH, PEGASIS, TEEN (Threshold Sensitive Energy Efficient Sensor Network Protocol), APTEEN,

## 3. LOCATION BASED (GEOGRAPHIC) PROTOCOLS

GPSR(Greedy Perimeter Stateless Routing ), GAF (Geographic Adaptive Fidelity), GEAR(Geographic and Energy-Aware Routing), Trajectory-based Forwarding

# Overview and classification

- Data dissemination – forwarding of data though the network
- Network-centric operation – data manipulation and control tasks
  - Network-centric pre-processing, e.g. data aggregation and fusion
  - In-network operation and control, e.g. rule-based approaches



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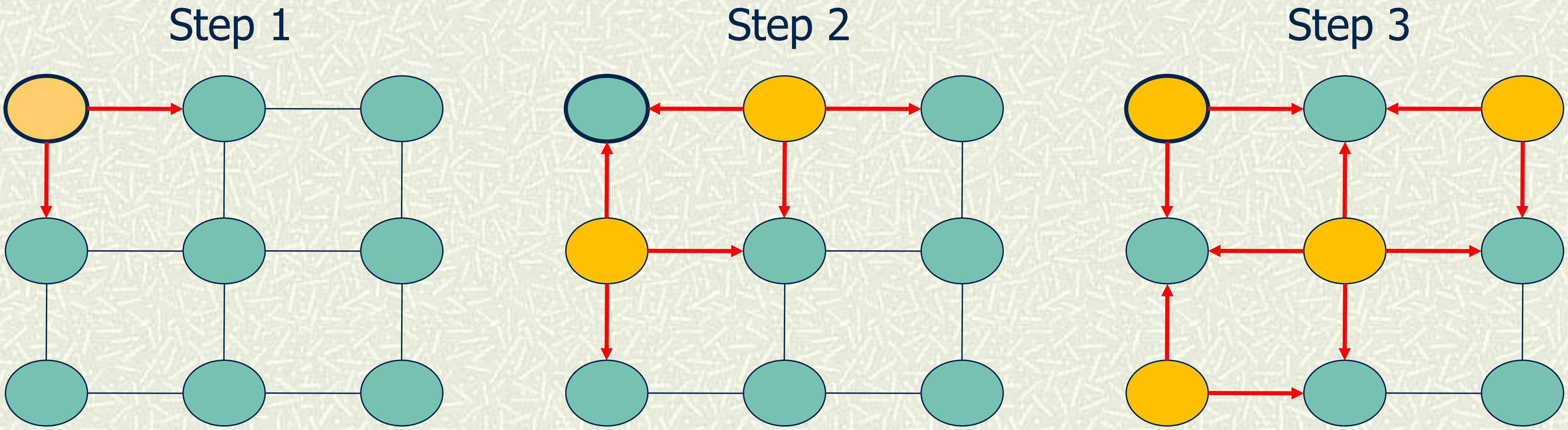
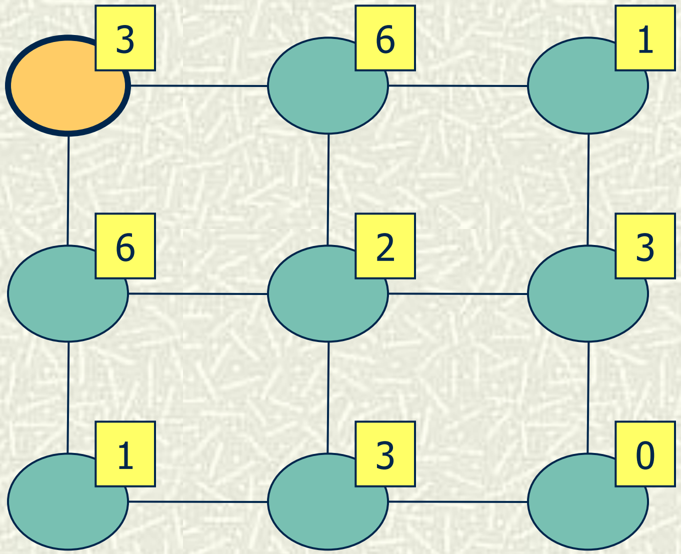
# Flooding

- Basic mechanism:
  - Each node that receives a packet re-broadcasts it to all neighbors
  - The data packet is discarded when the maximum hop count (TTL) is reached

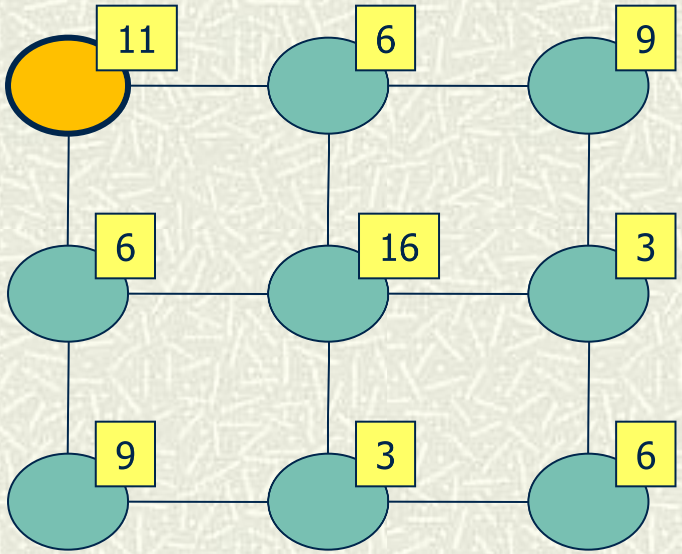


# Flooding

TTL 3




TTL 4




- Advantages
  - No route discovery mechanisms are required
  - No topology maintenance is required
- Disadvantages
  - ***Implosion:*** duplicate messages are sent to the same node
  - ***Overlap:*** same events may be sensed by more than one node due to overlapping regions of coverage → duplicate report of the same event
  - ***Resource blindness:*** available energy is not considered and redundant transmissions may occur → limited network lifetime

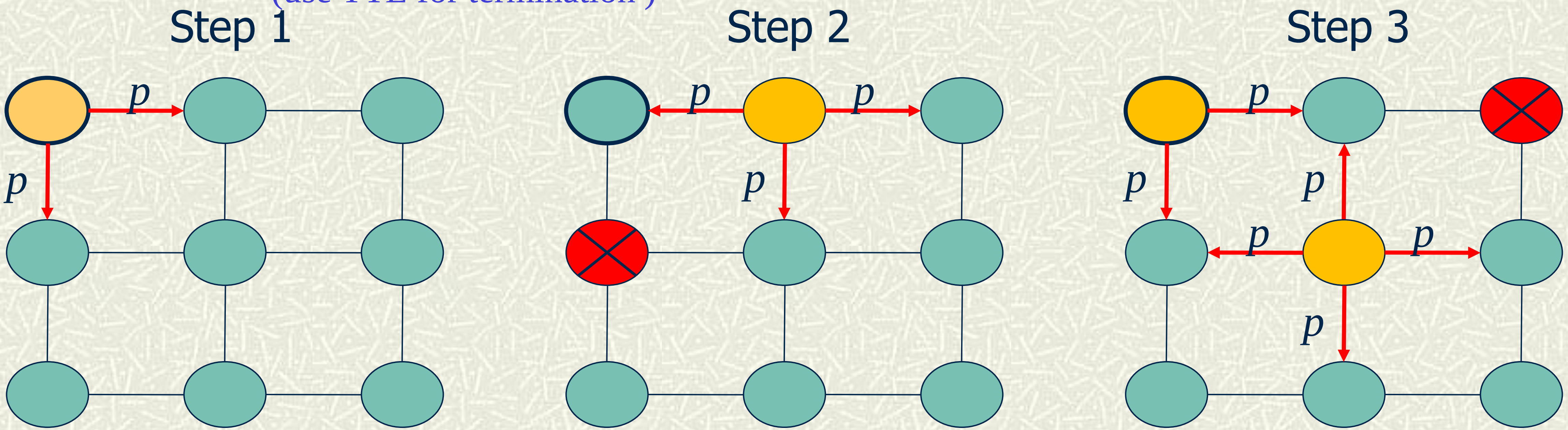
# Simple gossiping

- Packets are re-broadcasted with a gossiping probability *p*
- GOSSIP(*p*) – Probabilistic version of flooding

**for each** message m

**if** random(0,1) < *p* **then** rebroadcast message m

(use TTL for termination )



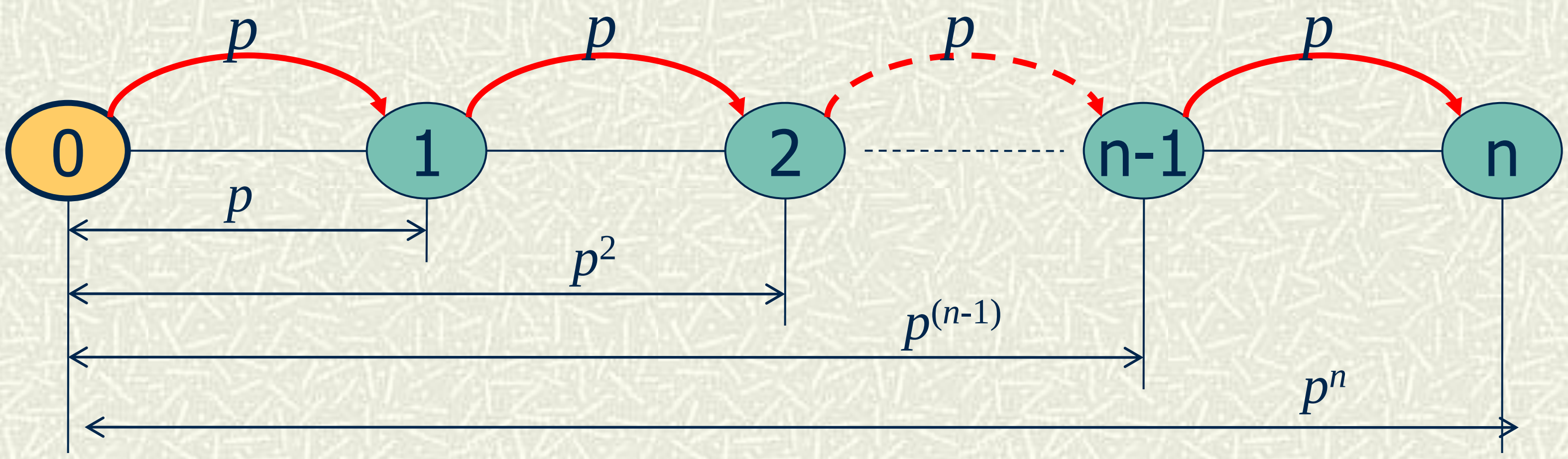
# Simple gossiping

## Advantages

- Avoids packet implosion
- Lower network overhead compared to flooding

## Disadvantages

- Long propagation time throughout the network
- Does not guarantee that all nodes of the network will receive the message (similarly do other protocols but for gossiping this is an inherent "feature")



# Problems of Flooding and Gossiping

**PROBLEMS:**

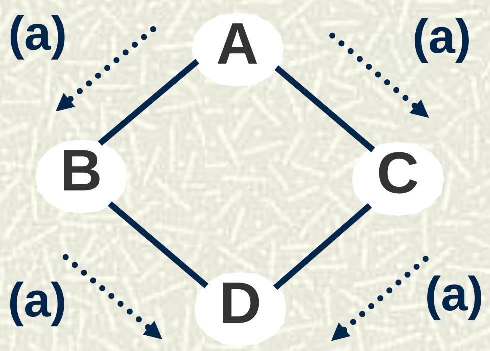
**Although these techniques are simple and reactive, they have some disadvantages including:**

* Implosion

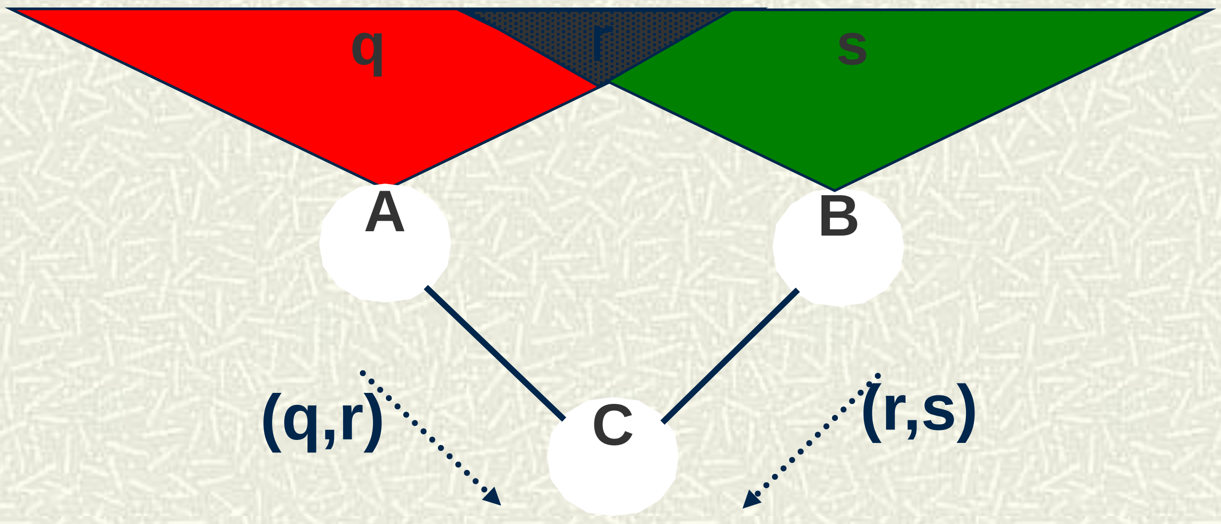
  (Gossiping version where only one neighbor is selected avoids this; but this causes delays to propagate the data through the network)
* Overlap
* Resource Blindness
* Power (Energy) Inefficient

# Problems

Implosion




*Data Overlap*




Resource Blindness

No knowledge about the available power of resources

# SPIN: Sensor Protocol for Information via Negotiation

* Uses three types of messages: ADV, REQ, and DATA.
* When a sensor node has something new, it broadcasts an advertisement (ADV) packet that describes the new data, i.e., the meta data.
* Interested nodes send a request (REQ) packet.
* Data are sent to the nodes that request by DATA packets.
* This will be repeated until all nodes will get a copy.

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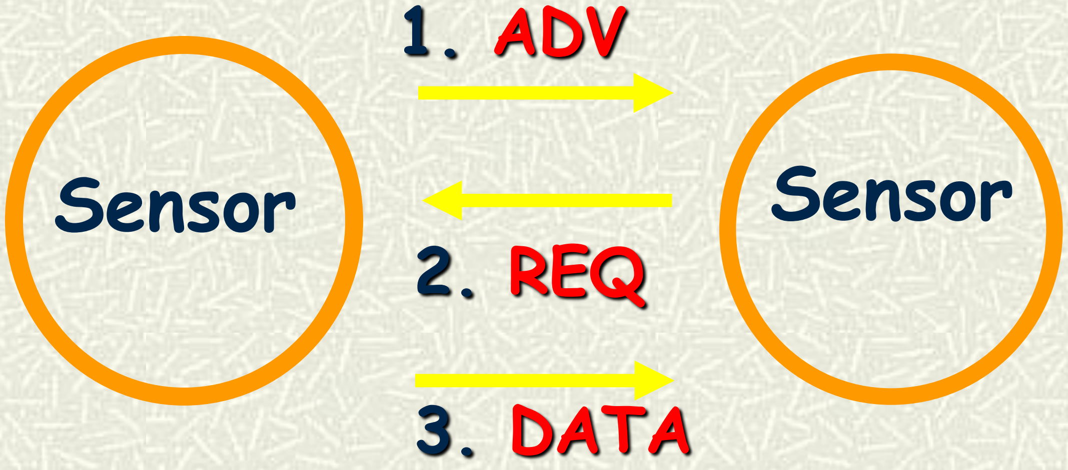
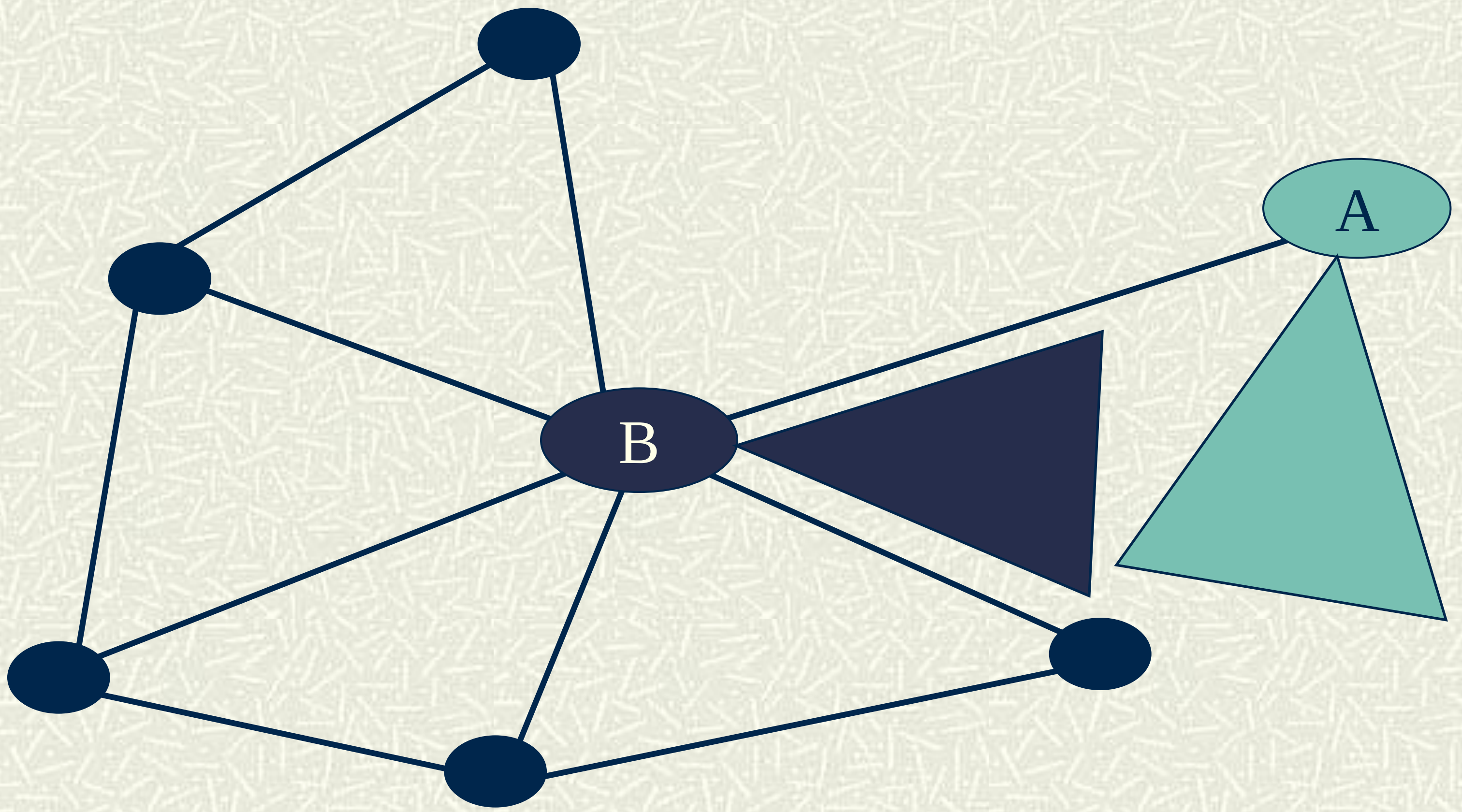
# SPIN

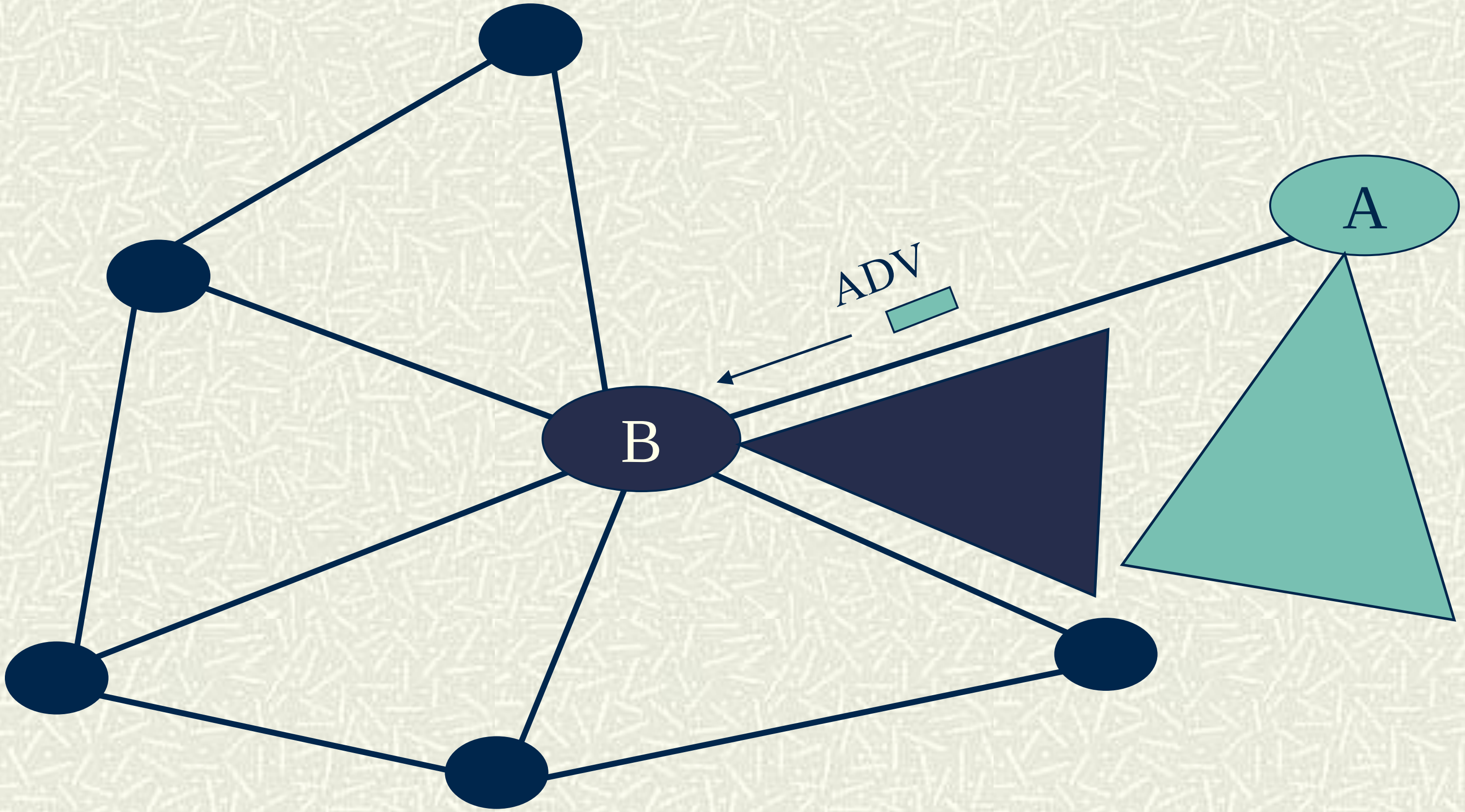
- Good for disseminating information to all sensor nodes.
- SPIN is based on data-centric routing where the sensors broadcast an advertisement for the available data and wait for a request from interested sinks



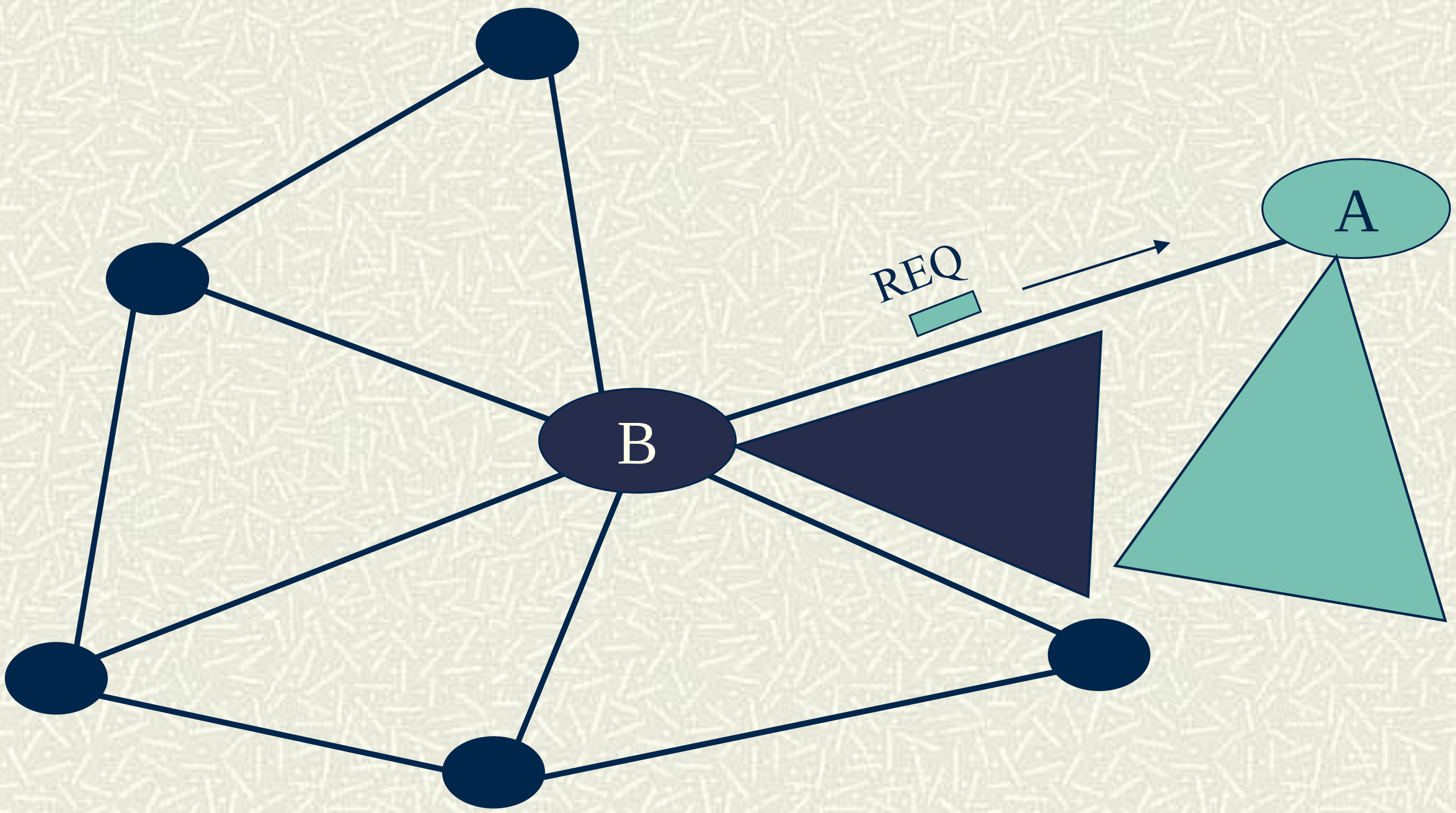
# SPIN Example



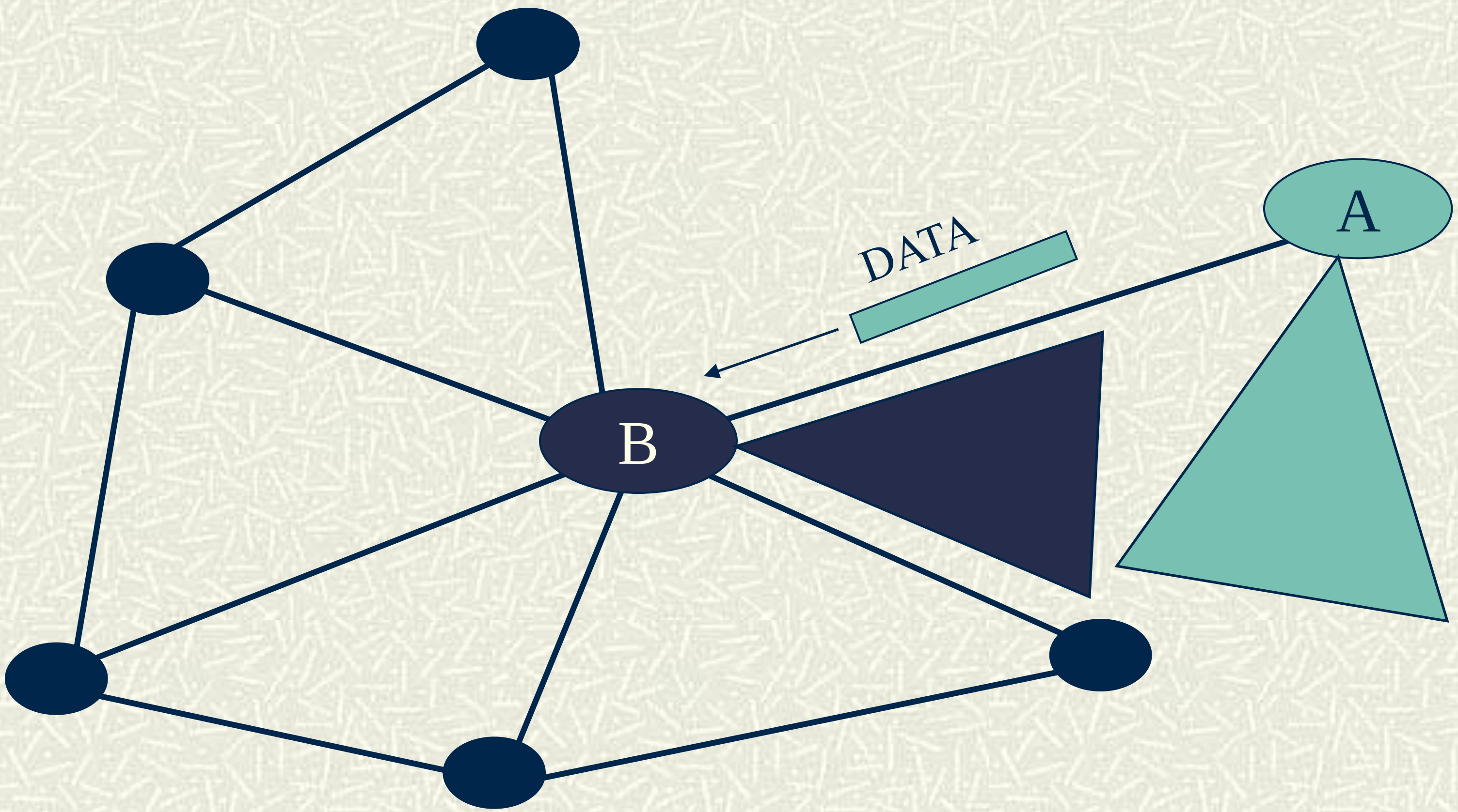
# SPIN Example



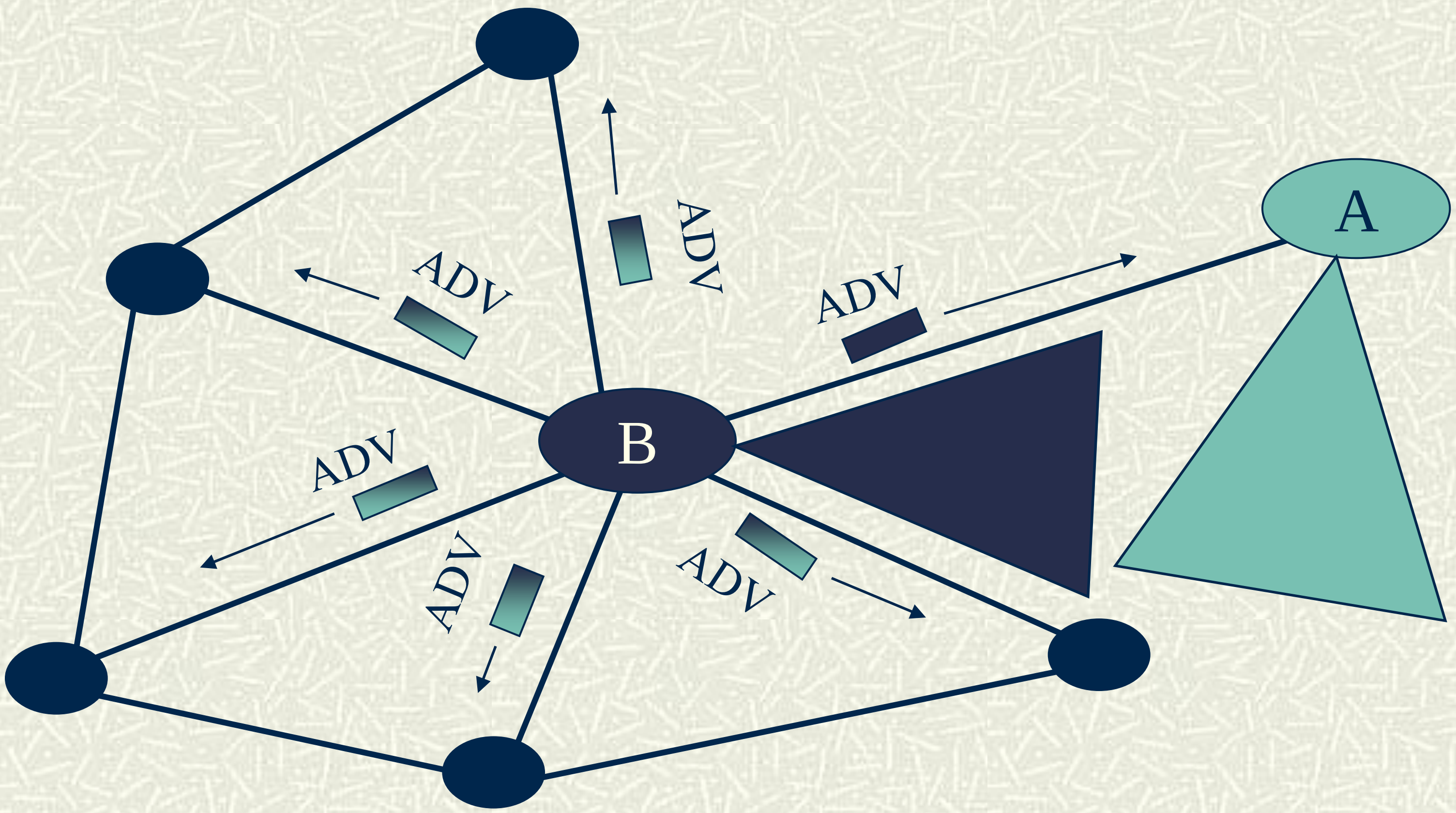
# SPIN Example



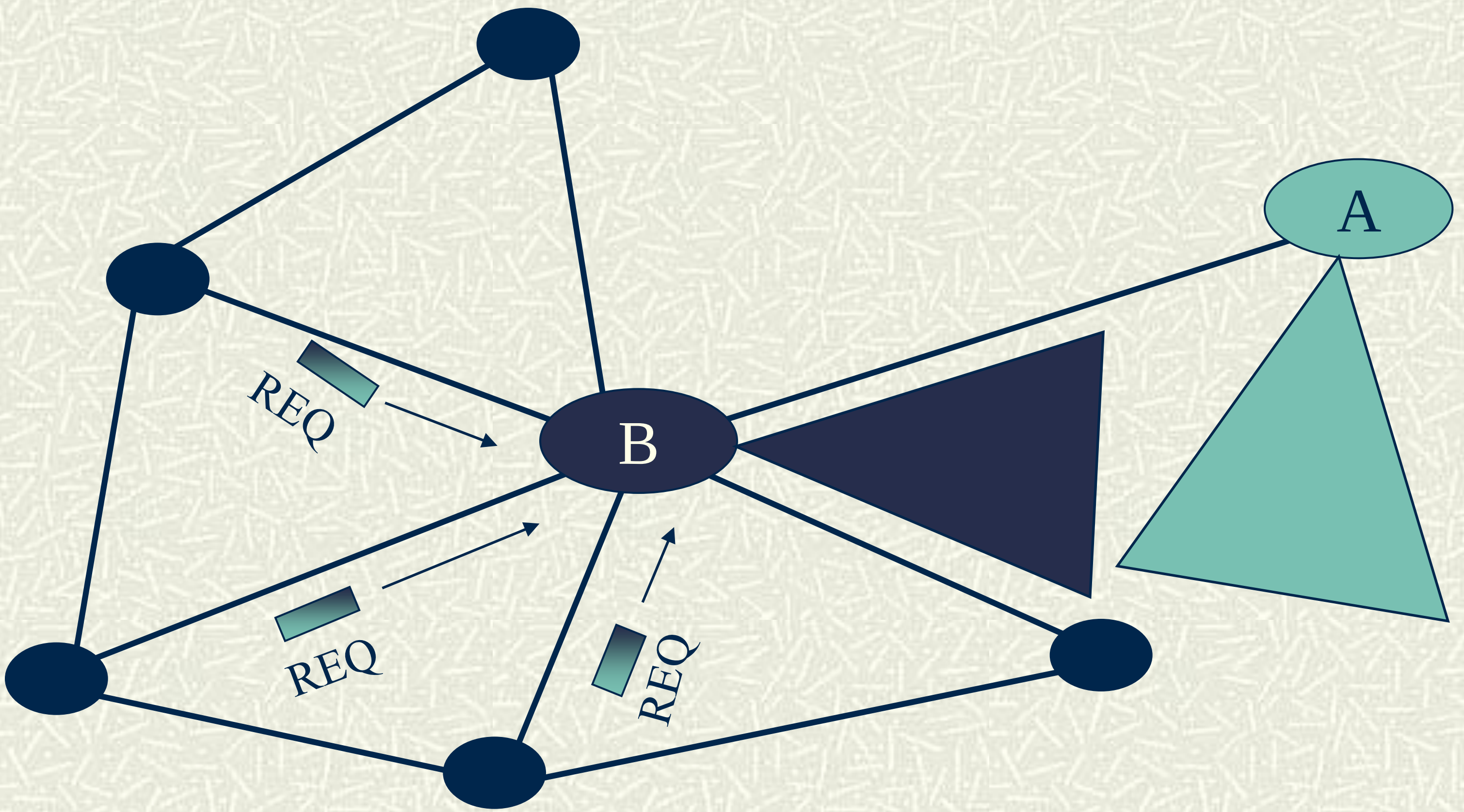
# SPIN Example



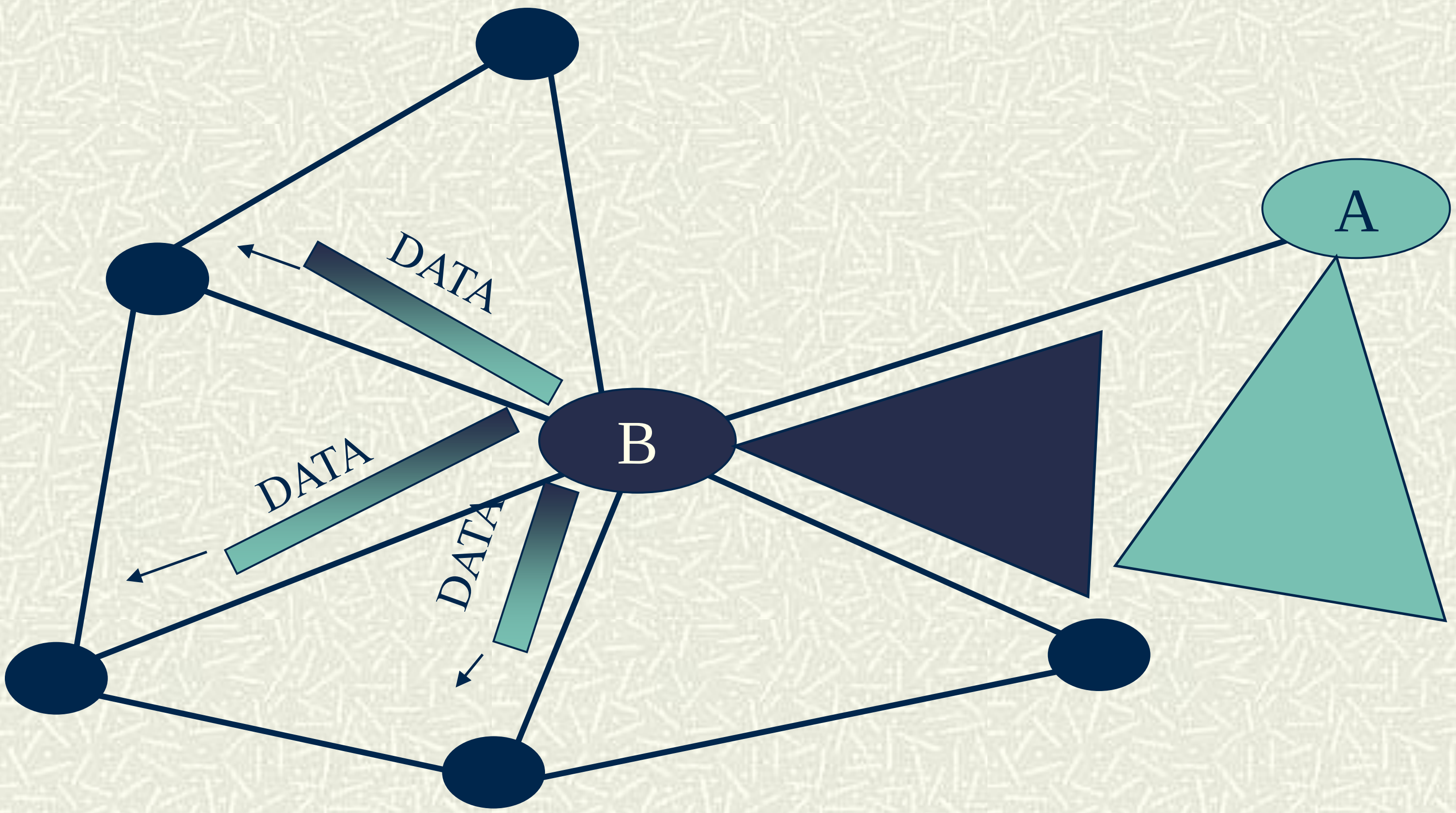
# SPIN Example



# SPIN Example



# SPIN Example



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# Family of SPIN Protocols

- **SPIN-PP – For point-to-point communication**
- **SPIN-EC – Similar to SPIN-PP but with energy conservation heuristics added to it**
- **SPIN-BC – Designed for broadcast networks. Nodes set random timers after receiving ADV and before sending REQ to wait for someone else to send the REQ**
- **SPIN-RL – Similar to SPIN-BC but with added reliability. Each node keeps track of whether it receives requested data within the time limit, if not, data is re-requested**

# SPIN-PP Protocol

- SPIN-PP
  - 3-stage handshake protocol
  - Advantages
    - Implosion avoidance
    - Minimal start-up cost
    - Simple
  - **Disadvantages**
    - **Does not guarantee delivery of data**
    - **Consumes unnecessary power.**

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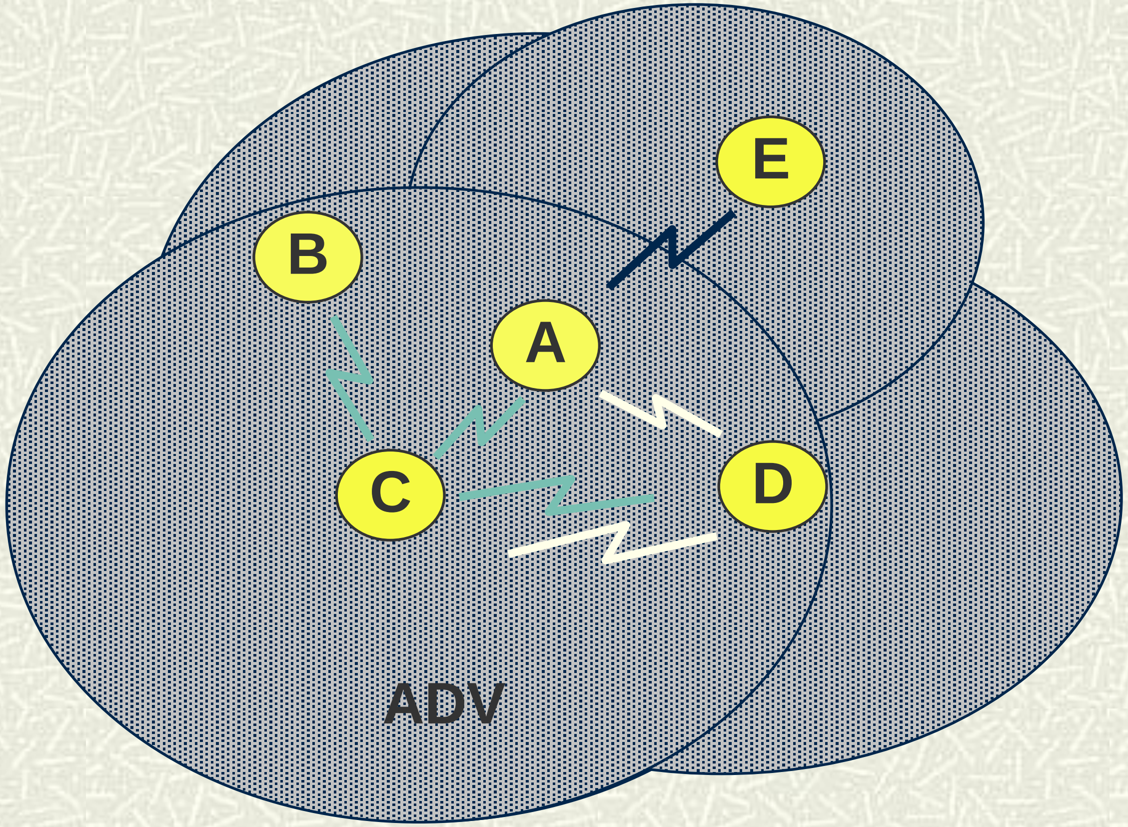
# SPIN-EC

- Spin-EC
  - SPIN-PP + low-energy threshold
  - Modifies behavior based on current energy resources

# SPIN-EC

- Adds a simple energy conservation heuristic
- When energy is plentiful, SPIN-EC behaves like SPIN-PP
- When energy approaches a low-energy threshold, SPIN-EC node reduces its participation in the protocol (DORMANT)
  - participates in a stage of protocol only if the node believes that it can complete all the remaining stages

# SPIN BC (for broadcast networks )



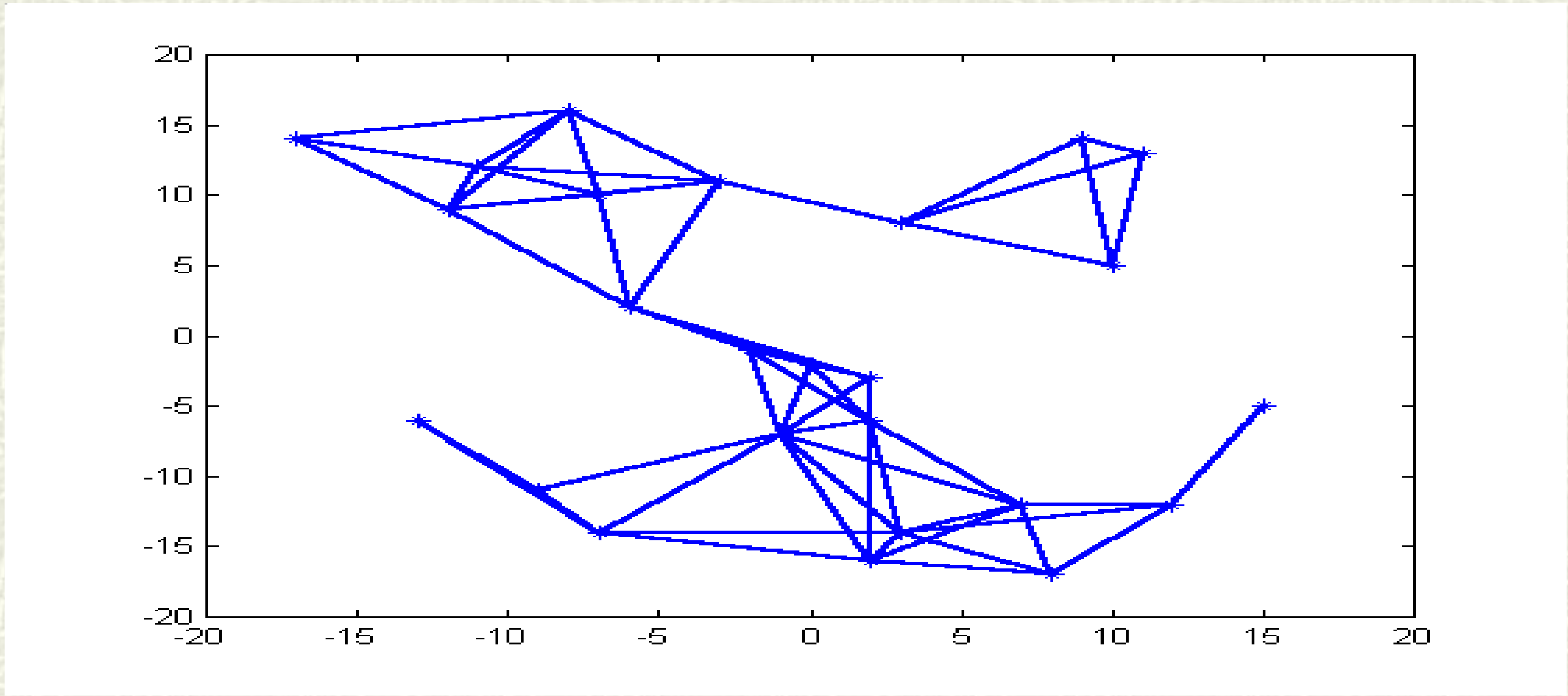


**Nodes with data**

**Nodes without data**

**Nodes waiting to transmit REQ**

# Test Network



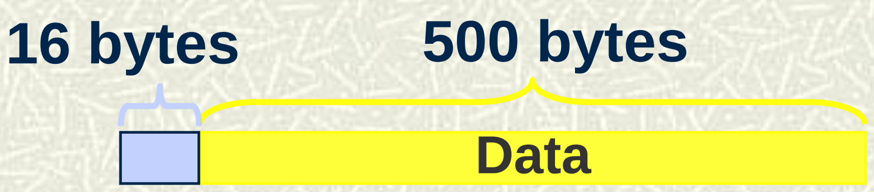

**25 Nodes**

**59 Edges**

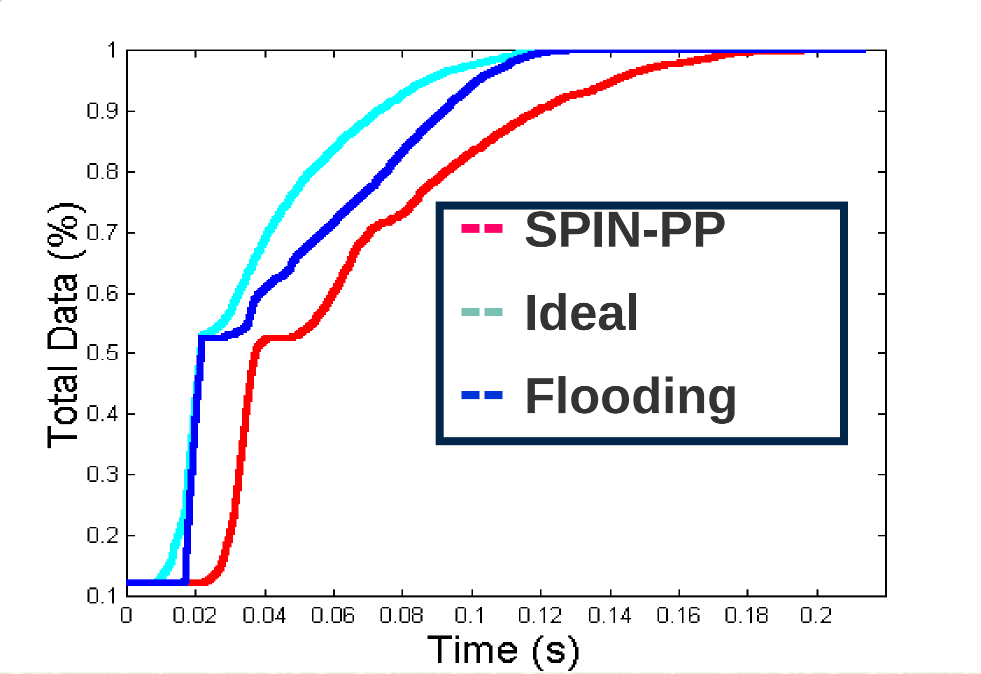
**Average degree = 4.7 neighbors**

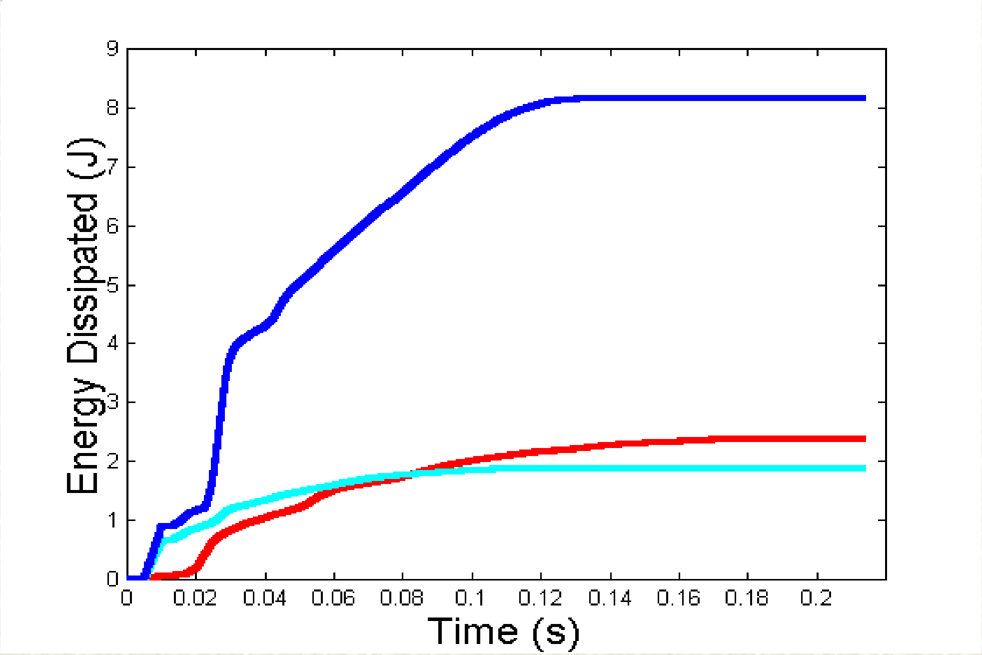
**Network diameter = 8 hops**

**Antenna reach = 10 meters**



# Unlimited Energy Simulations

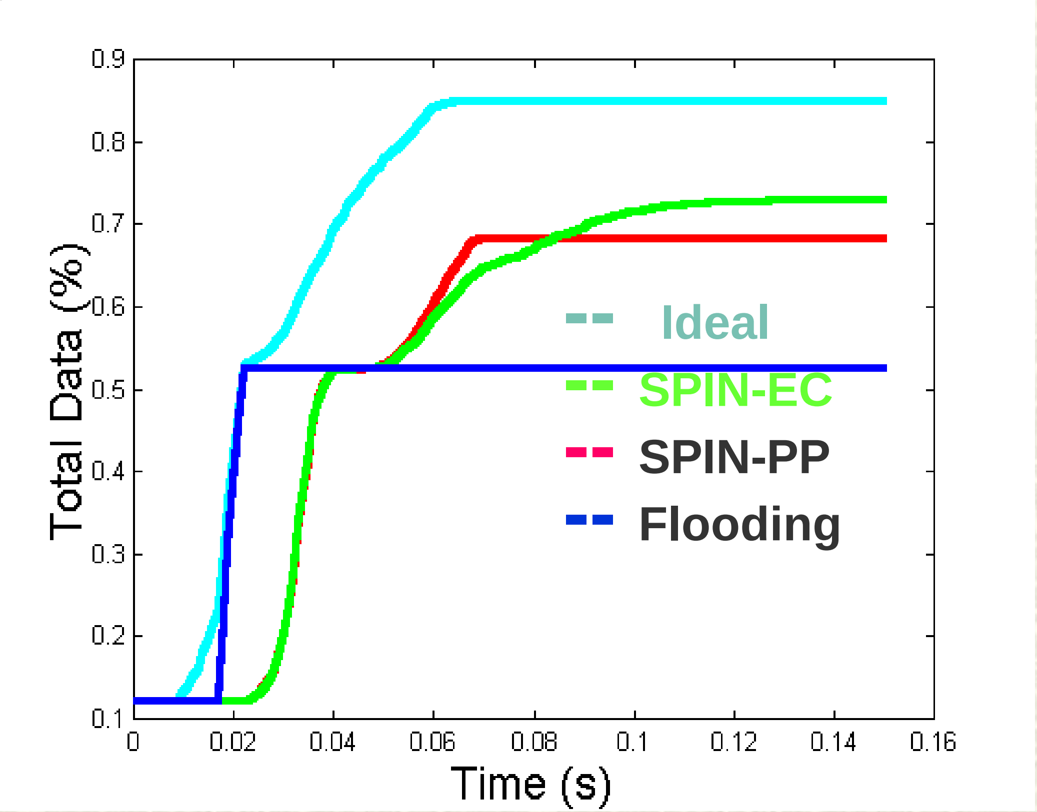


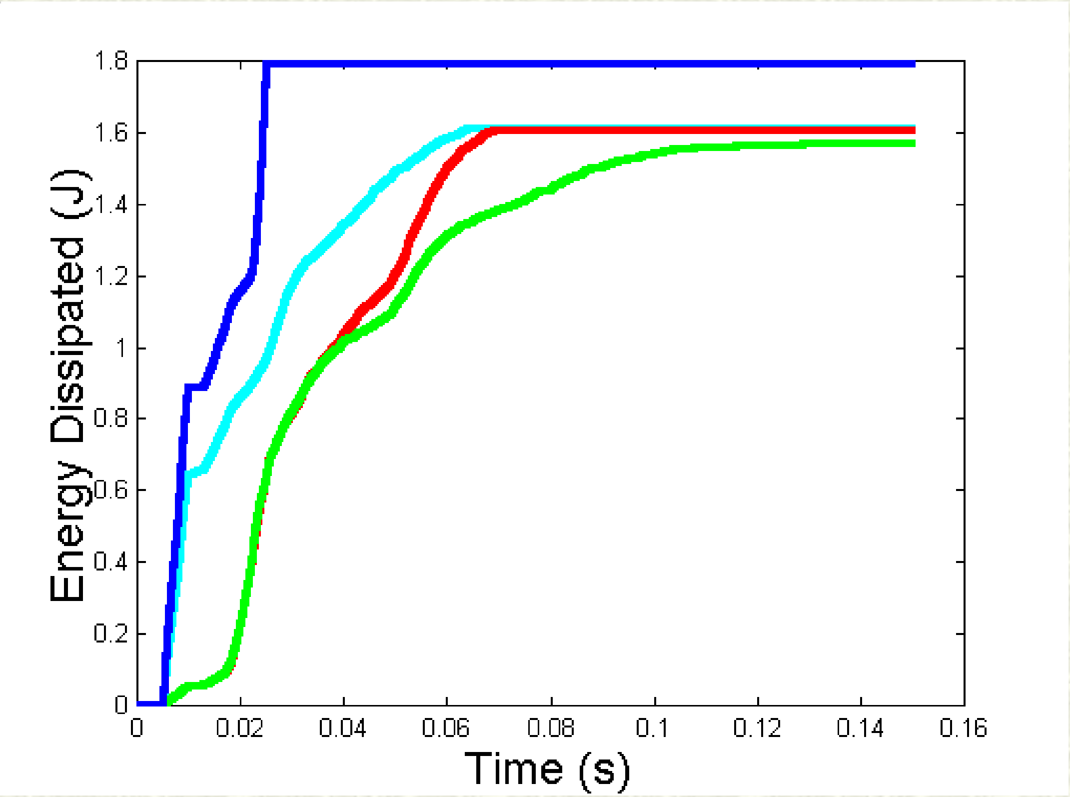




- Flooding converges first
  - No queuing delays

- **SPIN-PP**
  - **Reduces energy by 70%**
  - **No redundant DATA messages**

# Limited Energy Simulations




SPIN-EC distributes additional 10% data

# SPIN- CONCLUSIONS

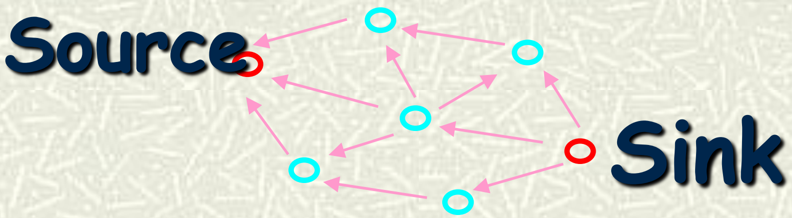
- Flooding converges first
  - No delays
- SPIN-PP
  - Reduces energy by 70%
  - No redundant DATA messages
- SPIN-EC distributes
  - 10% more data per unit energy than SPIN-PP
  - 60% more data per unit energy than flooding

# SPIN- CONCLUSIONS (2)

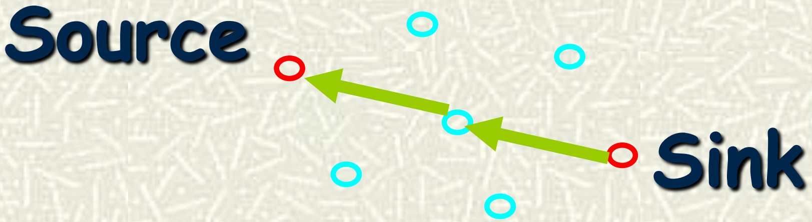
- **Energy** – More efficient than flooding
- **Latency** – Converges quickly
- **Scalability** – Local interactions only
- **Robust** – Immune to node failures

# Directed Diffusion Routing Algorithm

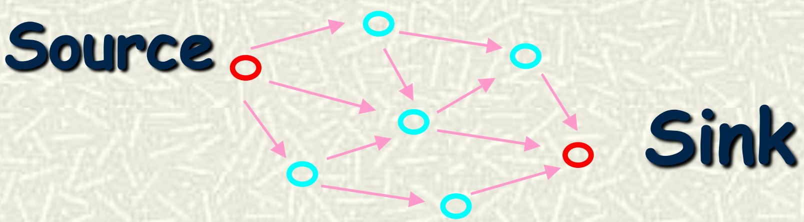
C. Intanagonwiwat, et.al.,
"Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks", IEEE/ACM Transactions on Networking, 2003.



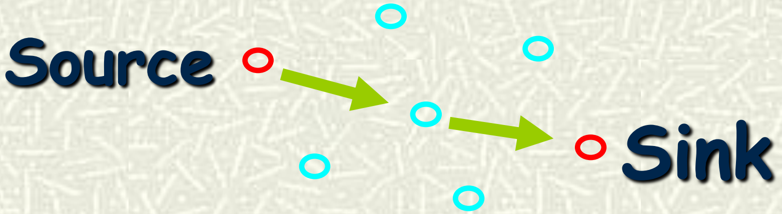

Interest Propagation




Reinforcement




Gradient Setup




Data Delivery

# Basic Principles

- DATA CENTRIC ROUTING scheme
- Very large number of sensors → impossible to assign specific IDs.
- Without a unique identifier, gathering data may become a challenge.
- To overcome this challenge, some routing protocols gather/route data based on the description of the data, i.e., data-centric.

# What is DATA CENTRIC?

- Data-Centric
  - Sensor node does not need an identity!!!
    - What is the temp at node #27 ?
  - Data are named by attributes
    - Where are the nodes whose temperature recently exceeded 30 degrees ?
    - How many pedestrians do you observe in region X?
    - Tell me in what direction that vehicle in region Y is moving?

# What is Data-Centric Routing?

**Requires attribute based naming where the users are more interested in querying an attribute of the phenomenon, rather than querying an individual node.**

**Example:**

**"the areas where the temperature is over 70F"**

**is a more common query than**

**"the temperature read by a certain node (e.g., #27)".**

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# Elements of Directed Diffusion

- Naming Scheme
  - *Data* is named using attribute-value pairs
- Interests
  - A node requests data by sending *interests for named data*
- Gradients
  - *Gradients* is set up within the network designed to “draw” events, i.e. *data matching the interest.*
- Reinforcement
  - Sink *reinforces* particular neighbors to draw higher quality (higher data rate) events

Pull-based approach

# NAMING SCHEME

* Data generated by sensor nodes is NAMED by ATTRIBUTE-VALUE pairs

* In order to create a query, an interest is defined using a list of attribute-value pairs such as name of *objects, interval, duration, geographical area, etc.*

* An arbitrary sensor node (usually the SINK) uses attribute-value pairs (interests) for the data and queries the sensors in an on-demand basis.

# NAMING SCHEME

## Request:
## Interest (Task) Description

**Example: (Animal Tracking Task)**

- ***Type*** **= four legged animal (detect animal location)**
- ***Interval*** **= 30 s (send back events every 30 s)**
- ***Duration*** **= 1h (.. for the next hour)**
- ***Rec*** **= [-100,100,200,400] (from sensors within the rectangle)**

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# NAMING SCHEME

**The data sent in response to interests are also named similarly.**

**Example: REPLY**

**Sensor detecting the animal generates the following data:**

***Type*** **– four legged animal (type of animal seen)**

***Instance*** **= elephant (instance of this type)**

***Location*** **= (125,220) (node location)**

***Intensity*** **= 0.6 (signal amplitude measure)**

***Confidence*** **= 0.85 (confidence in the match)**

***Timestamp*** **= 01:20:40 (event generation time)**

# INTERESTS

* The sink periodically broadcasts an interest to sensor nodes to query information from a particular area in the field.

* As the interest propagates, data may be *locally transformed* (e.g., *aggregated*) at each node, or be *cached*.

* Every node maintains an interest cache
* Each item corresponds to a distinct interest
* Interest aggregation: identical type, completely overlapping rectangle attribute

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# INTERESTS

* Each entry in the cache has several fields
    * Timestamp: last received matching interest
    * Several gradients: data rate, duration, direction

* Other sinks may express *interests* based on these attributes

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# Interest Propagation and Gradient Set Up

- Inquirer (sink) broadcasts exploratory interest, ***i1***
  - Intended to discover routes between source and sink
- Neighbors update interest-cache and forward ***i1***
- Gradient for ***i1*** set up to upstream neighbor
  - No information about the sink
  - Gradient – a weighted reverse link
  - Low gradient → Few packets per unit time needed

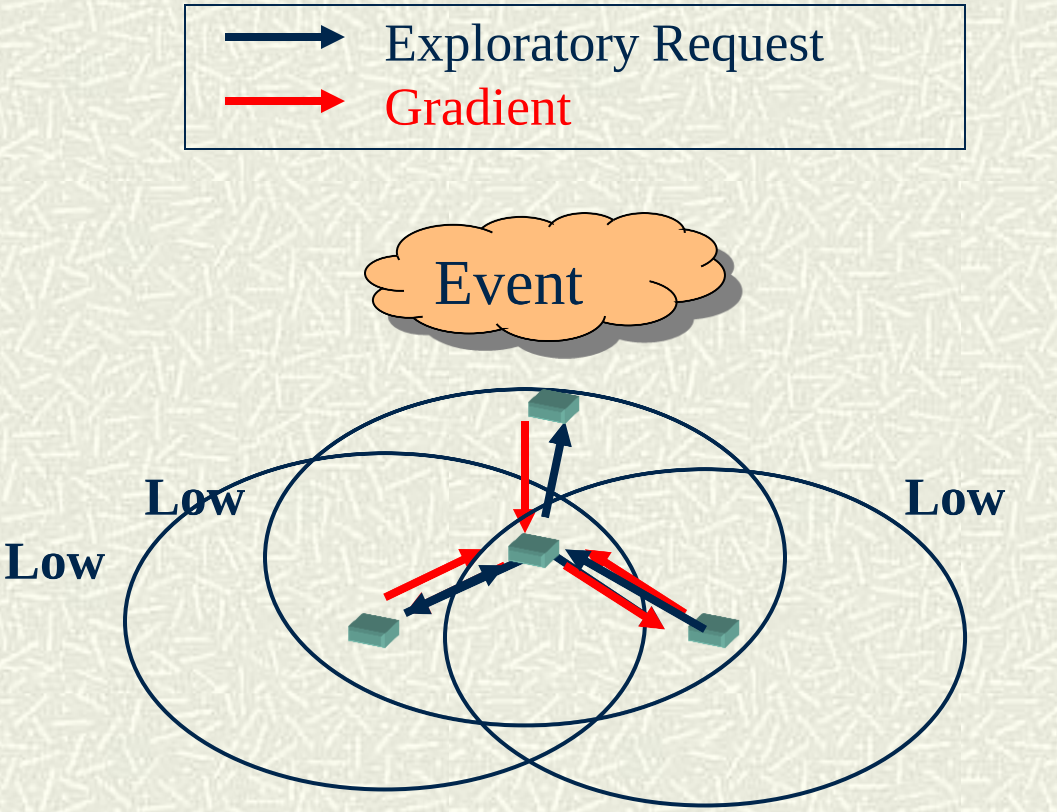
# Interests

- When a node receives an interest, it:
  - Checks cache to see if an entry is present.
  - If no entry, creates an entry with a single gradient to neighbor who sent this interest
  - If there is an entry and gradient update timestamp and duration fields (or add new gradient)
  - Gradient specifies the direction and data rate.

# Interests

- Resend interest to (a subset of ) its neighbors
  - This is essentially flooding-based approach
  - Other probabilistic, location-based and other intelligent forwarding approaches possible

# Exploratory Gradient




Bidirectional gradients established on all links through flooding

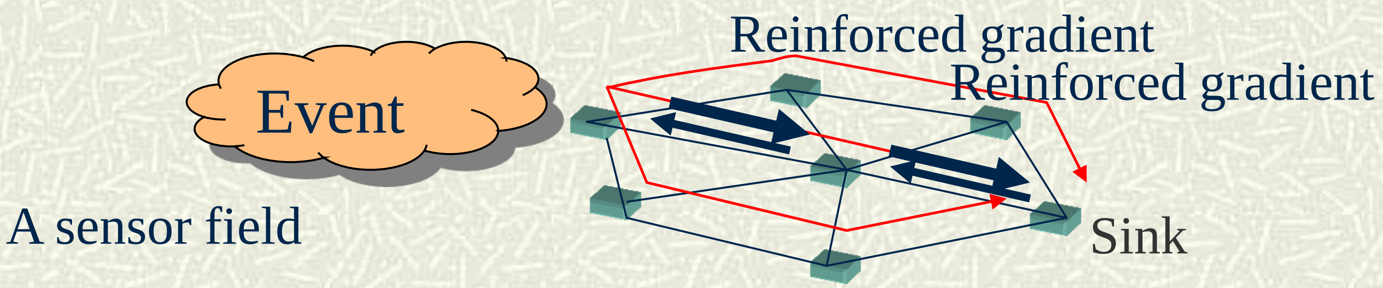
# Local Rules for Propagating Interests

- Just flood interest
- More sophisticated techniques possible:

  * Directional interest propagation based on cached aggregate information

  "I recently heard about suspicious activity from neighbor A, so let me try sending this interest for recent intrusions to that neighbor"

# Gradient Reinforcement




- From exploratory gradients, reinforce optimal path for high-rate data download → Unicast
  - By requesting higher-rate-***i1*** on the optimal path
  - Exploratory gradients still exist – useful for faults

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# Gradient Reinforcement

- The sink selects one of the neighbors as a best-candidate (best link, low delay, etc.) to be reinforced for the particular interest/request.

- As a result, sink unicasts the reinforcement packet to the next hop.

  Subsequently/recursively each node selects one of its (downward) neighbors to be reinforced.

- At the end, the data path from source to destination will be established.

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# Event-data propagation

- Event *e1* occurs, matches *i1* in sensor cache
  - *e1* identified based on waveform pattern matching
- Interest reply diffused down data gradient (unicast)
  - Data also sent along exploratory gradients to other neighbors
- Cache filters suppress previously seen data
  - Node maintains data cache in addition to interest cache
  - Helps in loop prevention