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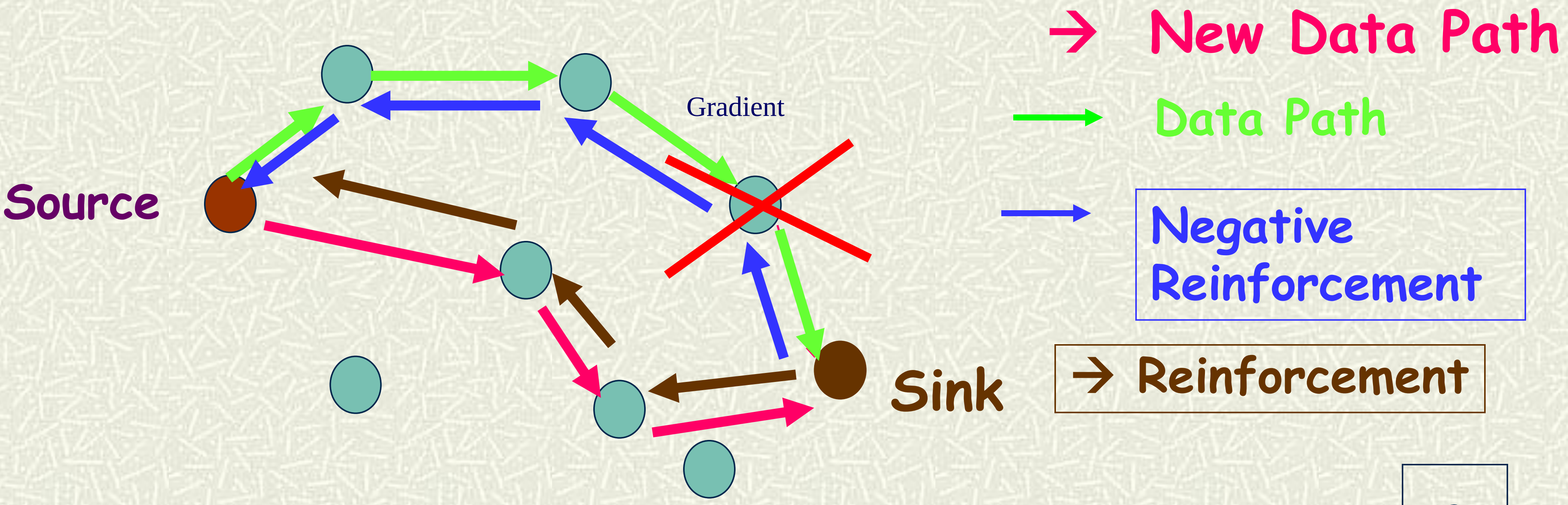
ROUTING ALGORITHMS

Part 2: Data centric and hierarchical protocols

Negative Reinforcement

- Time out
- Explicitly degrade the path by re-sending interest with lower data rate.



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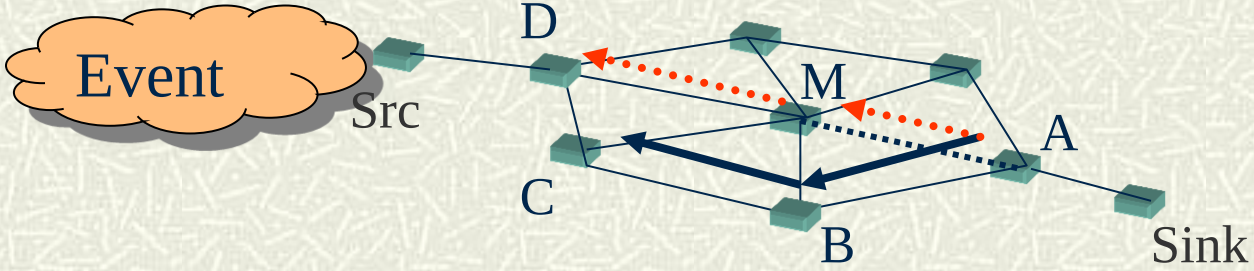
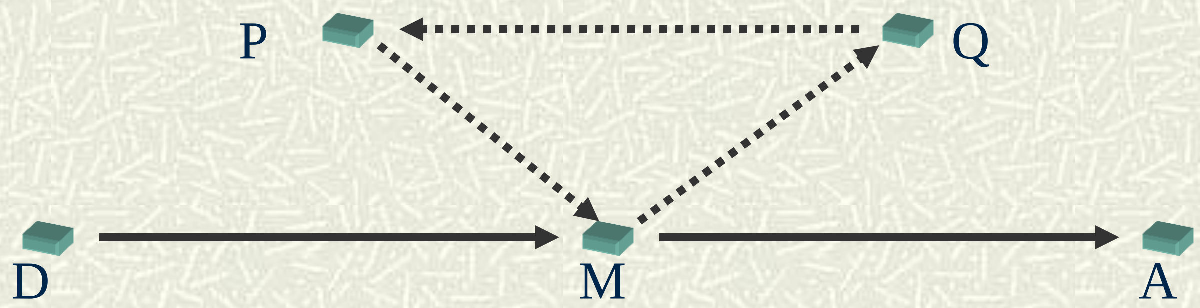
Path Failure / Recovery

- Link failure detected by reduced rate, data loss
  - Choose next best link (i.e., compare links based on infrequent exploratory downloads)
- Negatively reinforce lossy link
  - Either send *i1* with base (exploratory) data rate
  - Or, allow neighbor's cache to expire over time



<u>Link A-M lossy</u>
A reinforces B
B reinforces C …
D need not
A (–) reinforces M
M (–) reinforces D

Loop Elimination



- M gets same data from both D and P, but P **always** delivers late due to looping
  - M negatively-reinforces (nr) P, P nr Q, Q nr M
  - Loop {M → Q → P} eliminated
- Conservative nr useful for fault resilience

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Local Behavior Choices

1. For propagating interests
   - In our example, flooding
   - More sophisticated behaviors possible: e.g. based on cached information, GPS

2. For setting up gradients
   - Highest gradient towards neighbor from whom we first heard interest
   - Others possible: towards neighbor with highest energy

3. For data transmission
   - Different local rules can result in single path delivery, multi-path delivery, single source to multiple sinks …

4. For (negative) reinforcement
   - reinforce one path, or part thereof, based on observed losses, delay variances etc.
   - other variants: inhibit certain paths because resource levels are low

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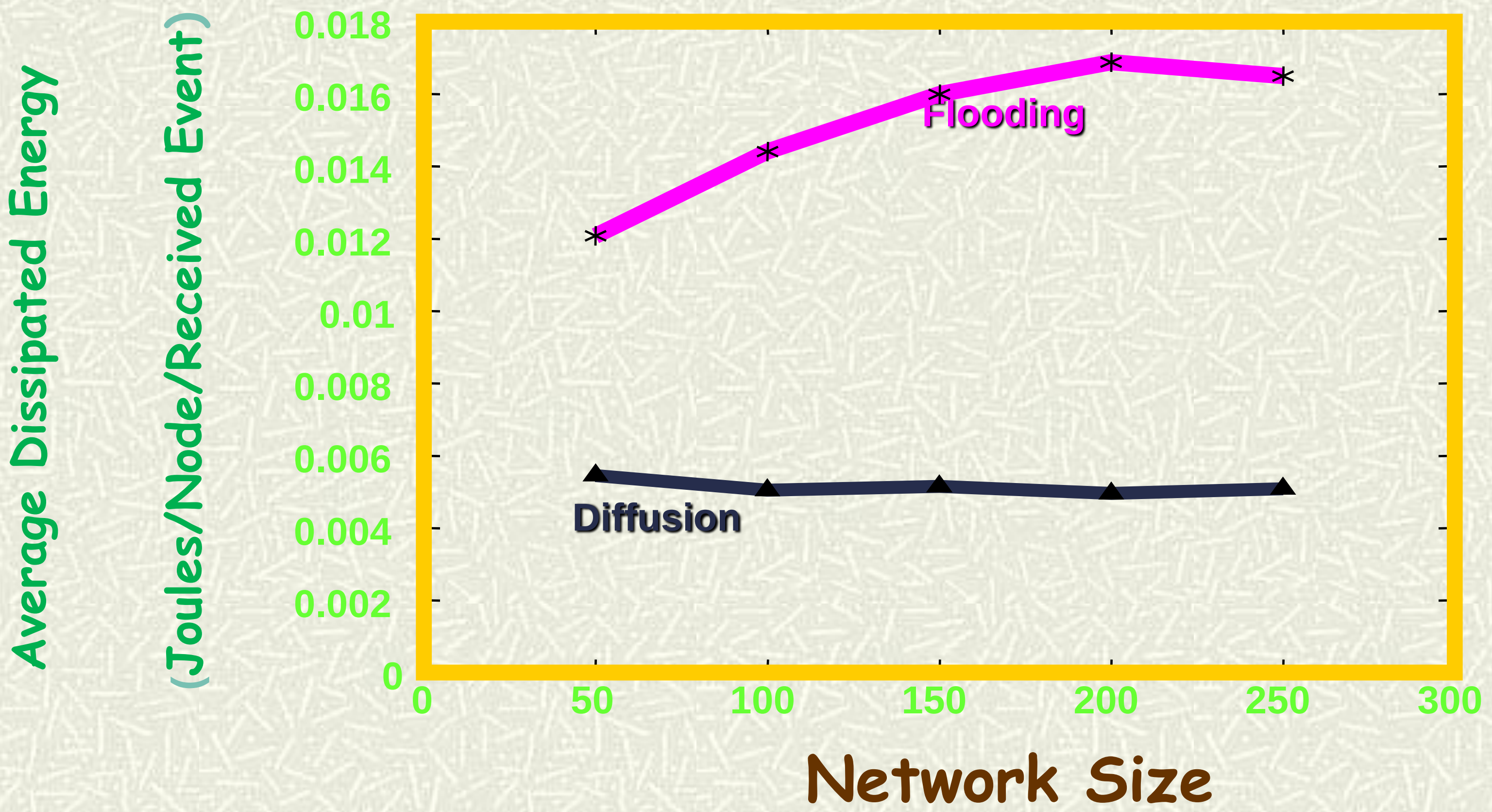
Simulation

- Simulator: *ns-2*
- Network Size: 50-250 Nodes
- Total area for 50 nodes 160m x 160m
- Transmission Range: 40m
- Constant Density: 1.95×10^{-3} nodes/m^2 (9.8 nodes in radius)
- MAC: Modified Contention-based MAC
- Energy Model: Mimic a realistic sensor radio
  - 660 mW in transmission, 395 mW in reception, and 35 mw in idle

Performance Metrics

- Average Dissipated Energy
  - Ratio of total dissipated energy per node in the network to the number of distinct events seen by sinks.
- Average Delay
  - Average one-way latency observed between transmitting an event and receiving it at each sink.
- Event Delivery Ratio
  - Ratio of the number of distinct events received to number originally sent.

Average Dissipated Energy (Sensor Radio Energy Model)



Diffusion outperforms flooding. WHY ?

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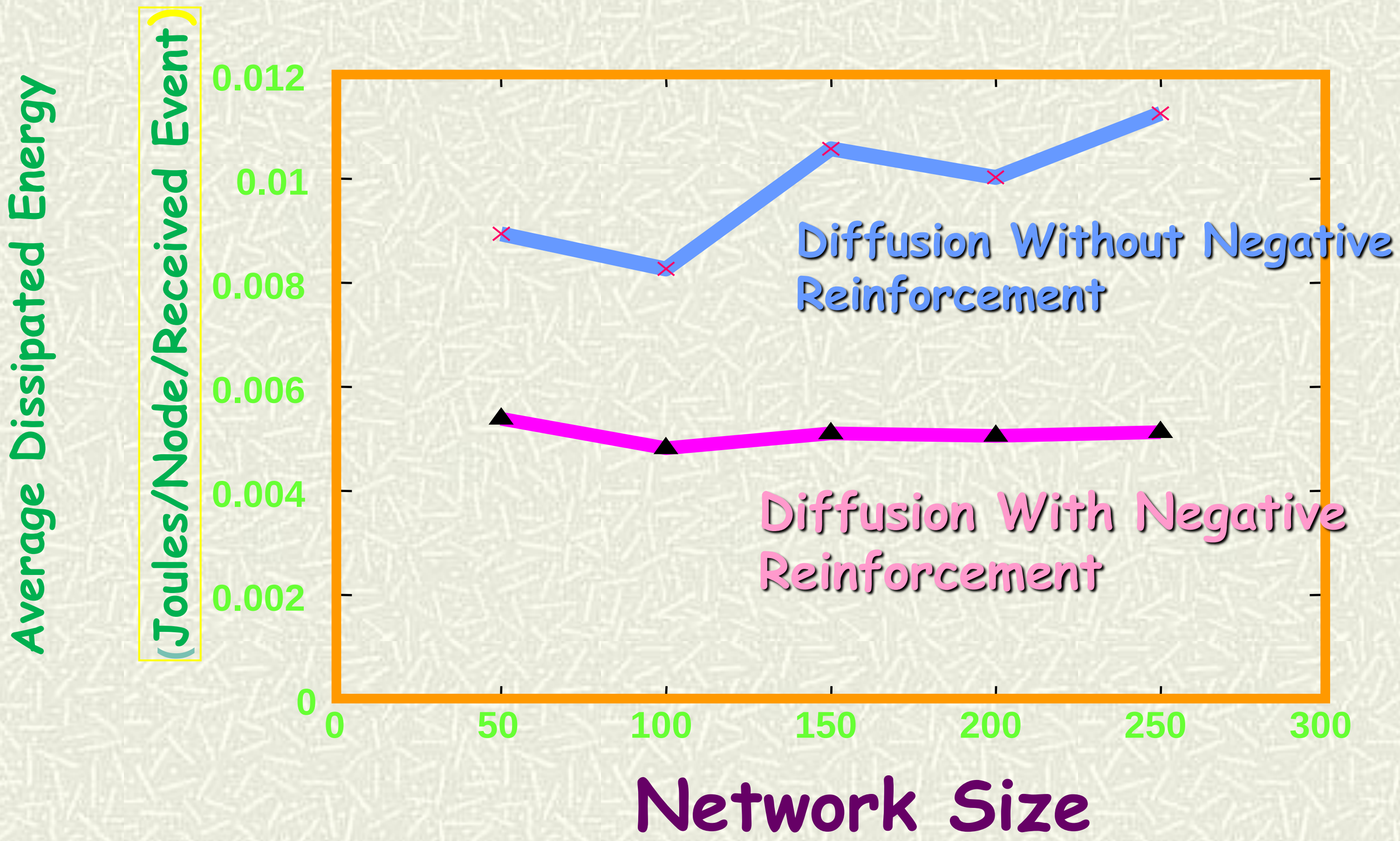
Impact of Negative Reinforcement



Reducing high-rate paths in steady state is critical

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Directed Diffusion – Extensions

- Two-Phase Pull suffers from interest flooding problems

- Push Diffusion – Data Advertisement by the Sources
  - Sink sends reinforcement packet.

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Directed Diffusion vs SPIN

- In DD → Sink queries sensors if a specific data is available by flooding some interests.

In SPIN → Sensors advertise the availability of data allowing sinks to query that data.

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Directed Diffusion *Advantages*

* DD is data centric → no need for a node addressing mechanism.

* Each node is assumed to do aggregation, caching and sensing.

* DD is energy efficient since it is on demand and no need to maintain global network topology.

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Directed Diffusion
Disadvantages

- Not generally applicable since it is based on a query driven data delivery model.
- For DYNAMIC applications needing continuous data delivery (e.g., environmental monitoring) → DD is not a good choice.
- Naming schemes are application dependent and each time must be defined a-priori.
- Matching process for data and queries cause some overhead at sensors.

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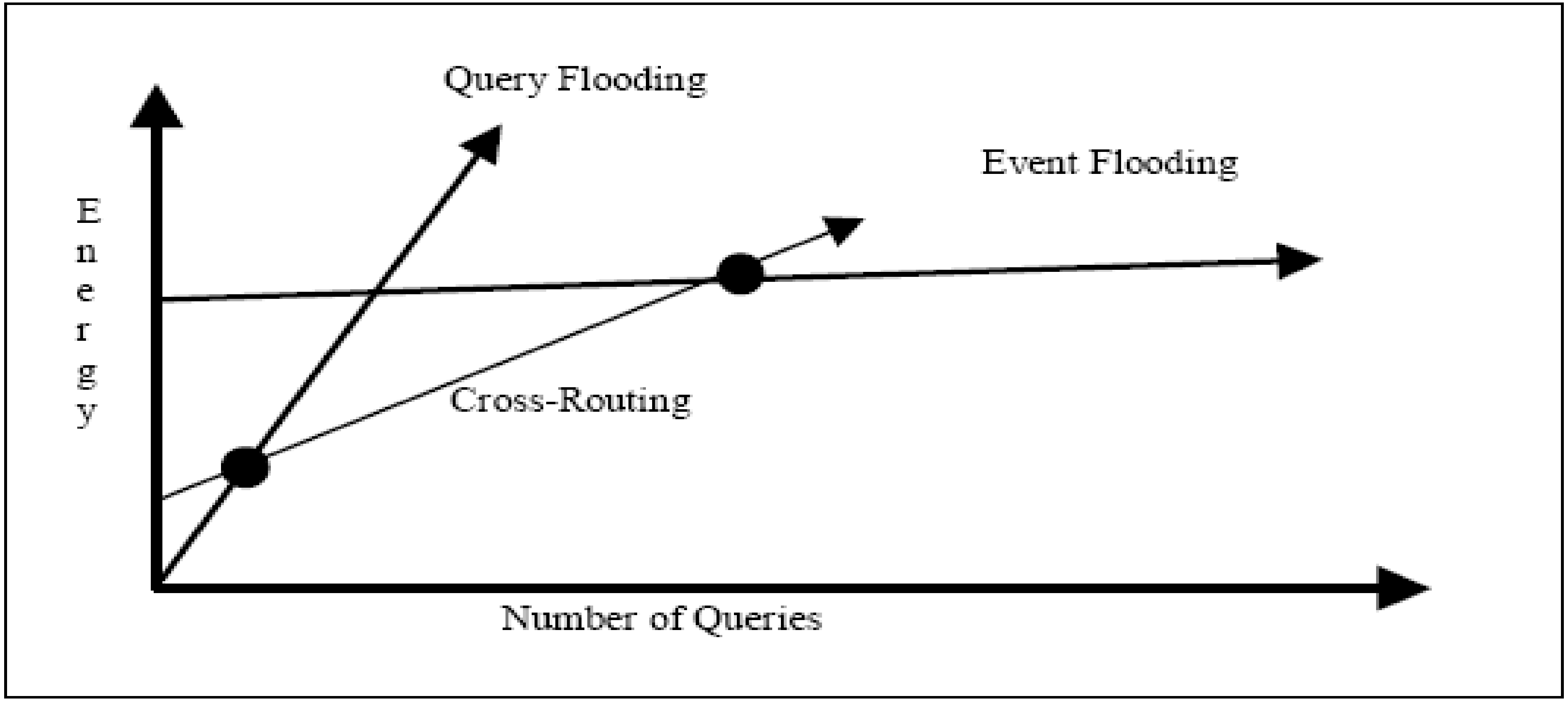
Rumor Routing

- Motivation
  - Sometimes a non-optimal route is satisfactory
- Advantages
  - Tunable best effort delivery
  - Tunable for a range of query/event ratios
- Disadvantages
  - Optimal parameters depend heavily on topology (but can be adaptively tuned)
  - Does not guarantee delivery
- Designed for query/event ratios between query and event flooding

Rumor Routing



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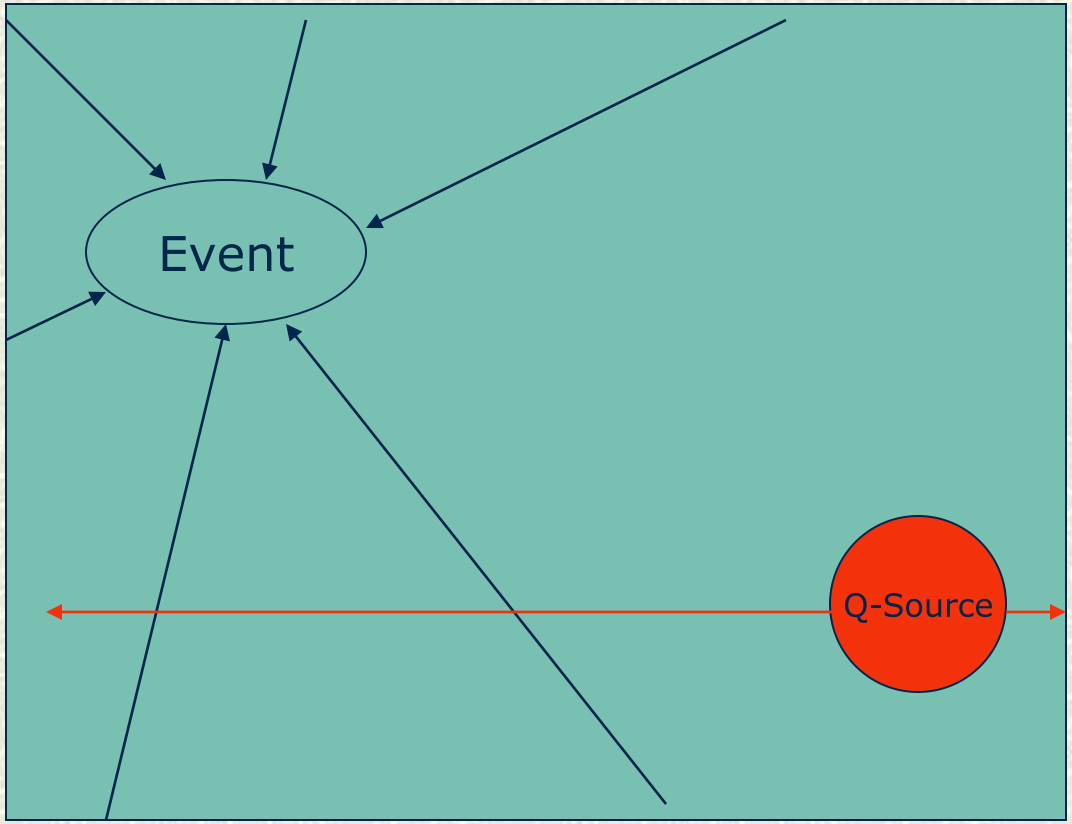
Basis for Algorithm

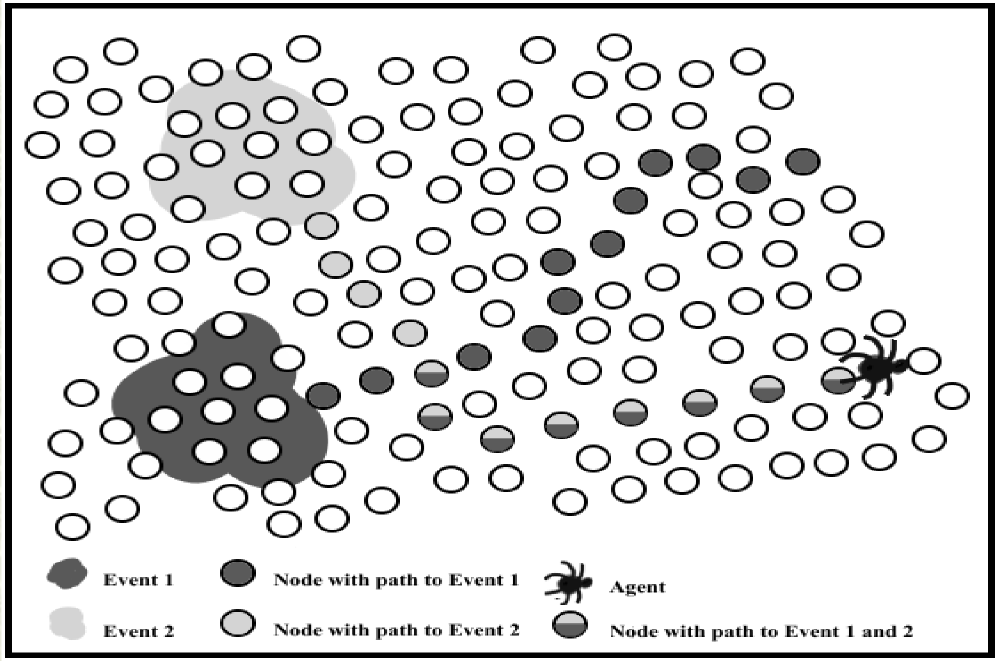
- Observation: Two lines in a bounded rectangle have a 69% chance of intersecting

- Create a set of straight line gradients from event, then send query along a random straight line from source until it meets an event line.



Creating Paths

- Nodes that observe an event send out agents which leave routing info to the event as state in nodes
- Agents attempt to travel in a straight line
- If an agent crosses a path to another event, it begins to build the paths to both
- Agent also optimizes paths if they find shorter ones



Algorithm Basics

- All nodes maintain a neighbor list
- Nodes also maintain an event table
  - When it observes an event, the event is added with distance 0
- Agents
  - Packets that carry local event info across the network
  - Aggregate events as they go
  - Agents do a random walk: among the one-hop neighbors, find the one that was not visited recently.

Agents

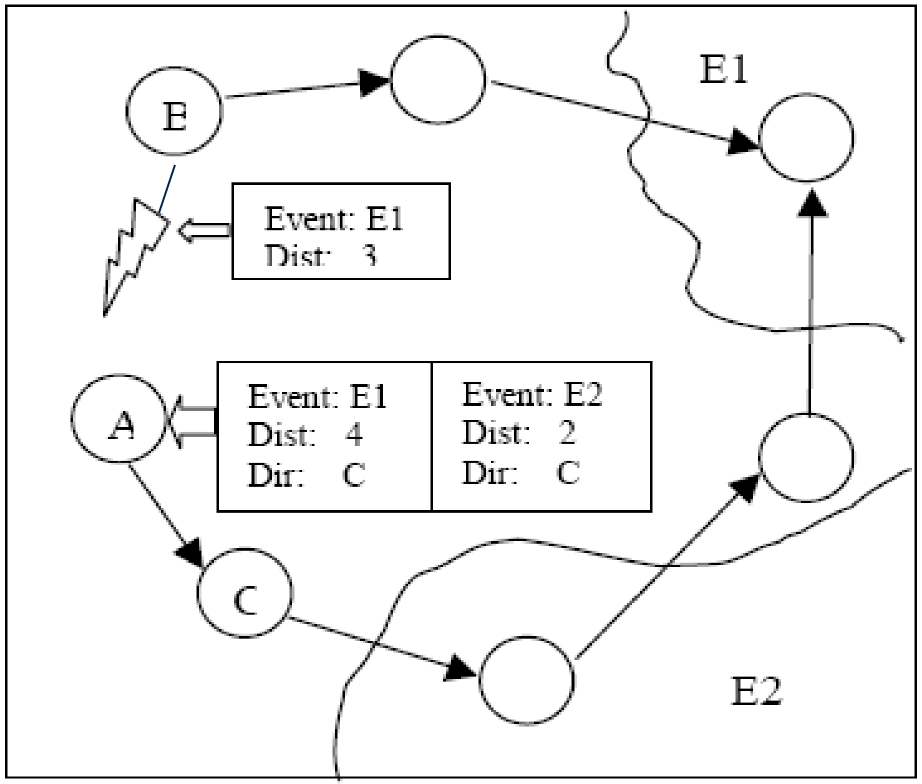


Figure 5

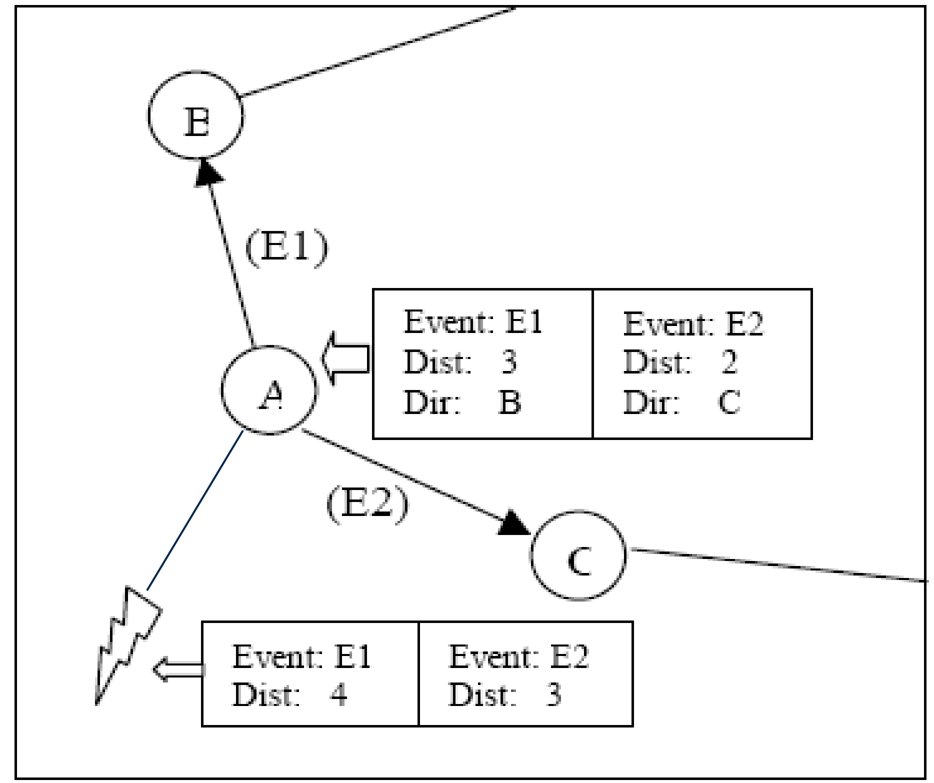


Figure 6

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Agent Path

- Agent tries to travel in a “somewhat” straight path
  - Maintains a list of recently seen nodes (RSN)
  - When it arrives at a node it adds the node’s neighbors to the list RSN
  - It next tries to find a node not in RSN

    -this avoids loops
  - Important to find a path regardless of “quality”

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Query propagation--following paths

- A query originates from a source, and is forwarded along until it reaches the event or it's TTL expires
- Forwarding Rules:
  - If a node has a route to the event, it forwards the query to the neighbor along the route
  - If a node has seen the query before, it forwards it to a neighbor using a straightening algorithm (query also keeps track of RSN)

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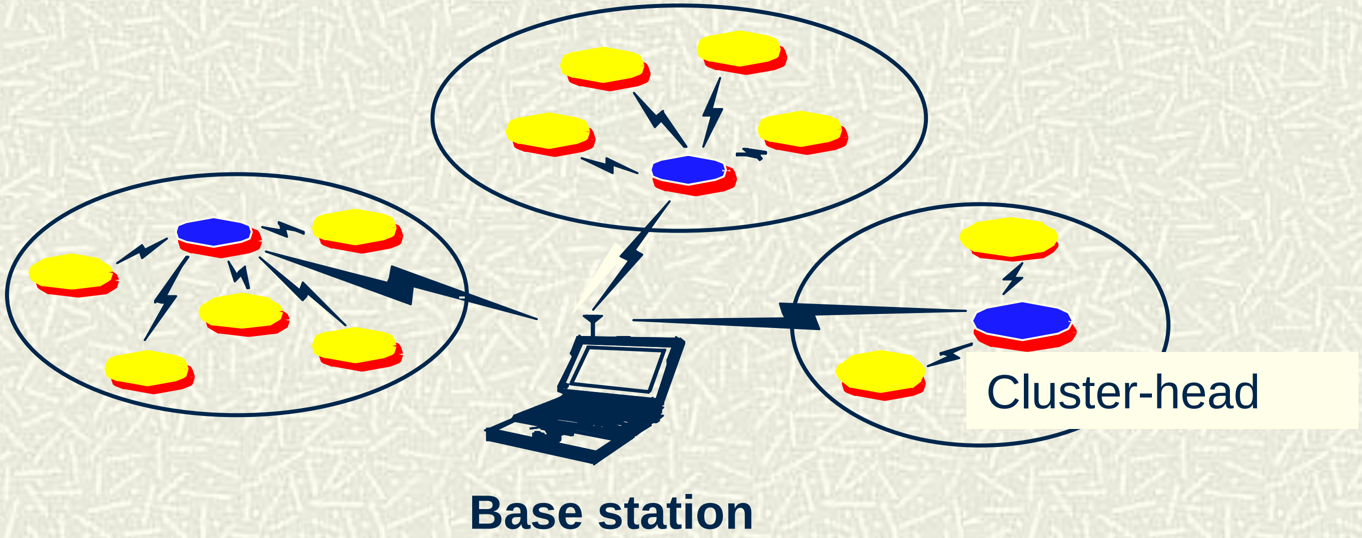
Hierarchical Protocols

- **Hierarchical-architecture protocols are proposed to address the scalability and energy consumption challenges of sensor networks.**
- **Sensor nodes form clusters where the cluster-heads aggregate and fuse data to conserve energy.**
- **The cluster-heads may form another layer of clusters among themselves before reaching the sink.**

Hierarchical Protocols

- **Low-Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman'02)**
- **Power-efficient GAthering in Sensor Information Systems (PEGASIS)**
- **Threshold sensitive Energy Efficient sensor Network protocol (TEEN)**
- **Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN)**

LEACH Protocol Architecture



- Low-Energy Adaptive Clustering Hierarchy
  - Adaptive, self-configuring cluster formation
  - Localized control for data transfers
  - Low-energy medium access control
  - Application-specific data aggregation

Low Energy Adaptive Clustering Hierarchy

W. R. Heinzelmn, A. Chandrakasan, and H. Balakrishnan,
"Energy-Efficient Communication Protocol for Wireless Microsensor Networks," IEEE Tr. on Wireless Com., pp.660-670, Oct. 2002

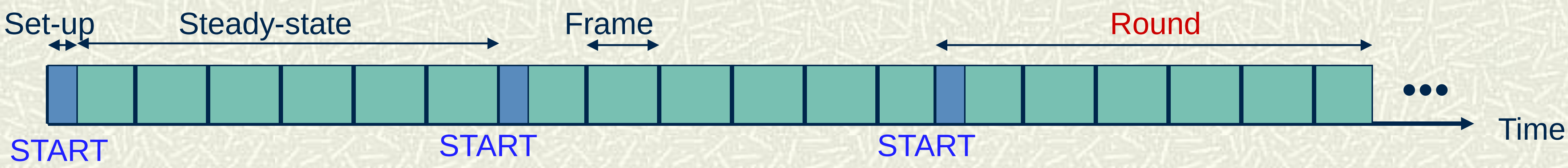
Idea:

*** Randomly select sensor nodes as cluster heads, so the high energy dissipation in communicating with the base station is spread to all sensor nodes in the network.**

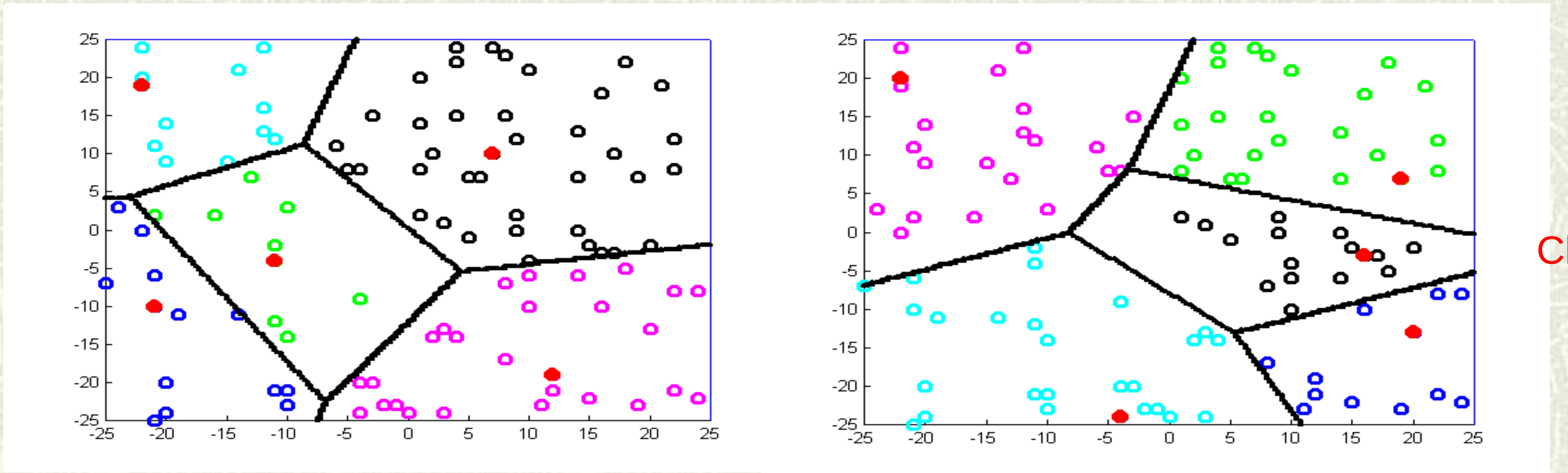
*** Forming clusters is based on the received signal strength.**

*** Cluster heads can then be used kind of routers (relays) to the sink.**

Dynamic Clusters



- Cluster-head rotation to evenly distribute energy load
- Adaptive clusters
  - Clusters formed during set-up
  - Scheduled data transfers during steady-state



Cluster-heads = •

Distributed Cluster Formation

Assume nodes begin with equal energy
Design for *k* clusters per round

k = system param.
(Analytical optimum)

Want to evenly distribute energy load

$$\mathbf{E[\#\ CH]} = \sum_{i=1}^{N} \mathbf{P_i}(t) * 1 = k$$

⇨ Each node CH once in *N*/*k* rounds

$$\mathbf{P_i}(t) = \begin{cases} \dfrac{k}{N - k * r \bmod (N/k)} & \mathbf{C_i}(t) = 0 \\ 0 & \mathbf{C_i}(t) = 1 \end{cases}$$

$C_i(t)$ = 1 if node i a CH in last *r mod (N/k)* rounds

Can determine $P_i(t)$ with unequal node energy

LEACH

- After the cluster heads are selected, the cluster heads advertise to all sensor nodes in the network that they are the new cluster heads.

- **Each node accesses the network through the cluster head that requires minimum energy to reach.**

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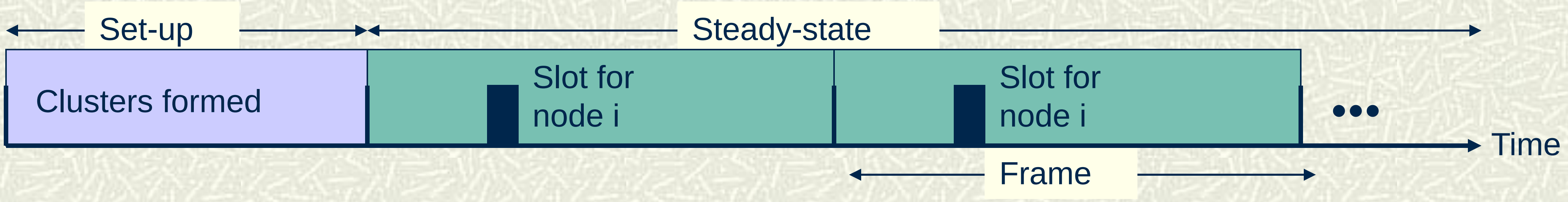
LEACH

- **Once the nodes receive the advertisement, they determine the cluster that they want to belong based on the <u>received signal strength</u> of the advertisement from the cluster heads to the sensor nodes.**

- **The nodes inform the appropriate cluster heads that they will be a member of the cluster.**

- **Afterwards the cluster heads assign the time slots during which the sensor nodes can send data to them.**

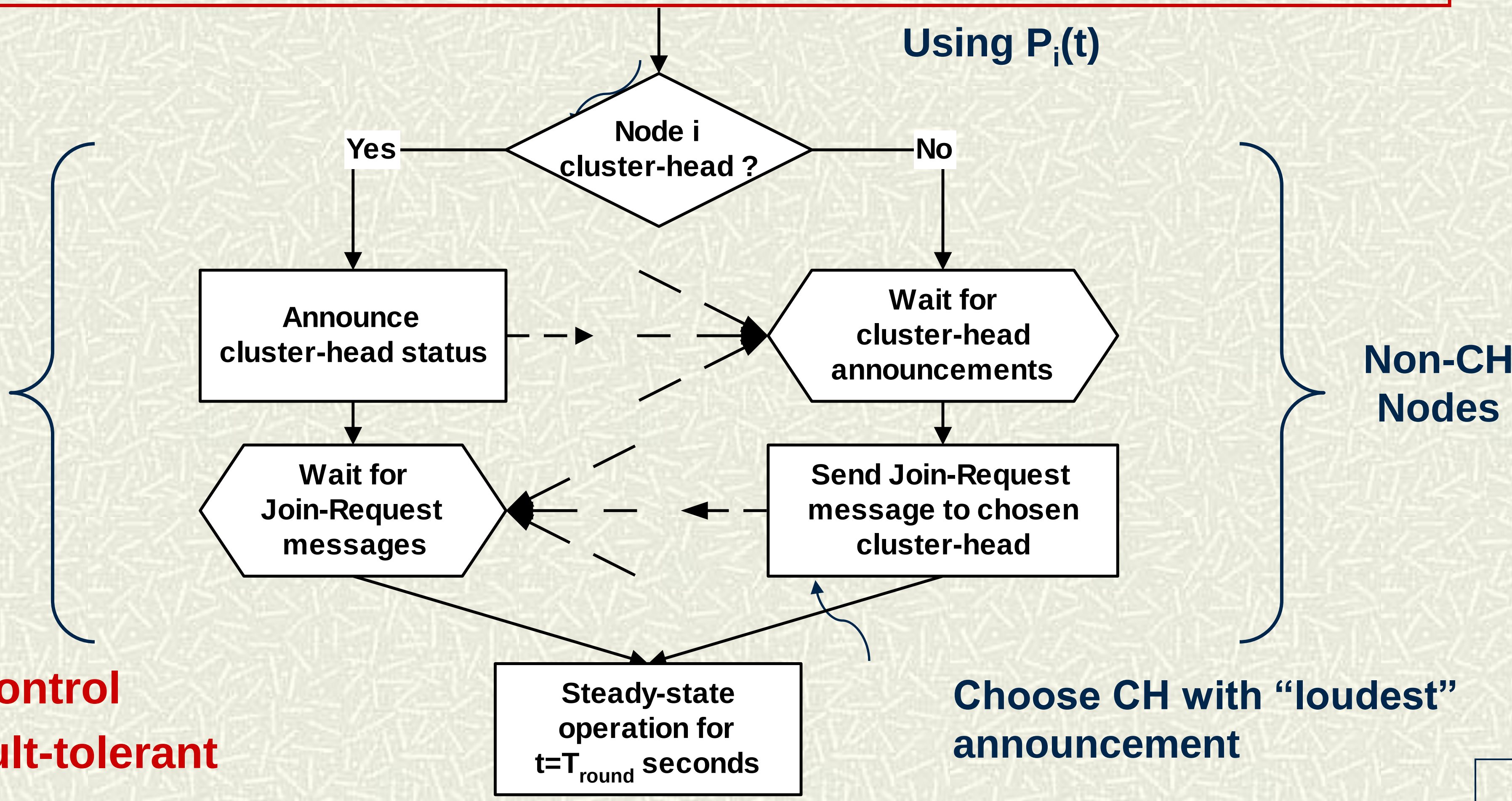
LEACH Steady-State



- Cluster-head coordinates transmissions
  - Time Division Multiple Access (TDMA) schedule
  - Node i transmits once per frame
- Cluster-head broadcasts TDMA schedule
- Low-energy approach
  - No collisions
  - Maximum sleep time
  - Power control

Distributed Cluster Formation

Autonomous decisions lead to global behavior



- No global control
- Flexible, fault-tolerant

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LEACH

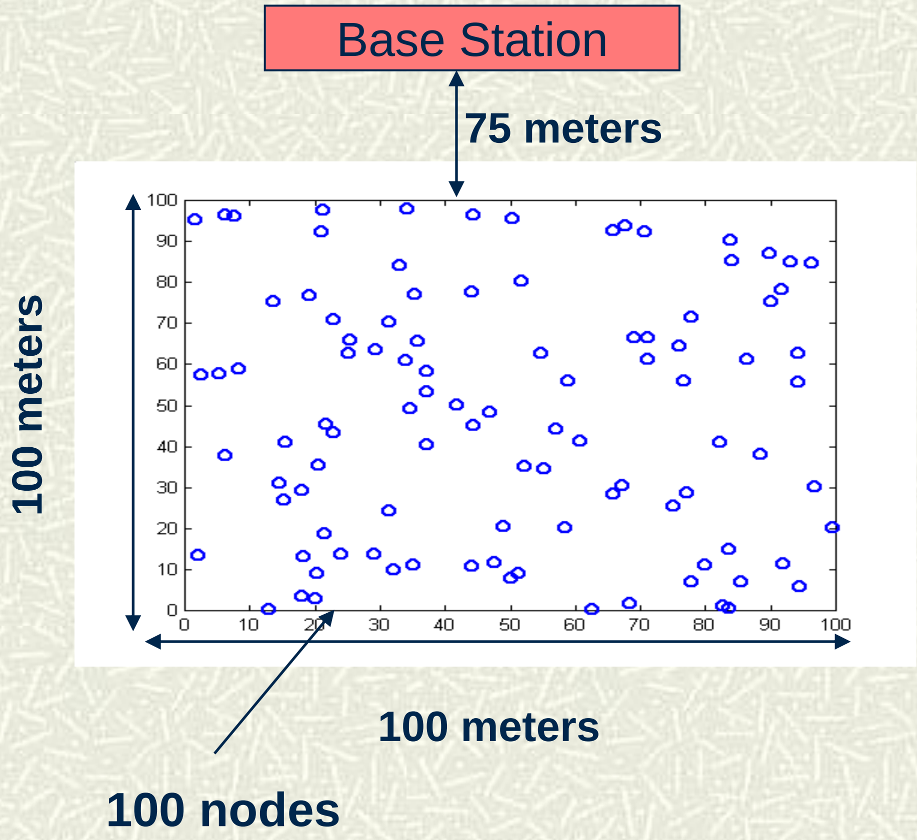
STEADY STATE PHASE:

- Sensors begin to sense and transmit data to the cluster heads which aggregate data from the nodes in their clusters.
- After a certain period of time spent on the steady state, the network goes into start-up phase again and enters another round of selecting cluster heads.

Base Station Cluster Formation

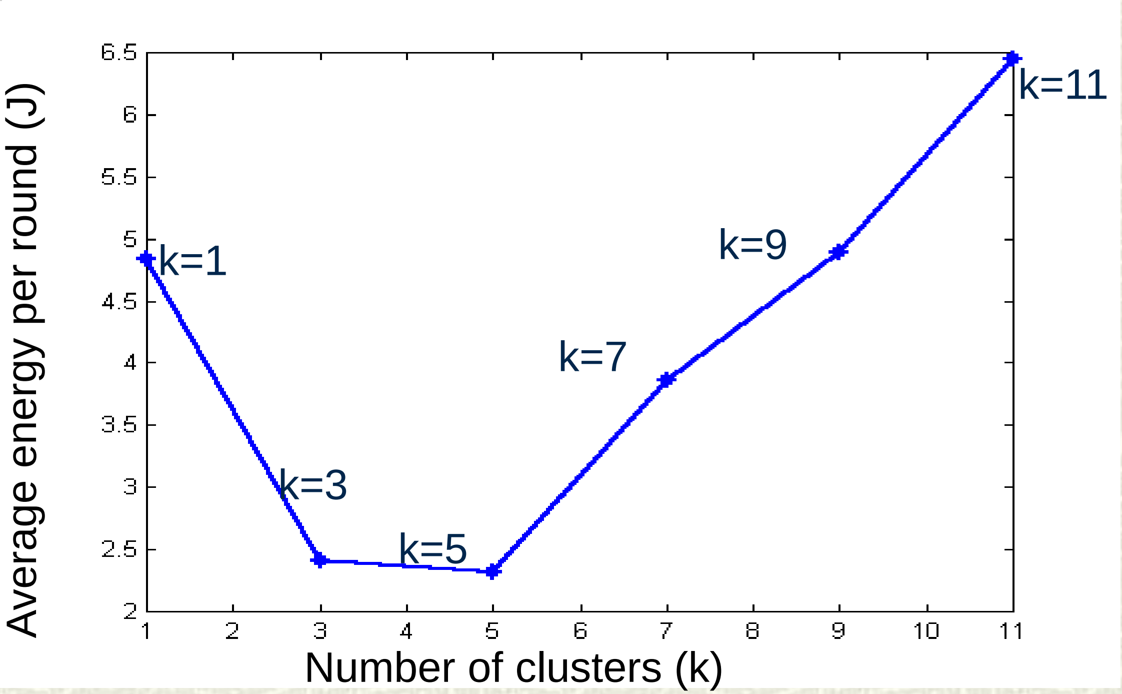
- Get optimal clusters for comparison
- LEACH-C
  - Requires communication with base station
  - Nodes send base station current position
  - Base station runs optimization algorithm to determine best clusters
- Need GPS or other location-tracking method

Simulation Parameters



Processing delay	50 μs
Bit rate	100 kbps
Radio electronics	50 nJ/bit
Transmit amplifier	100 pJ/bit/m^2
Aggregation cost	5 nJ/bit/signal
Data size	500 bytes

Optimum Number of Clusters



- Too few clusters ⇨ cluster-head nodes far from sensors
- Too many clusters ⇨ not enough local signal processing

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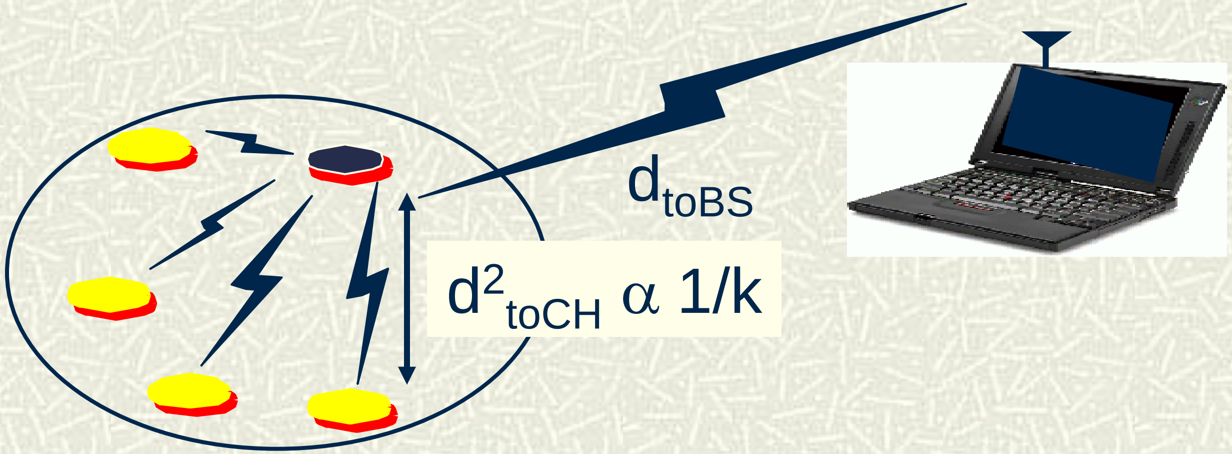
Analytical Optimum

k clusters ⇨ N/k nodes/cluster:

$$E_{CH} = \alpha \frac{N}{k} + \beta$$

$$E_{non-CH} = \gamma \frac{1}{k} + \delta$$



$$k_{opt} = \rho \frac{\sqrt{N}M}{d_{toBS}^{2}}$$

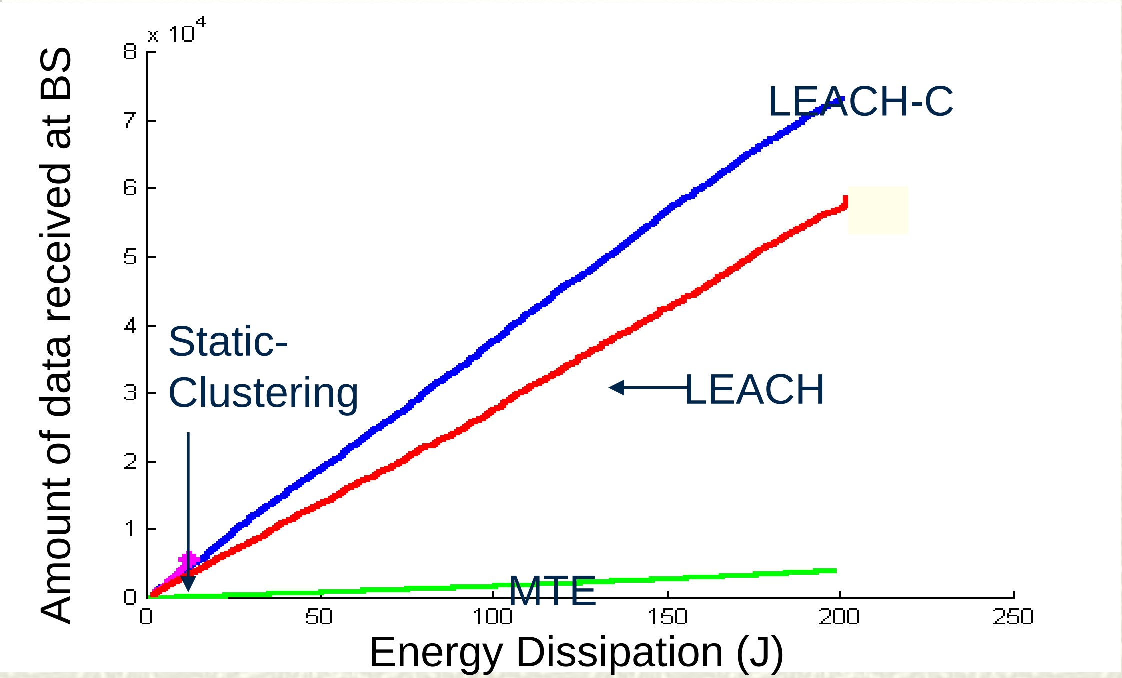
N=100
M=100
$75 < d_{toBS} < 185$

⇨ $2 < k_{opt} < 6$

- Simulation agrees with theory

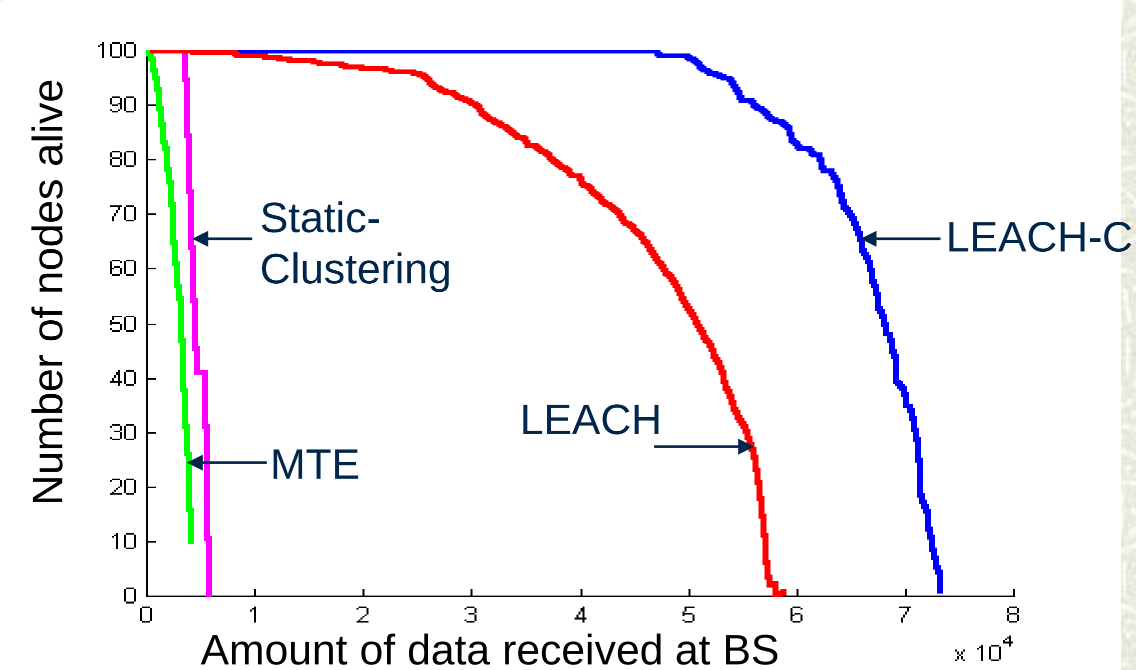
Data per Unit Energy

Nodes begin with limited energy



- LEACH achieves order of magnitude more data per unit energy
  - 2 hops v. 10 hops average
  - Data aggregation successful

Network Lifetime



- LEACH delivers over 10 times amount of data for any number of node deaths
- Rotating cluster-head effective

LEACH - CONCLUSIONS

- It is not applicable to networks deployed in large regions.
- Furthermore, the idea of dynamic clustering brings extra overhead, e.g., head changes, advertisements etc. which may diminish the gain in energy consumption.