Wireless Sensor Networks Routing Protocols

MO809 - Tópicos em Computação Distribuída

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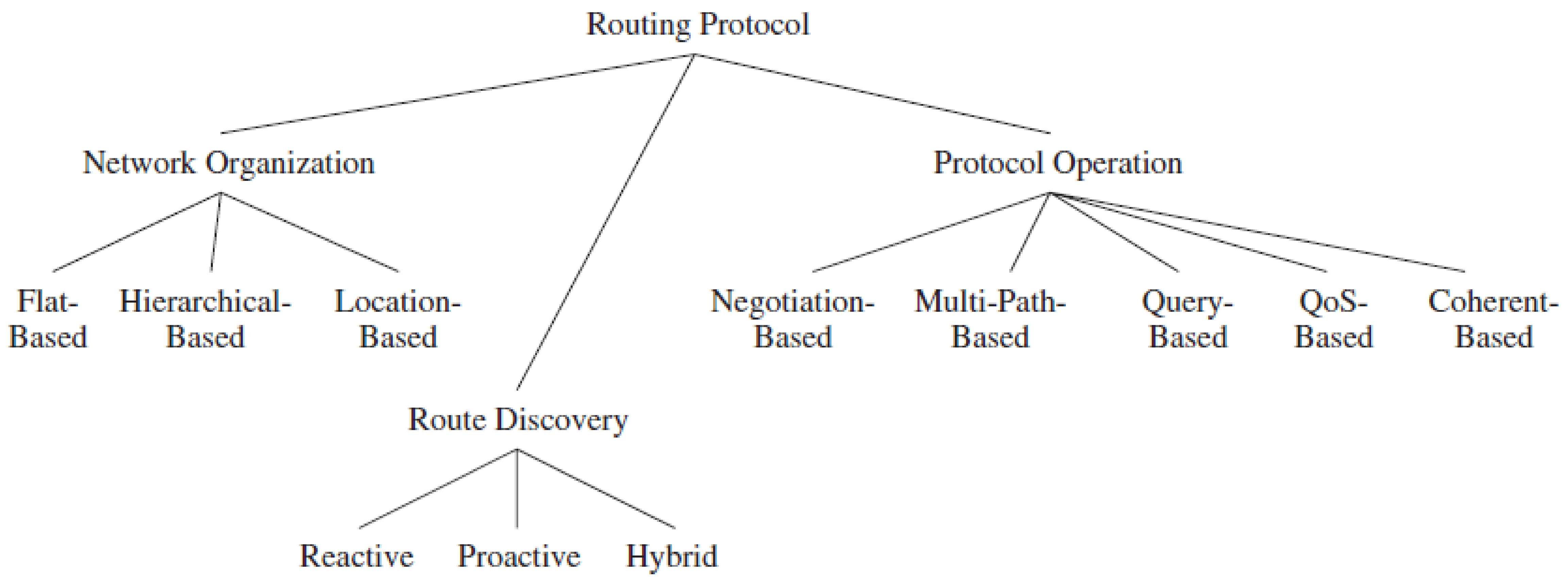
Topics

- Protocols
  - Data-Centric
  - Proactive
  - On-demand
  - Hierarchical
  - Location-based
  - QoS-based

Routing protocols



Network Organization

Routing protocols

- **Flat-based** routing protocols consider all nodes of equal functionality or role.
- **Hierarchical-based** routing protocols, different nodes may assume different roles in the routing process, that is, some nodes may forward data on behalf of others, while other nodes only generate and propagate their own sensor data.
- **Location-based** routing protocols rely on the location information from nodes to make routing decisions.

Route Discovery

Routing protocols

- **Reactive** protocols discover routes *on-demand*, that is, whenever a source wants to send data to a receiver and does not already have a route established.
- **Proactive** routing protocols establish routes before they are actually needed. *table-driven*, because local forwarding decisions are based on the contents of a *routing table* that contains a list of destinations, combined with one or more next-hop neighbors that lead toward these destinations and costs associated with each next hop option.
- **Hybrid** exhibit characteristics of both reactive and proactive protocols.

Operation
Routing protocols

- **Negotiation-based** protocols aim to reduce redundant data transmissions by relying on the exchange of negotiation messages between neighboring sensor nodes before actual data transfers occur
- **Multipath-based** protocols use multiple routes simultaneously to achieve higher performance or fault tolerance
- **Query-based** routing protocols are receiver-initiated, that is, sensor nodes send data in response to queries issued by the destination node
- **QoS-based routing** protocols is to satisfy a certain Qualityof-Service (QoS) metric (or a combination of multiple metrics), such as low latency, lowenergy consumption, or low packet loss
- **Coherent-based** protocols perform only a minimum amount of processing (e.g., eliminating duplicates, time-stamping) before sensor data is sent to receivers and data aggregators. However, in noncoherent-based protocols, nodes may perform significant local processing of the raw data before it is sent to other nodes for further processing.

Routing Metrics

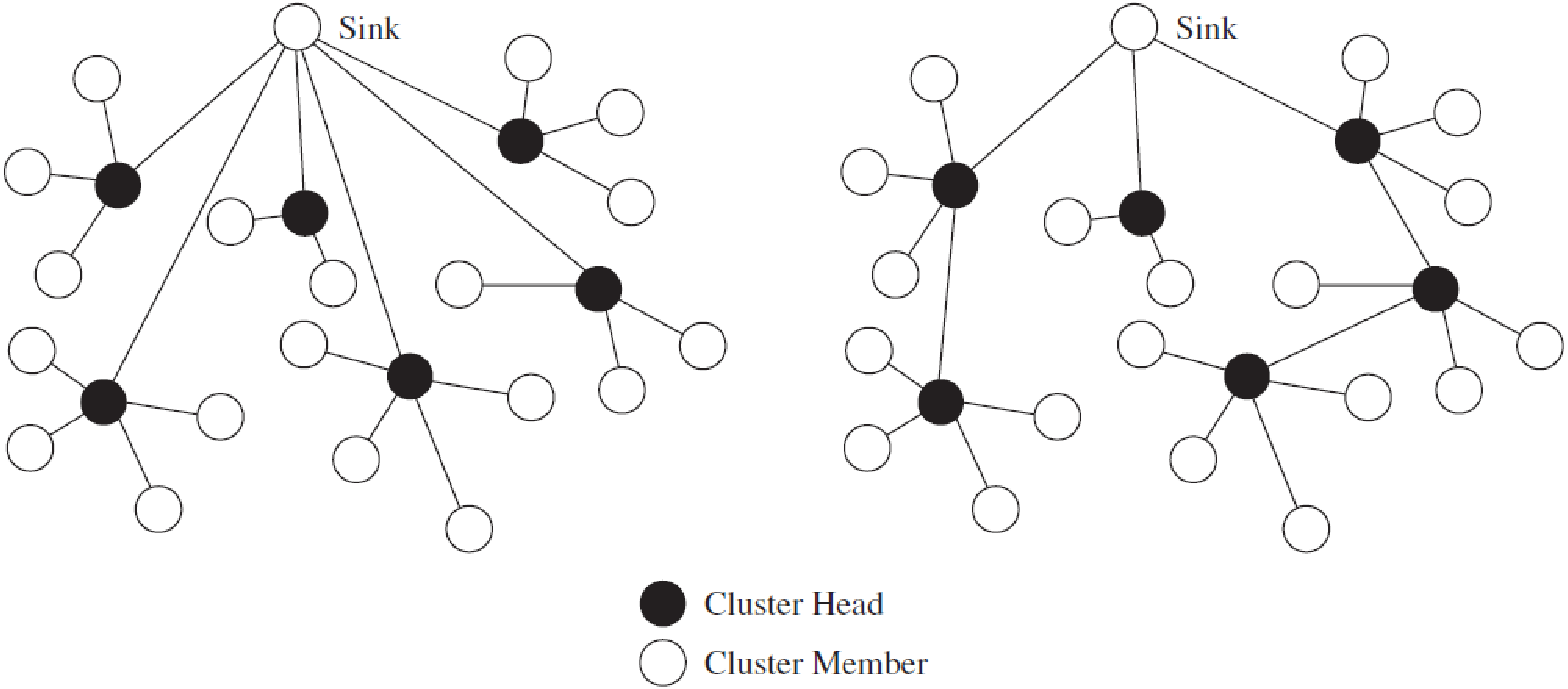
- **Minimum Hop:** smallest number of relay nodes (hops)
- **Energy**
  - *Minimum energy consumed per packet*
  - *Maximum time to network partition*
  - *Minimum variance in node power levels*
  - *Maximum (average) energy capacity*
- **Quality-of-Service:** performance in networks, including end-to-end latency (or delay) and throughput, but also jitter (variation in latency) and packet loss (or error rate).
- **Robustness:** stability and reliability for long periods of time

Protocol	Characteristics
SPIN	Flat topology, data-centric, negotiation-based
Directed diffusion	Flat topology, data-centric, query-based, negotiation-based
Rumor routing	Flat topology, data-centric, query-based
GBR	Flat topology, data-centric, query-based
DSDV	Flat topology with proactive route discovery
OLSR	Flat topology with proactive route discovery
AODV	Flat topology with reactive route discovery
DSR	Flat topology with reactive route discovery
LANMAR	Hierarchical with proactive route discovery
LEACH	Hierarchical, support of MAC layer
PEGASIS	Hierarchical
Safari	Hierarchical, hybrid route discovery (reactive near, proactive remote)
GPSR	Location-based, unicast
GAF	Location-based, unicast
SPBM	Location-based, multicast
GEAR	Location-based, geocast
GFPG	Location-based, geocast
SAR	Flat topology with QoS (real-time, reliability), multipath
SPEED	Location-based with QoS (real-time)
MMSPEED	Location-based with QoS (real-time, reliability)

4 Hierarchical Routing

- Clusters - goal: scalability, efficiency
- Sensor nodes communicate only directly with a leader node in their own cluster (cluster head)
- Cluster heads: may be more powerful and less energy-constrained

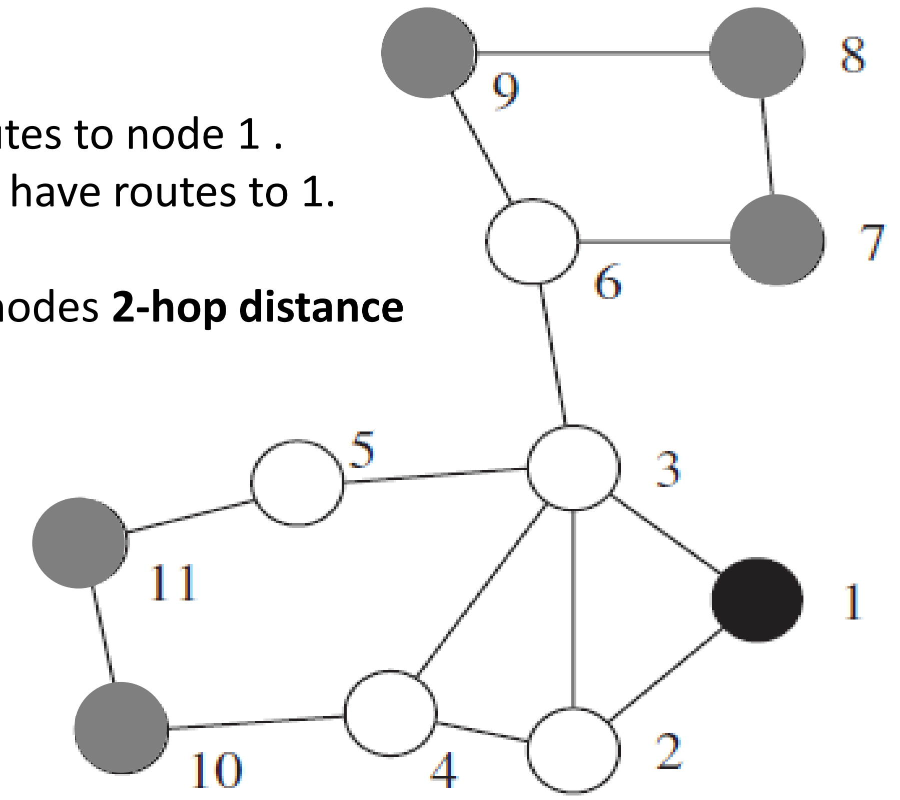
- Advantages:
  - reduce collision in wireless medium
  - Facilitate duty cycling of sensor nodes
  - Facilitates in-network data aggregation
- Challenges:
  - Selection of cluster heads
  - Formations of cluster
  - Adaptation to network changes


Sink
Sink
Cluster Head
Cluster Member

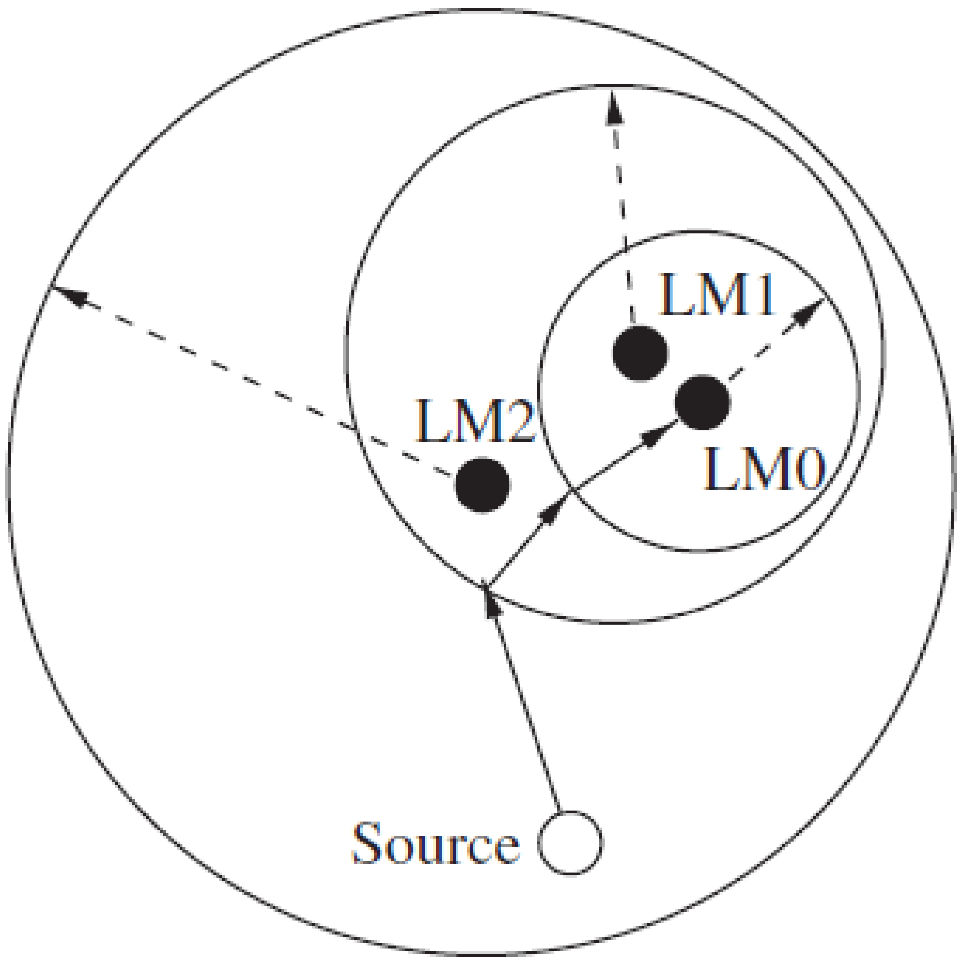
Landmarks

2–6: have routes to node 1 .
7–11: do not have routes to 1.

1: landmark nodes **2-hop distance**



Hierarchy of Landmarks



Landmark **radius *n*:** all nodes within ***n*** **hops** have routing information toward the node

4.1 Landmark Ad Hoc Routing (LANMAR)

- Extension of Landmark Routing with Fisheye State Routing
- Landmarks: head of logical subnet
- Fisheye State Routing: link state protocol – frequency of updates depends on the distance.
- In LANMAR: routing update exchanged between immediate neighbors
- Routing: direct (neighbor) or through head of logical subnet

4.2 Low-Energy Adaptive Clustering Hierarchy (LEACH)

- Clustering approach with MAC-layer techniques (TDMA)
- Assumes that every cluster head can directly communicate with base
- Cluster head is rotated
- Cluster heads:
  - Responsible for communication between cluster members and base station.
  - Aggregation of data.
  - Must always be awake

- Setup-phase
  - Heads determination
  - Only nodes that have not been a head recently are candidates
  - Alternative approach: consider available remaining energy
  - Head broadcasts messages informing it is the head
  - Joining: node selects a head that can be reached with the smallest amount of transmit energy
- Steady-State Phase
  - Sensor node communicates only with the cluster head (TDMA)
  - Communication between cluster heads and the base station is based on this fixed spreading code and CSMA
  - Before a cluster head transmits data, it first senses the channel to see if there is an ongoing transmission using the same spreading cod

4.3 Power-Efficient Gathering in Sensor Information Systems (PEGASIS)

- Assumes that all nodes can communicate with the base
- Nodes are organized in a chain
- Responsibility for relaying packets to the base is changed in turns
- Node exchange data only with its closest neighbors
- Advantage: high energy efficiency since nodes communicates only with the closest
- Problem: Packets may experience significant delays

4.4 Safari

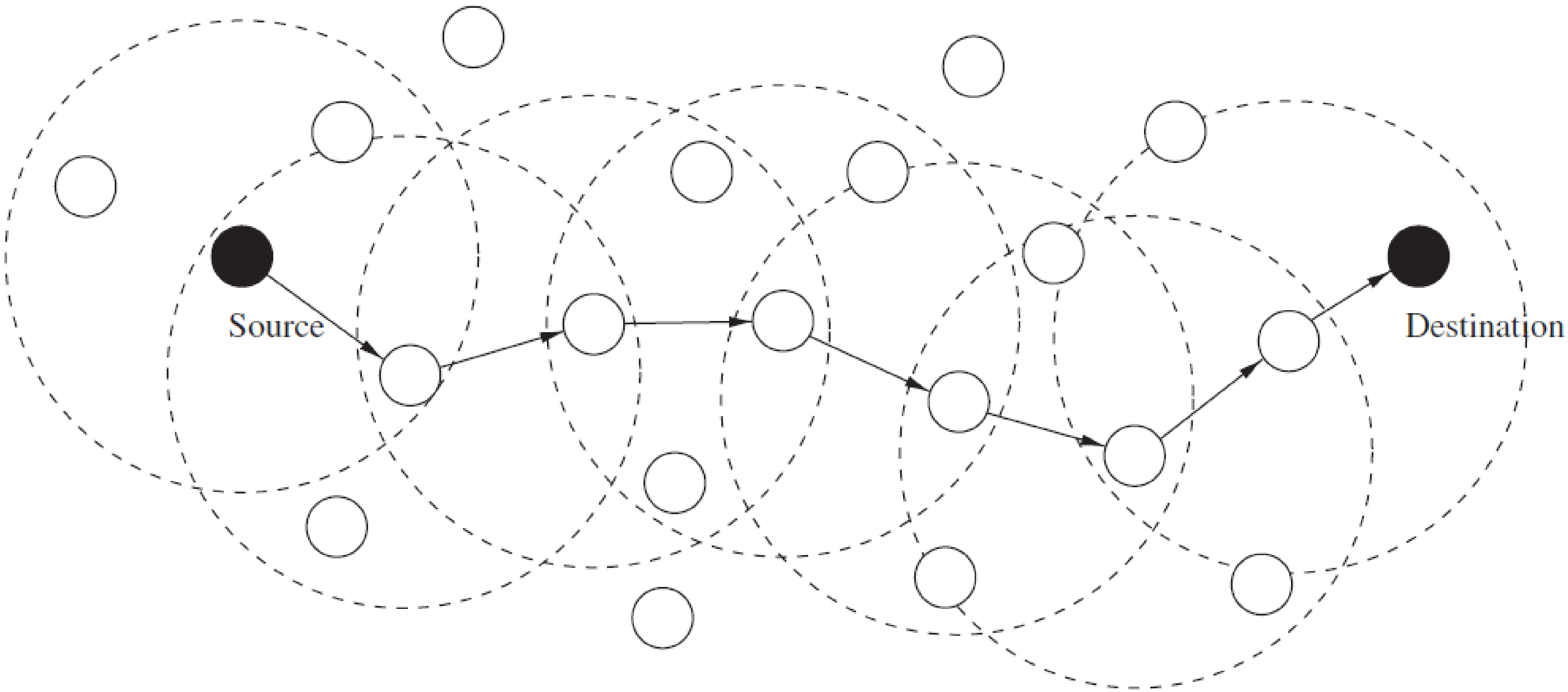
- Landmarsk = drums: periodically sends a beacon
  - Indication of their topological location within the hierarchy
  - provide routing information toward the drum’s cell
  - Do not have any special role in data forwarding
- Level 0: node, Level 1: fundamental cells, Higher-level cells: multiple cells
- Each node maintains
  - A local view of its surrounding network
  - Progressively more coarse-grained information about distant parts of the network
  - Beacons it overhears
- Hybrid: Reactive DSR (Dynamic Source Routing) + proactive routing approach is used to compute routes to more distant nodes
- Routing: the packet is forwarded according to the hierarchical address of the packet’s destination, routing recursively at each level towards the drum for the destination node’s cell

5 Location-Based Routing

- Sensor nodes know their position
- The location of the node is more important than its identity
- Destination: the location of a node or a geographic region
- Instead of topological connectivity information, sensors use geographic information to make forwarding decisions
- Advantages:
  - Only geographic information is needed for forwarding decisions
  - Not necessary to maintain routing tables or to establish end-to-end paths between sources and destinations, eliminating the need for control packets (apart from the beacon messages among neighbors).

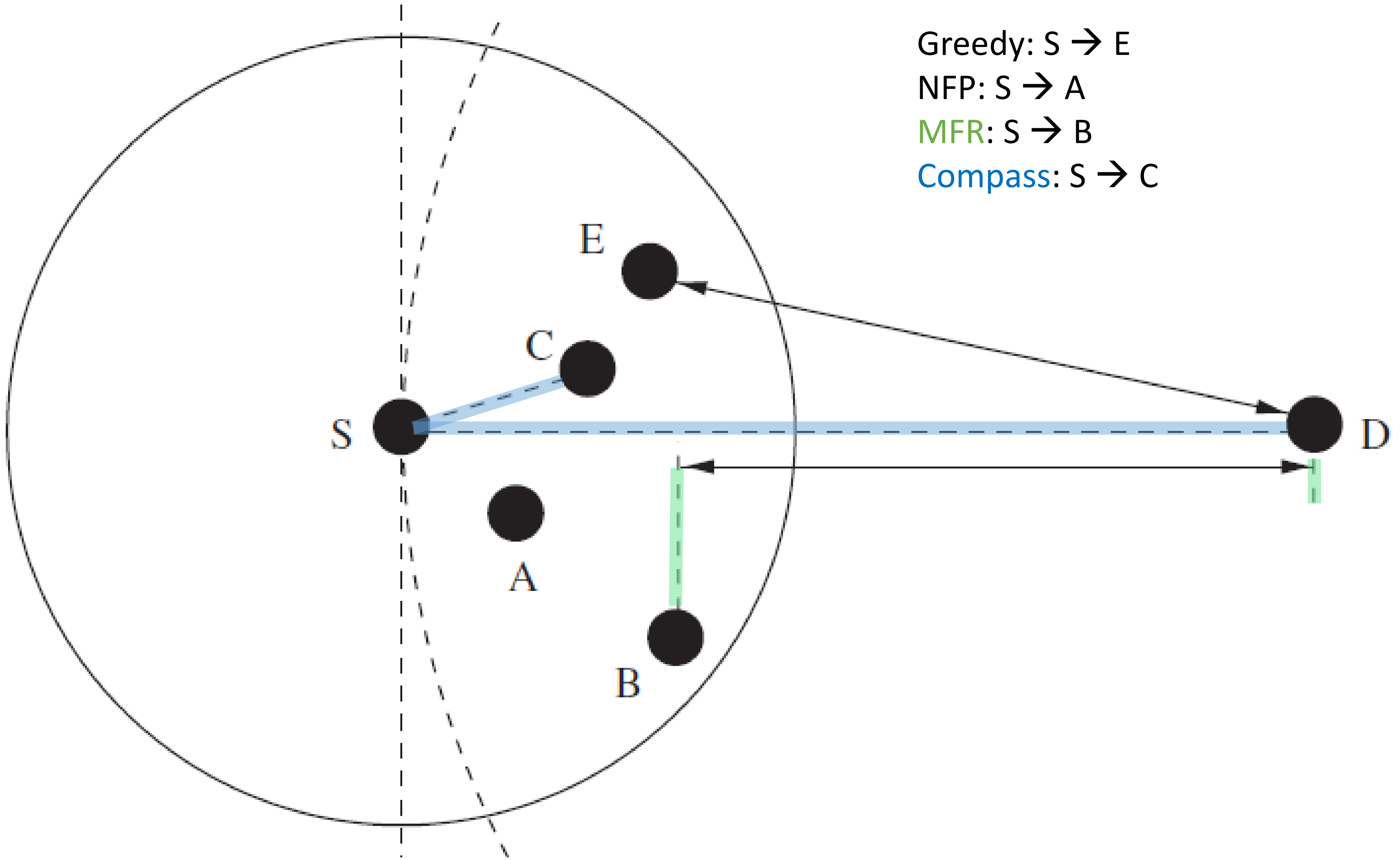
5.1 *Unicast Location-Based Routing*

- Goal: propagate a packet to a specific node located at a position
- It is only required that each node knows its own location and the location of its neighbors
- *Greedy forwarding* approach: a local forwarding decision to ensure that a packet moves closer to the destination with each hop.
- Problem: Packet may arrive at a node that does not have any neighbors that could serve as next hops to bring the packet closer to the destination


Source
Destination

5.1.1 Forwarding Strategies

1. *Greedy:* chooses a neighbor that minimizes the distance to the destination in each hop. Goal: minimize the number of hops required to reach the destination.
2. *Nearest with Forwarding Progress (NFP): c*hooses the nearest neighbor of all neighbors that make a positive progress toward the destination. Sensor nodes that can adapt their transmission powers can choose the smallest transmission power necessary to reach this neighbor
3. *Most Forwarding Progress within Radius (MFR):* elects the neighbor that makes the greatest positive progress towards the destination, where progress is defined as the distance between the source and its neighbor node projected onto a line drawn from the source to the destination. Attempts to minimize the number of hops a packet must travel
4. *Compass Routing:* chooses the neighbor with the smallest angle between a line drawn from the source to the neighbor and the line connecting the source and the destination. This approach (which would select node C in Figure 7.15) attempts to minimize the spatial distance that a packet has to travel.

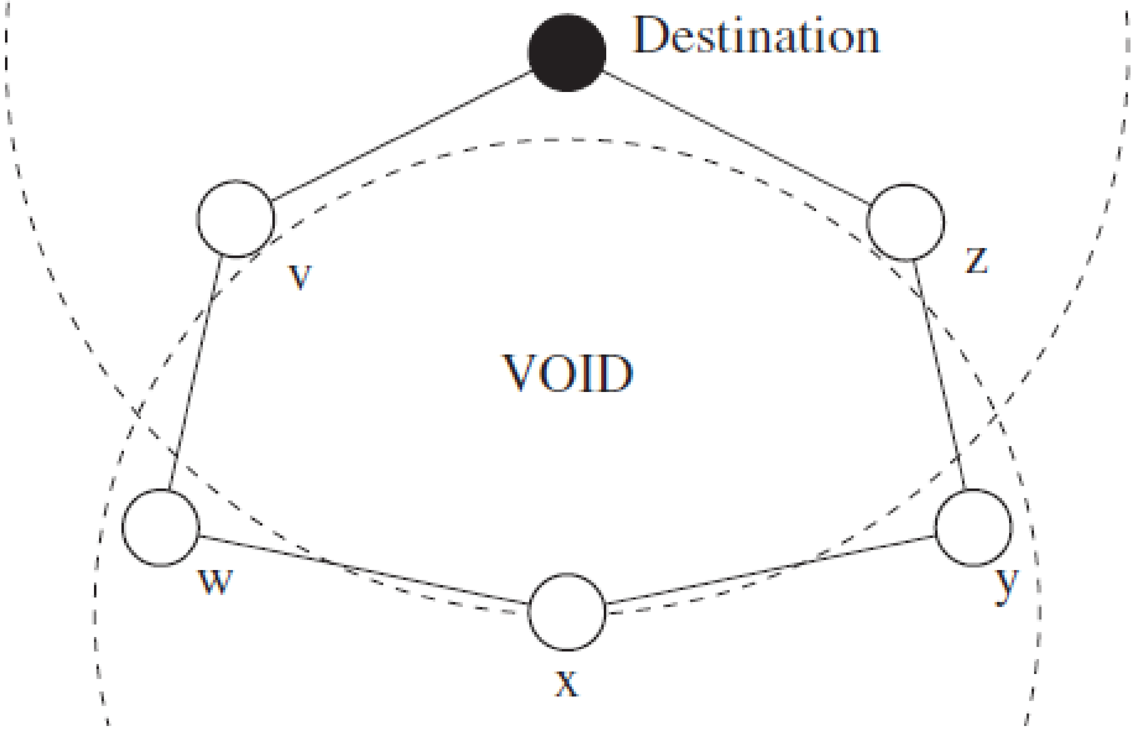


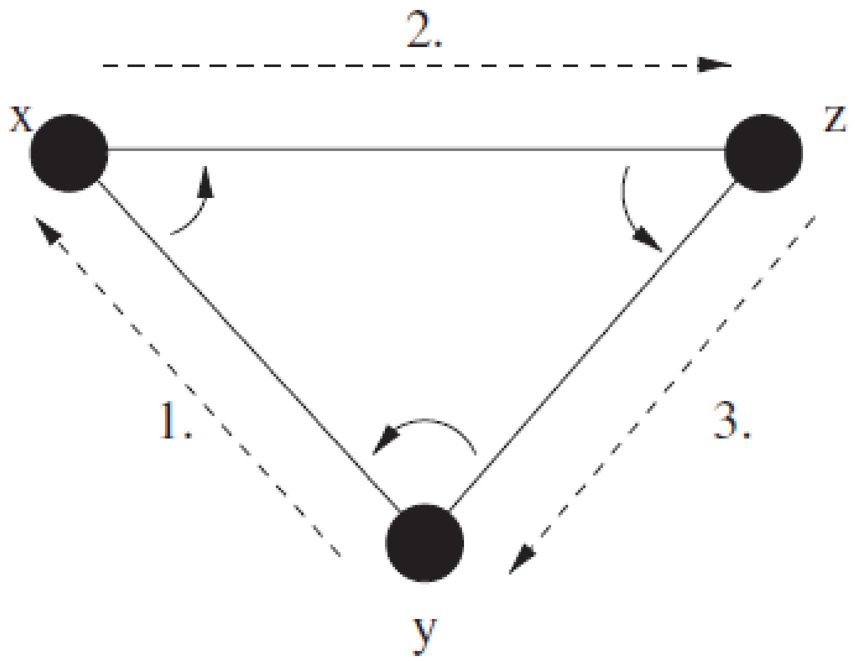
Greedy: S → E
NFP: S → A
MFR: S → B
Compass: S → C

5.1.2 Greedy Perimeter Stateless Routing (GPSR)

- Greedy approach: node searches its neighbor table for the neighbor geographically closest to the destination

- Routing
  - If there is a neighbor closest to the destination: forward
  - If not: perimeter routing mode and records in the packet the location where greedy forwarding failed.





- Node x is closer to destination than w and y
- The greedy approach wouldn’t find a way to route the packet

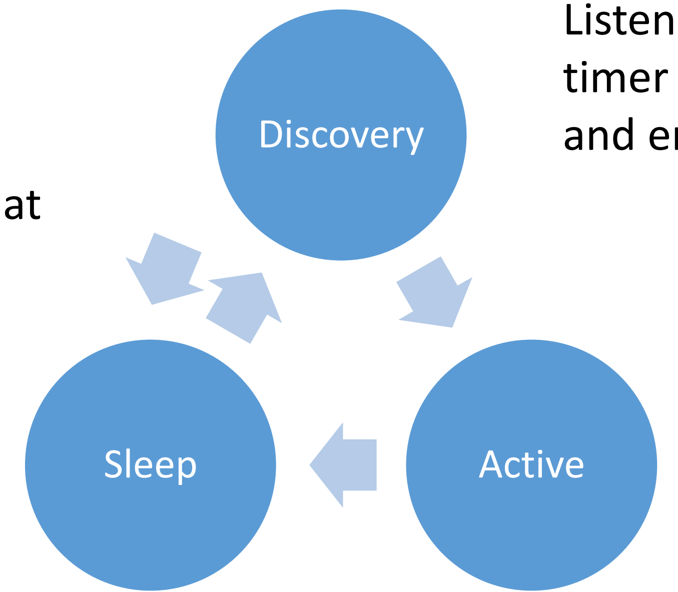
- Right-hand rule to avoid voids
- The next edge traversed is the next one sequentially counterclockwise about *x* from edge (*x, y*).

5.1.3 Geographic Adaptive Fidelity (GAF)

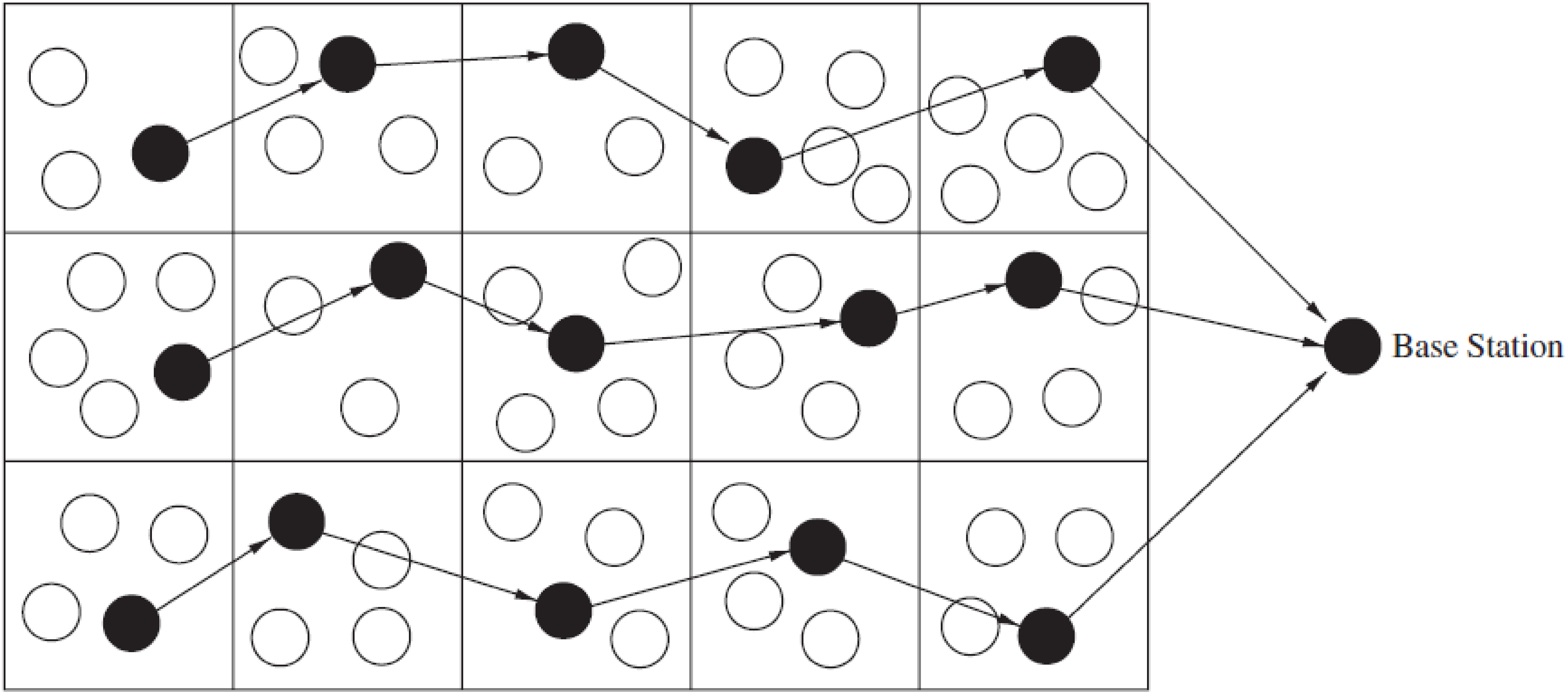
- The network region is divided into a virtual grid
- Only a single device in each grid cell serves as the forwarding node
- This node is then responsible for relaying data to the base station, while all other nodes can go to sleep
- States

Listen for messages within a cell. Sets timer to broadcast discovery message and enter active state

Sleep transition: whenever it determines that other node is going to forward packets



Active: periodically rebroadcasts discovery. Forwarder - only one per cell

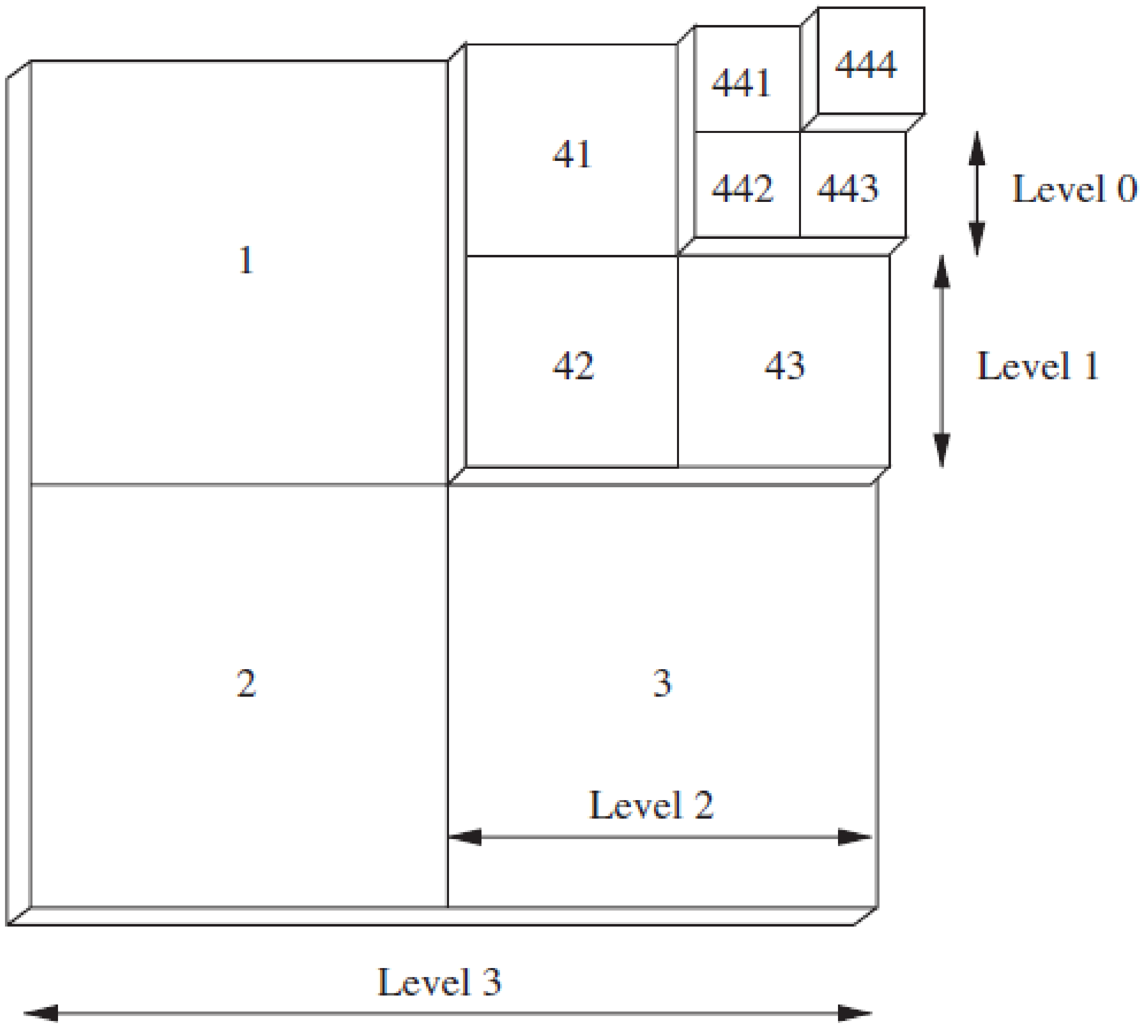

Base Station

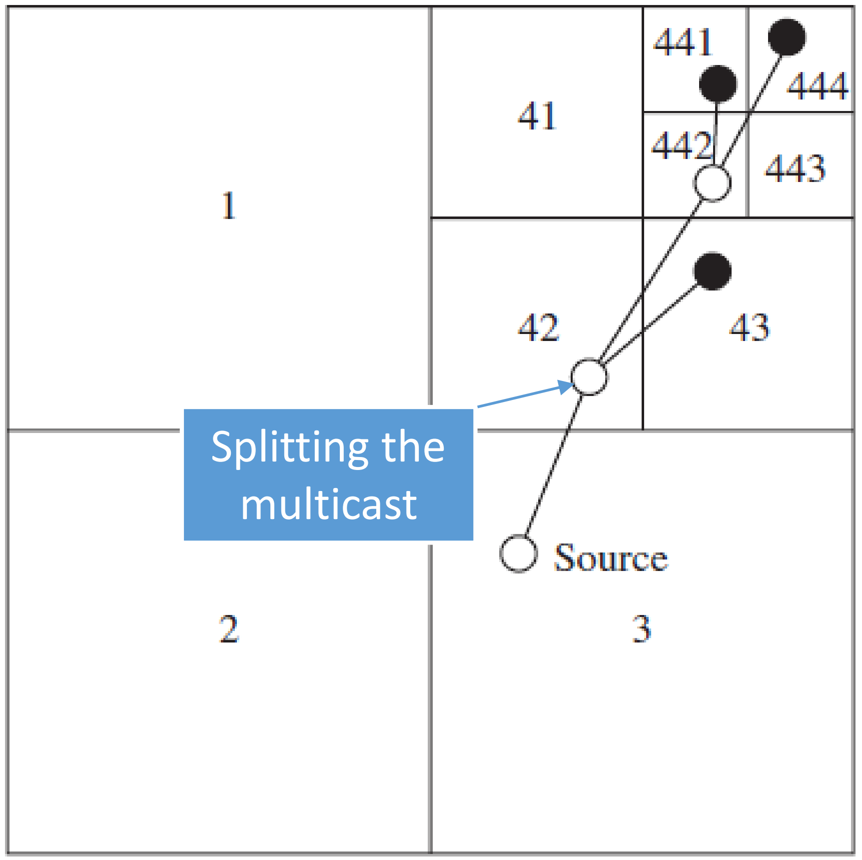
5.2 Multicast Location-Based Routing

- Deliver the same packet to multiple receivers.
- Simple approach: deliver the packet to each receiver separately via unicast routing. Resource-inefficient: does not exploit the fact that routes to different receivers may share paths.
- Efficient delivery: minimizing the number of links the packet has to travel to reach all destinations.
- Common technique: *multicast tree* rooted at the packet source with the destinations as leaf nodes.

5.2.1 Scalable Position-Based Multicast (SPBM)

- *Group management scheme:* list of all destinations for a particular packet.
- Hierarchical group membership management
- Network represented as a quad-tree with a predefined number of levels
- A node mantains
  - *A global member table:* three neighboring squares for each level - the square’s identifier and a list of nodes located in the square
  - *Local member table:* all members of the node’s level-0 neighbors
- Routing similar to GPSR - Greedy forwarding approach
- *Splitting* a multicast packet: heuristic that provides a tradeoff between the total number of nodes forwarding the packet and the optimality of the individual routes toward the destinations





Source → 441, 444, 43

5.2.2 Receiver Based Multicast (RBMulticast)

- Similar to SPBM: divides the network into *multicast regions*
- Stateless: no need of membership tables - multicast region represented by a *virtual node*
- It is up to the MAC layer to ensure that the neighbor closest to the location of the virtual node takes responsibility for forwarding the packet

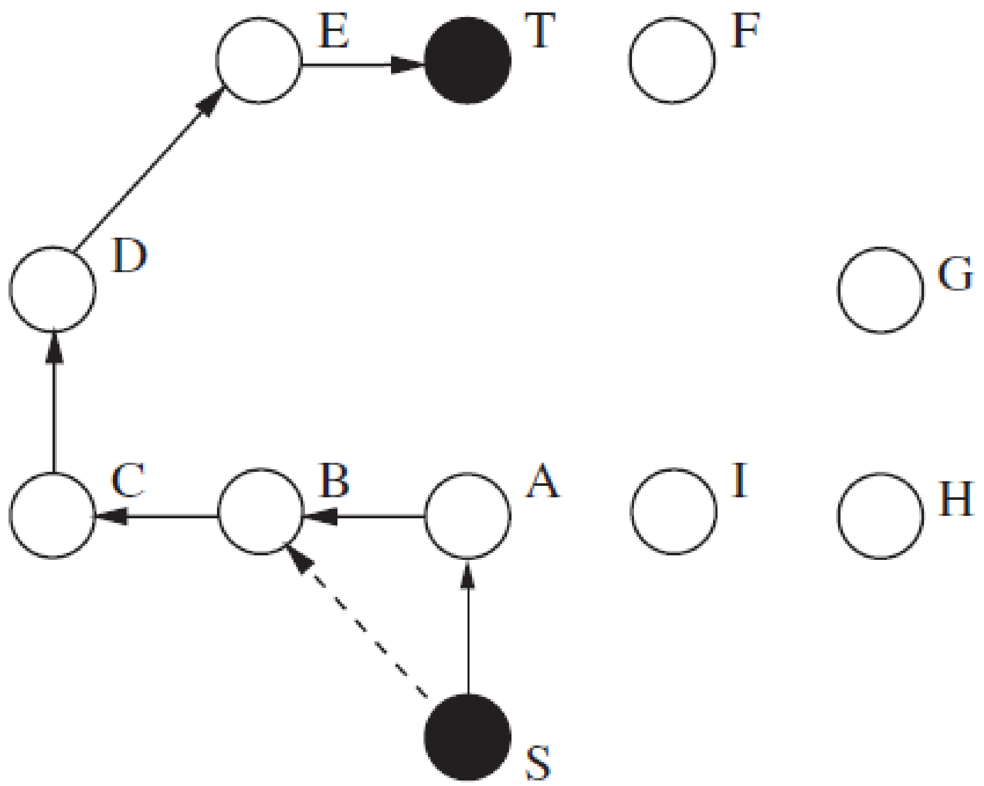
5.3 Geocasting

- Propagate information to all nodes in a specific geographic region
- Challenges:
  - Propagating a packet *near* the target region
  - Distributing a packet within the target region
- Geocasting: combination of both unicast and broadcast geographic routing

5.3.1 Geographic and Energy Aware Routing (GEAR)

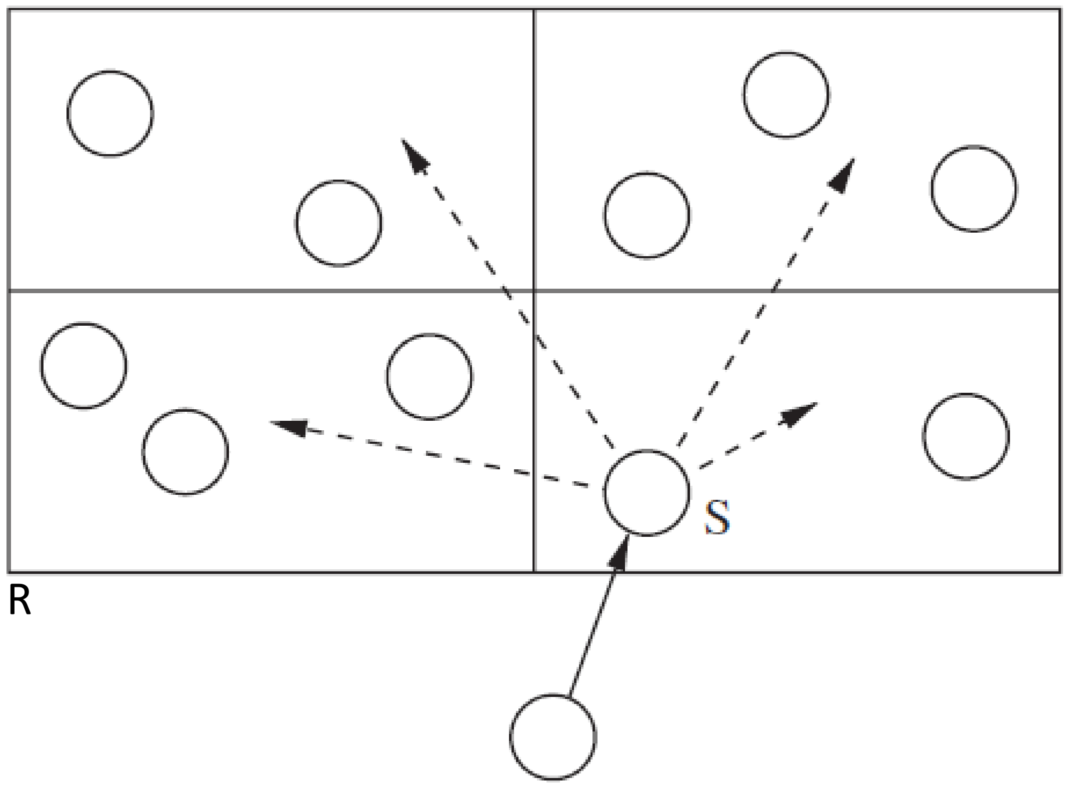
- Energy-aware neighbor selection algorithm
- Each node in the network maintains two types of costs of reaching a destination via its neighbors
  - *Estimated cost:* distance + energy
  - *Learned cost*: refinement of the estimated cost that allows nodes to circumvent voids or holes in the network
- Routing to region R: similar to GPSR
- Once a packet reaches the target region *R*: *Recursive Geographic Forwarding*

Learning



- S will forward the packet to the lowest cost neighbor, which is A. Node A will find itself in a hole and it will forward the packet to the neighbor with the minimum learned cost, for example, node B and update its cost
- The next time a packet for T arrives at node S, S will forward the packet directly to B instead of A to circumvent the hole

Recursive Geographic Forwarding

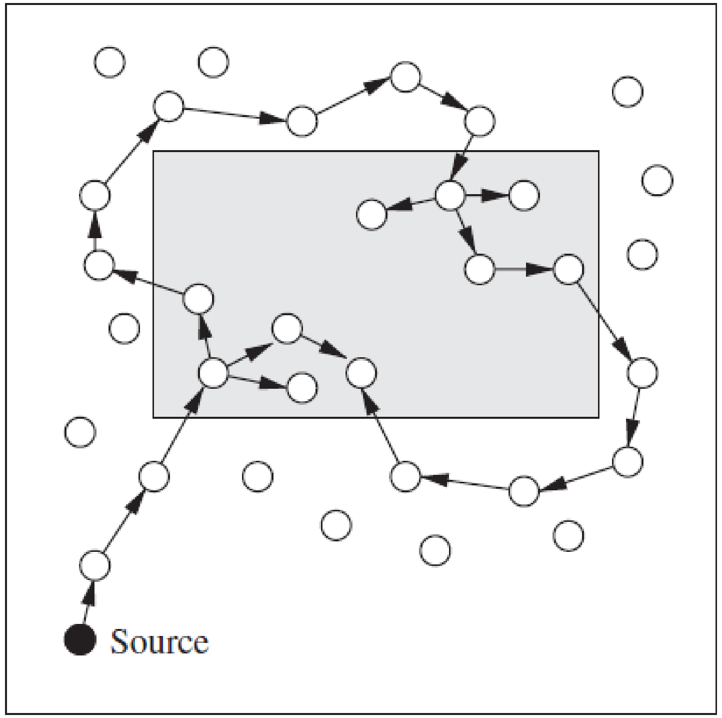


S creates four new copies of the packet bound to four smaller subregions. For each subregion, GEAR repeats the forwarding and splitting process until a packet reaches a node that is the only one within the current subregion

5.3.2 Geographic-Forwarding-Perimeter-Geocast (GFPG)

- GPRS to propagate the package near the region
- Once near R: perimeter routing

- Floods all nodes in region and send packet to *region border nodes* (have at least one neighbor outside the region)
- Border nodes forward the packet using the right-hand rule to neighbors in the planar graph and, as a consequence, the packet travels around the face until it enters the region again
- The first node inside the region to receive the perimeter packet floods this packet to its neighbors if it has not seen this packet before



6 QoS-Based Routing Protocols

- Explicitly address one or more QoS routing metrics
- The goal of these protocols is to find feasible paths between sender and destination, while satisfying one or more QoS metrics
  - Latency
  - Energy
  - Bandwidth
  - Reliability
  - Optimizing the use of the scarce network resources.

6.1 *Sequential Assignment Routing (SAR)*

- *Multipath* routing approach
- Multiple trees, each rooted at a 1-hop neighbor of the sink
- These trees grow outward from the sink, while avoiding nodes with low QoS (e.g., high delay).
- SAR selects a route for a packet based on the QoS metric, energy and the priority level of the packet.
- The availability of multiple routes ensures fault-tolerance and quick recovery from broken paths.
- Disadvantage: establishing and maintaining the trees (i.e., routing tables) are expensive tasks, particularly in large sensor networks.

6.2 *SPEED*

- *Soft* real-time requirements – Congestion handling
- Location-based routing protocol
- Periodic beacons: delay estimation, Backpressure
- A node maintains: table with node ID, position, expiration time and two delays called ReceiveFromDelay and SendToDelay
  - SendToDelay: delay received from the beacon message
  - ReceiveFromDelay: estimated by measuring the delay experienced by a packet in the MAC layer of the sender plus a propagation delay
- Stateless Nondeterministic Geographic Forwarding (SGNF)

Stateless Nondeterministic Geographic Forwarding

Forwarding Candidates (FS): node in range and are closer to the destination

1. If there is no node inside the FS, packets are dropped and a backpressure beacon is issued to upstream nodes to prevent further drops
2. FS - two groups: nodes that have relay speeds larger than a certain desired speed S and the others that have not.
3. The forwarding candidate is chosen from the first group, and the neighbor node with highest relay speed has a higher probability to be chosen as the forwarding node.
4. If there are no nodes belonging to the first group, a relay ratio is calculated. Whether a packet drop will really happen depends on whether a randomly generated number between (0,1) is bigger than the relay ratio

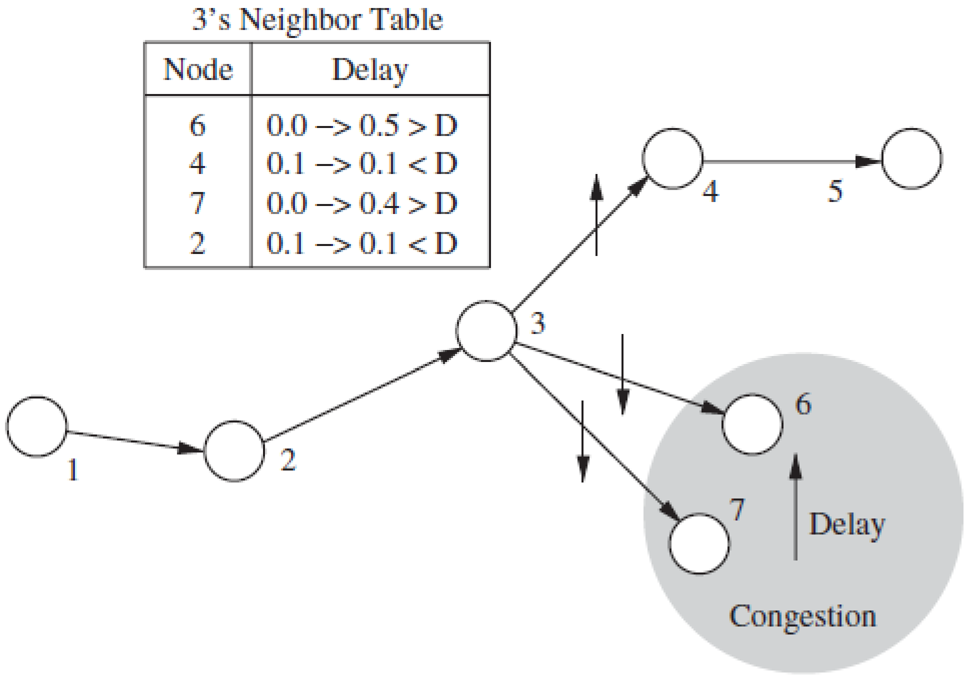
Backpressure

1. Preventing voids that occur when a node fails to find a next hop node
2. Reducing congestion using a feedback approach

All forwarding nodes of 3 are congested

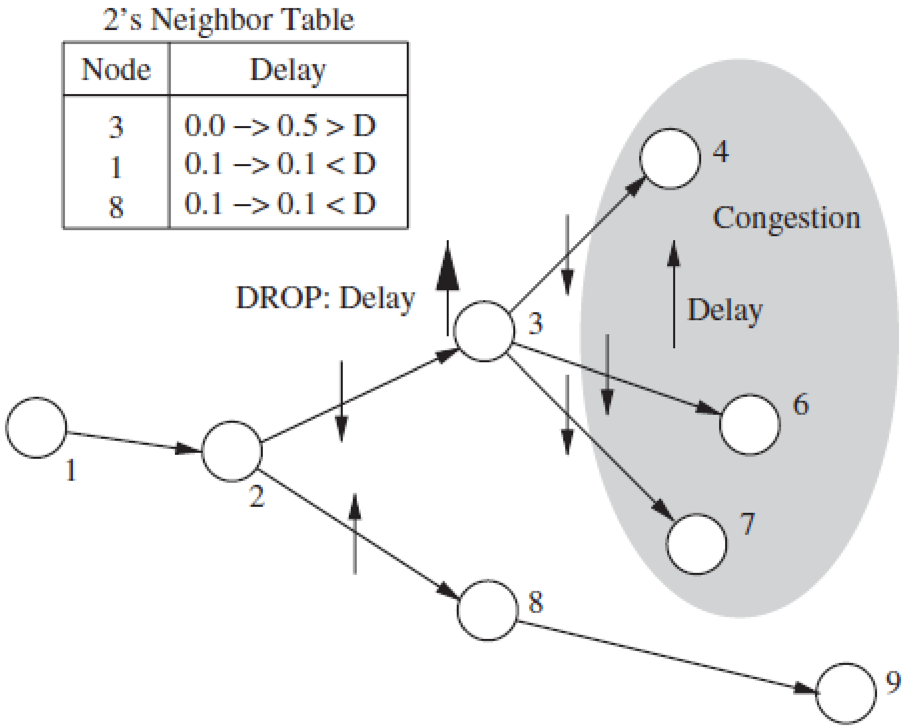
3's Neighbor Table

Node	Delay
6	0.0 –> 0.5 > D
4	0.1 –> 0.1 < D
7	0.0 –> 0.4 > D
2	0.1 –> 0.1 < D



2's Neighbor Table

Node	Delay
3	0.0 –> 0.5 > D
1	0.1 –> 0.1 < D
8	0.1 –> 0.1 < D

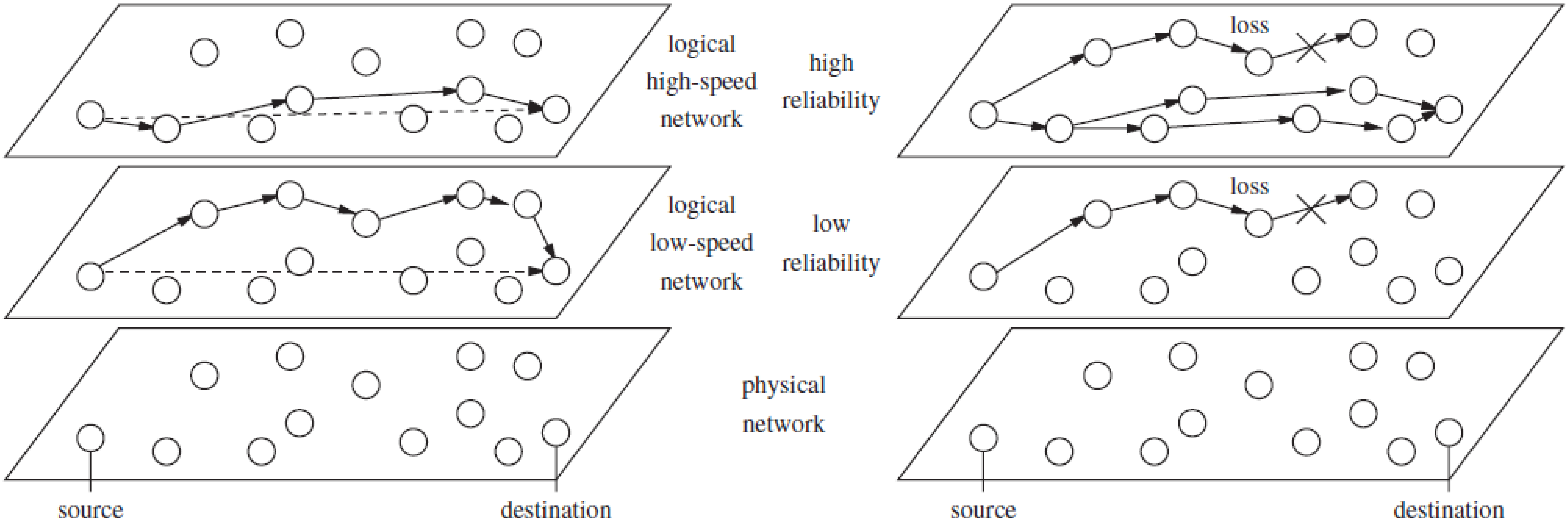


Beacon message informs node 3 of the delay in 7 and 6

Node 3 may drop a certain number of packets
The average delay of 3 will increase, which will be detected by 3's upstream nodes

6.3 *Multipath Multi-SPEED* (MMSPEED)

- Offers packets multiple delivery speed options and levels of reliability that are guaranteed throughout the network
- Virtual overlay of multiple SPEED layers on top of a single physical layer
- Each layer *L* is associated with a SetSpeed_L (lowerbound speed)
- Slow packets can be *boosted* by using a higher layer at a subsequent node.
- Measures the elapsed time at each node and piggybacks this information onto a packet such that subsequent nodes can determine the remaining time to the deadline.


logical
high-speed
network
logical
low-speed
network
physical
network
source
destination
high
reliability
low
reliability
loss
loss
source
destination

References

- Waltenegus Dargie and Christian Poellabauer. 2010. *Fundamentals of Wireless Sensor Networks: Theory and Practice*. Wiley Publishing.
- Yick, Jennifer, Biswanath Mukherjee, and Dipak Ghosal. "Wireless sensor network survey." *Computer networks* 52.12 (2008): 2292-2330.