BASIC ARCHITECTURAL FRAMEWORK

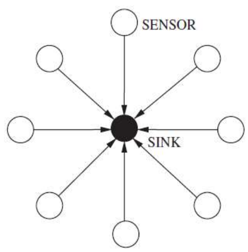
NETWORK LAYER

OUTLINES

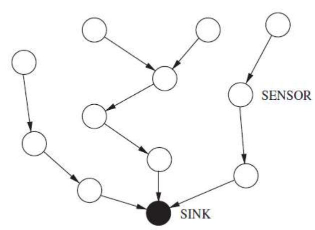
- Routing basics
- Data-centric routing
- Proactive routing
- On-demand routing
- Hierarchical routing
- Location-based routing
- QoS-based routing

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

- The key responsibility of the network layer is to find paths from data sources to sink nodes (e.g., gateways).
- In the *single-hop routing model*, all sensor nodes are able to communicate directly with the sink device.
- This *direct communication model* is the simplest approach, where all data travels a single hop to reach the destination.
- However, in practical settings, this single-hop approach is *unrealistic* and a *multi-hop communication model* must be used. In this case, the critical task of the network layer of all sensor nodes is to identify a path from the sensor to the sink across multiple other sensor nodes acting as *Relays.*



Single-hop routing model



multi-hop routing model (right)

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

- Data collected by sensor nodes in a Wireless Sensor Network (WSN) is typically propagated toward a base station (gateway) that links the WSN with other networks where the data can be visualized, analyzed, and acted upon.
- In large networks sensor nodes generate own information and serve as relays or forwarding nodes for other sensor nodes.

"Routing is the process of selecting or establishing the path through which message will be relayed to its destination. It is a responsibility of the network layer of the communication protocol stack."

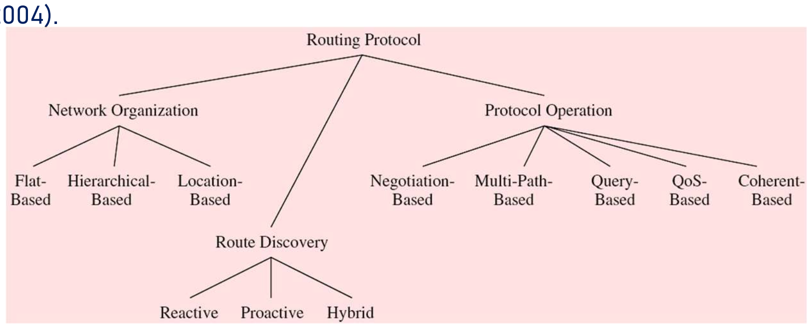
- Routing protocol is responsible for finding and maintaining path from sensor to sink.
- When the nodes of a WSN are deployed in a *deterministic manner*, communication between them and the gateway can occur using *predetermined routes*.
- By contrast when the nodes are deployed in a *randomized manner*, the resulting *topologies are non-uniform and unpredictable*.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

- Current problems at the network layer can be classified into three categories:
  - Topology control,
  - Routing, and
  - Coordination.
- A *well-organized network topology* can not only prolong the lifetime of a network, but also enhance data communications.
- *Quality of Service (QoS) routing* as well as multicast, broadcast, and geocast, the primary goal is to fulfill a given communication task successfully between nodes in the network.
- Wireless sensor actuator networks require *coordination* not only among sensors or actuators, but also between them.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

- In WSN the design of a *routing protocol is challenging* due to the unique characteristics of the network as *resource scarcity and unreliability of the wireless medium.*
- The limited processing, storage, bandwidth, and energy capacities require routing solutions that are lightweight, while the frequent dynamic changes in a WSN require routing solutions that are adaptive and flexible.
- There are various ways to classify routing protocols. Figure presents three different classifications based on the network structure or organization, the route discovery process, and the protocol operation (Al-Karaki and Kamal 2004).



NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Network organization

Flat Topology

- Flat topology treats all nodes equally.
- Flat topology is mainly for homogeneous networks where all nodes are of same characteristics and have same functionality.
- Each router node routinely collects and distributes routing information with its neighboring routers. The entire participating node addressed by flat routing protocol performs an equal role in the overall routing mechanism.
- Examples are:
  - Gradient based routing (GBR),
  - Cougar,
  - Constrained anisotropic diffusion routing (CADR),
  - Rumor routing (RR)
- Advantages
  - Minimal overhead to maintain the infrastructure
  - Potential for the discovery of multiple routes between communicating nodes for fault tolerance

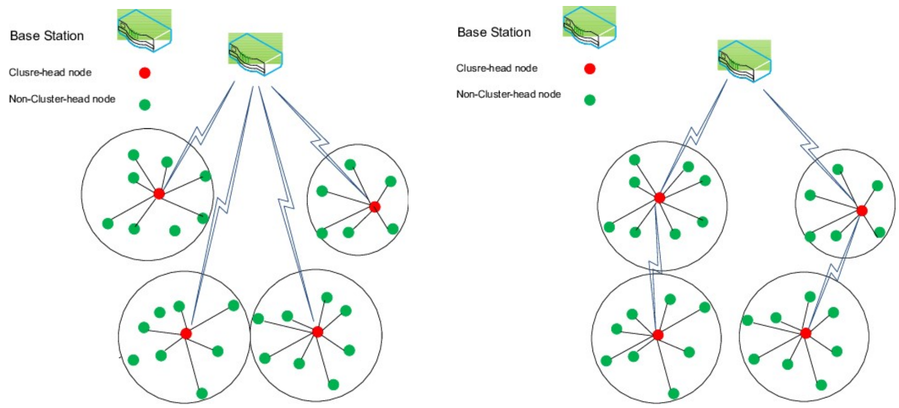
NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Network organization

Hierarchical

- Achieve energy efficiency, stability, and scalability.
- Different "roles" for different nodes (e.g., cluster heads versus cluster members).
- Mostly heterogeneous networks apply hierarchical routing protocols where some nodes are more advance and powerful than the other nodes.
- A node with higher residual energy will cluster head.
- The cluster head is responsible for coordinating activities within the cluster and forwarding information between clusters .
- The clustering scheme is more energy efficient and more easily manageable.
- Examples are:
  - Threshold sensitive energy efficient sensor network (TEEN)
  - Adaptive threshold sensitive energy efficient sensor network (APTEEN)
  - Low energy adaptive clustering hierarchy (LEACH)
  - The power-efficient gathering in sensor information systems (PEGASIS)
  - Virtual grid architecture routing (VGA)
  - Self-organizing protocol (SOP)
  - Geographic adaptive fidelity (GAF)

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES



NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Network organization

Location-based:

- In location based routing the nodes have capability to locate their present location using various localization protocols.
- Location information helps in improving the routing procedure and also enables sensor networks to provide some extra services.
- Location- based routing is useful
  - In applications where the position of the node within the geographical coverage of the network is relevant to the query issued by the source node.
- Query may specify a specific
  - Area where a phenomenon of interest may occur or
  - The vicinity to a specific point in the network environment.
- Examples are:
  - SPEED
  - Geographical and energy aware routing (GEAR)
  - SPAN

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Route Discovery Protocols

Reactive (on-demand):

- Find route only when needed.
- In Reactive Protocol if there are sudden changes in the sensed attribute beyond some pre-determined threshold value, the nodes immediately react. This type of protocol is used in time critical applications.
- Establish routes to a limited set of destinations on demand.
- Do not maintain global information across all nodes of the network.
- Rely on a dynamic route search to establish paths between a source and a destination.
- Typically involves flooding a route discovery query, with the replies traveling back along the reverse path.
- Strategies vary in the way
  - Control the flooding process to reduce communication overhead
  - The way routes are computed and reestablished when failure occurs.
- **Example:** The Threshold sensitive Energy Efficient sensor Network(TEEN) is an example of a reactive protocol.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Route Discovery Protocols

Proactive (Table-driven):

- Establish routes before they are needed.
- In a Proactive Protocol the nodes switch on their sensors and transmitters, sense the environment and transmit the data to a BS through the predefined route.
- Example: The Low Energy Adaptive Clustering hierarchy protocol (LEACH) utilizes this type of protocol.
- Also referred as table driven.
- Periodic dissemination of routing information.
- Maintain consistent and accurate routing tables across all nodes of the network. .
- The structure of the network can be either
  - Flat proactive routing – strategies needs to compute optimal paths – The overhead required to compute these paths in a dynamically changing environment
  - Hierarchical routing – Better suited to meet the routing demands of large ad hoc networks.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Route Discovery Protocols

Hybrid

- Protocols with reactive and proactive characteristics.
- They first compute all routes and then improve the routes at the time of routing. Example: Adaptive Periodic TEEN(APTEEN) is an example of Hybrid Protocols.
- To achieve stability and scalability in large networks.
- Network is organized into mutually adjacent clusters maintained dynamically as nodes join and leave their assigned clusters.
- A hybrid routing strategy can be adopted whereby – Proactive routing is used within a cluster – Reactive routing is used across clusters.
- The main challenge is to reduce the overhead required to maintain the clusters.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Protocol Operation

Multipath routing protocols

- Multi-path routing protocols provide multiple paths for data to reach the destination providing load balancing, low delay and improved network performance as a result.
- The multiple routing protocol also provide alternate path in case of failure of any path.
- Dense networks more interested in multiple path networks.
- To keep the paths alive some sort of periodic messages have to a send after some specific intervals hence multiple path routing is not more energy efficient.
- Multipath routing protocols are:
  - Multi path and Multi SPEED (MMSPEED)
  - Sensor protocols for information via negotiation (SPIN)

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Protocol Operation

Query based routing protocol

- These type of routing protocols are mostly receiver-initiated.
- The sensor nodes will only send data in response to queries generated by the destination node.
- The destination node sends query of interest for receiving some information through the network and the target node sense the information and send back to the node that has initiated the request.
- **The examples are**
  - Sensor protocols for information via negotiation (SPIN)
  - Directed diffusion (DD)
  - COUGAR

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Protocol Operation

Negotiation based routing protocols

- In these types of protocols, to keep the redundant data transmission level at minimum, the sensor nodes negotiate with the other nodes a and share their information with the neighboring nodes about the resources available and data transmission decisions are made after the negotiation process.
- Examples are:
  - Sensor protocols for information via negotiation (SPAN)
  - Sequential assignment routing (SAR)
  - Directed diffusion (DD)

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Protocol Operation

QoS based routing protocols

- To get good Quality of Service these protocols are used.
- QoS aware protocols try to discover path from source to sink that satisfies the level of metrics related to good QoS like throughput, data delivery, energy and delay.
- But also making the optimum use of the network resources.
- Examples are:
  - Sequential assignment routing (SAR)
  - SPEED
  - Multi path and Multi SPEED (MMSPEED)

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Protocol Operation

Coherent data processing routing protocol

- The nodes perform minimum processing (time stamping, data compression etc.) on the data before transmitting it towards the other sensor nodes or aggregators.
- Aggregator performs aggregation of data from different nodes and then passes to the sink node.
- Examples are:
  - Directed diffusion (DD)

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Routing Metrices

Wireless sensor networks and their applications vary widely in their constraints and characteristics, which must be taken into consideration in the design of a routing protocol.

- Node deployment
- Energy consumption without losing accuracy
- Data reporting method
- Node/link heterogeneity
- Scalability
- Data aggregation
- Quality of service

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Routing Metrices

Routing metrics are used to express a variety of objectives of a routing protocol with respect to the consumption of these resources or the performance an application perceives.

- Minimum hop (shortest hop)
  - The routing protocol attempts to find the path from the sender to the destination that requires the smallest number of relay nodes (hops).
- Energy
  - minimum energy consumed per packet
  - maximum time to network partition
  - minimize variance in node power levels
  - maximum (average) energy capacity
  - maximum minimum energy capacity
- Quality-of-Service
  - latency (delay), throughput, jitter, packet loss, error rate
- Robustness
  - link quality, link stability

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Data Centric Routing

- Data centric routing is used to control the redundancy of data.
- This is because the sensors nodes don not have global identification number which specifies them uniquely; hence data is transmitted to each node with significant redundancy.
- In data centric routing, the sink requests for data by sending the query, so that the nearest sensor node transmits the data selected and that is understood in the query.
- The property of data is specified by attribute based naming.
- The protocols used in data centric routing include:
  - Flooding and Gossiping,
  - Sensor Protocols for Information via Negotiation (SPIN),
  - Directed Diffusion,
  - Energy-aware routing, Rumor routing,
  - Constrained Anisotropic Diffusion Routing (CADR),
  - COUGAR,
  - ACtiveQUery forwarding In sensoRnEtworks (ACQUIRE)

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Traditional Routing Techniques

Flooding

- Every sensor node (re-)broadcasts sensor data to all of its neighbors.
- Simple and reliable technique.
- Incurs large traffic overhead (maximum-hop counts and sequence numbers can be used to limit broadcasts and eliminate duplicates).
- Flooding Uses a reactive approach whereby each node on receiving a data or control packet sends the packet to all its neighbors.
- After transmission, a packet follows all possible paths.
- Unless the network is disconnected, the packet will eventually reach its destination
- If network topology changes, the packet transmitted follows the new routes.
- Disadvantages :
  - Flooding cause packets to be replicated indefinitely by network nodes.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Traditional Routing Techniques

Flooding Problem

- Packet circulates indefinitely in the network.
  - *Solution – Hop Count Field*
    - Field is included in the packet with value set to approximately the diameter of the network.
    - As the packet travels across the network, the hop count is decremented by one.
    - When the hop count reaches zero, the packet is simply discarded.
  - *Other Solution – Using a time-to-live field*
    - To records the number of time units that a packet is allowed to live within the network
    - At the expiration of this time, the packet is no longer forwarded.
  - *Drop all the packets that it has already forwarded*
    - Requires maintaining at least a recent history of the traffic, to keep track of which data packets have already been forwarded.

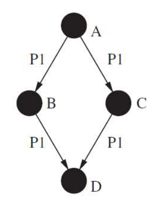
NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Traditional Routing Techniques

Drawbacks of Flooding

Traffic Implosion Effect is caused by duplicate control or data packets being sent repeatedly to the same node.

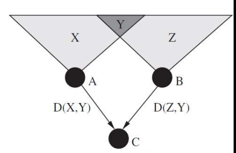
Node A broadcasts packet P1 to both of its neighbors, B and C. B forwards this packet to its own neighbor D and, finally, C also forwards this packet to node D. Even if D discards the duplicate packet, energy has been wasted on the transmission of the packet from C to D.



implosion problem

Overlapping Problem occurs when two nodes covering the same region send packets containing similar information to the same node

Here, sensors A and B share the region marked as Y. Therefore, these sensors gather overlapping data and both forward their collected information to their neighbor C.



overlap problem

Resource Blindness The forwarding rule used to route packets does not take into consideration the energy constraints of the sensor nodes.

Node's energy may deplete rapidly, reducing considerably the lifetime of the network.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Traditional Routing Techniques

Gossiping

- A variation of flooding is gossiping (Hedetniemi *et al.* 1988), where a node does not necessarily broadcast data.
- Instead, it uses a probabilistic approach, where it decides to forward the data to its own neighbors with a probability p and to discard the data with a probability derivative approach referred to as gossiping.
- Each node sends the incoming packet to a randomly selected neighbor.
- The neighbor selected randomly chooses one of its own neighbors and forwards the packet to the neighbor chosen.
- The process continues iteratively
  - Until the packet reaches its intended destination OR
  - The maximum hop count is exceeded

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Traditional Routing Techniques

Gossiping

- *Advantages*
  - Gossiping avoids the implosion problem by limiting the number of packets that each node sends to its neighbor to one copy.
- *Disadvantages*
  - The latency that a packet suffers on its way to the destination may be excessive, particularly in a large network.
  - Caused primarily by the random nature of the protocol, which, in essence, explores one path at a time.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Sensor Protocols for Information via Negotiation (SPIN)

- Example of data-centric routing
- Objective – To efficiently disseminate observations gathered by individual sensor nodes to all the sensor nodes in the network
- Uses negotiations to address all problems of flooding
  - Implosion: nodes negotiate before data transmission
  - Overlap: nodes negotiate before data transmission
  - Resource blindness: resource manager keeps track of actual resource consumption and adapts routing and communication behavior
- SPIN uses meta-data to succinctly and completely describe sensor data
- Requirements:
  - if *x* describes the meta-data for some sensor data *X*, the size of *x* (in bytes) must be less than the size of *X*.
  - if two pieces of sensor data differ, their meta-data representations should differ too.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Sensor Protocols for Information via Negotiation (SPIN)

- The basic of protocols are
  - Data negotiation
  - Resource adaptation
- Nodes running SPIN "learn" about the content of the data before any data are transmitted between network nodes.
- Nodes associate metadata with data they produce to perform negotiations before transmitting the actual data (eliminates the possibility of overlap).
- A receiver that expresses interest in the data content can send a request to obtain the data advertised.
- It assures
  - Data are sent only to interested nodes
  - Eliminating traffic implosion
  - Reducing significantly the transmission of redundant data throughout the network

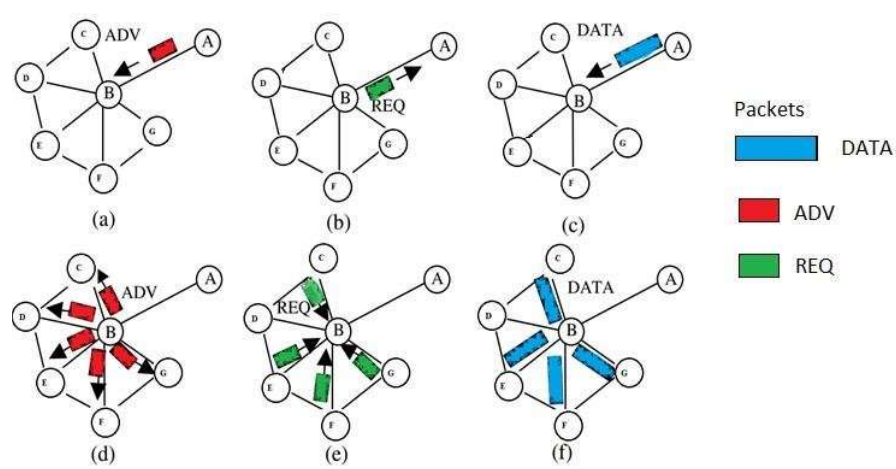
NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Sensor Protocols for Information via Negotiation (SPIN)

- To carry out negotiation and data transmission, nodes running SPIN use three types of messages:
  - ADV (advertisement), REQ (request), DATA
- *ADV (Advertisement)*
  - Used to advertise new data among nodes
  - A network node that has data to share can advertise its data
  - Transmitting an ADV message containing the metadata describing the data.
- *REQ:*
  - Used to request an advertised data of interest
  - Upon receiving an ADV containing metadata a network node interested in receiving specific data sends a REQ message to the metadata advertising node
- *DATA:*
  - Contains the actual data collected by a sensor, along with a metadata header
  - Message is typically larger than the ADV and REQ messages.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Sensor Protocols for Information via Negotiation (SPIN)



NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Sensor Protocols for Information via Negotiation (SPIN)

SPIN Protocols

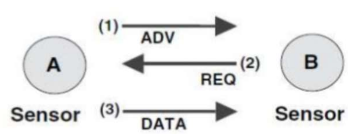
- SPIN-PP (SPIN Point-to-Point)
  - a 3-stage handshake protocol for Point-to-Point media.
- SPIN-EC (SPIN Energy Conservation)
  - SPIN-PP with a low-energy threshold for Energy Conservation.
- SPIN-BC (SPIN Broadcast)
  - 3-stage handshake protocol for Broadcast media.
- SPIN-RL (SPIN Reliability)
  - SPIN-BC for lossy networks.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Sensor Protocols for Information via Negotiation (SPIN)

SPIN-PP (SPIN Point-to-Point)

- The simplest version of SPIN referred to as point –to- point comm. network.
- The three-step handshake protocol used by SPIN-PP
  1. The node holding the data, node A, issues an advertisement packet (ADV)
  2. Node B expresses interest in receiving the data by issuing a data request (REQ)
  3. Node A responds to the request and sends a data packet to node B (DATA)

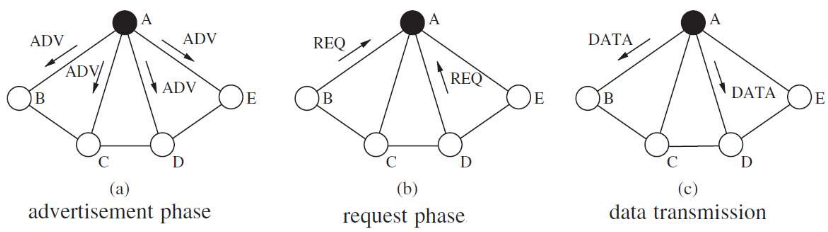


- SPIN-PP uses negotiation to overcome the implosion and overlap.
- The protocol also achieves high data dissemination rates.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Sensor Protocols for Information via Negotiation (SPIN)
SPIN-PP (SPIN Point-to-Point)

- Flooding occurs using a 3-way handshake:
  - Node A advertises newly available data using ADV (advertisement) message (containing data's meta-data)
  - Neighbor nodes (B, C, D, E) check if advertised data needed and if so, respond with REQ (request for data) message
  - A sends DATA message to nodes that responded (i.e., B and D)



NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Sensor Protocols for Information via Negotiation (SPIN)
SPIN EC(SPIN Energy Conservation)

- SPIN-EC designed for point-to-point communication.
- Adds simple heuristic to protocol to add energy conservation.
- As long as energy sufficient, node participates in 3-way handshake.
- Incorporates a threshold based resource-awareness mechanism to complete data negotiation.
- Nodes does not participate if it believes that this will reduce its energy below a certain low-energy threshold.
- If a node receives an advertisement, it does not send out an REQ message if its energy resource is not high enough to transmit an REQ message and to receive data.
- Node initiates handshake only if it has sufficient energy to send DATA to all neighbors.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

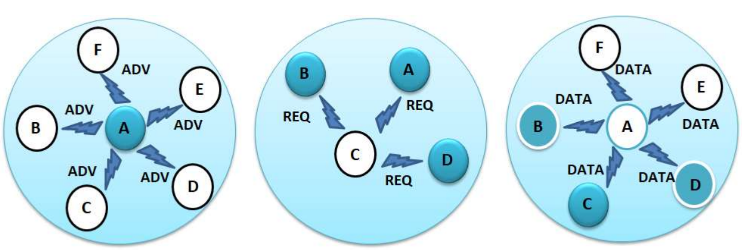
Sensor Protocols for Information via Negotiation (SPIN)
SPIN BC (SPIN Broadcast)

- Designed for broadcast networks.
- The packet transmitted by a node is received by all the other nodes within a certain range of the sending node.
- Node which has received an ADV message does not respond immediately with an REQ message.
- Node waits for a certain amount of time and Monitors the communications channel.
- If the node hears an REQ message issued by another node which is interested in receiving the data, it cancels its own request(eliminating any redundant requests for the same message).
- The advertising node sends the data message only once, even when it receives multiple requests for the same message.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Sensor Protocols for Information via Negotiation (SPIN)
SPIN BC (SPIN Broadcast)

- SPIN-BC protocol basic operations
  - A sends a ADV packet to advertise the data to its neighbors
  - All nodes hear the advertisement, but node C is first to issue a REQ packet (E & F not interested)
  - Nodes B and D hear the broadcast request and refrain from issuing their own REQ packets
  - Upon hearing node C's request, node A replies by sending the data packet.
  - All nodes within the transmission range of A receive the data packet, including nodes E and.



NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Sensor Protocols for Information via Negotiation (SPIN)
SPIN-RL (SPIN Reliability)

- Extends the capabilities of SPIN-BC to enhance
  - Reliability
  - Overcome message transmission errors by a lossy channel.
- Reliability is achieved by periodic broadcasting of ADV and REQ messages.
- Each node in SPIN-BC keeps track of the advertisements it hears and the nodes where these advertisements originate.
- If a node requesting specific data of interest does not receive the data requested within a certain period of time, it sends the request again.
- Improved reliability by re-advertising metadata periodically.
- SPIN-RL nodes limit the frequency of resend the data messages.
- After sending out a data message, a node waits for a certain time period before it responds to other requests for the same data message.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Sensor Protocols for Information via Negotiation (SPIN)
SPIN-RL (SPIN Reliability)

- The SPIN-RL protocol incorporates two adjustments to SPIN-BC to achieve reliability.

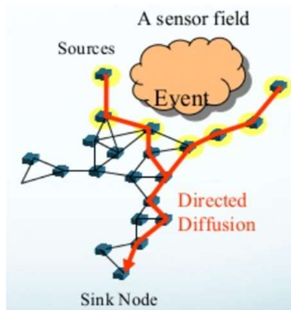
  1. First, each SPIN-RL node keeps track of which advertisements it hears from which nodes, and if it does not receive the data within a reasonable period of time following a request, the node re-requests the data. It fills out the originating-advertiser field in the header of the REQ message with a destination, randomly picked from the list of neighbors that had advertised that specific piece of data.

  2. Second, SPINRL nodes limit the frequency with which they will resend data. If a SPIN-RL node sends out a DATA message corresponding to a specific piece of data, it will wait a predetermined amount of time before responding to any more requests for that piece of data.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Directed Diffusion (DD)

- The Problem
  - Where should the data be stored?
  - How should queries be routed to the stored data?
  - How should queries for sensor networks be expressed?
  - Where and how should aggregation be performed?



NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Directed Diffusion (DD)

- Directed diffusion is data-centric.
- Useful where the sensor nodes themselves generate requests/queries for data.
- Data generated by sensor nodes is named by attribute-value pairs.
- A sink node requests data by sending interests for named data.
- Data matching the interest is then "drawn" down toward that node.
- Intermediate nodes can cache, or transform data and may direct interests based on previously cached data Section.
- The human operator's query would be transformed into an interest that is diffused (e.g., broadcasted, geographically routed) toward nodes in regions X or Y.
- When a node in that region receives an interest, it activates its sensors which begin collecting information about pedestrians.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

- When the sensors report the presence of pedestrians, this information returns along the reverse path of interest propagation.
- Intermediate nodes might aggregate the data, e.g., more accurately pinpoint the pedestrian's location by combining reports from several sensors.
- An important feature of directed diffusion is that interest and data propagation and aggregation are determined by localized interactions (message exchanges between neighbors or nodes within some vicinity).

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

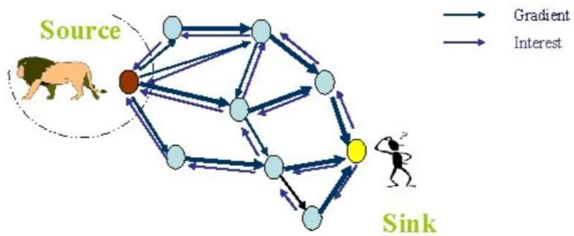
Interest and Event Naming

- Sensor nodes are monitoring animals
- Users are interested in receiving data for all 4-legged creatures seen in a rectangle
- Users specify the data rate
- **Query/interest:**
  - Type=four-legged
  - animal Interval=20 ms (event data rate)
  - Duration=10 seconds (time to cache)
  - Rect=[-100, 200, 400]
- **Reply:**
  - Type=four-legged
  - animal Instance = elephant
  - Location = [125, 220]
  - Intensity = 0. 6
  - Confidence = 0. 85
  - Timestamp = 01: 20: 40
- Attribute-Value pairs, no advanced naming scheme

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Directed Diffusion (DD)

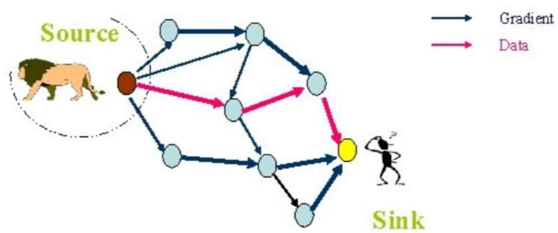
- Directed diffusion consists of several elements: interests, data messages, gradients, and reinforcements.
  - An interest message is a query or an interrogation which specifies what a user wants. Each interest contains a description of a sensing task that is supported by a sensor network for acquiring data.
  - Interest Propagation
    - Flood interest
    - Constrained or Directional flooding based on location is possible
    - Directional propagation based on previously cached data Gradient Source Interest Sink



NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Directed Diffusion (DD)

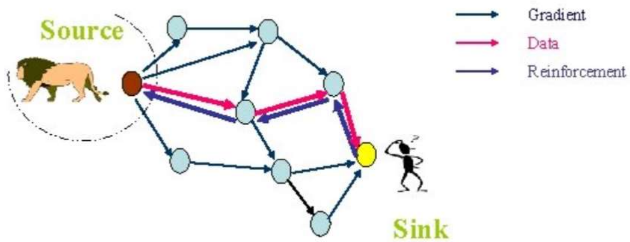
- Typically, data in sensor networks is the collected or processed information of a physical phenomenon. Such data can be an event, which is a short description of the sensed phenomenon.
  - In directed diffusion, data is named using attribute-value pairs.
  - A sensing task (or a subtask thereof) is disseminated throughout the sensor network as an interest for named data.
- This dissemination sets up gradients within the network designed to "draw" events (i.e., data matching the interest).
  - Specifically, a gradient is direction state created in each node that receives an interest. The gradient direction is set toward the neighboring node from which the interest is received.

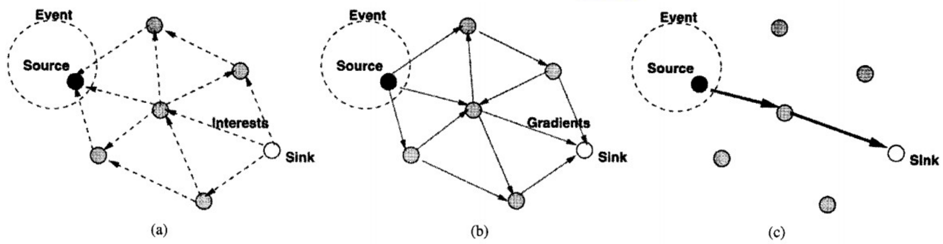


NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Directed Diffusion (DD)

- Events start flowing toward the originators of interests along multiple gradient paths. The sensor network reinforces one or a small number of these paths.





Simplified schematic for directed diffusion. (a) Interest propagation. (b) Initial gradients setup. (c) Data delivery along reinforced path.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Rumor Routing

- Rumor routing is a kind of directed diffusion and is used for applications where geographic routing is not feasible.
- While the classic flooding approach can be described as *event flooding* (i.e., a source propagates its sensor data via an event throughout the network), *query flooding* describes the process used to propagate queries to all nodes in the network when no localization information is available to steer the query toward the appropriate sensors.
- It combines query flooding and event flooding protocols in a random way. It has the following assumptions:
  - The network is composed of densely distributed nodes.
  - Only bi-directional links exits.
  - Only short distance transmissions are allowed.
  - It has fixed infrastructure.
- In case of directed diffusion flooding is used to inject the query to the entire network.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Rumor Routing

- Sometimes the requested data from the nodes are very small and thus the flooding is unnecessary, so we can use another approach which is to flood the events when the number of events is small and the number of queries is large. The queries are rooted to that particular nodes that are belongs to the interested region.
- In order to flood events through the network, the rumor routing algorithm employs long-lived packets, called agents.
- When a node detects an event, it adds such event to its local table (events table), and generates an agent.
- Agents travel the network on a random path with related event information. Then the visited nodes form a gradient towards the event.
- When a node needs to initiate a query, it routes the query to the initial source.
- If it gets some nodes lying on the gradient before its TTL expires, it will be routed to the event, else the node may need to retransmit, give up or flood the query.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

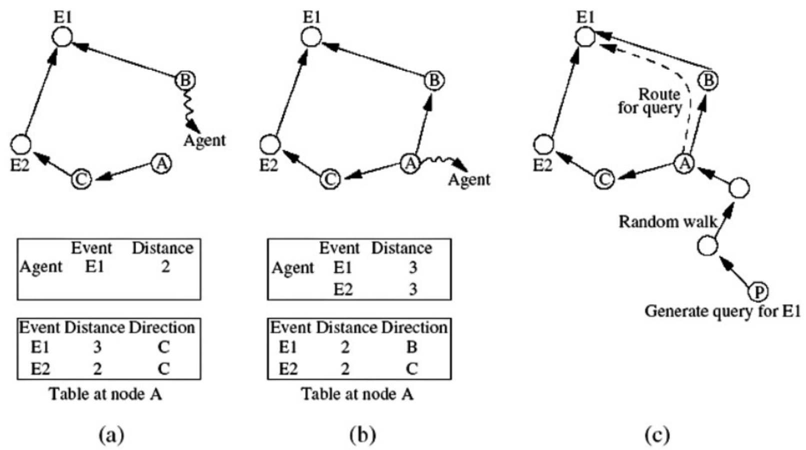
Rumor Routing

- Rumor routing is an agent-based path creation algorithm. Agents, or “ants,” are long-lived entities created at random by nodes. These are basically packets which are circulated in the network to establish shortest paths to events that they encounter. They can also perform path optimizations at nodes that they visit.
- When an agent finds a node whose path to an event is longer than its own, it updates the node’s routing table. Figure illustrates the working of the rumor routing algorithm.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Rumor Routing

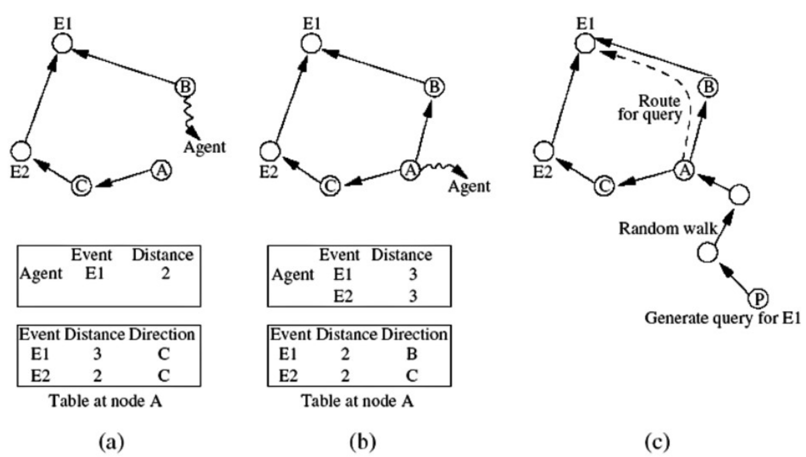
- In Figure 12.4 (a), the agent has initially recorded a path of distance 2 to event E1. Node A 's table shows that it is at a distance 3 from event E1 and a distance 2 from E2. When the agent visits node A , it updates its own path state information to include the path to event E2.



NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Rumor Routing

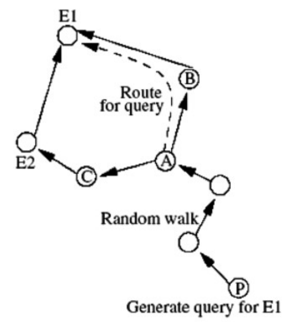
- The updating is with one hop greater distance than what it found in A, to account for the hop between any neighbor of A that the agent will visit next, and A. It also optimizes the path to E1 recorded at node A to the shorter path through node B . The updated status of the agent and node table is shown in Figure 12.4 (b).



NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Rumor Routing

- When a query is generated at a sink, it is sent on a random walk with the hope that it will find a path (pre-established by an agent) leading to the required event.
- This is based on the high probability of two straight lines intersecting on a planar graph, assuming the network topology is like a planar graph, and the paths established can be approximated by straight lines owing to high density of the nodes. If a query does not find an event path, the sink times out and uses flooding as a last resort to propagate the query.
- For instance, as in Figure 12.4 (c), suppose a query for event E1 is generated by node P . Through a random walk, it reaches A , where it finds the previously established path to E1. Hence, the query is directed to E1 through node B , as indicated by A 's table.



(c)

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

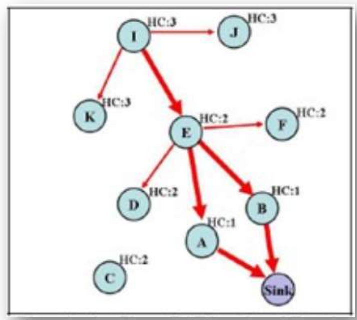
Rumor Routing

- Unlike directed diffusion, where data can be routed through multiple paths at low rates, Rumor routing only maintains one path between source and destination.
- Rumor routing performs well only when the number of events is small.
- For a large number of events, the cost of maintaining agents and event-tables in each node becomes infeasible if there is not enough interest in these events from the BS.
- Moreover, the overhead associated with rumor routing is controlled by different parameters used in the algorithm such as time-to-live (TTL) pertaining to queries and agents.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Gradient Based Routing

- Another variant of directed diffusion.
- Gradient is determined on the basis of the number of hops to the sink
  - A sink floods interest message
  - Each interest message records number of hops traveled
  - Therefore, a node can determine its distance (called height) to sink
  - Gradient is difference between a node's height and height of neighbor
  - Packet is forwarded on the link with the largest gradient



NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Gradient Based Routing

- Nodes can establish a Data Combining Entity (DCE), which is responsible for data compaction.

- Nodes can use a traffic spreading technique to balance traffic over network
  - ***Stochastic Scheme***: node selects next hop randomly when there are two or more with same gradient
  - ***Energy-based scheme***: node increases its height when its energy level is low
  - ***Stream-based scheme***: new streams are diverted away from nodes that already serve other streams (e.g., by reporting increased heights)

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Proactive Routing

- Routes are established before they are actually needed
- Also called table-driven 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.
- *Examples are:*
  - *DSDV (*Destination-Sequenced Distance Vector)
  - *OLSR (Optimized Link State Routing)*

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

DSDV (Destination-Sequenced Distance Vector)

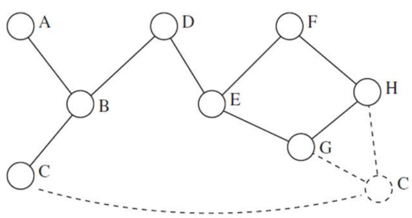
- DSDV is a modified version of class Distributed Bellman-Ford algorithm.

- Concept of Distance-Vector Algorithms:
- Node i maintains a list of distances $\{d_{ij}x\}$ for each destination x via node j.
- Node i selects k as next-hop if $d_{ik}x = min \{d_{ij}x\}$.
- Distances stored in routing table, along with sequence number for each entry (assigned by destination node)
  - purpose of sequence number is to identify stale routes
- Nodes broadcast their routing tables to their neighbors periodically and whenever significant information is available
  - Full dump packet: contains entire routing table
  - Incremental packet: contains only changed table entries
  - A receiving node updates its table if the received information has a more recent sequence number or if sequence number is identical, but new route is shorter.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

DSDV (Destination-Sequenced Distance Vector)

- Figure shows a possible network topology, indicating node locations and connectivity, including node D's routing table (first table).
- Suppose that node C moves from its current location to a new location in the vicinity of nodes H and G, which become node C's new neighbors. Update packets from D's neighbors will ultimately inform D that the route to C via B is invalid and that a new route to C via node E exists. Therefore, node D will replace C's information in its routing table to show E as the next hop neighbor and to reflect the new distance of three



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

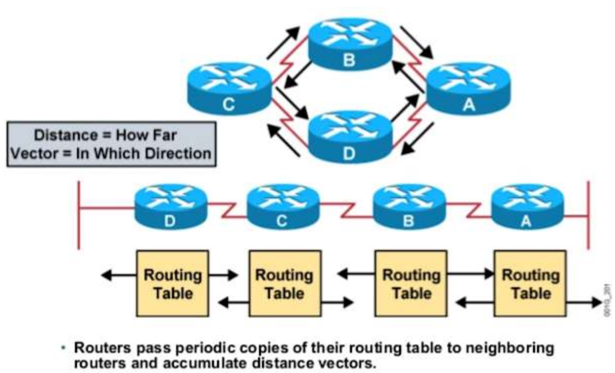
Destination	NextHop	Distance
A	B	2
B	B	1
C	E	3
D	D	0
E	E	1
F	E	2
G	E	2
H	E	3

Node D's Table After C's Move

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Distance Vector Routing

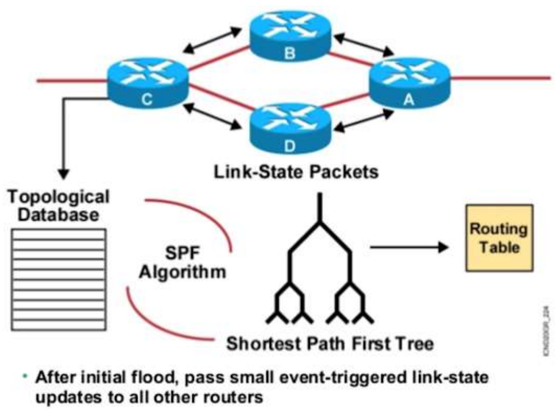
- Each node knows the distance (=cost) to its directly connected neighbors.
- A node sends periodically a list of routing updates to its neighbors.
- If all nodes update their distances, the routing tables eventually converge.
- New nodes advertise themselves to their neighbors.



NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Link State Routing

- Each node knows the distance to its neighbors.
- The distance information (=link state) is broadcast to all nodes in the network.
- Each node calculates the routing tables independently.



NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

OLSR (Optimized Link State Routing)

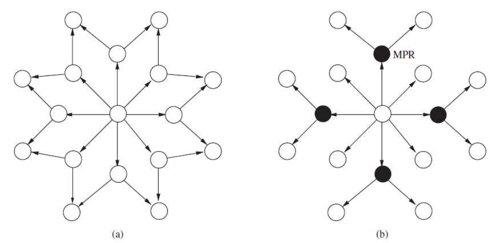
- OLSR is a protocol based on the link state algorithm.
  - Nodes periodically broadcast topological information updates to all other nodes in the network.
  - Allows nodes to obtain complete topological map and to compute paths.

- Nodes use neighbor sensing using HELLO messages:
  - Allows nodes to identify neighbors and to detect changes in neighborhood.
  - HELLO message contains node's identity (address) and list of all known neighbors.
  - If node A can receive node B's HELLO messages, but is not in node B's list of known neighbors, the link B → A is asymmetric (otherwise symmetric).
  - Instead of flooding HELLO messages to all nodes in network, OLSR uses multipoint relays (MPRs).

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

OLSR (Optimized Link State Routing)

- *Multipoint relays:*
  - A node selects a set of symmetric neighbors as MPRs (MPR selector set); each node can use different algorithm/heuristic for the selection process
    - Example: node determines its 2-hop neighbors (using HELLO messages) and selects minimum set of 1-hop neighbors to reach all 2-hop neighbors.
  - Only MPRs forward messages to other nodes.
  - HELLO messages contain addresses of MPRs, i.e., a node advertises its reachability via MPRs only instead of all neighbors.



Comparison of (a) classic flooding and (b) MPR-based OLSR.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

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
- *Examples are:*
  - AODV (Ad Hoc On-Demand Distance Vector)
  - DSR (Dynamic Source Routing)

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

AODV (Ad Hoc On-Demand Distance Vector)

- AODV relies on broadcast route discovery mechanism, which is used to dynamically establish route table entries at intermediate nodes
- Path discovery process:
  - Initiated whenever a source needs to transmit data to a sink and the source does not have an entry for the sink in its routing table.
  - Source broadcasts route request (RREQ) packet containing:
    - Addresses of source and sink
    - Hop count value
    - Broadcast ID (incremented whenever source issues a new RREQ)
    - Two sequence numbers
- Upon receiving RREQ, if a node knows a route to the destination, responds by sending a unicast route reply (RREP) message back to source
- Otherwise RREQs are re-broadcast or duplicate RREQs (identified by source address and broadcast ID) are discarded

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

AODV (Ad Hoc On-Demand Distance Vector)

- Use of sequence numbers:
  - Every node maintains own sequence numbers.
  - Source's RREQ includes its own sequence number and the most recent sequence number (if known) from the destination.
  - Intermediate nodes only reply to RREQ if the sequence number of their route to the destination is greater than or equal to the destination sequence number in the RREQ.
  - When RREQ is re-broadcast, node records the address of neighbor from which RREQ came (establishing a reverse path towards source).
  - As RREP travels towards source, intermediate nodes set up forward pointers to the node from which the RREP came and records latest destination sequence number.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

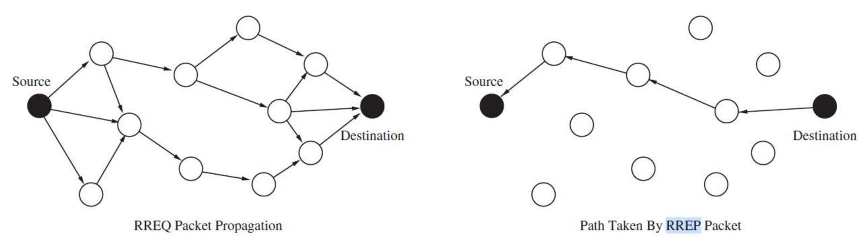
AODV (Ad Hoc On-Demand Distance Vector)

- Use of RREPs:
  - RREP contains:
    - Addresses of source and destination
    - Destination sequence number
    - Hop count
  - Intermediate node propagates RREP only if
    - This is the first copy of this RREP the node sees.
    - Or destination sequence number in RREP is greater than that of previous RREP.
    - Or destination sequence number is the same as in previous RREP, but the hop count is smaller.
  - Limits the number of RREPs in network and ensures that the RREP over the shortest route reaches the source.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

AODV (Ad Hoc On-Demand Distance Vector)

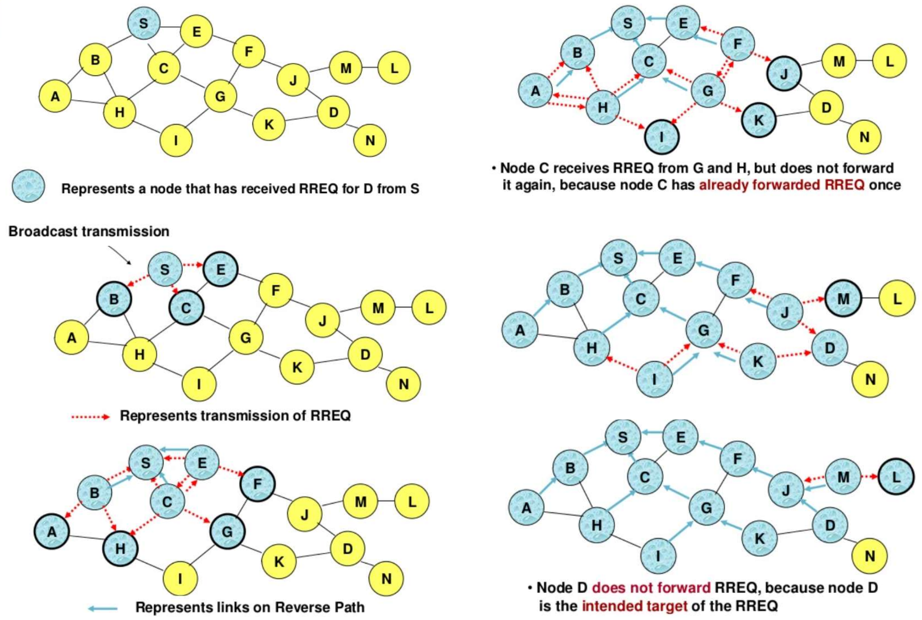
- Routes expire after certain amount of time
  - Link state monitored using HELLO messages among neighbors.
  - When a link/route breaks, the node noticing this issues a route error (RRER) packet towards the source (which can re-initiate route discovery).
- Summary:
  - Routes are established only when needed
  - No need for route table updates and exchanges for unused routes
  - Periodic HELLO messages
  - Initial transmission delay if route must be discovered first
  - RREP uses reverse path of RREQ, i.e., AODV assumes symmetric links



Path discovery process of AODV.

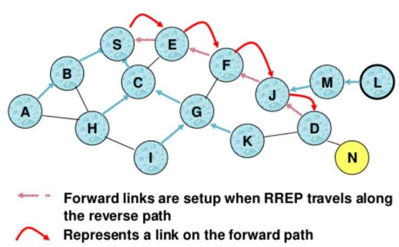
NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

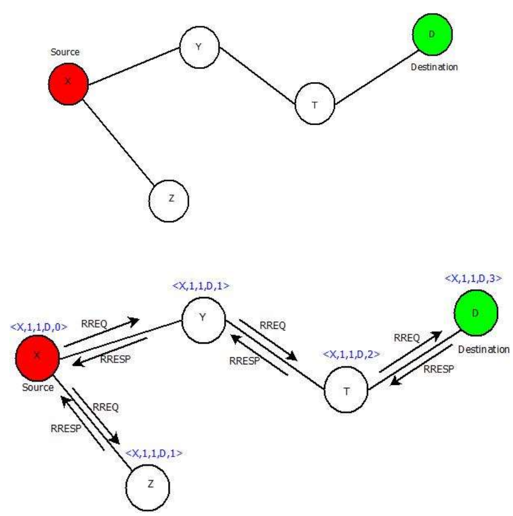
AODV (Ad Hoc On-Demand Distance Vector)



NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

AODV (Ad Hoc On-Demand Distance Vector)





NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

AODV (Ad Hoc On-Demand Distance Vector)

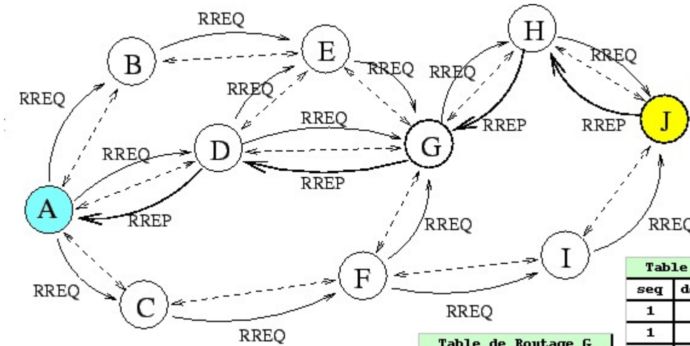


Table de Routage J			
seq	dest	next	hop
1	A	H	4
1	D	H	3
1	G	H	2
1	H	H	1

Table de Routage H			
seq	dest	next	hop
1	A	G	3
1	D	G	2
1	G	G	1
1	J	J	1

Table de Routage G			
seq	dest	next	hop
1	D	D	1
1	A	D	2
1	H	H	1
1	J	H	2

Table de Routage A			
seq	dest	next	hop
1	D	D	1
1	G	D	2
1	H	D	3
1	J	D	4

Table de Routage D			
seq	dest	next	hop
1	A	A	1
1	G	G	1
1	H	G	1
1	J	G	2

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Hierarchical Routing

Sensor nodes communicate directly only with a cluster head

- Cluster head:
  - Responsible for propagating sensor data to sink
  - Sometimes more powerful than "regular" nodes
  - Experiences more traffic than "regular" nodes

- Challenges in cluster formation:
  - Selection (election) of cluster heads
  - Selection of cluster to join
  - Adaptation of clusters in response to topology changes, failures, etc.

- Advantages:
  - Potentially fewer collisions (compared to flat routing)
  - Easier duty cycling (energy efficiency)
  - Easier routing process (though routes may be longer)
  - Easier in-network data aggregation

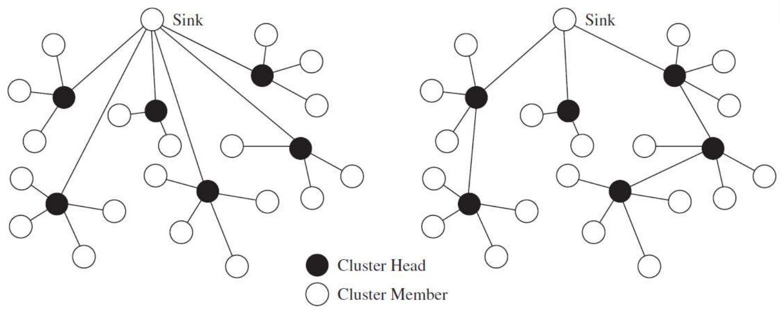
- Examples are:
  - LR, LANMAR, LEACH, PEGASIS, SAFARI etc.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Hierarchical Routing

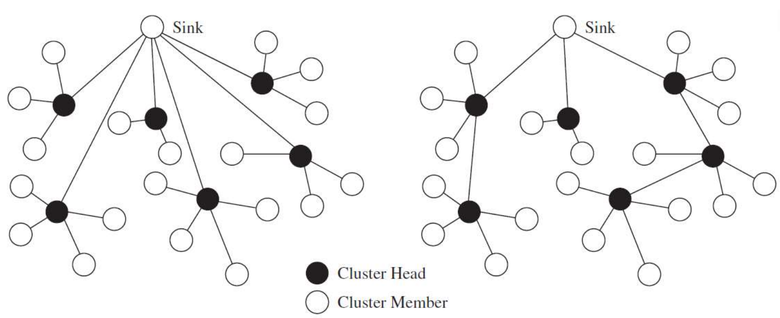
Variations of Hierarchical Routing

- When all cluster heads communicate directly with the sink node (left graph), the routing challenge is reduced to the ***cluster formation problem***.
- When cluster heads do not directly communicate with the sink (right graph), a ***cluster-based routing protocol*** must also establish multi-hop routes from all cluster heads to the sink.



Clustering with single-hop connections to the sink (left) and clustering with multi-hop connections to the sink (right).

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES
Hierarchical Routing
Variations of Hierarchical Routing
- When all cluster heads communicate directly with the sink node (left graph), the routing challenge is reduced to the ***cluster formation problem***.
- When cluster heads do not directly communicate with the sink (right graph), a ***cluster-based routing protocol*** must also establish multi-hop routes from all cluster heads to the sink.



Clustering with single-hop connections to the sink (left) and clustering with multi-hop connections to the sink (right).

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

Location-based Routing

- Also referred to as Geographic Routing
- Used when nodes are able to determine their (approximate) positions
- Nodes use location information to make routing decisions
  - Sender must know the locations of itself, the destination, and its neighbors
  - Location information can be queried or obtained from a location broker

- Types of geographic routing:
  - Unicast: single destination
  - Multicast: multiple destinations
  - Geocast: data is propagated to nodes within certain geographic area

- Examples are:
  - **Unicast:** GPSR (Greedy Perimeter Stateless Routing), Forwarding Strategy, Geographic Adaptive Fidelity,
  - **Multicast:** SPBM (Scalable Position-Based Multicast), Geographic Multicast Routing (GMR), Receiver Based Multicast (RBMulticast).
  - **Geocast:** Geographic and Energy Aware Routing (GEAR), Geographic-Forwarding-Perimeter-Geocast.

NETWORK LAYER FUNCTIONS/RESPOSIBILITIES

QoS-Based Routing Protocols

- Protocols that explicitly address one or more Quality-of-Service (QoS) metrics

- Examples of QoS metrics:
  - low (end-to-end) latency/delay
  - low jitter
  - low energy consumption
  - low bandwidth requirements
  - high reliability

- *Examples are:*
  - Sequential Assignment Routing (SAR)
  - SPEED
  - Multipath Multi-SPEED