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Networked Embedded Applications

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CS 6 : (WSN Routing)

6

WSN Routing

**Sensor Protocols for Information via Negotiation,
Sequential Assigned Routing Protocol,
Energy-Aware Routing Protocol in Cluster-Based
Sensor Networks**

**MECN,
STEM**



Flooding Protocol

- Flooding is a **common technique** frequently used for path discovery and information dissemination in wired and wireless ad hoc networks.
- Each node receiving a data or control packet sends the packet to all its neighbours.
- After transmission, a packet follows all possible paths.
- Unless the network is disconnected, the packet will eventually reach its destination.
- Furthermore, as the network topology changes, the packet transmitted follows the new routes.
- To prevent a packet from circulating indefinitely in the network, a **hop count** field is usually included in the packet.



Flooding Protocol

- Initially, the hop count is set to approximately the **diameter** of the network.
- As the packet travels across the network, the hop count is decremented by one for each hop that it traverses.
- When the hop count reaches zero, the packet is simply discarded.
- A similar effect can be achieved using a **time-to-live field**, which records the number of time units that a packet is allowed to live within the network.



Flooding Protocol

- Advantages of Flooding
 - Simplicity of forwarding rules
 - Low maintenance cost
- Disadvantages of Flooding
 - **Traffic implosion:** Duplicate packets are sent to the same node multiple time
 - **Overlapping:** Overlapping occurs when nodes of the same region sends duplicate packets to the same node
 - **Resource blindness:** The energy of a node is not taken into picture.



Gossiping Protocol

- Contrary to flooding, gossiping requires that **each node sends the incoming packet to a randomly selected neighbour.**
- Upon receiving the packet, it chooses **one of its own neighbours randomly** and forwards the packet to the neighbour chosen.
- This process continues iteratively until the packet reaches its intended destination or the maximum hop count is exceeded.
- Advantages
 - Simplicity of forwarding rules
 - Low maintenance cost
 - Avoids the implosion problem
- Disadvantages
 - Increased latency
 - The energy of a node is not taken into the picture.



Overview of Energy-Saving Routing Protocols for WSNs

- Optimization-Based Routing Protocols
 - Aim at **reducing overall energy consumption**.
 - Trying to **minimize energy consumed per message** may lead to **poor routing choices** i.e. some nodes could be unnecessarily overloaded and thus could quickly extinguish their batteries.
 - **Minimization of cost/packet ratio** involve labelling different links with different costs and choosing the best option, will lead to **delay in network partitioning**.
 - So the aim of the optimization-based protocols is to **maximize network connectivity as long as possible**.



Overview of Energy-Saving Routing Protocols for WSNs

➤ Data-Centric Routing Protocols

- Obtain low-power consumption by implementing mechanisms which reduce energy wastage.
- Energy is wasted due to **data redundancy** (if the same data is transmitted multiple times, energy consumption happens –communication mechanisms cause more energy consumption in the sensor network **compared to computing operations**).
- The cause of data redundancy is lack of global identifiers for the sensor nodes.
- One approach is to use **data negotiation** between nodes using **meta-data** (high-level data descriptors).
- Another approach is to **aggregate the data at the relaying nodes** and eliminate the duplicates (using functions such as average, minimum, maximum, etc).
- Data aggregation is called '**Data Fusion**'.



Overview of Energy-Saving Routing Protocols for WSNs

- Cluster-Based Routing Protocols
 - Nodes closer to the sink and on the optimal path perform more relaying than other nodes.
 - So they drain down energy faster than other nodes.
 - Cluster-based routing tries to address this issue.
 - In Cluster-based routing, the network is divided into certain clusters.
 - Each cluster will have a **cluster leader** or **cluster head**.
 - These cluster leaders collect data from the sensor nodes of their clusters and forward the aggregated data to the sink.



Overview of Energy-Saving Routing Protocols for WSNs

- Location-Based Routing Protocols
 - These protocols use location information for data relaying.
 - Location information can be used for energy-efficient data routing by sending the data query to a particular region of the network rather than the whole network.
- QoS-Enabled Routing Protocols
 - Routing algorithms belonging to this category take some kind of QoS into account for determining the routes.
 - QoS is usually addressed in terms of either end-to-end or average delay or deadline miss ratio.
 - Some of these protocols are energy-aware, while others are not.



SPIN - Sensor Protocols for Information via Negotiation

- **Data-Centric Routing Protocols**
- The basic idea in SPIN is to name the data using high-level descriptors called metadata.
- The use of metadata negotiation reduces the transmission of redundant data throughout the network, as compared to the classic Flooding protocol.
- Hence, SPIN protocols address major problems of flooding, i.e., message implosion, overlap, and resource blindness (as SPIN protocols are energy-aware).
- This is done by negotiating data at the sensor nodes before transmission occurs and introducing resource adaptation.
- In SPIN each sensor node features a resource manager that keeps track of power consumption and triggers energy-aware behavior.

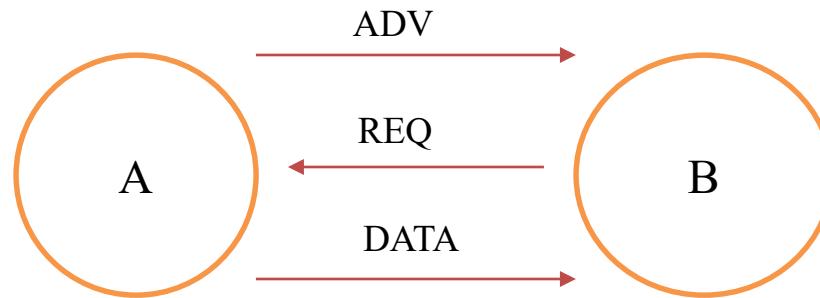


SPIN - Sensor Protocols for Information via Negotiation

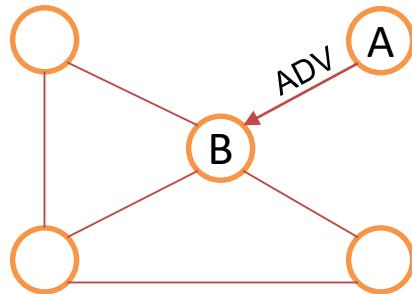
- SPIN does not specify a standard metadata format, as it is application-specific.
- However, as metadata exchange is done before data transmission, in order to maintain energy efficiency the size of metadata should be significantly less than that of sensor data.
- Three types of messages are introduced by SPIN protocols.
 - ADV messages, which allow a sensor to advertise that a node has data to share. This message contains the metadata used to identify the sensor data.
 - REQ messages, which allow a node to request specific data.
 - DATA messages, which contain the actual sensor data.

SPIN - Sensor Protocols for Information via Negotiation

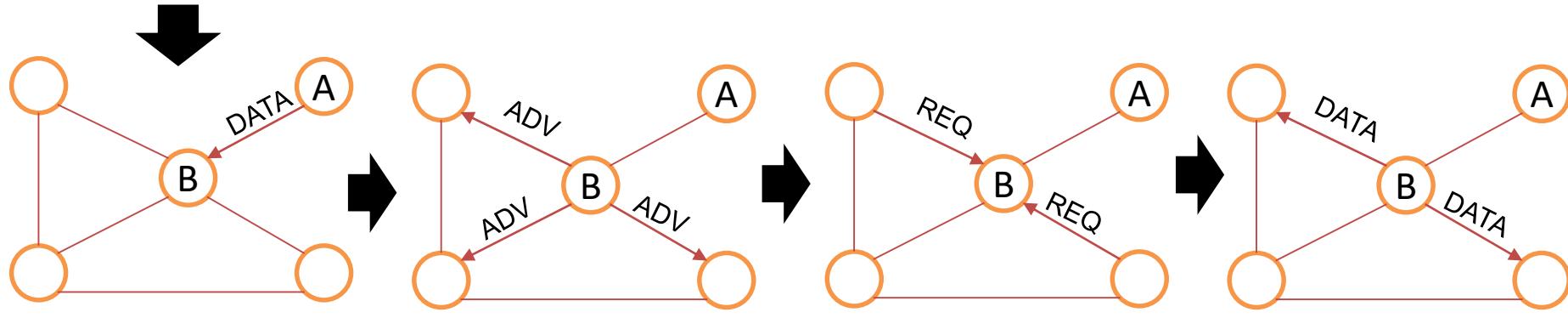
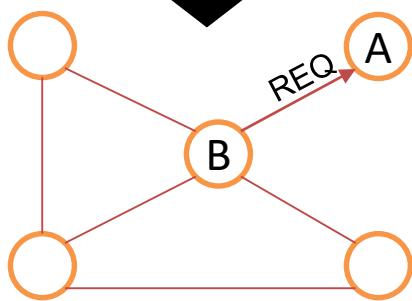
- Node A advertises that it has data to share by sharing corresponding meta-data via **ADV** message
- Node B requests the data through a **REQ** message
- Node A sends the data through the **DATA** message



SPIN - Sensor Protocols for Information via Negotiation



- A advertises the data to node B
- B requests the data
- A sends the data to B
- B advertises the data to its neighbouring nodes
- Interested neighbouring nodes request the data
- B sends the data to the interested neighbouring nodes





SPIN - Sensor Protocols for Information via Negotiation

- Upon receiving data, a node can apply data aggregation techniques and then advertise the aggregated data.
- Furthermore, a low-energy threshold can be used to reduce participation in the protocol, i.e., a node will participate in a stage only if its remaining energy is sufficient to complete the following stage.
- As compared to classical Flooding and Gossiping protocols, SPIN features shorter dissemination times and higher reliability.
- As the power consumption of the nodes during the transmission of DATA packets is usually much higher than that needed for ADV/REQ packets, SPIN also provides lower energy consumption than flooding.



Direct Diffusion Protocol

- Data-Centric Routing Protocols
- Basic idea: Node requests data by sending interests
- An interest defines a list of attribute-value pairs that describe the sensing task, i.e. type, interval, duration, sensing area etc.
- The sink node periodically broadcasts its interests to the neighbouring nodes.
- Then the neighbouring nodes broadcast these interests to their neighbouring nodes, and the process goes on.

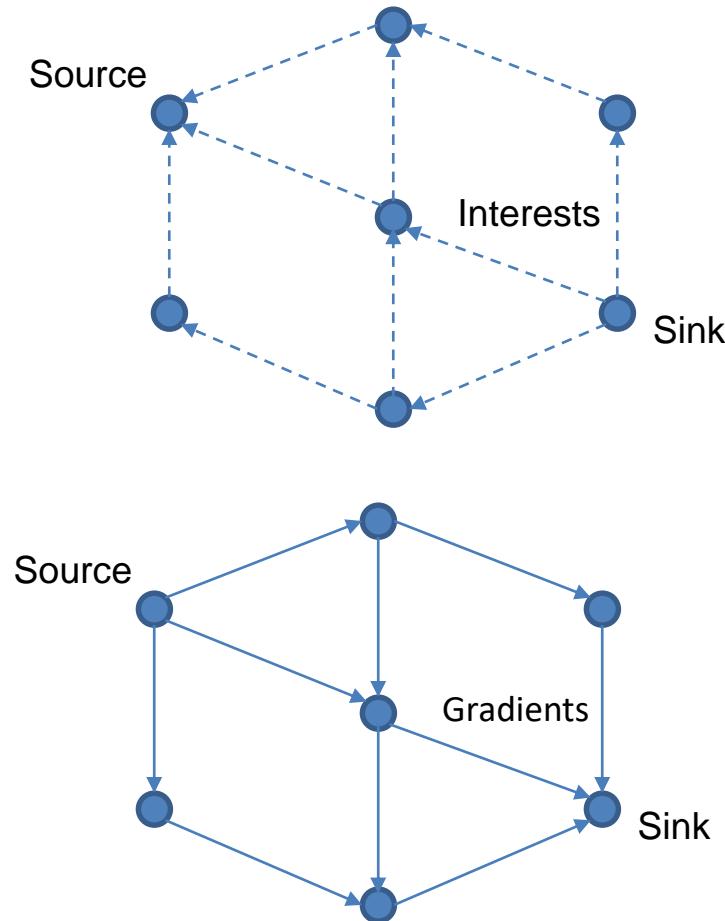


Direct Diffusion Protocol

- Gradient is a reply link to the neighbour from where the interest was received.
- Gradient also contains the data rate (derived from the duration attributes of the interest) and a duration field (derived from the time stamp and expire At attributes of the interest).
- Interest parameters and gradient are updated each time a node receives an interest.
- Each node has
 - An interest cache: Stores the interests and gradients.
 - A data cache: Used to direct interests (thereby avoiding flooding and transmission loops).

Direct Diffusion Protocol

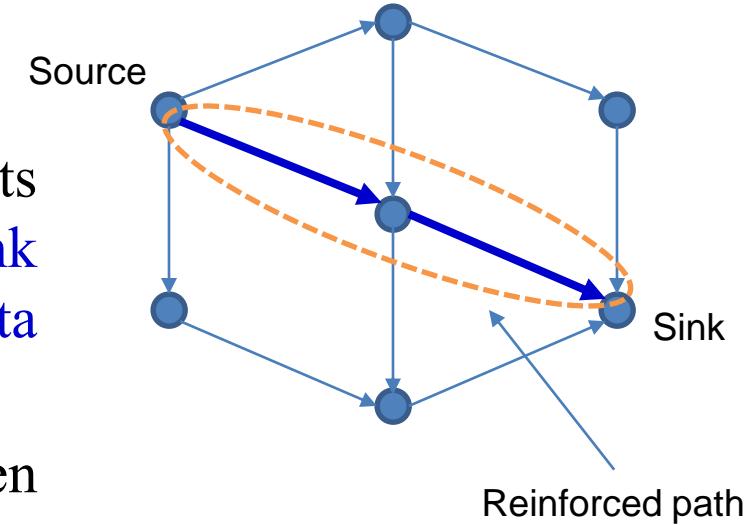
- When a node receives a data message from a neighbouring node,
 - It matches it with the interests in the interest cache.
 - If a matching interest is found, then it will send the data to all the nodes for which it has the gradients matching.
 - If no matching interest is found, the data packet is silently dropped by the node.
 - It avoids flooding.
 - But the sink may receive the same data several times from different paths.
 - So, a ‘reinforcement scheme’ is introduced.



Direct Diffusion Protocol

Reinforcement Scheme

- Sink broadcasts the low data rate interests.
- Once gradients are setup (i.e. it starts receiving low data rate messages), the sink selects one neighbour and increases its data rate.
- That node realizes that it has been reinforced.
- Then that node select one of its neighbour and reinforces it.
- This sequence of reinforcement continues till the path is established between the sink and the source.





WSN Routing

Rumor Routing

- It is a bit similar to direct diffusion and is done where geographic routing is futile.
- When little data is requested from the nodes, flooding as in directed diffusion becomes unnecessary and irrelevant.
- An alternative approach is to flood the events if the number of events is small, and the number of queries is large.
- The queries experiencing similar data types must be connected to the same nodes.
- In this way, we can retrieve information about the events occurring.
- Agents are employed to conduct rumor routing successfully.



WSN Routing

➤ Rumor Routing

- They are long living packets.
- If a node detects an event, it keeps on saving it in an event table.
- They together compile to form the so called agent.
- These agents make it possible to transmit the data to very far off nodes which is quite a difficult task in case of a normal network.
- Only the nodes which form the part of route of the query respond to the change in system due to the query.
- Therefore, it makes the communication cheaper in terms of cost and energy.



WSN Routing

➤ Minimum Cost Forwarding Algorithm (MCFA)

- It uses the property that the direction of routing is always known, and it is towards the main BS.
- Hence, a sensor node need not have a unique ID nor maintain a routing table.
- Instead, each node maintains the least cost estimate from itself to the base-station.
- Each message to be forwarded by the sensor node is broadcast to its neighbours.
- When a node receives the message, it checks if it is on the least cost path between the source sensor node and the base-station.
- If this is the case, it re-broadcasts the message to its neighbours. This process repeats until the base-station is reached. After the BS is reached, it goes to the required PC of the user.



WSN Routing : Sequential Assigned Routing protocol

- SAR: a table-driven, multi-path routing protocol, to route packets along multiple paths depending on the energy and QoS requirements.
- Each path is assigned two parameters by each node: a QoS metric and an energy resource, that is, the number of packets to be sent through that path before the node energy runs out.
- Path selection is performed by the source node, through computation of a weighted QoS metric, obtained from the additive QoS metric multiplied by a weight coefficient depending on the packet priority.

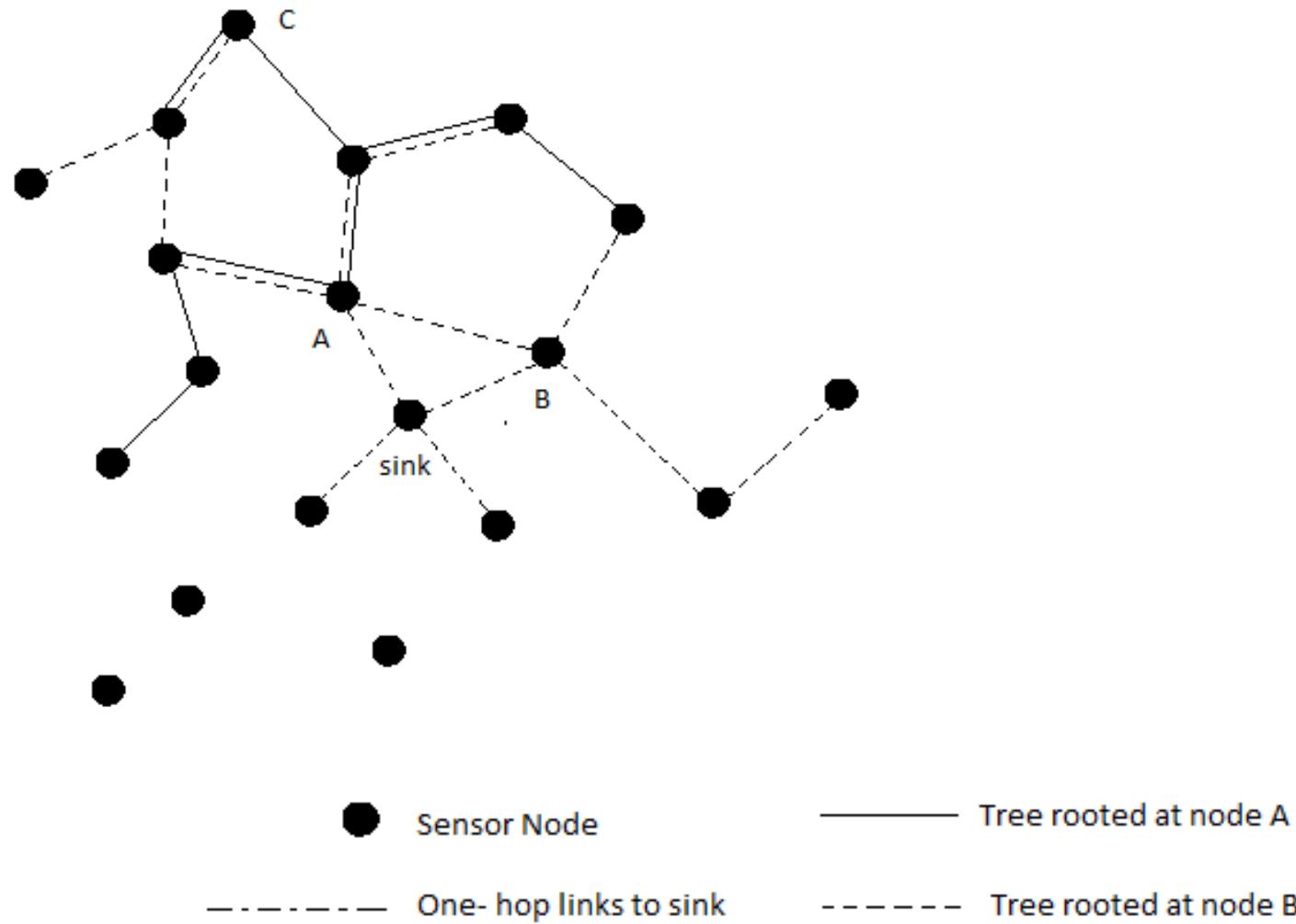


WSN Routing : Sequential Assigned Routing protocol

- Notice that by choosing the path, the one-hop neighbour of the sink is also selected
- The SAR algorithm creates multiple trees, where the root of each tree is a one-hop neighbour of the sink.
- Each tree grows from the sink and avoids nodes with low throughput or high delay.
- At the end of procedure, most nodes belong to multiple trees.

- The SAR protocol features better performance than algorithms that always select the minimum-energy path regardless of network conditions

WSN Routing : Sequential Assigned Routing protocol





WSN Routing

➤ Energy Aware Routing (EAR)

- Its primary objective is to increase the network lifetime.
- Its variation from directed diffusion is that it maintains a set of paths rather than an optimal path.
- When different paths are chosen every single time, the energy of a single path won't deplete early.



WSN Routing

➤ Hierarchical Network Routing

- It is cluster based routing known for its scalability and efficient communication.
- It performs energy efficient routing by forming various clusters and giving special tasks to different cluster heads.
- It is basically a 2 layer process where;
 - One layer is used to select cluster heads
 - The other layer is used for routing



Low Energy-Adaptive Cluster Hierarchy (LEACH) Protocol

- **Cluster-Based** Energy-Efficient Routing Protocol
- Nodes are grouped in clusters, each containing a cluster-head node
- Non-cluster-head nodes only transmit to their cluster-heads
- Cluster-heads perform long-distance transmission to the sink directly.
- The long-distance transmission by the cluster-heads is expensive in terms of power consumption.



Low Energy-Adaptive Cluster Hierarchy (LEACH) Protocol

- Hence if the cluster-heads continue to do it for a long time, they would drain their batteries fast.
- In order to avoid this, LEACH proposes rotation of the cluster heads.
- In general, LEACH proposes the followings
 - Rotation of cluster heads
 - Data fusion to reduce communication costs
 - Duty cycle reduction for non-cluster nodes



Low Energy-Adaptive Cluster Hierarchy (LEACH) Protocol

- Cluster head selection happens periodically.
- The time duration between selection of cluster heads is called a ‘round’
- In fact in each round cluster heads are selected and clusters are formed.
- Each round has 4 phases:
 - Advertisement
 - Cluster set-up
 - Schedule creation
 - Data transmission



LEACH Protocol Phases

Advertisement

- Each node independently decide, whether to become leader or not. The process is following.
 - A node ' n ' generates a random number in the interval $[0, 1]$
 - It compares the random number with a threshold $T(n)$, where

$$T(n) = \begin{cases} \frac{p}{1 - p(r \cdot \text{mod } \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

where

p is the desired percentage of cluster heads

r is the current round number

G is the set of nodes that were not cluster heads during the last $1/p$ rounds

- If the random number is less than the threshold, it becomes the leader, otherwise not.
- As per the above formula, each node will be a cluster head approximately once in every ' $1/p$ ' rounds.



LEACH Protocol Phases

Advertisement

- Then all the self-elected nodes broadcast ADV messages to all other nodes.
- CSMA MAC protocol is used for this communication
- Non-cluster nodes collect the ADV messages received.
- At the end of the phase each of the non-cluster-leader nodes select the cluster featuring the cluster head with the best signal strength



LEACH Protocol Phases

Cluster set-up

- After a node has chosen the cluster to join, it has to communicate its choice to the cluster head.
- CSMA MAC protocol is used for this communication

Schedule creation

- Cluster head creates a TDMA schedule for the cluster nodes.



LEACH Protocol Phases

Data transmission

- The TDMA transmission **schedule** is **broadcasted** by the cluster-heads to the non-cluster nodes.
- When the turn comes, non-cluster-head nodes transmit their data to the cluster-head.
- Once data is collected from every sensor, the cluster head can run a data aggregation or specific signal processing algorithms to compress the data into a single packet and then sends it to the sink.
- For good performance and moderate overheads, the data transmission phase should be much longer than the previous three phases.
- The data transmission continues till end of the round, when the new election will be initiated.



WSN Routing

- Power Efficient Gathering in Sensor Information Systems (PEGASIS)
 - It is an advanced version of LEACH protocol.
 - The nodes mostly communicate with nearby nodes and in turns communicate directly with the BS.
 - But unlike LEACH, it only uses one node to communicate with base station. It has 2 objectives;
 - Increase the lifetime of each node
 - Allow local communication between nearby nodes



WSN Routing

- **Small Minimum Energy Communication Network (MECN)**
 - It is a sub network that becomes a part of the main network.
 - It works mainly to improve energy efficiency.
 - It identifies relay region for every node that comprises of the neighboring nodes.
 - MECN is also a location or geographic based protocol which is designed for minimizing the energy consumption during transmission in WSN



WSN Routing

- **Small Minimum Energy Communication Network (MECN)**
- The basic idea of this protocol is that instead of creating a larger one it establishes multiple small subnetworks so that the requirements of the energy must be less during transmission of data between nodes.
- This protocol is a self reconfiguration protocol which is based on low power GPS technology and it can compute a minimum spanning tree which stores the minimum power path for each sensor to sink.



WSN Routing

➤ Small Minimum Energy Communication Network (MECN)

The whole procedure of MECN is divided into two distinct phases. These are

- i. Graph Construction: In this phase, MECN constructs an enclosure graph based on the locality of its neighbouring sensors which contain all the sensors and its vertices. Once the construction of the graph is done, it starts sending data through this graph.
- ii. Cost Construction: In this phase, MECN performs the cost distribution function in which all the non optimal links of the directed graph are simply deleted to form a new graph where every sensor is connected with a direct link to the sink and broadcast its cost to its neighbour.

WSN Routing

➤ Small Minimum Energy Communication Network (MECN)

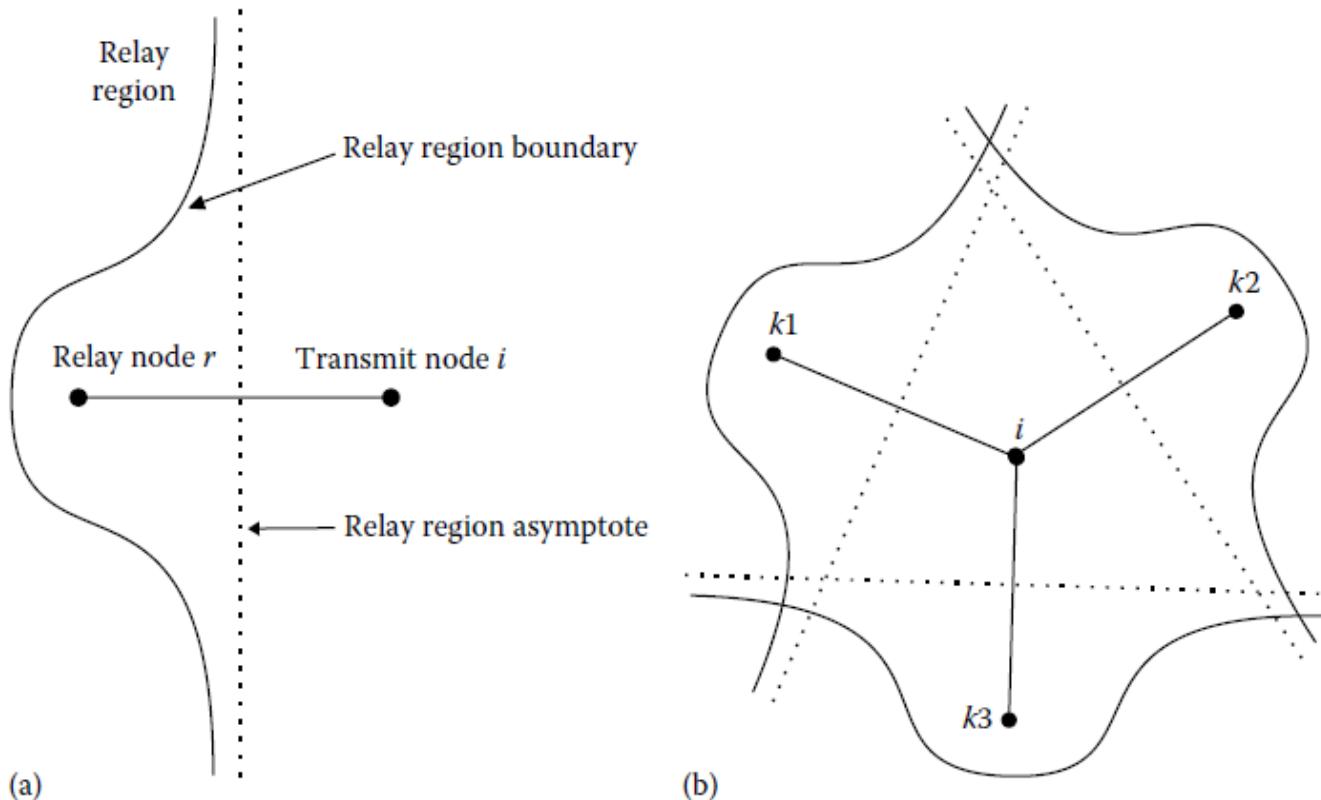


FIGURE 7.7 MECN regions. (a) Relay region of a transmit–relay node pair. (b) Representation of an enclosure. (Redrawn from Shahani, A.R., Schaeffer, D.K., and Lee, T.H., A 12 mW wide dynamic range CMOS front-end for a portable GPS receiver, in *Proceedings of IEEE International Solid-State Circuits Conference*, vol. 40, pp. 368–369, Feb. 1997.)



WSN Routing

- **Small Minimum Energy Communication Network (MECN)**
- Advantages:
 - It is a self reconfiguration protocol.
 - It consumes less energy.
- Disadvantages:
 - Fault tolerant depends on specific applications.



WSN Routing

- **Two-Tier Data Dissemination (TTDD)**
 - It provides the data packets to multiple mobile base stations.
 - The data ports build a grid structure beforehand to send the data fast and efficiently through maximum throughput and minimum time delay.
 - Sources are static but tail can be dynamic. Both are location aware.



WSN Routing

➤ Location Based Routing

- In these routing techniques, the nodes are divided and addressed by means of their locations.
- The strength of the incoming signal or GPS can be used to determine the exact location of the nodes.
- The nodes can be programmed to go into sleep when they are inactive or dormant.



Topology Control Protocols

- Topology control protocols runs at a lower level than standard routing protocols
- Objective is to improve energy efficiency of routing protocols of the wireless network by co-ordinating the sleep transition of nodes
- It turns off the radio of the nodes when the nodes are idling (sleep state)
- These protocols exploits the redundancy in dense network (multiple nodes may be doing the same work at same time) in order to put the nodes into sleep while maintaining the network connectivity.



Geographic-Adaptive Fidelity (GAF) Protocol

- A Topology Control Protocol
- It divides the whole area into virtual grids, where each grid is small enough that each node in a cell can hear from each node of the adjacent cells.
- Nodes are **location aware** so that each node obtains its **co-ordinate** in the virtual grid from its location information.
- Nodes in the same cell co-ordinate active and sleep periods, so that at least one node per cell is active at any point of time.

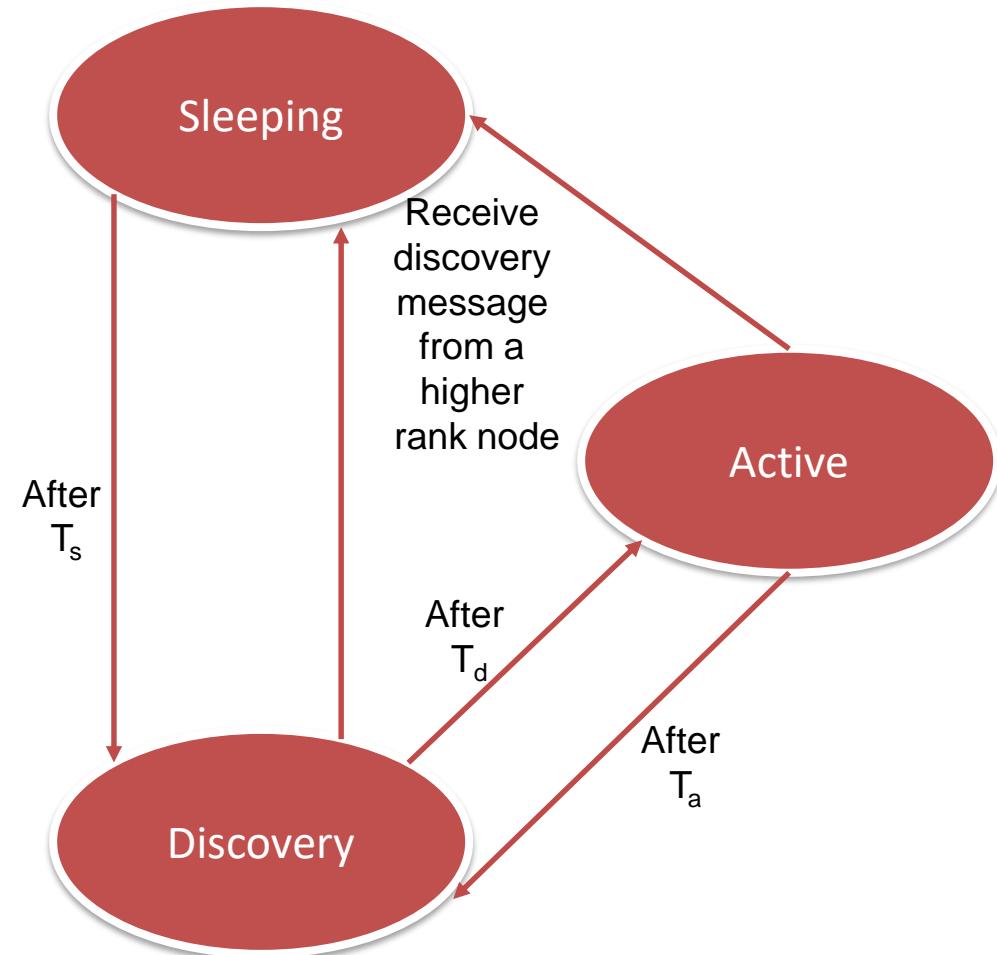


Geographic-Adaptive Fidelity (GAF) Protocol

- A node can be in any of the three states at any point of time: **Discovery**, **Sleeping** & **Active**.
- In **discovery state**, the nodes are active and **exchanges** discovery messages in order to find the nodes within the same cell.
- After time T_d (called Discover Timeout), the node **moves to active state** from the **discovery state**.
- In the **active state**, the node stays for time T_a , and then it **moves to discovery state** again.
- In the **active state**, it does **data transfers**.
- Even in the **active state**, a sensor periodically broadcasts its **discovery message** to inform equivalent sensors about its state.
- While in **discovery or active state**, if a node finds **its rank** to be less than any other node in the cell, then it moves to **sleep state**. It means when a node receives a **discovery message** from a higher ranked node, it moves to **sleep state**.
- In the **sleep state**, a node stays for a time T_s and then moves to **discovery state** again.

Geographic-Adaptive Fidelity (GAF) Protocol

- Rank of a node at any point of time is determined as follows.
- Nodes in active state always have higher rank than those in the discovery state.
- When in the same state, a node with a longer expected lifetime (i.e. more energy) has a higher rank than a node with smaller expected lifetime.





WSN Routing

- **The Sparse Topology and Energy Management (STEM)**
- The Sparse Topology and Energy Management (STEM) protocol is based on the assumption that most of the time the sensor network is only sensing the environment, waiting for an event to happen
- In other words, STEM may be seen as better suitable for reactive sensor networks where the network is in the monitoring state for vast majority of time
- One example of such an application is a sensor network designed to detect fires in a forest
- These networks have to remain operational for months or years, but sensing only on the occurrence of a forest fire
- Clearly, although it is desirable that the transfer state be energy-efficient, it may be more important that the monitoring state be ultra-low-power as the network resides in this state for most of the time
- This observation holds true for many other applications as well

WSN Routing

- **The Sparse Topology and Energy Management (STEM)**
 - The idea behind STEM is to turn on only a node's sensors and some preprocessing circuitry during monitoring states
 - Whenever a possible event is detected, the main processor is woken up to analyze the sensed data in detail and forward it to the data sink
 - However, the radio of the next hop in the path to the data sink is still turned off, if it did not detect the same event
 - STEM solves this problem by having each node to periodically turn on its radio for a short time to listen if someone else wants to communicate with it
 - The node that wants to communicate, i.e. , the initiator SN, sends out a beacon with the ID of the node it is trying to wake up, i.e. , the target SN



WSN Routing

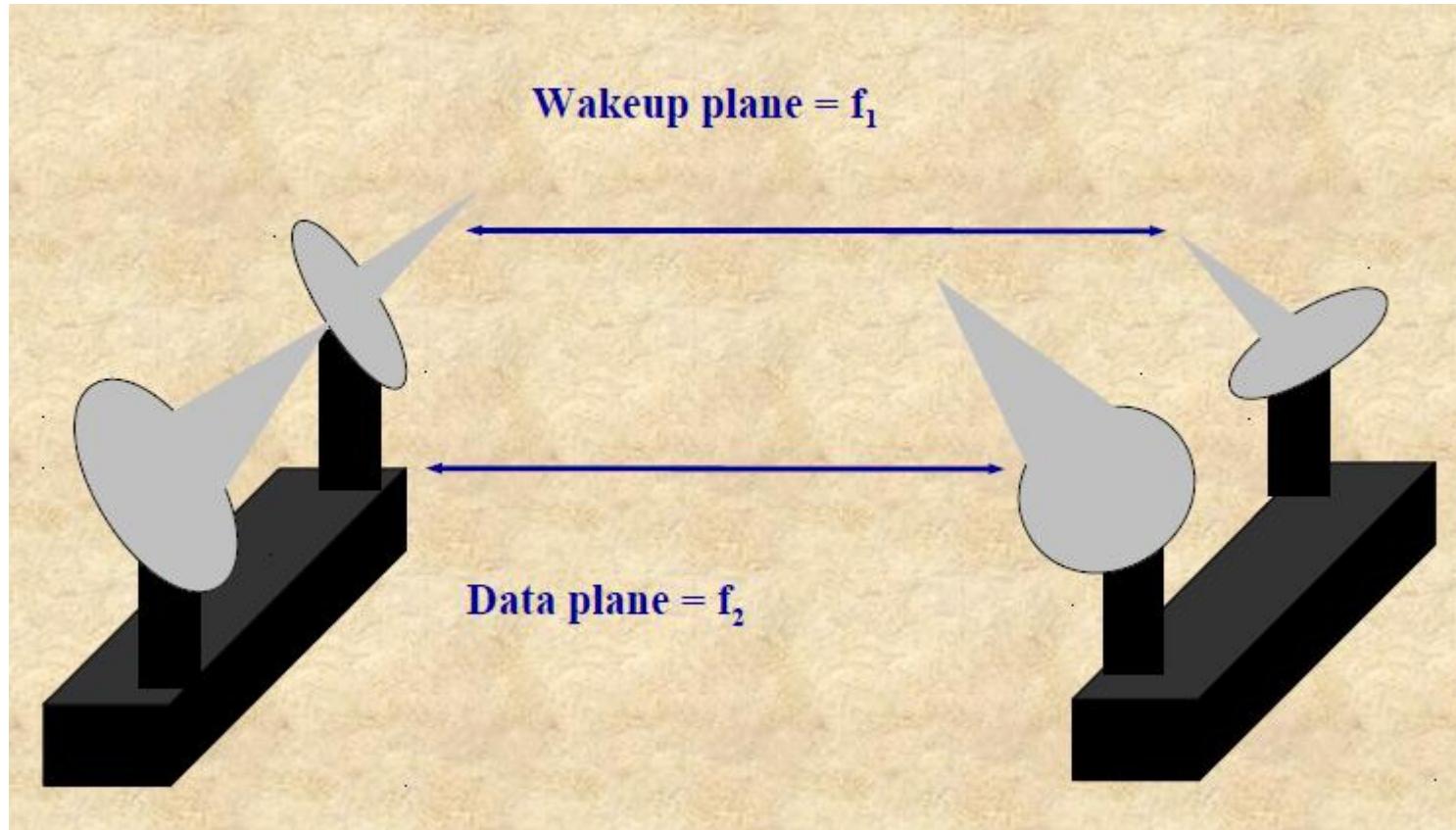
- **The Sparse Topology and Energy Management (STEM)**
- This can be viewed as a procedure by which the initiator SN attempts to activate the link between itself and the target SN
- As soon as the target SN receives this beacon, it responds back to the initiator node and both keep their radio ON at this point
- If the packet needs to be relayed further, the target SN will become the initiator node for the next hop and the process is repeated
- Once both the nodes that make up a link have their radio ON, the link is active and can be used for subsequent packets
- However, the actual data transmissions may still interfere with the wakeup protocol

WSN Routing

- **The Sparse Topology and Energy Management (STEM)**
 - To overcome this problem, STEM proposes the wakeup protocol and the data transfer to employ different frequency bands as depicted in next Figure
 - In addition, separate radios would be needed in each of these bands
 - In Figure , we see that the wakeup messages are transmitted by the radio operating in frequency band f1
 - STEM refers to these communications as occurring in the wakeup plane
 - Once the initiator SN has successfully notified the target SN, both SNs turn ON their radio that operates in frequency band f2
 - The actual data packets are transmitted in this band, called the dataplane

WSN Routing

➤ The Sparse Topology and Energy Management (STEM)





Thank You