SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

www.sathyabama.ac.in

SITA1501

Wireless Sensor Networks and Architecture

Ms.R.Sakthi Prabha

Assistant Professor,

Department of ECE

Sathyabama Institute of Science

and Technology

UNIT III

SYSTEM ARCHITECTURE AND DESIGN ISSUES

SYSTEM ARCHITECTURE AND DESIGN ISSUES

- ✓Design Constraints for Routing in Wireless Sensor Networks
- ✓Classification of Routing Protocols in Wireless Sensor Networks-Hierarchy Role of Nodes in the Network, Data Delivery Model
- ✓Optimization Techniques for Routing in Wireless Sensor Networks
- ✓Application of the Optimization Techniques: Routing Protocols

Design Constraints for Routing in Wireless Sensor Networks

- WSN networks have several restrictions, e.g., limited energy supply, limited computing power, and limited bandwidth of the wireless links connecting sensor nodes.
- One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques.
- The design of routing protocols in WSNs is influenced by many challenging factors. These factors must be overcome before efficient communication can be achieved in WSNs.
- Some of the routing challenges and design issues that affect routing process in WSNs.

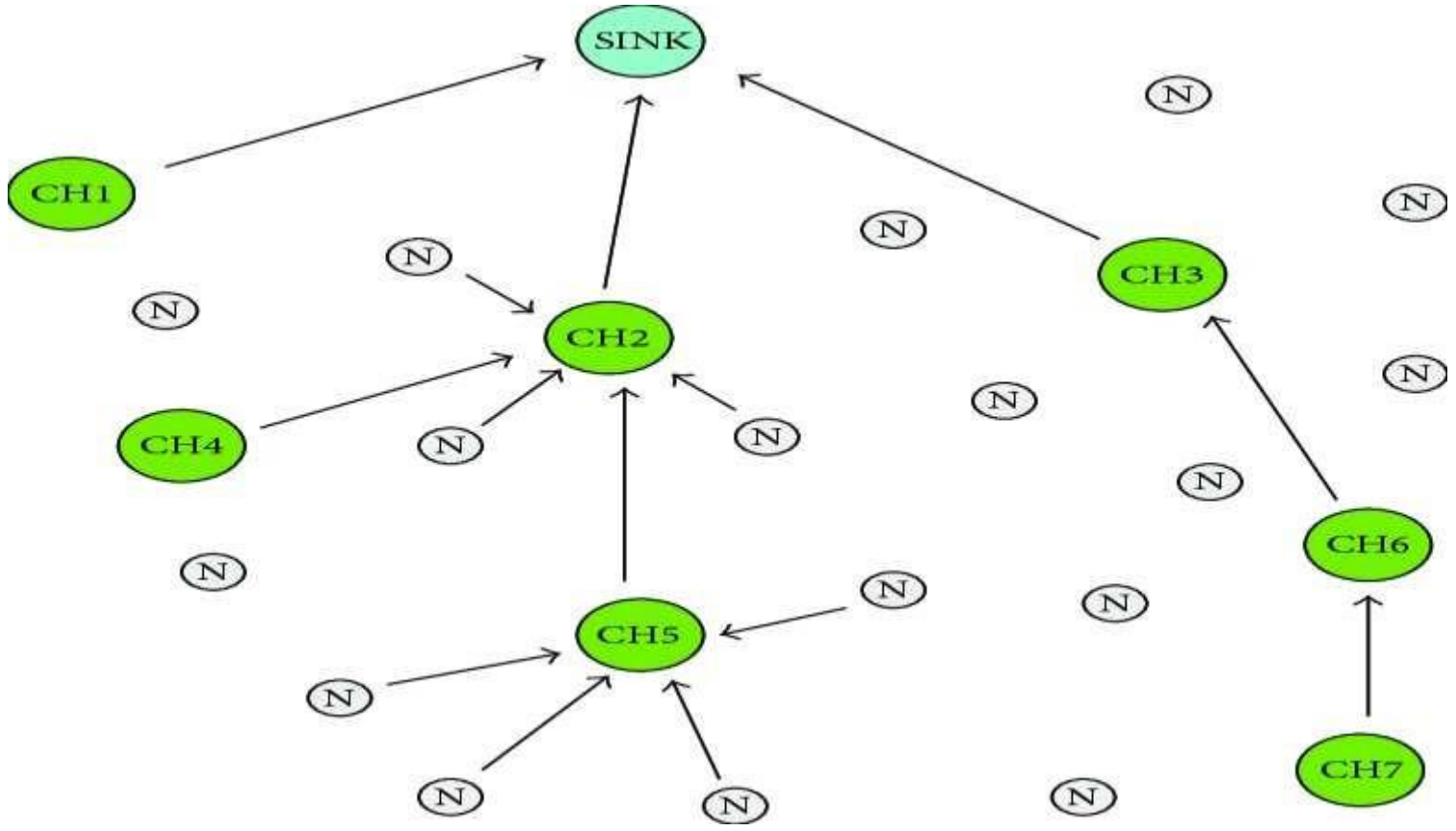
Design Constraints for Routing in Wireless Sensor Networks

- *Node deployment*
- *Energy consumption without losing accuracy*
- *Data Reporting Model*
- *Node/Link Heterogeneity*
- *Fault Tolerance*
- *Scalability*
- *Network Dynamics*
- *Transmission Media*
- *Connectivity*
- *Coverage*
- *Data Aggregation*
- *Quality of Service*

Node deployment

- Node deployment in WSNs is application dependent and affects the performance of the routing protocol.
- The deployment can be either deterministic or randomized. In deterministic deployment, the sensors are manually placed and data is routed through pre-determined paths.
- In random node deployment, the sensor nodes are scattered randomly creating an infrastructure in an ad hoc manner.
- If the resultant distribution of nodes is not uniform, optimal clustering becomes necessary to allow connectivity and enable energy efficient network operation.
- Inter-sensor communication is normally within short transmission ranges due to energy and bandwidth limitations.

Node deployment



Energy consumption without losing accuracy

- Sensor nodes can use up their limited supply of energy performing computations and transmitting information in a wireless environment.
- Energy-conserving forms of communication and computation are essential. Sensor node lifetime shows a strong dependence on the battery lifetime.
- In a multi-hop WSN, each node plays a dual role as data sender and data router.
- The malfunctioning of some sensor nodes due to power failure can cause significant topological changes and might require rerouting of packets and reorganization of the network.

Data Reporting Model

- Data sensing and reporting in WSNs is dependent on the application and the time criticality of the data reporting.
- Types of data driven model
  - ✓ time-driven model(continuous)
  - ✓ event-driven & query-driven model
  - ✓ hybrid model

Types of Data Reporting Model

- Time Driven model

✓ Suitable for applications that require periodic data monitoring. As such, sensor nodes will periodically switch on their sensors and transmitters, sense the environment and transmit the data of interest at constant periodic time intervals.

- Event-driven and query-driven models

✓ Sensor nodes react immediately to sudden and drastic changes in the value of a sensed attribute due to the occurrence of a certain event or a query is generated by the BS. As such, these are well suited for time critical applications.

- Hybrid model

- A combination of the previous models is also possible. The routing protocol is highly influenced by the data reporting model with regard to energy consumption and route stability.

Node/Link Heterogeneity

- All sensor nodes were assumed to be homogeneous, i.e., having equal capacity in terms of computation, communication, and power. However, depending on the application a sensor node can have different role or capability.
- The existence of heterogeneous set of sensors raises many technical issues related to data routing. For example, some applications might require a diverse mixture of sensors for monitoring temperature, pressure and humidity of the surrounding environment, detecting motion via acoustic signatures, and capturing the image or video tracking of moving objects.

Node/Link Heterogeneity

- These special sensors can be either deployed independently or the different functionalities can be included in the same sensor nodes. Even data reading and reporting can be generated from these sensors at different rates, subject to diverse quality of service constraints, and can follow multiple data reporting models. For example, hierarchical protocols designate a cluster- head node different from the normal sensors.
- These cluster heads can be chosen from the deployed sensors or can be more powerful than other sensor nodes in terms of energy, bandwidth, and memory. Hence, the burden of transmission to the BS is handled by the set of cluster-heads.

Fault Tolerance

- Some sensor nodes may fail or be blocked due to lack of power, physical damage, or environmental interference.
- The failure of sensor nodes should not affect the overall task of the sensor network. If many nodes fail, MAC and routing protocols must accommodate formation of new links and routes to the data collection base stations.
- This may require actively adjusting transmit powers and signaling rates on the existing links to reduce energy consumption, or rerouting packets through regions of the network where more energy is available.
- Therefore, multiple levels of redundancy may be needed in a fault-tolerant sensor network.

Network Dynamics

- Most of the network architectures assume that sensor nodes are stationary. However, mobility of both BS's or sensor nodes is sometimes necessary in many applications.
- Routing messages from or to moving nodes is more challenging since route stability becomes an important issue, in addition to energy, bandwidth etc.
- Moreover, the sensed phenomenon can be either dynamic or static depending on the application, e.g., it is dynamic in a target detection/tracking application, while it is static in forest monitoring for early fire prevention.
- Monitoring static events allows the network to work in a reactive mode, simply generating traffic when reporting. Dynamic events in most applications require periodic reporting and consequently generate significant traffic to be routed to the BS.

Transmission Media

- In a multi-hop sensor network, communicating nodes are linked by a wireless medium.
- The traditional problems associated with a wireless channel (e.g., fading, high error rate) may also affect the operation of the sensor network
- In general, the required bandwidth of sensor data will be low, on the order of 1-100 kb/s. Related to the transmission media is the design of medium access control (MAC).
- One approach of MAC design for sensor networks is to use TDMA based protocols that conserve more energy compared to contention based protocols like CSMA (e.g., IEEE 802.11).
- Bluetooth technology can also be used.

Connectivity and Coverage

Connectivity*:* High node density in sensor networks precludes them from being completely isolated from each other. Therefore, sensor nodes are expected to be highly connected. This, however, may not prevent the network topology from being variable and the network size from being shrinking due to sensor node failures. In addition, connectivity depends on the, possibly random, distribution of nodes.

Coverage*:* In WSNs, each sensor node obtains a certain *view* of the environment. A given sensor's view of the environment is limited both in range and in accuracy; it can only cover a limited physical area of the environment. Hence, area coverage is also an important design parameter in WSNs.

.

Data Aggregation

- Since sensor nodes may generate significant redundant data, similar packets from multiple nodes can be aggregated so that the number of transmissions is reduced.
- Data aggregation is the combination of data from different sources according to a certain aggregation function, e.g., duplicate suppression, minima, maxima and average.
- This technique has been used to achieve energy efficiency and data transfer optimization in a number of routing protocols. Signal processing methods can also be used for data aggregation
- .In this case, it is referred to as data fusion where a node is capable of producing a more accurate output signal by using some techniques such as beamforming to combine the incoming signals and reducing the noise in these signals.

Quality of Service

- In some applications, data should be delivered within a certain period of time from the moment it is sensed, otherwise the data will be useless. Therefore, bounded latency for data delivery is another condition for time-constrained applications.
- However, in many applications, conservation of energy, which is directly related to network lifetime, is considered relatively more important than the quality of data sent.
- As the energy gets depleted, the network may be required to reduce the quality of the results in order to reduce the energy dissipation in the nodes and hence lengthen the total network lifetime. Hence, energy-aware routing protocols are required to capture this requirement.

Classification of Routing Protocols in Wireless Sensor Networks

1. *Hierarchy Role of Nodes in the Network*
2. *Data Delivery Model*

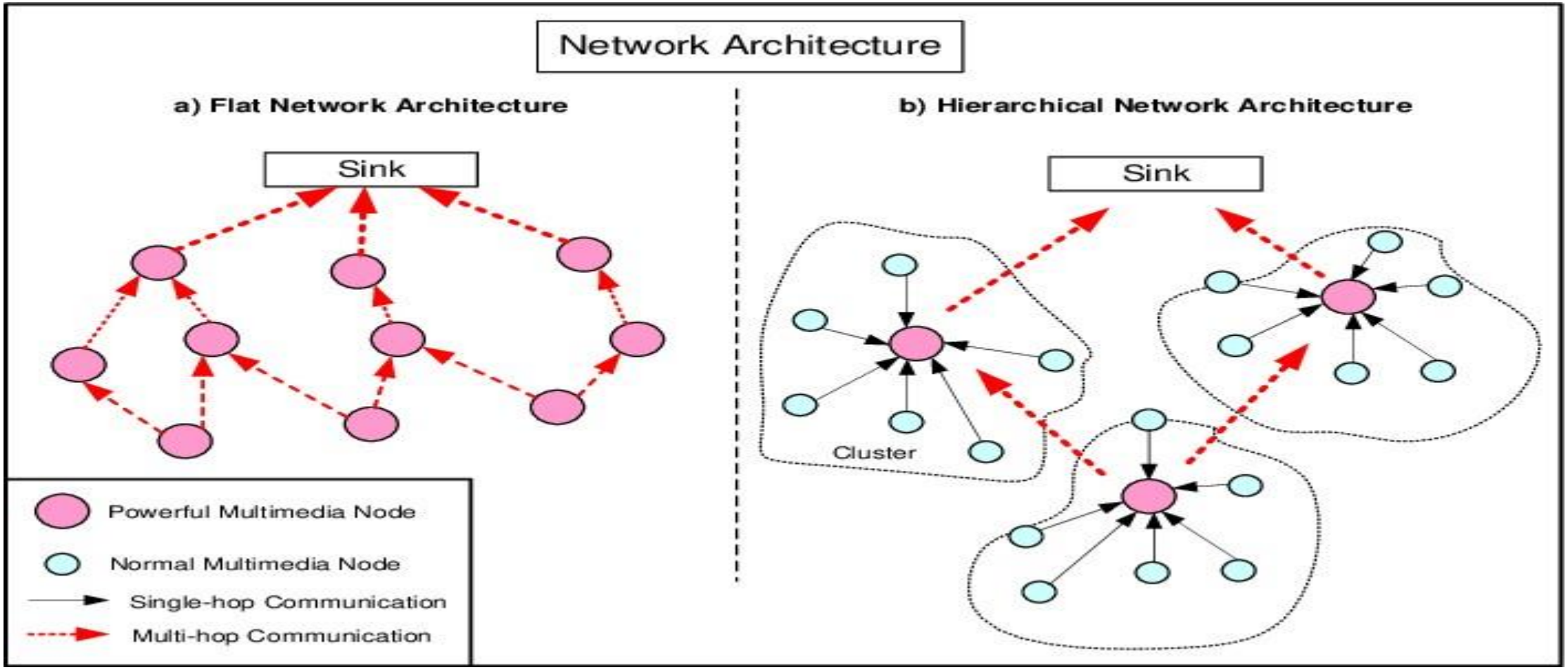
Hierarchy Role of Nodes in the Network

- In the flat schemes, all sensor nodes participate with the same role in the routing procedures. On the other hand, the hierarchical routing protocols classify sensor nodes according to their functionalities.
- The network is then divided into groups or clusters. A leader or a cluster head is selected in the group to coordinate the activities within the cluster and to communicate with nodes outside the own cluster. The differentiation of nodes can be static or dynamic.

Types of Routing in WSN

- ✓ Flat routing
- ✓ Hierarchical routing
- ✓ Location based routing

Flat and Heirarchical Network Architecture



Data Delivery Model

- Depending on the application, data gathering and interaction in wireless sensor networks could be accomplished on several ways. The data delivery model indicates the flow of information between the sensor nodes and the sink.
- The data delivery models are divided into the following classes:
  - ✓ Continuous
  - ✓ event-driven
  - ✓ query-driven
  - ✓ hybrid.
- In the continuous model, the nodes periodically transmit the information that their sensors are detecting at a pre-specified rate.
- In contrast, the query-driven approaches force nodes to wait to be demanded in order to inform about their sensed data.
- In the event-driven model, sensors emit their collected data when an event of interests occurs.
- Finally, the hybrid schemes combine the previous strategies so sensors periodically inform about the collected data but also response to queries. Additionally, they are also programmed to inform about events of interest.

Optimization Techniques for Routing in Wireless Sensor Networks

- The particular characteristics of wireless sensor networks and their constraints have prompted the need for specific requirements to routing protocols. When compared to mobile ad hoc networks routing protocols, the algorithms in wireless sensor networks usually realize the following specifications:

✓ ***Attribute-based***
✓ ***Energy Efficiency***
✓ ***Data Aggregation***
✓ ***Addressing Scheme***
✓ ***Location-based***
✓ ***Multipath Communication***
✓ ***Quality of Service***

Attribute-based

- The sink sends queries to certain regions and waits for the response from the sensors located in this area. Following an attribute-value scheme, the queries inform about the required data.
- The selection of the attributes depends on the application.
- An important characteristic of these schemes is that the content of the data messages is analyzed in each hop to make decisions about routing.

Energy Efficiency

- Multiple routes can communicate a node and the sink.
- The aim of energy-aware algorithms is to select those routes that are expected to maximize the network lifetime.
- The routes composed of nodes with higher energy resources are preferred.

Data Aggregation

- Data collected in sensors are derived from common phenomena so nodes in a close area usually share similar information. A way to reduce energy consumption is data aggregation.
- Aggregation consists of suppressing redundancy in different data messages. When the suppression is achieved by some signal processing techniques, this operation is called data fusion.

Addressing Scheme

- Wireless sensor networks are formed by a significant number of nodes so the manual assignation of unique identifiers is infeasible. The use of the MAC address or the GPS coordinates is not recommended as it introduces a significant payload. However, network-wide unique addresses are not needed to identify the destination node of a specific packet in wireless sensor networks.
- In fact, attribute-based addressing fits better with the specificities of wireless sensor networks. In this case, an attribute such as node location and sensor type is used to identify the final destination. Concerning these identifiers, two different approaches have been proposed.
- Firstly, the ID reuse scheme allows identifiers to be repeated in the network but keeping their uniqueness in close areas. In this way, a node knows that its identifier is unique in a *k*-hop neighborhood, being *k* a parameter to configure. On the other hand, the field-wide unique ID schemes guarantee that the identifiers are unique in the whole application. With this assumption, other protocols such as routing, MAC or network configurations can be simultaneously used.

Location-based

- A node decides the transmission route according to the localization of the final destination and the positions of some other nodes in the network.

Multipath Communication

- Nodes use multiple paths from an origin to a destination in the network. As multipath communications are intended to increase the reliability and the performance of the network, these paths should not share any link.
- Multipath communications can be accomplished in two ways. Firstly, one path is established as the active communication routing while the other paths are stored for future need, i.e. when the current active path is broken. On the other hand, it is also possible to distribute the traffic among the multiple paths.

Quality of Service

- The network application business and its functionalities prompt the need for ensuring a QoS (Quality of Service) in the data exchange. In particular, effective sample rate, delay bounded and temporary precision are often required.
- Satisfying them is not possible for all the routing protocols as the demands may be opposite to the protocol principles.
- For instance, a routing protocol could be designed to extend the network lifetime while an application may demand an effective sample rate which forces periodic transmissions and, in turn, periodic energy consumptions.

Application of the Optimization Techniques: Routing Protocols

- **Attribute-based or Data-centric Routing Protocols**
- **Geographical Routing Protocols**
- **Hierarchical Routing Protocols**
- **Multipath Routing Protocols**

Attribute-based or Data-centric Routing Protocols

.

In Wireless Sensor Networks, data centric routing is **used to control the redundancy of data**.

- 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.

- ✓ **i) SPIN (Sensor Protocols for Information via Negotiation)**
- ✓ **ii). Directed Diffusion**
- ✓ **iii). Rumor**
- ✓ **iv). COUGAR**
- ✓ **V) ACQUIRE (Active Query Forwarding in Sensor Networks)**

SPIN (Sensor Protocols for Information via Negotiation)

- It **transfers all the useful data only from each node to every node in the network assuming** that all the nodes in the network are Base Station.
- SPIN node uses three types of messages for communication.

✓ ADV- It is used to advertise new data.

✓ REQ- REQ is used to receive the actual data.

✓ DATA- DATA is the actual message itself.

SPIN (Sensor Protocols for Information via Negotiation)

Working of SPIN protocol

1. Node A starts by Advertising its data to the node B.

1. Node B responds by sending a request to the node A.

2. As soon as node B receives the request it sends the original data to its neighbor nodes and similarly the process goes on till all the nodes in the network receives the data.

This process continues till all the nodes receives the data.

SPIN (Sensor Protocols for Information via Negotiation)

- A family of adaptive protocols, called SPIN (Sensor Protocols for Information via Negotiation), that efficiently disseminate information among sensors in an energy-constrained wireless sensor network.
- Nodes running a SPIN communication protocol name their data using high-level data descriptors, called meta-data. They use meta-data negotiations to eliminate the transmission of redundant data throughout the network.
- In addition, SPIN nodes can base their communication decisions both upon application-specific knowledge of the data and upon knowledge of the resources that are available to them. This allows the sensors to efficiently distribute data given a limited energy supply.

✓ Four specific SPIN protocols

- SPIN-PP and SPIN-EC- optimized for a point-to-point networks
- SPIN-BC and SPIN-RL-optimized for a broadcast network.

SPIN-PP

- In point-to-point networks, the sender announces that it has new data with an advertisement message to each neighbor.
- When the neighbor receives the message, the node checks the metadata to know if it already stores the data item. If the neighbor is interested in the information, it responds with a request message. Upon receiving it, the sender transmits the information in a data message.
- The neighbor that receives the data, inform about its availability to its own neighbors with an advertisement message. The three-handshake protocol is then repeated.

SPIN-EC & SPIN BC,SPIN-RL

- SPIN-EC introduces a technique in the nodes so when their current energy resources do not exceed a predetermined threshold that allows them to complete the three hand-shake protocol, they do not participate in the process.
- The SPIN-BC and SPIN-RL variants extend the algorithm to support broadcast transmissions.

✓ In this way, one advertisement message can reach all the neighbors.

✓ In this case, the neighbors do not respond immediately with a request message but they must wait a random time.

✓ To optimize the process, a node different from the advertising one cancels its own request message when it detects another similar message. Taking into account the broadcast transmission, the advertising node also responds with just one data message even when it has received multiple request messages.

SPIN-RL

- SPIN-RL incorporates some reliability functionalities. Specifically, nodes keep track of the advertisement messages that they receive and their corresponding originators.
- If they send a request message, but the announcing node does not respond in a given interval, the node asks again for the data with a request message.

SPIN (Sensor Protocols for Information via Negotiation)

- Comparing the SPIN protocols to other possible approaches, the SPIN protocols can deliver 60% more data for a given amount of energy than conventional approaches in a point-to-point network and 80% more data for a given amount of energy in a broadcast network.
- In addition, in terms of dissemination rate and energy usage, the SPIN protocols perform close to the theoretical optimum in both point-to-point and broadcast networks. One of the major advantages of these protocols is that nodes are only required to know its 1-hop neighborhood.

Directed Diffusion

- Directed diffusion is a very general approach toward problems of this type.
- Nodes requesting information are called sinks, while those generating information are called sources.
- Records indicating a desire for certain types of information are called interests. Interests are propagated across the network, looking for nodes with matching event records.
- BS continuously sends query to the neighboring nodes
- Node with the desired data transmit all the way back to BS

❖ Saving energy by selecting the optimal return path

❖ Not practical for continuous data demand cases

Rumor Routing

- Rumor routing is **a wireless sensor network routing algorithm**, which aims at lower energy consumption than algorithms that flood the whole network with query or event messages.
- The algorithm is tunable and its usefulness depends on how well the configuration parameters are set for the particular event and query distribution in the network. The algorithm also handles node failures and allows for tradeoffs between setup overhead and delivery reliability.

COUGAR

- Views the network as a huge distributed database
- Declarative queries to abstract query processing from network layer functions
- Introduces a new query layer
- Leader node performs data aggregation and transmits to the sink

✓ **LIMITATIONS**

- Additional query layer brings overhead in terms of energy consumption and storage
- In network data computation requires synchronization (i.e. wait for all data before sending data)
- Dynamically maintenance of leader nodes to prevent failure

ACQUIRE (Active Query Forwarding in Sensor Networks)

- Views network as a distributed database
- Node receiving a query from the sink tries to respond partially and then forwards packet to a neighbor
- Use of pre-cached information
- After the query is answered, result is returned to the sink by using the reverse path or the shortest path
- If cache information is not up to date - node gathers information from neighbors within look ahead of d hops
- Motivation: Deal with one shot complex queries
- Efficient routing by adjusting parameter d
- If d equals network size
- behaves similar to flooding
- If d too small the query has to travel more hops

Geographical Routing Protocols

- Geographic routing also called georouting or position-based routing
- Routing principle that relies on geographic position information.
- Source sends a message to the geographic location of the destination instead of using the network address.
- Geographic routing requires that each node can determine its own location and that the source is aware of the location of the destination.
- With this information, a message can be routed to the destination without knowledge of the network topology or a prior route discovery.

Geographical Routing Protocols

- Each node knows the location of its direct neighbors (neighbors within its radio range).
- The source inserts the destination location inside the packet.
- During packet forwarding, each node uses the location information of its neighbors and the location of the destination to forward the packet to the next-hop.
- Forwarding could be to a single node or to multiple nodes.
- Forwarding to multiple nodes is more robust and leads to multiple paths to the destination, but it could waste a lot of resources (energy and bandwidth) and thus forwarding to a single node is more efficient and it is the common approach among unicast protocols.
  - ✓ Greedy algorithm
  - ✓ GAF (Geographic Adaptive Fidelity)

Greedy Algorithm

- A node decides about the transmission path based on the position of its neighbors.
- To proceed, the source compares the localization of the destination with the coordinates of its neighbors. Then, it propagates the message to the neighbor which is closest to the final destination.
- The process is repeated until de packet reaches the intended destination. Several metrics related to the concept of closeness have been proposed for this context. Among them, the most popular metrics are the Euclidean distance and the projected line joining the relaying node and the destination.

Greedy Algorithm

- With this strategy, flooding processes are restricted to one-hop and the network is able to adapt proficiently to the topological changes.
- This simple forwarding rule is modified according to the reliability of links.
- The unreliable neighbors are not taken into account for the retransmissions. On the other hand, the geographic information is also used in SPEED (Stateless Protocol for End-to-End Delay) to estimate the delay of the transmitted packets.
- The greedy algorithm with the 'most-forward-within-R' forwarding technique opts to select the most distant neighbor of the packet holder which is closer to the final destination as the next hop.
- In contrast, the 'nearest-forward-process' chooses the nearest neighbor that is closer to the intended destination as the next relaying node.

Limitations of Greedy Algorithm

- Transmission may fail when the current holder of the message has no neighbors closer to the destination than itself. This could occur even when there is a feasible path between the two extremes, for instance, when an obstacle is present.

GAF (Geographic Adaptive Fidelity)

- Optimizing the performance of wireless sensor networks by identifying equivalent nodes with respect to forwarding packets.
- Two nodes are considered to be equivalent when they maintain the same set of neighbor nodes and so they can belong to the same communication routes. Source and destination in the application are excluded from this characterization.
- To identify equivalent nodes, their positions are necessary. Additionally, a virtual grid is constructed. This grid is formed by cells whose size allows to state that all the nodes in one cell can directly communicate with the nodes belonging to adjacent cells and *vice versa*. In this way, the nodes in a cell are equivalent.

GAF (Geographic Adaptive Fidelity)

- Nodes identify equivalent nodes by the periodic exchange of discovery messages with the nodes in their cells. With the information contained in these messages, the nodes negotiate which one is going to support the communications.
- The other nodes will stay powered off. With this procedure, the routing fidelity is kept, that is, there is uninterrupted connectivity between communicating nodes. However, the elected node periodically rotates for fair energy consumption. To do so, the nodes wake up periodically.

Hierarchical Routing Protocols

- The main objective of hierarchical routing is to reduce energy consumption by classifying nodes into clusters.
- In each cluster, a node is selected as the leader or the cluster head. The different schemes for hierarchical routings mainly differ in how the cluster head is selected and how the nodes behave in the inter and intra-cluster domain.
  - ✓ i). LEACH (Low Energy Adaptive Clustering Hierarchy)
  - ✓ Ii) PEGASIS (Power-Efficient Gathering in Sensor Information Systems)
  - ✓ iii). TEEN (Threshold Sensitive Energy Efficient Sensor Network Protocol)
  - ✓ iv). DirQ (Directed Query Dissemination)

LEACH (Low Energy Adaptive Clustering Hierarchy)

- In LEACH the role of the cluster head is periodically transferred among the nodes in the network in order to distribute the energy consumption.
- The performance of LEACH is based on rounds. Then, a cluster head is elected in each round. For this election, the number of nodes that have not been cluster heads and the percentage of cluster heads are used. Once the cluster head is defined in the setup phase, it establishes a TDMA schedule for the transmissions in its cluster.
- This scheduling allows nodes to switch off their interfaces when they are not going to be employed. The cluster head is the router to the sink and it is also responsible for the data aggregation. As the cluster head controls the sensors located in a close area, the data aggregation performed by this leader permits to remove redundancy.

LEACH (Low Energy Adaptive Clustering Hierarchy)

- ✓ Set-up phase
- ✓ Steady-phase.
- In the set- up phase, some sensor nodes are selected as cluster heads (CHs) according to certain rules and other nodes join in the clusters as member nodes.
- In the steady-state phase, the CHs collect and aggregate the data coming from their own cluster members and then transmit them to a base station (BS).

PEGASIS (Power-Efficient Gathering in Sensor Information Systems)

- The algorithm forms chains of the sensor nodes. Based on this structure, each node transmits to and receives from only one closest node of its neighbors.
- The nodes adjust the power of their transmissions. The node performs data aggregation and forwards it the node in the chain that communicates with the sink. In each round, one node in the chain is elected to communicate with the sink. The chain is constructed with a greedy algorithm.

TEEN (Threshold Sensitive Energy Efficient Sensor Network Protocol)

- TEEN is other hierarchical protocol for reactive networks that responds immediately to changes in the relevant parameters. In this protocol a clusters head (CH) sends a hard threshold value and a soft one.
- The nodes sense their environment continuously. The first time a parameter from the attribute set reaches its hard threshold value, the node switches on its transmitter and sends its data.
- The nodes then transmits data in the current cluster period if the following conditions are true: the current value of the sensed attribute is greater than the hard threshold, and the current value of the sensed attribute differs from sensed value by an amount equal to or greater than the soft threshold. Both strategy looks to reduce energy spend transmitting messages.

TEEN (Threshold Sensitive Energy Efficient Sensor Network Protocol)

✓ LIMITATIONS

- If the thresholds are not reached, the nodes will never communicate; the user will not get any data from the network at all and will not come to know even if all the nodes die.
- Not well suited for applications where the user needs to get data on a regular basis.

DirQ (Directed Query Dissemination)

- The main objective is that the queries are just propagated by the minimum number of nodes that ensure that the queries arrive at the nodes that are able to service the query.
- Certain information is exchanged in the network. The periodicity of the update messages depend on the rate of variation of the physical parameters that the network is sensing. Then, each node autonomously maintains its own threshold (δ).
- If a sensor node has a value V of a desired parameter and the next measurement period gets the same or a similar value in the interval between $(\delta - V, V + \delta)$ then it decides not to send anything to sink. However, if the sink does not receive any message from a specific node then it assumes that this node has a measured value that has not changed much from what has been reported recently.

DirQ (Directed Query Dissemination)

- To allow a precise delivery of applications, all network nodes must be capable of storing information which can be considered a disadvantage depending on the amount of information stored in the topology and the number of nodes.
- DirQ is a protocol suitable for situations where the number of requests is high and times of transmission of requests are known.

Multipath Routing Protocols

- Source knows multiple routes to a destination. The routes can be simultaneously used or one of them can be active while the others are maintained for future needs.

✓ SAR (Sequential Assignment Routing)

✓ Maximum Lifetime Routing in Wireless Sensor Networks

✓ Energy Aware Routing in Wireless Sensor Networks

✓ M-MPR (Mesh Multipath Routing)

SAR (Sequential Assignment Routing)

- It is based on the association of a priority level to each packet. Additionally, the links and the routes are related to a metric that characterizes their potential provision of quality of service.
- This metric is based on the delay and the energy cost. Then, the algorithm creates trees rooted at the one-hop neighbors of the sink.
- Several parameters such as the packet priority, the energy resources and the QoS metrics are taken into account. The protocol must periodically recalculate the routes to be prepared in case of failure of one of the active nodes.

Maximum Lifetime Routing in Wireless Sensor Networks

- It combines the energy consumption optimization with the use of multiple routes. In this algorithm an active route (also called the primary route) is monitored to control its residual energy. Meanwhile other routes can be discovered.
- If the residual energy of the active route does not exceed the energy of an alternative route, the corresponding secondary route is then used.

Energy Aware Routing in Wireless Sensor Networks

- Once multiple paths are discovered, this algorithm associates a probability of use to each route
- This probability is related to the residual energy of the nodes that form the route but it is also considers the cost of transmitting through that route.

M-MPR (Mesh Multipath Routing)

- Two operation modes.

✓ D-MPR with selective forwarding

✓ D-MPR with data replication

- Disjoint MPR (D-MPR) with Selective Forwarding each packet is individually analyzed by the source and it is routed through different routes.
- D-MPR with data replication is based on the simultaneous transmission of multiple copies of the same packet through different routes.
- Specifically, all the known routes that communicate the source and the destination propagate the packet. For the route discovery, information about the position of the nodes and about their residual energy is exchanged.

Comparison

- Hierarchical and geographic routing protocols are considered scalable solutions.
- Keeping a hierarchical structure demands the coordination of nodes by means of transmitted messages. In dense networks, the use of the cluster-based structure makes up for this cost. However, this benefit does not hold in small networks.
- A similar behavior is observed for geographic approaches. When the network is composed of a significant number of nodes in an extended area, the exchange of messages to establish the location of neighbors becomes negligible compared to the reduction of transmissions that the geographic algorithm achieves. In these two approaches, the topology of the network must be stable.

Comparison

- On the contrary, the cluster structure and the geographic information must be frequently updated which leads to additional costs. For instance, in stable networks, PEGASIS is usually more efficient than LEACH. However, the construction of the chains in PEGASIS could lead to significant resource consumption in highly dynamic topologies.
- Attribute-based techniques become relevant when the data sensed by the nodes are not usually of interest to the rest of the nodes. Under these circumstances, the algorithms could greatly reduce the network overhead. The decision about which algorithm should be selected mainly depends on the data delivery model that the application forces. When the communication should be triggered by events,
- SPIN is the most suitable attribute-based algorithm. However, Directed Diffusion, Rumor, COUGAR and ACQUIRE are query-driven protocol. They roughly differ in how the query is propagated and resolved in the network.

Comparison

- Concerning the multipath routing protocols, their main disadvantage lies on the cost of maintaining the paths. This cost comprises memory resources as well as network overhead. Therefore, they are not appropriate for networks critically constrained by their reduced batteries. However, they become necessary when reliability is a strong requirement in the application business.