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Networked Embedded Applications

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CS 5 : (WSN Routing)

5	**WSN Routing** Introduction Optimization-based Data-centric Cluster-based Location-based QoS Enabled	

Introduction to Routing

- What is Routing?
  - **Routing** is the process of selecting a path for traffic in a network or between or across multiple networks.
  - In packet-switching networks, routing is the higher-level decision-making that directs network packets from their source toward their destination through intermediate network nodes by specific packet forwarding mechanisms.
  - Packet forwarding is the transit of logically addressed network packets from one network interface to another.
  - Intermediate nodes are typically network hardware devices such as routers, bridges, gateways, firewalls, or switches.

Introduction to Routing

- What is Routing? (continued….)
  - The routing process usually directs forwarding on the basis of routing tables, which maintain a record of the routes to various network destinations.
  - Thus, constructing routing tables, which are held in the router's memory, is very important for efficient routing.
  - Most routing algorithms use only one network path at a time.
  - Multipath routing techniques enable the use of multiple alternative paths.

Introduction to Routing

- Delivery Schemes
  - Routing schemes differ in how they deliver messages:
    - unicast delivers a message to a single specific node.
    - anycast delivers a message to any one out of a group of nodes, typically the one nearest to the source.
    - multicast delivers a message to a group of nodes that have expressed interest in receiving the message.
    - geocast delivers a message to a geographic area.
    - broadcast delivers a message to all nodes in the network.
  - Unicast is the dominant form of message delivery on the Internet.

Introduction to Routing

- Desirable properties of a router are as follows:
  - Correctness and simplicity: The packets are to be correctly delivered. The simpler the routing algorithm, it is better.
  - Robustness: Ability of the network to deliver packets via some route, even in the case of failures.
  - Stability: The algorithm should converge to equilibrium fast in the case of changing conditions in the network.
  - Fairness and optimality: obvious requirements, but conflicting.
  - Efficiency: Minimum overhead.

Introduction to Routing

- While designing a routing protocol it is necessary to take into account the following design parameters:
  - Performance Criteria: Number of hops, Cost, Delay, Throughput, etc
  - Decision Time: Per packet basis (Datagram) or per session (Virtual-circuit) basis
  - Decision Place: Each node (distributed), Central node (centralized), Originated node (source)
  - Network Information Source: None, Local, Adjacent node, Nodes along route, All nodes
  - Network Information Update Timing: Continuous, Periodic, Major load change, Topology change

Introduction to Routing

- Routing Algorithm Metrics (system / standard of measurements):
  - Routing tables contain information used by switching software to select the best route.
  - Routing algorithms have used many different metrics to determine the best route.
  - Path length is the most common routing metric. Some routing protocols allow network administrators to assign arbitrary costs to each network link. In this case, path length is the sum of the costs associated with each link traversed.
  - Hop count, a metric that specifies the number of passes through internetworking products, such as routers, that a packet must pass through in a route from a source to a destination.

Introduction to Routing

- Routing Algorithm Metrics (system/standard of measurements):
  - Routing delay refers to the length of time required to move a packet from source to destination through the internet.
  - The delay depends on many factors, including the bandwidth of intermediate network links, the port queues (receive and transmit queues in the routers) at each router along the way, network congestion on all intermediate network links, and the physical distance to be travelled. Because delay is a conglomeration of several important variables, it is a common and valuable metric.

Introduction to Routing

- Routing Algorithm Metrics (system / standard of measurements):
  - Bandwidth refers to the available traffic capacity of a link.
  - All other things being equal, a 10-Mbps Ethernet link would be preferable to a 64-kbps leased line.
  - Although bandwidth is a rating of the maximum attainable throughput on a link, routes through links with greater bandwidth do not necessarily provide better routes than routes through slower links.
  - For example, if a faster link is busier, the actual time required to send a packet to the destination could be greater.
  - Load refers to the degree to which a network resource, such as a router, is busy. Load can be calculated in a variety of ways, including CPU utilization and packets processed per second. Monitoring these parameters on a continual basis can be resource-intensive itself.

Introduction to Routing

- Routing Algorithm Metrics (system / standard of measurements):
  - Communication cost is another important metric, especially because some companies may not care about performance as much as they care about operating expenditures. Although line delay may be longer, they will send packets over their own lines rather than through the public lines that cost money for usage time.
  - Reliability, in the context of routing algorithms, refers to the dependability (usually described in terms of the bit-error rate) of each network link. Some network links might go down more often than others. After a network fails, certain network links might be repaired more easily or more quickly than other links. Any reliability factor can be taken into account in the assignment of the reliability ratings, which are arbitrary numeric values, usually assigned to network links by network administrators.

WSN Routing

- The main task of wireless sensor nodes is to sense and collect data from a target domain, process the data, and transmit the information back to specific sites where the underlying application resides.
- Achieving this task efficiently requires the development of an energy-efficient routing protocol to set up paths between sensor nodes and the data sink.

WSN Routing

- Data Dissemination and Gathering
  - Data dissemination is a process by which data and queries for data are routed in the sensor network.
  - In a scope of data dissemination, a **source** is the node that generates the data and a node that is interested in data is called **sink**.
  - Data gathering is to transmit data that has been collected by the sensor nodes to the base station.

WSN Routing

- Routing Challenges
  - Network Scale and Time-Varying Characteristics:
    - The densities of the WSNs may vary widely, ranging from very sparse to very dense.
    - In many applications, the sensor nodes numbering in the hundreds, if not thousands are deployed in an ad-hoc and often unsupervised manner over wide coverage areas.
    - In these networks, the behaviour of sensor nodes is dynamic and highly adaptive.

WSN Routing

- Routing Challenges
  - Resource Constraints:
    - Energy is a key concern in WSNs, which must achieve a long lifetime while operating on limited battery reserves.
    - Also, the WSN nodes have low technical specifications that must be taken into consideration when designing a WSN routing protocol.

WSN Routing

- Routing Challenges
  - Sensor Applications Data Models:
    - The data model describes the flow of information between the sensor nodes and the data sink.
    - These models depends on the nature of the application.
    - The need to support a variety of data models increases the complexity of the routing design problem.

WSN Routing

- Routing Strategies in Wireless Networks
  - Routing in WSNs is challenging due to distinguishing it from other wireless networks like mobile ad hoc networks or cellular networks.
    1. It is not possible to build a global addressing scheme for a large number of sensor nodes. Thus, traditional IP-based protocols may not be applied to WSNs. In WSNs, sometimes getting the data is more important than knowing the IDs of which nodes sent the data.
    2. In contrast to typical communication networks, almost all applications of sensor networks require the flow of sensed data from multiple sources to a particular BS.
    3. Sensor nodes are tightly constrained in terms of energy, processing, and storage capacities. Thus, they require careful resource management.

WSN Routing

- Routing Strategies in Wireless Networks

4. In most application scenarios, nodes in WSNs are generally stationary after deployment except for, may be, a few mobile nodes.
5. Sensor networks are application specific, i.e., design requirements of a sensor network change with application.
6. Position awareness of sensor nodes is important since data collection is normally based on the location.
7. Finally, data collected by many sensors in WSNs is typically based on common phenomena, hence there is a high probability that this data has some redundancy.

WSN Routing

- Routing Strategies in Wireless Networks
  - The task of finding and maintaining routes in WSNs is nontrivial since energy restrictions and sudden changes in node status (e.g., failure) cause frequent and unpredictable topological changes.
  - To minimize energy consumption, routing techniques proposed for WSNs employ some well-known routing strategies, e.g., data aggregation and in-network processing, clustering, different node role assignment, and data-centric methods were employed.

WSN Routing

- Routing Design Considerations
  - 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.
    - Node deployment
    - Energy considerations
    - Data delivery model
    - Node/link heterogeneity
    - Fault tolerance
    - Scalability
    - Network dynamics
    - Transmission media

WSN Routing

- Routing Design Considerations
  - Connectivity
  - Coverage
  - Data aggregation / converge cast
  - Quality of service

WSN Routing

- Routing Design Considerations
  - 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 predetermined paths.
    - In random node deployment, the sensor nodes are scattered randomly creating an infrastructure in an ad hoc manner.

WSN Routing

- Routing Design Considerations
  - Energy Considerations
    - 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.
    - 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.

WSN Routing

- Routing Design Considerations
  - Data Delivery Model
    - Time-driven (continuous)
      - Suitable for applications that require periodic data monitoring
    - Event-driven
      - React immediately to sudden and drastic changes
    - Query-driven
      - Respond to a query generated by the BS or another node in the network
    - Hybrid
      - The routing protocol is highly influenced by the data reporting method

WSN Routing

- Routing Design Considerations
  - Node / Link Heterogeneity
    - Depending on the application, a sensor node can have a different role or capability.
    - The existence of a heterogeneous set of sensors raises many technical issues related to data routing.
    - Even data reading and reporting can be generated from these sensors at different rates, subject to diverse QoS constraints, and can follow multiple data reporting models.

WSN Routing

- Routing Design Considerations
  - Fault Tolerance
    - Some sensor nodes may fail or be blocked due to lack of power, physical damage, or environmental interferences
    - It may require actively adjusting transmission 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

WSN Routing

- Routing Design Considerations
  - Scalability
    - The number of sensor nodes deployed in the sensing area may be on the order of hundreds or thousands, or more.
    - Any routing scheme must be able to work with this huge number of sensor nodes.
    - In addition, sensor network routing protocols should be scalable enough to respond to events in the environment.

WSN Routing

- Routing Design Considerations
  - Network Dynamics
    - Routing messages from or to moving nodes is more challenging since route and topology stability become important issues
    - Moreover, the phenomenon can be mobile (e.g., a target detection/ tracking application).

WSN Routing

- Routing Design Considerations
  - Transmission Media
    - 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 MAC.
      - TDMA (time-division multiple access)
      - CSMA (carrier sense multiple access)

WSN Routing

- Routing Design Considerations
  - Connectivity
    - High node density in sensor networks precludes them from being completely isolated from each other.
    - However, may not prevent the network topology from being variable and the network size from shrinking due to sensor node failures.
    - In addition, connectivity depends on the possibly random distribution of nodes.

WSN Routing

- Routing Design Considerations
  - Coverage
    - In WSNs, each sensor node obtains a certain view of the environment.
    - A given sensor's view of the environment is limited in both range and accuracy.
    - It can only cover a limited physical area of the environment.

WSN Routing

- Routing Design Considerations
  - Data Aggregation/Convergecast
    - Since sensor nodes may generate significant redundant data, similar packets from multiple nodes can be aggregated to reduce the number of transmissions.
    - Data aggregation is the combination of data from different sources according to a certain aggregation function.
    - Convergecasting is collecting information “upwards” from the spanning tree after a broadcast.

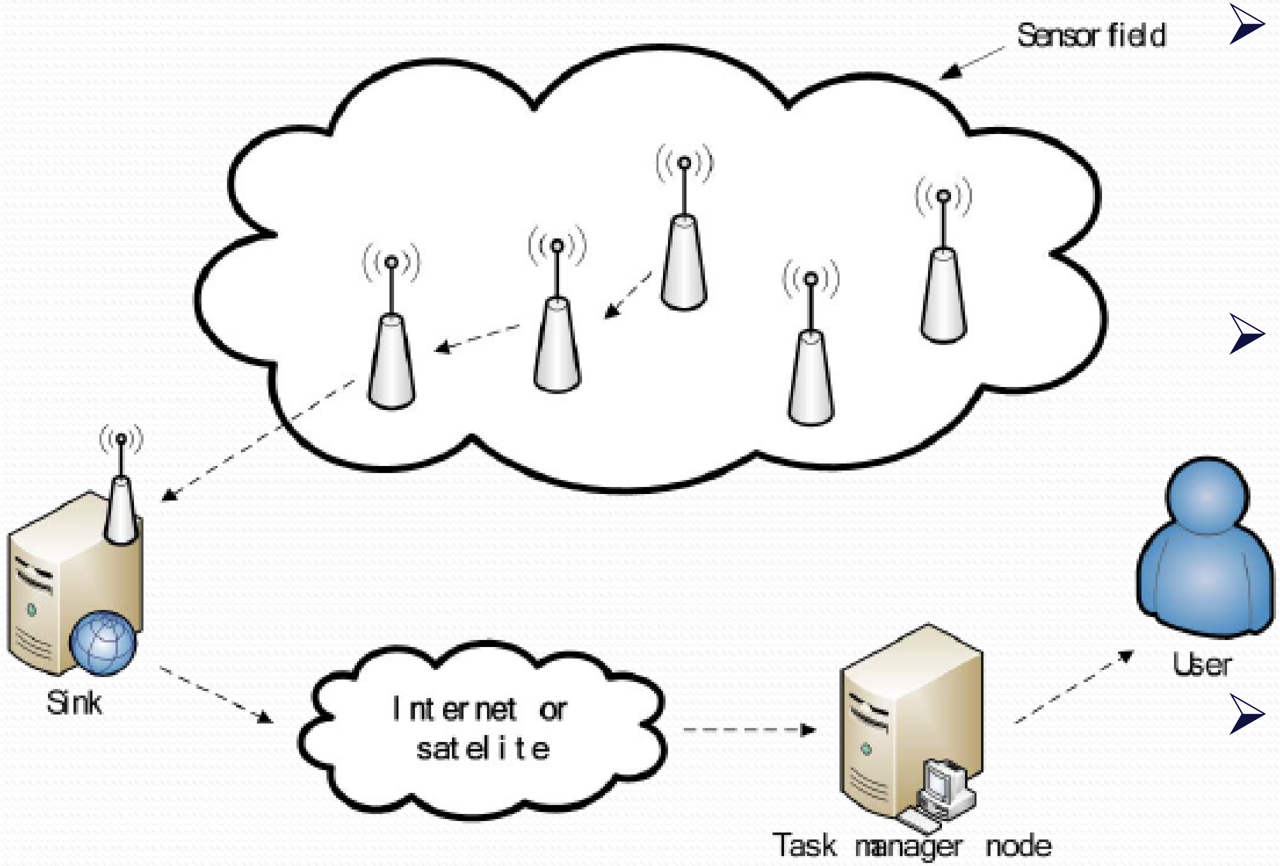
WSN Routing

- Routing Design Considerations
  - Quality of Service
    - In many applications, conservation of energy, which is directly related to network lifetime.
    - As energy is depleted, the network may be required to reduce the quality of results in order to reduce energy dissipation in the nodes and hence lengthen the total network lifetime.

Traditional Routing vs Routing in WSNs

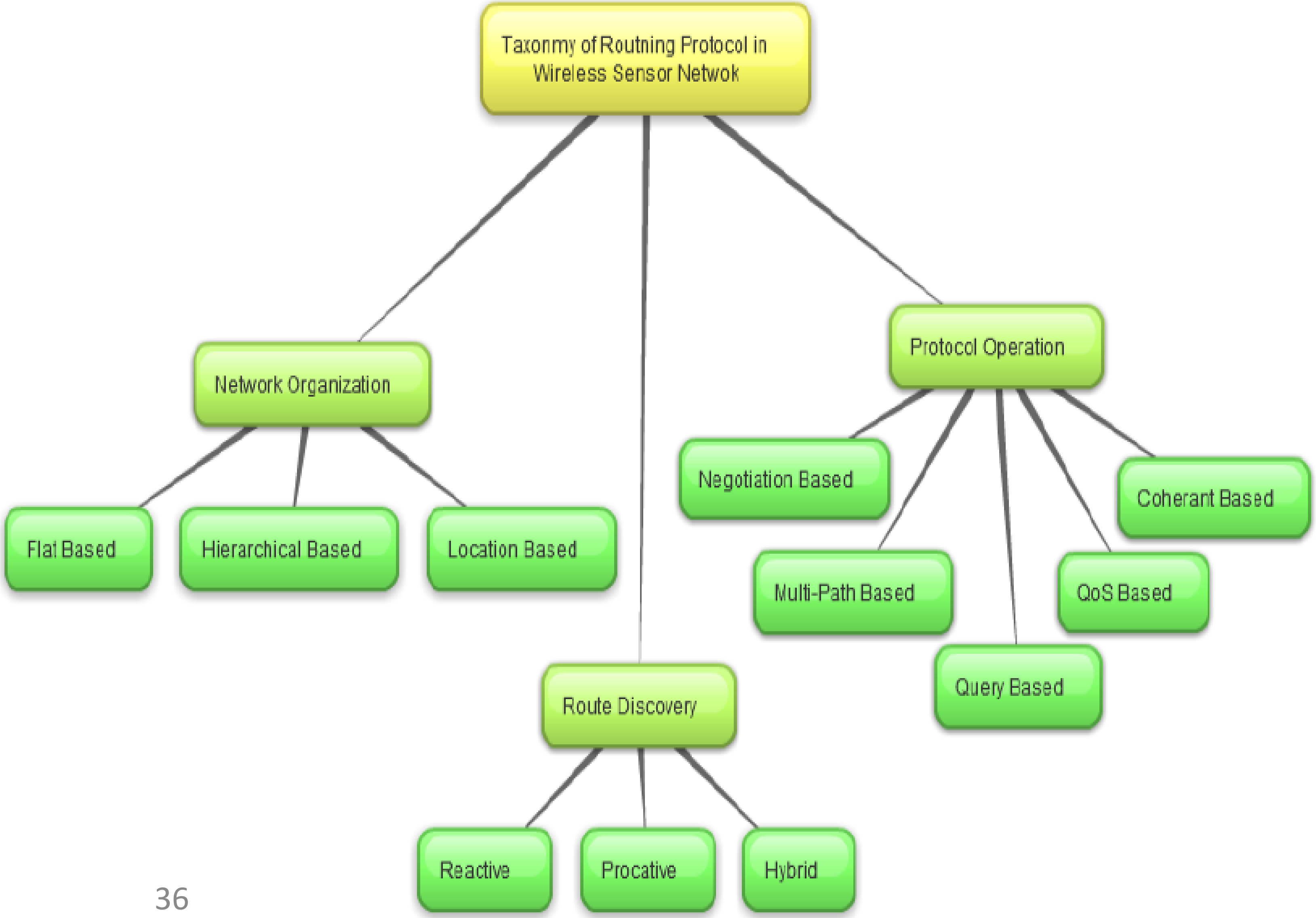
Traditional	WSNs
Wired	Wireless
Reliable connections	Error-prone connections
Symmetrical links	Asymmetric links
Unlimited power	Scarce power
Generally non-real-time	Typically real-time
Each individual node is important	Aggregate behaviour counts
Location-independent	Location-dependent
Usually resource is abundant	Resource-limited

WSN Communication Architecture



- The sensor nodes are usually scattered in a sensor field.
- Sensor nodes can collect data and route data back to sink.
- The sink may communicate with the task manager node via Internet or Satellite.

Routing protocols in WSNs



Routing protocols in WSNs

- In WSN, the data routing is classified according to the three main categories, namely flat, hierarchical and location based routing.

Data Routing	Routing protocols
Flat routing	SPIN, DD, RR, MCFA, GBR, IDSQ, CADR, EAR.
Hierarchical routing	LEACH, PEGASIS, TEEN & APTEEN, MECN, SOP, TTDD, HPAR, and VGA.
Location based routing	GAF, GEAR, MFR.

Routing protocols in WSNs

- Terms Related To WSN Routing Protocol.

Routing Protocols	Designing Characteristics
FBR	Flat Based Routing
HR	Hierarchical Routing.
LBR	Location Based Routing.
NB	Negotiation Based.
MBR	Multipath Based Routing.
QBR	Query Based Routing.
QOSBR	QOS Based Routing.
CBR	Coherent Based Routing.
SPIN	Sensor Protocols for Information via Negotiation.
DD	Directed Diffusion.
RR	Rumor Routing.
GBR	Gradient Based Routing.
CADR	Constrained Anisotropic Diffusion Routing.

Routing protocols in WSNs

➢ Terms Related To WSN Routing Protocol.

Routing Protocols	Designing Characteristics
EAR	Energy Aware Routing
LEACH	Low Energy Adaptive Clustering Hierarchy.
TEEN & APT EEN	[Adaptive Periodic] Threshold sensitive Energy efficient sensor network.
PEGASIS	Power efficient gathering in sensor information systems.
VGA	Virtual Grid Architecture Routing.
SOP	Self organizing protocol.
GAF	Geographic Adaptive Fidelity.
SPAN	An efficient Routing Protocol.
GEAR	Geographical and Energy Aware Routing.
SAR	Sequential Assignment Routing.
SPEED	A real time routing protocol.
ReBR	Reactive Based Routing.
PrBR	Proactive Based Routing.

Routing protocols in WSNs

- Terms Related To WSN Routing Protocol.

Routing Protocols	Designing Characteristics
HBR	Hybrid Based Routing.
MCFA	Minimum Cost Forwarding Algorithm
IDSQ	Information-Driven Sensor Querying
MECN	Minimum Energy Communication Network
TTDD	Two-Tier Data Dissemination
HPAR	Hierarchical Power-Aware Routing
MFR	Most Forward within Radius
DIR	Directional Routing
GEDIR	Geographic Distance Routing
GOAFR	Greedy Other Adaptive Face Routing

WSN Routing Routing Based on Route Discovery

- 3 strategies for constructing routing tables:
- Proactive
  - Table driven
  - Relies on periodic dissemination of routing information to maintain consistent and accurate routing tables across all nodes of the network
- Reactive
  - Establish routes to a limited set of destinations on demand.
  - Do not typically maintain global information across all nodes of the network.
  - Therefore, rely on a dynamic route search to establish paths between a source and a destination.
  - This typically involves flooding a route discovery query, with the replies traveling back along the reverse path.

WSN Routing

Routing Based on Route Discovery

- 3 strategies for constructing routing tables:
- Hybrid
  - Rely on the existence of network structure to achieve stability and scalability in large networks.
  - The network is organized into mutually adjacent clusters, which are 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 and reactive routing is used across clusters.
  - The main challenge is to reduce the overhead required to maintain the clusters.

WSN Routing Techniques

- Flat network architecture
  - All nodes are considered peers.
  - A flat network architecture has minimal overhead
- Cluster architecture
  - Network is divided into clusters
  - High energy nodes are elected as cluster leader (Heads)
  - Good for optimizing energy and hence lifetime of the network

WSN Routing Techniques

- Data-centric approach
  - Disseminate interest within the network.
  - Uses attribute-based naming, whereby a source node queries an attribute for the phenomenon rather than an individual sensor node.
  - The interest dissemination is achieved by assigning tasks to sensor nodes and expressing queries to relative to specific attributes.
  - Different strategies can be used to communicate interests to the sensor nodes, including broadcasting, attribute-based multicasting etc

WSN Routing Techniques

- Location-based routing
  - 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.
  - Such a query may specify a specific area where a phenomenon of interest may occur

Performance Metrics of WSN Routing Protocols

- Average delay per packet or delivery
- Energy efficiency (very important)
- Time to get the network partitioned (important for algorithms aim to maintain network connectivity as long as possible)

The most important objective of a routing protocol is to ***maximise the network lifetime***.

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: 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
  - Energy of a node is not taken into picture.

Thank You