Routing Protocols in Wireless Sensor Network: A Survey

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***Abstract* - Wireless Sensor Networks (WSNs) is a collection of thousands of tiny nodes that are capable of sensing, computing, and wireless communications. Energy consumption is the major design issue which arises while designing routing protocols for wireless sensor network. . Since wireless sensor network protocols are application specific, so the focus has been given to the routing protocols that might differ depending on the application and network architecture. The study of various routing protocols for sensor networks presents a classification for the various approaches pursued. The routing protocols have been categorized into two type based on network structure and based on the type of operation performed by the protocols. Various protocols have been examined along with their pros and cons.**

***IndexTerms* – Wireless Sensor Network(WSN), Base Station(BS), Cluster Head(CH)**

I. INTRODUCTION

A wireless sensor network (WSN) is a network of small, low powered sensor nodes that are spatially distributed to monitor the various environmental phenomenons. These sensor nodes are light weight in nature, have limited computational capability and communication bandwidth. These sensor nodes are small, smart sensing and communicating devices that are programmed for sensing the environment conditions (like fire, humidity, etc), gathering the data, and processing it to draw some meaningful information. The processed information is then transmitted from node to node towards the base station where the actual data is collected, analyzed and monitored. These sensor nodes may be mobile or stationary located randomly on a dynamically changing environment. Each sensor node is equipped with a small battery which is not rechargeable due to the kind of environment in which these nodes are placed. Unlike the other networks whose performance deteriorates with growth in the size of their network, WSN tend to get stronger and performs much better as the number of nodes in the network increases.

Wsn Vs Adhoc Network [1]

S.No	WSN	AdHoc Networks
1.	Sensor networks are mainly focused on information gathering	AdHoc Networks are designed for the distribution of information.
2.	Sensors are deployed by one owner.	AdHoc Networks could be deployed by several unrelated units.
3.	Magnitude of sensor nodes is large.	Magnitude of nodes in these networks is relatively smaller.
4.	Have limited energy and memory and are not easily rechargeable in nature.	Have unlimited power and memory and are easily rechargeable.
5.	Data flows either from the sink to the nodes or from the nodes to the sink.	Data flow is irregular.
6.	Have short range communication	Have enough communication range
7.	Have changing network topology due to fading and failures.	Have fixed network topology.
8.	Sensor nodes don't have global IDs.	Global Addressing scheme can be applied to these networks.

Architecture of Wireless Sensor Networks

A sensor network is a collection of sensor nodes that are densely deployed either inside the phenomenon or very close to it. Sensor networks are mainly focused on information gathering. These are the networks that have changing network topology due to failures and fading. Sensor networks are application specific in nature, i.e., design requirements of a sensor network change with application. The data collected by many sensors in WSNs is redundant as it is based on a common phenomenon. The Structure of a typical wireless sensor network has four main parts. These are:

1. Sensor Field: This is the quarter or the territory in which the sensor nodes are forever deployed or placed. The rectangular field that surrounds the sensor nodes.
2. Sensor Nodes: Sensors nodes are the main part of the wireless sensor network. Sensors are tiny devices, which can sense various activities in their residing environment. It is the responsibility of the sensor nodes to gather information and transmit to the sink or base station.
3. Sink: Sink receives data from various nodes, and then process and stores all the data collected from the nodes.

4. Task Manager: The tasks Manger acts as a gateway to other networks. The base station also called the centralized control room for data extraction, spread information back and forth to the networks, data processing and storage center with user access controls.[2]

Hardware Components of Sensor Node

Each of the sensor node consists of five major components [2]. These are:

1. Sensors: It consists of sensors which generate measurable reaction signals due to changes in environments like weather conditions, pressure, humidity and temperature. Analog signal sensed data are digitized by an analog-to-digital converter (ACD) and transferred to the embedded processor for additional processing. A sensor node can consist of numerous sensors integrated in or connected to the node. The primary objective for providing power supply for sensor nodes is to ensure that enough energy is made available to the nodes at the least cost, volume, weight, recharge time and longer lifespan.[2]
2. Central Processing Unit(CPU): The main task of the CPU is to perform the processing of data and managing the various other hardware components of the sensor node. It is also responsible for performing the programming tasks.[2]
3. Power Supply: The consumption of energy in sensor nodes is through sensing data, processing of data and communication. Power is more likely to be consumed by communication of data than when compared with data processing and also sensing data. Battery and capacitors act as storage facilities for power and then supply the power for the sensor nodes.[2]
4. Communication Unit (Transceiver): The actual wireless communication of the sensor nodes is the responsibility of the transceiver. There are four operational states of transceiver:
   - Transmit: the state when the data is sent to other nodes or to the base station.
   - Receive: the state of collecting the packets transmitted by other nodes.
   - Idle: the state in which the transceiver is available to receive the packets but not ready to start.
   - Sleep: to limit the ability of the transceiver to receive any data we prefer to switch off considerable sections of transceiver [2].
   - Memory: As the sensor networks are application dependent in nature, so different type of sensor network requires unique memory requirements. There are three types of in built memories of sensor nodes: chip flash memory, RAM of microcontroller and external flash memory.[2]

Advantages of WSN:[3]

- Network setups can be done without fixed infrastructure.
- Ideal for the non-reachable places such as across the sea, mountains, rural areas or deep forests.
- Flexible if there is ad hoc situation when additional workstation is required.
- Implementation cost is cheap.

Disadvantages of WSN:[3]

- Less secure because hackers can enter the access point and get all the information.
- Lower speed compared to a wired network.
- More complex to configure than a wired network.
- Easily affected by surroundings (walls, microwaves, large distances due to signal attenuation, etc.)

Applications of WSN [3]

- Intruder detection in military surveillance:
- Detection of forest fire/ Floods
- Seismic activity detection
- Detection of ocean environment
- Monitoring humidity, temperature and light etc
- Environmental conditions monitoring
- Health applications

Traffic Patterns In WSN[5]:

Based on the main function of the WSN to collect the data, they exhibit different traffic patterns. In WSN sensor nodes send their data persistently to the base station while the base station occasionally send control messages to the sensor nodes. There are five types of traffic pattern exhibited by WSNs. These are:

1. Local Communication: This type of pattern is used by the sensor nodes to broadcast their status to their neighbor nodes. It is also used to transmit data directly between two nodes.
2. Point-to-Point: It is used to send a data packet from an arbitrary node to another arbitrary node. It is commonly used in a wireless LAN environment.
3. Convergence: In this type, data is collected from multiple nodes and is transmitted to a single node.
4. Aggregation: In this type, data packets from multiple nodes can be processed by some common node and the common node then sends the aggregated value to the base station.
5. Divergence: The base station uses this pattern to transmit control messages or commands to the sensor nodes.

Routing In WSN [4]

Routing is a process of determining a path between source and destination upon request of data transmission. Main aim of any routing strategy is to minimize the energy consumption and maximize the lifetime of the network.

Routing Protocol Design Challenges[4]

WSNs suffer from various network constraints like limited energy, bandwidth, resources, storage, etc. due to which designing routing protocols becomes more challenging. The various challenges faced while designing a routing protocol are:

1. Limited Energy Capacity: Sensor nodes being battery powered have limited energy capacity. They will not function properly as their energy crosses certain threshold value which will further affect the network performance. Thus routing protocol should be energy efficient to prolong the network lifetime and increase the network performance.
2. Limited hardware resources: Sensor nodes can perform only limited computational functionalities due to limited processing and storage capacities. These hardware constraints thus present many challenges in software development and routing protocol design.
3. Massive and random node deployment: Sensor node deployment can be either manual or random due to the application dependent nature of the sensor nodes which affects the network performance. Thus the deployment of the sensor nodes should be as such to enable energy efficient network operations.
4. 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 technique has been used to achieve energy efficiency and data transfer optimization in a number of routing protocols.
5. Scalability: Routing protocols should be able to scale with the network size.

II. Classification of Routing Protocols in WSN [5]

Routing is a process of determining a path between source and destination upon request of data transmission. Main aim of any routing strategy is to minimize the energy consumption and maximize the lifetime of the network. Finding and maintaining routes in WSNs is a major issue since energy constraints and unexpected changes in node status (e.g., inefficiency or failure) give rise to frequent and unforeseen topological alterations. Routing protocols in WSNs are classified on two basis:

1. Based on Network Structure: These are categorized further into three main types:
   a) Flat Network Routing
   b) Hierarchical Network Routing
   c) Location Network routing
2. Based on Protocol operation: These are categorized further in four types:
   a) Negotiation Based
   b) Coherent & Non-Coherent Based
   c) Multipath Based
   d) Quality of Service (QoS) Based

I. Network Structure Based: [5]

- This category is based on the way the nodes are connected and route the information i.e based on node deployment.
- There are usually two types of nodes deployment:
  - o Nodes with same level connections
  - oNodes with different hierarchy
- Types:
  - a. Flat Protocols
  - b. Hierarchical Protocols
  - c. Location Based Protocols

a) **Flat Protocols**:[5]

- In flat network, each node typically plays the same role and sensor nodes collaborate together to perform the sensing task.
- All the nodes in the network are treated equally.
- When a node wishes to send data, it will send the data using several hops to the sink. The probability of the nodes participation in the data transmission process is higher for those nodes that are around the sink than those nodes which are far away from the sink. So, the nodes which are around the sink will drain off their power soon. When compared to the nodes far from the sink.
- Types:

i) Pro-active or Table Driven Protocols

ii) Reactive or Source Initiated On demand Routing Protocols

iii) Hybrid Protocols: Hybrid protocols combine the advantages of both pro-active and re-active routing protocols; they locally use pro-active routing and inter-locally use re-active routing. This is partly based on the following two assumptions: a) Most communication in WSNs takes place between nodes that are close to each other, and b) Changes in topology are only important if they happen in the vicinity of a node. When a link fails or a node disappears on the other side of the network, it affects only the local neighborhoods; nodes on the other side of the network are not affected.

Table 1. Comparison of Pro-Active & Reactive Protocols [5]

Pro-Active	Reactive

1. Proactive protocols require a lot of routing information and maintain routing information independently of the need for communication in form of routing tables.	1. Reactive protocols are on demand and require less amount of routing information for each node and thus less energy consumption for the sensor nodes
2. No latency in route discovery, so they are suitable for real time traffic.	2. There is a delay due to route discovery, which is called route acquisition delay which may not be appropriate for real time communication.
3. Waste bandwidth and energy to periodic updates	3. Do not require periodic updating and so they save energy and bandwidth during inactivity.
4. Send update messages throughout the network periodically or when the topology changes.	4. There is no need to send the update message when topology changes

b) **Hierarchical Routing Protocols: [5]**

◦ The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes.

◦ Performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink.

◦ In a hierarchical architecture, higher energy nodes can be used to process and send the information while low energy nodes can be used to perform the sensing of the target.

◦ Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other layer is used for routing.

i) LEACH (Low Energy Adaptive Clustering hierarchy protocol): LEACH is a cluster-based protocol, which includes distributed cluster formation. It randomly selects a few sensor nodes as cluster heads (CHs) and rotate this role to evenly distribute the energy load among the sensors in the network. In LEACH, the cluster head (CH) nodes compress data arriving from nodes that belong to the respective cluster, and send an aggregated packet to the base station in order to reduce the amount of information that must be transmitted to the base station. uses a TDMA/CDMA MAC to reduce inter-cluster and intra-cluster collisions. However, data collection is centralized and is performed periodically.

Two phases:

a) Setup : Clusters organization and Cluster Heads selection(CH)

- A sensor node choses a random number r.
- If r > threshold then the node becomes the CH.
- Non CH nodes select to which cluster to belong after receiving advertisement message from the CHs
- Each CH creates a TDMA schedule and broadcast it to all the nodes in the cluster.

b) Steady: Data transfer

- Sensor nodes start sensing & transmitting data to the CHs
- CHs aggregate data and send it to the Base Station (BS)

After predetermined time the network goes back to the setup phase. [5]

ii) PEGASIS (Power-Efficient Gathering in Sensor Information Systems): PEGASIS is a near optimal chain-based protocol. The basic idea of the protocol is that in order to extend network lifetime, nodes need only communicate with their closest neighbors and they take turns in communicating with the base-station. When the rounds of all the nodes communicating with the base-station ends, a new round will start and so on. This reduces the power required to transmit data per round as the power draining is spread uniformly over all nodes.

PEGASIS has two main objectives.

- First, increase the lifetime of each node by using collaborative techniques and as a result the network lifetime will be increased.
- Second, allow only local coordination between nodes that are close together so that the bandwidth consumed in communication is reduced.

Unlike LEACH, PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the BS instead of using multiple nodes. [6]

Advantage of PEGASIS is that transmitting distance is reduced. Disadvantage is that there is no consideration about the location of the BS and energy of the nodes when one of the nodes is selected as the head node.

iii) TEEN (Threshold-sensitive Energy Efficient sensor Network protocol): Reactive Protocols (TEEN): The nodes react immediately to sudden and drastic changes in the value of a sensed attribute.

- At every cluster change time, the cluster-head broadcasts to its members
- Hard Threshold (HT): This is a threshold value for the sensed attribute. It is the absolute value of the attribute beyond which, the node sensing this value must switch on its transmitter and report to its cluster head.
- Soft Threshold (ST): This is a small change in the value of the sensed attribute which triggers the node to switch on its transmitter and transmit.
- The first time a parameter from the attribute set reaches its hard threshold value, the node switches on its transmitter and sends the sensed data.
- The sensed value is stored in an internal variable in the node, called the sensed value (SV).

- The nodes will next transmit data in the current cluster period, only when both the following conditions are true:
  - The current value of the sensed attribute is greater than the hard threshold.
  - The current value of the sensed attribute differs from SV by an amount equal to or greater than the soft threshold.[5]

Advantage: It works well in conditions like sudden change in some sensed attribute like temperature. Disadvantage: If the thresholds are not reached, the user will not get any data from the network at all and will not come to know even if all the nodes die. This scheme practical implementation would have to ensure that there are no collisions in the cluster.

iv) APTEEN (Adaptive Periodic Threshold-sensitive Energy Efficient sensor Network protocol): It is a hybrid protocol that changes the periodicity or threshold values used in the TEEN protocol according to the user needs and the type of the application. [6]

In APTEEN, the cluster-heads broadcasts the following parameters:

- Attributes (A): this is a set of physical parameters which the user is interested in obtaining information about.
- Thresholds: this parameter consists of the Hard Threshold (HT) and the Soft Threshold (ST).
- Schedule: this is a TDMA schedule, assigning a slot to each node.
- Count Time (CT): it is the maximum time period between two successive reports sent by a node.[6]

It aims at both capturing periodic data collections and reacting to time-critical events[5] As soon as the base station forms the clusters, the cluster heads broadcast the attributes, the threshold values and the transmission schedule to all nodes. After that the cluster heads perform data aggregation, which has as a result to save energy.[5]

Advantage: Nodes consume less energy. Disadvantage is its complexity & long delay times.

c) Location Based Protocols [5]

- Sensor nodes are addressed by means of their locations.
  - The distance between neighboring nodes can be estimated on the basis of incoming signal strengths.
  - Relative coordinates of neighboring nodes can be obtained by exchanging such information between neighbors.
- To save energy, some location based schemes demand that nodes should go to sleep if there is no activity.
- More energy savings can be obtained by having as many sleeping nodes in the network as possible.

II. Protocol Operation Based

In this the categorization of the protocol is done on the basis of the operation they are specified to carry out.

a) Coherent and Non-Coherent-Data Processing Based Protocols [5]: In coherent routing, the data is forwarded to aggregators after a minimum processing consisting of time-stamping & duplicate suppression tasks. In non-coherent data processing routing, nodes locally process the raw data before it is sent to other nodes for further processing.

i) SWE(Single Winner Algorithm) : A single aggregator node is elected for complex processing based on energy reserve and computational capability of that node.

Advantage: It builds a minimum hop spanning tree. Disadvantage is its complexity.

ii) MWE(Multiple Winner Algorithm): The MWE process makes each sensor in the network to have a set of minimum-energy paths to each Source Node (SN). After that, SWE is used to find the node that yields the minimum energy consumption. This node can then serve as the central node for coherent processing.

Advantage: Each sensor in the network to have a set of minimum-energy paths to each Source Node (SN). Disadvantage: Long delays and low scalability

b) Negotiation-Based Protocols: [5]

- They use meta-data negotiations to reduce redundant transmissions in the network. Negotiation-based routing protocols or Sensor Protocols for Information via Negotiation (SPIN) is among the early works to pursue a data-centric routing mechanism.
- Before transmitting data, nodes negotiate with each other to overcome implosion and overlap.
- Only useful information will be transferred
- Observed data must be described by meta-data

i) SPIN-BC(SPIN for broadcast): Designed for broadcast networks in which the nodes share a single shared channel.

- a node sends out a message and all the other nodes within a certain range of the sender receive it.
- A node, which has received an ADV message, does not immediately respond with an REQ message, but wait for a certain time before sending out the REQ message.
- In case that a different node receives the REQ message, it cancels its own request, in order to avoid redundant requests for the same message.
- After the advertising node receives an REQ message, it sends the data message only once because it is a broadcast network even though it might have got multiple requests for the same message.

Advantage: Better than SPIN-PP for broadcast networks by using cheap, one-to-many communication. Disadvantage: Has to wait for a certain time before sending out the REQ message.

ii) SPIN-EC(SPIN for Energy Conservation): The sensor nodes communicate using the same 3- way handshake protocol as in SPIN-PP but there is an energy conservation heuristic added to it. If a node receives an advertisement, it will not send out an REQ message if it does not have enough energy to transmit an REQ message and receives the corresponding DATA message.

Advantage: Whenever energy comes close to low-energy threshold, it adapts by reducing its participation. Disadvantage: Dosen't prevent nodes from receiving messages such as ADV, REQ below the low energy threshold.

iii) SPIN-PP (SPIN for Point to Point Communication): A three-stage handshake protocol
for point-to-point media is followed:

- ADV – data advertisement: Node that has data to share can advertise this by transmitting an ADV with meta-data attached
- REQ – request for data: Node sends a request when it wishes to receive some actual data
- DATA – data message: Contain actual sensor data with a meta-data header Usually much bigger than ADV or REQ messages

Advantage: Simplicity, implosion avoidance & minimal start up cost. Disadvantage: Does not guaranty the data delivery & consumes unnecessary power

iv) SPIN-RL (SPIN with Reliability): This protocol makes two changes to the above SPIN-BC protocol.

- 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 certain period of time, it sends out the request again. The important point of this protocol is that nodes have a limit on the frequency with which they resend the data messages.
- After having sent out a data message, a node will wait for a certain period of time before it responds to other requests for the same data message.

Advantage: Disseminates the data through a broadcast even when a network loses packets. Disadvantage: Time consuming

c) Multipath-Based Protocols: They achieve load balancing and are more resilient to route failures.

i) Routing On-demand Acyclic Multipath (ROAM): ROAM presents an on-demand distance-vector algorithm called Routing On-demand Acyclic Multipath (ROAM). It uses a concept called feasible distance to maintain routes and loop freedom. ROAM detects network partitions by requiring nodes to send update messages to neighboring routing whenever there is a change in distance to a certain destination.

Advantage: It can inform routers when destination is unreachable and prevent routers from sending unnecessary search packets. Disadvantage: It needs to send HELLO messages to maintain the active nodes.

ii) Label-based Multipath Routing (LMR): The LMR broadcasts a control message throughout the network for a possible alternate path. During the process, labels are assigned to the paths the message passes through. The label information is used for segmented backup path search if a disjoint path is not achievable. The LMR is designed to use only the localized information to find disjoint paths or segments to protect the working path. With one flooding, LMR can either find disjoint alternate paths or several segments to protect the working path.

Advantage: The label information can reduce the routing overhead & backup path setup delay. Disadvantage: Overhead to find alternate paths.

d) QoS-Based Protocols: The network has to balance between energy consumption and data quality. Whenever a sink requests for data from the sensed nodes in the network, the transmission has to meet specific level of quality.

i) Sequential Assignment Routing (SAR): Routing decision in SAR is dependent on three factors: energy resources, QoS on each path, and the priority level of each packet.

- To avoid single route failure, a multi-path approach is used and localized path restoration schemes are used.
- To create multiple paths from a source node, a tree rooted at the source node to the destination nodes (i.e., the set of base-stations (BSs)) is built. The paths of the tree are built while avoiding nodes with low energy or QoS guarantees.
- At the end of this process, each sensor node will be part of multi-path tree.
- The objective of SAR algorithm is to minimize the average weighted QoS metric throughout the lifetime of the network.
- If topology changes due to node failures, a path re-computation is needed.[6]

Advantage: Offers less power consumption and ensures fault-tolerance and easy recovery. Disadvantage: Overhead of maintaining the tables and states at each sensor node especially when the number of nodes is huge.

ii) SPEED: SPEED strive to ensure a certain speed for each packet in the network so that each application can estimate the end-to-end delay for the packets by dividing the distance to the BS by the speed of the packet before making the admission decision. Moreover, SPEED can provide congestion avoidance when the network is congested. The routing module in SPEED is called Stateless Geographic Non-Deterministic forwarding (SNFG) and works with four other modules at the network layer. Delay estimation at each node is basically made by calculating the elapsed time when an ACK is received from a neighbor as a response to a transmitted data packet. By looking at the delay values, SNGF selects the node, which meets the speed requirement. If it fails, the relay ratio of the node is checked, which is calculated by looking at the miss ratios of the neighbors of a node (the nodes which could not provide the desired speed) and is fed to the SNGF module.[6]

Advantage: It performs well in terms of end-to-end delay and miss ratio. Disadvantage: It does not perform well in heavy congestion.

III. CONCLUSION

The energy efficiency is a very important issue for the networks especially for WSNs which are characterized by limited battery capabilities. In our report routing protocols have been classified as flat, hierarchical, query-based, coherent and non- coherent based, negotiation-based, location-based, multipath-based, QoS-based based on either their network structure or based on the type of operation performed by the protocol. The flat protocols may be an ideal solution for a small network with fixed nodes. However, in a large network they become infeasible because of link and processing overhead. The hierarchical protocols try to solve this problem and to produce scalable and efficient solutions. Thus, hierarchical protocols are suitable for sensor networks with heavy load and wide coverage area. On the other hand, the location based protocols may be useful for high dynamic networks as they do not need a state in routers nor in packet header and does not cause flood in the search. They use location information in order to calculate the distance among nodes, thus minimizing the energy consumption and extend the lifetime of the network. The negotiation based protocols can perform close to the theoretical optimum in both point-to-point and broadcast networks. On the other hand, they cannot guarantee the successful delivery of data. The multipath protocols maintain multiple paths from nodes to sink. This ensures fault tolerance and easy recovery but as they need to find multiple paths they suffer from the overhead of maintaining the tables and states at each sensor node especially. The coherent-based routing protocol is an energy efficient

mechanism where only the minimum processing is done by the sensor node. At non-coherent data processing based on routing, the sensor nodes locally process the actual data and then send to the other nodes for further processing. Therefore, the application of the proper routing protocol will increase the network lifetime and at the same time it will ensure the network connectivity and efficient data delivery.

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