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Routing Protocols for WSNs

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Abstract
Wireless sensor network- a network with sensors ranging from small to large and having at least one base station –sink node . This ia a network is composed of multiple small and tricky sensors and at least a sink node or a base station. Thus, the primary problem in the wireless sensor network is the battery limitation of the sensor nodes applied in the network. Therefore, to boost the amount of energy of the sensor nodes, one should distribute the energy through the wireless sensor network. Therefore, the target for prolonging the lifetime is to design efficient and energy-aware protocols. Routing protocols can be divided into two categories, network structure-based or protocol operation-based.
This paper offers a thorough tutorial on the routing techniques in use for wireless sensor networks at present. Energy utilization and network lifetime are the two main considerations for Wireless Sensor Network . In the below-mentioned subsequent sections, we will discuss different routing protocols and their advantages and disadvantages. A sensor field contains many dedicated sensor nodes in a wireless sensor network, and these are backhauled to a central base station. The base station is where the collected information is stored for further processing and analysis.[1].

Keywords: Routing, base station, energy, sensor nodes, WSN

1. INTRODUCTION

WSNs (Wireless Sensor Networks) have been adopted in several applications, including the detection of troops and tanks on a battlefield, the calculation of traffic flow on roadways, the measurement of humidity and other factors in fields, and the tracking of personnel in buildings. A sensor node contains a sensing unit, power unit, and processing unit.
Following are the properties of Wireless Sensor Networks:
1. Power constraint
2. Nodes are prone to failures
3. Heterogeneous nodes
4. Do not have global identification
5. DYNAMIC NETWORK TOPOLOGY

2. APPLICATION OF WSNS

Sensor nodes are utilised in numerous application-specific events that require continuous monitoring and detection [2][3]. Several applications are listed below.

1. Personal heath monitoring.
2. Agriculture.
3. Inventory control system.
4. Greenhouse monitoring.
5. Forest fire and flood detection.
6. Battlefield surveillances and monitoring
7. Detects explosive material, biological, radiological, chemical, nuclear etc

3. ISSUES IN THE DESIGNING OF ROUTING PROTOCOL

Originally, Wireless Sensor Networks (WSNs) were primarily driven by the need for military applications, specifically for monitoring and gathering information on battlefields. Wireless sensor networks have been subsequently explored in various civilian application domains, including environmental monitoring, healthcare, production, and smart home systems. In order to achieve this diversification, it is necessary to take into account the following important design considerations of the sensor network:

Fault tolerance refers to the capability of a sensor network to maintain its capabilities without any interruption caused by failures of sensor nodes.Scalability is a crucial need for routing protocols as they need to be able to handle and adapt to significant increases in the number of sensor nodes in the environment field.

The sensor nodes can be installed in various environmental circumstances.

Power Consumption: Sensor nodes have a finite battery life.

Data delivery models refer to the methods used to establish the timing of data delivery from a node.

Data aggregation involves the fusion and transmission of data from the regular nodes to the clustehead of the cluster.

Quality of Service refers to the level of service quality that is necessary for the application.

Network dynamics: Sensor nodes possess mobility, resulting in a non-static sensor network.

4. ROUTING IN SENSORS NETWORK

Routing in wireless sensor networks is particularly complex because of the unique properties that differentiate them from exixting communication and wireless ad-hoc networks. WSNs have minimal infrastructure and the wireless links they use are known for their lack of reliability. The sensor nodes are densely planted either within the sink or in close proximity to it, and they possess limited power, computing capacity, and memory. Sensor nodes are highly prone to failures.

A multitude of sensor nodes are tightly distributed.

The main objective of a WSN is to generate information based on the data collected by each individual sensor, while also maximising the lifespan of the network. The limited capabilities of sensor nodes mandate the design of communication protocols that are energy-efficient.

Routing in Wireless Sensor Networks (WSNs) is an arduous task due to its significant difference from wireless ad-hoc networks and cellular networks. The difference arises from various factors:

1. Densely distribution of Sensor nodes.
2. Limited memory and power resources of Sensor nodes.

There are three main groups of Wireless sensor network routing protocols:

1. Flat-based routing protocol

2. Hierarchical routing protocol
3. Location-based routing protocol.

Flat based routing protocol:- It refers to a network structure where each node has an equal role and sensor nodes work together to carry out the sensing task.

Hierarchical Routing protocol:- In this routing, nodes with higher energy levels are responsible for processing and transmitting information, while nodes with lower energy levels are responsible for sensing in proximity to the target. Creating clusters and assigning specific tasks to cluster leaders will significantly enhance the overall lifespan of the network and improve energy efficiency.

Hierarchical routing is a highly effective method for reducing energy consumption in a cluster. It achieves this by aggregating data, which in turn reduces the number of messages that need to be transmitted to the sink node.

Nodes can fulfil distinct functions inside the network, such as serving as cluster heads or cluster members in hierarchical-based routing.

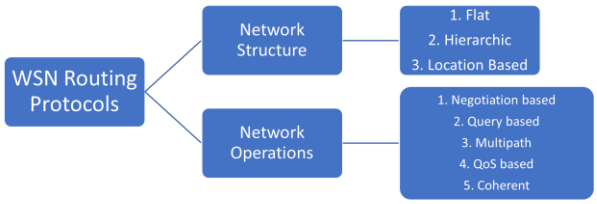

Fig. 1: Flowchart showing routing protocols in WSNs

Location based:- The location based sensor nodes are always identified by their location. The total Distance between neighbouring nodes can be calculated using incoming signal strength. To determine relative coordinates of neighbouring nodes, neighbours can exchange information or communicate with a satellite via GPS. In order to conserve the energy, certain location-based schemes require nodes to sleep when not in use. Location-based routing uses estimated sensor node placements to route all the data throughout the network.

1. Flat-based Routing Protocols

Multihop flat routing protocol is the first category of the routing protocols. In this, each node typically has a comparable job and collaborates with others to carry out the sensing task. This scenario subsequently resulted in the implementation of data-centric routing. Datacentric routing involves the sink sending queries to specific regions and then waiting for data from the sensors placed in those regions.

SPIN is the very first data-centric protocol. SPIN also negotiate the date between nodes to eliminate redundant information and conserve energy [4]. After this Directed Diffusion was developed. Subsequently, other alternative protocols have been suggested, either utilising Directed Diffusion or following to a similar concept [5]. This section provides a comprehensive explanation of these protocols.

a)SPIN (Sensor Protocols for Information via Negotiation)

SPIN (Sensor Protocols for Information via Negotiation) aims to assign high-level descriptors to the data. The essential characteristic of SPIN is the swapping of meta-data across sensors before transmission using a data advertisement method. After receiving fresh data, Each node disseminates it to its neighbouring

nodes. Neighbours, which do not possess the data, seek the information by sending a request message. SPIN's meta-data negotiation effectively eliminates the common problems associated with floods, such as the transmission of redundant information, resulting in significant energy efficiency. SPIN defines three messages for exchanging data between nodes. An ADV message is used to advertise certain meta-data from a sensor. A DATA message carries the actual data, while a REQ message is used to request specific data. In the SPIN protocol, topological changes are confined to specific areas as each node only requires knowledge of its immediate neighbouring node [4].

Furthermore, SPIN is not utilised for applications, such as intrusion detection, that require consistent and dependable transmission of data packets at regular intervals.

b) Directed Diffusion (DD)

Directed Diffusion (DD) is a protocol that is created next to SPIN. Directed Diffusion is a data diffusion technique that utilises a naming strategy to propagate data through sensor nodes.DD use attribute-value pairs to store and retrieve data from sensors as needed. To create a query, an interest is specified by collection of attribute-value pairs, including the name of the object, geographical area, duration, interval, and so on. This interest is propagated by a sink to its neighbouring nodes. Each node that gets this interest has the capability to cache it for future utilisation. The nodes possessed the capability to do data aggregation within the network.

The contents of the caches are thereafter utilised to compare the received data with the values in the interests. The interest item also includes diverse gradient fields. This gradient could serve as a response link to a neighbouring node from whence the interest was received. DD is more energy efficient than other systems since it operates on demand and does not require the maintenance of a global network structure [5]. However, its applicability is limited to specific sensor network applications due to its reliance on a query-driven data delivery paradigm [6].

c) Rumor Routing (RR)

Rumour Routing is a method that strikes a balance between flooding queries and its event alerts. The primary objective of this routing is to establish pathways that connect to each and every event, as opposed to event flooding that generates a gradient field that spans the whole network.

Therefore, in the case of query generation, it does not spread over the network. In that case query can be sent on a random walk until it finds the event path. Once the event path is identified, it can be immediately directed to the event. Alternatively, if the program is unable to locate the path, it may attempt to resubmit the query or inundate it. The Rumour Routing (RR) method is an effective approach for transmitting requests to events in a vast network [7].

2. Hierarchical Routing Protocols

This research provides a description of several routing protocols that are based on a hierarchical structure. A number of researchers conducted research in the field of hierarchical routing.

The network is divided into clustered layers using a hierarchical technique. Within hierarchical protocols, nodes are organised into clusters, each of which is overseen by a cluster head. Primarily, a cluster head bears the responsibility of routing from one to another cluster heads or to the base stations. Data is transmitted from a lower to higher level of cluster. Despite its ability to traverse across nodes and vary greater distances. This technique accelerates the transmission of data to the base station.

a) Low-energy adaptive clustering hierarchy (LEACH)

LEACH is a widely used energy-efficient hierarchical clustering algorithm for wireless sensor networks.

It was designed to minimise energy usage.

It employs the technique to condense the original data into a smaller size that contains only relevant information for all individual sensors. It divides the network into several clusters of sensors in order to decrease the quantity of data that is sent to the sink. This also improves the scalability and resilience of routing and data distribution. The LEACH protocol utilises a randomised rotation of high-energy CH positions instead of statically picking them. This approach ensures that all sensors have an opportunity to function as CHs, preventing the rapid decrease of an individual sensor's battery.

This hierarchy utilises single-hop routing, enabling every node to transmit data directly to the cluster head and the sink. It is not suitable for large-scale regional networks. Within the LEACH protocol, the Cluster Heads (CHs) expend a significant quantity of energy as nodes are positioned at greater distances from the sink. Following are the main benefits of this protocol:

- To ensure balanced energy usage, the system spins the cluster heads in a randomised manner.
- Sensors are equipped with synchronised clocks to accurately determine the start of a new cycle.
- The Sensors do not know the distance or locational information.

Enhanced Low-Energy Adaptive Clustering Hierarchy (E-LEACH)

The E-LEACH is a proposed algorithm for selecting cluster heads in sensor networks with varying initial energy levels among the sensors. To minimise the total energy usage, the total number of cluster heads needs to increase proportionally to the square root of the total number of sensor nodes.

LEACH-Centralized (LEACH-C) protocol

The LEACH-C protocol utilises a centralised clustering algorithm and employs the same steady-state protocol. In the the set-up phase, each and every node transmits information regarding its present location and energy level to the base station (BS). The BS will identify the cluster, CH and non-CH for each cluster.

The base station utilises the network's global information to generate more efficient clusters that necessitate reduced energy for data transmission.

Multi-hop LEACH (M-LEACH)

Multi-hop is an enhanced version of LEACH that enables sensor nodes to utilise multi-hop communication within the cluster, hence improving the energy efficiency of the protocol. This technique enhances the current options by enabling multi-hop inter-cluster communication in sparse wireless sensor networks (WSNs) where communication between cluster heads (CHs) or the sink is not feasible due to the distance between them. The core concept of the suggested method is to use a multi-hop strategy both within and outside the cluster.

Cluster heads (CHs) perform data fusion to receive the data, which enables a decrease in the overall amount of data transmitted and forwarded in the network.

b)Power efficient gathering in sensor information systems (PEGASIS)

Power efficient gathering in sensor information systems (PEGASIS) is an extended version of the LEACH protocol. PEGASIS establishes a sequential connection between the sensor nodes, enabling each node to transmit and receive data from its neighbouring node. Only a single node is selected from the chain to send data to the base station (sink). The data is collected and transmitted sequentially through various nodes before being ultimately transmitted to the base station.

PEGASIS [9] typically avoids the formation of clusters and only use a single node in a sequential manner to transfer data to the base station (sink), rather than utilising numerous nodes. In the PEGASIS protocol,

if a sensor fails or becomes inoperative owing to insufficient power, the chain is reconstructed using the greedy method with bypassing the failed sensor.

Hierarchical PEGASIS

Hierarchical PEGASIS is an extended version of PEGASIS. It was implemented with the aim of reducing the delay for packets during transmission to the base station. H-PEGASIS offers a solution to the issue of collecting data by taking into account both energy and delay metrics.

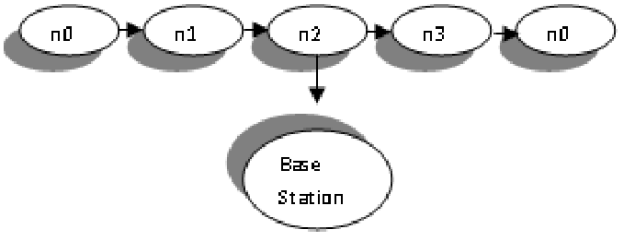

Fig 2: Chaining in PEGASIS

C) Hybrid, Energy-Efficient distributed Clustering (HEED)

The Hybrid, Energy-Efficient Distributed Clustering (HEED) approach builds upon the LEACH technique by incorporating residual energy and node degree as criteria for selecting clusters, thus achieving power balancing. HEED functions within single-hop networks, using an adaptive transmission power for inter-clustering communication. The four main objectives in HEED are as follows:

Extending the lifespan of the network by evenly spreading the usage of energy.

Ending the process of forming clusters within a fixed number of iterations.

Minimising the amount of control overhead Generating cluster heads (CHs) that are evenly distributed and clusters that are compact. Below are the

key characteristics of this protocol:

- HEED enhances the longevity of the nodes in the network, hence stabilising neighboring node.
- HEED does not require node capabilities, such as the ability to recognise position.
- HEED does not make any presumptions on the distribution of nodes. In multi-hop networks, the nodes automatically update their neighbour sets by regularly transmitting and receiving messages.
- The nodes just need information from their neighbourhod to create the clusters.

d) Threshold Sensitive Energy-Efficient sensor network (TEEN)

The TEEN protocol is a hierarchical clustering approach that is responsive to thresholds and designed to be energy-efficient for sensor networks. The TEEN protocol organises the sensors into clusters, each of which is supervised by a Cluster Head (CH).

The sensors in a cluster transmit their sensed data to their cluster head. The CH transmits the consolidated data to higher-level CH nodes until the data reaches the sink.

Therefore, the sensor network architecture in TEEN is structured hierarchically, with nodes in close proximity forming clusters that transmit their combined data to the base station or sink.

TEEN employs a data-centric methodology that utilises a hierarchical approach.The protocol has several significant advantages:

- The user receives time-critical data within less time.
- Thresholds are used to manage data transmission by selectively transmitting only sensitive data, hence reducing energy consumption and improving the efficiency and usefulness of the received data.

- A lower value of the soft threshold provides a more precise representation of the network, but this comes with the drawback of higher energy consumption.

***e)Adaptive* Threshold Sensitive Energy-Efficient sensor network (*AP*TEEN)**

The APTEEN protocol is designed to be adaptive, threshold-sensitive, energy-efficient, and suitable for sensor networks. It combines the features of both the LEACH protocol, which focuses on periodic data collecting, and the TEEN protocol, which prioritises time-critical events. APTEEN is a routing system that combines clustering and hybrid techniques to enable sensors to regularly transmit their collected data. CHs also engage in data aggregation to conserve energy. APTEEN offers help for several types of queries, as stated below:

- Historical query, for the purpose of examining previous data values
- one time query to obtain a snapshot of the network at a specific moment.
- persistent quey to monitor an event over a prolonged period of time.

APTEEN exhibits significantly reduced energy dissipation, resulting in a higher number of operable sensor nodes.

3.Location based Protocols

The location-based routing protocol utilises location information to direct the process of routing discovery, as well as for maintenance and data forwarding. Additionally, it facilitates the transmission of information in a certain route and prevents excessive information dissemination throughout the entire network.

In order to estimate and reduce energy usage, it is necessary to have location information to determine the distance between two specific nodes [13].

i) GEAR: Yu et al. [15] explain that in this system, each node maintains an estimated cost and a learning cost for reaching the goal through neighbouring nodes. The estimated cost is often determined by considering both the residual energy and the distance to the destination. A hole often arises when a node lacks any immediate neighbours that can reach the target. If there are no holes, the estimated cost is same to the learned cost. The cost is retroactively transmitted one step back each time a packet reaches its destination, allowing the route for the next packet to be altered accordingly. The advantage of GEAR is not limited to decreasing energy usage during route configuration; it also achieves better packet delivery.

ii)Geographic Adaptive Fidelity (GAF):- GAF is utilised in Wireless Sensor Networks (WSN) because to its preference for energy conservation. The process consists of three distinct phases: discovery, active, and sleeping [14]. When a sensor transitions into the sleeping state, it deactivates the radio in order to conserve energy.During the discovery phase, a sensor sends exchange discovery messages in order to gather information about other sensors within the grid. When a sensor is in an active state, it periodically sends out a discovery message to tell other sensors of its current state. The GAF protocol demonstrates excellent performance as a typical ad hoc routing protocol in terms of low latency and minimal packet loss. Additionally, it effectively enhances the network's lifespan by conserving energy during transmission.

iii)MECN:- MECN, short for Minimum Energy Communication Network, is a system that creates and sustains a network with the least amount of energy consumption in wireless networks. This is achieved by utilising low power GPS technology. The protocol consists of two distinct phases:
1. It maps the location of a 2-dimensional plane and creates a thin graph that includes all the boundaries of

each transmitting node in the network. The enclosed graph consists of globally optimal relationships in terms of energy consumption.
2. Identifies the optimal links on the enclosure graph. MECN uses a distributed algorithm for finding the shortest path, where the cost metric is the power consumption.

II)SMECN:- The small minimum energy communication network (SMECN) is a modified version of MECN. In the SMECN protocol, every sensor identifies its nearby neighbours by transmitting a discovery message using an initial power level that is gradually adjusted.

An advantage of SMECN is its lower energy consumption compared to MECN, as well as reduced maintenance costs for the links. However, a disadvantage is that the algorithm incurs additional overhead when searching for a sub-network with fewer edges.

Routing protocols	Classification	Power usage	Data-aggregation	Multipath	Query-based	QoS
SPIN	Flat	Ltd.	Yes	Yes	Yes	No
Directed diffusion	Flat	Ltd.	Yes	Yes	Yes	No
Rumor routing	Flat	Low	Yes	No	Yes	No
GBR	Flat	Low	Yes	No	Yes	No
LEACH	Hierarchical	High	Yes	No	No	No
PEGASIS	Hierarchical	Max.	No	No	No	No
TEEN and APTEEN	Hierarchical	High	Yes	No	No	No
ECRA	Hierarchical	Max.	Yes	No	No	No
MECN and SMECN	Hierarchical	Low	No	No	No	No
GEAR	Location	Ltd.	No	No	No	No
GAF	Location	Ltd.	No	No	No	No
N-to-1 multipath	Flat	Ltd.	Yes	Yes	No	No
MMSPEED	QoS	Low	No	Yes	No	Yes
Braided multipath	Flat	Ltd.	Yes	Yes	Yes	No
Energy aware	Flat	N/A	No	No	Yes	No

Table 2:- Comparison & Classification of routing protocols in WSNs

4. Protocol Operation Routing Protocols

In this section, we examine routing protocols that are categorised depending on their protocol operation.

i) Multipath-based: These systems utilise several paths instead of a single path in order to enhance network performance. By maintaining several pathways between the source and destination, fault tolerance can be increased. However, this comes at the cost of greater energy consumption and traffic creation [4].

ii) Query-based: In Query-based protocols, destination nodes disseminate a query for data from a node around the network; a node transmits the data that corresponds to the query back to the node that originated it. Two examples of this form of routing are the DD and RR protocols.

iii) Negotiation-based:- These protocols utilise advanced data or information descriptors to eliminate unnecessary data transmissions through negotiation. The SPIN protocols are examples of negotiation-based routing protocols.

iv) QoS-based:- This routing involves the network's need to optimise energy usage while maintaining high data quality. The network must adhere to QoS metrics, such as delay, bandwidth, and energy consumption, when transmitting data or information to the base station (BS). Sequential Assignment Routing (SAR) and SPEED are two examples of protocols belonging to this category.

v) Coherent based:- In coherent routing, data is transmitted to aggregators after undergoing processing tasks such as time stamping and duplicate suppression. Coherent processing is typically chosen to achieve energy-efficient routing. An example of coherent data processing is the utilisation of multiple winner algorithms.

DISCUSSION AND CONCLUSION

Routing in sensor networks is a developing field of study with a small but rapidly growing body of research. This paper, on the other hand, presents a comprehensive review of routing algorithms in wireless sensor networks. As a result, all of these networks have the same overall objective: to extend the lifespan of the sensor network while also guaranteeing the delivery of data. In general, routing can be divided into three broad categories: network structure-based and protocol operation-based, and in network structure-based routing it can be a flat-based, hierarchical-based, and location-based routing protocol .

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