Analysis of Hierarchical Routing Protocols in WSNs

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Abstract: **The recent advances in wireless sensor networks have led to the development of many new protocols where energy supply, computational capacity and communication bandwidth are essential considerations. As the sensor networks are application dependent, a single routing protocol cannot be efficient for all the applications. There are many existing protocols and techniques which are used in wireless sensor network. The sensor nodes have a limited transmission range and their processing and storage capabilities as well as their energy resources are also limited. Routing protocols for wireless sensor networks are responsible for maintaining the routes in the network and have to ensure reliable multi-hop communication under these conditions. This paper surveys on recent hierarchical routing protocols for the wireless sensor networks, compares them with respect to some properties and explains their strengths and limitations. The six main categories discussed in this paper belong to the hierarchical routing protocol.**

Keywords: Wireless Sensor Network (WSN); Routing Protocol; Cluster Head (CH); Base Station (BS); TEEN; APTEEN; PEGASIS; LEACH; TREEPSI; HEED.

I. INTRODUCTION

The emerging field of wireless sensor networks (WSNs) combines sensing, computation, and communication into a single tiny device. The power of wireless sensor networks lies in the ability to deploy large numbers of tiny nodes that assemble and configure themselves. In addition to drastically reducing the installation costs, wireless sensor networks have the ability to dynamically adapt to changing environments [1]. Adaptation mechanisms can respond to changes in network topologies or can cause the network to shift between drastically different modes of operation. For example, the same embedded network performing leak monitoring in a chemical factory might be reconfigured into a network designed to localize the source of a leak and track the diffusion of poisonous gases. The network could then direct workers to the safest path for emergency evacuation.

Unlike traditional wireless devices, wireless sensor nodes do not need to communicate directly with the nearest high-power control tower or base station, but only with their local peers. Instead of relying on a pre-deployed infrastructure, each individual sensor or actuator becomes part of the overall infrastructure. A sensor network is a group of specialized transducers with a communication infrastructure intended to monitor and record conditions at diverse locations. Commonly monitored parameters are temperature, humidity, pressure, wind direction and speed, illumination intensity, vibration intensity, sound intensity, power-line voltage, chemical concentrations, pollutant levels and vital body functions.

A sensor network consists of multiple detection stations called sensor nodes, each of which is small, lightweight and portable. Every sensor node is equipped with a transducer, microcomputer, transceiver and power source. The transducer generates electrical signals based on sensed physical effects and phenomena. The microcomputer processes and stores the sensor output. The transceiver, which can be hard-wired or wireless, receives commands from a central computer and transmits data to that computer. The base stations are one or more components of the WSN with much more computational, energy and communication resources. They act as a gateway between sensor nodes and the end user as they typically forward data from the WSN on to a server.

The topology of the WSNs can vary from a simple star network to an advanced multi-hop wireless mesh network.

The propagation technique between the hops of the network can be routing or flooding. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance. Today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, fire detection and traffic control and so on [2].

The rest of the paper is organized as follows. Section II describes the characteristics of a sensor network. Section III presents an overview of various applications of sensor networks. Section IV provides brief information regarding routing objectives. Section V enlightens on various routing protocols. Section VI contains information about various hierarchical routing protocols. Section VII illustrates a comparative study of different hierarchical routing protocols. Finally section VIII gives conclusions.

A. Characteristics of sensor network

The main characteristics of WSN include power consumption constrains for nodes using batteries or energy harvesting, ability to cope with node failures, mobility of nodes, dynamic network topology, communication failures, heterogeneity of nodes, scalability to large scale of deployment, ability to withstand harsh environmental conditions, ease of use, power consumption.

B. Applications of sensor networks

Sensor networks can be applied in many areas. Some of the applications are described below.

1) ***Area monitoring***: In area monitoring, the WSN is deployed over a region where some phenomenon is to be monitored.
2) ***Environmental sensing***: Environmental sensing includes sensing volcanoes, oceans, glaciers, forests, etc.
3) ***Air pollution monitoring***: Wireless sensor networks have been deployed in several cities (Stockholm, London or Brisbane) to monitor the concentration of dangerous gases for citizens.
4) ***Forest fire detection***: A network of sensor nodes can be installed in a forest to detect when a fire has started. The nodes can be equipped with sensors to measure temperature, humidity and gases which are produced by fires in the trees or vegetation.
5) ***Greenhouse monitoring***: Wireless sensor networks are also used to control the temperature and humidity levels inside commercial greenhouses.
6) ***Landslide detection***: A landslide detection system makes use of a wireless sensor network to detect the slight movements of soil and changes in various parameters that may occur before or during a landslide.
7) ***Machine health monitoring***: Wireless sensor networks have been developed for machinery condition-based maintenance (CBM) as they offer significant cost savings and enable new functionalities.
8) ***Agriculture***: Using wireless sensor networks within the agricultural industry are increasingly common; using a wireless network frees the farmer from the maintenance of wiring in a difficult environment.
9) ***Structural monitoring***: Wireless sensors can be used to monitor the movement within buildings and infrastructure such as bridges, flyovers, embankments, tunnels etc. enabling Engineering practices to monitor assets remotely without the need for costly site visits.
10) ***On-site tracking of materials***: Since the cost of ownership of wireless sensors is lowering it will provide the opportunity to track and trace large and expensive products

C. Routing objectives

Some sensor network applications only require the successful delivery of messages between a source and a destination. However, there are applications that need even more assurance. These are the real-time requirements of the message delivery, and the maximization of network lifetime [4].

1) **Non-real time delivery:** The guarantee of message delivery is essential for all routing protocols. It means that the protocol should always find the route between the communicating nodes, if it really exists. This correctness property can be confirmed in a formal way, while the average case performance can be evaluated by measuring the message delivery ratio.

2) **Real-time delivery:** Some applications require that a message must be delivered within a specified time, otherwise the message is of no use or its information content becomes invalid after the time bound. Therefore, the main objective of these protocols is to completely control the network delay. The average-case performance of these protocols can be evaluated by measuring the message delivery ratio with time constraints.

3) ***Network lifetime:*** This objective is essential for those networks, where the application must run on sensor nodes as long as possible. The protocols aiming this concern try to balance the energy consumption equally among nodes considering their residual energy levels.

D. Routing protocols for sensor networks

Routing in sensor networks is very challenging due to several characteristics that distinguish them from contemporary communication and wireless ad-hoc networks[5,6,7]. Since the number of sensor nodes is very high, a global addressing scheme cannot be used for the sensor nodes. Thus classical IP-based protocols cannot be applied to sensor networks. The traditional communication network does not involve flow of data from multiple regions to a particular sink and the data traffic does not contain redundancy unlike sensor networks. These issues require a proper resource utilization which can save the energy of the sensor nodes and increases the processing capacity of the nodes.

Due to these differences, many new algorithms have been proposed for the problem of routing data in sensor networks. They can be classified as data-centric, location-aware, hierarchical and Quality of Service (QoS) based routing protocols.

1) **Data-centric protocols** are query-based and depend on the naming of desired data, which helps in eliminating many redundant transmissions. Here the sink sends queries to certain regions and waits for data from the sensors located

in the selected regions [8]. Since data is being requested through queries, attribute based naming is necessary to specify the properties of data. Here data is usually transmitted from every sensor node within the deployment region with significant redundancy. In this protocol when the source sensors send their data to the sink, intermediate sensors can perform some form of aggregation on the data originating from multiple source sensors and send the aggregated data toward the sink. This process can result in energy savings because of less transmission required to send the data from the sources to the sink.

2) **Hierarchical protocols** aim at clustering the nodes so that cluster heads can do some aggregation and reduction of data in order to save energy [9]. Clustering is an energy-efficient communication protocol that can be used by the sensors to report their sensed data to the sink.

3) **Location-based protocols** utilize the position information to relay the data to the desired regions rather than the whole network. In location aware routing nodes know where they are in a geographical region [10]. Location information can be used to improve the performance of routing and to provide new types of services. QoS based routing protocols are the protocols that try to meet some QoS requirements along with the routing function. They help find a balance between energy consumption and QoS requirements services. In QoS based routing protocols data delivery ratio, latency and energy consumption are mainly considered. To get a good QoS (Quality of Service), the routing protocols must possess more data delivery ratio, less latency and less energy consumption.

The routing protocols designed for WSNs are generally data-centric or geocentric unlike Ad-hoc routing protocols which are node-centric protocols. Routing protocols can also be classified according to the sensor network architecture [11]. Some WSNs consist of homogenous nodes, whereas some consist of heterogeneous nodes. Based on this concept we can classify the protocols whether they are operating on a flat topology or on a hierarchical topology.

In Flat routing protocols all nodes in the network are treated equally. When node needs to send data, it may find a route consisting of several hops to the sink. A hierarchical routing protocol is a natural approach to take for heterogeneous networks where some of the nodes are more powerful than the other ones. The hierarchy does not always depend on the power of nodes. In Hierarchical (Clustering) protocols different nodes are grouped to form clusters and data from nodes belonging to a single cluster can be aggregated. The clustering protocols have several advantages like they are scalable and energy efficient in finding routes and they are also easy to manage.

E. An introduction to hierarchical protocols

Many research projects in the last few years have explored hierarchical clustering in WSN from different perspectives [2]. Clustering is an energy-efficient communication protocol that can be used by the sensors to report their sensed data to the sink. In this section, we describe a sample of layered protocols in which a network is composed of several clumps (or clusters) of sensors. Each clump is managed by a special node, called cluster head, which is responsible for coordinating the data transmission activities of all sensors in its clump.

A hierarchical approach breaks the network into clustered layers. Nodes are grouped into clusters (as shown in fig.1) with a cluster head that has the responsibility of routing from the cluster to the other cluster heads or base stations.

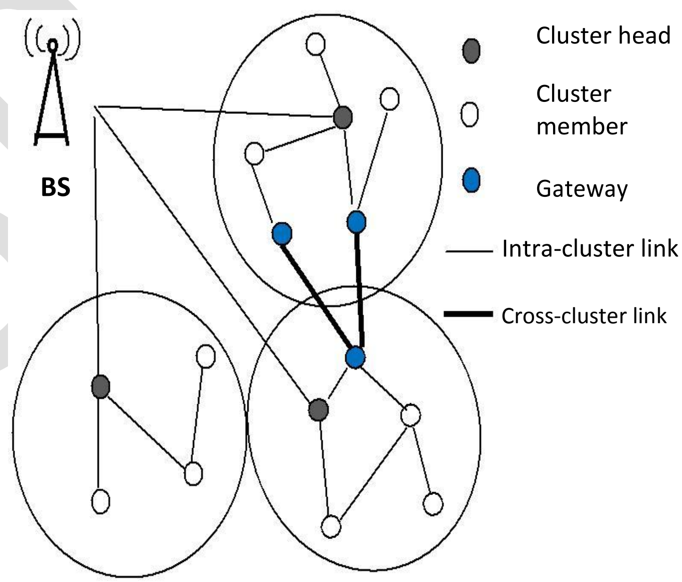

Figure 1 Clustering in sensor network

The structure of a typical cluster has been shown in fig. 2. The cluster heads, namely gateways, are less energy constrained than sensors and assumed to know the location of sensor nodes. The sensor nodes in a cluster can be in one of four main states: sensing, relaying, sensing-relaying and inactive state. Data travel from a lower clustered layer to a higher one. Although, it hops from one node to another, but as it hops from one layer to another it covers larger distances. This moves the data faster to the base station. Clustering provides inherent optimization capabilities at the cluster heads. In this section, we review a sample of hierarchical-based routing protocols for WSNs.

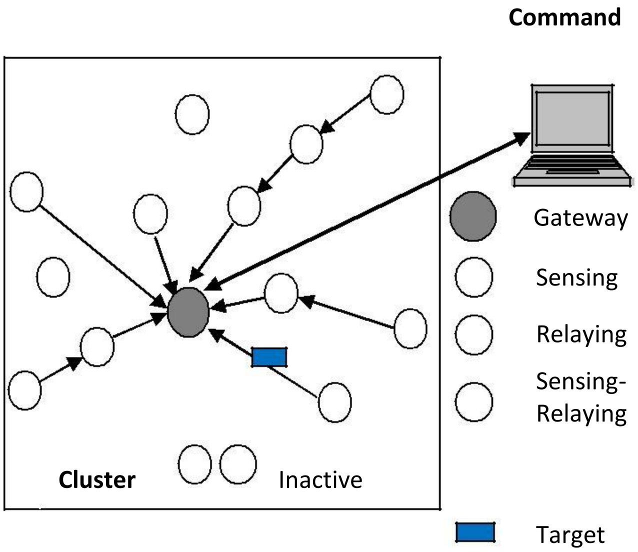

Figure 2 A cluster in sensor network

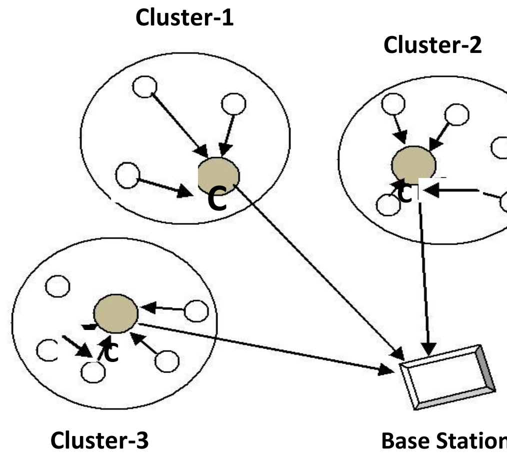

Figure 3 CHs communicating with the BS in LEACH Protocol

Hierarchical or cluster-based routing methods, originally proposed in wire line networks, are well-known techniques with special advantages related to scalability and efficient communication. As such, the concept of hierarchical routing is also utilized to perform energy-efficient routing in WSNs. 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 in the proximity of the target. The creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster, performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other for routing. In this section, we review a sample of hierarchical-based routing protocols for WSNs.

1) Low Energy Adaptive Clustering Hierarchy (LEACH)

Heinzelman introduced a hierarchical clustering algorithm for sensor networks, called LEACH. LEACH [12] is the first hierarchical cluster-based routing protocol for wireless sensor network which partitions the nodes into clusters. In each cluster a dedicated node with extra privileges called cluster head (CH) is present, shown in Fig.3, which is responsible for creating and manipulating a TDMA (Time Division Multiple Access) schedule and sending aggregated data from nodes to the BS. Remaining nodes are cluster members.
LEACH randomly selects a few sensor nodes as cluster heads (CHs) and rotates this role to evenly distribute the energy load among the sensors in the network.

LEACH uses a TDMA/CDMA (Code-Division Multiple Access) MAC to reduce inter-cluster and intra-cluster collisions. However, data collection is centralized and performed periodically. Therefore, this protocol is most appropriate when there is a need for constant monitoring by the sensor network.
The operation of LEACH is separated into two phases, the setup phase and the steady state phase. In the setup phase, the clusters are organized and CHs are selected. In the steady state phase, the actual data transfer to the BS takes place. The duration of the steady state phase is longer than the duration of the setup phase in order to minimize overhead.

- Advantages

  1)It can reduce power consumption on avoiding the communication directly between sink and sensor nodes.

  2)Distributed and no global knowledge of network required.

  3)It uses randomization to rotate the cluster heads and by rotating the cluster-head randomly, energy consumption is expected to be uniformly distributed. It achieves a factor of 8 improvement compared to the direct approach, before the first node dies.

- Drawbacks

  4)It is not applicable to networks deployed in large regions.

  5)The idea of dynamic clustering brings extra overhead.

  6)The protocol assumes that all nodes begin with the same amount of energy capacity in each election round, assuming that being a CH consumes approximately the same amount of energy for each node.

  7)No particular attention has been given to the time criticality of the target application in sensor networks.

2) Power-Efficient Gathering in Sensor Information Systems (PEGASIS)

In [13], an enhancement over the LEACH protocol was proposed named as PEGASIS. The PEGASIS protocol is a near optimal chain-based protocol. The basic idea of the protocol is that in order to extend network lifetime, nodes need to only communicate with their closest neighbors, and they take turns in communicating with the BS. Rather than forming multiple clusters, PEGASIS forms chains (as shown in fig. 4) from sensor nodes so that each node transmits and receives from a neighbor and only one node is selected from that chain to transmit to the base station (sink).

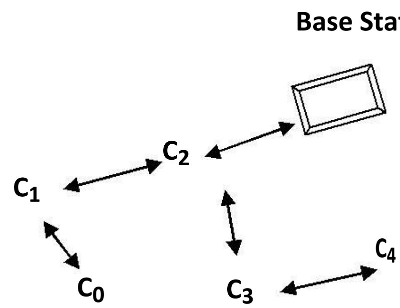

Figure 4 Data gathering in a chain based scheme in PEGASIS.

When the round of all nodes communicating with the BS ends, a new round starts, and so on, shown in Fig.5. Hence, PEGASIS has two main objectives. First, increase the lifetime of each node by using collaborative techniques. Second, allow only local coordination between nodes that are close together so that the bandwidth consumed in communication is reduced.

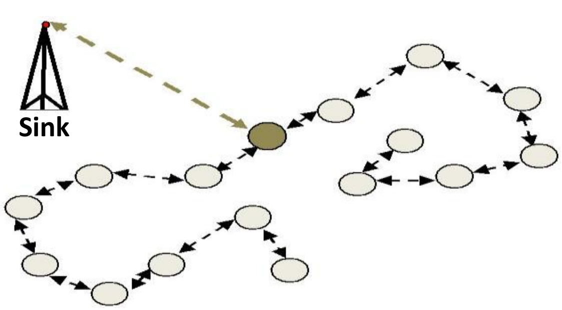

Figure 5 Chaining in PEGASIS

- Advantages:

1) PEGASIS performs better than LEACH by about 100 to 300% when 1%, 20%, 50% and 100% of nodes die for different network sizes and topologies [11].

2) Balanced energy dissipation among the sensor nodes to have full use of the complete sensor network.

3) Near optimal performance.

- Drawbacks:

1) It assumes that each sensor node is able to communicate with the BS directly.

2) It assumes that all sensor nodes have the same level of energy and are likely to die at the same time.

3) Since greedy algorithm is used to form the chain it does not always guarantee optimal performance.

4) PEGASIS introduces excessive delay for distant node on the chain. In addition the single leader can become a bottleneck.

3) Tree-based Efficient Protocol for Sensor Information(TREEPSI)

TREEPSI is a tree-based protocol that is different from the above-mentioned protocols. Before the data transmission phase, the WSNs select a root node among all of the sensor nodes [14]. The root is identified by id = j. There are two ways to build the tree path: the first is computing the path centrally using the sink and broadcasting the path information to the network. The second can be the same tree structure using a common algorithm in each node.

The data transmission phase begins after the tree is built. All of the leaf nodes will start sending sensed data towards their parent nodes. The parent nodes will collect the received data together with their own data that is then sent to their parents (as shown in fig.6). The transmission process will be repeated until all of the data received by the root node is sent. After the root node has aggregated the data, it sends the collected data directly to the sink. The process will repeat until the root node has no more data to send. The WSN will then reselect a new root node. The new root identification number would be j + 1.

It allows nodes in the network to communicate in close neighbors and let the nodes take turns to become the leader for transmission to the BS. This helps in consumption of minimum possible amount of energy and also distributes the load evenly among the nodes in the network. TREEPSI and PEGASIS use the same method to transmit data from the leaf node to the chain/root head.

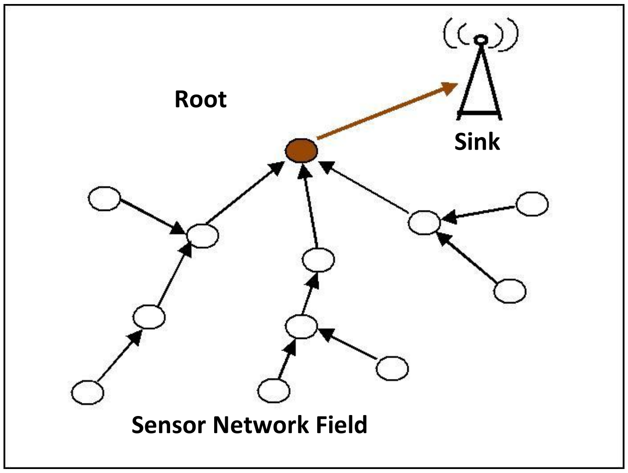

Figure 6 Construction of path tree for gathering data in TREEPSI

- Advantages:

  1)It is better than PEGASIS in terms of energy efficiency.

  2)Better load distribution among the nodes.
- Drawbacks:

  1)Delay in data collection.

4) Threshold sensitive Energy Efficient sensor Network protocol (TEEN)

TEEN [15,16] is a hierarchical clustering protocol, which groups sensors into clusters with each led by a CH. The sensors within a cluster report their sensed data to their CH. The CH sends aggregated data to higher level CH until the data reaches the sink. Thus, the sensor network architecture in TEEN is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until the BS (sink) is reached. TEEN is useful for applications where the users can control a trade-off between energy efficiency, data accuracy, and response time dynamically.

TEEN uses a data-centric method with hierarchical approach. Important features of TEEN include its suitability for time critical sensing applications. Also, since message transmission consumes more energy than data sensing, so the energy consumption in this scheme is less than the proactive networks. However, TEEN is not suitable for sensing applications where periodic reports are needed since the user may not get any data at all if the thresholds are not reached.

- Advantages:

  1)Responsive to sudden changes in the sensed attributes.

  2)Suitable for time critical sensing applications.

  3)It also allows the user to control the energy consumption and accuracy to suit the application.
- Drawbacks:

  1) TEEN is not good for applications where periodic reports are needed since the user may not get any data at all if the thresholds are not reached.

  2) Overhead and complexity of forming clusters in multiple levels, implementing threshold-based functions and dealing with attribute-based naming of queries.

5) Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN)

The APTEEN [17] is an extension to TEEN and aims at both capturing periodic data collections and reacting to time-critical events. The architecture is same as in TEEN (as shown in fig.7). APTEEN is a hybrid clustering-based routing protocol that allows the sensor to send their sensed data periodically and react to any sudden change in the value of the sensed attribute by reporting the corresponding values to their CHs. The architecture of APTEEN is same as in TEEN, which uses the concept hierarchical clustering for energy efficient communication between source sensors and the sink. APTEEN supports three different query types namely (i) historical query, to analyze past data values, (ii) one-time query, to take a snapshot view of the network; and (iii) persistent queries, to monitor an event for a period of time. APTEEN guarantees lower energy dissipation and a larger number of sensors alive.

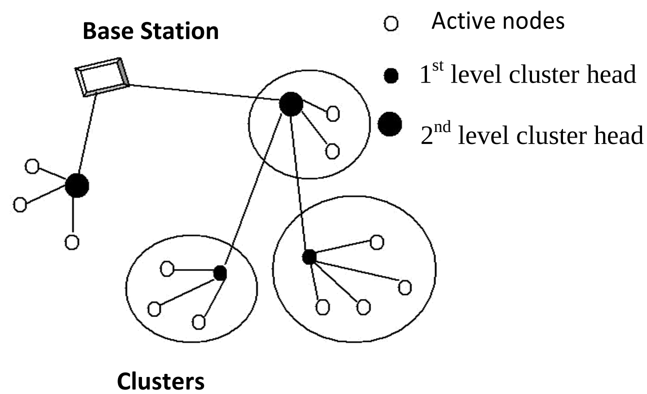

Figure 7 Hierarchical clustering in TEEN and APTEEN

- Advantages:

  1)Capturing Periodic data collections and reacting to time-critical events.

  2)Better than TEEN in terms of energy dissipation and network lifetime.

- Drawbacks:

1)Overhead and complexity of forming clusters in multiple levels, implementing threshold-based functions and dealing with attribute-based naming of queries.

6)Hybrid Energy-Efficient Distributed Clustering protocol(HEED)

In HEED [18] every sensor node has multiple power levels. It uses residual energy as primary parameter and network topology features like node degree. Distances to neighbors are only used as secondary parameters to break tie between candidate cluster heads as a metric for cluster selection to achieve load balancing. It periodically selects CHs according to the node residual energy and node degree. The clustering process is divided into a number of iterations and each iteration nodes which are not covered by any cluster head double their probability of becoming a cluster head. T_{CP} is the clustering process duration and T_{NO} is the network operation interval. Clustering is activated every T_{CP} + T_{NO} seconds. Initial number of CHs is C_{prob}. The probability of a node to become a CH is CH_{prob}.

$$CH_{prob}=C_{prob} \times E_{residual}/E_{max}$$

Where, $E_{residual}$ refers to residual energy level of the concerned node and E_{max} corresponds to maximum battery energy. Intra-cluster as well as Inter-cluster communication is possible here.

- Advantages:

1)It is energy efficient as cluster head selection is based on residual energy of a node.

- Drawbacks:

1)Since this protocol enables every node to independently and probabilistically decide on its role in the clustered network, they cannot guarantee optimal elected set of cluster heads.

F. Comparison of the protocols

A hierarchical protocol breaks the network into clustered layers. Nodes are grouped into clusters with a cluster head that has the responsibility of routing from its own cluster to the other cluster heads or base stations. Data travel from a lower clustered layer (hierarchy) to a higher one and finally to the base station. When data hops from one layer to another it covers larger distances. This moves the data faster to the base station. Clustering provides inherent optimization capabilities at the cluster heads.

In this section we have compared different features of the above discussed routing protocols with respect to the following properties:

1) *Structure*:

The sensor network can be hierarchical, chain-based or treelike in structure.

LEACH: A hierarchical cluster is formed. **PEGASIS:** A chain is constructed instead of clusters. So there is no overhead of dynamic cluster formation.

TREEPSI: A hierarchical cluster is formed. **APTEEN:** Uses hierarchical cluster based approach. **TEEN:** Uses hierarchical cluster based approach. **HEED:** A hierarchical cluster is formed.

2) *Communication*:

While sending information to the base station a node can communicate directly with its cluster head or with its neighboring node.

LEACH: Nodes communicate with their local cluster head.

PEGASIS: Nodes communicate with their closest neighbors.

TREEPSI: Nodes communicate with their parent in the hierarchy.

APTEEN: Nodes communicate with their immediate cluster head thus saving energy.

TEEN: Nodes communicate with their immediate cluster head like APTEEN.

HEED: Nodes communicate with their neighbors.

3) *Aggregation*:

After receiving the information from another node the receiver node fuses the data with its own. The receiver node can be a cluster head or a parent node or any adjacent node.

LEACH: The cluster head fuses the received data to compress the amount of data to be transmitted.
PEGASIS: Every node fuses the received message with its own message to compress the amount of data to be transmitted.

TREEPSI: Only leaf nodes sense the information and send it to their parents. But collision can occur due to simultaneous data transmission. Non-leaf nodes only receive and transmit the information. Data fusion occurs at parent nodes.

APTEEN: If in a pair of adjacent nodes both are sensing similar data then one of them can receive the query and send it to its CH while the other one can go to sleep. The CH fuses the received data and sends it to the higher level CH.

TEEN: The cluster head aggregates the received data and sends it to its higher level CH or the BS.

HEED: Every node fuses the received message with its own message to compress the amount of data to be transmitted.

4) *Sending information*:

The local cluster heads or only one node that is the leader or the root can send data to the base station.

LEACH: The local cluster heads sends data to the base station which reduces the energy of only the cluster heads.

PEGASIS: Only one node takes turn being the leader to send to Base Station, which minimizes the data transmission distance for non-leader nodes and energy depletion is balanced in the network.

TREEPSI: Only the root will send data to the base station which minimizes energy consumption.
APTEEN: The final level CHs send data to the BS.
TEEN: The final level CHs send data to the BS.
HEED: The final level CHs send data to the BS.

5) *Cluster formation:*

Cluster can be formed by the nodes or by the base station.

LEACH: Sensors elect themselves to be the local cluster heads with a certain probability at a given time. Clustering is done by the nodes themselves. Each node determines to which cluster it wants to belong based on minimum communication energy.

PEGASIS: Greedy algorithm is used to construct the chain which performs well with different size networks. When the leader dies a new chain is formed.

TREEPSI: The tree is formed by the BS or locally by all nodes using a common algorithm.

APTEEN: Every cluster is formed by the base station. A cluster exists for a fixed period of time after which the BS regroups the cluster.

TEEN: The hierarchy is formed and supervised by the base station. The root is selected by the BS.

HEED: Cluster head selection is primarily based on the residual energy of each node and its communication cost. A node joins the cluster head with minimum degree (neighborhood size) to distribute cluster head load or joins the one with maximum degree (neighborhood size) to create dense clusters.

6) *Cluster head*:

Cluster head is chosen randomly or using some parameters like residual energy, etc.

LEACH: As the cluster head is chosen randomly the energy load is evenly distributed among the sensors. First node death occurs over 8 times later than the first node death in direct transmission.

PEGASIS: Since leader is chosen randomly less energy will be consumed for transmission and the nodes will die at random locations, which will make the network robust to failures.
TREEPSI: Root is chosen randomly.

APTEEN: Every node has the capability to become the CH Clusters and CHs are selected by the BS.

TEEN: Every node takes turn to become the CH.
HEED: Every node has the capability to become the cluster head. Cluster head selection is primarily based on the residual energy of each node. Since the energy consumed per bit for sensing, processing, and communication is typically known, and hence residual energy can be estimated. The cluster head yielding lower intra-cluster communication cost are favored.

7) *Communication overhead:*

Communication overhead occurs in the establishment of the communication path during data transmission which depends on the cluster formation and head selection.

LEACH: Cluster is formed only once so less overhead occurs in the establishment of the communication path.
PEGASIS: As chain is formed only once, overhead per communication round is less.

TREEPSI: Since path is selected only once, overhead per communication round is less as compared to energy spent in data collection.
APTEEN: Since the cluster is reformed periodically the overhead of resetting the communication path is more than other protocols.

TEEN: Only Cluster head is chosen periodically. So communication overhead is less.

HEED: As cluster formed is not fixed overhead per communication round is more

8) *Number of transmissions:*
Multiple CHs or one CH can transmit data at the final level to the base station.

LEACH: Multiple transmissions to the BS from multiple cluster heads.

PEGASIS: One transmission to the BS per round which conserves memory.

TREEPSI: One transmission to the BS (from root node).

APTEEN: One transmission to the BS (from the final CH at the last level).

TEEN: One transmission to the BS by the root.

HEED: One transmission to the BS (from the final CH at the last level)

9) Proactive/Reactive:

In proactive network data transmission occurs through predefined route and in reactive network it occurs dynamically.

LEACH: It is suitable for a proactive network. In a proactive protocol the nodes switch on their sensors and transmitters, sense the environment and transmit the data to a BS through the predefined route.

PEGASIS: It is suitable for a reactive network. In case of a reactive protocol if there are sudden changes in the sensed attribute beyond some predetermined threshold value, the nodes immediately react. This type of protocol is used in time critical applications.

APTEEN: It incorporates both proactive and reactive concepts. They first compute all routes and then improve the routes at the time of routing.

TEEN: It is an example of a reactive protocol.

HEED: It is suitable both for proactive as well as reactive networks.

II. CONCLUSIONS

The above study has demonstrated that APTEEN's performance is between LEACH and TEEN in terms of energy dissipation and network lifetime. In LEACH sensed data is sent to CHs periodically, and after aggregation, data is passed on to the BS for storing the information. Since it collects data periodically from its environment and then respond to a query when it arrives, it cannot give particular attention to the time criticality of the target application which is very much required in a sensor network.

TEEN gives the better performance since it decreases the number of transmissions. The main drawbacks of TEEN and APTEEN are the overhead and complexity of forming clusters in multiple levels, implementing threshold-based functions and dealing with attribute-based naming of queries. PEGASIS is a chain based protocol that is an improvement over LEACH. In PEGASIS, each node communicates only with a close neighbor and takes turns in transmitting to the base station, thus reducing the amount of energy spent per round. But TREEPSI which is a tree based protocol gives better performance than PEGASIS. The reason is, for densely deployed sensor nodes, multi-hop routing consumes less energy as compared to single hop communication.

It provides longer life to the sensor field as compared to PEGASIS for various network topologies. The HEED clustering improves network lifetime over LEACH clustering because LEACH randomly selects CHs (and hence cluster size), which may result in faster death of some nodes. The final CHs selected in HEED are well distributed across the network and the communication cost is minimized. However, the cluster selection deals with only a subset of parameters, which can possibly impose constraints on the system. Thus we can conclude that a single routing protocol can never be the best in a particular situation. But they should be as energy efficient as possible to prolong the life time of individual sensors, and hence the network lifetime.

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