Classification of Hierarchical Routing Protocols in Wireless Sensor Network: A Survey

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Abstract

The popularity of wireless sensor networks is increasing tremendously day by day due to the vast potential of sensor networks to provide many applications such as military applications , health monitoring, environmental monitoring etc. For the different application areas there are different technical issues that the researchers are resolving. Wireless sensor networks consists of small low cost sensor nodes, having a limited transmission range and their processing, storage capabilities and energy resources are limited. This network gather the information from nodes and transmits to base station for further processing. To perform routing in wireless sensor network with this limitation of low power, energy and storage capabilities is a major problem. Routing protocols are used for discovering and maintaining the routing in sensor networks. The most important consideration in designing protocols for WSN is the energy constraint of nodes due to limited power This paper reviews the main hierarchical routing protocols that are used in wireless sensor networks.

Keywords: *Wireless sensor network, Hierarchical, Routing protocol.*

I. INTRODUCTION

A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices that use sensors to monitor physical or environmental conditions. These autonomous devices, or nodes, combine with routers and a gateway to create a typical WSN system. Each node consists of processing capability (one or more microcontrollers, CPUs or DSP chips), may contain multiple types of memory (program, data and flash memories), have a RF transceiver (usually with a single Omni-directional antenna), have a power source (e.g., batteries and solar cells), and accommodate various sensors and actuators. The nodes communicate wirelessly and often self-organize after being deployed in an ad hoc fashion. Systems of 1000s or even

1000 nodes are anticipated. [1]. The WSN structure consists of sensor nodes (SNs) and a sink node, usually called a base station (BS). SNs are placed in the sensing field and BS is usually located further away to collect and analyze the sensing data. Typically, SNs could send data to BS directly or indirectly via other intermediate SN(s). Since SNs usually operate by using limited energy sources such as batteries, it is undesirable to replace or recharge SNs due to high maintenance cost. In this case, Relay Stations (RSs) serve an essential role to receive and forward data from SNs to BS such that the energy-limited SNs can operate for a desired period of the network lifetime. The position of sensor nodes need not be engineered or pre-determined. This allows random deployment in inaccessible terrains or disaster relief operations. On the other hand, this also means that sensor network protocols and algorithms must possess self-organizing capabilities [2].

The basic philosophy behind WSNs is that, while the capability of each individual sensor node is limited, the aggregate power of the entire network is sufficient for the required mission. In many WSN applications, the deployment of sensor nodes is performed in an ad hoc fashion without careful planning and engineering. Once deployed, the sensor nodes must be able to autonomously organize themselves into a wireless communication network. Sensor nodes are battery-powered and are expected to operate without attendance for a relatively long period of time. In most cases it is very difficult and even impossible to change or recharge batteries for the sensor nodes. WSNs are characterized with denser levels of sensor node deployment, higher unreliability of sensor nodes, and sever power, computation, and memory constraints.

Thus, the unique characteristics and constraints present many new challenges for the development and application of WSNs. [2]

A WSN system is ideal for an application like environmental monitoring in which the requirements mandate a long-term deployed solution to acquire water, soil, or climate measurements. In structural health monitoring, wireless sensors can be used effectively to monitor highways, bridges, and tunnels. Sensor nodes can be used for continuous sensing, event detection, event ID, location sensing and local control of actuators. The concepts of micro-sensing and wireless connection of these nodes promise many new application areas. Sensor networks categorize the applications into military, environment, health, home and other commercial areas. [3]. Another unique feature of sensor networks is the cooperative effort of sensor nodes. Sensor nodes are fitted with an on-board processor.Instead of sending the raw data to the nodes responsible for the fusion, they use their processing abilities to locally carry out simple computations and transmit only the required and partially processed data. The above described features ensure a wide range of applications for sensor networks. [3]. in the application of WSN, energy-efficient is the first important factor of routing protocol, QoS is less important.

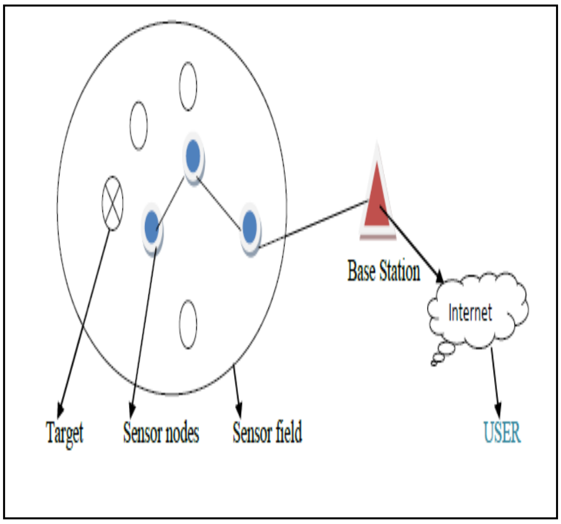

Fig.1. Architecture of wireless sensor network

II. DESIGN PARAMETER FOR ROUTING PROTOCOLS IN WIRELESS SENSOR NETWORK

The design of routing protocols for WSNs is challenging because of several network constraints. WSNs suffer from the limitations of several network resources, for example, energy, bandwidth, central processing unit, and storage. Due to the reduced computing, radio and battery resources of sensors, routing protocols in wireless sensor networks are expected to fulfill the following requirements:

- Energy Efficiency: Routing protocols should prolong network lifetime while maintaining a good grade of connectivity to allow the communication between nodes. It is important to note that the battery replacement in the sensors is infeasible since most of the sensors are randomly placed.
- Scalability: The numbers of sensor nodes in sensor networks are in the order of tens, hundreds, or thousands, network protocols designed for sensor networks should be scalable to different network sizes.
- Reliability: Network protocols designed for sensor networks must provide error control and correction mechanisms to ensure reliable data delivery over noisy, error-prone, and time-varying wireless channels.
- Mobility Adaptability: The different applications of wireless sensor networks could demand nodes to cope with their own mobility, the mobility of the sink or the mobility of the event to sense. Routing protocols should render appropriate support for these movements.
- QoS support: In sensor networks, different applications may have different quality-of-service (QoS) requirements in terms of delivery latency and packet loss. Thus, network protocol design should consider the QoS requirements of specific applications.
- Resilience: Sensors may unpredictably stop operating due to environmental reasons or to the battery consumption. Routing protocols should cope with this eventuality so when a current-in-use node fails, an alternative route could be discovered.
- Autonomy: The assumption of a dedicated unit that controls the radio and routing resources does not stand in wireless sensor networks as it could be an easy point of attack. Since there will not be any centralized entity to make the routing decision, the routing procedures are transferred to the network nodes.
- Data Latency and Overhead: These are considered as the important factors that influence routing protocol design. Data aggregation and multi-hop relays cause data latency. In addition, some routing protocols create excessive overheads to implement their algorithms, which are not suitable for serious energy constrained networks.
- Node Deployment: Node deployment is application dependent and affects the performance of the routing protocol. The deployment is either deterministic or self-organizing. In deterministic situations, the sensors are manually placed and data is routed through pre-determined paths. When the distribution of nodes is not uniform, optimal

positioning of cluster head becomes a pressing issue to enable energy efficient network operation. [4],[5]

III. CLASSIFICATION OF HIERARCHICAL ROUTING PROTOCOLS IN WSN

Routing protocol is one of the most important components of WSN. Routing protocol has to monitor the change of network's topological structure, exchange the routing information, locate the destination node, choose the route and transfer the information through route.[4]. The main target of hierarchical routing or cluster based routing is to efficiently maintain the energy usage of sensor nodes by involving them in multi-hop communication within a particular cluster. Cluster formation is generally based on the energy reserve of sensors and sensors proximity to the Cluster Head (CHs). Clustering plays an important role for energy saving in WSNs. With clustering in WSNs, energy consumption, lifetime of the network and scalability can be improved. Because only cluster head node per cluster is required to perform routing task and the other sensor nodes just forward their data to cluster head. Clustering has important applications in high-density sensor networks, because it is much easier to manage a set of cluster representatives (cluster head) from each cluster than to manage whole sensor nodes. In WSNs the sensor nodes are resource constrained which means they have limited energy, transmit power, memory, and computational capabilities. Energy consumed by the sensor nodes for communicating data from sensor nodes to the base station is the crucial cause of energy depletion in sensor nodes. [6] The main hierarchical protocols are: LEACH, PEGASIS, TEEN, APTEEN and HEED.

A. LEACH

Low Energy Adaptive Clustering Hierarchy (LEACH) 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 responsible for creating and manipulating a TDMA (Time division multiple access) schedule and sending aggregated data from nodes to the BS where these data is needed using CDMA (Code division multiple access). Remaining nodes are cluster members. This protocol is divided into rounds; each round consists of two phases:

- Setup phase
- Steady phase

1) Setup Phase: In the setup phase, a sensor node selects random number between 0 and 1. If this number is less than the threshold *T(n)*, the node becomes a CH. *T(n)* is computed as:

$$T(n) = \begin{cases} p/1-p*(r \bmod 1/p) & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

r is the current round; *p*, the desired percentage for becoming
CH; and *G* is the collection of nodes not elected as a CH in the last 1/ *p* rounds.

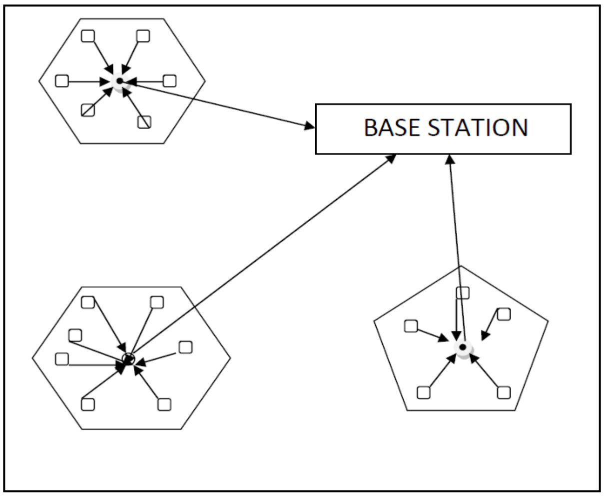

Fig.2. LEACH PROTOCOL

Each node decides independent of other nodes if it will become a CH or not. This decision takes into account when the node served as a CH for the last time (the node that hasn't been a CH for long time is more likely to elect itself than nodes that have been a CH recently). In the following advertisement phase, the CHs inform their neighborhood with an advertisement packet that they become CHs. [7]
Non-CH nodes pick the advertisement packet with the strongest received signal strength. In the next cluster setup phase, the member nodes inform the CH that they become a member to that cluster with "join packet" contains their IDs using CSMA. After the cluster-setup sub phase, the CH knows the number of member nodes and their IDs. Based on all messages received within the cluster, the CH creates a TDMA schedule, pick a CSMA code randomly, and broadcast the TDMA table to cluster members. After that steady-state phase begins.

2) Steady-State Phase: Data transmission begins; Nodes send their data during their allocated TDMA slot to the CH. This transmission uses a minimal amount of energy (chosen based on the received strength of the CH advertisement). The radio of each non-CH node can be turned off until the nodes allocated TDMA slot, thus minimizing energy dissipation in these nodes. When all the data has been received, the CH aggregate these data and send it to the BS. [8]

B. *PEGASIS*

PEGASIS stands for Power-Efficient Gathering in Sensor Information Systems. This is a chain based protocol that provide improvement over LEACH algorithms. So PEGASIS is an extension of the LEACH protocol. PEGASIS protocol requires formation of chain which is achieved in two steps:

- Chain construction
- Gathering data

1) Chain Construction: This is a chain based protocol that forms chains 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). The chain construction is performed in a greedy way, starting from the node farthest to the sink. The nearest node to this node is put as the next node in the chain. This procedure is continued until all the nodes are included in the chain. A node can be in the chain at only one position. During each round, a leader node is randomly selected.[9]

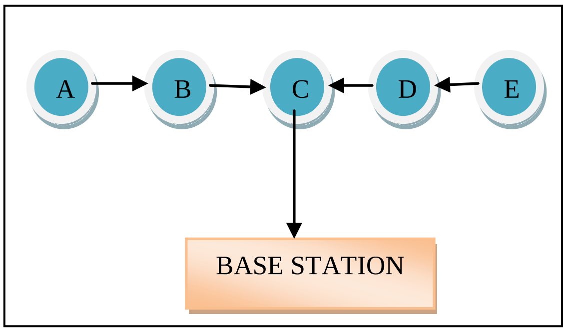

Fig.3 Chain forming and data gathering in PEGASIS

During the construction phase assumes that all the sensors have global knowledge about the network, particularly, the positions of the sensors, and use a greedy approach. When a sensor fails or dies due to low battery power, the chain is constructed using the same greedy approach by bypassing the failed sensor.

2) Gathering Data: The data is gathered and moves from node to node, aggregated and eventually sent to the base station. Unlike LEACH, PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the BS (sink) instead of using multiple nodes. A sensor transmits to its local neighbors in the data fusion phase instead of sending directly to its CH as in the case of LEACH.[9]

For example as shown in fig.3node A passes its data to node B. Node B aggregates node A's data with its own and then transmits to the leader. After node C passes the token to node E, node E transmits its data to node D. Node D aggregates node E's data with its own and then transmits to the leader C. Node C waits to receive data from both neighbors and then aggregates its data with its neighbors' data. Finally, node c transmits one message to the base station.

Simulation results showed that PEGASIS is able to increase the lifetime of the network twice as much the lifetime of the network under the LEACH protocol. Such performance gain is achieved through the elimination of the overhead caused by dynamic cluster formation in LEACH and through decreasing the number of transmissions and reception by using data aggregation. Although the clustering overhead is avoided, PEGASIS still requires dynamic topology adjustment since a sensor node needs to know about energy status of its neighbors in order to know where to route its data. Such topology adjustment can introduce significant overhead especially for highly utilized networks. .Because In PEGASIS, each node communicates only with a close neighbor and takes turns transmitting to the base station, thus reducing the amount of energy spent per round.. Energy saving in PEGASIS over LEACH takes place by many stages: First, in the local data gathering, the distances that most of the sensor nodes transmit are much less compared to transmitting to a cluster-head in LEACH. Second, only one node transmits to the BS in each round of communication. PEGASIS outperforms LEACH by limiting the number of transmissions, eliminating the overhead of dynamic.[9]

C. TEEN

TEEN (Threshold sensitive Energy Efficient sensor Network protocol) 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. In this scheme, at every cluster change time, in addition to the attributes, the cluster-head broadcasts to its members the following:

- Hard Threshold: 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 : This is a small change in the value of

the sensed attribute which triggers the node to switch on its transmitter and transmit.

The nodes sense their environment continuously. The first time a parameter from the attribute set reaches its hard threshold value, the node switches on its transmitter and sends 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:

(i) The current value of the sensed attribute is greater than

the hard threshold.

(ii) The current value of the sensed attribute differs from SV by an amount equal to or greater than the soft threshold.

Whenever a node transmits data, SV is set equal to the current value of the sensed attribute. Thus, the hard threshold tries to reduce the number of transmissions by allowing the nodes to transmit only when the sensed attribute is in the range of interest. The soft threshold further reduces the number of transmissions by eliminating all the transmissions which might have otherwise occurred when there is little or no change in the sensed attribute once the hard threshold.[10].

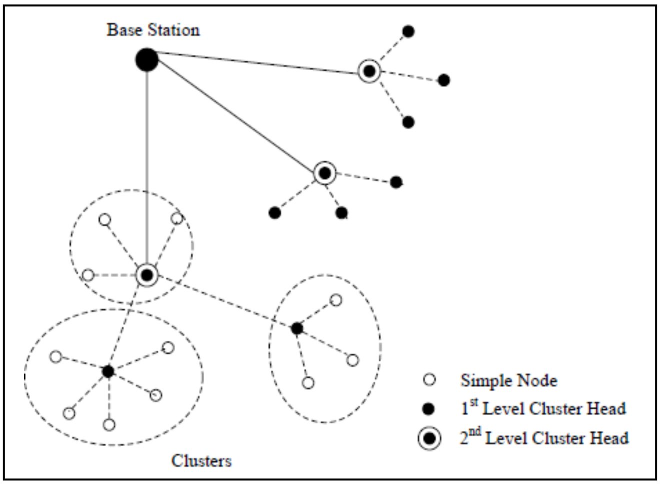

Fig.4. Hierarchical Clustering in TEEN

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.[4]

D. APTEEN

APTEEN is Adaptive Periodic Threshold-sensitive Energy Efficient Sensor Network Protocol. In APTEEN once the CHs are decided, in each cluster period, the cluster head first broadcasts the following parameters:

- Attributes (A): This is a set of physical parameters which the user is interested in obtaining data about.
- Thresholds: This parameter consists of a hard threshold (HT) and a soft threshold (ST). HT is a particular value of an attribute beyond which a node can be triggered to transmit data. ST is a small change in the value of an attribute which can trigger a node to transmit data again.
- Schedule: This is a TDMA schedule assigning a slot to each node.
- Count Time (TC): It is the maximum time period between two successive reports sent by a node. It can be a multiple of the TDMA schedule length and it accounts for the proactive component.

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
(iii) Persistent queries, to monitor an event for a period of time.

The main features of APTEEN Protocol are :

- By sending periodic data, it gives the user a complete picture of the network. It also responds immediately to drastic changes, thus making it responsive to time critical situations.
- It offers a flexibility of allowing the user to set the time interval (TC) and the threshold values for the attributes.
- Energy consumption can be controlled by the count time and the threshold values.
- The hybrid network can emulate a proactive network or a reactive network, by suitably setting the count time and the threshold values.

The main drawback of this scheme is the additional complexity required to implement the threshold functions and the count time. However, this is a reasonable trade-off and provides additional flexibility and versatility. [11]

E. HEED

HEED is Hybrid, Energy-Efficient Distributed Clustering protocol. HEED extends the basic scheme of LEACH by using residual energy and node degree or density as a metric for cluster selection to achieve power balancing. It operates in multi-hop networks, using an adaptive transmission power in the inter-clustering communication. HEED was proposed with four primary goals namely:

(i) Prolonging network lifetime by distributing energy consumption,
(ii) Terminating the clustering process within a constant number of iterations
(iii) Minimizing control overhead
(iv) Producing well-distributed CHs and compact clusters.

In HEED, the proposed algorithm periodically selects CHs according to a combination of two clustering parameters. The primary parameter is their residual energy of each sensor node (used in calculating probability of becoming a CH) and the secondary parameter is the intra-cluster communication cost as a function of cluster density or node degree (i.e. number of neighbors). The primary parameter is used to probabilistically select an initial set of CHs while the secondary parameter is used for breaking ties. 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. These methods are suitable for prolonging the network lifetime rather than for the entire needs of WSN. [11],[12]

IV. CONCLUSION

Due to limited energy resources of sensor nodes, the main challenges in the design of routing protocols for WSNs ,is energy efficiency. The main objective behind the routing protocol design is to keep the sensors operating for as long as possible, so that the lifetime of wireless sensor network can be increased. The energy consumption of the sensor nodes is dominated by data transmission and reception. In this paper the energy efficient routing protocols are described. Hierarchical protocols such as LEACH, PEGASIS, TEEN, APTEEN, HEED are described in this paper that are energy efficient because main aim of such protocols is to efficiently maintain the energy usage of sensor nodes by involving them in multi-hop communication within a particular cluster.

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