IJIRST –International Journal for Innovative Research in Science & Technology| Volume 1 | Issue 7 | December 2014
ISSN (online): 2349-6010

Energy Efficient Hierarchical Cluster Based Routing Protocols In WSN - A Survey

Sumaiya Begum D
PG Student
Department of IT
K.S.R.C.T

Nithya R
Assistant Professor
Department of IT
K.S.R.C.T

Prasanth K
Associate Professor
Department of IT
K.S.R.C.T

Abstract

Current research in wireless networking technologies introduce several energy efficient routing protocols in sensor networks. These protocols aim to prolong the overall lifetime of network by reducing the energy consumption of nodes. Transfer of gathering information from the sensing field to the base station must be done in proficiently to sustain the network longer. Clustering is one of the process to achieve this goal. Cluster based hierarchical routing protocol have proven to be effective in management of network topology, minimize the energy level, data aggregation and so on. In this paper, we intend to discuss some of the major hierarchical routing protocols adhering towards sensor networks. Moreover, we examine and compare several aspects and characteristics of few explored hierarchical cluster-based protocols, and its operations in wireless sensor networks (WSN). This paper also presents a discussion on the future research topics and the challenges of hierarchical clustering in WSNs.
Keywords: Wireless sensor networks, Hierarchical routing, Clustering, Energy Efficiency.

I. INTRODUCTION

Wireless sensor networks (WSNs) are composed of a large number of wireless sensor nodes that are densely deployed either inside the phenomenon or very close to it. WSNs are used in different domains towards military applications, medical engineering, environment and industrial task automation [1]. Based on this serious expectation, in several significant WSN applications the sensor nodes are remotely deployed randomly in larger numbers and operated separately. In these unattended environments the sensors cannot be charged and replaced, thus energy constraints are the most serious problem so as to must be considered [2]. Usually routing protocols on the basis of network structure are divided into two main groups: flat and hierarchical routing [3]. Here, the hierarchical routing protocols also known as cluster-based routing proposed in wireless sensor network. In order to support data aggregation through efficient network group, nodes can be partitioned into an amount of small groups called clusters [4]. All clusters have a manager, referred to as a cluster head and a number of member nodes. The cluster formation process eventually leads to a two-level hierarchy where the cluster head (CH) nodes from the highest level and the cluster-member nodes of the small level. Sensor nodes sometimes broadcast their data to the corresponding cluster head. The cluster head collects and grouping the data and transmit them to the base station (BS) either directly or through the intermediate communication with extra CH nodes. Though, because the CH nodes send all the time data to higher distances than the ordinary (member) nodes, they of course spend energy at higher rates. A general solution in order to balance the energy consumption between all the network nodes is to sometimes re-elect new CHs in each cluster [5]. Energy consumption in the network can be reduced by forming cluster structures in an efficient way; so many energy aware routing protocols are designed on the basis of the cluster configuration.

II. RELATED WORK

Unlike flat protocols, where each node has its unique global address and all the nodes are peers, in hierarchical protocols nodes are grouped into clusters. Every cluster has a cluster head the election of which is based on different election algorithms. The cluster heads are used for higher level communication, reducing the traffic overhead. Clustering may be extended to more than just two levels having the same concepts of communication in every level. The use of routing hierarchy has a lot of advantages. It reduces the size of routing tables providing better scalability.

A. LEACH

Low-Energy Adaptive Clustering Hierarchy (LEACH): LEACH is one of the first hierarchical routing approaches for sensor networks. LEACH is a self organizing, adaptive clustering protocol. It reduces the energy significantly. The LEACH is a cluster based protocol and randomly selects the Cluster-heads for each cluster. [6], [7]. The operation of the LEACH protocol consists of two phases:

- The Setup Phase. In this Phase, the sensor nodes organize themselves into local clusters, in which one node acting as the cluster head [8]. The cluster heads aggregate, compress and forward the data to the base station. The nodes in the clusters determines that whether it will become a cluster head, in this round, by using a stochastic algorithm on each round. If a node becomes a cluster head for one time, it cannot become cluster head again for N rounds, where N is the desired percentage of cluster heads. Thereafter, the possibility of a node to become a cluster head in each round is 1/N. This rotation of cluster heads leads to a balanced energy consumption to all the nodes and hence to a longer lifetime of the network.
- The Steady State Phase. In this Phase, the data is sent to the base station. The lifetime of the steady state phase is longer than the lifetime of the setup phase in order to minimize overhead. Furthermore, each node that is not a cluster head selects the closest cluster head and joins that cluster. After that the cluster head creates a routing for each node in its cluster to transmit its data.

1) *Merits*

(1) It provides scalability in the network by means of limiting most of the communication inside the different clusters of the network.[9]
(2) Single-hop routing is possible from sensor node to cluster head, and by this means we can able to save the energy of the network.
(3) Distributiveness property within the cluster, where it distributes the role of CH to the other cluster members within the cluster
(4) The dynamic clustering may result in adding an overhead.[10]

2) *Demerits*

(1) It significantly relies on cluster heads rather than cluster members, of the cluster for communicating to the sink. Due to this it incurs robustness issues like failure of the cluster heads.[11]
(2) In LEACH CHs are not uniformly distributed within the cluster that means CHs can be located at the edges of the cluster.
(3) It does not work well with the applications that require large area coverage along with multi-hop inter-cluster communication.
(4) The cluster heads are elected randomly, so the optimal number and distribution of cluster heads cannot be ensured [12].

B. LEACH-C

Low-Energy Adaptive Clustering Hierarchy Centralized (LEACH-C): LEACH-Centralized [13] is an advancement of LEACH, it uses the same steady state protocol as of LEACH but, uses a centralized clustering algorithm. The LEACH-C utilizes the base station forcluster formation, unlike LEACH where nodes self-configurethemselves into clusters [13]. During the setup phase, theBase Station (BS) receives information regarding the locationand energy level of each node in the network. After that,using this information, the BS finds a predetermined numberof cluster heads and configures the network into clusters.The cluster groupings are selected to minimize the energy required for non-cluster-head nodes to transmit their data to their respective cluster heads. The improvements of this algorithm compared to LEACH are the following:

- The Base Station utilizes its global information of the network to generate clusters that require less energy for data transmission.
- In LEACH the number of CH varies from round to round due to the lack of global coordination among nodes, in LEACH-C the number of cluster heads in each round equals a predetermined optimal value.

1) *Merits*

The different advantages that the LEACH-C protocols as follows [14]

(1) The energy consumption of CH can be reduced by efficiently selecting the CH using the location information of the member nodes.
(2) LEACH-C protocol does not always provide better routing than LEACH protocol.
(3) The requirement of getting exact location information of all member nodes causes additional energy consumption.
(4) LEACH-C is more efficient than LEACH because it delivers 40% more data per unit energy than LEACH.

C. ELCH

Extending Lifetime of Cluster Head (ELCH):ELCH (Extending Lifetime of Cluster Head) routing protocol has a self-configuration and hierarchal routing properties [15]. It constructs clusters on the basis of radio radius and the number of cluster members. The clusters in the network are equally distributed.In ELCH the sensors vote for their neighbors in order to elect suitable cluster heads [15]. This protocol achieves to consume low energy and thus extending the life of the network utilizing a hybrid protocol, which combines the cluster architecture, with multi-hop routing. This protocol presents two phases:

- Setup Phase. In this phase, the cluster formation and the cluster-head selection is performed. The nodes vote their neighbor sensors. The most voted sensor becomes the cluster-head.
- Steady-State Phase. In this phase, the creation of clusters, the forwarding to the head and forwarding to the sink are performed. The clusters are formed in such a way that they consist of one cluster-head and some sensors. These sensors have been chosen based on their location. This means that the sensors located in a radius less than the radio radius are selected. Then, the time slot TDMA for each cluster member in each round is used. Moreover, each cluster-head maintains a table with maximum power for each node at each selection round. As soon as the above are completed the data transmission can start. When the clusters have been organized, the CH can form a multi-hop routing backbone. The data are forwarded directly to the cluster head by each node. Moreover, for the communication between the cluster heads and the sink, a multi-hop routing is adopted. This technique can minimize the transmitted energy and the network can be more balanced in terms of energy efficiency.

D. PEGASIS

Power-Efficient Gathering in Sensor Information Systems (PEGASIS): The PEGASIS protocol is a chain-basedprotocol and an improvement of the LEACH [16]. In PEGASISeach node communicates only with a nearby neighbor inorder to send and receive data. It takes turns transmitting tothe BS, thus reducing the amount of energy spent perround. The nodes are organized in such a way that to form asequence, which can either be accomplished with the sensor nodesthemselves, using a greedy algorithm starting from some node,or the BS can compute this chain and broadcast it to all thesensor nodes.In [16] a simulation is performed in a network that has 100-random located nodes. The BS is placed at a remote distancefrom all the other nodes. Thus, for a 50m x 50m plot, theBS is located at (25, 150) so that the BS is at least 100m faraway from the closest sensor node. In order to construct thechain, it is assumed that all nodes have global knowledge ofthe network and that a greedy algorithm is employed. Thus,the construction of the chain will start from the far away nodeto the closest node. If a node dies, the chain is reconstructedin the same manner to bypass the dead node. In general, the PEGASIS protocol presents twice or moreperformance in comparison with the LEACH protocol [17],[18]. However, the PEGASIS protocol causes the redundantdata transmission from one of the nodes in the chain hasbeen selected. Unlike LEACH, the transmitting distance formost of the nodes is reduced in PEGASIS. Experimentalresults show that PEGASIS provides enhancement by factor 2 compared to LEACH protocol for 50m x 50m network andimprovement by factor 3 for 100m x 100m network. ThePEGASIS protocol, still, has a critical problem that is theredundant transmission of the data. The cause of this problemis that there is no consideration of the base station's locationabout the energy of nodes when one of nodes is selected asthe head node.

E. TEEN

Threshold sensitive Energy Efficient sensor Network protocol (TEEN): The TEEN is a hierarchical protocol designedfor the conditions like sudden changes in the sensed attributessuch as temperature [19]. The sensitivity is important for time-critical applications, where the network operates in a reactive mode. The sensor network architecture in TEENis based on a hierarchical grouping where closer nodes fromclusters and this process goes on the second level until thesink is reached.In this scheme the cluster-head broadcasts to its membersthe Hard Threshold (HT) and the Soft Threshold (ST). The HT is a threshold value for the sensed attribute. It is the complete value of the attribute away, from which, the node sensing thisvalue should switch on its transmitter and report to its clusterhead. The ST is a small change in the value of the sensedattribute which triggers the node to switch on its transmitterand transmit. The nodes sense their environment continuously.Initially a parameter from the attribute set reaches itshard threshold value, the node switches on its source andsends the sensed data. The sensed value is stored in avariable in the node, called the sensed value (SV).

1) *Merits*

(1) It works well in theconditions like sudden changes in the sensed attributes suchas temperature.
(2) In large area networks andwhen the number of layers in the hierarchy is small, TEENtends to consume a lot of power, because of long distancetransmissions.
(3) When the number of layers increases,the transmission overhead in the setupphase is occurring as well as the operation of the network exist.

2) *Demerits*

(1) If the hard threshold is never reached, no data messages will be forwarded towards the base station.

F. APTEEN

Adaptive Threshold sensitive Energy Efficient sensor Network (APTEEN): APTEEN is a hybrid routing protocol (APTEEN) which allows for comprehensive data recovery. The nodes in such a network not only respond to time-critical applications, but also give an overall picture of the network at periodic intervals in a very energy efficient manner [20]. Such a network enables the user to request all time data from the network in the form of historical, one-time and regular queries respectively. The APTEEN is an improvement ofTEEN. [20]. The base stationforms the clusters, the cluster heads transmit the threshold values, the attributes and the transmission schedule to all nodes.After that the cluster heads perform data aggregation, whichhas as an outcome to save energy.

1) *Merits*
   (1) It consumes less energy compared to TEEN.
   (2) It offers a flexibility of allowing the user to set the time interval (TC) and the threshold values for the attributes
   (3) The hybrid network can emulate a proactive network or a reactive network, by properly setting the count time and the threshold values. [20]

2) *Demerits*
   (1) The main drawback of this scheme is the additional complexity required to implement the threshold functions and the count time.

G. HPAR
Hierarchical Power Aware Routing (HPAR): The HPAR is a power aware routing protocol that divides the network into a group of sensors called zones [21]. Each zone is a group of geographically close sensor nodes and is treated as an entity. Thus the first step of this protocol is to format the clustered zones. The next step is the function of the routing scheme to decide how a message is routed across other zones hierarchically so that the battery life of nodes in the system is maximized. This can be done with a message that is routed along a path with a maximum power over all minimum remaining powers. This path is called max-min path. The main idea of making such a decision is that it may be possible that a path with high residual power has more energy consumption than the minimum energy consumption path. This scheme presents an approximation algorithm called max-min ZPmin algorithm. The algorithm first finds a path with less power consumption by applying the Dijkstra algorithm. It then finds a second path that maximizes the minimal residual power in the network. The protocol then tries to optimize both solution criteria.

1) *Merits*
   (1) The main advantage of this protocol is that it takes into consideration both the transmission power and the minimum battery power of the node in the path.
   (2) In addition, it makes use of zones to take care of the large number of sensor nodes.

2) *Demerits*
   (1) The discovery of the power estimation may consult on the overhead to the network.

H. SHPER
Scaling Hierarchical Power Efficient Routing (SHPER):he SHPER protocol supposes the coexistence of a basestation and a set of homogeneous sensor nodes [22]. Thesenodes are randomly distributed within a delimited area ofinterest. The base station is located a long distance far away fromthe sensor field. The base station and the set of the sensornodes are supposed to be fixed. In addition, the base station isable to transmit with a high enough power to all the networknodes, due to its unlimited power supply.The operation of SHPER protocol consists of two phases:initialization and steady state phase. In the first phase the basestation broadcasts a TDMA schedule and requests the nodes toadvertise themselves. The nodes transmit their advertisementsand the relative distances among them are identified. After thatthe base station randomly elects a predefined number of high and low level cluster heads and broadcasts the IDs of the newcluster heads and the values of the thresholds. In the steadystate phase the cluster head defines the most energy efficientpath to route its messages to the base station.

1) *Merits*
   (1) The main advantage of this protocol is that it performs thecluster leadership by taking into account the residual energy ofnodes and energy balance is achieved and the power depletionamong the nodes is performed in a more even way.
   (2) The data routing is based on a route selection policy whichtakes into consideration both the energy reserves of the nodesand the communication cost associated with the potentialpaths.

2) *Demerits*
   (1) It does not support the mobility of the nodes.

I. HEED
Hybrid energy efficient Distributed Clustering (HEED) [23] is a multi-hop clustering algorithm for wireless sensor networks. It is considered to choose different cluster heads in a field, based on the amount of residual energy that is distributed in relation to a neighboring node. The random selection of cluster head is not suitable in HEED, because it decreases the lifetime of the network.

The main goals of the network

(1) Extend the network lifetime by distributing energy consumption.
(2) Terminate the clustering process within a constant number of cycles.
(3) The control overhead should be minimized
(4) Produce well-distributed cluster heads and compact clusters.

The cluster head selection is the most important method in HEED. Cluster head is chosen based on two important parameters. One parameter depends on the nodes remaining energy, and the other parameter is the intra-cluster communication cost as a function of cluster density. The residual energy of each node is most heads. That parameter is normally used in many other clustering schemes. Intra-cluster communication cost reflects the node degree or node's nearness to the neighbor and is used by the nodes in deciding to join the cluster.

1) *Merits*

(1) HEED distribution of energy; improve the lifetime of the nodes within the network this method stabilizing them neighboring node.
(2) Does not require particular node's ability, such as location-awareness.
(3) Does not create assumptions about node distribution. Operates suitably eve when nodes are not synchronized.

2) *Demerits*

(1) The random selection of the cluster head may cause higher communication overhead.
(2) The cyclic cluster head rotation or election needs extra energy to reconstruct clusters.

J. DHAC

Distributed hierarchical agglomerative clustering (DHAC):The main idea in the DHAC is that a node needsthe knowledge of only one hop neighbor to build the clusters[24]. The steps in the DHAC to form clusters are thefollowing:

- Obtain input data set and build resemblance matrix. In this step each node elects itself as a cluster head and exchanges the information via HELLO messages to its neighbors.
- Execute the DHAC algorithm. In this phase, each cluster establishes its own local resemblance matrix and the minimum coefficient can be easily found. Also, each cluster then determines its minimum cluster head.
- Cut the hierarchical cluster tree. In case that a predefined upper bound size of clusters is reached, the control conditions correspond to the step of cutting the hierarchical cluster tree.
- Control the minimum cluster size. The next is to generate the clusters by running DHAC, the minimum cluster size can also be used to limit, the lower bound of cluster size by performing the procedure "MERGE CLUSTERS".
- Choose CHs. To choose the CHs, the DHAC choose the lower id node between the two nodes that join the cluster at the first step. The CH chosen does not require extra processing.

Following, the DHAC uses the sequence of nodes merging into the current cluster as the schedule. Each cluster member gets its assigned role and starts to send data to the CH in turns.

In Table I, Hierarchical Routing Schemes Comparison is presented. Thus, for example protocols: LEACH, LEACH-C, PEGASIS, TEEN, APTEEN, SHPER and DHAC are more robust than the others of this category. Moreover, protocols PEGASIS and ELCH use the greedy route policy selecting nodes in order to achieve the energy efficiency of the nodes. In addition to this, LEACH, LEACH-C, PEGASIS, TEEN, APTEEN, SHPER and DHAC are more scalable than the other protocols of this scheme.

Table -1
Comparison of Hierarchical Routing Protocols

Scheme	*Network type*	*Mobility*	*Energy Efficiency*	*Scalability*	*Route Metric*	*Robust*	*Scheme*
LEACH	*Proactive*	*Fixed BS*	*Very low*	*Good*	*Shortest Path*	*Good*	*LEACH*
LEACH-C	*Proactive*	*Fixed BS*	*Very high*	*Good*	*The best route*	*Good*	*LEACH-C*
ELCH	*Proactive*	*Fixed BS*	*High*	*Limited*	*It selects the node with maximum residual energy*	*Good*	*ELCH*
PEGASIS	*Proactive*	*Fixed BS*	*Low*	*Good*	*Greed route selection*	*Good*	*PEGASIS*
TEEN	*Reactive*	*Fixed BS*	*Very high*	*Good*	*The best route*	*Limited*	*TEEN*
APTEEN	*Reactive*	*Fixed BS*	*Moderate*	*Good*	*The best route*	*Good*	*APTEEN*
HPAR	*Reactive*	*No*	*High*	*Low*	*It initially selects the shortest path and then tries to optimize it based on the total energy consumption*	*Good*	*HPAR*

SHPER	*Proactive*	*Fixed BS*	*High*	*Good*	*The best route*	*Good*	*SHPER*
HEED	*Proactive*	*Fixed BS*	*Moderate*	*Good*	*The best route*	*Good*	*HEED*
DHAC	*Proactive*	*No*	*Low*	*Good*	*The best route*	*Limited*	*DHAC*

III. CONCLUSION

Recent developments in wireless communications have enabled the development of low-cost, low-power WSNs with wide applicability. Minimizing energy consumption and hence prolonging the network lifetime are key requirements in the design of optimum sensor networking protocols and algorithms. In this paper, we have reviewed some of the existing 'hierarchical clustering' routing protocols, specifically with respect to their network lifetime and reliability requirements. In addition, we also provided a comparative study of some protocols reacting towards various networking parameters. The factors affecting CH communication and cluster formation are highlighted and those challenges are pinpointed for future research directions in this regard.

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