Analysis of Energy Efficient Cluster Based Routing Protocol for Wireless Sensor Networks

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Abstract

Energy awareness is a very important design issue for Wireless Sensor Networks, even though a number of routing, power management and data dissemination protocols have been designed in particular. To prolong network lifetime and provide scalability, nodes are formed as disjoint groups and mostly overlapping groups of clusters. The goal of this paper is to analyze different categories of clustering approaches that have been proposed for WSNs. These protocols have also been compared, based on their features such as energy efficiency, scalability, data aggregation and multipath. This paper gives the future direction for optimal energy efficiency.

Keywords: Wireless Sensor Networks, Clustering, Energy Efficiency, Routing

1. Introduction

The Micro-Electro-Mechanical Systems technology has led to plenty of changes in wireless networking. This makes the system low cost, low power consuming and smaller micro-computer with appropriate sensors attached called sensor nodes. The collection of such self-organized inexpensive miniature devices capable of processing, communicating and sensing is called Wireless Sensor Networks (WSNs). It observes the previously unobservable at a fine resolution over large spatiotemporal scales. The applications of WSN includes industry, science, transportation, security etc [1][7]. The basic components of a WSN includes sensors, memory, micro-controller, transceiver, ADC and power source [16].

![Figure 1. Components of WSN](image)

The major challenges of WSN are energy efficiency, robustness, self configuration, adaptation, scalability, heterogeneity, privacy and security. Of the aforesaid, energy efficiency is a major challenge since nodes in WSNs operate on battery power with limited energy [10][18][19][20].

Clustering is one important method for extending the lifetime of sensors in a network. WSN forms clusters of each having a coordinator called Cluster Head responsible for collecting data from the nodes within a cluster and sending it to the Base Station (Sink). The cluster heads can be identified randomly or based on some criteria. The CH acts as a gateway between the sensor nodes and BS. In some way, the CH is the Sink for cluster nodes and the BS is the Sink for CHs [13][14][21].
The above figure shows the data communication in a clustered network. The member nodes send their data to respective CHs and the CHs send their data directly to Sink or through other BSs. Since CHs transmit data to long distances, they lose energy quickly while compared to member nodes. So the network is to be reclustered periodically in order to balance the energy on all the nodes. The creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, extended lifetime and energy efficiency. The protocols are analyzed based on their design approach, clustering criteria and overhead.

2. Cluster Routing Protocols in WSNs

In this section, different clustering routing protocols for WSNs are analyzed based on their design approach, clustering, overhead, scalability, energy efficiency, advantages and disadvantages.

2.1. LEACH (Low Energy Adaptive Clustering Hierarchy)

LEACH uses the distributed cluster formation technique which enables self-organization of large numbers of nodes. The nodes organize themselves into local clusters, with one node acting as the cluster head. The cluster head performs signal processing functions on the data and transmits data to the remote BS. The clustering process involves only one iteration, after which, a node decides whether to become a CH or not. In order to balance the energy among all the nodes, LEACH assigns a fixed probability to every node, so as to elect itself as a CH. After its identification, each CH broadcasts an advertisement message, to all non-clustering nodes that determines which cluster to belong to, by choosing the CH that can be reached using the least communication range. This is called set-up phase. The clusters are formed dynamically in each iteration and the time to perform the iteration are also selected at random [2][3][11][15][17].

During Steady-State phase, frames are formed and nodes transmit their data to the Cluster Head. Once the CH receives all the data, it performs data aggregation. It makes use of a TDMA/CDMA MAC scheme to reduce inter and intra-cluster collisions. The advantages of LEACH includes: CH once elected will not be identified next; TDMA schedule prevents CHs from collisions. The drawbacks of LEACH are: it is not well suited for large region networks, since it supports one hop communication directly from CH to Base station. It cannot ensure load balancing, since CH selection is not based on nodes energy and dynamic clustering makes overhead [12].
2.2. PEGASIS (Power-Efficient Gathering in Sensor Information Systems)

In PEGASIS, a chain is formed with nodes instead of cluster. Each node transmits and receives from their neighbor and only one node from the chain is identified as a leader to transmit to the BS.

![Figure 3. Chaining in PEGASIS](image)

In the above figure, nodes C0 transmits its data to node C1. Node C1 cumulates node C0’s data with its own and then transmits it to the leader C2. After receiving the token from node C2, node C4 transmits its data to node C3. Node C3 cumulates node C4’s data with its own and then transmits to the leader node C2. Node C2 waits to receive data from both neighbors and then cumulates its data with its neighbors data. Finally, node C2 transmits one message to the Base Station. Nodes become leaders in a sequential order. Nodes will not become the leaders if the distance between neighbors is higher than a certain threshold. Leader node will pass a token to the nodes which are connected in a chain so that they can know who the leader is and which direction the message is to be passed. When a node dies, the chain is reconstructed in the same manner to bypass the dead node [6]. The advantages of PEGASIS are dynamic cluster formation overhead is reduced, energy is uniformly distributed in the network and the transmission distance for most of the distance is reduced. The disadvantage is that the redundant data transmission and nodes die fast [12][17].

2.3. TEEN (Threshold Sensitive Energy Efficient Sensor Network Protocol)

It is useful for time bound critical applications. In TEEN [4], during cluster change period CH broadcasts Hard Threshold (Threshold value for the sensed attribute) and Soft Threshold (small change in the value of the sensed attribute which triggers the node to switch on its transmitter and transmit) to its members. Nodes senses the environment continuously and the first time a parameter from the attribute set reaches its Hard Threshold value, the node goes on its transmitter and sends the sensed data. This sensed data is stored in a variable called Sensed Value (SV). The nodes will transmit the data only when the following conditions are true:

i) The present value of the sensed attribute is greater than the Hard Threshold.

ii) The present value of the sensed attribute differs from SV by an amount equal to or greater than the Soft Threshold.

The advantages of TEEN are Based on two threshold values: transmission is controlled and transmission energy consumption is reduced by using two threshold values. The main drawback is that if the threshold values are not obtained then the nodes will never go for communication and will not come to know even if all the nodes die[12][17].

2.4. APTEEN (Adaptive Periodic Threshold-sensitive Energy Efficient Sensor Network Protocol)

In APTEEN [5] also CH broadcasts attributes(set of parameters which the user is interested in obtaining data about), Hard Threshold(HT), Soft Threshold(ST), TDMA schedule (slot to each node) and Count time(maximum time period between two successive reports sent by a node) to its members during every cluster change period. The node senses the environment continuously and only those nodes which sense a data value at or beyond the hard threshold can transmit. Once a node senses a value beyond HT, it then transmits data only when the value of that attributes changes by an amount
equal to or greater than the ST. If a node does not send data for a time period equal to the count time, it is forced to sense and retransmit the data. A TDMA schedule is used and each node in the cluster is assigned a transmission slot.

The main advantages of APTEEN are that it combines both proactive and reactive policies. It offers more flexibility by allowing the user to set count time and threshold values for the attributes and the energy consumption can be controlled by changing the count time and also the threshold values. The main drawback of APTEEN is additional complexity required to implement the threshold functions and the count time [12].

2.5. HEED (Hybrid Energy Efficient Distributed Protocol)

In HEED, CHs are selected based on their residual energy and nodes’ proximity to its neighbors or nodes degree. The clustering process completes quickly. The main advantages of HEED are that network lifetime is extended by distributing energy consumption, clustering process is completed within a constant period, reduction of control overhead, compact clusters are formed, each node is mapped exactly to one cluster and any node can directly communicate to its CH [8]. The main advantages are nodes do not require global information to form the clusters. The algorithm guarantees that every sensor is part of just one cluster and, the CHs are well distributed. The main drawbacks of HEED includes: random selection of CHs may cause communication overhead, the periodic CH rotation or election needs extra energy to rebuild clusters and the CHs near to Sink will die fast due to heavy load[12].

2.6. EEUC (Energy Efficient Unequal Clustering)

The main objective of EEUC [9][32] is to design the network with clustering and multi hop routing to extend the network life time. This protocol will choose the CHs with more residual energy. In EEUC clusters near to BS, size will be small than that of clusters far away from BS. The result is that clusters closer to the BS will consume low energy during the intra-cluster data processing. The BS broadcasts a “hello” message to all nodes at a certain energy level. So each node can calculate the approximate distance to the BS based on the received signal strength. This helps us to generate the clusters of unequal size. First, tentative CHs are identified to compute final CH election. Every node can become a tentative cluster with the probability T, a predefined Threshold. Each CH calculates the competition radius in which the energies are compared with those of tentative CHs and the one with maximum energy is elected as a new CH. In the case of tie in energies, the node with smaller node ID is elected as CH. In order to support multi hop routing more clusters to be formed nearer to the BS [9].

The main advantages of EEUC includes: unequal clustering mechanism is used to solve hot spot problem, supports multi hop routing to extend the life time of the network. The major drawbacks of this protocol are: clustering imposes overhead, because each node should send and receive lot of competition messages for CH election and, global data aggregation leads to additional overhead and degrades network performance [12].

2.7. EECCPAR (Energy Efficient Clustered Chain Based Power Aware Routing )

In EECCPAR [26][27][32], clustering does not happen in each round, and so it uses nodes’ residual energy to find a CH for the next round. It consists of three rounds: i) Clustering Phase ii) Chain Formation Phase iii) Data Transmission Phase. In clustering phase there are two stages: Cluster Head selection and Cluster formation. Neighboring tables are maintained to store the information about the neighbors. Each node broadcasts their neighboring information and nodes which are within the range will update their table by receiving the broadcast message. The nodes individually calculate their weight and distance to its neighbors. Based on their weight CHs are selected. After identifying the CHs, it will send an advertising message to the node. Based on the energy received, nodes will send a joining request message to a CH, under which they want to join.

After forming the clusters and identifying the CH, chains are formed in each cluster. So each node receives information from neighboring nodes and accumulates with its own and then passes to the central node. CHs transmits the received data to the BS. In the data transmission phase, CHs will
receive the information from its members and sends them to the BS. This protocol performance, outperforms PEGASIS. The advantages of EECPPAR includes: there is no overhead of forming clusters, the energy is uniformly distributed among all the nodes in a cluster. The main drawback is redundant data transmission and nodes will die fastly.

2.8. EELBCRP (Energy-Efficient Level Based Clustering Routing Protocol)

In EELBCRP [28][29][32], there are three phases: i)setup phase, ii)cluster setup phase iii)inter cluster routing phase. In the setup phase BS sends a minimum power signal with level 1. Nodes that are receiving this signal will set their level as 1. Then BS increases its power to reach the next level and transmit. Now the receiving nodes will set their level as 2. This process continues until BS sends the messages to all levels. The next phase, is cluster setup phase in which each level is divided into a number of clusters. Like LEACH, in each level a node has to decide whether to become a CH or not for a present round by choosing a random number between 0 and 1. All CHs transmit their advertisement message to their energy levels. By receiving this message, the member nodes have to identify their clusters for a present round. Once the clusters are formed the nodes can send a data to its CH with a signal strength of advertisement message. After receiving data from all member nodes CH will do data aggregation. The last phase is the inter cluster routing, in which CH transmits the aggregated data to the next level. In the next, CH will do aggregation and send the same to further nodes until it reaches the level closer to the BS. The CH which is near BS will do aggregation and transmit it to the BS. The advantages are energy consumption of CHs, number of cluster formation and extended lifetime of the network. The main drawback is overhead due to different levels.

2.9. H-HEED (Heterogeneous Hybrid Energy Efficient Distributed )

It is an advanced version of HEED protocol. In H-HEED [30] according to node energy it is divided into different levels. Based on the energy value different levels like 2-level, 3-level and multilevel is introduced. In 2-level two types of sensor nodes are available namely: advanced nodes and normal nodes. In level-3 three types of sensor nodes are used namely: super nodes, advanced nodes and normal nodes. The advantages of H-HEED are that the number of nodes die in a single round and is significantly reduced in comparison to HEED and in multi level H-HEED all nodes have different energy levels so that the nodes will die randomly. Hence the network lifetime is extended significantly. The disadvantage is that it cannot perform well in a homogeneous environment.

2.10. ECHERP (Equalized Cluster Head Election Routing Protocol)

In ECHERP [31] BS is to be considered with unlimited residual energy and communication power. As the distance goes longer from the BS to the transmitter node the energy consumption also will be high. Nodes are grouped into clusters and one node in each cluster will act as a CH. The CHs which are closer to the BS are called as first level CHs. They have direct communication to the BS with less energy consumption. CHs which are closer next to the BS is called second level CHs and the next is called third level CHs etc. CHs far away from BS will transmit it to its closer level CH towards BS. In order to make this protocol as an energy efficient one BS generates a TDMA schedule and asks the nodes to advertise with their energy and location information. So each node starts advertising their energy level and location information to its neighbours. Depending on this information each node will maintain a neighbour information table. This process continues till all the nodes in the network reach BS, so that BS will have a global knowledge of the network.

When the advertisement is completed, BS selects the nearest node as CH of high level. Nodes which are not receiving the advertisement message are treated as low- level CHs. The BS sends the unique IDs of the identified CHs and their members to the nodes so that it will be helpful for the nodes to form their clusters which they belong to. Each CH generates a TDMA schedule and broadcasts the same to their member nodes stating the time slot that it can transmit. The nodes are turned off other than the transmission period. So the energy consumption of individual node is reduced a lot. During the assigned transmission time, the nodes will transmit the collected data to their CHs. So the interference with other transmissions and the energy consumption is reduced. The received data are aggregated by
the lower level CHs and transmitted to the higher level CHs and from CHs data are transmitted to the BS. The main advantage in energy consumption is reduced, since reclustering is not happening in each round. The disadvantages are overhead due to data aggregation and extra overhead to maintain a neighbouring table.

3. Conclusion and Future Enhancement

Clustering nodes into groups not only reduce the consumption of energy but also increases the scalability, reduces delay and provides optimal path for routing. This paper briefs only few cluster based routing protocols used in WSN along with their pros and cons.

<table>
<thead>
<tr>
<th>Protocol Name</th>
<th>Energy Efficiency</th>
<th>Scalability</th>
<th>Data Aggregation</th>
<th>Multipath</th>
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<td>Poor</td>
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<td>No</td>
</tr>
<tr>
<td>PEGASIS</td>
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<td>Poor</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
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<td>Yes</td>
<td>No</td>
</tr>
<tr>
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<td>No</td>
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<tr>
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</tr>
<tr>
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<td>Yes</td>
</tr>
<tr>
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<td>Poor</td>
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<td>No</td>
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<tr>
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</table>

In future, protocol can be modified such that it could minimize energy consumption more and also looping can be avoided while transmitting.

4. References


