Application of Alternate Energy Efficient Clustering Protocols for Heterogeneous Networks

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Abstract
Due to the wide range of application of Wireless Sensor Networks (WSN) the past few years have witnessed the potential use of it and also become a hot research area now a days. Conserving sensor energy is one of the primary issues in WSN network, to prolong the lifetime of the network. Routing protocols developed for various other ad hoc networks such as MANET, VANET etc. can’t apply directly in WSN due to energy constrains of nodes. Various clustering based protocols have been suggested over the years including LEACH, TEEN, PEGASIS etc. Most of the clustering protocols however assume the nodes to bear same characteristic i.e. homogenous, which is just a hypothetical case. As, we know there can be difference in the sensors being used according to the type of usage they are put into. Thus node heterogeneity is required to be taken into account while designing any network protocol in Wireless Sensor Network paradigm. In this paper work, which a gist of the research work in the same area, the author tries to analyze the various heterogeneous clustering based routing protocols and to suggest a novel approach towards attaining energy efficiency in the form of a hybrid energy efficient protocol.

Keywords—ClusterHead, HEED, LEECH, Wireless Sensor Networks.

1. INTRODUCTION
The wireless sensor networks have been an ever increasing domain with the advent of technological advancements in electronics. Mostly these networks are deployed in areas which are required to perform a comprehensive process of sensing, measurement, measurement logging, data transfer and management through a wireless data network. The wireless sensor can be a tiny small device embedded to accomplish all these functions measurements and computation, in a small package. A bulk or set of sensors connected though network in mesh form perfuming a networking protocol. The hopping data of the sensors from one sensor to another is a major protocol and technique, the sensors that hopping data from one to each other is so called sensor nodes. The wireless sensor nodes don’t require communicating directly with the nearest control center which is of high power or even don’t require directly communicating to the base station. But it communicates with the nodes local peers only. The base station can be assumed as a master node. Data sensed by the network is routed back to a base station. The base station is a larger computer where data from the sensor network will be compiled and processed [1]. The base station thus is the single point of communication for the whole network with the outer world. It can do so over standard wired or wireless mediums.

Topology control in a wireless sensor network is required to balance the load on sensor nodes and increases network scalability and network lifetime, as well. Clustering of the sensor nodes is an effective topology control approach. HEED [2] proposes a novel distributed clustering approach for long-lived ad hoc sensor networks. The proposed approach does not make any assumptions about the presence of infrastructure or about node capabilities, other than the availability of multiple power levels in sensor nodes. The protocol abbreviated as HEED i.e. Hybrid Energy-Efficient Distributed clustering, is a novel clustering based protocol that periodically selects cluster heads according to a hybrid of the node residual energy and a secondary parameter, such as node proximity to its neighbors or node degree. The authors have shown that the HEED protocol a significant increase in network scalability and lifetime. In [2], a hybrid HEED protocol which can be assumed to be extension of the HEED, the feasibility of the HEED protocol for a heterogeneous network is studied and a novel algorithm which includes the node heterogeneity in terms of node energy is proposed.

This paper and research work takes inspiration from above two research methodologies and suggests a novel approach where apart from node energy, the node distance from base station is also a key factor in determining the node selection.
2. LITERATURE REVIEW

2.1 LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY (LEACH):
LEACH [6] [7] is one of most popular clustering algorithm for WSN. It forms the cluster based on the received signal strength and uses the CH nodes as routers to communicate with the base station (sink). Cluster formation in LEACH is done using a distributed algorithm, where each node makes decision without any centralized control. The operation of LEACH is divided into two phases namely:

2.1.1 Setup Phase: It is an advertisement phase in which nodes uses CSMA MAC protocol to advertise their status, CSMA MAC protocols main task is to prevent two advertisement messages from colliding with each other. Thus, all non-cluster head nodes must keep their receiver ON during the setup phase to receive the message. Initially a node decides to a CH with a probability \( p \) and broadcasts its decision. Each non-CH node determines its cluster by choosing the CH that can be reached using the least energy. CH is been rotated periodically among the nodes of the cluster to balance load. The rotation is performed by getting each node to choose a random number “T” between 0 and 1. A node becomes the CH for the current round if the number is less than the following threshold:

\[
T(n) = \begin{cases} 
\frac{p}{(1 - p) \left( \frac{r - \text{mod} \left( \frac{1}{p} \right)}{p} \right)}, & \text{if } n \in G \\
0, & \text{otherwise}
\end{cases}
\]

Where \( p \) is the desire percentage of the CH nodes in the sensor population, \( r \) is the current round number, and \( G \) is the set of nodes that have not been CHs in the last \( 1/p \) rounds.

2.1.2 Steady-State Phase: Once the network is divided into clusters, CH uses TDMA schedule for its sensors to send the data. Data sent by the nodes in the cluster is aggregated at the CH and compresses the aggregated data before sending it to the sink. After the compression of data is done it is been send to the sink. Though LEACH is an energy-efficient routing protocol still it has some drawbacks:
- It is only suitable for small networks and not suitable for network deployed in large area.
- TDMA schedule wastes the bandwidth because some nodes might not have data to send.
- Large amount of energy is wasted if the CH is located away from the sink.
- If the CH fails due to some reason between the processes the whole process has to be repeated again which leads to wastage of energy.

2.2 LEACH-CENTRALIZED (LEACH-C):
In LEACH-C proposed in [8] [9] [10], is a centralized clustering algorithm developed as an improvement over LEACH. the nodes in the network sends their location and energy information to the base station. Location information may be sent using some location identifying devices imported on the sensors like GPS etc. On the basis of this information the base station forms clusters, select CH and the members of clusters. In this way the setup phase is completed. The steady-state phase is same as that of LEACH. It is costlier due to the use of location finding devices and less reliable due to single point of failure.

2.3 THERSHOLD SENSITIVE ENERGY-EFFICIENT SENSOR NETWORK PROTOCOL (TEEN):
TEEN [12] is a clustering routing protocol, which groups nodes into cluster with each led by a CH. Once the cluster is formed CH broadcast two types of threshold values to the nodes in the cluster namely hard threshold value and soft threshold value. The parameters in the attribute set of the node reaches its hard threshold value, the node switches on its transmitter and sends its data if the sensed attribute is greater than the head threshold, and the current value of the sensed attribute differs from sensed value by an amount equal to or greater than the soft threshold.

The main drawback of TEEN is that if the threshold values are not reached, the node will never communicate. And not even come to know if the entire nodes are alive or dead.

2.4 ADAPTIVE PERIODIC THRESHOLD SENSITIVE ENERGY EFFICIENT SENSOR NETWORK PROTOCOL (APTEEN):
APTEEN is an improvement over TEEN. APTEEN [13] is a clustering routing protocol that allows its nodes to send the sensed data periodically and react to any sudden changes in the value of the sensed data by reporting it to the CHs. Architecture of APTEEN is similar to that of TEEN.

APTEEN supports three types of queries namely:

2.4.1 Historic Query: To analyze past data value.
2.4.2 One Time Query: To view the whole network.
2.4.3 Persistent Query: To monitor an event for a period of time.

APTEEN guarantees energy efficiency and larger number of sensor alive.

2.5 ENERGY EFFICIENT HIERARCHICAL CLUSTERING (EEHC):
EEHC is a distributed, Randomized clustering algorithm for WSNs. It is based on two stages [5]:
2.5.1 Initial: In the initial stage, each node announces itself as a CH with probability \( p \) to the neighboring nodes within the communication range. These announcements are done by direct communication or by forwarding. These CHs are named as the volunteer CHs. The nodes which receives the announcement and is not itself a CH becomes the member of the cluster. The node which doesn’t received the announcements within a time interval \( t \) that is calculated based on the duration for a packet to reach a node becomes a forced CH.

2.5.2 Extended: Multi-level clustering is performed in this stage. CHs at the level-1 transmit aggregated data to the level-2 CHs and so on. At the top level CHs transmit the aggregated data to the base station.

2.6 HYBRID ENERGY-EFFICIENT DISTRIBUTED CLUSTERING (HEED):
HEED is a distributed clustering algorithm developed as an improvement over LEACH. The enhancement is done in the CH selection method. HEED \[1\] selects CH on the basis of energy as well as communication cost. In HEED, each node is mapped to exactly one cluster. It is divided into three phases:

2.6.1 Initialization Phase: Each sensor node sets the probability \( C_{\text{prob}} \) of becoming a CH as follows:

\[
C_{\text{prob}} = C_{\text{prob}} \frac{\text{E}_{\text{residual}}}{\text{E}_{\text{max}}}
\]  

(1)

Where \( C_{\text{prob}} \) is the initial percentage of CH required in the network, \( E_{\text{residual}} \) is the current energy of the node and \( E_{\text{max}} \) is the maximum energy of the fully charged battery.

2.6.2 Repetition Phase: This is an iterative phase in which each node repeats the same process until it find a CH to which it can transmit with least cost. If any node finds no such CH, the elects itself to be a CH and sends the announcement message to its neighbors. Initially sensor node become tentative CH, it changes its status later if it finds a lower cost CH. The sensor node becomes permanent CH if its \( C_{\text{prob}} \) has reached 1.

2.6.3 Finalization Phase: In this phase nodes either picks the least cost CH or itself becomes a CH.

Though it is an improvement over LEACH still it has some disadvantages like more CH are generated than expected and it is not aware of heterogeneity.

3. NETWORK MODEL

The network is organized into a clustering hierarchy, and the cluster-heads collect measurements information from cluster nodes and transmit the aggregated data to the base station directly. Moreover, we suppose that the network topology is fixed and not varying on time. We assume that the base station is located at the center.

![Network Model](image)

The network being studied here is a two-level heterogeneous network, where we have two categories of nodes, \( mN \) advanced nodes with initial energy \( E_0(1+a) \) and \( (1 + m)N \) normal nodes, where the initial energy is equal to \( E_0 \). The total initial energy of the heterogeneous networks is given by:

\[
E_{\text{total}} = N(1+m)E_0 + Nm E_0(1+a) = NE_0(1+am)
\]  

(2)

According to the radio energy dissipation model illustrated in figure and in order to achieve an acceptable Signal-to-Noise Ratio (SNR) in transmitting an L-bit message over a distance \( d \), the energy expended by the radio is given by:

\[
E_{\text{tx}}(L,d) = LE_{\text{elec}} + LE_{\text{fs}}d^2 \quad \text{if} \quad d < d_0 \\
E_{\text{elec}} + LE_{\text{mp}}d^4 \quad \text{if} \quad d > d_0
\]  

(3)

Where \( E_{\text{elec}} \) is the energy dissipated per bit to run the transmitter (ETX) or the receiver circuit (ERX). The \( E_{\text{elec}} \) depends on many factors such as the digital coding, the modulation, the filtering, and the spreading of the signal. \( E_{\text{fs}} \) and \( E_{\text{mp}} \) depend on the transmitter amplifier model used, and \( d \) is the distance between the sender and the receiver. For the experiments described here, both the free space (\( d^2 \) power loss) and the multi path fading (\( d^4 \) power loss) channel models were used, depending on the distance between the transmitter and the receiver. If the distance is less than a threshold, the free space (fs) model is used; otherwise, the multi path (mp) model is used. we have fixed the value of \( d_0 \).

The various equations for estimating average energy of networks and the cluster head selection algorithm which is based on residual energy where:

The average energy of \( r \)th round is set as follow

\[
E(t) = \frac{1}{R} E_{\text{total}} (1 - \frac{r}{R})
\]  

(4)

where \( R \) denote the total rounds of the network lifetime and is defined as:

\[
R = \frac{E_{\text{total}}}{E_{\text{round}}}
\]  

(5)
E_{round} is the total energy dissipated in the network during a round, is equal to:

\[ E_{\text{round}} = L(2NE_{\text{elec}} + NE_{\text{DA}} + kE_{\text{mp}}d_{\text{toBS}}^2 + NE_{\text{fs}}d_{\text{toCH}}^2) \]  

(6)

where \( k \) is the number of clusters, \( E_{\text{DA}} \) is the data aggregation cost expended in the cluster heads, \( d_{\text{toBS}} \) is the average distance between the cluster head and the base station, and \( d_{\text{toCH}} \) is the average distance between the cluster members and the cluster head.

The probability to be a cluster head for normal and advanced nodes:

\[
P_i = \begin{cases} 
P_{\text{opt}}E_i(r) \left(1 + am\right)E(r) & \text{for normal nodes} \\ 
\frac{P_{\text{opt}}E_i(r)}{\left(1 + am\right)E(r)} & \text{for advanced nodes} \\ 
\end{cases}
\]

(7)

4. SIMULATION RESULT

The simulation of above algorithm has been done using the MATLAB software tool. The graphical, programming and calculation capabilities of the tool makes it fairly easy to generate a simulation of the proposed algorithm.

Let us assume the network parameters the network area is of 100x100m. The number of nodes is taken as 200. The sink is situated out of the network area at (150,50). The optimal selection probability for this simulation \( p_{\text{opt}} \) is taken as 0.2.

The below table shows other key network assumptions taken for the simulation:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sink</td>
<td>At (150,50)</td>
</tr>
<tr>
<td>Threshold distance, ( d_0 )</td>
<td>( \sqrt{E_{\text{fs}}/E_{\text{mp}}} )</td>
</tr>
<tr>
<td>Energy consumed in the electronics circuit to transmit in or receive the signal, ( E_{\text{elec}} )</td>
<td>50 nJ/bit</td>
</tr>
<tr>
<td>Energy consumed by the amplifier to transmit at a short distance, ( E_{\text{fs}} )</td>
<td>10 pJ/bit/m</td>
</tr>
<tr>
<td>Energy consumed by the amplifier to transmit at a longer distance, ( E_{\text{mp}} )</td>
<td>0.0013 pJ/bit/m</td>
</tr>
<tr>
<td>Data Aggregation Energy, ( E_{\text{DA}} )</td>
<td>5 nJ/bit/signal</td>
</tr>
<tr>
<td>Message Size</td>
<td>4000 bits</td>
</tr>
<tr>
<td>Initial Energy, ( E_0 )</td>
<td>0.5 J</td>
</tr>
</tbody>
</table>

Table 1: Simulation Parameters

The below figure shows the clustering and formation of dead nodes. The red dots appearing in the below figure are the dead nodes after the rounds.

The number of dead nodes remaining is plotted in figure 3 and a comparison against LEACH is shown. The blue curve is for the proposed work and shows a considerable improvement in the number of dead nodes as compared to LEACH.

5. CONCLUSION

In this research work, the energy model of a Wireless Sensor Network was thoroughly studied along with the various protocols which are being used or proposed erstwhile. In this research work a number of clustering protocols were studied and their key features were noted. The heterogeneity of a wireless network has been taken into account and a method using the distance factor i.e. the distance of nodes from cluster heads and the base station, for better use of sensor energy is proposed and simulated. The results show a considerable improvement in the network lifetime, as compared with LEACH protocol.
6. FUTURE SCOPE

The future research in the Wireless Sensor Network can use the energy modeling of the network mentioned in this paper, to use it along with other popular clustering methods.

7. REFERENCES


