Enhanced Energy-Efficient Balanced Clustering Protocol for WSN

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Abstract
The sensor nodes in wireless sensor network are of fixed battery power. Therefore energy utilization in an efficient way is the most important matter of concern in the design and development of wireless sensor network (WSNs). In this paper, we have proposed a cluster based routing protocol, enhanced energy efficient balanced clustering protocol (EEEEBCP) which reduces the energy consumption of sensor nodes in wireless sensor network. MATLAB simulation results show that proposed routing protocol performs better than Energy Efficient Protocol with Static Clustering (EEPSC) in terms of overall network lifetime and data packets received at base station. It also indicates that the rate with which energy is consumed in the EEEBCP is significantly lower than that in EEPSC resulting in a lower decay rate of the nodes too and hence achieving a longer network lifetime.

Keywords: Clustering, Routing Protocol, Balanced Clustering Protocol, Energy efficiency, Wireless Sensor Network

Introduction
Wireless sensor networks can be considered as the network of several spatially distributed sensor nodes for environmental monitoring by tracking data from the central location. As the price and the size of the sensors are decreasing with the technological advancements, the applications can be widely used in the industrial, health, military and traffic sectors [2-7]. These sensors can get hold of the environment conditions through different measurements. Now, the measurements can be converted into signals which can easily unveil some of the features of the environmental phenomenon of the specific area through these sensors. The WSN comprises of a large number of sensor nodes which are Micro electro mechanical systems (MEMS) based and helps in communicating with the external world through Bs/sink [1]. The applications of WSN can be spread throughout a wide range like measurement of light, sound and temperature and forecasting and monitoring the weather conditions, military activities, as well as disaster management [7]. For some of the conventional wireless networking problems, researchers have been working to meet the energy conservation requirements. These are referred to as: finding energy-efficient solutions to WSN problems. Several methods to meet the energy efficiency requirements have been developed. But, researchers are never satisfied and there is always a craze for more efficient methods than those available. Sensor networks consist of much higher number of sensor nodes as compared to ad-hoc networks which are densely deployed and are prone to failures. If the sensor nodes are considered as mobile, then for specific applications the topology of a sensor networks changes and that too very frequently. The paradigm used by the sensor nodes in WSNs is mainly a broadcast communication unlike point to point communications based most of the ad-hoc networks. Sensor nodes have three limitations in: memory, power and their capacity of computation and they consist of large amount of overheads and sensor. The annihilation of this inefficiency at all layers of protocol stack of communication in WSN is required. Especially at network layer, one needs to devise some novel energy-efficient routing schemes that provide consistent data communication among the deployed sensor nodes and external base station to prolong the network lifetime.

Related Work
The LEACH [8], Heinzelman, et al. introduced a hierarchical clustering algorithm for wireless sensor networks, known as Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH protocol is based on a clustering scheme that reduces energy dissipation by random selection of few sensor nodes as cluster heads (CHs), and then periodically rotates the role of cluster heads for even distribution of the energy load among the sensors nodes in the network. In LEACH protocol, the CH nodes collect and aggregate data from member nodes of the respective cluster and transmit an aggregated data to the BS/sink with an objective to reduce the redundancy and amount of information. LEACH uses a TDMA/CDMA based MAC scheme to minimize inter-cluster and intra-cluster collisions. This protocol ensures constant monitoring and periodic data transmission by the WSN. However, periodic data transmission may be useless and may result in decreasing the fixed energy of the sensor nodes. The function of LEACH protocol is divided into two phases, the setup phase and the steady state phase. Setup phase involves in cluster formation and CH selection. Steady state phase involves in data transmission from CHs to BS/sink. In the setup phase, a preset fraction of the total member nodes, p, select themselves as CHs. A member node of the sensor network randomly chooses a number, r, between 0
and 1. If the value of the random number, r, is less than a threshold value, T(n), the member node elect itself as a CH for the current round. An equation calculates the threshold value and integrates the current round, the required percentage to become a CH, and the set of member nodes that have not been selected as a CH in the last (1/p) rounds. It is represented as:

\[
T(n) = \frac{P}{1 - P(r \mod \frac{1}{P})}
\]

Where G is a set of member nodes that have not been cluster heads in the last 1/p rounds. An advertisement message is broadcast by all the CHs to non CHs nodes that are elected as new CHs. On receiving this advertisement message, all the non CH nodes decide that which cluster they must belong. The non CH node informs the appropriate CH that they want to become the member of the respective cluster. On the basis of the number of member nodes in a cluster, the CH generates a TDMA schedule and allocates a fixed time slot for each member node to transmit data. The member nodes send their data to respective cluster heads within allocated time slot. The cluster head performs data fusion, aggregation and transmit it to base station. This protocol enhances the energy consumption because the transmission is directly performed by only cluster heads rather than the direct transmission by all the sensor nodes. LEACH performs better for homogeneous network but not suitable for heterogeneous network.

However, to compensate the cited inefficiencies, authors of LEACH proposed a new algorithm called LEACH-C [9] that requires all deployed nodes to send the information regarding their location and energy to base station where it in turn forms appropriate clusters and elects centralized cluster-heads using simulated annealing algorithm. Moreover, the presumption by LEACH-C that every node has an adequate amount of transmission power to communicate with the base station. Nevertheless, in most cases this is a very unrealistic assumption.

Next, Lindsey and Raghvendra presented PEGASIS [10] which was an upgradation of the LEACH protocol. Power-Efficient Gathering in Sensor Data Systems (PEGASIS) i s a close ideal chain-based convention. The essential thought of the convention is that so as to enhance the lifetime of system, communication of sensor nodes with just their closest neighbors is required and they take alternately in communication with the base station. In this way, the power needed to transmit information in every round is reduced as the dissipated energy is spread consistently all over the sensor nodes. Consequently, PEGASIS has two fundamental goals. One is the increment in lifetime of every node by utilizing collaborative methods. Other is to permit neighborhood coordination between sensing node that is close together so that the data transfer capacity devoured in correspondence is diminished. Dissimilar to LEACH, PEGASIS dodges cluster formation and instead of multiple nodes it uses just a single node in chain to transmit information to the BS. In PEGASIS, to find the closest neighbor node, the signal strength is used by every node to gauge the separation with all neighboring nodes and in order to listen only one node, the signal strength is adjusted. A path to the base station consisting of sensor nodes lying closest to each other is considered to be a path in PEGASIS. The collected information in aggregated form by any one node is sent to BS and every other node in the chain takes part alternately in this transmission. The chain development is performed in a voracious manner. Results obtained after simulation demonstrated that PEGASIS has the capacity to expand the lifetime of the system twice as compared to the LEACH convention. O. Younis et al. have proposed HEED [11], Hybrid Energy-Efficient Distributed Clustering, to attain well-distributed clusters that influence the energy-efficiency. In HEED, selection of cluster-head is focused around two parameters, node residual and its average distance from neighboring nodes or degree of node. On the basis of their residual energy, the initial set of cluster head nodes is made first. Alongside this, the node degree is utilized for tie-breaking and also to structure well-distributed clusters. It gives surety of a well distribution of cluster-heads. For the cluster-head selection, the time complexity is of the order of 1, i.e. O(1), which is free of size or topology of the network. At the point, when LEACH uses single-hop, to reduce the energy consumption, HEED embraces multi-hop communication. The ETSSSEP [12], Shekhar Kumar et al. proposed a cluster based routing protocol for heterogeneous wireless sensor network, known as Enhanced Threshold Sensitive Stable Election Protocol for Heterogeneous Wireless Sensor Network. ETSSSEP selects cluster head on the basis of residual energy level of nodes and minimum number of clusters per round. Payal Khurana Batra and Krishna Kant proposed LEACH-MAC: a new cluster head selection algorithm for wireless sensor network [13]. This is a new clustering based routing scheme to make cluster head count stable by restricting the number of cluster head advertisement.

Further, static clustering approach was developed for creating energy-efficient routing protocols. An Energy-Efficient Protocol with Static Clustering, EEPSC, was presented by Amir Sepasi Zahmati et al.[14], in which partitioning of network is done into static clusters which in turn eliminates the dynamic clustering overhead. In regard to lifetime of the network, EEPSC performs better than LEACH by using temporary-cluster-heads to disseminate the load of energy among the nodes with high power. Cluster-head is selected on the basis of residual energy of individual sensor nodes after distance based clusters are formed in EEPSC. For the present round, the node with highest residual energy is chosen as cluster-head whereas with minimum energy as temporary cluster-head for next round. At that point, the information exchange among the nodes and base station happens.

Network Model and Assumptions
Consider a WSN consists of N randomly and uniformly distributed sensor nodes in M * M m² region. We consider a WSN with the following properties [9-11]:

- All the deployed sensor nodes are motionless and homogeneous with a fixed battery power.
- The nodes are equipped with power control capabilities to vary their transmitted power.
- Sensor network follows continuous data flow model instead of event driven model.
- Base station is fixed and not located between sensor nodes.
Radio Model

In this paper, the first order radio model [8] has been used for energy dissipation analysis. According to the first order radio model shown in Fig. 1, the energy required for transmitting K-bits at a distance d is given as:

$$E_{Tx}(K, d) = \begin{cases} K \cdot E_{elec} + K \cdot E_{fs} \cdot d^2 & \text{if } d < d_0 \\ K \cdot E_{elec} + K \cdot E_{amp} \cdot d^4 & \text{if } d \geq d_0 \end{cases}$$  \hspace{1cm} (1)

**Figure 1:** Radio energy dissipation model

The energy required for receiving K-bit message is given as:

$$E_{Rx}(K) = K \cdot E_{elec}$$  \hspace{1cm} (2)

Where, d refers to the distance between cluster-member-node and cluster-head or between cluster-head and base station and $d_0$ is threshold distance. $E_{elec}$ is the transmitter/receiver electronics' energy expense and $E_{fs}$, $E_{amp}$ are transmitter-amplifier energy-expenses by a node when $d < d_0$ and $d \geq d_0$ respectively.

$$d_0 = \sqrt{\frac{E_{fs}}{E_{amp}}}$$  \hspace{1cm} (3)

Proposed System

The present scheme, EEEBCP, is a modification of an existing scheme, Energy-Efficient Protocol with Static Clustering (EEPSC) [14]. In EEPSC, cluster-head selection is performed based on the residual energy of the nodes and temporary-cluster-head is used for cluster-head selection process. The node with the highest residual-energy in a cluster is selected as the cluster-head for the current round. If this newly selected cluster-head is located near the boundary position of cluster, energy consumption for other member nodes of the cluster may increase in transmitting the sensed data to cluster-head i.e. often election of nodes located nearer to the boundary as cluster heads may increase the communication-cost for the nodes lying on the other side of boundary which may result in quick drain of battery mounted on nodes. Thus spatial distribution of nodes in cluster is also an important parameter and therefore the distribution should be considered for the event of cluster-head selection. Here, we propose an amendment on EEPSC to accomplish the only objective of prolonged network lifetime. This is achieved by forming well distributed clusters through even distribution of sensor nodes. Also, intra cluster communication cost is reduced by locating the cluster head nearest to central position.

Protocol Architecture

Like EEPSC [14], EEEBCP is also a self-organizing, static clustering scheme in which clusters are formed only once during the network action. The whole network-operation is supposed to be consisted of several rounds where each round is further divided into three phases: setup phase, steady-state phase, and at last the responsible node selection phase; each of these three phases are described in the following subsections.

Set-up Phase

In the set-up phase, the clusters are formed once at the start of network operation. At the start of operation, after the node-deployment, every node communicates with the base station (BS) as to be considered for the role of TCH and is acknowledged by the BS in turn with its respective relative location in the network. BS then select k number of nodes as TCHs, where k is the desired number of clusters, known a priori (here k=4 as the scheme forms 4 clusters with equal distributions of nodes) while ensuring that the distance between any two TCHs is A/2 and diagonally opposite pair of such selected nodes be at least but approximately at A/√2 distance where the sensing field is of the dimension A*+A. Such distance is maintained so that the network can be partitioned into four equal portions. Once the TCHs are selected, They, TCHs, start broadcasting their status so that other nodes may join them, hence forming the clusters. Then the TCHs locate the midpoint of their respective clusters and appoint the node, nearest to this location as Cluster-Head for the very first round.

Remaining nodes attempt to these TCHs based on the received signal strengths by sending the JOIN-REQ message to the respective TCHs. Sensor nodes use CSMA to prevent collision while transmitting the JOIN-REQ messages to their TCH. TCHs confirm the nodes of their membership by sending them the ACK message, containing the TDMA schedule of the nodes too. Along with these ACK packets, TCHs also request their members sending their respective coordinates. After having such information, TCHs compute the mid-points of their clusters and appoint a node in their cluster as the Cluster Head (CH). With the finalization of CHs and TCHs, set-up phase is complete.

Steady State Phase

This phase is same as steady-state phase of EEPSC [14]. In the steady-state phase, nodes send the measured data to their corresponding CHs during their pre-allocated time-slots and phase is further broken into frames. Since the duration of each time-slot is fixed and constant, time required to send a frame depends upon the number of nodes in the clusters. Direct transmission approach is used for communication among CHs and the bases station. In a cluster, radio of the member nodes are kept off until their allocated timeslot but radio of cluster-head is kept on always to receive data from all the nodes.

Responsible Node Selection Phase

In this phase, cluster-heads (CHs) and the temporary-cluster-heads (TCHs) for the next round are selected in each cluster. In this phase at the beginning of every round, nodes in each cluster...
send their residual energy information ($E_{\text{residual}}$) to the corresponding TCH. TCH then declares the node with the highest value of $E_{\text{residual}}$ as cluster head for the current round and the node with the least value of $E_{\text{residual}}$ as TCH for the next round. Then CH broadcasts a roundstart packet including responsible nodes id into whole of its cluster which indicates the beginning of next round to other sensor nodes. This point sounds like the same as that is EEPSC, but this gives a significant improvement with respect to the older one as the first choice of CHs has been made around the central positions in the respective clusters.

**Simulation Environment**

To evaluate the performance of the proposed scheme, EEEBCP, MATLAB 7.1 is used as a simulation tool. We consider that the sensor nodes are deployed randomly across a plain area. Each node is equipped with equal amount of energy at the beginning of the simulation. Further, we assume that WSN is working in continuous data flow application domain. Table 1 represents various parameters and their values used in simulation.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Area</td>
<td>100m X 100m</td>
</tr>
<tr>
<td>Base Station’s Position</td>
<td>(50m, 175m)</td>
</tr>
<tr>
<td>Number of deployed sensors</td>
<td>100</td>
</tr>
<tr>
<td>Initial energy for nodes</td>
<td>2 Joule</td>
</tr>
<tr>
<td>Size of data message</td>
<td>4000 bits</td>
</tr>
<tr>
<td>$E_{DA}$</td>
<td>5 nj</td>
</tr>
<tr>
<td>$E_{elec}$</td>
<td>50 nj</td>
</tr>
<tr>
<td>$E_{fs}$</td>
<td>10 pJ/bit/m$^2$</td>
</tr>
<tr>
<td>$E_{amp}$</td>
<td>0.0013 pJ/bit/m$^4$</td>
</tr>
</tbody>
</table>

**Simulation Results**

A set of experiments is conducted to test the performance of both schemes, EEEBCP and EEPSC. From the results of various simulations performed as depicted in Fig. 2(a)-Fig. 2(d), it can be firmly stated that the proposed scheme, An Enhanced Energy-Efficient Balanced Clustering Protocol (EEEBCP) outperforms EEPSC in term of network lifetime.

Figure 2(a): Number of Nodes Alive Over Time

Figure 2(a) shows the comparative plot of number of nodes alive over time in both schemes. It indicates that the last node dies after 780 sec. in EEPSC whereas the same event occurs after 1000 sec. in EEEBCP, hence a gain of more than 20% in terms of network lifetime has been achieved. Some of the authors have also defined network lifetime as the time when the first node dies in the network; even in that regard too, the proposed scheme outperforms the EEPSC as shown clearly in the figure 2(a). Not only the network lifetime, but also the nodes death rate is also lower than that in EEPSC; which confirm its supremacy over EEPSC.

Figure 2(b): Number of Data Packets Received at BS

Figure 2(b) shows that the overall messages received at BS in case of EEEBCP are higher than with respect to EEPSC which is a clear indication of increased network-lifetime.
Figure 2(c): Energy Consumed in the Network over Time

Figure 2(c) clearly shows that the rate with which energy is consumed in the EEEBCP is significantly lower than that in EEPSC resulting in a lower decay rate of the nodes too and hence achieving a longer network lifetime.

Figure 2(d): Packets Received at BS per amount of Energy

Figure 2(d) describes that the number of messages received at base station for any amount of energy consumed in the network is greater in EEEBCP than that in EEPSC. EEEBCP results in greater data packets at less cost of network-energy in a consistent manner.

Conclusion

An energy-efficient clustering scheme, An Enhanced Energy-Efficient Balanced Clustering Protocol for WSN (EEEBCP) is proposed here with a target of delaying network lifetime. Based on these simulation results, we can conclude that the proposed scheme, An Enhanced Energy-Efficient Balanced Clustering Protocol beats the existing one, An Energy-Efficient Protocol with Static Clustering in terms of network lifetime. Efficiency of the scheme, EEEBCP, is measured against EEPSC via simulating a set of experiments which accepts the utilization of EEEBCP keeping in mind the end goal to attain better performance in terms of network life time and energy consumption. As a future expansion of this work, event-driven applications with heterogeneous energy model of sensor nodes may be investigated.

References