An Energy-Efficient Multi-layered Data Forwarding Scheme for Large Scale Wireless Sensor Networks

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Abstract

Energy conservation is the primary concern in Wireless Sensor Networks (WSNs). In most applications, nodes are randomly deployed in the sensing field. Therefore, it is impracticable to replace their energy sources. Hence, energy efficient routing is necessary in order to prolong network life time several times. In the proposed work we utilize an Energy Efficient Data Forwarding scheme (EEMDF) to route the data effectively in multilayered architecture in large scale wireless sensor networks. We employ the energy metrics to discover the optimal path for routing the aggregated data. Specifically, we will analyze the network life time and energy consumption for the proposed work. Performance evaluation is done by simulation which shows the effectiveness of the work carried out so far.

Keywords: Energy Efficiency, Network Life Time, Wireless Sensor Networks (WSNs)

1. Introduction

Wireless Sensor Networks (WSNs) typically consist of many tiny, low cost, small power communication devices called sensor nodes. Each node has limited sensing, processing, and transmission capabilities. Because of the limited energy supply, WSNs are required to be operated efficiently. Therefore a number of energy efficient routing protocols are developed to conserve energy and hence enhance the network life time.

In recent times clustering is a widely used scheme to increase the life span of WSNs. According to the clustering scheme, there are generally two types of nodes in a cluster, Cluster Head (CH) and non-cluster head members. CHs are used to process and transmit the information to Base Station (BS), while other cluster members can be used to perform the sensing in the vicinity of the target. LEACH, TEEN and HEED are the various existing cluster based protocols. Clustering is especially useful for applications that require scalability to about hundreds or thousands of nodes. Scalability here implies the need for load balancing, data aggregation, and better resource utilization.

Once the clustering is done, the communication among sensor nodes can be either intra-cluster or inter-cluster. In intra-cluster communication, the transmission of messages is carried out between the CH and normal nodes. While inter-cluster communication includes the transmission of messages among the CHs or between the CHs and the BS. The operation of all the clustering based protocols identifies the following phases: 1. Setup phase and 2. Data transfer or steady state phase. In the setup phase, the clusters are formed and CHs are selected. In the steady state phase the actual data transfer takes place. The range of sensors’ radio is quite short as compared to the network area. Multi hop routing is preferably used for the transmission of the sensed data to the BS because most of the nodes would be far away from the BS and thus requires multiple hops to reach the BS.

In our proposed scheme EEMDF, a multilayered hierarchical structure is used, where the whole sensing area is divided into multiple layers as well as every single layer into clusters. Head of each cluster is selected by considering the various parameters like initial energy, residual energy, centrality in cluster, and the location of node from

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BS. The data is collected at the lowest layer and is aggregated subsequently by the upper layers to reach to the BS. Thus, the data forwarding is done through an energy efficient shortest path to consider energy awareness along with the distance parameter. In this algorithm we consider the energy parameters (initial energy, residual energy) along with the distance parameter which discovers an optimal route of minimum hops having maximum average node energy.

Rest of the paper is organized as follows: Related work is discussed in Section 2, which gives a general idea about various existing cluster based routing protocols in literature. The network and energy model is presented in Section 3. We explain the implementation of routing algorithm over multilayered architecture in Section 4. Section 5 discusses the performance evaluation and simulation results and Section 6 concludes the paper.

2. Related Work

Clustering is a widely used technology in recent years. In clustering topology scheme the whole sensing network is divided into two types, one is Cluster Heads (CHs) and other is member nodes. This is an efficient technique to reduce the energy consumption, where we perform data aggregation and fusion in order to reduce redundant data transmissions to the Base Station (BS).

LEACH\(^2\) is one of the first cluster based approach for WSNs which includes distributed cluster formation. The idea of the LEACH is to select a few sensor nodes as cluster heads and rotate this role evenly throughout the network to distribute the energy load. In LEACH the CHs compress data arriving from other member nodes in order to remove redundant information, and forward an aggregated packet to the sink node. Although LEACH is a simple enough and completely distributed, but there are number of issues regarding assumptions used in this technique. LEACH assumes that all the nodes have enough transmission and computational power to reach the BS if needed. Furthermore dynamic clustering adds an extra overhead, which may increase the energy consumption.

TEEN\(^4\) protocol was proposed for time critical applications. In TEEN, data sensing is performed continuously, but data transmission is done less frequently. Neighbor nodes form clusters with CHs to transmit data to next higher layers. A CH broadcasts a hard threshold (threshold value of sensed attribute) and a soft threshold (small change in the threshold attribute) to its members. Thus hard threshold allows nodes to transmit only, if event occurs in the range of interest. Furthermore soft threshold prevents redundant data transmission. This way we obtain a significant reduction in transmission delay. The main limitation of TEEN is the complexity and overhead associated with the implementation of threshold based functions and formation of clusters.

Another approach is HEED\(^5\). HEED is an iterative-based clustering which primarily considers residual energy in selecting cluster heads. Intra-cluster communication cost metrics (node degree or density) are the secondary parameter to be considered during CHs selection. We see that HEED clustering enhances the network lifetime over LEACH because LEACH randomly selects CHs, which may result in early death of some nodes. However, cluster selection involves only subset of parameters.

PEGASIS\(^10\) is considered as an optimization scheme of LEACH\(^3\) approach. Rather than dividing nodes into clusters, this algorithm forms a chain of sensor nodes and every node needs communicate with their closest neighbors only. RSSI is used to locate the closest neighbors and the distance to all neighboring nodes. A greedy algorithm is implemented in each round to select one node in chain that communicates with the sink. PEGASIS is able to enhance the network life time by reducing dynamic clustering overhead. Note also that PEGASIS introduces extra delay for distant nodes and the single leader can become a bottleneck.

Due to the random selection procedure of CHs and assumption of directly assessing the BS by CHs over larger distances, these protocols are not much suitable for communication without further transformation.

3. Network and Energy Model

Let us consider a sensor network, consisting of \(n\) nodes, randomly deployed over an area. The following assumptions are taken about sensor nodes.

- A base station is fixed and located at middle of the network.
- All sensor nodes are fixed and homogeneous i.e., possess same capabilities.
- All Nodes are location-unaware, i.e., not equipped with GPS-devices.
• Each node is equipped with power control capabilities to vary their transmission power.
• Base station can transmit variable power levels.

All the assumptions are taken to make our simulation easier and more real. In our work the entire network is divided into multiple layers. Here we utilize a three layer structure for implementing the routing algorithm. The first and lowest layer contains regular nodes, which sense the data and forward to their respective CHs called Local Cluster Heads (LCHs). LCHs constitute the next upper layer i.e. second layer, which aggregate the data of regular nodes. At last the data of these LCHs is aggregated by MCHs (Master Cluster Heads) situated at third layer and then forwarded to the BS as shown in Figure 1.

The energy model is used same as in literature\textsuperscript{11}. The total energy consumption to transmit an l-bit message over the distance $d$ is given by-

$$E_t = l^* (E_{el} + E_{fa}d^2)$$  \hspace{1cm} (1)

Where $E_{el}$ is the Energy dissipated by transmitter electronics and $E_{fa}$ is the amplifier energy of free space model. Also to receive l-bit message, the energy computed as

$$E_r = l^* E_{el}$$  \hspace{1cm} (2)

4. Proposed Multi-Layered Data Forwarding Scheme (EEMDF)

In this section we describe the three layered hierarchical structure\textsuperscript{12}. Unlike other clustering approaches here, first all clusters are formed and then data is forwarded through preselected paths.

The architecture employed in EEMDF is shown in Figure. In this paper we assume that the network has only three layers, the normal nodes at layer 1, the LCHs at layer 2, the MCHs at layer 3, and the BS as a root of this tree. This way we can reduce the extra overhead and route delay by employing data aggregators at subsequent levels\textsuperscript{12}. First we explain the local cluster head and master cluster head selection algorithms, and then we describe how efficiently we route the data to BS.

4.1 Local and Master Cluster Head Selection

As the energy dissipation is primarily based on the distance between transmitter and receiver. Therefore it is important to consider residual energy and location of each node in their respective clusters as well as from base station\textsuperscript{12,15}. Since the energy consumption per bit for sensing, processing, and transmission is typically known, and hence residual energy for each round can be estimated easily. So the probability of selecting a regular node as LCH is given as-

$$P_{LCH}(i) = \frac{E_{res} \cdot d_{m(Rc)}}{E_o \cdot d_{(LBS)}}$$  \hspace{1cm} (3)

where $E_{res}$ and $E_o$ are the residual and maximum energy of node $i$, respectively, and $d_{m(Rc)}$ and $d_{(LBS)}$ indicate the distance of farthest node in the cluster range and distance to BS from node $i$. Thus we can easily infer that the nodes located closer to the centre of cluster along with higher residual energy are more likely to be selected as new cluster heads. As the operation begins all the nodes broadcast a LCH-Req packet within which includes and its node ID. Afterwards each node waits for a random time seconds to receive the packet from its neighbors. If the node found of the received message greater than its, it waits to receive the LCH-ADV message from its neighbors, otherwise it elects itself as a new LCH by broadcasting LCH-ADV message within.

After LCH selection some nodes are selected as MCHs to perform inter-cluster communication. These nodes aggregate the data received from lower layers which must be forwarded to the BS. So it is very important for MCHs to have an adequate energy level. Here we use a timer for MCH selection. According to given value we assure that the nodes having more residual energy and more neighbors are selected as new MCHs.

$$T_{MCH}(t) = \frac{E_o - \frac{1}{d_T(t)}}{E_{res}}$$  \hspace{1cm} (4)
where \(d_{\text{nei}}\) indicates the number of layers neighbors of node \(i\). The number of such neighbors can be estimated by receiving their headers. As the node's timer expires and node received no advertisement message, it elects itself as a new MCH and broadcasts a MCH-ADV message to all its neighbors within master cluster range (is kept larger than so that we could cover more bottom layer nodes).

### 4.2 Data Transmission

After completion of the setup phase, nodes start sensing according to their attributes and send data to their respective LCHs located at next layer. Further all LCHs perform data aggregation and forward the fused data to MCHs, and finally MCH collects all the received data with its own data then aggregates and forwards to the BS. Note that this data forwarding is done by considering the energy metrics primarily because energy efficiency is the main concern of this work. A threshold value can be set for residual energy to make the route initiations more effective. A low threshold value may allow the nodes to make unnecessary route initiations and a high threshold may deny the nodes to make its own communication due to the energy constraints. Here, a TDMA schedule may be constructed by each CH along with the long sleep time for the regular nodes to avoid collision within a cluster.

### 5. Performance Evaluation and Results

The performance of our proposed algorithm (EEMDF) is experimentally observed by using MATLAB (version 7.10), 64 bit. Here we consider a network of size 100×100 in which 100 sensor nodes are randomly distributed. We assume that the BS is located at the centre of the field and each node is having \(2J\) of maximum energy at the beginning of simulation. If the energy level of a node reaches to \(0J\) it is declared as a dead node. Here our proposed protocol EEMDF is compared with the well-known clustering protocol modified LEACH to support multi-hop approach.

All the simulation parameters are summarized below in Table 1.

In our simulation study, network lifetime is defined by the number of alive nodes in accordance with the number of rounds as shown in Figure 2. We can see from figures that about 10% improvement in network life time is achieved by EEMDF over MOD-LEACH. One round is defined as the total operation time from the beginning of cluster formation until the BS receives all the packets from MCHs. Although EEMDF is energy efficient and can prolong the network life time over other clustering schemes, it increases the latency of network due to the local and master cluster formation as well as multi-hop inter-cluster communication. Thus, the performance of EEMDF in delivering data to BS is saturated after certain number of rounds. We evaluate this factor by calculating the total number of data packets received at BS in 2000 rounds as shown in Figure 3.

### Table 1. Parameters of simulation

| Parameter                          | Value                        |
|------------------------------------|------------------------------|
| Number of nodes                    | 100                          |
| Network size                       | 100×100                      |
| Base station location              | (50,50)                      |
| Data packet size                   | 250 byte                     |
| Radio electronics energy           | 50nJ/bit                     |
| Amplifier parameter of free space model | 10pJ/bit/                   |
| Initial energy \(E_o\)             | 0.5J                         |
| Data aggregation energy            | 5nJ/bit/signal               |
| Cross-over distance                | 87 m                         |
| Cluster range                      | 25 m                         |

### Figure 2.

Figure 3. Number of data packets received at BS over number of rounds.

### 6. Conclusion

This paper proposes EEMDF scheme, a multilayered clustering approach for large scale WSNs. Here we divide the whole sensing area into multiple layers, as well as each layer into some local clusters and master clusters. For the cluster head selection EEMDF uses various energy metrics to evenly distribute the energy load throughout the network. Centrality in a particular cluster is also a crucial parameter to select various LCHs and MCHs. Simulation results show that the EEMDF outperforms its counterparts in terms of energy efficiency and network lifetime. Although there is a small delay in the network due to extra overhead associated with the cluster formation and cluster head selection.
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