Energy Efficient Relay Based Multi-hop Clustering Protocol for Wireless Sensor Networks

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ABSTRACT

The quest for better protocol design that can minimize communication cost and energy usage in WSN has fuelled various researches into employing different kinds of communication modes that promise a better utilization of network resources. When sensor nodes are organized in a hierarchy or multi-level cluster structure using multi-hop communication mode, it is obvious that the nodes closer to the BS dies out first as a result of being over-burdened from relaying packets of other far away nodes. In this work an energy efficient protocol that balances the energy consumption in clusters which are placed at various distances from the base station is designed (EEMRC- Energy Efficient Multi Hop Relay Clustering). The selection of the relay nodes for Multiple Input Single Output technique with relay nodes has been implemented to increase the lifetime. Comparison of the proposed protocol with the standard LEACH protocol for life time yielded results which showed a large improvement.

Keywords: Energy efficient, SISO, MISO, Relay based.

1. INTRODUCTION

Recent natural calamities like floods earthquakes and tsunami have demonstrated the necessity of rapid deployment of a reliable, fast and low power communication service which will help in monitoring and controlling of physical environments with better accuracy for optimal rescue organization. In such devastating situations, use of traditional cellular communication is impossible as it requires the installation of a large infrastructure. The advances in wireless communication embedded computing and electronics have enabled the development of the low power wireless sensor network (WSN) technologies. The replacement of heavy weighted wired technology with many small, low cost wireless sensor nodes ensure a wide range of applications for WSNs. A WSN consists of a large number of low-cost micro-sensors, which are randomly deployed and self-organized through wireless links. The primary function of a sensor network is to collect the physical data from the environment and propagate to sink node or base station (BS). Sensor nodes are capable of monitoring a wide variety of ambient conditions. They can also be deployed over a battle field for military surveillance as well as emergent environments for search and rescue. A sensor node is typically powered by a battery, and energy saving is of critical importance since these networks are usually deployed in unfriendly remote environments such as a forest. This isolation makes changing or charging the battery expensive, if not impossible. Thus, maximizing the lifetime of a sensor network, keeping an acceptable performance level, has seen substantial interest After performing survey of relevant literature, a need for further investigations in performance of relay nodes based on their positions and performance of SISO and MISO for cluster based sensor network was found necessary. The next section deals with the survey of the related work carried out in this field. In section 3, a description of the EERMC protocol along with the energy analysis has been given and section 4 deals with the results and discussions. The paper concludes with section 5.

2. RELATED WORK

Low-Energy Adaptive Clustering Hierarchy (LEACH) [1] is a clustering based protocol that minimizes energy dissipation in sensor networks. The purpose of LEACH is to randomly select sensor nodes as cluster heads, so the high energy dissipation in communicating with the base station is spread to all sensor nodes in the sensor network. This protocol offers no guarantee about the placement and/or number of cluster head nodes. Since the clusters are adaptive, obtaining a poor clustering set-up during a given round will not greatly affect overall performance. In BCDCP [2], the main activities are cluster setup, cluster head selection, CH-to-CH routing path formation, and schedule creation for each cluster. During each setup phase, the base station receives information on the current energy status from all the nodes in the network. Based on this feedback, the base station first computes the average energy level of all the nodes,
and then chooses a set of nodes, denoted $\mathcal{S}$, whose energy levels are above the average value. Cluster heads for the current round will be chosen from the set $\mathcal{S}$, which ensures that only nodes with sufficient energy get selected as cluster heads, while those with low energy can prolong their lifetime by performing tasks that require low energy. Cooperative MIMO technique has been seen to decrease the energy consumption in WSN over multipath fading channels. Based on the cooperative MIMO technique several protocols were proposed in [3]-[8]. In [9], Cui et al. point out, that for the same throughput requirements Multi Input Multi Output systems require less transmission energy than Single Input Single Output system and they compared MIMO transmission technique with cooperative MIMO transmission technique.

3. Protocol Design

3.1 System Model

Consider a two dimensional network area where large numbers of energy constrained sensor nodes are randomly deployed and the sink node or base station, BS placed far away from all the sensor nodes. Additionally, following assumptions are made:

- Sensor nodes can estimate their positions with the help of embedded GPS devices.
- All nodes are homogeneous in terms of computation, communication capabilities and power resources and
- Each sensor node has power control capabilities to vary their transmission power depending on distance to receiver.

The BS broadcast the control messages to the sensors which helps it to synchronize the local time or clock with the BS. To determine the position of the sensor node with respect to the base station, BS sends control messages containing the current directionality information and the transmit power level (indicating the relative distance between the sensor and the base station) through successive scans of the network. A nodes location is thus determined by the directionality of the last BS transmission (called sector number SN), as well as the lowest power level that it can receive from the base station (called TN). We therefore define the id of a sensor to be the 2-tuple \{SN; TN\}. The index associated with the direction of the current transmission is SN and TN is the index associated with the current transmits power. The field ScanNum is the number of the scan. Additional and control information can also be carried in the packet. When a sensor receives multiple control messages with the same ScanNum, its id is chosen as below:

\[
\text{SN} = \max \{\text{SN}_i.\text{rcvd ctrl msgs with ScanNum}\} \\
\text{TN} = \min \{\text{TN}_i.\text{rcvd ctrl msgs with ScanNum}\}
\]

Initially, the directional antenna broadcasts a message with \{SN=1, TN=1\} to all nodes with in this region. Sensors located in this region will then obtain there id as \{SN,TN\} = \{1,1\}. Next the base station adjusts its transmit power to the next higher level and broadcasts a message with location information \{SN=1, TN=2\}. Those sensor nodes that have acquired id \{1,1\} from the earlier transmission will not change their id. By repeating this procedure, all sensor nodes can derive their ids via receiving broadcast control messages from the base station. During this process, as there is no need for any sensor node to exchange any information with its neighbors, power is saved and the complexity has been effectively shifted from sensor node to the BS. Based on received information, BS selects the primary set of Cluster Head (CH) nodes using cluster head selection algorithm described later and broadcasts the selected CHs’ ID to all the nodes in network. The remaining operation of EERMC protocol is divided into two different phases: the setup phase and the data transmission phase.

3.1.1 Setup phase

When a node finds its ID in the CHs list, it becomes a CH for the current round and broadcasts the advertise packet (ADV-PK) using CSMA MAC protocol. All non-CH nodes receives the ADV-PK from each CH node and decides to which cluster it belongs based on Received Signal Strength Indicator (RSSI). After selecting the suitable cluster, a node transmits joining request (JOIN-PK) to chosen CH. After a predefined time, based on the received JOIN-PK messages each CH node creates the TDMA schedule for its cluster members and broadcast the schedule along with specified spreading code to overcome the intra cluster interference in network.

3.1.2 Data Transmission Phase

In this phase, data transmission in intra-cluster and inter-cluster takes place using TDMA and CSMA MAC protocols, respectively.

3.2 Cluster Head Selection Algorithm

Anytime a cluster formation is necessary, the current CH nodes collect the residual energy information of the members and transmit to the BS. After receiving the information about network, BS finds the desired number of CHs using equation in [1] as

\[
K = \left(\frac{(n - d_{\text{dead}}) \cdot E_{D_{\text{bs}}} \cdot X_m \cdot Y_m}{2 \cdot \pi \cdot E_{m2}}\right)^{1/(A_{d_{BS}})}
\]

(1)
Where \( n_{\text{dead}} \) is the total number of nodes participating in the network, \( X_m \times Y_m \) is the network area, \( E_{fs} \) and \( E_{mp} \) are the energy for free space and multipath respectively, \( A_d2bs \) is the minimum distance from network to the base station. Once BS finds the desired number of CHs as required, it forms a set, with nodes whose residual energy greater than the average network energy. Remaining selection procedure of the CH nodes from the set follows as:

1. From the set BS selects the two nodes as CHs, which are spatially separated with maximum distance.
2. Next cluster head is selected based on the algorithm developed in [10], considering both the energy and the distance using equation

\[
Y_i = \frac{P_{\text{Rem}}}{D_{i_{\text{Mean}}}}
\]

(2)

\[
Y_{\text{Threshold}} = \frac{\sum_{i=1}^{\text{no of nodes}} Y_i}{\text{no of nodes}}
\]

(3)

Where, \( P_{\text{Rem}} \) is the remaining energy in the \( i \)th node
And \( D_{i_{\text{Mean}}} \) = mean distance of the sensor node i from all other sensor nodes in the cluster.

3. The desired number of CH nodes is selected and they broadcast their IDs to network.

4. The CH election is based on their present energy, previous round energy and network average energy. It does not take place for every round but only if any one of the CH does not have sufficient energy to serve next round. CH now sends a small packet to inform the requirement of cluster formation. All the CHs collect their member energy information and transmit to the BS along with present round data.

Relay positions are chosen on the basis of the distance of CH from the BS to balance the energy consumption in clusters which are near and far away from BS. When the CH is far away from the BS then two relay nodes are selected and for the while one relay node is selected when CH is near. Based on the CH positions, the relay nodes are selected and their ID’s are broadcast along with CH ID’s. The energy efficiency of MIMO techniques is particularly useful for WSN where the energy consumption is the most important design criterion. SISO is used for intra-communication and MISO for inter communication. In MISO (Almouti 2x1) the CH having two relay nodes form a MISO and the CH which are have single relay will form MISO by assuming itself as a relay node.

4. SIMULATIONS AND RESULTS

To evaluate the performance of EERMC protocol, we have simulated a network generated over 100mx100m area in MATLAB. We randomly deployed \( N=100 \) sensor nodes in network area with initial energy of 50 joules in each node. The BS was placed at (50,175) and is assumed to be powered by external source. Fig. 1a and 1b gives the cooperative relay position in network such that it balances the energy dissipation in cluster which are near and far from BS, minimize the total energy consumption in the network respectively. Certainly, optimum relay positions minimize the energy imbalanced hotspots in the network through approximately balancing the energy consumption.

![Fig 1(a) and (b) Energy consumption for various relay positions and Optimum relay positions](image-url)
From the network lifetime graph (Fig.2) which is a plot of number of nodes alive Vs. rounds, it can be concluded that EEMRC protocol with uniform clustering technique improves the network life time than LEACH protocol. Observations from slope of the curve after the death of first node shows that EEMRC protocol with Relay and uniform clustering technique utilizes the entire network energy without making any partitions in network.

![Network Lifetime Graph](image)

**Fig 2** Network Lifetime Graph

It is also observed that the proposed protocol has the death of its first node after 900 rounds compared to that of LEACH where node dies at about 500 rounds. Further in LEACH the nodes far away from the base station die faster thus portioning the network. The time the final network dies as compared to LEACH is earlier but having a few nodes alive will not be of use because the cluster heads would have depleted their energy faster and died leaving a few cluster members alive. This is equivalent to a dead network since data received at the base station is negligible. It shows that the data collection is distributed throughout the network.

![Snapshot](image)

**Fig 3:** Snap shot of condition when half the nodes are dead (a) for EEMRC protocol (b) LEACH

The figure 3 (a) and (b) shows the condition of the network when half the nodes in the network are dead for both the new protocol and the LEACH protocol. It is observed that the proposed protocol overcomes the network hot spots as the death of the nodes is more uniform. This is achieved since the algorithm takes into account the residual energy of the node while determining the cluster head selection.

![Network Lifetime Graph](image)

**Figure 4:** Network lifetime graph

From the above Network lifetime graph it is also observed that the proposed EERMC protocol has all the nodes alive for a longer time compared to LEACH and BCDCP. It is seen that when the number of rounds increase, the number of nodes alive falls drastically. This is because the cluster heads close to the base station gets depleted and the network begins to die. Fig 5 shows the total energy of the network vs the number of nodes. Graph shows that the total remaining Network Energy is higher when compared with the LEACH protocol since the energy consumed during clustering is now taken care by the base station and control packets to be transmitted is reduced.
Figure 6 shows a graphical illustration of the variation in the energy consumed per round with respect to cluster size and network diameter. The x-axis, y-axis, and z-axis represent the network diameter, the cluster size, and the energy consumed in one round, respectively. The number of data frames in one iteration is 10,000 and the number of clusters = 5. As expected, the graph shows that energy consumption is reduced when the cluster size is increased since re-clustering is not needed frequently and the energy is conserved.

5. CONCLUSION

The main objectives of this work were to design an energy efficient protocol that balance the energy consumption in clusters which are placed at various distances from the sink and to select the relay nodes such that dual-hop MISO technique with relay nodes could be implemented to increase the lifetime. Comparing the proposed protocol lifetime with the standard LEACH protocol and BCDCP, we can see a large improvement. This is because of the linear decrease in the energy of the network.

REFERENCES


**AUTHOR**

Jayanthi K Murthy is an Associate Professor at BMS College of Engineering, Bangalore and is currently pursuing her Ph.D in Visvesvaraya Technological University, Belgaum, Karnataka in the field of power management in Wireless Sensor Networks. She has 3 Journal publication, 2 National and 3 International papers to her credit. She is also working on VGST(Vision Group of Science and Technology, Government of Karnataka) sanctioned project.