A Coverage Maintaining Protocol For Cluster Head Election

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ABSTRACT

Clustering is a preferred method to save energy in Wireless sensor networks by assigning role of relaying and aggregation to nodes called cluster heads. These are elected among all nodes based on certain criteria that differ from technique to technique. Moreover, for even distribution of load, the CHs are re-elected after regular intervals. Recently, nature-inspired techniques for optimization are being used for CH election through construction of appropriate objective functions. But such global objective functions require information of entire network and generate much overhead. This paper proposes local objective functions so that a distributed control algorithm can be designed and local election is performed.

Keywords: wireless sensor networks, clustering in WSNs, cluster head, enrgy-efficient

I. INTRODUCTION

Advances in techniques of micro-electrical and mechanical systems have made it possible to have small-sized sensor devices [1]. These sensor devices are capable of sensing their environment and record quantities like pressure, temperature, humidity, flow etc. Moreover, the sensing devices are also equipped with a communication circuitry that is able to communicate with similar devices through radio or wireless communication. Thousands of such sensors are deployed in a field called Region of Interest (RoI) which needs to be sensed for certain quantities. The sensors sense the data and connect to each other to form an ad-hoc network so that all the data can be routed and transmitted to the Base station (BS). This network is called wireless sensor network. Wireless technology is much better than wired one as it does not need any prior establishment for deployment. With least infrastructure cost and flexible topology and self-organization, a WSN is very useful for applications that involve monitoring of harsh terrains and environment. WSNs are increasingly becoming popular for applications of defence, weather, forests, health care, etc.

The sensor nodes of the WSNs are very small devices operated by batteries. Their deploymentin such environments that is very difficult or impossible to replace batteries when exhausted. Hence, if the nodes deplete all their energy, the network becomes disconnected and the application may fail. So there is a need to save energy of nodes as much as possible, without affecting the operation of the network. Often, for redundancy purposes, several nodes are deployed ina region. And, a sleeping schedule is set so that only few out of all are activated such that RoI is covered. Rest of the nodes are in sleep mode and can save their energy. Yet, there is always a primary requirement to save energy of the nodes to increase lifetime of network.

The energy of sensor nodes is consumed in three functions: sensing, communicating and routing. Designing communication and routing protocols such that energy is saved is a primary research topic related to WSNs. Several algorithms have been proposed for this. Most of the researchers agree that data aggregation and clustering is best technique to save energy lost in routing and communication. Few nodes are given an extra role of cluster head (CH). Other nodes join the CHs as members of their clusters. The members send the sensed data to the CH only instead of BS. Since, CH is much nearer than BS, energy is saved. Also, CH can aggregate the data collected from the members and reduce the actual data load to be sent to the BS. This further saves energy. Though, this might deplete energy of the CH itself faster. That's why, researchers have suggested to elect CH frequently and change them such that the load gets distributed evenly in the network.

Heinzelman et al [2] proposed the pioneering work for clustering in WSNs. They proposed a probabilistic approach towards selecting CH nodes and rotated them to achieve even energy consumption in the network. The protocol called LEACH doesn't elect CH based on any criteria hence does not perform well, yet it is popular as the baseline with which to compare performance. There have been many improvements to LEACH like LEACH-C[3], TL-LEACH[4], LEACH-FL[5], LEACH-FS[6] etc. Other popular energy-efficient protocols for clustering and routing in WSNs are HEED[7], EECS[8], SEECH[9] etc. Every method suggests some criteria for CH election, mainly the residual energy of the node and its distance from BS. Recently, some nature-inspired algorithms have been proposed that set an objective function that should be minimized or maximized in order to find best candidates for CH. But all such algorithms require global information of the network. The overhead caused by collecting and disseminating so much of information may itself consume much energy. Hence, it is better to construct some cost functions that are based on local information and decisions can be taken with lesser communication between the nodes.

We propose here a method of clustering that sets a cost function which can be computed using only local information. Based on the cost, a CH is selected in each neighbourhood region. Simulation results show the performance of our proposal.

Rest of the paper is organized as follows. Section II discusses those previous works that have set a cost function or an objective function to decide CHs. Section III describes the proposed cost function and the clustering method. Section IV presents the results of simulation.

II. RELATED WORK

With the first method as LEACH, there have been many methods proposed in the literature for clustering.

Here we discuss the methods that have used some kind of cost functions to use for CH election.

In DEGRA [10], Cluster head are determined according to the density of each node, computed as

$$Den(s_i) = \sum_{0<x\leq N \,\&\, d(s_i,s_x)\leq R} l$$

The concept of density represent number of nodes located within a circle transmission region of neighboring nodes with itself as center. Where R=radius, = the i-th node and = distance between and another node . Thereafter, a utility of each node is calculated as:

$$U_i = \frac{E_{residual}(s_i)}{E_{total\ cost}(s_i)/Den(s_i)}$$

Where, = residual energy for one node.

= Total energy consumption of its neighbourig nodes

= average energy consumption among its neighbor node, a standard of average cost of energy in its cluster.

In EEDUC[11], the nodes are required to wait for different time lengths to broadcast a competition message. The message is transmitted within the competition radius. Waiting time is computed as:

$$[(1-\alpha) \times N_i/N_{MAX}] + [\alpha \times V_{random}]$$

Where =number of neighborhood nodes of node i

=number of total sensor nodes

= random number between 0 and 1

=constant coefficient between 0 and 1. During round 0, each node has same energy with other nodes

Competition radius of HELLO message:

$$R_{comp} = [1 - w_1\left(1 - \frac{TS_i}{TS_{MAX}}\right) - w_2\left(1 - \frac{E_i}{E_{MAX}}\right) - w_3\left(1 - \frac{N_i}{N_{MAX}}\right)]R_{MAX}$$

Where, = distance between node I and base station.

= maximum distance between sensor node and the Base Station.

=residual energy of node i.

=maximum energy of sensor node

=maximum cluster size

= constant coefficient between 0 and 1.

Oladimeji et al [12] have proposed an objective function that is optimized using a genetic algorithm. they have named their protocol as DLSACH for dynamic local search-based algorithm for clustering hierarchy. The objective function is

$$F(i) = 0.9 * \frac{AvgENCH}{AvgECH} + 0.1 * R$$

Here, is the average energy of all non-CH nodes and is the average energy of all CH nodes. R is computed as the risk penalty if the number of selected CHs are above or below than optimum range. It is a global objective function that is evaluated with different possibilities of CHs and then the best CHs are selected. Each time a random selection is made and a genetic mutation and combination operator is applied to obtain a better selection.

III. PROPOSED CLUSTERING TECHNIQUE AND COST FUNCTION

The aim of clustering is to appoint CHs and balance the energy consumption load such that no node dies prematurely leaving the network disconnected. Here we first set the aims of our clustering algorithm as:

a) Reducing energy consumption by limiting the information used in CH selection. When information is to be collected from all nodes of the network, much of energy is wasted in collecting it. Moreover, if the information is about values that may change like residual energy, then overhead is too much. Thus, the information to be used for CH election should be available more locally, around the node or with the node itself. If some global information is required, it should be preferably be static so that it can be collected at the time of deployment only during setup phase. Also, the memory required to store such information should also be considered. The nodes have limited memory.

b) Establishing cost function such that the nodes having higher energy and more central position among its members gets higher chance of being elected. The cost function should have a variable input so that different nodes get chance of being CH at different rounds. This helps in balancing. Distance from BS can also be a good criterion.

c) In case of redundant deployment, coverage of the region must be ensured. And all extra nodes be put in sleep mode. Thus, marking redundant nodes for sleep mode is also an aim in our algorithm.

d) Ensuring network coverage all the time is a condition to be met.

A minimal coverage can satisfy the last two aims. We design an activity schedule such that coverage is ensured. Now, we design a cost function that involves all possible criteria with minimal exchange of information among the nodes.

We develop a local objective function to be a function of energies of a node and its neighbors and number of times a node has been elected as a CH. Thus, the basic idea of load distribution by rotating the CHs as in LEACH is involved. Also, the most popular method of selecting the CH based onthe idea that a CH should be the node of highest residual energy among its neighbors is also involved.

The function is

$$F(i) = \alpha * \frac{AvgEN_i}{energy_i} + (1 - \alpha) * freq_i$$

The weight has been included to decide the contribution or importance of a factor towards making a node a CH. Generally, value of 0.8 or 0.9 is suitable so that the energy of the node has more importance as selection criteria as compared to the frequency of CH role. is the average energy of neighbor nodes of i-th node. It has to be viewed in proportion to the energy of i-th node itself at current round. The number of times i-th node has been continuously CH, that is the number of rounds since when i-th node was CH is .

IV. SIMULATION AND EXPERIMENTS

We simulate a WSN using MATLAB. The radio model of [12] is considered. The members of a cluster transmit the sensed data to the CH using single-hop transmission. The CHs transmit the aggregated data packets to the BS using single-hop transmission. The sensor nodes can have two power levels for transmission. For distances smaller than the threshold distance , free-space power level is used. For larger distances, the signal is amplified and multi-path power level is used. The parameters used for energy dissipation computations in our experiments are listed in Table 1.

TABLE I. SIMULATION PARAMETERS

Parameter	*Description*	*Value*
l	No. of transmitted bits	4000
E_{elec}	Energy consumed in transmission and reception	50 nJ/bit
ε_{fs}	Energy dissipated in free space propagation	10 pJ/bit/m^2
ε_{mp}	Energy dissipated in multipath propagation	0.0013pJ/bit/m^4
Data Packet Size	Size of a data packet	500 bytes
Control Packet Size	Size of a control packet	25 bytes
d_0	Threshold distance	87 m

A. Assumptions

The WSN is assumed with the following characteristics for our algorithm to work upon in experiments;

a) All nodes have same capabilities and initial energy, that is network is homogenous.
b) All nodes and BS are stationary.
c) The sensing field is a square with sensors deployed randomly.
d) The nodes do not have any location sensing device and estimate their distances from other nodes at the time of setup through received signal strength indicator of the 'hello' message.
e) Node dies due to energy depletion only.

B. Performance Metrics

The performance of the proposed algorithm is compared with the work of [], upon following metrics:

a) Rounds – The number of rounds algorithm takes to execute before the network dies
b) FND – Firs Node Die is the number of rounds the algorithm completes before first node in the network dies.
c) HND – Half Node Die is the number of rounds the algorithm completes before half of the nodes of the network are dead.

C. Results

The results are recorded for increasing the area of RoI, increasing the number of nodes when area is fixed and increasing the range of nodes keeping area and number of nodes fixed.

Fig 1, 2 and 3 show the number of rounds recorded by the proposed algorithm as compared to the work of [12]. In all cases, the number of rounds of the proposed algorithm is more or nearly same. When we increase area but keep number of nodes fixed. The density of nodes in any region decreases, and the distances between the nodes increase. This means cost of communication increase and energy is consumed more. Therefore, the number of rounds decreases when area is increased as seen in Fig 3. Yet, in work of [12], the communication overhead is high, hence energy gets consumed faster. So number of rounds of the proposed protocol is higher.

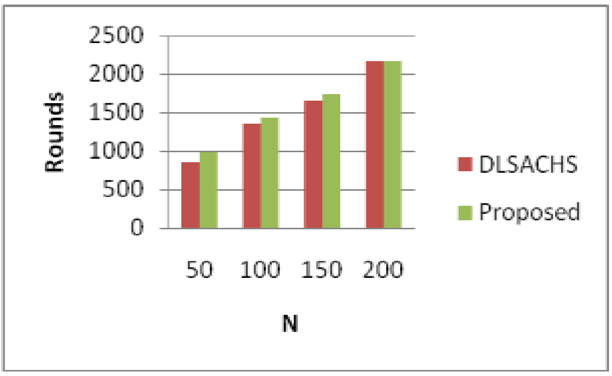

Fig 1 Number of rounds when nodes are increased

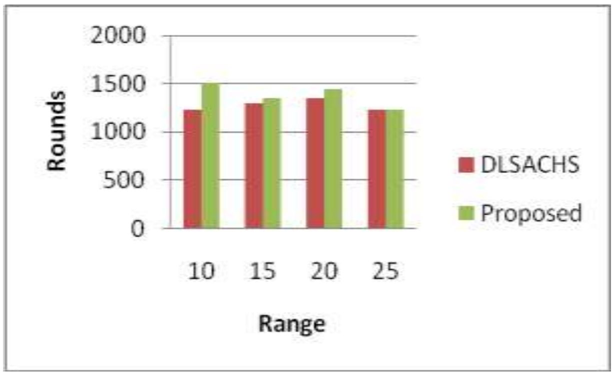

Fig 2 Number of rounds when range is increased

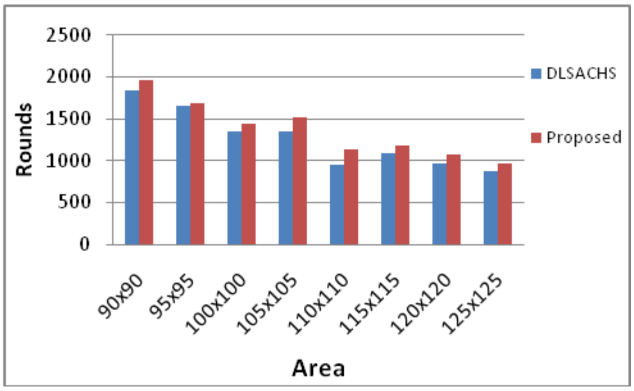

Fig 3 Number of rounds when area of sensing field is increased

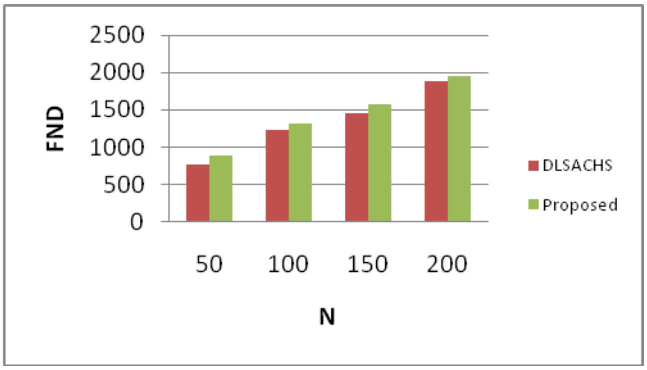

Fig 4 Value of FND when nodes are increased

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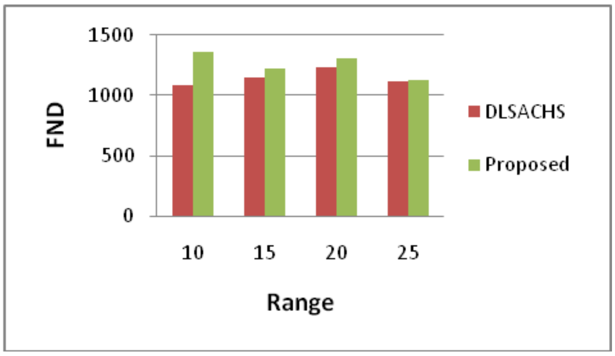

Fig 5 Value of FND when range is increased

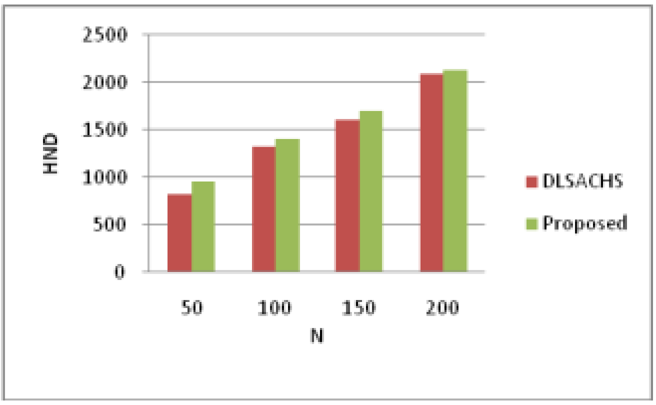

Fig 6 Value of HND when number of nodes is increased

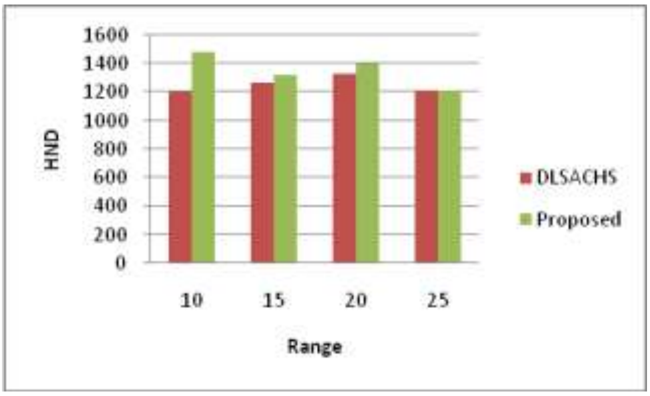

Fig 7 Value of HND when range is increased

The values of FND and HND are higher for the proposed protocol. This indicates that even distribution of load takes place.

V. CONCLUSION

Wireless sensor networks have a variety of applications. Since the devices are limited in energy source, there is demand of energy-efficient algorithms for clustering and routing. There are many algorithms in literature that elect CHs based on some criteria which are combined together as accost function or through fuzzy logic or through some nature-inspired technique of optimization. Many such proposals require global information about all nodes to determine exact values of the cost functions. We have proposed here a cost function that involves only local information and hence saves the communication overhead. Simulation results show that the performance of the proposed work is better than the previous work.

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