Adaptive Cluster Head probability for LEACH protocol

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Abstract. LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol is one of the clustering routing protocols in wireless sensor networks. The advantage of LEACH is that each node has the equal probability to be a cluster head. The LEACH [1] protocol is an elegant solution to data collection problem, where a small number of clusters are formed in a self-organized manner. Generally nodes consume more energy as cluster head than non-cluster head for transmitting the data. This energy consumption also increases as distance increases from Base Station (BS). So, assigning the same probability for electing as Cluster Head for all the nodes can lead to uneven energy consumption. In this paper, we proposed Distance based probability for Cluster Head election (D-LEACH) to make uniform energy consumption of Cluster Heads (CHs), which makes the routing protocol more energy efficient and prolongs life time of a wireless sensor network. Simulation results show that D-LEACH improves network life time compared to LEACH.

Keywords: Wireless sensor networks, LEACH, D-LEACH, Clustering, First_Node_Dead.

I. INTRODUCTION

Wireless sensor networks (WSNs), which consist of a number of small battery-powered devices, are frequently used to obtain various sorts of data from surroundings. These devices sense physical properties, such as sound, humidity, pressure, luminosity, temperature, or chemical concentration, and transmit the gathered data to a base station (BS) for further analysis and processing. Since WSNs consist of many sensors with limited energy, an energy-efficient network protocol is an important consideration in WSN applications. [2]. Position of sensor nodes need not be engineered or predetermined. This allows random deployment in inaccessible terrains or disaster relief operations and thus sensor network protocols and algorithms must possess self-organizing capabilities. Another unique feature of sensor networks is the cooperative effort of sensor nodes. Sensor nodes are fitted with an onboard processor. Instead of sending the raw data to the BS, they use their processing abilities to locally carry out simple computations and transmit only the required and partially processed data. Some of the application areas for WSNs are health, military, and home. In military, for example, the rapid deployment, self-organization, and fault tolerance characteristics of sensor networks make them a very promising for military command control, communications, computing, intelligence, surveillance, reconnaissance, and targeting systems [2]. In order to support data aggregation through efficient network organization, nodes can be partitioned into a number of small groups called clusters. Each cluster has a coordinator, referred to as a cluster head (CH), and a number of member nodes. Clustering results in a two-tier hierarchy in which cluster heads (CHs) form the higher tier while member nodes form the lower tier [3]. Creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency [4]. The remaining part of this paper is organized as follows. Section II gives a short overview of LEACH protocol and its energy and radio models. Section III highlights some related work concerning the proposed algorithm. Section IV describes the proposed algorithm. Section V presents simulation results and analysis. Finally, we conclude the paper in section VI.

II. ENERGY-EFFICIENT COMMUNICATION PROTOCOLS

We now briefly describe the LEACH protocol, and then present our proposed distance base LEACH algorithm.

A. Clustering Hierarchy in LEACH

LEACH operates in several rounds, each round comprises of a set-up and a steady-state phase. LEACH creates a set-up phase for CHs' selection, and a steady-state phase for time slot scheduling and transmission. Each node becomes member of a cluster when it is not a CH. Each non-CH node transmits sensed data to its closest CH. The CH of each cluster receives and aggregates the data from cluster members and then transmits the aggregated data to the Base Station (BS) through a single-hop relay. LEACH uses a threshold function parameterized by a probability *p* input by user (*p* is a measure to specify probability of a node to become CH). However, the performance of sensor network is very sensitive to the value of *p*. When *p* is large, many clusters are formed and could result in high energy consumption since many CHs dissipate energy in transmitting to the BS. On the other hand, when *p* is small, only a few clusters are formed, which may increase energy dissipation when member nodes transmit to CHs.

Each sensor node *n* decides independently of other sensor nodes whether it will claim to be a CH or not, by picking a random *r* between 0 and 1 and comparing *r* with a threshold function value T(n) based on a user-specified probability *p*. If r <= T(n) then the node claims to become CH. The threshold is defined as follows [1]:

$$T(n) = \begin{cases} \dfrac{p}{1 - p\left(r \bmod \dfrac{1}{p}\right)} & if \;\; n \in G \\ 0 & otherwise \end{cases}$$

where *G* is the set of nodes that have not been CHs in the last *1/p* rounds. When a node decides to be a CH, it broadcasts an advertisement message, with the node's ID and a header, using a non-persistent carrier-sense multiple access (CSMA) MAC protocol (to ensure the elimination of collisions) to the entire sensor field. The size of the message is small, so that it can be efficiently broadcasted to reach all of the nodes in the network. Non-CH nodes (or member nodes) decide to join the cluster defined by the CH with the strongest received signal. Next, each non-CH sends a join-request containing their ID, to the closest CH using CSMA.

After the cluster-setup phase, the CH recognizes the number of member nodes and IDs of the nodes. Based on all join-request messages received within the cluster, the CH creates a TDMA schedule, assigns a unique code, and transmits them to cluster members at the beginning of steady-state phase. Thereafter, all nodes in the cluster transmit their data packets to their CHs in the pre-specified TDMA time slot, using this code. As we know, TDMA-based protocols are naturally energy preserving, because they have time slots built-in, and do not suffer from collisions. Also, each member node can enter a sleep mode at all times except during its corresponding time slots in order to decrease node's energy dissipation. When the data packets sent by a node have been received by a CH, the CH aggregates and forwards them to the BS. These actions are repeated in each round.

B. Energy Consumption Model

We use the same radio model as stated in and shown in Fig1 [1]. According to this radio energy dissipation model, the energy consumption of transmitting *l*-bit data over a distance *d* is

$$E_{Tx}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2 & if\ d \le d_0 \\ lE_{elec} + l\varepsilon_{fs}d^4 & if\ d > d_0 \end{cases}$$

Here $d_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$ denotes the threshold distance, E_{elec} represents the energy consumption in the electronics for sending or receiving one bit, and□ $\varepsilon_{fs}\ d^2$ and $\varepsilon_{mp}\ d^4$ represent amplifier energy consumptions for free space and multipath fading channel transmissions, respectively. To receive an *l*-bit message, the energy $E_{Rx}(l)$ required by the receiver is given by $E_{Rx}(l) = lE_{elec}$

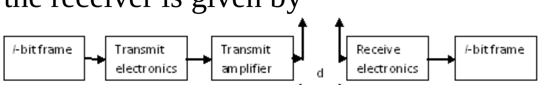

Fig.1 Radio energy model

Let a total of *n* sensor nodes be distributed randomly in the sensor field of size *M*×*M* meters, and be grouped into *k* clusters. The energy required per round for a CH to receive data packets from member nodes, and aggregate and transmit them a distance d_{toBS} to the BS is

$$E_{CH}(l,d) = \begin{cases} l\left[E_{elec}\left(\frac{n}{k}-1\right) + E_{DA}\left(\frac{n}{k}\right) + E_{elec} + \varepsilon_{fs}d_{toBS}^2\right] & if\ d_{toBS} \le d_0 \\ l\left[E_{elec}\left(\frac{n}{k}-1\right) + E_{DA}\left(\frac{n}{k}\right) + E_{elec} + \varepsilon_{fs}d_{toBS}^4\right] & if\ d_{toBS} > d_0 \end{cases}$$

Similarly, when the node is not elected as CH, it sends the data to the nearest CH and the energy consumed for this process is given as $E_{non\text{-}CH}$

$$E_{non-CH}(l,d) = lE_{elec} + l\varepsilon_{fs}d_{toCH}^2$$

If a node directly sends the data to BS then

$$E_{Direct}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs}d_{toBS}^2 & if\ d_{toBS} \le d_0 \\ lE_{elec} + l\varepsilon_{fs}d_{toBS}^4 & if\ d_{toBS} > d_0 \end{cases}$$

III. RELATED WORK

Clustering communication protocols represent a superior approach, and result in more balanced patterns of energy use in WSNs. The first low-energy adaptive clustering hierarchy was LEACH [1]. Several enhanced versions of LEACH have appeared in the literature [5]. Yun Li *et all* investigated the influence of time length of rounds on the performance of LEACH protocol in [6]. In [7] Erfan. Arbab proposed algorithm to solve the extra transmissions problem that can occurs in LEACH algorithm. Andrea Depedri [8] presented a new strategy of cluster heads election & cluster formation to vary their election's frequency considering the dissipated energy and total path energy dissipation between the node and the final receiver. Ankit Thakkar and K Kotecha [9] proposed Coverage based Low-Energy Adaptive Clustering Hierarchy routing protocol CVLEACH to make uniform distribution of Cluster Heads (CHs) by creating non-overlapped cluster regions using overhearing properties of the sensor nodes, which makes the routing protocol more energy efficient and prolongs life time of a wireless sensor network. Baiping Li1, Xiaoqin Zhang [10] proposed low energy-consumption chain-based routing protocol LEACH-CC. This chain routing between clusters is established to reduce the energy to communicate with the base station. Jose Anand [11] carried out simulations for LEACH, LEACH-C and DEEAC using NS-2. J.Gnanambigai [12] highlighted some of the drawbacks and issues in LEACH and discussed how these issues are overcome by the descendants of LEACH. Nazia Majadi [13] proposed approach U-LEACH, to address and describes a uniform distribution technique that is Uniform Distribution Technique (UDT) for selecting CHs and their corresponding clusters.

IV. PROPOSED ALGORITHM

LEACH uses a threshold function parameterized by a probability *p* input by user (*p* is a measure to specify probability of a node to become CH). However, the performance of sensor network is very sensitive to the value of *p*. When *p* is large, many clusters are formed and could result in high energy consumption since many CHs dissipate energy in transmitting to the BS. On the other hand, when *p* is small, only a few clusters are formed, which may increase energy dissipation when member nodes transmit to CHs. Looking at the fig.2 N_1 and N_2 are nodes located at distances d_1 and d_3 respectively from Baste Station (sink). According to LEACH algorithm, they get elected as CH with a probability *p* and work in non-CH mode with probability (*1-p*) in each round. Assume the energy consumption in non-CH is same for both N_1 and N_2 for simplicity. And also energy consumed while aggregating the data from other non-CH nodes is also small. In such cases, energy consumed by N_2 is much less than energy consume by N_1 after few rounds of transmission. This is because of the distances N_2 and N_1 are from BS. This leads early death of farther nodes than closer nodes to BS. In other words, First_Node_dead (FND) occurs at much earlier farther nodes. This can be improved by adapting different CH election probability to N_1 and N_2. Detailed analysis of this variable CH election probability is given below:

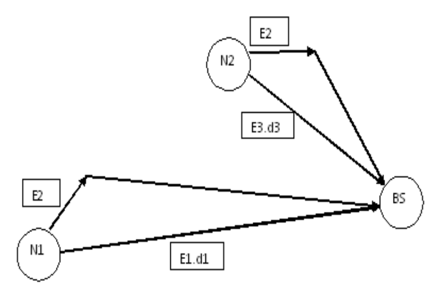

Fig.2 Typical node positions for proposed algorithm.

Let us assume, N_1 consume E_1 energy when it is in CH mode and E_2 energy when it is in non-CH mode. Similarly, N_2 consumes E_3 energy while in CH mode and E_2 energy when it is in non-CH mode. Probability of becoming CH for N_1 and N_2 are *p* and *q* respectively.

Now, the total energy consumed by N_1 and N_2 at the end of a round is given by

$$pE_1 + (1-p)\, E_2 \qquad (1)$$

$$qE_3 + (1-q)\, E_2 \qquad (2)$$

Assuming $\Delta p = p-q$, $\Delta d = d_1 - d_3$, $\Delta e = E_1 - E_3$

And Equating 1 & 2 we get

$$\Delta p = p\frac{E_1 - E_3}{E_2 - E_3} \qquad (3)$$

Where $E_1 = E_{CH}(l,d)$ of node N_1 , $E_3 = E_{CH}(l,d)$ of Node N_2 and E_2 is $E_{non\text{-}CH}(l,d)$ of node N_1, N_2. Here we assume $E_{non\text{-}CH}(l,d)$ is same for both N_1 and N_2 for simplicity and Node N_1 is at d_1 distance and Node N_2 is at d_3 distance from Base station (sink). For simplicity purpose, here we consider only free space condition for d_1 and d_3.

$$\Delta p = p\,\frac{l\varepsilon_{fs}d^2 - l\varepsilon_{fs}(d-\Delta d)^2}{R + l\,\varepsilon_{fs}(d-\Delta d)^2} \qquad (4)$$

$$\Delta p = (pl\,\varepsilon_{fs})\frac{-\Delta d^2 + 2d\Delta d}{R + l\,\varepsilon_{fs}(d^2 + \Delta d^2 - 2d\Delta d)} \qquad (5)$$

Where

$$R = E_{non\_CH}(l,d) + l\left[\begin{matrix} E_{elec}\left(\frac{n}{k} - 1\right) \\ + E_{DA}\left(\frac{n}{k}\right) + E_{elec}\end{matrix}\right] \qquad (5A)$$

Ignoring the terms containing Δd^2 and $\Delta d \Delta p$ in (5) we get

$$\Delta p\left[R + l\,\varepsilon_{fs}d^2\right] = 2dp\,l\,\varepsilon_{fs}\Delta d \qquad (6)$$

$$\frac{\Delta d}{\Delta p} = \frac{R}{2dpl\varepsilon_{fs}} + \frac{d^2 l\varepsilon_{fs}}{2dpl\varepsilon_{fs}} \qquad (7)$$

$$\frac{\Delta p}{\Delta d} = \frac{2dpl\varepsilon_{fs}}{R + l\,\varepsilon_{fs}d^2} \qquad (8)$$

$$\frac{\Delta^2 p}{\Delta d^2} = \left[R + l\,\varepsilon_{fs}d^2\right]\frac{\Delta p}{\Delta d}(2dpl\varepsilon_{fs}) - 2dpl\varepsilon_{fs}\frac{\Delta p}{\Delta d}(R + l\,\varepsilon_{fs}d^2) \qquad (9)$$

For optimality we equate the second order derivative to zero.

$$\frac{\Delta^2 p}{\Delta d^2} = \left[2Rl\varepsilon_{fs} + 2\,l^2\varepsilon_{fs}^2 d^2\right](p+d) - 4d^2pl^2\varepsilon_{fs}^2 \qquad (10)$$

$$\left[2Rl\varepsilon_{fs} + 2\,l^2\varepsilon_{fs}^2 d^2\right][p+d] - 4d^2pl^2\varepsilon_{fs}^2 = 0 \qquad (11)$$

$$2Rl\varepsilon_{fs}p + 2Rl\varepsilon_{fs}d + 2\,l^2\varepsilon_{fs}^2 d^3 = 2d^2pl^2\varepsilon_{fs}^2 \qquad (12)$$

$$Rp + Rd + l\varepsilon_{fs}d^3 = d^2pl\varepsilon_{fs} \qquad (13)$$

$$R(p+d) + l\varepsilon_{fs}d^2(d-p) = 0 \qquad (14)$$

$$p = \frac{Rd + l\varepsilon_{fs}d^3}{(d^2 l\varepsilon_{fs} - R)} \qquad (15)$$

Thus we can make CH election probability a distance related. Pseudo code of the proposed D-LEACH algorithm is given below at fig.3

BEGIN

1: Specify the initial probability (p), number of nodes (n);

2: set $E_{init}(s)=E_0$, for s=1,2, …, n;

3: specify E_{DA}, E_{elec}, ε_{fs} ε_{mp}

4: compute distance of each node from BS

5: normalize the distance to farther node distance from BS

6: compute distance matrix between nodes

7: computer R as per equation 5A

(Taking sensing radius for non-CH transmission d =15m)

1: for *r = 1 to rmax*

(I) SET-UP PHASE

2: ***if*** *mod(r, round(1/p) = 0) then //node can be considered for CH*

3: reset all n odes to non-CH

4: ***endif****;*

5: ***for s*** *= 1 to n*

4: compute revised p as per equation 15

6: temp = random(0-1) and compute T(s);

7: ***if*** *(temp < T(s)) & (E(s)>0)* ***then***

8: CH{s} = TRUE; //node s be a candidate CH

9: ***else***

```
          CH{s} = FALSE; //node s not be a
candidate CH
       end if
       if (CH{s}=TRUE) then
          BC (ADV) □□□broadcast an
advertisement message;
          Join(IDi); //non-cluster head node i
join into the closest CH
          Cluster(c); //form a cluster c;
       end if
      if  (E(s) <=0) then
         set s to dead
        compute dead nodes
      end if
   end
```

(I) STEADY-STATE PHASE

```
   for s = 1 to n
       If (CH(s)=TRUE) then
          Receive(IDi, DataPCK) //receive data
from members;
          Aggregate(IDi, DataPCK) //aggregate
received data;
          Tansmit ToBS(IDi, DataPCK);
//transmit received data;
       else
       If (IDiTimeSlot=TRUE) then
          find nearest CH
          Tansmit To CH(IDi, DataPCK);
//transmit sensed data to nearest CH;
      end if
   end
end // one round is completed
END   // BEGIN-END
```

Fig3. Pseudo-code of the Proposed D-LEACH Algorithm

V. SIMULATION RESULTS

In this section, we evaluate the performance of our proposed algorithm through the simulations. We compare our proposed algorithm with LEACH based on three performance metrics: i) Number of times node has been elected CH before FND; ii) Remaining energy of each node at FND; iii) spread of the dead/alive nodes at (Half Nodes Dead) HND; and iv) Number of packets transmitted at FND, HND, AND (All Nodes Dead). The reference network of our simulations consists of 100 nodes distributed randomly in an area of 100 m × 100 m. The BS is located at position (50, 50). Here we use the typical values E_{elec} = 50 nJ/bit, ε_{fs} = 10 pJ/bit/m^2 and ε_{mp} = 0.0013 pJ/bit/m^4. As noted previously, the cluster heads are responsible for aggregating their cluster members' data. The energy for data aggregation is set as E_{DA} = 5 nJ/bit/signal. The initial energy of all nodes set to 0.1 J. Every node transmits a 4000-bit message per round to its cluster head. Here we assume every node having knowledge of other node position and compute distance from BS. We normalize the distance of each node to longest node distance from BS. p is set to 0.1 (about 10% of nodes per round become cluster heads). However p is recomputed for every node taking distance into account.

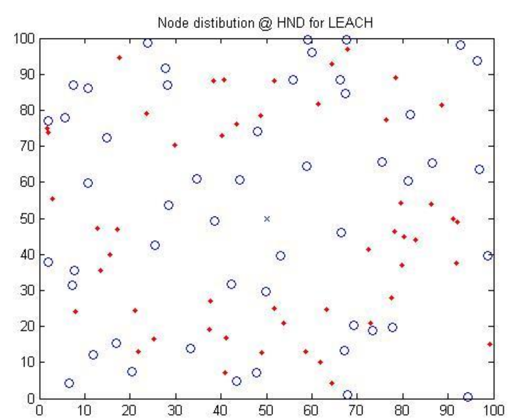

Fig4. Node distribution at HND for LEACH algorithm

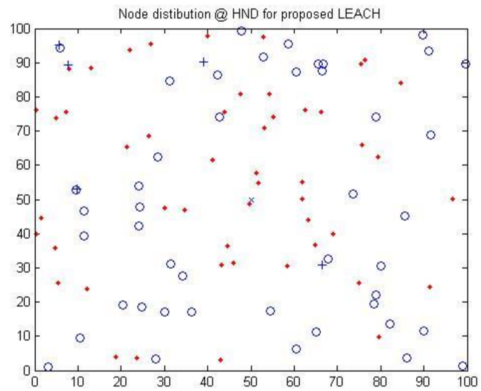

Fig5. Node distribution at HND for proposed LEACH algorithm

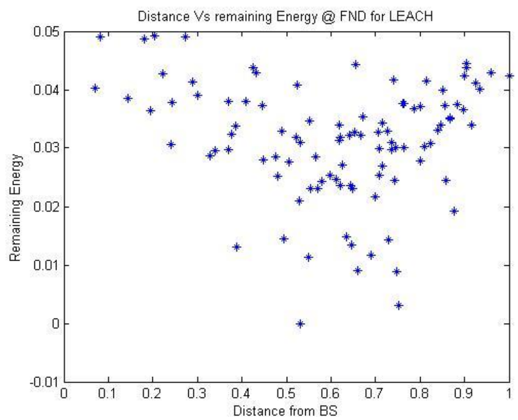

Fig6. Remaining energy at FND in LEACH algorithm

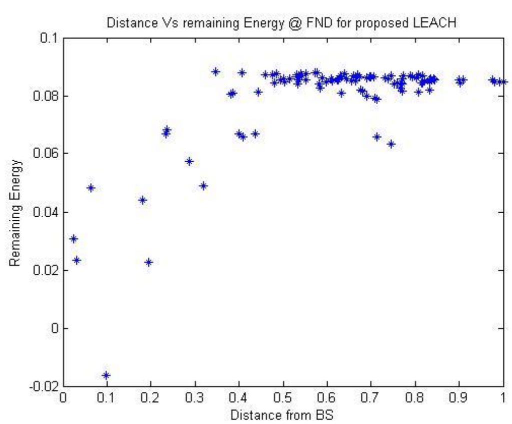

Fig7. Remaining energy at FND in proposed algorithm

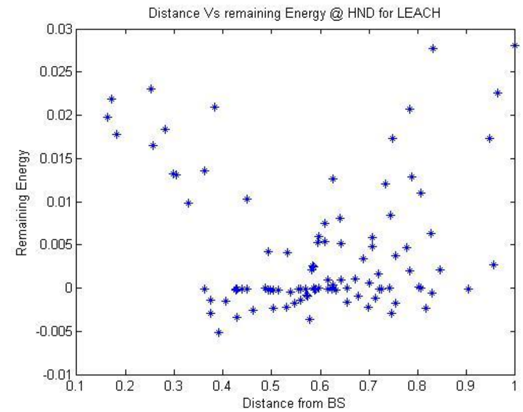

Fig8. Remaining energy at HND in LEACH algorithm

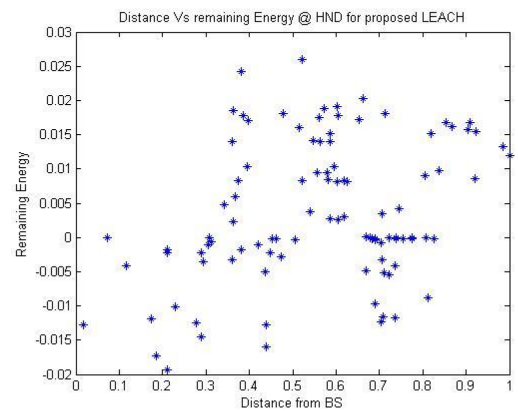

Fig9. Remaining energy at HND in proposed algorithm

Fig.4 & Fig.5 show the nodes distribution at HND. We can observe that less number farther nodes are died in the proposed algorithm. Similarly, Fig6 & Fig7 display the remaining energy of the nodes at FND and Fig8 & Fig9 display the remaining energy of the nodes at HND. It is apparent that proposed algorithm left more energy at distant nodes. We have also compared and tabulated (Table1.) the packets transmitted to BS before FND, HND, AND. Initially, we assumed energy consumed by node electronics is same for transmitting or receiving 1-bit. When we took different values, packets transmitted have increased accordingly.

Table1: Comparison of packets transmitted by LEACH and D-LEACH

	E_{elec} same for transmit and receive		E_{elec} different for transmit and receive (5:1)	
	LEACH	D-LEACH	LEACH	D-LEACH
Packets @ FND	1365	1295	3086	3600
Packets @HND	2290	5218	3569	7550
Packets @AND	2428	5999	3661	8063

VI. CONCLUSION

In this paper, we considered a well known energy efficient clustering algorithm for WSNs called LEACH algorithm and proposed a new clustering algorithm D-LEACH. In this new approach, we made distance as a parameter to compute probability of CH election. This makes energy consumption more uniform for nodes of all distances than in LEACH algorithm and hence increases network lifetime. The simulation results show that the proposed algorithm can make the remaining energy more uniform throughout the network at every round. In the present work we assumed E_{DA}, E_{elec}, K cluster size to be constant. However, they can also influence the *p*. In future work, we can improve our algorithm for condition taking these parameters into account.

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