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Distance Based Residual Energy For Cluster Head Selection In Wireless Sensor Networks

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Abstract

In this paper, a distance based cluster head selection algorithm (DBR-LEACH) is proposed for improving the network life time, which estimates the minimum energy required for a node to become a cluster head by considering its residual energy and the distance of the node frombase station or sink node. The objective of this modified cluster head selection algorithm is to reduce the frequency of re-clustering and to ensure that nodes that are selected close to the base station possess more energy than the nodes that are farther to the base station. The experiment result shows that the proposed algorithm outperforms LEACH and D-LEACH protocol in terms of energy consumption, first node die time, alive nodes and thereby improved network life time.

Keywords: Cluster head selection, clustering, residual energy, distance, network lifetime,LEACH, D-LEACH.

Introduction

Wireless sensor Network (WSN) forms a subset of Ad-hoc wireless networks. In WSN, sensor nodes are made up of small electronic devices which are capable of sensing, processing and transmitting the data to a distant base station connected to a server. These sensor nodes are mainlybattery operated and get depleted at a faster rate because of the processing and communication operations. The failure of one node can disrupt the working of entire system or application. Consequently, routing techniques that minimizes the energy consumption are highly desirable to improve the network lifetime.Clustering is an effective technique that has greatly contributed to overall system scalability, improved lifetime, and energy efficiency in wireless sensor networks (WSNs) [1].Routing protocols build around the clustering methodologies have proved to be efficient in terms of energy conservation [2].LEACH is one of the foremost protocols that employ cluster formation technique to extend the network lifetime [3]. LEACH employs a probabilistic model in cluster head selection todistribute the energy consumption by giving a fair chance to all nodes to become cluster heads.Even though the performance of LEACH protocols is appreciable; it also suffers from drawbacks like random selection of CHs ignoring the residual energy of nodes and wasting substantial amount of energy in high frequency of re-clustering at the end of each round.

Since all the communications between the sensor nodesand sink nodes occur only through cluster head (CH), it is necessary that the CHs possess sufficient energy. Also the energy expense for the CHs increases with increase of its distance from the base station (BS). Several modificationshave been designed around LEACH protocol to make further efficient utilization of the resourcesin sensor nodes and to prolong the network lifetime [4][5][6][7].

Related Work

Researchers have developed novel algorithms for selection of best node as cluster head, based on the parameters like node's residual energy, distance from base station, energy consumption rate, number of neighbour nodes and its proximity. Comprehensive study on various cluster head selection schemes carried out by Naveen Sharma et al [8] reveals the significance of residual energy, distance and density of nodes in achieving energy efficiency and prolonging of network lifetime.A novel cluster head selection algorithm (L-LEACH) developed by Qian Liao et al [9] considers the distance between a node to CH and base station along with its residual energy for CH selection. The first node death time in L-LEACH was extended by 51% when compared to LEACH. Protocol PDCNS-E&D developed by Jian Li et al [10] for cluster heads (CHs) selection, considers the value of an information factor, instead of comparing a randomly generated number with threshold. The information factor contains information of node's residual energy and distancebetween the node and base station. Even though exchange of information involves certain amount of overhead, network life time interms of first node die time is found improved by 22% in the proposed protocol, when compared to LEACH. Modified CH selection algorithm of LEACH proposed by SnehalKole [11] considers the minimum distance of a node to the BS through CHs for cluster formation and network life time in found to be extended by 17% when compared to LEACH. Algorithm proposed by S. Taruna et al [12] chooses the mid-point between sensor node and BS as a criterion to select the CH. Energy conservative clustering protocol (ECCP) proposed by HarshitaPatidar et al [13] elects two tier CHs with tier I cluster formation in first phase and election of leaders among the CHs in second phase, based on shortest distance to sink and its residual energy.Algorithm proposed by Sang H. Kang et al [14] takes into account thedistances from sensors to a base station to balancethe energy consumption among the sensors. The high frequency of re-clustering wastes certain amount of energy, and in order to make the energy distribute more evenly among different nodes, the equation used in LEACH is modified for selecting CHs by considering the dynamic change of nodes' energy. In the algorithm proposed by madheswaran et al [15], a threshold is set for residual energy which aims to diminish the energy consumption spent on the re-clustering and prolong the time of being in a steady-state phase and substantial improvement was observed in energy consumption and network lifetime.

Energy Consumption Analysis of Leach Protocol

LEACH protocol is implemented in two phases. In the set up phase, cluster head selection and cluster formation takes place and in the steady state phase, the sensing and transferring of a sensed data to the BS through the CHs takes place.When the sensorsare far away from the BS, a single-hop sensor network is notappropriate because of the constraint of the limited power in a sensor to transmitsignals over a long distance.Hence, multi-hop communication between CHs to a BS is assumed in the analysis in contrast to single hop communication.

Assume that there are N sensor nodes randomly deployed in an area of M × M [m^2] and all nodes possess an equal amount of initial energy. LEACH adopts the following energy model.The energy dissipated by a node in transmitting an l-bit message over a distance d is given by:

$$E_{Tx}(l,d) = lE_{elec} + ld^2E_{amp} \tag{1}$$

And the energy required to receive the message of l-bits bya node is given by:

$$E_{Rx}(l) = lE_{elec} \tag{2}$$

where E_{elec}, the energy consumed by the transmitter and receiver electronics and $E_{amp}$is the energy consumed by amplifier in transmitting system.

A node acting as a cluster member has to sense a desired phenomenon and transmit the same to the cluster head in the allotted time slot. When the nodes are at one-hop distance, the energy required to transmit *l* bits is given by

$$E_{Mem} = l(E_{elec} + E_{amp}) \tag{3}$$

A node acting as cluster head perform the actions like, communicating with members to form a cluster, aggregate the received data from its member nodes, transmit the aggregated data to the BS and act as a rely node in passing the aggregated data from other CHs to the BS. When the nodes are at one-hop distance, the energy consumed by a cluster head is given by:

$$E_{CH} = E_{OH} + E_{Tx}(l,d) + E_{Rx}(l) \tag{4}$$

$$= E_{OH} + lE_{elec}(E_{amp} + 1) \tag{5}$$

Where E_{OH} is the energy dissipation of a cluster head and member node in cluster formation process during the set-up phase.

Let the number of sensor nodes in a network be N, forming k clusters in each round. Then there are average of $\frac{N}{k}$ nodes in eachcluster, including one cluster head and $\left(\frac{N}{k}-1\right)$ member nodes. Let the initial energyof each node beE_{Init}, the length of data message be l bits, and the length of control message be m bits.

In the set-up phase, the energy dissipation of the cluster head node and a membernode during cluster formation process is made-upof the following components:

- The energy consumption in CH selection process in a node for the next round - E_{CH_Sel}.
- The energy consumption of a cluster head node in broadcasting its identity message to the whole network - $E_{CH}(BC\_Tx)$.
- The energy consumption of a member node to receive a BROADCAST message - $E_{Mem}(BC\_Rx)$.
- The energy consumption of a member node to send JOIN-REQ message to its cluster head - $E_{Mem}\ (J\_Req\_Tx)$.
- The energy consumption of a cluster head to receive a JOIN-REQ messages from its cluster member nodes - $E_{CH}\ (J\_Req\_Rx)$.

In order to reduce the energy consumption, data aggregation is done by forming a TDMA frame and its time slot is assigned to all member nodes for sending the collected information to the cluster heads. The energy consumed during cluster formation also includes:

- The energy consumption of a cluster head to send a TDMA_SCHD message to its cluster member nodes - E_{CH} (Tdma_Tx).
- The energy consumption of a member node to receive TDMA_SCHD message from its cluster head - E_{Mem} (Tdma_Rx).

The energy consumed for the above intra-cluster communication during the cluster formation process is given by:

$$E_{CH}(BC\_Tx) = mE_{elec} + md^2E_{amp} \tag{6}$$

$$E_{Mem}(BC\_Rx) = mE_{elec} \tag{7}$$

$$E_{Mem}(J\_Req\_Tx) = mE_{elec} + md^2E_{amp} \tag{8}$$

$$E_{CH}(J\_Req\_Rx) = mE_{elec}\left(\frac{N}{k}-1\right) \tag{9}$$

$$E_{CH}(Tdma\_Tx) = (mE_{elec} + md^2E_{amp})\left(\frac{N}{k}-1\right) \tag{10}$$

$$E_{Mem}\ (Tdma\_Rx) = mE_{elec} \tag{11}$$

Therefore, the total energy dissipation as overhead in a node that to become a Cluster head is given by:

$$E_{OH-CH} = E_{CH\_Sel} + E_{CH}(BC\_Tx) + E_{CH}(J\_Req\_Rx) + E_{CH}(Tdma\_Tx)$$

$$= E_{CH\_Sel} + mE_{elec} + md^2E_{amp} + mE_{elec}\left(\frac{N}{k} - 1\right) + \left(mE_{elec} + md^2E_{amp}\right)\left(\frac{N}{k} - 1\right)$$

$$= E_{CH\_Sel} + m\,(E_{elec} + E_{amp}) + m\left(\frac{N}{k} - 1\right)\left(2E_{elec} + E_{amp}\right) \quad (12)$$

Therefore, the total energy dissipation as overhead in a node to become a cluster member during cluster formation process is given by:

$$E_{OH-Mem} = E_{Mem}(BC\_Rx) + E_{Mem}(J\_Req\_Tx) + E_{Mem}\,(Tdma\_Rx)$$

$$= mE_{elec} + mE_{elec} + md^2E_{amp} + mE_{elec}$$

$$= m(3E_{elec} + E_{amp}) \quad (13)$$

The total energy consumed by a node is equal to the sum of energy dissipated when acting as cluster head and when acting as a member node. If there are *p* frames in each steady state of a round and if there is *T* number of CHs that communicate to the base station via this node when acting as CH; then the energy consumed by a node *n* at the i^{th} round, is given by:

$$E_{Con}(n) = \sum_1^i \begin{cases} E_{OH-CH} + plE_{elec}\left(d^2E_{amp} + 1\right)(1 + T)\,;\ n \in CH \\ E_{OH-Mem} + pl(E_{elec} + E_{amp});\ n \in Mem \end{cases} \quad (14)$$

From the equation (14), we can conclude that high frequency of re-clustering will result in more consumption of energy as overhead during CH selection process and more number of CHs that communicate to the BS through a specific CH, would require additional energy in such CH to rely the aggregated data of other CHs to BS.

Distance Based Residual Energy Algorithm

As the nodes acting as CH which are close to the BS will spend more energy in communicating its own aggregated data and for transferring of the sensed data from other CHs to BS by acting as a rely node, the minimum residual energy in a node to become CH can be made as a function of its distance from the BS. The figure 1 shows an illustration of communication that takes place in sending the aggregated data from CHs to the BS.

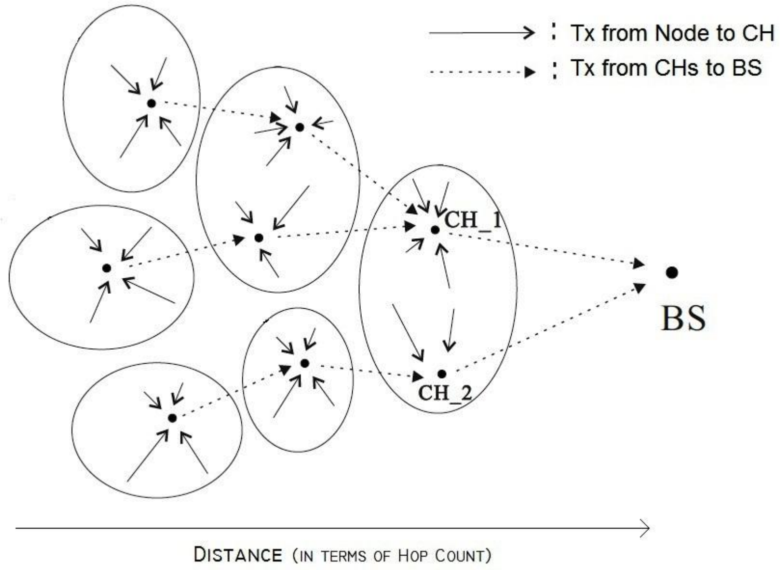

Figure 1: Illustration for estimation of distance between CHs and BS

Thus, a modified LEACH-based CH selection algorithm (DBR-LEACH) is proposed in which nodesare selected to become CHs with a criterion that determines the minimum required residual energy in a node based on its distances with the BS, such thatCH selection can be made nearly optimal.The process carried out in the modified algorithm (DBR-LEACH) for the CH selection is given as flow chart in the figure 2.

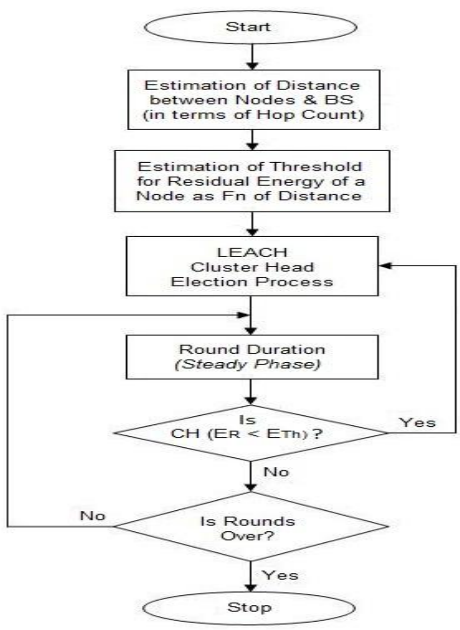

Figure 2: DBR-LEACH Algorithm

At the beginning, a control message is flooded in the network by the BS to all nodes to determine the shortest distance between a node and BS in terms of hop count. The CHs for the first round is selected based on the probabilistic model of LEACH using threshold T(n) as follows:

$$T(n) = \begin{cases} \frac{p}{1-p\times\left(i\times mod\frac{1}{p}\right)} & n\in G \\ 0 & n \notin G \end{cases} \tag{15}$$

Where*p* is the probability of nodes to be selected as CH in a round, G is the nodes set including those nodes not yet been selected as CH in recent *1/p* rounds. If the random number generated for a node *n* is less than the threshold calculated *T(n)*, then node is selected as CH.

At the end of first and each round, the residual energy in all CHs are checked and the nodes are allowed to continue as CHs for the next round if it possess the minimum required energy$E_{Th}(n)$,given by the equation:

$$E_{Th}(n) = \begin{cases} E_{Max\_Th} - (HC_n \times C) & 1 \leq HC_n \leq 3 \\ 0.6\, E_{Max\_Th} & HC_n > 3 \end{cases} \tag{16}$$

Where $E_{Max_Th}$are maximum threshold energy needed in a node to become CH from second round, HC_n is the distance between a node acting as CH and BS in terms of hop count in routing the data to the BS and C being the constant that specifies the reduction in energy from the maximum required threshold energy as the nodes' distance increases from the BS.

If the residual energy of the CH is less than threshold energy, then the CHs are selected for the next round using the same threshold equation (15) with the slight modification as follows.If the random number generated for a node *n* is less than the threshold calculated *T(n)* and the node's residual energy is greater than the threshold energy calculated based on its distance from BS, then node is selected as CH, given by equation (16). Thus, by estimating the residual energy of a node acting as CH and its minimum required threshold energy, the round time can be extended without the re-clustering process.

Results and Discussion

In this section, the performance of improved protocol (DBR-LEACH) throughNS2 simulation [16] is examined for the objective of reducing the frequency of re-clustering and there-by improved network lifespan. A network of 100 nodes deployed in an area of500m × 500m is considered for simulation with BS at two locations, at centre (250, 250) and at edge (0, 500). The main parametersof the simulation experiments are described in Table 1.

Table 1: Summary of the parameters used in the simulation experiments

Simulation Parameters	Value
Network Area (m^2)	500x500
Total Simulation time	1000 Sec
Round Duration	10 Sec
Initial Energy in each node	0.1 J
Total Number of nodes	100
Probability of CH Selection	0.4
Threshold for E_R Comparison	Variable
Data Rate	1 Kbps

In order to compare the advantage of the improvedprotocol with the original LEACH, Static LEACH and D-LEACH, three performance metrics used for comparison are: numbers ofnodes alive over simulation time, numbers ofnodes alive over simulation time and the residual energy of thewhole network over simulation time for the three different protocols.The base station location for the simulation is taken initially as (0,500) and compared with the performance for the BS location at the centre of the network (250,250). The simulation results are illustrated in Figures 3–5.

In the comparison of CHs selected, the LEACH protocol is ignored because of fixed probability in CH selection, which is very high when compared to Static LEACH, D-LEACH and proposed algorithm DBR-LEACH. As the probability of CH selection in Static LEACH is constant and CHs are selected only once, at the beginning of first round, the number of CHs selected in Static LEACH remains constant throughout the simulation. The CH selection for D-LEACH and proposed algorithm DBR-LEACH starts only from the round 48 and 69 respectively. The maximum CHs selected at the end of simulation time (100 rounds) for DBR-LEACH being45 indicates that the number of re-clustering in the proposed algorithm is greatly reduced. The figure 3 shows the number of CHs selected over the simulation time of 100 rounds for various CH selection algorithms.

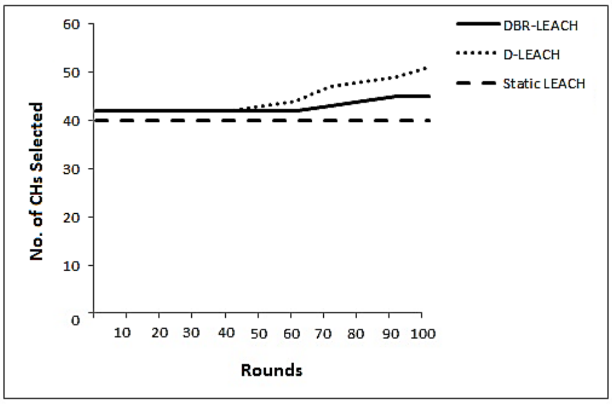

Figure 3: Comparison of CHs selected as function of Time (rounds)

Residual energy is the vital parameter that indicates the lifespan of the sensor network. Figs. 4 show the amount of residual energyof the entire network as a function of the simulation time (rounds) for LEACH, D-LEACH and DBR-LEACH respectively.For LEACH, CHs are selected at the end of every round ignoring the amount of residual energy in the CH and substantial amount of energy is dissipated in re-clustering process. Hence the graph slants steep at the end of the simulation time for LEACH, where as in D-LEACH, the CHs are selected only if the CHs' residual energy is less than the threshold energy. Notably for the DBR-LEACH, by considering the distance between the node and BS for the estimation of minimum required threshold energy for the nodes to continue as CHs, the depletion rate is much slower andgraph shows optimal energyconsumption.

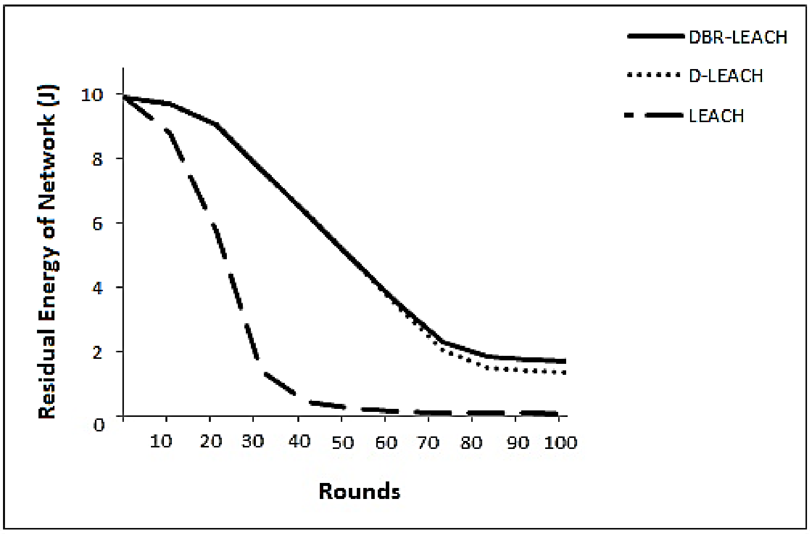

Figure 4: Comparison of Residual Energy as function of Time (rounds)

Fig. 5 shows the time of the death of first node and the number of alive nodes at the end of simulation for the four Static LEACH, LEACH, D-LEACH and DBR-LEACH. The time in the horizontal axes is in rounds. As seen, DBR-LEACH outperformsother schemes in terms of the number of alive nodes and the time at which first node die. Table 2 also showsthe improvement of DBR-LEACH over the other three schemesin both mean time to first node death and mean time of nodelifespan. It can be noted that the increase of lifespan by the proposed DBR-LEACH is greater than LEACH by 1.4 times and 5% over D-LEACH.

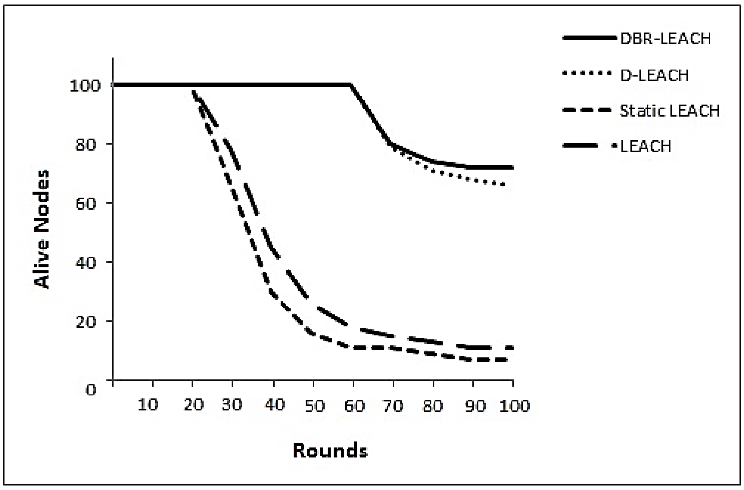

Figure 5: Comparison of Alive Nodes as function of Time (rounds)

Table 2: Comparison of No. of Alive nodes and First Node Die (FND) time

Protocols	FND time *(at round)*	No. of Alive nodes *(after 100 rounds)*
Static LEACH	7	25
LEACH	8	27
D-LEACH	66	62
DBR-LEACH	72	65

Table 3 shows the comparison of performance of the proposed DBR-LEACH algorithm for various locations of the Base Station in the network. Notably, DBR-LEACH performs well for the BS situated at the edge of the network where the energy of the nodes acting as CHs situated close to the BS depletes faster than the nodes situated farther from BS.

Table 3: Comparison of Residual Energy In The Network For Different BS Location

Protocols	Edge of Network Location: 0, 500	Centre of Network Location: 250, 250
Static LEACH	0.062396	0.045757
LEACH	0.075177	0.050118
D-LEACH	1.336530	1.060630
DBR-LEACH	1.700240	1.107080

Conclusion

The modified CH selection algorithm (DBR-LEACH) overcomes the limitation of high frequency re-clustering and ignorance of residual energy of a node in the CH selection process of LEACH protocol by using the criteria for minimum required residual of a nodeto become a CH, based on its distance to the BS. Simulations show that DBR-LEACH outperformsthe original LEACH and D-LEACH with improved network lifetime over 21 times and 26% respectively in terms of residual energy.

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