A New Approach to Clustering with Respect to the Balance of Energy in Wireless Sensor Networks

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Abstract. In wireless sensor networks the sensor nodes are expected to be remotely deployed to operate autonomously in unattended environments. Since the sensor nodes are extremely power constrained, an energy efficient clustering algorithm is proposed for reducing the energy consumption and balancing the energy load among distributed clusters to increase the useful system lifetime and cluster stability. An analytical clustering model based on classic clustering algorithm LEACH, considering both distance and current energy parameters of the nodes at the time of cluster head election is presented in this paper. It improves the process of cluster head election. Based on our findings it reduces the adverse effect on total energy consumption of each cluster and avoid direct communication between the base station and ordinary nodes in the network. The simulation results demonstrate that the improved clustering algorithm can reduce the energy consumption effectively and prolongs 85% of the useful lifetime in terms of First Node Dies compared with the original LEACH protocol.

Keywords: Wireless sensor network, Energy-Efficient algorithms, First node dead, Half node alive, Low-Energy consumption.

1 Introduction

A Wireless Sensor Network (WSN) is composed of a number of wireless sensor nodes forming a sensor field and a base station. The energy sources of sensor nodes are usually powered by batteries which are very difficult or often impossible to be recharged or replaced. Therefore, improving the energy efficiency and maximizing the networking lifetime are the major challenges in sensor networks. Clustering is a key technique used to both extend the lifetime of the sensor networks and make them scalable by forming clusters [1].

LEACH algorithm is one of the fundamental clustering protocols. Using a clustering technique and frequent rotation of the cluster heads result in distributing the energy load uniformly between all nodes in the network [3]. However, the LEACH algorithm does not consider the current energy of the nodes at the time of cluster head selection which may cause early death of some nodes. Also, it does not take into account the location of the nodes which might lead to a sparse distribution of clusters and affect the total performance of the algorithm [2, 9].

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In this paper, we take advantage of LEACH algorithm as a fundamental algorithm of WSN and improve its process of cluster head selection in order to increase the total performance of LEACH. Similar to LEACH, in our proposed algorithm the nodes are organized in the form of clusters. Each node decides independently to become a cluster head or an ordinary member node according to the ratio of current energy of the node to the average distance between the node and all other nodes of the same cluster. It reduces the adverse effect on energy consumption of each cluster caused by non-uniform distribution of nodes by selecting the proper cluster head inside each cluster.

2 Related Works

LEACH algorithm [7] selects cluster heads based on generating a random number between 0 and 1 for each node. If the random number is less than the following threshold, the node becomes a cluster head for the current round.

$$T(n) = \begin{cases} \dfrac{P}{1 - P * (r \bmod \frac{1}{P})}, & \forall n \in G \\ 0 \quad , & \forall n \notin G \end{cases} \tag{1}$$

P is the cluster head probability, r shows the current round and G is the set of nodes that have not been cluster head in the last $1/P$ rounds. This algorithm ensures that every node becomes a cluster head once within $1/P$ rounds. Looking at the process of cluster head selection, it is possible that a node with low residual energy and far from the base station is selected as cluster head for the current round, therefore there is no guarantee about the location and the number of cluster heads [9].

An enhancement over the LEACH protocol, LEACH-C [3], uses a centralized clustering algorithm that requires location information of all nodes of the network. However, this location information in mobile wireless networks is only available through GPS which requires additional communication among the nodes.

V-LEACH [4], introduce the vice-cluster head in each cluster, that in case the cluster head dies, the vice cluster will start working as cluster head and collected data will reach the base station through the cluster head. There is no need to select the new cluster head, but this will cause extra energy to be used for vice cluster selection.

NEW-LEACH [6], Improves the energy efficiency of original LEACH by introducing the combinational factor. It considers three important factors: the energy of each node, the number of times a node is chosen as a cluster head and the distance between nodes and the base station. Also, the role of cluster head will be rotated among all nodes during the running rounds. However, this protocol imposes extra computational overhead on setup phase of LEACH algorithm.

FZ-LEACH protocol [8], come to solve the problem of “Existence of the large clusters in WSN”. It introduces the Far-Zone (FZ), including the nodes with low residual energy and far from the base station. Once the FZ is formed, the Zone Head (ZH) is selected. All nodes in the FZ can directly communicate with the ZH rather than cluster head. Cluster head then collects sensed data from the rest of the nodes and ZH and after aggregating transmits to the base station and this way it produces the equal clusters. But it is suitable for the networks that deployed in wide area.

3 The Algorithm Model

3.1 The Energy Consumption Model

In WSN, the main energy consumption of the active nodes is made up of three parts: message sending, message receiving and data signal processing. To simplify the network model we make some assumptions:

- All nodes are immobile and have static locations
- All nodes in the network are homogenous and energy constrained
- One-hop communication and symmetric propagation channel is considered

Our energy model is very similar to Heinzelman et al.'s [3]. Equation (2) represents the amount of energy consumed for transmitting l-bit message to distance d. Equation (3) represents the amount of energy consumed for receiving l-bits message.

$$E_{TX}(l,d) = E_{Tx-elec}(l) + E_{Tx-amp}(l,d)$$

$$\begin{array}{ll} l\,.E_{elec} + l_{\in fs}d^2 & d < d_o \\ l.E_{elec} + l_{\in mp}d^4 & d \gg d_o \end{array} \tag{2}$$

$$d_o = \sqrt{\frac{E_{fs}}{E_{mp}}}$$

$$E_{Rx}(l) = E_{Rx-elec}(l) = l.E_{elec} \tag{3}$$

E_{elec} is the electronics energy for the radio component that depends on some factors such as the digital coding, modulation, filtering and spreading of the signal. Energy consumption of the amplifier depends on both bit error rate and the distance to the receiver, E_{fs} for free space and E_{mp} for the multiple attenuation models, and d_o is a constant threshold which relies on the application environment.

3.2 The Clustering Model

Similar to LEACH, our proposed algorithm is round based and each round is divided into a starting stage and a stable working stage. In order to minimize energy consumption the stable working stage should be greatly longer than the starting stage. At the starting stage, cluster head is elected and TDMA (Time-Division Multiple Access) time slots are distributed to non-cluster head (non-CH) members by the cluster head [5]. Being a cluster head is more energy intensive than being a non-CH member because it has to receive and aggregate the data from all members inside the cluster and send it to the base station by one-hop communication. Therefore, completely independent random cluster head selection cannot guarantee the number and distribution of cluster heads in each round. It may select a node which is far away from the base station and with low residual energy to become a cluster head which causes quick dissipation of cluster head's limited energy. Once the cluster head runs out of energy, it is no longer operational and all the nodes that belong to that cluster head will lose their communication ability. In order to prevent such situations we will improve the cluster head selection procedure of LEACH by applying the distance and the current residual energy parameters of all member nodes of the same cluster. Actual cluster heads are selected in order to save more energy inside each cluster of the network.

3.3 The Proposed Algorithm

In the starting stage of each round, cluster head is selected similar to LEACH algorithm. Each sensor generates a random number between 0 and 1. If the random number is smaller than the predefined threshold, then the node becomes the temporary cluster head (TCH) of the current round. Each TCH acts as a cluster former and broadcasts an advertisement message using non-persistent Carrier Sense Multiple Access (CSMA) protocol. Each non-CH node selects the TCH from which the received advertisement signal is strongest as its cluster head and transmits a joint-request back to that TCH. After forming the clusters and before sending the collected data, all nodes in the same cluster calculate their sufficiency metric S and compare it with other nodes of the same cluster. The node with the highest S is elected as the actual cluster head (ACH) and introduces itself to the members of the cluster. Comparing S values allows the node with the highest residual energy per distance (average distance to all other nodes of the cluster) unit to be selected as the ACH. This method of cluster head selection causes the energy load to be more balanced over the members and utilizes energy of each cluster more efficiently.

$$S(i) = \frac{E_r(i)}{D_{ave}(i)} \tag{4}$$

Where $S(i)$ is the sufficiency metric of node i, $E_r(i)$ is the residual energy of node i and $D_{ave}(i)$ is the average distance between node i with all other members of the cluster.

After forming the clusters, each non-CH node in the cluster transmits its data packet to its ACH. Simultaneously, the ACHs collect these data packets and then aggregate and transmit them to the base station directly.

4 Performance Evaluation

In this section we have simulated four algorithms: the LEACH algorithm, the EN-LEACH algorithm which considers only the residual energy metric at the time of ACH selection, the Distance-LEACH algorithm which considers only the average distance to other nodes of the same cluster at the time of ACH selection along with our proposed algorithm which uses both mentioned metrics together. We present the results of our experiments and evaluate our proposed algorithm by comparing with LEACH, EN-LEACH and Distance-LEACH using MATLAB simulation software. Moreover, to be able to compare these algorithms in our simulation we need to run them on the same networks. This is achieved by using equal random seeds for each run in all algorithms. The simulation parameters are presented in Table1.

4.1 Network's Lifetime

The first evaluation parameter in WSNs is the lifetime of the network. Figure 1 illustrates the comparison between our proposed algorithm and three above mentioned algorithms. It

Table 1. Experiment simulation parameters

Parameter	Value
Number of nodes	100
Length of monitoring area	(100,100) m
Position of the base station	(50,150) m
Initial energy	0.3 J
Data packet size	4000 bits
Simulation end condition	Number of nodes < 3
$\boldsymbol{E_{elec}}$	50nJ/bit
$\in_{fs}$	10PJ/bit/m^2
$\in_{mp}$	0.0013PJ/bit/m^4

shows the number of live nodes at each round for each algorithm. It can be observed that our proposed algorithm increases the useful lifetime of the network in terms FND (First Node Dies) and HNA (Half of Nodes Alive) metrics. Our proposed algorithm outperforms LEACH as it takes the current residual energy of nodes into consideration during cluster head selection. This way, in each round, nodes with higher residual energies have better chances of becoming cluster heads and hence spend more energy comparing to non-cluster head nodes in that round. So, as the system ages (round-wise) the energy distribution over all nodes converges to uniform. This means that no node dies (discharges completely) while there are still other nodes with much higher energies. It reduces the time interval between the discharges of nodes and nodes are kept alive as long as possible. In our algorithm, almost over 95% of nodes lose their remaining energy at the end of useful lifetime of the network (last 50 rounds before complete discharge). This causes a steep slope that can be observed at the end of the diagram of our proposed model in Figure1 (last 50 rounds). Figure2 shows that our algorithm improved the first node dies by 85% and the half node live metric by 35% compared to LEACH.

4.2 Residual Energy

Network energy reduction rate is a useful metric for comparing these algorithms. Uniform energy consumption is very important for network load balancing and less energy consumption per round which leads to a better network performance. The results in Fig. 3 show that our proposed algorithm outperforms all three algorithms in the first 77% of the active rounds. Figure 3 illustrates that in our algorithm the energy consumption is more balanced and all nodes save their energy as long as possible. So, the energy is consumed more efficiently than other three algorithms.

4.3 Number of Packets Received at Base Station

Figure 4 illustrates the total number of packets received at the base station per consumed energy unit for both LEACH and our proposed algorithm. This graph

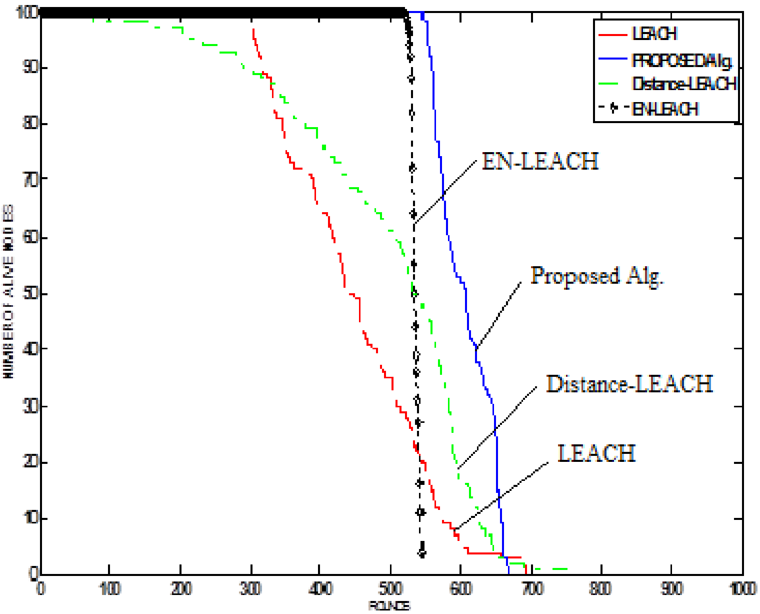

Fig. 1. Number of Live nodes per round

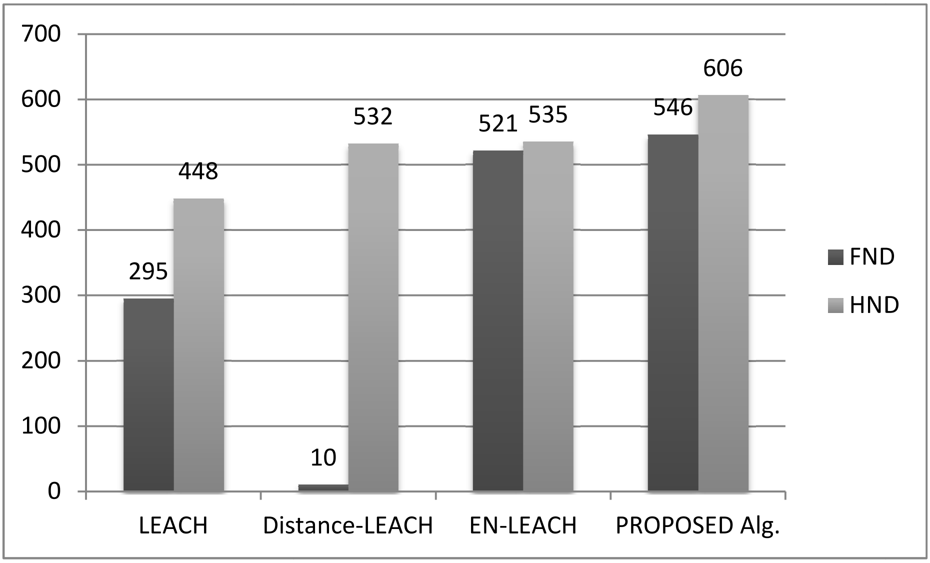

Fig. 2. Comparison diagram of FND and HNA

shows that our algorithm delivers more packets to the base station when the residual energies of the nodes become lower than 0.1J compared to LEACH. This is achieved because the nodes with more residual energy have higher probabilities to become cluster heads inside the clusters. Furthermore, as we mentioned above, we consider

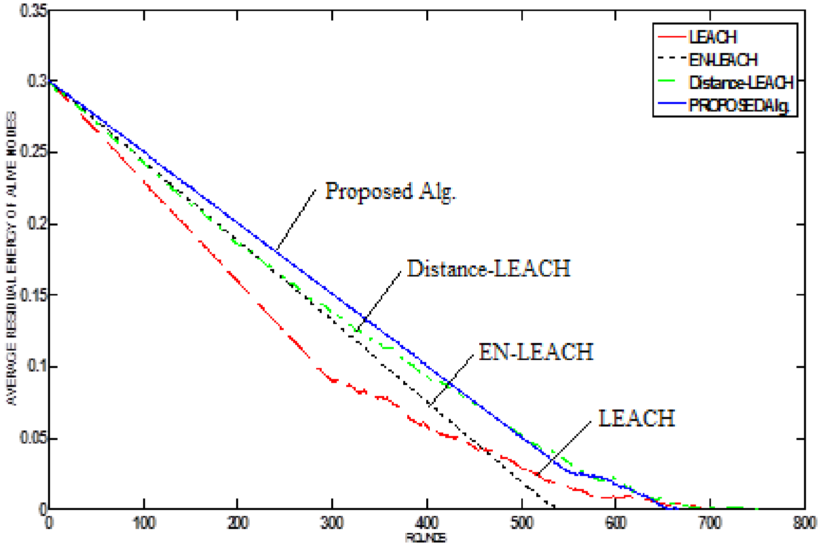

Fig. 3. Average Residual Energy of Alive nodes per Round

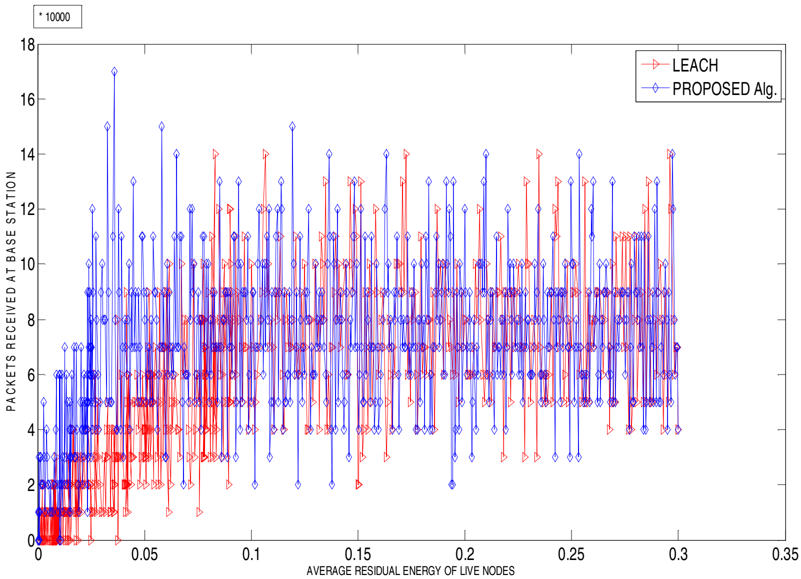

Fig. 4. Total amount of packets received at base station per energy unit

the distance metric at the time of proper cluster head selection. Such consideration results in saving the transmission energy. That is why the energy consumption load is uniformly distributed over all clusters in the network resulting in the message delivery to base station to be still more effective at the end of useful lifetime of the network.

5 Conclusion

This paper proposed an improved algorithm based on LEACH. It considers both residual energy and distance metrics at the time of cluster head selection. It forms the clusters using the LEACH protocol and then selects the node that has more residual energy and lower average distance to other nodes of the same cluster to become the cluster head. It makes cluster head distribution within actual limited regions to be more uniformly. It prolongs the network lifetime by 85% in terms of First Node Dies and prevents quick energy discharge of nodes by taking current residual energy of the nodes into consideration. Therefore, the stable clusters are formed and the energy load is balanced among all clusters effectively. Hence, in our proposed algorithm the number of packets received at the base station outperforms LEACH when the total residual energy of the network is lower than 0.1J. The results of simulations indicate that the improved algorithm effectively balances the energy load among distributed clusters and reduces total energy consumption of the network.

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