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Energy Efficient Static Clustering Algorithm for Maximizing Continues Working Time of Wireless Sensor Networks

Saman Toofani[1], Abolfazl Toroghi Haghighat[2]

[1] Electronic, Computer and IT Department, Science and Research Branch of Islamic Azad University, Qazvin, Iran
Saman6485@gmail.com

[2] Electronic, Computer and IT Department, Science and Research Branch of Islamic Azad University, Qazvin, Iran
A.T.Haghighat@qiau.ac.ir

Abstract

Sensor nodes should be made cheap and small due to application modes. As a result, the nodes always suffer from limited energy source. On the other hand, increased network operation period is considered as a measure to evaluate the performance of sensor networks, which motivates the designers to provide a method to increase the lifetime of sensor networks. So far, various methods were provided to manage and reduce energy consumption in a sensor network. Clustering is the most prominent method in this regard.

In this paper, the optimal number of clusters to minimize energy consumption was calculated by assuming that the sensor nodes were distributed randomly and uniformly in the medium. Then, the network was divided into a grid consisting of an optimal number of clusters. A cluster head was selected in each cluster in order to facilitate data collection process and transfer the data to the sink in a multi-hop communication. Clustering method used in the proposed method was static. As a result, optimum dimensions of clusters were calculated based on the one-hop optimal distance. Simulation results showed relative improvement of the proposed method, which were in line with those obtained from analysis of network continuous working time.

Keywords: Wireless sensor network, Energy consumption, Lifetime, Clustering.

1. Introduction

Wireless sensor networks consist of a large number of cheap and small nodes, which can process, hear and communicate with each other. One of the major challenges in these networks lies in the fact that the battery of nodes cannot be recharged. Sensor nodes are often cheap and a large number of them are needed to cover the area. Since the nodes are randomly distributed in the area, recovering and recharging cannot be economically justified. Therefore, an important part of research conducted on wireless sensor networks attempted to present a method to reduce the nodes' energy consumption. Reducing energy consumption increases network lifetime. Lifetime of any sensor network depends on lifetime of network nodes. Lifetime of a node refers to the period during which the node can perform its tasks. However, there is no consensus on definition of network lifetime, in [1] several definitions are presented.

Clustering is considered as one method to reduce energy consumption. Clustering refers to setting the network medium to share-free sets. Each set consists of a number of sensor nodes. In each cluster, a cluster node is responsible for the communication of the cluster with the rest of the network clusters and managing the communication of cluster members with each other. The responsible node is called the cluster head, which is determined based on the metrics, which vary depending on the network use. The metrics for selecting cluster heads are discussed in [2-5].

So far, many methods have been proposed based on clustering. An algorithm called LEACH is introduced in [6]. The algorithm divides time into several equal time intervals. Each time interval consists of two phases. In the first phase, called clustering, LEACH attempts to randomly select several nodes as the cluster heads in order to divide the network into a number of clusters. The second phase is called the stable phase. In this phase, each node sends its data to its cluster head. Then, the cluster heads aggregate the inputs in order to be sent to the sink.

HEED [7] algorithm is another well-known algorithm constructed based on LEACH algorithm. The difference between these two algorithms lies in data transmission from the cluster head to the sink. It is shown in [8] that the multi-hop communication between cluster head and sink lead to reduced energy consumption.

The present paper aimed to present a new method based on energy management and static clustering techniques to increase the lifetime of wireless sensor networks. To achieve this goal, it was attempted to partition the network

into several clusters with limited area, so that the network area would covered in a way that the communications within and between the clusters were associated with minimum energy consumption. In addition, several chains of interconnected nodes were used to send data to the sink in order to avoid energy dissipation and balancing energy consumption among all nodes in the network.
The reminder of this paper is organized as follows. Section 2 presents the model of network and energy consumption. Section 3 introduces LEACH-C literature and section 4 proposes our method. Simulation results are shown in section 5 and section 6 concludes this paper.

2. Energy Consumption Model

In this section, it was attempted to investigate the mechanism of energy consumption in the sensor networks. A sensor node is either active or inactive. An active node assists in operation of the network or sensing the area or sending the data to sink. Inactive node abandons either sensing or participating in operations of implementing a protocol temporarily or dies due to termination of energy.
Energy consumption in an active node is composed of three segments. Energy consumed for packet sending, packet receiving and data processing and the simplified model of energy consumption for each part are given in (1).

$$\begin{cases} P_T(k) = k \times \left(E_{elec} + E_{amp} \times d^{\gamma}\right) \\ P_R(k) = k \times E_{elec} \\ P_{cpu}(k) = k \times E_{cpu} \end{cases} \tag{1}$$

Based on (1), energy consumption in cluster head to send and receive a *k* bits packet is:

$$P = k \times \left(2E_{elec} + E_{cpu} + E_{amp} \times d^{\gamma}\right) \tag{2}$$

where *d* is the transmission distance (m) and *k* is the length of packets (bits). E_{amp} is the power above E_{elec} needed by the transmitter for an acceptable E_b/N_0 at the receiver's demodulator. The radio dissipates E_{elec} per bit to run the radio circuitry and E_{cpu} is the energy dissipation for processing per bit.
Energy consumption is directly related to the length of packet in (2). In addition, γ value (path loss exponent) is determined by the distance between transmitter and the receiver. If *d* is greater than d_{opt}, $\gamma = 4$; otherwise, $\gamma = 2$. The exact value of d_{opt} is calculated in [9-13]. This communication shows that network topology and distribution of nodes do not have any effect on γ.

$$d_{opt} = \sqrt{\frac{2E_{elec}+E_{cpu}}{E_{amp}}} \tag{3}$$

3. LEACH-C Algorithm

LEACH algorithm uses clustering to significantly reduce energy consumption in sensor networks compared to the previous methods. However, new problems were raised. For example, random selection of cluster heads in the network causes that all cluster heads be located in a part of the network in several time-slots. Since each non-cluster head node selects the nearest cluster head as its cluster head, several clusters will have more members than other clusters. The imbalance between the numbers of clusters causes an imbalance in energy consumption in cluster heads, which results in a sudden loss of energy. This problem led to proposing a new method called LEACH-C [14]. This algorithm like LEACH Algorithms has two phases including clustering and data transmission. Transmission phase is quite similar to the one in LEACH algorithm. The difference between these two algorithms lies only in the clustering phase. In LEACH-C, it is assumed that the sink knows position of the nodes at first. For example, it is assumed that each node is equipped with a GPS device in order to report its position to the sink. In the first phase, the sink calculates optimum percentage of clusters. Then, the sink selects a number of nodes as cluster heads based on remaining energy and position of the nodes. The cluster heads are selected in LEACH-C algorithm so as the cluster heads would be distributed in the best possible way. In other words, total distance of cluster heads from each other would be as the maximum possible value. In other words, LEACH-C attempts to select the best cluster heads among authorized nodes, so that no cluster heads would be located in a part of the network area. Optimal number of cluster heads (k_{opt}) is calculated according to (4).

$$k_{opt} = \begin{cases} \sqrt{\dfrac{N \times E_{fs}}{2\pi \times E_{amp}}} \times \dfrac{M}{d^2} & if \quad \gamma=2 \\[2ex] \sqrt{\dfrac{N}{2\pi}} \times \dfrac{M}{d^4} & if \quad \gamma=4 \end{cases} \tag{4}$$

4. Proposed Method

The proposed method uses a clustering like the one used in LEACH-C. The difference between these methods lies in the fact that LEACH and LEACH-C use dynamic clustering. The clusters are reconstructed in each time-slot in dynamic clustering while clustering is done once in static clustering and boundaries of the clusters are still held by the end of network lifetime.
Major energy dissipation in clustering algorithms such as LEACH algorithm occurs in the cluster head because the cluster heads are selected at random in this algorithm. Random selection of cluster heads leads to equal sized clusters. For this purpose, several cluster heads consume more energy than others do. In addition, a single-hop communication between the cluster head and the sink consumes significant energy in the cluster head. Hence, the proposed solution aimed to divide the network into equal sized clusters. In the next step, it was shown that how the multi-hop communication can reduce the energy consumption in cluster head nodes. Finally, it was observed that the proposed approach has significantly improved compared to the known solutions such as LEACH-C algorithm according to simulation results.
A fundamental flaw in LEACH-C algorithm lies in the fact that each cluster head sends its packet directly to the sink. This method imposes considerable energy consumption on the cluster heads far from sink (in this methods, the farthest cluster heads consume considerably more energy compared to nearest cluster heads). The proposed method attempts to replace the one-hop communication between a cluster head and sink with an optimal multi-hop communication. In an optimal multi-hop communication, the cluster head node sends the aggregated packet to the sink using intermediate nodes (Fig. 1).

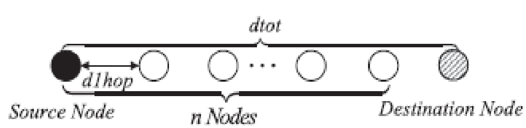

Fig. 1 Linear model with equal one-hop distance

As mentioned earlier, the distance between transmitter and receiver nodes have a significant effect on energy consumption. Even if the distance was not greater than d_{opt}, γ is equal to 2. The best method to send packet of a cluster head to the sink in a multi-hop manner lies in using the cluster heads closer to the sink. In this method, each cluster head receives the packets of those cluster heads farther to the sink. Then, these cluster heads deliver aggregated data to the cluster heads closer to the sink. Using static clustering allowed us to design the clusters so as a multi-hop communication could be established from the cluster head to the sink. If the network can be divided into a grid of $m \times n$ clusters (m rows and n columns) each cluster in row *i* and column *j* can be shown by the pair *(i, j)*. Then, a cluster head in cluster *(i, j)* can send its data to a cluster in cluster *(i-1, j)*, so that the data can be finally sent to the sink (Fig. 2).

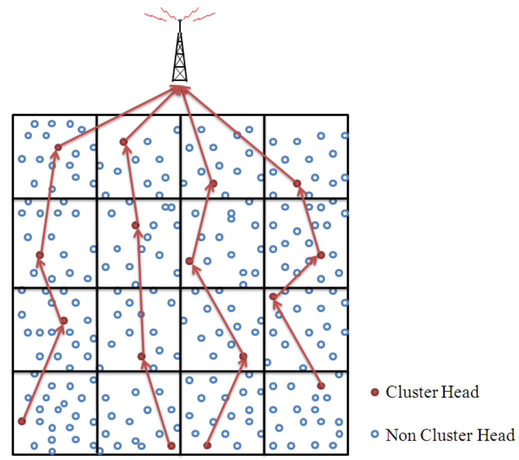

Fig. 2: A preview of clustering in proposed method

Now, *m* and *n* should be calculated. We aimed to divide the network into $m \times n$ clusters. As mentioned earlier, the optimal number of clusters can be calculated according to (4).

$$k_{opt} = m \times n \tag{5}$$

"γ" should be determined in order to calculate the optimal number of clusters. On the other hand, if we assume that the clusters are rectangular, we can calculate values of *m* and *n* by finding the length of sides of the clusters (*L* and *W*). If we assume that cluster head is located in the center of cluster (a simplifying assumption), data transmission from the cluster head of cluster (*i-1*, *j*) to the cluster head of cluster (*i*, *j*) will be costly when the distance between these two cluster heads (between center of the two clusters) was equal to d_{opt}. If the distance between two cluster heads was observed, then

$$L = d_{opt} \tag{6}$$

$$m = \left\lceil \frac{M}{d_{opt}} \right\rceil \tag{7}$$

As mentioned earlier, we assumed that cluster head is located in center of the cluster. Thus, the distance between cluster member nodes from the cluster was less than d_{opt} according to (6). Thus, if γ was considered as 2 for the communications within the clusters, (5) and (7) could be used to calculate value of *n*.

$$n = \frac{k_{opt}}{\left\lceil \frac{M}{d_{opt}} \right\rceil} \approx \frac{\sqrt{\frac{N}{2\pi}} \times \frac{M}{d_{opt}}}{\frac{M}{d_{opt}}} = \sqrt{\frac{N}{2\pi}} \quad (8)$$

Since the number of columns was determined, width of the clusters could be simply calculated according to (9).

$$w = \frac{M}{n} \quad (9)$$

So far, we managed to set the network to equal sized ($m \times n$) clusters with ($L \times W$) dimensions. The question is whether equal sized cluster work properly or not. If we wanted to increase the network lifetime, equal amount of energy should be consumed. In other words, such circumstances should be established that the cluster heads consume equal amount of energy in each time slot as far as possible.
The energy consumed in cluster heads from cluster 2 to cluster m is equal due to identical conditions while the energy consumed in cluster heads of the first row clusters is higher than other cluster heads. This is because the cluster heads were located in different distances to the next hop, i.e. the sink (Fig. 2).

$$E_{CH-i} = E_{CH-j} \quad 2 \le i, j \le m \quad (10)$$

$$E_{CH-1} \ge E_{CH-i} \quad 2 \le i \le m \quad (11)$$

E_{CH-i} indicates the energy consumed in cluster head of ith cluster in (10) and (11). As mentioned earlier, energy consumption is associated with two reasons in a cluster head:

- The number of cluster members
- The distance from the sink (or the next cluster head)

The higher the number of cluster members or the larger the distance between cluster heads and the next hop, the higher the energy consumption in the cluster head. Accordingly, decreasing the number of cluster members reduces energy consumption in cluster heads of the first row clusters. It is sufficient to reduce the size or area of the cluster in order to reduce the number of cluster members. In other words, we wanted to set the size of first row clusters so as to make equal the energy consumed in cluster heads of the first row clusters with the one consumed in other rows.

$$E_{CH-1} = E_{CH-i} \quad 2 \le i \le m \quad (12)$$

For this purpose, (12) and (13) should be applied:

$$\begin{aligned}(L \times E_{elec} \times x) + (L \times E_{DA} \times x) &+ \left(L \times E_{elec} + L \times E_{amp} \times d_{Sink}^2\right) \\ &= (L \times E_{elec} \times y) + (L \times E_{DA} \times y) + \left(L \times E_{elec} + L \times E_{amp} \times d_{opt}^2\right)\end{aligned} \quad (13)$$

Here, x represents average number of nodes in a cluster in the first row while y denotes average number of nodes in a cluster except the first row. Equation (14) is obtained by simplifying (13):

$$(E_{elec} + E_{DA}) \times x + \left(E_{amp} \times d_{Sink}^2\right) = (E_{elec} + E_{DA}) \times y + \left(E_{amp} \times d_{opt}^2\right) \quad (14)$$

The goal is to find the value of x, so we have:

$$x = y - \frac{E_{amp} \times \left(d_{Sink}^2 - d_{opt}^2\right)}{E_{elec} + E_{DA}} \quad (15)$$

As we mentioned at the beginning of this chapter, if the number of network clusters was shown as k_{opt}, the mean number of members in each cluster would be equal to $y = \frac{N}{k_{opt}}$. By inserting this value in (16), we have:

$$x = \frac{N}{k_{opt}} - \frac{E_{amp} \times \left(d_{Sink}^2 - d_{opt}^2\right)}{E_{elec} + E_{DA}} \quad (16)$$

According to (16), it is concluded that the number of node members of a cluster in the first row should follow (16), so that the amount of energy consumed in the first row cluster head would be equal to the one consumed in other cluster heads. Now that we have obtained an equation in order determine the number of cluster members in the first row, we need to know how much the areas of the clusters are. In other words, we need to obtain an equation for determining the area of clusters in the first row with respect to value of x.
We know that the density of rectangular shaped network with M side and N nodes is equal to (17). We also found out that the number of network nodes should be equal to x in order to establish (12). Accordingly, the following ratio was established:

$$\rho = \frac{N}{M^2} \tag{17}$$

$$\frac{x}{S} = \frac{N}{M^2} \tag{18}$$

In this equation, S represents the area of cluster, which can be calculated using (19):

$$S = L \times W = \frac{x \times M^2}{N} \tag{19}$$

It is not possible to change width of the clusters. This is because the number of columns will change if the width of cluster was changed. As a result, stepwise data transmission from the last row clusters to the first row clusters will be problematic. Thus, the cluster area should be changed so that the cluster width would not be changed. As a result, each first row cluster will consists of x nodes. Then, the cluster area will be constantly equal to $\frac{M}{n}$.

$$L = \frac{x \times M^2}{N \times W} = \frac{x \times M \times n}{N} \tag{20}$$

The cluster length should be adjusted according to (20), so that lifetime of a cluster head in the first row would be equal to lifetime of other cluster heads. It should be noted that the amount deducted (or added) from the length of a cluster in the first row is equally added (or deducted) to other clusters in the same column. In other words, the first row clusters have not the same size as other clusters in the network since the first row cluster have a direct communication with the sink. Fig. 3 shows the performance of this type of clustering.

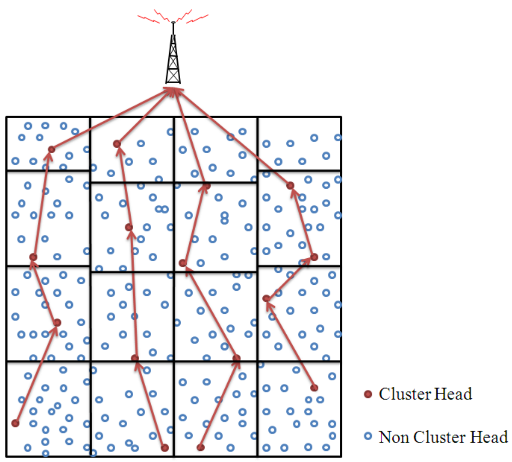

Fig. 3 Clustering in proposed method

5. Simulation and Analysis

The clustering method was simulated using MATLAB software to evaluate effectiveness of the proposed method. In this simulation, the proposed method was compared with one of the most dynamic clustering methods, i.e. LEACH-C method. It should be noted that the proposed idea only refers to network clustering phase. For this reason, MATLAB software was used, which notably helps to implement the algorithm (similar to what was presented in [9]). For this purpose, Table 1 is presented, which shows specifications of radio circuit sensor nodes and details of simulation area. Density of the network is considered as one node per square meter. It was assumed that the nodes are distributed uniformly in the area. In this simulation, a structure was designed, which matched characteristics of sensor nodes. Energy consumption model in this structure was developed in accordance with the proposed communications.

Table 1: The values of Simulation Parameters

Parameters	***Value***
Sink	(50, 100)
M	100 m
N	10000
E_{elec}	50 nJ/b
E_{amp}	0.659 nJ/b
E_{cpu}	7 nJ/b
E_{ini}	0.5 J
d_{opt}	12.5
Data Packet Length	1000 b
Control Packet Length	200 b

Based on above-mentioned materials, the one-hop optimum distance based on (3) is:

$$d_{opt} = \sqrt{\frac{(2E_{elec} + E_{cpu})}{E_{amp}}} = \sqrt{\frac{(2 \times 50 \times 10^{-9}) + (7 \times 10^{-9})}{0.659 \times 10^{-9}}} = 12.74$$

Value of d_{opt} was considered equal to 12.5m for simplicity of calculation. According to (4), the optimal number of clusters is:

$$k_{opt} = \sqrt{\frac{N}{2\pi}} \times \frac{M}{d_{opt}} = \sqrt{\frac{10000}{6.28}} \times \frac{100}{12.5} \approx 320$$

Given that the size of one-hop optimum distance was equal to 12.5m and the number of clusters is equal to 320. Thus:

m = 8,   n = 40,   L = 12.5 m,   W = 2.5 m

Prior to investigating simulation details and results, it is better to predict the time of death of the first node in the proposed algorithm based on mathematical analysis results. For convenience, we assumed that the selected cluster heads would act as the cluster heads in the first period until death. This assumption does not affect the LEACH-C algorithm and the proposed method. It helps to make easier and better comparisons. As mentioned earlier, most energy is consumed in the cluster head node in a network.

Since the amount of energy consumed in all cluster heads is equal in the proposed method, cluster (1, 1) was selected for calculation. At first, the cluster size (1, 1) was calculated for the case of 10,000 nodes in the network. Optimal number of the nodes for cluster (1, 1) is determined according to (18).

$$x = \frac{10000}{320} - \frac{0.659 \times 10^{-9} \times (49.15^2 - 12.5^2)}{(50+7) \times 10^{-9}} \approx 5.13$$

Now that the optimal number of nodes in the cluster (1, 1) was determined, cluster length was calculated according to (20).

$$L = \frac{5.13 \ \times 100 \times 40}{10000} = 2.05m$$

Therefore, the best size for cluster (1, 1) is 2.05 × 2.5 m^2 according to proposed equations. If the size of all clusters in the first row was calculated and corrected according to presented equations, it is hoped that the operation period of the network would increase by the death of the first sensor node. In these circumstances, it is expected that the amount of energy consumed in all clusters was equal in each column and each row. Table 2 shows the expected time of continuous operation of a network until death of the first node, which was calculated based on mathematical calculations.

Table 2: Network operation period until death of the first node for those networks with different densities

Continues working time (Analysis)	***Node Numbers***
259	10000
239	12000
228	14000
217	16000
199	18000
191	20000

As it can be observed, changing size of the first row clusters increases network operation period prior to death of the first node. Fig 4 shows simulation results for the networks using simulated nodes. As it can be observed, simulation results are largely consistent with analysis results.

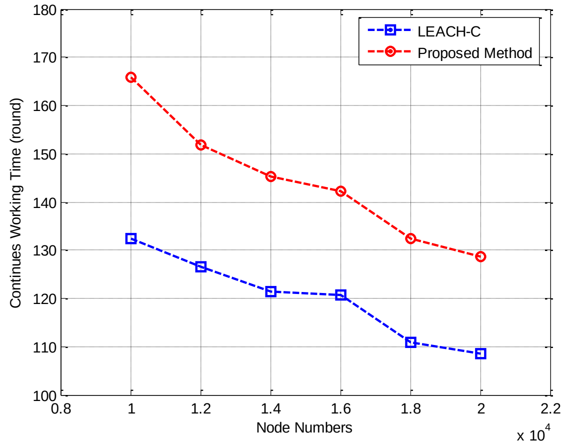

Fig. 4: Comparison continues working time between LEACH-C and proposed method

6. Conclusion

Constraints on design type and application of sensor nodes, reduced energy consumption in wireless sensor networks are considerably important. Therefore, many researches were conducted and numerous solutions were proposed in this area. In this paper, LEACH-C Algorithm was reviewed using a static clustering. It was shown that the network was divided into a grid of clusters with optimum sizes. In addition, the one-hop communication between cluster heads and the sink was replaced with a collaboration-based multi-hop communication. This measure has a significant impact on reducing energy consumption in the network.

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