Energy Efficient Wireless Sensor Network with Modified LEACH Algorithm

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Abstract

Wireless Sensor Networks (WSNs) are highly integrated technologies applying sensor technology, micro-electro-mechanical systems (MEMS) and wireless networks technologies. They are widely used in many applications to acquire and process information. Many routing protocols are proposed for controlling the networks. The main problem, which the WSN protocols face, is that the sensors’ limited batter energy. Then the protocols have to be energy efficient to prolong the networks lifetime. Nowadays, there are several routing protocols which are designed to prolong the network life. Low Energy Adaptive Clustering Hierarchy (LEACH) is an outstanding and commonly used protocol designed for this purpose. To be energy efficient, the protocol applies cluster organization on the networks. It divides the sensor nodes into several clusters, and sends fusion cluster data through a cluster head, which is a representative node of one region.

In this thesis, we propose the method which improves the LEACH algorithm. The proposed method firstly defines the fix round time. During the fixed round time, if a cluster head indicates lower energy level than the defined threshold, the cluster head will be transferred to another cluster member owning largest energy, and then the new cluster head continues to work until the round time is end. Therefore, the method avoids the unnecessary re-clustering of the whole network.

Simulation results show that the proposed method performs better on prolonging the lifetime of a network than LEACH. In a random distribution, the proposed method prolongs the lifetime of the network almost more 20% rounds than LEACH does. While in an unbalanced distribution, the proposed performs much better, prolonging about 33% in our simulation.

Keywords:

Clustering, Energy Efficiency, Fixed Round Time, LEACH, Wireless Sensor Networks
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Abbreviation

BS – Base Station
CDMA - Code Division Multiple Access
CH – Cluster Head
CM – Cluster Member
DS-CDMA - Direct Sequence Spread Spectrum - CDMA
HEED - Hybrid, Energy-Efficient, Distributed
LEACH - Low-Energy Adaptive Clustering Hierarchy
LEACH-B - LEACH-Balanced
LEACH-C - LEACH-Centralized
MEMS - Micro-Electro-Mechanism System
PEGASIS - Power-Efficient Gathering in Sensor Information Systems
PS - Pseudo-noise Sequence
SOC - System on Chip
TDMA - Time Division Multiple Access
WSNs - Wireless Sensor Networks
Chapter 1. Introduction

In the past few years, MEMS (Micro-Electro-Mechanical System), SOC (System on Chip), lower power consumption embedded technology and wireless communication technology have experienced rapid and successful development. They have triggered many new technologies and promoted further information technology development. WSN (Wireless Sensor Network) is an example of this kind of emergent technology. WSNs are considered to be the second largest networks in the world following after the Internet. Due to low power consumption, low cost, distributed model and self-organization, it yields a revolution in information sensing fields.

WSN is a network with many sensor devices (or sensor nodes) working together in a certain area. The sensor devices can form a multi-hop self-organized, ad hoc network using wireless communication to acquire and process information from objects, and then transmit it to the observer. The sensors, transceiver and observer are three key elements in a WSN. Due to the characteristics, WSNs have many applications such as industrial sensing, environmental detecting, earthquake predicting and military monitoring etc.

In a WSN, each sensor device consists of four main units: a sensing unit, a signal-processing unit, a communication unit and a power unit. The sensing unit is responsible for collecting data from the neighboring environment. The signal-processing unit focuses on data preprocessing and fusion. The communication unit sends or receives data by wireless. The power unit, which is the battery, supplies energy for the whole sensor device.

Although band utilization can be also an important issue in wireless communication, however, in a case of WSN, the first target is using energy with very high efficiency. The reason is that the battery on a sensor device cannot be replaced or charged. Therefore, the issue, how to make a network consume energy more efficiently, has become a very important research area.

There are many protocols to control WSNs, for example, Low Energy Adaptive Clustering Hierarchy (LEACH), direct communication and minimum-energy multi-hop routing, HEED (Hybrid, Energy-Efficient, Distributed clustering approach) and PEGASIS (Power-Efficient Gathering in Sensor Information Systems) and so on. LEACH firstly has introduced the idea of cluster organization in a WSN. Clustering makes a WSN much more
energy efficient than other protocols. This protocol has led researchers to work on enhancement of clustering algorithms and many new modified protocols are based on LEACH.

In this paper, we propose a LEACH modification. We set up a new mechanism, fixed round time, in the way that reduces un-necessary re-clustering even if one cluster head loses energy. With our method, clusters will not change before the round time is over; even if one of network clusters requires to re-cluster.

This is divvied into eight chapters organized in the following sequence: Chapter 2 shows related work on LEACH and WSN energy efficiency. Chapter 3 introduces our problem statement, research question, hypothesis and main contributions. In Chapter 4 and 5, we present theoretical background for LEACH protocol. Chapter 6 describes the new proposed algorithm, while Chapter 7 shows the scenarios, the simulation parameters, the results and their analysis. In addition, Chapter 8 concludes the paper and prospects further development.
Chapter 2. Related Works

There are many kinds of WSN energy efficient protocols designed to prolong a network lifetime. Direct communication and minimum-energy multi-hop communication are some of them but they are not efficient enough in respect to network lifetime. A hierarchical structure with clusters is an idea, which significantly improves energy saving in wireless sensor network.

LEACH (Low-Energy Adaptive Clustering Hierarchy), proposed by Heinzelman et al. [1], is an example of algorithm for a hierarchical clustering network. In LEACH a WSN is divided into several clusters, some nodes randomly are selected as cluster heads. Each cluster head organizes the nodes around itself and forms a local cluster. Then the cluster head collects information from other sensors of its cluster and after the fusion sends the data to base station or to the next cluster head. In a certain time, which is called round time [1], the whole network is re-clustered and the cluster heads are re-selected. Comparing with formal non-cluster algorithms, LEACH performs much better, and according to [1], the first node death occurs over eight times later than in WSN using a direct transmission or minimum-transmission-energy routing with a static clustering.

Since LEACH was published, it has been widely used and there are many modification based on it. In [2], authors proposed the idea of LEACH-Centralized (LEACH-C). LEACH-C improves clustering by dispersing the cluster head nodes through the network. However, it is not self–organized network. In addition, nodes need to communicate with BS by a GPS, which could consume much energy in each round.

In [3], a novel dynamic round time algorithm which is based on fixed LEACH (LEACH-F), is proposed. In LEACH-F, the network clusters are formed only once. The clustering mechanism is similar to LEACH-C and the clusters are fixed.

LEACH-B (LEACH-balanced) is researched in [4]. In LEACH-B, “At each round, after first selection of cluster head according to LEACH protocol, a second selection is introduced to modify the number of cluster head in consideration of node's residual energy. As a result the number of cluster head is constant and near optimal per round.” [4]. The problem is that the protocol needs twice cluster heads selection. This consumes extra energy.
LEACH-SM is proposed in [5] where the spare selection phase is added to LEACH. The authors propose to add a spare selection phase between LEACH cluster setup and steady state phases. The spare nodes added into WSNs, are initially asleep but they are ready to be switched on when any active node uses up its energy. The problem is that when the spare node joins network, the whole network needs to be established again that consumes extra energy for other nodes.

In [6], the authors proposed to use gateway nodes in each cluster to enable the cluster head reducing its transmission radius within the cluster in order to achieve better power saving. The problem is the complexity for relaying data. The gateway nodes perform like a router, which consumes much energy from these nodes.

In [7], “a new routing protocol and data aggregation method in which the sensor nodes form the cluster and the cluster-head elected based on the residual energy of the individual node calculation without re-clustering and the node scheduling scheme is adopted in each cluster of the WSNs” [7]. In the paper two node-scheduling schemes (ACTIVE and SLEEP) are adopted in each cluster of the WSNs. The disadvantage comes from cooperation mode between active and sleep nodes’ cooperation. Some sleep nodes cannot sense surrounding information.

Two other well-known clustering algorithms on saving energy to keep network living longer are called HEED (Hybrid, Energy-Efficient, Distributed clustering approach) and PEGASIS (Power-Efficient Gathering in Sensor Information Systems).

HEED periodically selects cluster heads according to a hybrid of the node residual energy and a secondary parameter, such as node proximity to its neighbors or node degree. However, the cluster heads election uses complex iterative algorithm, and considers only the remaining energy [8]. “HEED will not play a significant role in evening energy consumption of cluster heads for the entire network situation of some nodes” [9].

In PEGASIS, “each node communicates only with a close neighbor and takes turns transmitting to the base station, thus reducing the amount of energy spent per round” [10]. The disadvantage is that sensor nodes in a network using this algorithm need to know all information of other nodes.

Except these papers, there are some related papers, [11], [12], [13], working on improving LEACH algorithm. In paper [14], authors give a novel energy-efficient, balanced
Chapter 3. Problem Statement, Research Question, Hypothesis and Main Contributions

From previous section, we can see that, many researchers work on improvement of LEACH. However, they have not realized one drawback on LEACH related to a cluster head re-selection method. The decision, which node becomes a new cluster-head depends on the amount of energy remind at the node, [1]. However, it is possible that the selected cluster head energy is not enough for the whole round and it will stop to serve as a cluster head before the round time ends. In LEACH, since the round is un-fixed, the network would require a reselection before the round time is over. The reselection requires extra energy that affects the efficiency of network and reduces the network life. Most of the papers referred in Chapter 2 do not focus on reducing unnecessary re-clustering. Furthermore, it should be noticed that the whole network consumes a large amount of energy when the nodes communicate with each other for re-clustering in the network.

On base of the stated problem, we form our research question: How to modify LEACH to avoid the unnecessary re-clustering of wireless sensor network when the acting cluster head stops working before the end of a round?

To avoid the disadvantage of situation when the acting cluster head stops working before the round time is end, the network should switch the cluster head to another node within the clusters, when the cluster head notifies that the energy is below a threshold. We assume that there is an optimal threshold value, which can be found by experimental way. Assumedly, another node with largest energy becomes a new cluster head. In our mechanism, we propose to fix the round time within a certain time range which is determined by that the cluster with largest population in WSN. The round time equals the communication time of each node multiplied the largest cluster population. Within the round time, if a cluster head notifies energy below a threshold, the node within the cluster that has largest energy takes over the task as temporary cluster head before the end of the round. In this mechanism, the whole network does not need re-clustering.

Our work provides the following three main contributions:

a. Implementation of the proposed procedure into the LEACH algorithm.
b. Implementation the improved LEACH algorithm on MATLAB.
c. Design validation scenarios and verification of hypotheses by simulation results analysis.
Chapter 4. Theoretical Background

4.1 Hierarchical-based routing protocol

There are many protocols applied for WSNs. The protocols can be divided into several different categories depending on structure for example, flat-based routing protocol, hierarchical-based routing protocol and location-based routing protocol.

In hierarchical-based routings, which are also called cluster-based routing protocols, sensors play different roles and functions. By using this kind of protocol, a network is divided into several areas called clusters. A cluster consists of one cluster head (CH) and several cluster members (CMs). The CMs are the basic sensors whose duties are collecting environmental information and sending data packets to CHs. CHs have following functions: organizing cluster, collecting data from CMs in the cluster, data fusion, signals processing and sending data to BS (base station).

4.2 LEACH

LEACH is the abbreviation of Low Energy Adaptive Clustering Hierarchy, given by Wendi Rabiner Heinzelman, Anantha Chandrakasan and Hari Balakrishnan. LEACH is an example of hierarchical-based routing protocol. The basic idea of LEACH is random selection of cluster heads periodically and dislocating a network energy load to every node in the network in order to decrease the network energy consumption and prolong its lifetime. According to [1], comparing with the multi-hop routing protocol and the static hierarchical algorithms, LEACH performs much better on prolonging the lifetime: the first node death occurs over eight times later than in direct transmission or minimum-transmission-energy routing with a static clustering.

In Figure 1, a flowchart of LEACH is provided. LEACH executes the cluster construction periodically. Every cluster construction is considered as a round, see Figure 2. Every LEACH round can be divided into two phases: a cluster setup phase and a steady
phase for transmitting data. In order to save energy, the time of steady phase should be much longer than the time of setup phase.

4.2.1 Setup Phase

The setup phase could be divided into four steps: cluster head selection, cluster head advertisement, cluster formation and schedule creation.
In the CH selection step, LEACH selects some nodes in the network, which become the cluster heads. There is a specific way to select the cluster heads in LEACH: every node generates a random number $rd$ between zero and one, then compares $rd$ with valve $T(n)$ in (1). If the random number is smaller than $T(n)$, the node is selected as cluster head. If not, it will become a normal node.

$$T(n) = \begin{cases} 1 - P \cdot (r \mod \frac{1}{P}), & \text{if } n \in G \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

The selection mainly depends on: the desired percentage of cluster heads $P$, for example $P=0.05$, a parameter $r$ standing for current round and $G$ which is the set of nodes that have not been selected as cluster heads in the last $\frac{1}{P}$ rounds.

After some nodes are selected as the cluster heads, they will advertise to the whole network by sending a message or control packets. All network nodes receive these messages and then memorize them. These nodes have to make a decision which cluster to join based on the received signal strengthen, which indicates the distance between the nodes and the cluster heads. The nodes join the nearest cluster to them. This helps nodes and the cluster heads in saving energy. After deciding which cluster to join, the normal nodes inform the cluster head about joining its cluster by sending a control packet.

After forming the clusters, each cluster head decides about the communication time schedule for its own cluster. Within the cluster, the cluster head and cluster members use TDMA for communication. The cluster head distributes the data transmitting time slot to each cluster members when it can send data to its cluster head. The TDMA schedule helps nodes to reduce the number of unnecessary communication.

### 4.2.2 Steady Phase

In the steady phase which is the data communication phase, each sensor node collects data from environment and sends the data to its cluster head. Every sensor node follows the time schedule for communication.
The CHs receive the data from CMs and process the data fusion. The data fusion process reduces the abundant data and makes data packets smaller, which helps CHs to use less energy for sending data to the BS. In the last stage of steady phase, CHs send data packets to the BS.

4.2.3 Reconstruction

The steady phase lasts longer time than setup phase does. After the steady phase time, the network will go to the cluster construction process again which consists of a new setup phase and a new steady phase. The periodical process continues until the whole network dies. Figure 3 shows a round period of LEACH based on cluster’s population. Each row in the round means one time slot in TDMA (Time Division Multiple Access). Columns are different clusters’ members.

4.3 Radio interference

As radio wave is a broadcast medium, the transmission in one cluster will affect the communication in nearby cluster. Figure 4 illustrates an example of radio interference, the signal from A to B is affected by node C’s signal.

To solve the problem of communication interference, different clusters use different CDMA (Code Division Multiple Access) codes. Every cluster head selects a spread code and informs its cluster members about the code. So within each cluster, there is used a unique spread code to encrypt data. Therefore, signals received by the cluster head will be rightly deciphered. Because of applying CDMA, the interference is reduced. The neighboring clusters’ radio signal can be filtered out and will not corrupt the transmission of nodes in the cluster [1].


**Figure 3.** An example of LEACH round period and nodes distribution in cluster. “Node” means that clusters will change in the whole network.

**Figure 4.** Illustration of radio interference: node A’s transmission to node B is corrupted by node C’s signal.

**Figure 5.** First Order Radio Model.
4.4 First Order Radio Model

In Figure 5, First Order Radio Model is shown. A model consists of a transmitter circuit, a receiver circuit and a transmitter amplifier. The distance between the transmitter and the receiver is $d$. The transmitter circuit consumes energy for every transmission bit and receiver circuit needs energy for every reception bit. The energy that the amplifier applies is related to the transmission distance.

There are two energy consumption models, including the open space model (2) and the multi path model (3). The whole energy consumption for transmitting a packet of $K$ bits in distance $d$ is given by (4) and receiver consumes energy by (5). Here $E_{elec}$ stands for energy consumption to run the transmitter or the receiver circuitry. Moreover, $d_0$ is the distance threshold value that is obtained by $d_0 = \sqrt[2]{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$ where $\varepsilon_{fs}$ and $\varepsilon_{mp}$ are required energies for amplification of transmitted signals in the open space and in the multi path models respectively.

Energy dissipation per bit in open space model is:

$$E = \varepsilon_{fs} d^2$$ (2)

Energy dissipation per bit in multi path model is:

$$E = \varepsilon_{mp} d^4$$ (3)

Energy consumption for transmitter is:

$$E_{Tx}(K, d) = \begin{cases} E_{elec} * K + K * \varepsilon_{fs} * d^2, & d \leq d_0 \\ E_{elec} * K + K * \varepsilon_{mp} * d^4, & d > d_0 \end{cases}$$ (4)

Energy consumption for receiver is:

$$E_{Rx} = E_{elec} * K$$ (5)
Chapter 5. Proposed algorithm

In the previous chapter, the LEACH algorithm details were given. The algorithm has two phases: the setup phase and the steady phase. This chapter describes the proposed algorithm, which consists of the LEACH algorithm and the new protection mechanism. The new protection mechanism is added into the LEACH algorithm to reduce the number of needed re-clustering.

Figure 6 illustrates the new protection mechanism. According to LEACH at each time slot within a cluster, only one node communicates with its own cluster head. As mentioned in Chapter 3, the most populated cluster decides about the round time, which is fixed for the round. Let us assume that at the time depicted in Figure 6 by a bold ‘Node’ the cluster head notifies low energy level, and requires to be substituted by another node, which should work as a new cluster head. Then after the substitution, the new cluster head continues the job within the cluster until the round end.

![Figure 6](image_url)

Figure 6. An example of fixed round time and clusters information. Bold "Node" means that the cluster head switches to another node within the cluster while not in the whole network.
Applying the proposed mechanism, we show the algorithm flowchart in Figure 7. In this figure, we mark three loops, which have respective functions: advertisement, cluster set-up and cluster head transfer. The functions are described in the following sections.

5.1 Advertisement

During the first loop, $F$, every node in the network gets a random number and compares it with threshold value, which is got from experimental way. The purpose of this procedure is to find the cluster heads. After the selection, the cluster heads advertise messages to the whole network. This phase is same as in LEACH.

5.2 Cluster set-up

During the second loop, $S$, the clusters are formed. The algorithm is based on the estimation of the distance between the cluster members and the cluster heads. The cluster members decide which cluster to join according to the distances to the cluster heads. The nodes join in the nearest cluster head in order to save energy for communication. This phase is also same as in LEACH.

5.3 Cluster head transfer

The third loop, $T$, is the additive new stage, which is the new protection mechanism, for the LEACH algorithm. During this loop, the proposed algorithm adopts a monitoring mechanism, which controls the energy of the cluster heads, and a predefined threshold value. The purpose of this monitoring mechanism is for transferring cluster head based on the comparison result between the energy of cluster head and threshold value.

If cluster head’s energy is lower than the predefined threshold value, the third loop is applied to replace cluster head by another node, which poses the largest energy within the cluster. The new cluster head continues to cooperate with cluster members. This way protects the cluster heads, which have lower energy. This mechanism can protect cluster heads from quick death and prolong the network lifetime.
Figure 7. Algorithm flowchart. \( n \) is nodes number. \( Tn \) is threshold. \( F \) means first loop, \( S \) indicates second loop, and \( T \) stands for third loop.
Chapter 6. Validation

6.1 Initial conditions

In order to validate that the proposed algorithm prolongs the network lifetime, we set initial network conditions in Table I for our simulation.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Unit</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>Size of WSNs</td>
<td>m (meter)</td>
<td>200*200</td>
</tr>
<tr>
<td>N</td>
<td>Total number of nodes</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>P</td>
<td>Probability of being selected as a cluster head</td>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td>Ini.E</td>
<td>Initial energy of each node</td>
<td>J (Joule)</td>
<td>0.5</td>
</tr>
<tr>
<td>TR.E</td>
<td>Transmit or receive energy for sensor devices</td>
<td>J (Joule)</td>
<td>5 × 10^{-8}</td>
</tr>
<tr>
<td>E_{fs}</td>
<td>$E_{fs}$, free space transmit energy</td>
<td>J (Joule)</td>
<td>10^{-11}</td>
</tr>
<tr>
<td>E_{mp}</td>
<td>$E_{mp}$, multi path transmit energy</td>
<td>J (Joule)</td>
<td>1.3 × 10^{-15}</td>
</tr>
<tr>
<td>PS</td>
<td>Data or control packets size</td>
<td>b (bit)</td>
<td>4000</td>
</tr>
</tbody>
</table>

6.2 Networks setup for simulation

In this section, we setup two networks for the simulation. The networks have different nodes distribution. The distribution of first network is a uniform distribution, see Figure 8. The nodes are spread uniformly. The other network is non-uniformly distributed network, see Figure 9. In some area of this network, there are deployed more nodes while some area has just a few nodes. The both networks deploy 100 wireless sensor devices within 200 m * 200 m square.

The reason of using the uniformly distributed network is to validate if the new algorithm could make network living longer in a normal environment. The purpose of setup for non-uniformly distributed network is that this kind of network gives a high probability on forming a cluster with large population. In this case, the cluster heads could die quickly. The
The proposed algorithm should solve this kind of problem. We need to evaluate the algorithm on different kinds of network distributions to find possible applications.

![Figure 8. Uniform nodes distribution network.](image)

![Figure 9. Non-uniform nodes distribution network. Nodes are distributed in the three parts with different population using Gaussian function.](image)
6.3 Optimal threshold value

In the new algorithm, a threshold value is added in order to monitor the energy of cluster heads. It is used for deciding when to switch cluster head to another node within the round time. In this part, we use experimental way to find the optimal threshold value. In the following simulations, the new algorithm uses the optimal threshold value from this experiment.

In the simulations of the uniformly distributed network, the threshold is set from 0.01 J to 0.3 J while the increment is 0.01 J. For every threshold value, twenty simulations run. In order to avoid randomness, average values from the twenty simulations are calculated. All simulation results are shown in Figure 10. For the threshold values, which is located between 0.1 (20% of nodes’ initial energy) and 0.15 (30% of nodes’ initial energy), the network performs better than for other threshold values. From the figure, the optimal point is 0.13 (26% of nodes’ initial energy). Applying this optimal threshold value, the new algorithm prolongs network life time by 55 rounds (20.1%) more than LEACH.

Figure 10. Lifetime plot based on different threshold values. The optimal value is 0.13.
6.4 Simulation results

6.4.1 Simulation result on uniform distribution network

In this part, we simulate the new and classical LEACH algorithms on the uniformly distributed network. We analyze the number of alive nodes in every round.

During the simulation, the algorithms form several clusters. An example of clusters’ distribution in one round time in the network is shown in Figure 11.

![Clusters' distribution of one round in the uniform distribution network. Bigger nodes are cluster heads, and smaller ones depict normal nodes.](image-url)
Figure 12 illustrates the result of the simulation on the uniformly distributed network while the blue line stands for LEACH and the new algorithm with optimal threshold value is depicted in red. The most important mark is the round number for the first dead node. The first dead node of LEACH simulation occurs at round 280 while in the new algorithm simulation it occurs at round 337. The new algorithm improves the lifetime on 20.4% (57 rounds) compared with LEACH. This confirms our hypothesis that the proposed mechanism protects cluster heads from quick death.

In Figure 13, there are added some marks to specify our analysis. During segment B1 and segment R1, about 10% nodes die. The effect is that there is high probability that more nodes will communicate with cluster head with longer distance, and consume more energy in the future. Because of that, in segment B2 and segment R2, the nodes die very quickly. After B2 and R2, there are much fewer alive nodes.
Figure 13. Modification of Figure 11 for efficiency analysis. In this plot, some marks are added to help us on analyzing the efficiency of the two algorithms.

From Figure 13, we take information and shown in Table II. LEACH needs 229 rounds between the first node death and the death of 94 nodes. For the same number of death nodes, the new algorithm only needs 107 rounds. The new algorithm lets nodes die in more concentrated time period. In other words, the new algorithm performs much more efficient than LEACH.

<table>
<thead>
<tr>
<th>Unit</th>
<th>100 alive nodes</th>
<th>6 alive nodes</th>
<th>difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEACH (blue line)</td>
<td>round 280</td>
<td>509</td>
<td>229</td>
</tr>
<tr>
<td>the new algorithm (red line)</td>
<td>round 337</td>
<td>444</td>
<td>107</td>
</tr>
</tbody>
</table>
6.4.2 Simulation result on non-uniform distribution network

In this part, we simulate the LEACH and modified algorithms on the non-uniformly distributed network. The threshold value used in the modified algorithm is the optimal threshold value. The result is depicted in Figure 14.

![Figure 14. The results plot of network lifetime on the non-uniformly distributed network. Red line is for new algorithm, and blue line stands for LEACH.](image)

The new algorithm performs better than LEACH. The first dead node occurs at round 358 using new algorithm while LEACH makes it occur at round 266. In addition, from the shape of the lines, we can find that the new algorithm consumes energy more efficiently.

6.4.3 Simulation results comparison

After all simulations, we compare the results. From Figure 15, the LEACH columns show that LEACH works worse in the non-uniformly distributed network while the new algorithm columns show that the new algorithm works better in the non-uniformly distributed network. In the every network, the new algorithm always performs better than LEACH.

From Figure 15, we can see that LEACH performs the worst in the non-uniformly distributed network. There are two reasons which can explain such phenomena. Firstly, in
non-uniformly distributed network, some nodes can be placed far away from each other; these nodes consume more energy on communication, which makes them using up energy quicker. Secondly, in the cluster with large population, the cluster head also consumes more energy in each round.

The new algorithm performs best in the non-uniformly distributed network. In the non-uniformly distributed network, in the high-density area, there are clusters with large population. In such a cluster, the cluster head consumes energy quickly and could cause the network dead. However the proposed mechanism exchanges cluster head when its energy becomes lower than the threshold. The mechanism protects the cluster heads from early death and prolongs the lifetime of network.

Figure 15. Summarized results of two algorithms working on both uniformly and non-uniformly distributed networks.
Chapter 7. Conclusion and Future Work

After years of development, WSN plays an important role in many applications, such as severe environment detection, volcano monitoring, the military field etc. WSNs can help humans to get useful information without direct human activity in hazardous places. In many applications, one wants to keep the sensor network working as long as possible. However, the network lifetime is constrained by the power supply.

In order to handle this problem, scientists have developed many new routing protocols to improve the lifetime of networks by increasing its energy efficiency.

In this thesis, we propose an improvement of the LEACH algorithm. Fixed round time mechanism and cluster head substitution mechanism are proposed. In the new algorithm, if cluster head requires to be substituted, the new mechanism helps to transfer its task to another cluster member within the cluster, before the fixed round time is end. The cluster member that is selected is the node with highest energy. This method reduces the time of unnecessary re-clustering of the whole network which is required in LEACH.

For validation of our hypothesis, we set simulation network environments as uniformly distributed network and non-uniformly distributed network.

As we mentioned in the new algorithm, we add a threshold value for deciding to transfer cluster heads or not. We need to find an optimal threshold value for our next simulations. We take some simulations for the optimal threshold value. The result shows that the optimal threshold value is 26% of original node’s energy.

Applying the optimal threshold value, we implement two algorithms on some simulations in both networks. Both algorithms select cluster heads in the networks and setup clusters. Then the networks collect information by wireless communication. During the communication, the nodes consume energy until death. But in the simulations, the new mechanism in the proposed algorithm transfers the cluster heads into other nodes when the cluster heads’ energy is smaller than the optimal threshold value. The cluster heads are protected by this mechanism. The lifetime of network is prolonged.

In the uniformly distributed network, the simulation results of both algorithms show that our method improves LEACH on prolonging the lifetime of a network. It delays the death node by almost 20% compare to LEACH in the uniformly distributed network.
In the non-uniformly distributed network, we run two algorithms and the results show that the proposed algorithm performs even better. It prolongs the lifetime of the network about 33% than LEACH does. The results validate our hypothesis of the new mechanism.

As a further development, we propose to add sub-clusters mechanism into LEACH cooperating with the new algorithm to make energy consumption even more efficient. The sub-clusters mechanism is here. During the setup of a cluster, the cluster head asks those farther nodes in the cluster to communicate with some nodes, which are near to them while not communicate with the cluster head directly. Therefore, those farther distributed nodes could save energy because of shortening of communication distance. The mechanism can protect the nodes placed far away from cluster head in a cluster.
Reference


