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Hierarchical WSN Dual-hop Routing Protocol for Improvement of Energy Consumption

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Abstract

This paper proposes to increase the efficiency of energy in nodes, which rapidly drops during the transmission of the Low Energy Adaptive Clustering Hierarchy (LEACH), through the use of dual-hop layered application in the sensor field. Along with introducing the dual-hop method in the data transmission, the proposed single-hop method for short-range transmission and multi-hop transmission method between the cluster heads for remote transmission were also introduced. Additionally, by introducing a partial multi-hop method in the data transmission, a single-hop method for short range transmission method between the cluster heads for remote transmission was used. In the proposed DL-LEACH, the energy consumption of the cluster head for remote transmission reduced, as well as increased the energy efficiency of the sensor node by reducing the transmission distance and simplifying the transmission route for short-range transmission. As compared the general LEACH, it was adapted to a wider sensor field.

Keywords: *Routing Protocol, Wide-area WSN Layer, Multi-hop, Dual-hop, LEACH, DL-LEACH.*

1. Introduction

Recently, with the possibility of realizing the ubiquitous and technology on Internet of things becomes feasible, a study on the related technology of the Wireless Sensor Network which is the core technology that forms the ubiquitous network is attracting attention. In general, the Wireless Sensor Network consists of the sensor node that process and collects the data and the Base Station for aggregating the data. This sensor node periodically collects the environmental data such as temperature, humidity, illuminance and vibration, etc., and performs several processes and transmits them to the Base Station.

Due to the nature of being a wireless network, the sensor node operates with independent power which is difficult to recharge and transmits the data using a wireless communication method. Due to such characteristics, efficient use of limited power is the most important in the design of the Wireless Sensor Network [1]. Various methods are being studied in order to increase the overall lifespan by increasing the energy consumption efficiency of the Wireless Sensor Network. Among them, the efficient routing protocol is largely divided into horizontal, location-based and hierarchical, etc. Among them, various protocols based

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on LEACH (Low Energy Adaptive Clustering Hierarchy) of hierarchical routing are being proposed [2-6]. LEACH is an algorithm that divides the entire network into a random cluster and manages by forming the head for each cluster [7].

In the paper, it proposes an improved algorithm of DL-LEACH (Dual-hop Layered LEACH) by focusing on the phenomenon of a rapid drop in energy efficiency [8] which can occur when the cluster head becomes farther from the Base Station or when the sensor field becomes wider.

DL-LEACH introduces a new hierarchical layer and uses the dual-hop transmission method different from the previous LEACH. This dual-hop transmission method will allow the general nodes closer to the Base Station to use a single-hop transmission and the cluster heads far from the Base Station to use a multi-hop transmission method [9]. The paper is organized as follows. Chapter 2 is briefly described the basis concept of the LEACH and MTE, DT protocol, Chapter 3 describes the proposed protocol in this papers. It will be described the technical characteristics and the process for the proposed protocol in chapter 4 and in order to verify the proposed algorithm, Chapter 5 is described a simulation result by the MATLAB.

2. Related Works

2.1. LEACH Protocol

LEACH is the most well-known cluster-based hierarchical routing protocol proposed by W. Heinzelman in 2000 [7, 9]. LEACH divides the entire network into several clusters and has a hierarchical structure of classifying the nodes that form the clusters into the cluster head as the upper node and member node as the lower node. The following Figure 1 shows a hierarchical cluster structure of LEACH.

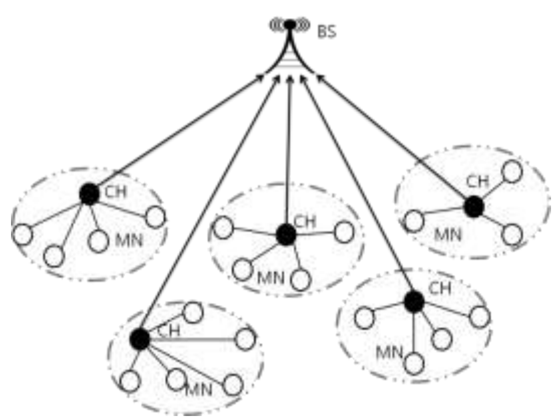

Figure 1. Hierarchical Cluster Structure of LEACH

The member node periodically senses the surrounding environment and transmits the collected data to the cluster head. The cluster head after receiving this data merges and compresses the data to reduce the amount and transmits the data to the Base Station [7]. Due to such hierarchical structure, the member node of LEACH can reduce the energy consumption due to a shorter transmission distance than the direct transmission. However, the cluster head has a high energy consumption due to its role of collecting, processing and transmitting the data to the Base Station. To prevent the excessive energy consumption of such cluster head, the LEACH protocol periodically changes the cluster head thereby dispersing the energy.

The process of LEACH protocol consists of Setup Phase and Steady Phase. First, in the setup phase, an election of probabilistic cluster head using Stochastic Threshold equation (1) is made [7].

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

Where, P – Election probability of cluster head

T(n) – Threshold value to compare

r – Current round

G – Set of nodes which did not become cluster heads in the previous round

Here, the elected cluster head sends out the ADV (advertisement) message including its own information. General nodes within this range sends out the Join-REQ message which informs the CH that it belongs to the corresponding cluster as a cluster head and thereby forms the containment relationship and assigns the time slot to each node through TDMA scheduling. Afterwards in normal state, the corresponding node of each time slot awakens to transmit their data and goes back to the sleep state. The cluster head collects and processes the data of the members and transmits the data to the Base Station using a code division transmission method. Periodically repeating these two processes are called a single round. The round configuration of LEACH is shown in Figure 2 [10].

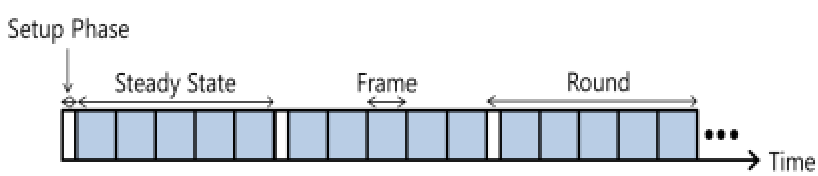

Figure 2. Round configuration of LEACH

2.2. MTE Protocol

MTE is a routing protocol that uses a multi-hop transmission method. This protocol tracks the shortest distance through other nodes in the moving direction when all nodes are transmitting the data to the Base Station. This method does not have a big energy consumption when the node transmits the data to the Base Station but increases the amount of data as the transmissions are repeated over to the next node thus the energy consumption proportional to hop will occur. The amount of data to transfer will become greater as it becomes closer to the Base Station with a rapid increase in energy consumption [11].

2.3. LEACH Analysis

Basically, LEACH has a two-hop transmission structure of 'member node → cluster head → base station.' When the cluster head becomes farther from the Base Station, the cluster head consumes an enormous amount of energy which is proportional to the total amount of data of cluster members during the data collection and the distance of the Base Station during the transmission. In other words, when the sensor field becomes widened, it becomes a big problem [5]. Figure 2 shows the changes of survival node according to the changes in the sensor field.

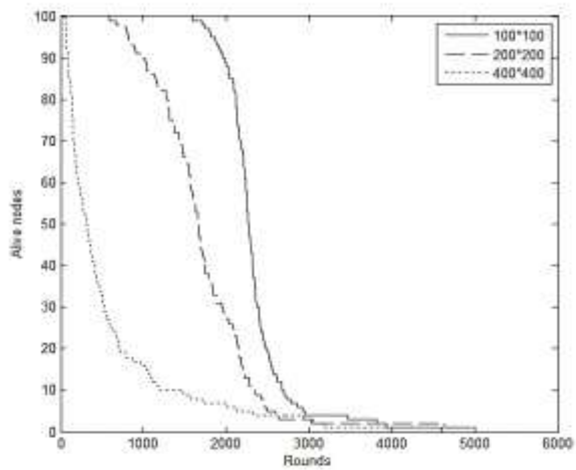

Figure 3. Changes of survival node per transmission distance of LEACH

Table 1. Changes of survival node according to the transmission distance of LEACH

Field	Node Alive Ratio	LEACH Protocol	DL-LEACH	Increase
200 * 200	80% Alive	1927	2106	9.29%
	50% Alive	2042	2291	12.19%
400 * 400	80% Alive	982	1638	74.74%
	50% Alive	1490	1900	27.51%

Like the results in Figure 3 and Table 1, the LEACH algorithm has decreased by 62% and 91% respectively each time the width of the sensor field was doubled. In other words, as the sensor field becomes larger the energy efficiency of the sensor node was significantly fallen. And the MTE has the multi-hop transmission structure of transmitting the data by setting the shortest path through the node in the direction of the Base Station. During the transmission, the MTE method has a greater energy consumption which is proportional to the total amount of transmitted data than the energy consumption proportional to the distance. Therefore, more data is accumulated and the energy consumption of the node near the Base Station becomes extremely greater.

In this paper, a protocol that can complement the disadvantages of these two approaches by applying each other's transmission method that is proposed. First, if the multi-hop transmission method of MTE can be applied to the long distance transmission of LEACH, it can reduce the large energy consumption proportional to the transmission distance of the cluster head located far away from the Base Station. At the same time, the problem on the lifespan of the node near the Base Station which is the disadvantage of multi-hop transmission method can be reduced by applying the dynamic clustering of LEACH and single-hope transmission [12].

3. DL-LEACH: Dual-hop Layered LEACH

DL-LEACH is a protocol for improving the energy consumption proportional to the maximum transmission distance and transmission distance by changing the previous transmission method of LEACH to a dual-hop (single-hop + multi-hop) transmission method. In other words, since the limitation of LEACH on the transmission distance appears by the two-hop transmission structure, this paper has focused on the changes and improvements of transmission method. In other words, two layers of [member node - cluster head] are maintained and the multi-hop routing technique was used on the transmission to the Base Station from the far away cluster head [13].

The multi-hop transmission of DL-LEACH is made of layer units and this layer is formed with a constant width basing on the Base Station. The layer is defined as a lower level when it is closer to the Base Station and the clustering is made within this layer. The cluster head of DL-LEACH transmits its data by seeking the cluster head closest to the layer one level lower than itself. The lower layer after receiving such data gathers this data with the data of its own and transmits to the layer one level lower then itself. At this time, in the absence of the cluster head in the lower layer for the transmission, it directly transmits the data to the Base Station and when any given node is closer to the Base Station than its cluster head, it transmits the data directly to the Base Station. This process falls under a single-hop transmission. The proposed algorithm for DL-LEACH is as follows.

3.1. Proposed Algorithm

Configure the operating process to a setup phase and normal phase like LEACH and when forming the sensor field define the level layer based on the Base Station and place the sensor node. And form the clusters in the setup phase. Like LEACH, the network should use the Stochastic Threshold equation (1) to elect the cluster head based on probability. Elected cluster head transmits the advertisement message to inform that he is the cluster head. General nodes within the transmission range verifies the layer information of advertisement message and when the transmitting cluster head is within the same layer, it sends the Join-REQ message and becomes incorporated into the cluster. At this time, it stores the ID of its cluster head and the distance and uses them during the transmission.

Next during the normal phase, each sensor member node starts collecting and transmitting the data. The member node periodically senses the surrounding, and after awakening from its time slot to transmit its sensing data to the cluster head, it goes back to the sleep state. The cluster head compares the distance between the cluster head of lower layer with the distance of the Base Station in order to transmit the collected data and transmits the collected data to the closer place. The cluster head of lower layer transmits the data received from the upper layer with the data collected from its cluster to the following place using the above method.

In the Figure 4, 5, 6 and 7, it shows the dual-hop transmission, layered structure and cluster formation process of proposed protocol, data transmission process and pseudo-code.

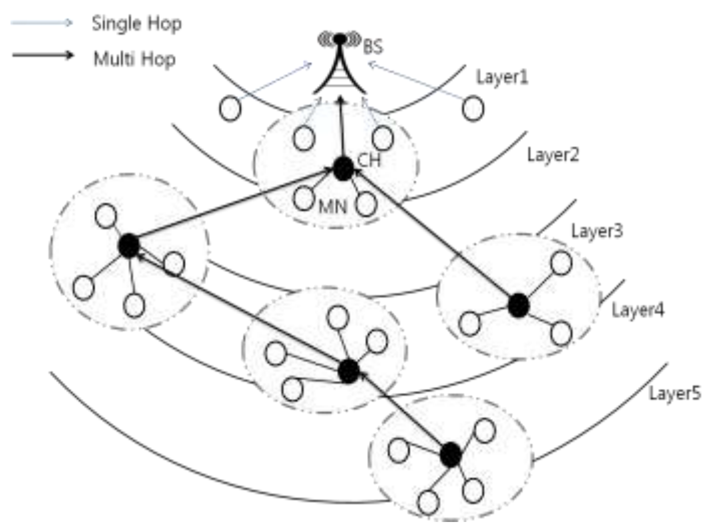

Figure 4. Dual Hop Transmission and Layered Structure of DL-LEACH

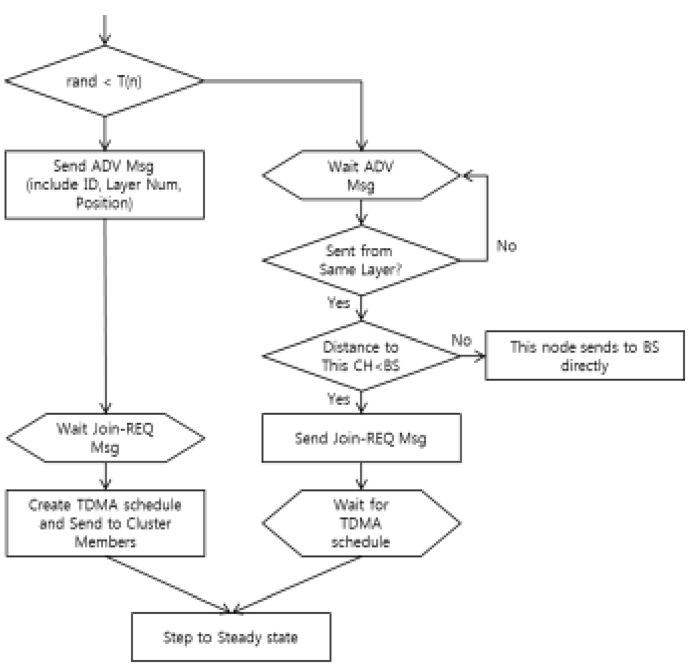

Figure 5. Cluster formation process of proposed protocol

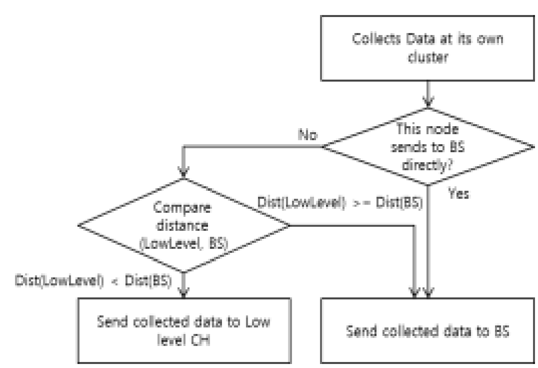

Figure 6. Data transmission process of proposed protocol

Sensor field initialize
{
for i = 1 ; i < NodeCount; i++ { // place sensor
SensorList(i).xPos = rand();
SensorList(i).yPos = rand(); //Randomly place
if (SensorList(i) in Layer n){ // create layer
SensorList(i).LayerNum = n;
}
SensorInit();
	This cluster's ClusterHead's msgSize += msgSize;
	EnergyConsume(msgSize, distanceToCH);
	}
	else {
	EnergyConsume(msgSize, distanceToBS);
	}
	}
	}

```
}
}

Round
{
DeadNodeCheck(); // check dead node
for(i = 1; i < NodeCount; ++i){ // elect CH
if ( SensorList(i) is not in G set && SensorList(i) is alive ){
if( rand(0, 1) <= (1 - p * mod (r, round(1/p)) ){
SensorList(i).type = ClusterHead;
G set = SensorList(i);
++cluster;
}
}
}
for(n = 1; n < LayerCnt; ++n){
for(i = 1; i < NodeCount; ++i){ // normal node transfer
if ( SensorList(i).LayerNum == n && SensorList(i) is alive ){
if( SensorList(i).type == NormalNode ){
if( distanceToBS > distanceToCH ){
}
}
n = LayerCnt
for(i = 1; i < ClusterHeadCount; ++i){ // cluster head transfer
if( CHList(i).LayerNum == n ){ // exist next layer and cluster head
NextCH = FindNextCH();
NextCH.msgSize += CHList(i).msgSize;
EnergyConsume(msgSize, distanceToNextCH);
}
else if( CHList(i).LayerNum == 1){ // next transfer is to BS
EnergyConsume(msgSize, distanceToBS);
}
--n;
}
}

EnergyConsume(msgSize, distance)
{
( (ETX + EDA) * (msgSize) + Efs * msgSize * ( distance * distance) )
}
```

Figure 7. Pseudo-code of proposed protocol

3.2. Definition of the performance

Evaluation items for comparison of performance between the protocols DL-LEACH and LEACH was defined by considering the following.

Network Lifetime

In general, the wireless sensor network life time is meant the time elapsed since the sensor network do the operability of the operation of the sensor network is started. The first node is dead time (FND), the last node that has the most considering the dead time (LND). In addition, by taking account of the case 80% of the node is dead, and defines the meaning of the absence of the network performance.

Energy Consumption

Energy consumption of the wireless sensor network refers to a network operating in the energy consumption for the sensor network nodes configured. This has a direct relationship to the lifetime of wireless sensor networks. That is, the evaluation to define the consumption energy and the remaining energy therefor.

Scalability

It refers to the receptivity in accordance with the change in extensibility of the number of nodes in the network size and the sensor field of the wireless sensor network. A wireless sensor network in a wide area field is required endpoints.

CH elected ratio

CH elected ratio in wireless sensor networks is the ratio of the number to be elected as a full member in the cluster head node clustering can work through the Setup-Phase. Considering the selection of a cluster head in each round is defined by the selection rate and the stability distribution of cluster head.

4. Simulation

4.1. Test Environment

In order to verify the proposed algorithm, LEACH and DL-LEACH protocol sensor field was structured using the MATLAB for simulation. In favor of demonstrate the effectiveness of the algorithm, the sensor field has considered the two fields of different sizes in order to compare the energy efficiency according to the changes of field width. As an index for comparing the energy efficiency, the number of survival node of two algorithms, FND (First Node Dead), LND (Last Node Dead) and a total energy consumption amount was measured.

When configuring the simulation, the First Order Radio Model [7, 14] like the Figure 8 was used for the data transmission and the parameter of each state is shown in the Table 2 and 3.

Table 2. Simulation parameters

Simulation Environment	
Sensor Field	200 * 200, 400 * 400
Sensor Node	100, random position

Table 3. Parameter of First Order Radio Model

Radio Model Parameter	
Initial Energy	0.5 J
Message Size	2000 bit
Transmit / Receive Energy	50 nJ/bit
Amplifier Energy	100 pJ/bit/m^2

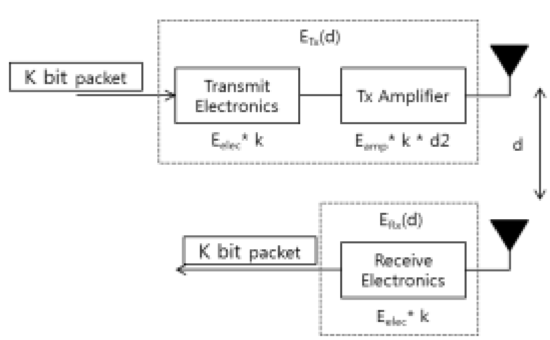

Figure 8. First Order Radio Model

- Energy Model in the proposed algorithm

The LEACH protocol selects random number of cluster heads and allots TDMA time slot to every sensor node. Our proposed dynamic clustering algorithm selects the optimal number of cluster heads and allots time slots dynamically according to node's occupied buffer level, which improves the energy efficiency of the network. In proposed algorithm, the energy consumption for transmitting a k bytes message over distance d is shown in Eq. (2).

$$E_{trans} = \begin{cases} k \times \varepsilon_{elec} + k \times \varepsilon_{amp} \times d^2 \ . \ d \leq \ d_0 \\ k \times \varepsilon_{elec} + k \times \varepsilon_{amp} \times d^4 \ . \ d > \ d_0 \end{cases} \quad (2)$$

The energy consumption for receiving a message of k bytes is shown in Eq. (3).

$$E_{receive} = k \times \varepsilon_{elec} \quad (3)$$

The εelec and εamp represent the energy consumption in transmitter electronics circuitry and radio frequency amplifier, respectively.

In the network, there are N nodes distributed in m×m area. Assume that the optimal number of cluster heads is M and each cluster has N/M- 1 member nodes. The energy consumption of the network like is as follows.

In cluster setup phase, the energy consumption of cluster head is shown in Eq. (4).

$$E_{CH-setup} = kE_{elec} + \ k\varepsilon_{fs}d^2_{CH-node} \ + \left(\frac{N}{M} - 1\right) kE_{elec} + \ \left(\frac{N}{M} - 1\right) \left(kE_{elec} + k\varepsilon_{fs}d^2_{CH-node}\right) \quad (4)$$

In the Eq. (8), the first part is the energy consumption for transmitting ADV messages to all member nodes. The second part represents the energy consumption for receiving request messages from N/M-1 member nodes. The third part represents the energy consumption of TDMA messages which are transmitted to N/M-1 member nodes. Due to the cluster heads distributed equally in the m×m area, the clustering radius is shown in Eq. (5).

$$d_{CH-node} = \sqrt{\frac{m^2}{M\pi}} \quad (5)$$

We put d_(CH-node)^2= m^2/Mπ into Eq. (4). The energy consumption of cluster head is expressed as Eq. (6).

$$E_{CH-setup} = \left(\frac{2N}{M} - 1\right) kE_{elec} + \ k\varepsilon_{fs} \frac{Nm^2}{M^2\pi} \quad (6)$$

The energy consumption of non-cluster head node is shown in Eq. (7).

$$E_{non-setup} = kE_{elec} + \ kE_{elec} + \ k\varepsilon_{fs}d^2_{CH-node} + \ kE_{elec} = 3kE_{elec} + \ k\varepsilon_{fs} \frac{m^2}{M\pi} \quad (7)$$

In the Eq. (7), the first part represents the energy consumption of broadcast messages which are received from the cluster head. The second part and the third represent the energy consumption for transmitting request messages to the cluster head and the energy consumption for receiving TDMA time schedule messages from the cluster head, respectively.

Next, in steady state phase, the energy consumption of cluster head is shown in Eq. (8).

$$E_{CH-strady} = \left(\frac{N}{M} - 1\right) kE_{elec} + kE_{da}\frac{N}{M} + kE_{elec} + k\varepsilon_{amp} d^4_{CH-node} \quad (8)$$

Where, the first part represents the energy consumption for receiving data from N/M-1 member nodes. The second part and the third part are the energy consumption of data fusion and the energy consumption of data transmission, respectively.

The energy consumption of non-cluster head node for transmitting data to the cluster head is shown in Eq. (9).

$$E_{non-steady} = kE_{elec} + k\varepsilon_{fs} d^2_{node\_CH} = kE_{elec} + k\varepsilon_{fs}\frac{m^2}{M\pi}\pi \quad (9)$$

The total energy consumption of one cluster is shown in Eq. (10).

$$\begin{aligned} E_{one-cluster} &= E_{CH-setup} + \left(\frac{N}{M} - 1\right) E_{non-setup} + E_{CH-steady} + (\frac{N}{M} - 1)E_{non-steady} \\ &= \frac{7N - 5M}{M} kE_{elec} + \frac{kN}{M} E_{da} + k(\varepsilon_{amp} d^4_{CH-BS} + \varepsilon_{fs}\frac{3Nm^2 - 2Mm^2}{M^2\pi} \end{aligned} \quad (10)$$

The total energy consumption of the whole network is shown in Eq. (11).

$$\begin{aligned} E_{total} &= M \times E_{one-cluster} \\ &= ME_{CH-setup} + \left(\frac{N}{M} - 1\right) E_{non-setup} + ME_{CH-steady} + \left(\frac{N}{M} - 1\right) E_{non-steady} \\ &= (7N - 5M)kE_{elec} + kNE_{da} + k(\varepsilon_{amp} Md^4_{CH-BS} + \varepsilon_{fs}\frac{3Nm^2 - 2Mm^2}{M\pi}) \end{aligned} \quad (11)$$

In order to obtain the optimal energy efficiency of the whole network, we make (dE_total)/dM=0. The optimal number of cluster heads is calculated in Eq. (12).

$$M_{optimal} = m\sqrt{\frac{3N}{\pi}}\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp} d^4_{CH-BS} - 5E_{elec}}} \quad (12)$$

We put Moptimal into Eq. (5). The distance between cluster heads is expressed as Eq. (13).

$$d_{CH-CH} = 2 \times d_{CH-node} = 2m\sqrt{\frac{1}{M\pi}} = 2\sqrt{\frac{m\sqrt{\varepsilon_{amp} d^4_{CH-BS} - 5E_{elec}}}{\sqrt{3N\pi\varepsilon_{fs}}}} \quad (13)$$

4.2. Simulation Results and Analysis

- The configuration of the layer

In order to solve this problem of how to evenly divide the sensor field, it can be obtained by examining the relationship between the number of layers and energy-consumption. When it is divided the area of the sensor field to uniformly layer, the relationship between the energy consumed and the number of layers is shown in Figure 8. As shown in Figure 9, when the sensor field is divided into 5, it is the minimum energy consumption. Therefore, in this paper, the sensor field is divided into five layers.

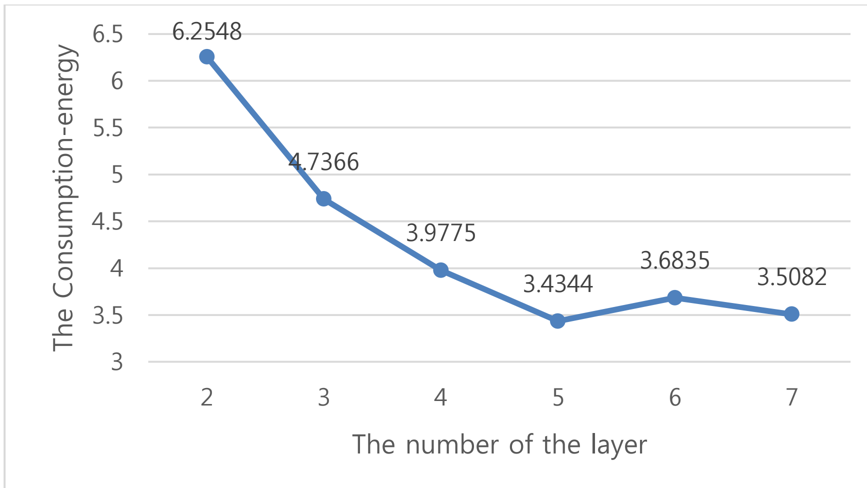

Figure 9. The consumption-energy vs. the number of the layer

Figure 10 shows a node of the status of the selected cluster head which is disposed in the sensor field. Here, the green dot represents the sensor node and the sensor nodes that are green with black dots indicate the cluster head and pink lines represent the layers. It shows that the clusters are distributed evenly and in each layer.

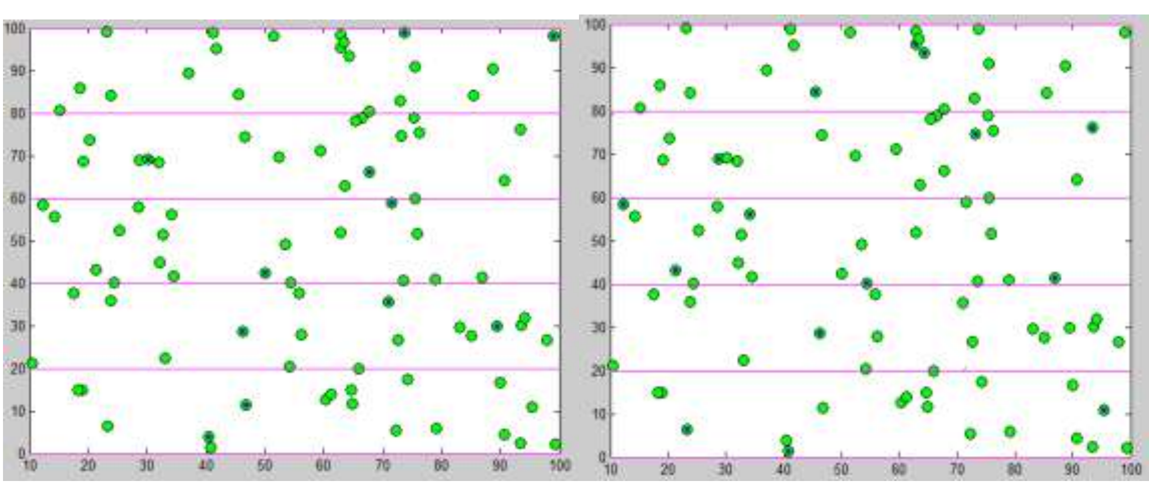

Figure 10. The Distribution of sensor nodes and cluster head in round 1 in 200*200 and 400*400

In order to compare the energy efficiency of LEACH and proposed protocol, the survival node per round in two fields having the width of 200 * 200 and 400 * 400 was measured and compared. And the position of the BS (Base Station) was positioned outside the center of the sensor field.

1) BS position is the center of the sensor field

Figures 11 can be stated in the surviving node on LEACH and DL-LEACH for the sensor field 200*200 and 400*400. If the base station is in the center of the sensor field 200*200, for FND (first dead node), the LEACH protocol is better than the proposed algorithm. This is due to the data transfer is proportional to the square of the distance. But, for the 400*400 sensor field, the proposed algorithm (DL-LEACH) is better than the LEACH. For FND and 50% alive node, it was improved 11%, 36.84% as compared to LEACH. It is briefly summarized in Table 4.

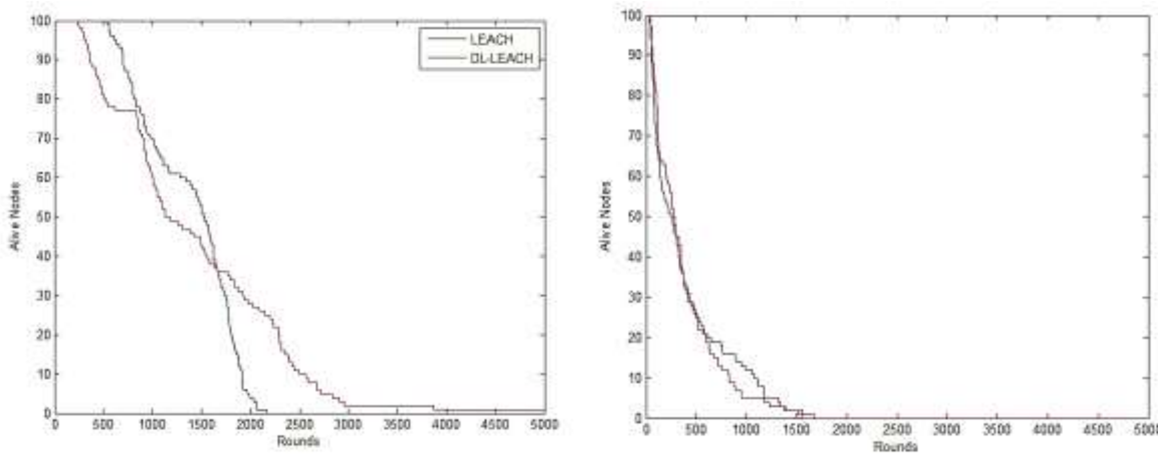

Figure 11. The comparative of alive node for the LEACH, DL-LEACH (Left: 200*200, Right: 400*400)

Table 4. The round FND, 80% and 50% alive node for the LEACH, DL-LEACH-BS center

Classify		LEACH Protocol	DL-LEACH	Increase / Decrease
200 x 200	FND	539	233	**-59%**
Sensor Field	80% Alive	808	510	**-36.88%**
	50% Alive	1520	1129	**-25.72%**
400 x 400	FND	35	39	**11%**
Sensor Field	80% Alive	76	104	**36.84%**
	50% Alive	247	275	**11.33%**

2) BS is the outside of the sensor field (0.5M*1.5M)

Figures 12 can be stated in the surviving node on LEACH and DL-LEACH for the sensor field 200*200 and 400*400 for BS position is outside sensor field. For the sensor field 200*200, the FND and 50% alive node of the proposed protocol is improved. As the sensor field is increased, the proposed algorithm shows that the more effective. This is according the data transfer is proportional to the fourth power of the distance. For FND, it was improved 438%, 900% as compared to LEACH in sensor field 200*200 and 400*400. For 50% alive node, it was improved 181.08%, 334.14% as compared to LEACH in sensor field 200*200 and 400*400. It is briefly summarized in Table 5. And Table 6 summarizes the average energy consumption per round. It illustrates the proposed method is that less energy is consumed.

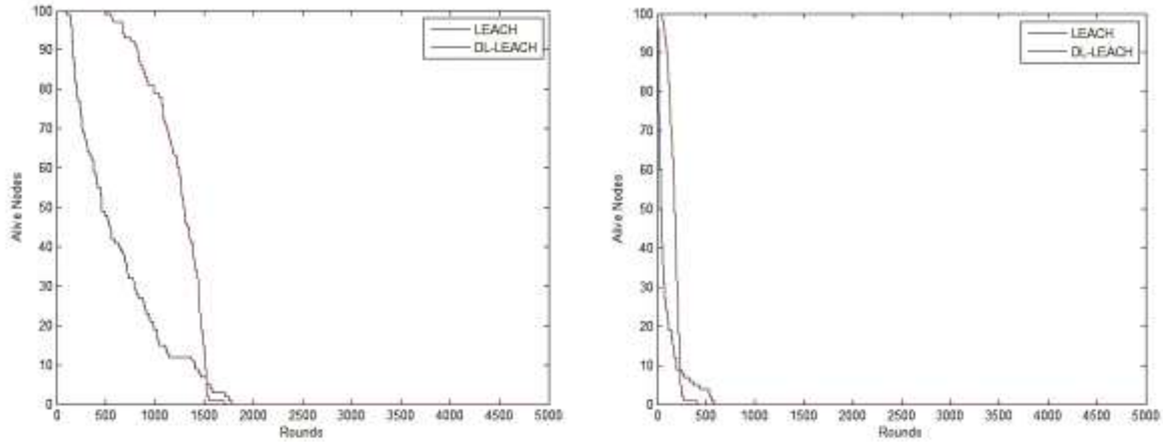

Figure 12. The comparative of alive node for the LEACH, DL-LEACH (Left: 200*200, Right: 400*400)

Table 5. The round FND, 80% and 50% alive node for the LEACH, DL-LEACH-BS outside

Classify		LEACH Protocol	DL-LEACH	Increase / Decrease
200 x 200	FND	99	533	**438%**
Sensor Field	80% Alive	204	989	**384.80%**
	50% Alive	460	1293	**181.08%**
400 x 400	FND	5	50	**900%**
Sensor Field	80% Alive	18	128	**611.11%**
	50% Alive	41	178	**334.14%**

Table 6. The average energy consumption per round(FND previous)

Classify	LEACH Protocol	DL-LEACH	Increase / Decrease
200*200	0.0442	0.0498	**12.67%**
400*400	0.425	0.6092	**43.34%**
200*200	0.1274	0.0364	**-71.42%**
400*400	1.7589	0.1939	**-88.98%**

When the field became wider in twofold than the previous test, the transmission efficiency of LEACH fell and the survival rate of the node decreased significantly. On the other hand, it was confirmed that the overall survival rate for the proposed protocol was improved. The energy efficiency of transmitting the data to a long distance using a dual-hop transmission method is improved.

DL-LEACH having a narrower sensor field has greater energy consumption than LEACH. As demonstrated in the Table 6, the basic energy consumption of DL-LEACH is greater than LEACH but despite the width of the field, it can be seen that the total energy consumption has not changed significantly.

5. Conclusion

In the proposed DL-LEACH, in order to solve a rapid energy consumption in a wider sensor field, the transmission method of LEACH was changed to dual-hop (single-hop + multi-hop) method to improve on the transmission distance and at the same time, the phenomenon of energy consumption bias near the Base Station of multi-hop method was improved through a dynamic clustering and partial single-hop transmission.

In order to achieve this, a separate hierarchical structured called the layer was placed to transmit the data over multiple hops and the nodes close to some Base Station made a direct transmission. As a result, the data transmission phase of the nodes close to the Base Station became shorter along with the total transmission distance and the amount of energy used for this process has decreased. Conclusively, DL-LEACH proposed in this paper has used the dual-hop transmission method to alleviate the problems of LEACH; a rapid decrease in the lifespan of the node as the sensor field became wider.

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