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Improvement of cluster head selection of LEACH Protocol

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Abstract

A Wireless Sensor Network is a network that is composed of wireless sensor nodes. There is no restriction on the place where it can be installed because it is composed wirelessly. Instead, sensor nodes have limited energy, such as batteries. Therefore, to use the network for a long time, energy consumption should be minimized. Several protocols have been proposed to minimize energy consumption, and the typical protocol is the LEACH protocol. The LEACH protocol is a cluster-based protocol that minimizes energy consumption by dividing the sensor field into clusters. Depending on how you organize the clusters of sensor field, network lifetimes may increase or decrease. In this paper, we will improve the network lifetime by improving the cluster head selection method in LEACH Protocol.

Keywords: WSN, Energy, Protocol, LEACH, Cluster, Head, Sensor

INTRODUCTION

A Wireless Sensor Network [1][2] is a network in which nodes equipped with measurable sensors are wirelessly configured and communicating. Since it is wirelessly configured, there is not much restriction on where the node can be installed. Unlike wired networks, however, nodes have limited energy, such as batteries. Usually, it is installed in a place where people cannot go. When the energy of the node is exhausted, the node can no longer be used. As the number of unavailable nodes increases, the network becomes unusable. Therefore, to use the network for a long time, the energy consumption of the node should be minimized. Several protocols have been studied and proposed to minimize the energy consumption of the nodes. One of the typical protocols is the cluster-based LEACH protocol [3].

BODY

LEACH Protocol

The LEACH Protocol is a cluster-based routing protocol that divides sensor field into multiple clusters. Each cluster has one node that is responsible for the cluster head. The cluster head receives data of the member nodes in the cluster, and then transmits the data to the base station after aggregation. The LEACH Protocol consists of a set-up phase to determine the cluster configuration and transmission schedule, and a steady-state phase to transmit as determined in the set-up phase. The cluster head consumes much energy because it collects the data of the member nodes in the cluster and then transmits it to the base station after aggregation. The LEACH protocol changes the cluster head every cycle in order to uniformly select all nodes and distribute the energy consumption without the cluster head having high energy consumption. In the set-up phase, selection of a cluster head in the threshold equation as equation (2.1).

$$T(n) = \begin{cases} \dfrac{p}{1 - p(r \bmod \frac{1}{p})} & if \quad n \in G \\ 0 & otherwise \end{cases} \tag{2.1}$$

Since the cluster head selection threshold of the LEACH Protocol does not consider the residual energy of the node, a node with insufficient energy to operate as a cluster head node can be selected.

Threshold considering residual energy

To solve these problems, M.J. Handy has improved the cluster head selection threshold to take into account the residual energy of the nodes. [4] Handy's proposal is shown in Equation (2.2) and Equation (2.3).

$$T_{new1} = T(n) \times \frac{E_{n_{current}}}{E_{n_{\max}}} \tag{2.2}$$

Equation (2.2) is Threshold considering the residual energy that multiplies the *T(n)* value of the LEACH Protocol by the residual energy ratio of the node. *T(n)* has a value between 0 and 1. In the LEACH protocol, the random number of each node is compared with the threshold value, and if the value of the threshold equation is larger, it is selected as the cluster head. Therefore, if the threshold value exceeds 1, the cluster head is always selected, so the threshold value should not exceed 1. In Equation (2.2), $E_{n_{\max}}$ is the initial energy of the node, and $E_{n_{current}}$ is the current energy of the node. Therefore, as the residual energy of the node becomes smaller, the value of the threshold equation becomes closer to 0 and it is not selected as the cluster head.

$$T_{new2} = T(n) \times \left(\frac{E_{n_{current}}}{E_{n_{\max}}} + (r_s \, div \, \tfrac{1}{p})\left(1 - \frac{E_{n_{current}}}{E_{n_{\max}}}\right)\right) \quad (2.3)$$

Equation (2.3) is threshold that considers energy and how long it has not been selected as a cluster head. In Equation (2.3), r_s is a variable indicating how many rounds have passed since the node became a cluster head. Each time a node is selected as a cluster head, r_s is initialized to zero. Therefore, the r_s *div* *1/p* is a number between 0 and 1, and it becomes closer to 1 as the cluster head is selected. Therefore, the probability of selecting a cluster head is increased for a node that has a large residual energy of the node and has not been selected as a cluster head for a long time.

However, considering only the residual energy of the node, the cluster head can be selected as a node far from the base station as shown in Figure 1. When the transmission distance is long, there is a problem that the FND can occur quickly because the energy consumed is increased.

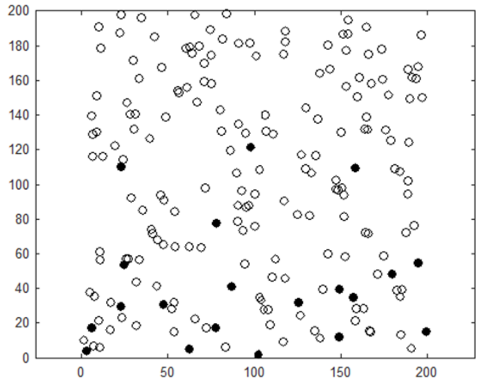


Figure 1. A node far from the base station is selected as the cluster head node

Threshold considering residual energy & distance

In order to solve this problem, J. Xu has improved the cluster head selection threshold to consider both the residual energy of the node and the distance to the base station. [5]

$$T_{new3} = T(n) \times \left(\alpha \times \frac{E_{n_{current}}}{E_{n_{\max}}} + \beta \times \frac{d_{\max} - d_{ns}}{d_{\max} - d_{\min}}\right) \quad (2.4)$$

The Xu's proposed Equation (2.4) is multiplies the T(n) value of the LEACH Protocol by the residual energy ratio of the node and how close it is to the base station. In Equation (2.4), d_{max} is the farthest distance between the base station and the node, and d_{min} is the closest distance between the base station and the node, and d_{ns} is the distance between the current node and the base station. Therefore, if the node is farthest from the base station, d_{ns} is equal to d_{max}, and d_{max}-d_{ns} is zero. If the node is closest to the base station, d_{ns} is equal to d_{min}, and d_{max} - d_{ns} is equal to d_{max} - d_{min}. So $\frac{d_{\max} - d_{ns}}{d_{\max} - d_{\min}}$ has a value between 0 and 1, and the closer the node is to the base station, the closer the value is to 1. For the value of Equation (2.4) to be between 0 and 1, $(\alpha \times \frac{E_{n_{current}}}{E_{n_{\max}}} + \beta \times \frac{d_{\max} - d_{ns}}{d_{\max} - d_{\min}})$ must have a value between 0 and 1. Therefore, $\alpha + \beta$ should be 1. By adjusting the values of α and β, energy consideration and distance between the base station weighting can be adjusted. This increases the probability of cluster head selection for nodes near the base station with high residual energy.

Considering only the residual energy and the distance from the base station, the adjacent node can be selected as the cluster head as shown in Figure 2. There is a problem that the clusters become ineffective when cluster head nodes are close to each other.

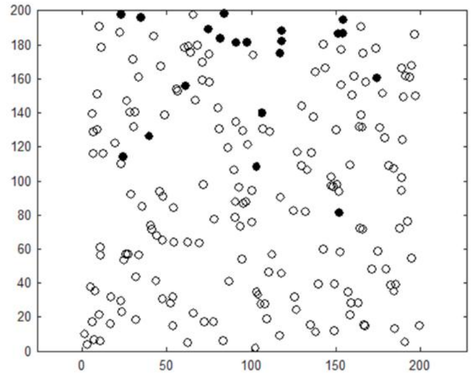


Figure 2. When the adjacent node is selected as the cluster head

PROPOSED METHOD

In this paper, we try to improve the network lifetime compared with the existing protocol by considering the residual energy of the node, the distance from the base station, and the number of cluster heads in close proximity.

The proposed method is also a weighting method for threshold formula like the Xu's method.

The residual energy ratio of the node is changed based on the maximum residual energy of the alive nodes in the sensor field, not based on the initial energy.($\frac{E_{n_{current}}}{E_{n_{\max}}}$ to $\frac{E_{n_{current}}}{MAX(E_{n_{current}})}$)

This solves the problem of lower cluster head selection probability when the residual energy of the entire node is small. And improved the problem of adding cluster head presence weights around neighbor node to select cluster heads among adjacent nodes. For this purpose, the number of nodes and number of cluster head nodes around the cluster head candidate node are checked to increase the possibility of selecting the cluster head candidate when the surrounding cluster head ratio is low. Therefore, we have proposed a weighting value as shown in Equation (3.1) below.

$$\frac{C_n - C_{n_{CH}}}{C_n} \tag{3.1}$$

C_n is the number of nodes in the range r of the node n. and $C_{n_{CH}}$ is the number of cluster head nodes in the range r of node n. The range r is defined as a circular range of one cluster region in the sensor field of M x M size. The range r is given by Equation (3.2) below. N is number of nodes, and p is the cluster head selection probability.

$$\pi r^2 = \frac{M\times M}{N\times p} = \frac{M^2}{N\times p} \rightarrow r^2 = \frac{M^2}{N\times p\times \pi} \rightarrow r = \frac{M}{\sqrt{N\times p\times \pi}} \tag{3.2}$$

The proposed cluster head selection threshold formula applying these improvements is shown in Equation (3.3) below.

$$T_{imp} = T(n)\times\left(\alpha\times\frac{E_{n_{current}}}{E_{n_{\max}}} + \beta\times\frac{d_{\max}-d_{ns}}{d_{\max}-d_{\min}} + \gamma\times\frac{C_n - C_{n_{CH}}}{C_n}\right) \tag{3.3}$$

For the value of Equation (3.3) to be between 0 and 1, $\left(\alpha\times\frac{E_{n_{current}}}{E_{n_{\max}}} + \beta\times\frac{d_{\max}-d_{ns}}{d_{\max}-d_{\min}} + \gamma\times\frac{C_n - C_{n_{CH}}}{C_n}\right)$ must have a value between 0 and 1. Therefore, $\alpha + \beta + \gamma$ should be 1.

SIMULATION & RESULTS

Simulation

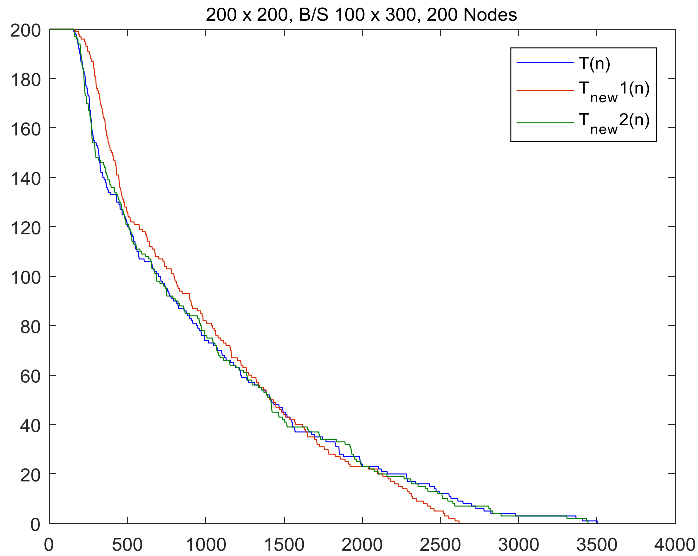
In this page, we are simulated with MATLAB to evaluate the performance of protocols as mentioned before. Table 1 is indicating the parameters of radio model and parameters of this simulation. These sensor nodes have placed randomly. And the base station is placed out of the sensor field.

Table 1. Simulation Parameters

Parameter	*Value*
Data Aggregation	5nJ/bit/signal
Energy dissipation to run the radio device	50nJ/bit
Free space model of Transmitter Amplifier	10pJ/bit/m2
Multi path model of Transmitter Amplifier	0.0013pJ/bit/m2
Number of Sensor Nodes	100
Sensor Field	100 x 100
Location of Base Station	50 x 50(center), 50 x 150(outside)
Initial Energy	0.5J

Results – Threshold considering residual energy

In the same simulation conditions, we compare the lifetime of the network by applying Equation (2.1), which is a critical equation of the existing LEACH Protocol, and Equation (2.2) ~ Equation (2.3), which are proposed by Handy. The number of alive nodes per round is shown in Figure 3 below.



	FND
T(n)	155
T**$_{new1}$**(n)	**167 (7%▲)**
T$_{new2}$(n)	158 (1%▲)

Figure 3. Network lifetime graph of Threshold considering residual energy

Comparing network lifetime, $T_{new1}(n)$ considering only residual energy showed the best network lifetime among the three.

Results – Threshold considering residual energy and distance

In the same simulation conditions, we compare the lifetime of the network by applying Equation (2.1), which is a critical equation of the existing LEACH Protocol, and Equation (2.4), which are proposed by Xu.

The FND (First Node Dead) according to the weight is shown in Table 2 below.

Simulation results show a maximum performance improvement of 36% over the LEACH protocol. And shows better performance when the energy weight is higher than the distance weight. The graph of the network lifetime based on α = 0.7 and B = 0.3 showing the best performance.

Results – Proposed Method

In the same simulation conditions, we compare the lifetime of the network by applying Equation (2.1), which is a critical equation of the existing LEACH Protocol, and Equation (3.3), which are proposed method.

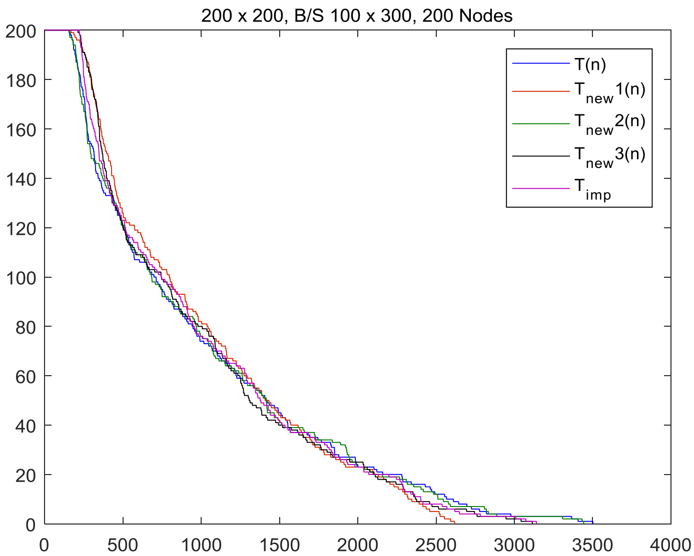
The FND according to the weight is shown in Table 3 below.

Table 2. Simulation Result of Threshold considering residual energy & distance

	LEACH Protocol										
		α	0.1	0.2	0.3	0.4	0.5	0.6	**0.7**	0.8	0.9
		B	0.9	0.8	0.7	0.6	0.5	0.4	**0.3**	0.2	0.1
FND	155		157 (1%▲)	163 (5%▲)	162 (4%▲)	161 (3%▲)	196 (26%▲)	199 (28%▲)	**212 (36%▲)**	191 (23%▲)	197 (27%▲)

Table 3. Simulation Result of proposed method

		α	0.8	**0.7**	0.7	0.6	0.6	0.6
	LEACH Protocol	B	0.1	**0.2**	0.1	0.3	0.2	0.1
		γ	0.1	**0.1**	0.2	0.1	0.2	0.3
FND	155		188 (21%▲)	**221 (42%▲)**	194 (25%▲)	184 (18%▲)	180 (16%▲)	165 (6%▲)



	FND
$T(n)$	155
$T_{new1}(n)$	167 (7%▲)
$T_{new2}(n)$	158 (1%▲)
$T_{new3}(n)$	212 (36%▲)
$\boldsymbol{T_{imp}(n)}$	**221 (36%▲)**

Figure 4. Network lifetime graph of proposed method

Simulation results show a maximum performance improvement of 42% over the LEACH protocol. The graph of the network lifetime based on α= 0.7, B= 0.2, and γ =0.1 showing the best performance is shown in Figure 4.

In simulation results, Handy's proposed method has increased up to 7% network lifetime than LEACH Protocol. Xu's proposed method has increased up to 25% network lifetime than Handy's proposed method. Proposed Method has increased up to 5% network lifetime than Xu's proposed method.

CONCLUSIONS

The LEACH protocol has the advantage of improving network lifetime by balancing energy consumption because all nodes are cyclically selected in the cluster head.

However, there is a problem in that the optimal cluster is not always constructed because the remaining energy of the node, the distance from the base station, and the number of the surrounding cluster heads are not considered when selecting the cluster head.

In this paper, we improve the cluster selection method of LEACH protocol to improve the network lifetime better than the existing protocol.

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