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Improving Network Lifetime using Fuzzy Logic in Cluster-based WSN Protocol

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Abstract

A wireless sensor network refers to a network in which Nodes equipped with sensors capable of collecting data in the real world are configured wirelessly. Since the sensor Node is configured wirelessly, a limited power such as a battery is used. Therefore, if the battery of the sensor Node is exhausted, the Node can no longer be used. If a certain number of Nodes become unavailable, the network may not operate normally.

There are many wireless sensor network Protocols to increase energy efficiency in order to maintain the network lifetime for a long time, and LEACH is a typical Protocol among them. The LEACH Protocol is a cluster-based Protocol that divides the sensor field into clusters, the Nodes in the cluster transmit data to the Cluster Head, and the Cluster Head transmits data to the Base Station, including the received data. Therefore, the network lifetime can be reduced or increased depending on how the cluster is configured.

In the case of the LEACH Protocol, clusters are formed by Cluster Head election threshold, but this may not always be optimal clusters.

To improve this, we will improve the Cluster Head election threshold method of LEACH Protocol and improve the Cluster Head election method by using Fuzzy logic.

Keywords: *WSN, Protocol, Energy, Fuzzy, logic*

1. Introduction

A wireless sensor network is a network in which Nodes with sensing capabilities communicate wirelessly [2]. Because the network is wireless, the sensor Nodes are not restricted by the installation location. So, it can be used in various environments [3].

However, wireless sensor networks use limited energy such as batteries, unlike wired networks. If the Node's remaining energy is exhausted, the Node will not operate. If the number of inoperative Nodes exceeds a certain number, the network will not function.

In order for the network to be maintained for a long time, the energy consumption of the Node needs to be minimized. In a typical wireless sensor network, sensor nodes transmit data directly to the Base Station. The longer the transmission distance, the more energy is consumed, so it will be not long before the Nodes far from the Base Station will consume all the energy. Clustering method has been proposed to improve this [1, 4, 5, 6, 7].

In clustering method, not all Nodes directly transmit data to the Base Station. that is, the sensor field is divided into clusters, and a representative Node of a cluster called a Cluster Head aggregates all data of Nodes in cluster and transmits them to the Base Station. Using the clustering method, the transmission distance of most Nodes can be

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reduced, and energy consumption can be reduced. However, any Node may be consecutively elected as Cluster Head. so, the energy consumption of the corresponding Node may become large. To improve this problem, LEACH Protocol had been proposed [9].

The LEACH Protocol is based on probability stochastic threshold and once elects all Nodes as Cluster Head. This dissipates energy consumption. However, the LEACH Protocol does not take into account the residual energy of the Node when electing the Cluster Head, so the Node with insufficient energy may be elected as the Cluster Head.

To improve this, the stochastic threshold was improved, or Cluster Heads were elected using Fuzzy logic [8].

In this paper, to improve the problem of LEACH Protocol and to improve the network life, Cluster Head election threshold is improved, or Cluster Head is elected by using Fuzzy logic and the improvement of network lifetime is confirmed.

2. Related Research

2.1. LEACH Protocol

The LEACH Protocol is a clustering-based wireless sensor network Protocol proposed by W. Heinzelman. [9]

In the LEACH Protocol, the Cluster Head is elected using the threshold Equation (1) for each Node.

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

In the above Equation (1), r is the current round. The set G is a set of Nodes not elected in the Cluster Head until the previous round. If the set G is empty and there are no Nodes that can be Cluster Heads anymore, put all the remaining energy in the set G so that it becomes the Cluster Head.

When each round begins, each Node independently checks whether it belongs to the set G, and if it belongs to the set G, it compares it with the threshold using an arbitrary number between 0 and 1.

If the random number is less than the threshold $T(n)$, the Node becomes the Cluster Head in the current round. Once all the Cluster Heads are elected, the member Nodes in the cluster transmit the data to the Cluster Head.

The Cluster Head collects the received data and transmits it together with its own data to the Base Station. The flowchart of the LEACH Protocol is shown in Figure 1 below.

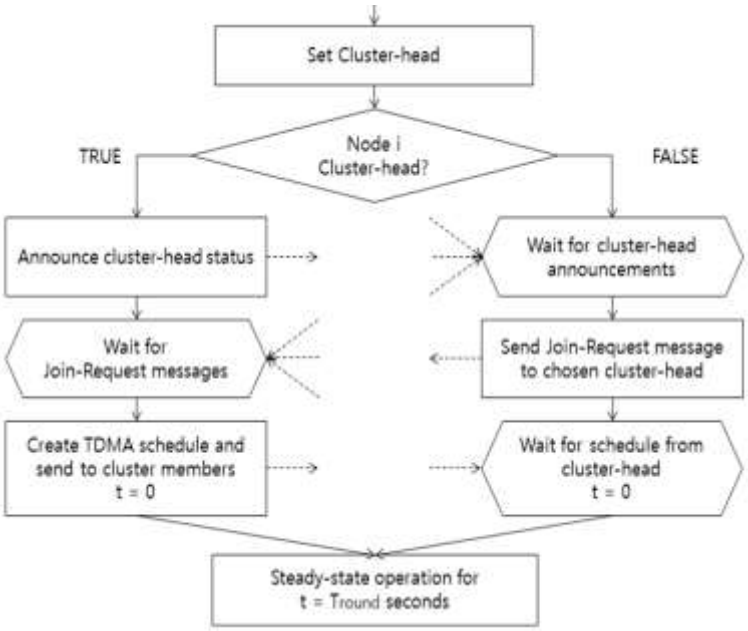
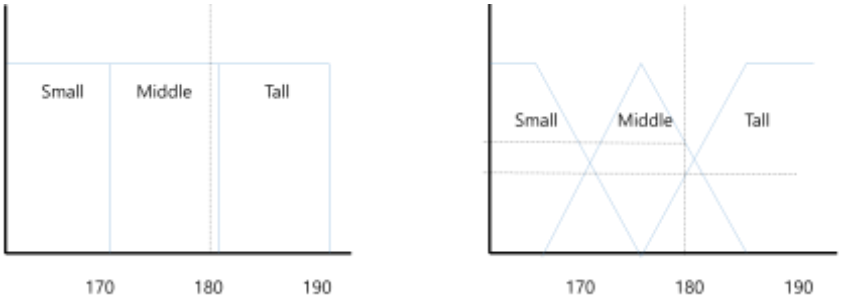


Figure 1. Flowchart of LEACH Protocol

2.2. Fuzzy Logic

Fuzzy logic is a form of many-valued logic in which the truth values of variables may be between 0 and 1. It is employed to handle the concept of partial truth, where the truth value may range between completely true and completely false.

The Fuzzy logic is basically based on the concept of the Fuzzy set proposed by Lotfi Asker Zadeh in 1965 and expresses that the comparison object belongs to the set A by one quantity using the Membership Function rather than the true binary logic. Figure 2 compares binary logic with Fuzzy logic.



(a) Binary Logic (b) Fuzzy Logic

Figure 2. Range of Height in Binary Logic and Fuzzy Logic

When a person with a height of 179.9 cm is judged by binary logic, the comparison object belongs to the 'Middle' set because it is less than 180 cm and therefore does not belong to the 'Tall' set.

However, when judged by the Fuzzy logic, a person with 179.9cm can be expressed as a mathematical function that belongs to a set of 'Middle' and 'Tall'.

2.3. Threshold Considering Residual Energy

M.J. Handy [10] improved the threshold for electing the Cluster Head as Equation (1) as shown in the following Equation (2) as a method to improve the fact that the residual energy of the Node, which is a problem of the LEACH Protocol, is not considered.

$$T(n) \times E = \frac{p}{1-p\times(r \bmod \frac{1}{p})} \times \frac{E_{n-current}}{E_{n-max}} \quad (2)$$

The closer the value of the election threshold is to 1, the higher the probability of being elected to the Cluster Head, and closer the value is to 0, the lower the probability of being elected to the Cluster Head.

2.4. Threshold Considering Residual Energy and Distance from Base Station

Considering additional energy, there is a problem of electing a Cluster Head as a Node that is far from the Base Station because there is a large amount of residual energy.

In order to improve this, we tried to improve the distance considering the distance from the Base Station.

For this, Equation (2) is improved as shown in Equation (3) below.

$$T(n) \times E \times d = \frac{p}{1-p\times(r \bmod \frac{1}{p})} \times \frac{E_{n-current}}{E_{n-max}} \times \frac{d_{max}-d_{ns}}{d_{max}-d_{min}} \quad (3)$$

As the value of the election threshold is closer to 1, the probability of being elected to the Cluster Head increases. Therefore, it is desired to reduce the probability of electing a Cluster Head at a Node that is short of residual energy or far from the Base Station.

The lower the remaining energy, the lower the probability of being elected, and the farther away from the Base Station the less the probability of being elected.

3. Proposed Method

The proposed method uses Fuzzy logic instead of existing Cluster Head election method. The Cluster Head is elected by the Fuzzy operation considering the residual energy of the node or the residual energy of the node and the distance between the node and the Base Station, instead of stochastic threshold.

The Fuzzy operation uses Mamdani reasoning method and proceed through the following process.

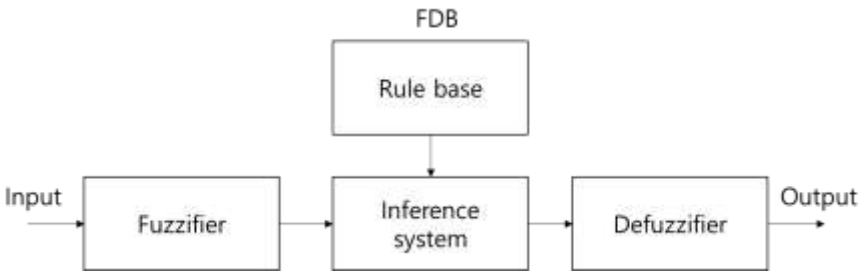


Figure 3. Process of Fuzzy Logic

1. **Input variable fuzzification**: input the residual energy of the node, the density of the node, and the centrality of the node to Determine the degree in which each input belongs to the appropriate fuzzy set and convert it to a member function.

2. **Fuzzy rule evaluation**: Assign fuzzy input variables using fuzzy rule and infer result.

3. **Output rules and aggregation**: Consolidate and output inferred results.

4. **Defuzzification**: The process of converting the output fuzzy values to their normal values.

Calculate using the center-of-gravity method in defuzzification. The Equation is shown in Equation (4) below.

$$COG = (\sum \mu_A(x) * x) / \sum \mu_A(x) \quad (4)$$

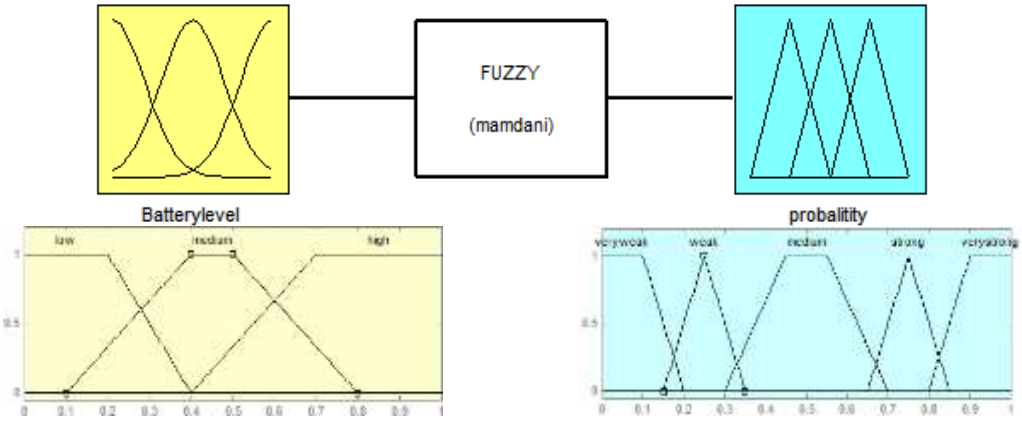


Figure 4. Fuzzy Sets: Considering Node's Residual Energy

Fuzzy logic was created corresponding to the improved stochastic threshold (2) in LEACH Protocol by considering residual energy of nodes. The Fuzzy set and its variables are shown in Figure 4.

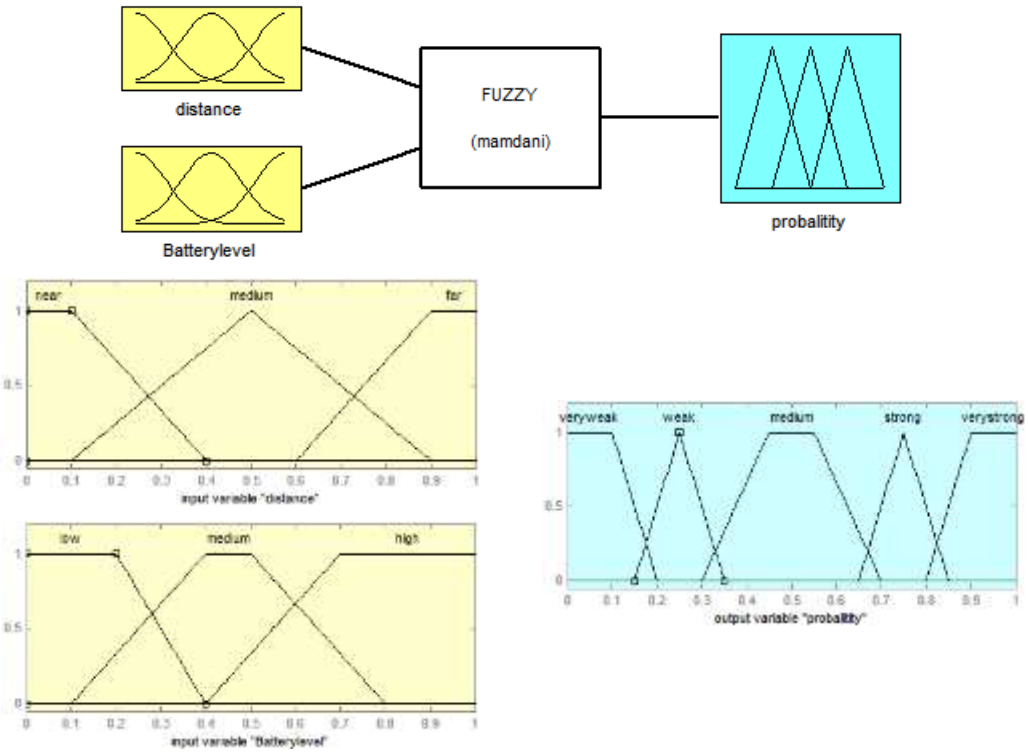


Figure 5. Fuzzy Sets: Considering Node's Residual Energy and Distance from Base Station

Fuzzy logic was created corresponding to the improved stochastic threshold (2) in LEACH Protocol by considering residual energy of nodes and distance from Base Station. The Fuzzy set and its variables are shown in Figure 5.

The operation result obtained by the Fuzzy operation has a value between 0 and 1. This value was used instead of the *T(n)* threshold value of the LEACH Protocol to elect the Cluster Head.

4. Simulation and Results

4.1. Radio Model

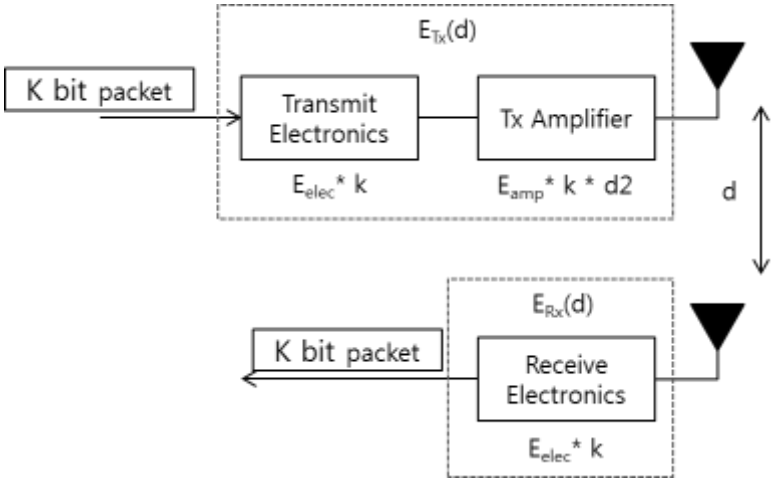


Figure 6. Flowchart of Radio Model

The radio model used in the simulation is shown in Figure 6.

When transmitting data, the transmission energy according to data size and amplification energy depends on the distance are required.

Energy consumption is proportional to the square of the distance if the transmission distance is within the free space distance and is proportional to the fourth power of the transmission distance when the transmission distance is outside the free space. Therefore, in a wireless network, energy consumption increases as the transmission distance increases. This is shown in Equation (2).

$$E_{TX}(l,d) = E_{TX-elec}(l) + E_{TX-amp}(l,d)$$
$$E_{TX}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2, & d \le d_0 \\ lE_{elec} + l\varepsilon_{mp}d^4, & d > d_0 \end{cases} \quad (2)$$

When receiving data, it requires receiving energy according to the size of the data message. The energy Equation required at this time is shown in Equation (3).

$$E_{RX}(l) = E_{RX-elec}(l) = lE_{elec} \quad (3)$$

The parameters of the radio model are shown in Table 1 below.

Table 1. Radio Model Parameters

	Values
Data Aggregation	5nJ/bit/signal
Energy dissipation to run the radio device	50nJ/bit
Free space model of Transmitter Amplifier	10pJ/bit/m^2
Multi path model of Transmitter Amplifier	0.0013pJ/bit/m^4

4.2. Simulation

In this paper, we compare two cases of improvement of threshold algorithm of LEACH Protocol and of Fuzzy logic using MATLAB.

The simulation parameters are shown in Table 2 below. Node placement is randomly placed in the sensor field.

Table 2. Simulation Parameters

	Values
Number of Sensor Nodes	100
Sensor Field	200 x 200
Position of Base Station	50 x 150
Initial Energy	0.5J

4.3. Simulation Result – Considering Residual Energy

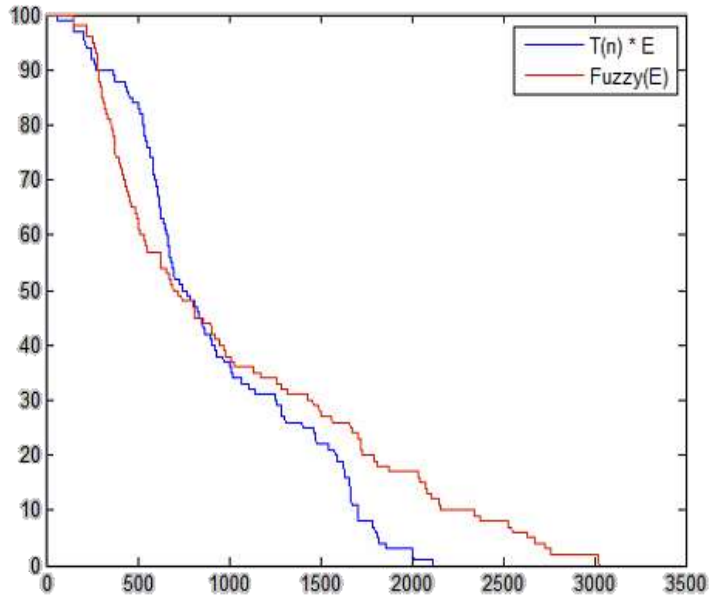


Figure 7. Network Lifetime Graph of Considering Residual Energy

We compared the case where only residual energy of the Node is considered by using $T(n) \times E$ and Fuzzy logic which modified the threshold Equation of LEACH Protocol under the same condition as the same Node arrangement.

As a result of comparison between the two, the graph of the living Node by round is as shown in Figure 6. Fuzzy logic was used as a criterion when the First Node Died (FND). Table 3 below shows the round comparison Table where FND occurred.

Table 3. Comparison of First Node Dead(FND) According to Simulation Results

	FND	Improved ratio
T(n) * E	61	
Fuzzy(E)	**152**	**149.2% ▲**

4.4. Simulation Result – Considering residual Energy & Distance from Base Station

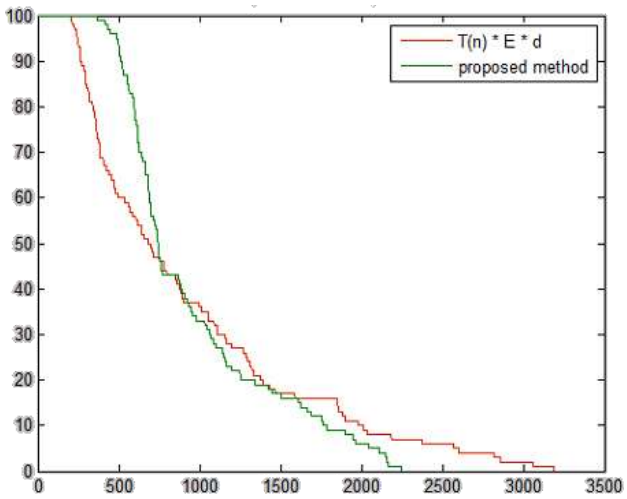


Figure 8. Network Lifetime Graph of Considering Residual Energy & Distance from Base Station

We compared the case where the residual energy of the Node and the distance between the Base Station are considered by using the $T(n) \times E \times d$ and the Fuzzy logic which modified the threshold Equation of the LEACH Protocol under the same condition as the same Node arrangement.

As a result of comparison between the two, the graph of the living Nodes by round is as shown in Figure 8. Fuzzy logic was used as a criterion when the FND. Table 4 below shows the round comparison Table where FND occurred.

Table 4. Comparison of First Node Dead(FND) According to Simulation Results

	FND	Improved ratio
T(n) * E * d	209	
Fuzzy(E*d)	**366**	**75.1%▲**

5. Conclusions

One of the important issues in wireless sensor networks is to maximize network lifetime. For maximizing network lifetime, many Protocols had been proposed and LEACH Protocol is a representative algorithm based on clustering among them. In the LEACH Protocol, since LEACH Protocol elects Cluster Head depending on probability, the electing of Cluster Head always be not optimized. Therefore, we tried to improve the stochastic threshold Equation or to use different Cluster Head electing method to improve network lifetime.

As a result, method using Fuzzy logic is more better rather than the method improving stochastic threshold Equation. when Cluster Head is elected through method improving stochastic threshold, the more energy is reduced or distance from Base Station is far, the more probability of Cluster Head election is reduced.

To improve this, we use the Fuzzy logic rather than method improving stochastic threshold. This has resulted in an improvement in the network lifetime.

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