Improvement of cluster-based WSN protocol using fuzzy logic

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ABSTRACT

A wireless sensor network is a collection of wireless nodes with sensor devices that can collect data from the real world. This is because sensor nodes usually use limited-powered batteries. Therefore, if the battery on the sensor node is exhausted, the node will no longer be available. If the battery on some nodes is discharged, the sensor network will not work properly. To maintain sensor network system, there are many wireless sensor network protocols to increase energy efficiency of nodes. One of the energy-efficient methods is cluster-based protocols. These protocols divide the sensor fields into clusters and send and receive data between nodes. Thus, depending on how the cluster is constructed, the network's lifetime may be reduced or increased. Cluster-based protocols cannot always be optimal cluster configurations. These problems have been improved using fuzzy logic. In general, fuzzy logic is used to elect cluster heads based on node residual energy, node concentration and node centrality. However, it is possible that nodes close to each other at a high density area are elected as cluster heads. In this paper, we propose a method to consider the number of adjacent cluster heads instead of Node Concentration to improve the problem.

Keywords: Cluster, Fuzzy, Protocol, WSN

1. INTRODUCTION

Wireless sensor network is a network that wirelessly configures sensor nodes that collect data. Sensor nodes can be installed on homes, natural environments, or roads to measure or observe changes. Also, the sensor nodes are wirelessly configured, so they are typically installed in places that are not easily accessible by themselves [1-10]. This kind of wireless sensor network is used in many areas and makes our lives more convenient. Wireless sensor networks have these advantages and disadvantages. Unlike wired networks, wireless sensor networks operate with limited power sources, such as batteries for each sensor node. Once the battery is discharged, the sensor node is no longer available. So it is necessary to optimize energy consumption in order to extend the network's lifetime [11-14]. There are many wireless sensor network protocols to increase the energy efficiency of the network. One of the typical ways to increase energy efficiency is to use cluster-based protocols [15-18]. However, these protocols does not take into consideration the residual energy of nodes or the distance between nodes, consequently clusters could be formed inefficiently. To improve this, Gupta's Fuzzy Logic, LEACH-FL, which considers Node Energy, Node Concentration, and Node Centrality using Fuzzy Logic has been proposed. This helps to form more efficient clusters. However, it may happen that adjacent nodes are elected as cluster heads. If the cluster head nodes are close to each other, they can be configured inefficiently in a cluster configuration. To overcome this, we consider Node Energy, Node Centrality and add new concept, “the number of cluster head(s) to the number of nodes ratio around a cluster head candidate”. Process of Fuzzy logic as shown in Figure 1.
2. RELATED RESEARCH

2.1. Fuzzy logic
The Fuzzy logic [19-30] operation uses Mamdani inference method and goes through the following process:

a) Input variable fuzzification: Determine the extent to which the appropriate fuzzy set belongs to the appropriate set of values entered in the input variable and convert it to a member function.

b) Output rules and aggregation: Consolidate and output inferred results.

c) Defuzzification: Process for converting the output fuzzy values to normal values

d) Calculate using the COG(center-of-gravity) method in defuzzification. COG method is shown in (1).

\[ \text{COG} = \frac{\sum \mu_A(x) \cdot x}{\sum \mu_A(x)} \]  

(1)

2.2. Gupta’s fuzzy logic
Gupta [31-36] tried to improve the Cluster-based Protocol through Fuzzy logic. The cluster head is elected by fuzzy operation, which takes into residual energy of the node, centrality of the node, and the density of the node. Gupta's Fuzzy Logic has input and output variables as shown in Tables 1, 2, and a fuzzy set as shown in Figure 2. where node density refers to the node density within 20M x 20M space, assuming that the reference node is at the center of the 20M x 20M space, the density is obtained.

| Variable name         | Set Value     |
|-----------------------|---------------|
| energy                | low med High  |
| concentration         | low med High  |
| centrality            | close adeq Far|

| Variable name | Set Value |
|---------------|-----------|
| chance        | Vsmall    |
|               | Small     |
|               | Rsmall    |
|               | Medium    |
|               | Rlarge    |
|               | Large     |
|               | vlarge    |

Figure 1. Process of fuzzy logic

Figure 2. Fuzzy set for input and output variable of Gupta’s fuzzy logic
In Gupta's Fuzzy Logic, the chance value for all nodes are calculated for every round. When the chance value calculation is completed, the cluster heads are elected in ascending order of the chance value. The centrality of the node is the sum of the distances from the node located within a certain range $r$ to the node, $A$ as shown in Figure 3. The range is given by (2).

$$r = \frac{M}{\pi np} \quad (2)$$

Where $M$ is the size of the sensor field, $P$ is the cluster head election probability, and $n$ is the total number of nodes.

$$\text{Node Centrality} = d1 + d2 + d3 + d4 + d5 + d6$$

Figure 3. Total distance from other nodes in the $r$ range by node A

### 2.3. LEACH-FL

LEACH-FL [37-43] has input and output variables as shown in Tables 3, 4, and a fuzzy set as shown in Figure 4. Obtain the fuzzy probability value by using the following fuzzy set and following (3).

$$\text{Probability value} = (\text{Node Energy}) \times 2 + (\text{Node density}) + (2 - \text{Node Centrality}) \quad (3)$$

### Table 3. Input variable of LEACH-FL

| Variable name        | Set Value |
|----------------------|-----------|
| Node Energy          | 0 (Low)   |
|                      | 1 (Med)   |
|                      | 2 (High)  |
| Node Concentration   | 0 (Low)   |
|                      | 1 (Med)   |
|                      | 2 (High)  |
| Node Centrality      | 0 (Close) |
|                      | 1 (Adeq)  |
|                      | 2 (Far)   |

### Table 4. Output variable of LEACH-FL

| Variable name | Set Value      |
|---------------|----------------|
| Probability   | VeryWeak       |
|               | Weak           |
|               | LittleWeak     |
|               | LowerMedium    |
|               | Medium         |
|               | HigherMedium   |
|               | LittleStrong   |
|               | Strong         |
|               | VeryStrong     |
In the case of LEACH-FL, it operates almost the same as the LEACH Protocol. The LEACH protocol elects the cluster head by comparing the random number of each node with the stochastic threshold (T(n)). However, LEACH-FL elects the cluster head by comparing the calculated fuzzy probability value with T(n).

3. PROPOSE METHOD

The proposed method is to consider the adjacent cluster head nodes instead of Node Concentration in existing LEACH-FL. Fuzzy Logic of the proposed method has input variables as shown in Table 5.

| Variable name   | Set Value |
|-----------------|-----------|
| Node Energy     | Low, Med, High |
| Adjacent CH     | Little, Med, Many |
| Node Centrality | Close, Adeq, Far |

a) Node Energy: The cluster head consumes much energy because it needs to receive data of nodes in the cluster and to aggregate and transmit data. Therefore, the node elected as the cluster head need to have a large residual energy. Node Energy variables as shown in Figure 5.

b) Adjacent CH: the number of cluster head(s) to the number of nodes ratio around a cluster head candidate within the radius \( r \). The radius \( r \) is given by (2). Distances between the node within \( r \) as shown in Figure 6. The lower the number, the less cluster head nodes are in the vicinity, and the number of cluster heads that are adjacent to each other can be reduced. Adjacent CH variables as shown in Figure 7.
c) Node Centrality: sum of the distances from nodes located within a certain range $r$ to the node within radius $r$. The lower the value is, the shorter the distance between adjacent nodes is. The radius $r$ is given by (2). As the cluster head is located in the middle of the cluster, the transmission distance of the member node is minimized, which can increase the network lifetime. Node Centrality variables as shown in Figure 8. Fuzzy Logic of the proposed method has output variables as shown in Table 6.

| Variable name                  | Set Value          |
|--------------------------------|--------------------|
| Probability                    | Very weak          |
|                                | Weak               |
|                                | Little weak        |
|                                | Lower medium       |
|                                | Medium             |
|                                | Higher medium      |
|                                | Little strong      |
| Probability                    | Strong             |
|                                | Very strong        |


Figure 8. Input variable: node centrality

d) Probability: The output value is determined by fuzzy 3 inputs. The higher this value, the higher the likelihood of being elected to the cluster head. Probability variables as shown in Figure 9.

Figure 9. Fuzzy set for output variable of proposed method
4. SIMULATION AND RESULT

4.1. Simulation

We compared the network lifetime of the proposed protocol and the existing protocol using Fuzzy Logic. The simulation was conducted when the position of the base station is at the center of the sensor field. Simulation parameters as shown in Table 7.

| Parameter          | Value             |
|--------------------|-------------------|
| $E_{EA}$           | 5nJ/bit/signal    |
| $E_{elec}$         | 50nJ/bit          |
| $\epsilon_{fs}$    | 10pJ/bit/m$^2$    |
| $\epsilon_{mp}$    | 0.0013pJ/bit/m$^4$|
| Number of Sensor Nodes | 100           |
| Sensor Field       | 100 x 100         |
| Location of Base Station | 50, 50 (center) |
| Initial Energy     | 0.5J              |

4.2. Results

The network lifetime of the proposed method is 32.6% higher than Gupta’s Fuzzy logic and 13.3% higher than LEACH–FL. Simulation results as shown in Table 8. Simulation results as shown in Figure 10.

|                          | Gupta’s method | LEACH-FL | Proposed method |
|--------------------------|----------------|----------|-----------------|
| FND                      | 2581           | 3021     | 3423            |
| 80% Alive                | 3754           | 2764     | 3791            |

Figure 10. Simulation results

5. CONCLUSION

The simulation results show that proposed method has better performance in network lifetime aspect among two protocols using Fuzzy Logic. In the case of a protocol using existing fuzzy logic, the cluster head election probability is increased when node density is high. Considering only the density of nodes without checking whether or not there are nodes elected as the cluster head in the vicinity may cause to be elected cluster heads very close in the high density area. To overcome this, we adjust the cluster head election probability according to the number of nearby cluster heads instead of node density, which resulted in the improvement of the actual network lifetime.
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