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Improved fuzzy logic based clustering algorithm for enhancing the lifetime of wireless sensor network

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Abstract

Objectives: The major objective is enhancing the network lifetime and overall performance of the system and reducing the energy consumption of the nodes by using Improved Fuzzy Logic based Clustering (IFLC) algorithm.
Methods: In this paper, a Sugeno-type Fuzzy Inference based Clustering (SFIC) algorithm is proposed along with regression based threshold estimation for improving the network lifetime as well as reducing the energy consumption.
Findings: In wireless sensor networks (WSN), the sensor nodes are densely arranged in an aggressive environment for monitoring, detecting, and analyzing the physical phenomenon and large amount of energy is consumed during information transmission. Therefore, the replacement of battery is not possible regularly and maintaining the network lifetime is also difficult. Hence, these issues are the major challenges in WSN.
Applications/improvements: The experimental results show that the proposed sugeno-type fuzzy inference system based clustering algorithm has better performance than the other clustering algorithms.

Keywords: Wireless Sensor Network, Fuzzy Logic Clustering, Sugeno-Type Fuzzy Inference, Regression Based Threshold Estimation.

1. Introduction

The wireless sensor networks [1] are used to sense the different parameters like humidity, temperature, pressure etc., it can be used in various applications like monitoring applications, detection applications, and surveillances. It has several sensor nodes where each sensor node is connected to common sink node. Due to nature of network, different issues are raised like power consumption, capacity of computation, and etc. Therefore, the network lifetime improvement [2] and energy consumption reduction are the most difficult in WSN. To avoid these issues, different clustering techniques are developed.

In fuzzy based clustering algorithm [3, 4], the selection of super cluster head (SCH) is proposed. Here, the SCH is selected based on the selection of appropriate fuzzy descriptors like residual energy, mobility and centrality of base station, among different sensor nodes. The SCH is chosen by using fuzzy inference engine. Though, for large number of sensor nodes, this system is not useful such that the selection of SCH is more difficult. Hence, in this paper, an improved fuzzy based clustering algorithm is proposed.

In [5], proposed an energy-aware distributed dynamic clustering protocol (ECPF) based on non-probabilistic cluster head (CH) selection, fuzzy logic and on-demand clustering. The CH is selected based on the residual energy of the nodes by using non-probabilistic manner. This is achieved by introducing the delay which is inversely proportional to the residual energy of the nodes. Moreover, fuzzy logic is proposed for evaluating the node fitness function which is utilized for final CH selection among neighboring CH. However, this proposed technique should not satisfy QoS requirements such as complete coverage of the monitored area over long period of time is an outstanding issue.

In [6], proposed a strategy for the movement of base station based on fuzzy logic. The base station is made to move on a certain predefined path and its effect on network lifetime is studied. Fuzzy logic inference mechanism governs the direction in which base station moves. Fuzzy logic based control system is used when they do not have an exact mathematical model of the system and it takes computationally less memory and less computational power. So, it suits the resource constrained sensor network. In the last decade a number of researches have shown that fuzzy controllers have potentials to replace conventional controller. In fuzzy logic, linguistic variables are used. They choose a node with highest priority using fuzzy inference technique and then base station is moved towards node having highest priority. The result has been compared with the method having stationary base station and fuzzy logic governed motion of base station without following any predefined path. However energy consumption of node and base station are slightly high there is no minimization technique are used.

In [7], an F-MCHEL technique is proposed which is a homogenous energy protocol. In the proposed fuzzy logic technique, CH is selected based on descriptors such as energy and proximity distance. The master cluster head is selected by using the selected CH and based on their residual energy. Initially, energy efficient clusters are formed and each cluster has its own cluster head. The CH is utilized for collecting and aggregating the data form cluster members and the collected data are transmitted to the base station either directly or using CH. But performance of protocol is not measured in heterogeneous network.

In [8], a fuzzy logic based cluster head selection is proposed. In the proposed system, the cluster head nodes are selected by considering energy level and distance to the base station. For all iteration, node die time and data stream are guaranteed. The requirements of the local information, global positioning system for sensor nodes are removed by the proposed system. Here, the base station is more powerful than the sensor nodes in terms of power consumption, unlimited memory and power storage. But energy consumption of cluster head is high and major problem is in reality all nodes equipped with GPS receiver are not suitable.

In [9], a method based on LEACH protocol was developed by using Fuzzy Logic to cluster heads selection. Here, the CH selection is achieved based on the variables such as battery level, density of the nodes and distance from base station. The cluster is formed by the base station which selects the appropriate sensor nodes which have the highest chance in order to become the CH based on the fuzzy logic method. The above three variables are the input functions of the fuzzy system and determine the degree of the membership function.

In [10], an algorithm is proposed for hybrid energy efficient routing in wireless sensor networks based on EF-Tree (Earliest-First Tree) and SID (Source-Initiated Dissemination) algorithms for data dissemination. The proposed algorithm is also utilized for employing the fuzzy method in order to select the CH and act as switch between SID and EF-Tree. Here, the CH is selected by clustering the entire network into different clusters based on the fuzzy variables. The analysis of fuzzy variables changes are achieved for generating the rules in order to route the information.

In [11], recent progress in mobile WSNs are studied and compared in terms of their models and mobility management methodologies. Initially, mobility management of mobile sensors is discussed for providing better WSN, improving the network coverage and connectivity and relocating the sensor nodes. Then, the path-planning techniques are introduced for data ferries in order to transmit the data between isolated sensors. The comprehensive study is also presented in order to illustrate the effectiveness of the different techniques.

2. Materials and methods

In this section, the proposed Sugeno-Type Fuzzy Inference based Clustering algorithm and regression based threshold estimation for wireless sensor network is discussed briefly. The proposed algorithm is performed based on the following steps:

- System assumption
- Base Station (BS) Selection
- Clusters Formation
- Base Station (BS) visits Clusters
- Cluster Heads (CH) Selection
- Cluster Heads (CH) Collection by Base Station (BS)
- Super Cluster Head (SCH) Selection
- Data Transmission to BS

2.1. System assumption

The proposed system is assumed by following statements for deploying into the network.

1. Base Station is portable
2. All sensor nodes in the network are stationary except that the base station.
3. Initially, all sensor nodes are having equivalent initial energy.
4. The distance between the base station and the nodes is estimated by using the strength of received signal.
5. The distances between cluster heads, super cluster head and base station are determined using mobility.

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2.2. Base station (BS) selection

The base station is referred as the gateway between sensor nodes and end user. The BS is provided for forwarding the data from WSN to the server. Generally, the BS is portable and deployed at long distance from the sensor nodes. The proposed method consists of 50 nodes (0 – 49) nodes. Here, the BS is the mobile phone and itself moves to the cluster nodes in the network. The BS is located in the XY interaction point of the network.

2.3. Clusters formation

In WSN, the network lifetime is improved by the most significant technique named clustering. The clustering technique provides the two-level hierarchy in which the CHs are utilized for generating the higher level and cluster member nodes are utilized for forming the lower level. The sensor node periodically transmits their data to corresponding CH nodes. Clusters involves grouping of sensor nodes into clusters based on the distance to the BS. The considered 50 nodes are placed randomly in the network. Each node has the membership functions such as the mobility, centrality and the energy level. In our proposed system, the coordinate is divided into the four regions and each region is represented as the clusters and the nodes in the specific clusters are called as cluster members. The number of nodes in each cluster is varied compared with the nodes in other clusters.

2.4. Base station (BS) visits clusters

The clusters are formed by the nodes in the network according to the sensor nodes and base station coordinates. Once the cluster is formed then, the base station visits every cluster members in each cluster since the base station is mobile. Then, the membership functions such as mobility, centrality and residual energy are checked by the base station.

2.5. Cluster heads (CH) selection – Regression-based threshold estimation

The sensor nodes are placed randomly in the network and are static. In hierarchical network structure each cluster has leader called a Cluster Head (CH). The CH is defined as the sensor node which is used for collecting the data from the every cluster members in the clusters. In addition, the data aggregation and delivery to the base station are also achieved by the CH. For cluster members, CH is act as the sink node. For CH, base station is act as sink node. The hierarchical routing such as regression-based threshold estimation is used for selecting the CH [12].

Then, LEACH protocol is provided for forming Dynamic Cluster (DC) in order to reduce the energy consumption of the nodes based on the SCH selection among all clusters. The CH is selected by using regression based threshold estimation model based on the LEACH protocol which is the hierarchical routing protocol. In which, the linear regression is utilized for computing the probability of threshold selection based on the linear combination of the explanatory variables and the set of regression coefficients. The linear prediction function is given as,

$$f(x) = \delta . H_x \qquad (1)$$

In above equation, δ is the regression coefficient and h_x is the explanatory pseudo-variables. In the network, each node selects any number between 0 and 1 randomly in order to become the CH. Thus, the CH for current round is selected by the randomly selected number and threshold value. If the threshold value is greater than the selected number, then the node is considered as the CH for current round. The threshold value is selected by high probability of linear prediction function.

2.6. Cluster heads (CH) collection by base station (BS)

The sensor nodes are grouped into clusters. Each sensor node has its own membership functions such as the mobility, centrality and the energy value. The cluster members in each cluster are monitored by the base station. The CH is selected based on the node with the highest residual energy in each cluster. The selected CH is having the bidirectional nature. Once the CH is selected, then the nodes are travelled in both directions and CH is moved to the base station directly. Then, the SCH is selected by the CHs by using theSugeno-Type Fuzzy Inference method.

2.7. Super cluster head (SCH) selection -Sugeno-type fuzzy inference based clustering

A Super Cluster Head is the highest residual valued node among the collected cluster heads or cluster nodes. The Super Cluster Head (SCH) is responsible for reducing the energy cost and increasing the lifetime of the sensor nodes. The Cluster Heads (CH) transmit the packets including the energy level information and node ID to the rest of nodes, in which each CH compare the energy level information of other headers in order to select only one SCH. Sugeno-type fuzzy inference model is provided for selecting the super cluster head for data transmission in the proposed system.

The Sugeno-Type Fuzzy Inference Based Clustering is utilized to provide the natural framework which defines the relationship between input and output can be easily incorporate with rules. It provides most efficient way to select proper and crisp output by using weighted average methods. This can be processed by two phases are fuzzifying the input membership functions and applying the fuzzified inputs to the fuzzy operator. The output membership may be either linear or constant. The output value of Sugeno-Type Fuzzy is described as follows:

$$y = ai + bm + c \qquad (2)$$

Where i and m are input variables, y is the output level and c is the constant. If the value of a and b are zero then the output level becomes constant.

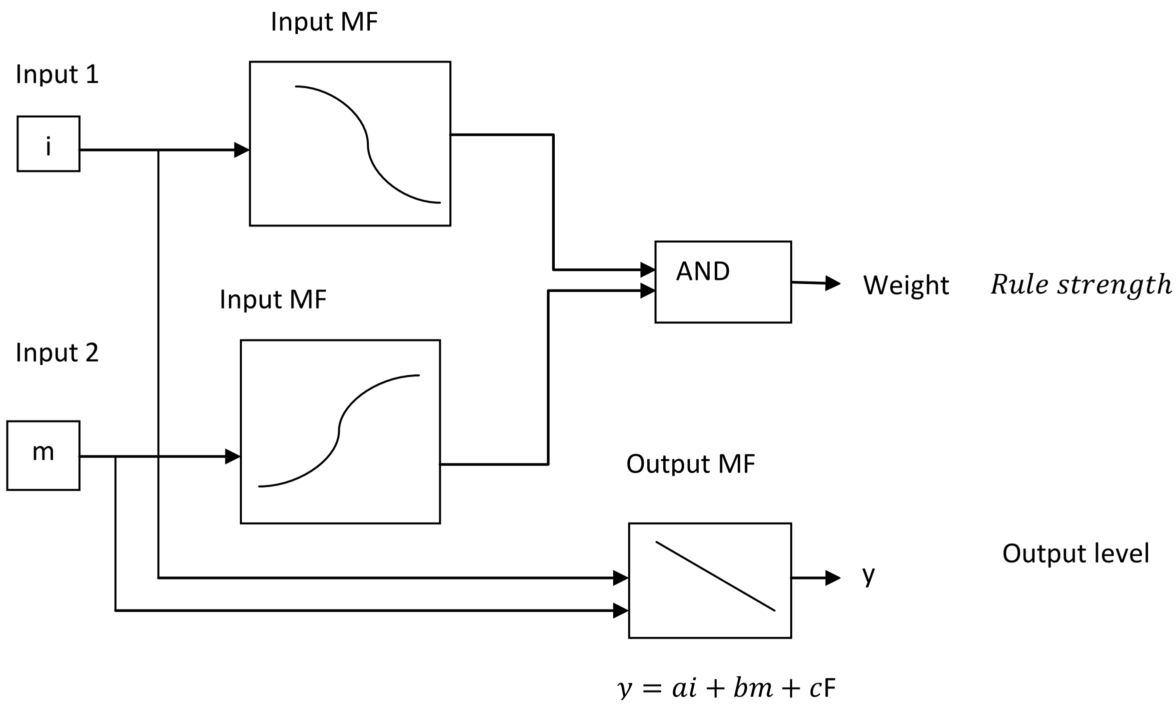
The rule strength is achieved based on weighted average rule and is denoted as,

$$Rulestrength = \frac{\sum_{x=1}^{N} weight_x h_x}{\sum_{x=1}^{N} weight_x} \qquad (3)$$

where N is the number of rules. The weight value id calculated by using following formula:

$$weight_x = ANDMETHOD(F_1(i).F_2(m))$$

Where $F_1(i)$ *and* $F_2(m)$refers the membership functions for input i and input m.



In our proposed system, three fuzzy input variables are considered to select the super cluster head (SCH). All the three input variables have three membership functions each. The threes input variables are battery power, distance and concentration. The fuzzy set that represents the first input variable is remaining battery power. The linguistic variables for the fuzzy set is less, medium and high. Triangular membership function which has high computation speed has been considered for less, medium and high. The second fuzzy input variable is the distance to the base station. The linguistic variables for the distance to BS are taken as close, adequate, and far. The third fuzzy input variable is the concentration that means how many nearby nodes around the leader node. The linguistic variables for concentration are considered as low, medium and high.

Our proposed system used 27 rules in the fuzzy inference which is given in table 1. These rules are represented as B, D, C and CH. B defines the battery power, D defines the distance to base station, C defines the concentration and CH represents the chance. The output chance comprised of 7 membership functions areStrong, Very Strong, Very Poor, Poor, average, below average and above average which are given in table 2 and 3. This chance value is evaluated based on three input variables are concentration by the fuzzy rules, remaining battery power and distance to the base station. Such rules are obtained by using following equation.

$$CH = weight * \text{minimum}\ valueofmembershipfunction \qquad (4)$$

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ISSN (Print) : 2277-5366

Table 1. 27 Fuzzy rules

Remaining Battery Power	**Mobility**	**Centrality**	**Chance**
Less (0)	Low (0)	Close(0)	Very Weak (-1)
Less (0)	Low (0)	Adequate (1)	Weak(0)
Less (0)	Low (0)	Far(2)	Lower Medium(1)
Less (0)	Moderate(1)	Close(0)	Weak (0)
Less (0)	Moderate(1)	Adequate (1)	Lower Medium(1)
Less (0)	Moderate(1)	Far(2)	Medium (2)
Less (0)	Frequent(2)	Close(0)	Lower Medium(1)
Less (0)	Frequent(2)	Adequate (1)	Medium (2)
Less (0)	Frequent(2)	Far(2)	Higher Medium(3)
Medium(1)	Low (0)	Close(0)	Weak (0)
Medium(1)	Low (0)	Adequate (1)	Lower Medium(1)
Medium(1)	Low (0)	Far(2)	Medium (2)
Medium(1)	Moderate(1)	Close(0)	Lower Medium(1)
Medium(1)	Moderate(1)	Adequate (1)	Medium (2)
Medium(1)	Moderate(1)	Far(2)	Higher Medium(3)
Medium(1)	Frequent(2)	Close(0)	Medium (2)
Medium(1)	Frequent(2)	Adequate (1)	Higher Medium(3)
Medium(1)	Frequent(2)	Far(2)	Strong (4)
High(2)	Low (0)	Close(0)	Lower Medium(1)
High(2)	Low (0)	Adequate (1)	Medium (2)
High(2)	Low (0)	Far(2)	Higher Medium(3)
High(2)	Moderate(1)	Close(0)	Medium (2)
High(2)	Moderate(1)	Adequate (1)	Higher Medium(3)
High(2)	Moderate(1)	Far(2)	Strong (4)
High(2)	Frequent(2)	Close(0)	Higher Medium(3)
High(2)	Frequent(2)	Adequate (1)	Strong (4)
High(2)	Frequent(2)	Far(2)	Very Strong (5)

Table 2. Membership functions for input variables

MEMBERSHIP FUNCTIONS		
Remaining battery power	**Mobility**	**Centrality**
Less (0)	Low (0)	Close (0)
Medium (1)	Moderate (1)	Adequate (1)
High (2)	Frequent (2)	Far (2)

Table 3. Membership functions for output variable

Membership Functions
Chance
Very Weak (-1), Weak (0), Lower Medium (1), Medium (2), higher medium(3), Strong(4), Very Strong (5)

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2.8. Data Transmission to base station-distance measurement

Once the SCH is selected, then the data is transmitted to the base station based on the distance measurement. The distance between the Cluster Head and Super Cluster Head or Base Station and Cluster Head are calculated. The distance measurement is useful for improving the lifetime of the nodes by means of reducing the energy consumption.

If the distance between SCH and BS is smaller than the distance between CH and BS then CH will transmit the data to the BS through SCH otherwise CH will transmit the data directly to the BS.If the distance between CH and BS is less than the CH and SCH then the data transmitted directly to the BS. Thus, multi hop data transmission is introduced by which data from cluster members are directly transmitted to the BS.

There are several steps that have to be followed for data transmission are given below:

1. Constructing proximity matrix using distance. i.e., distance between CH and SCH, distance between CHs and BS
2. Cluster formation using LEACH
3. Identify shortest path
4. If the distance between CH and SCH is greater than that of distance between CH and BS, then data in the CH node is directly transferred to the BS

Thus the energy consumption is further reduced by which network lifetime increases in an efficient manner.

Algorithm

1. Begin
2. Initialize the number of nodes
3. Dynamic cluster formation using LEACH
4. Compute threshold based on linear prediction function using (1)
5. Select Cluster Head
6. Generate a set of Sugeno-type Fuzzy rules
7. Fuzzifying the inputs using the input membership functions
8. Combining the fuzzified inputs according to the fuzzy rules to establish the rule strength
9. Combining the consequences to get an output function
10. De-fuzzifying the output function
11. Choose Super Cluster Head based on (2)
12. Calculate the distance, d_1 between CH and SCH
13. Calculate the distance, d_2 between CH and BS
14. $If\,(d_1 > d_2)$ then
15. Transmit the data directly from CH to BS
16. Else
17. Transmit the data to BS through CH and SCH
18. End if
19. End

3. Results and discussion

To prove the effectiveness and validity of proposed protocol, NS-2 simulator has been used to compare the performance of existing and proposed technique. In this experiment we have considered 50 nodes randomly deployed over the area between (x=0, y=0) and (x=100) y=100) with BS location (x=50, y=50). We assume four numbers of clusters. Each round duration is 20s. The bandwidth of the channel is 1 Mbps. Each data message is 500 bytes long; packet header length is 25 bytes.

3.1. End to end delay

End to end delay is defined as the maximum time taken by the packets to travel from one node to another node. Figure 1 shows that end to end delay comparison between fuzzy based and proposed scheme in terms of delay time values. The result shows that the proposed system provides lower delay time than the existing fuzzy techniques.

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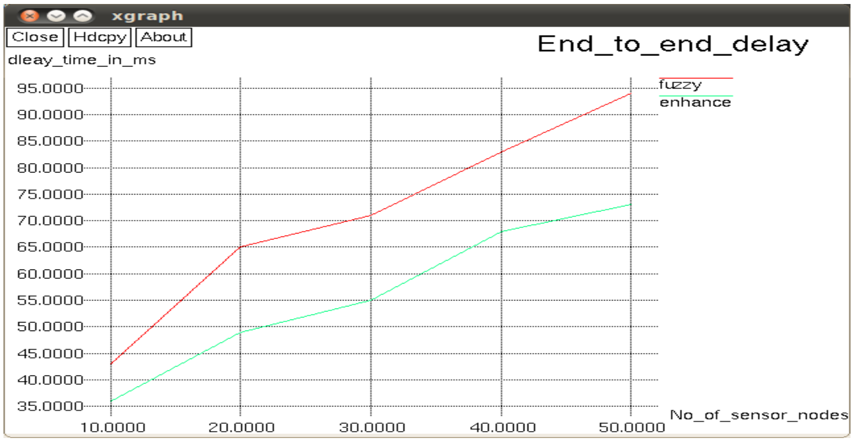
Figure 1. End to end delay comparison



3.2. Network lifetime

The lifetime of network is defined as the operational time of the network during which it is able to perform the dedicated task.

Figure 2 shows that network lifetime comparison between fuzzy based and proposed scheme in terms of network time values. The result shows that the proposed system provides higher network lifetime than the existing fuzzy techniques.

3.3. Packet delivery ratio

The ratio of packets that are successfully delivered to a single node compared to the number of packets that have been sent out by another node.

Figure 2. Network lifetime comparison

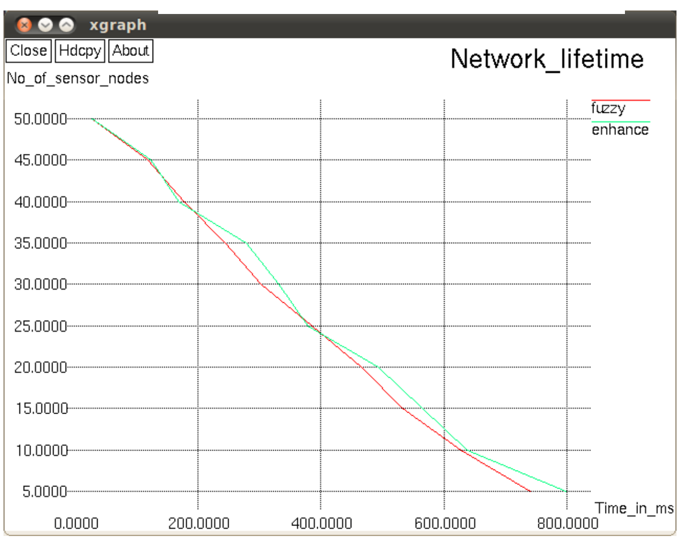


Figure 3. Packet delivery comparison

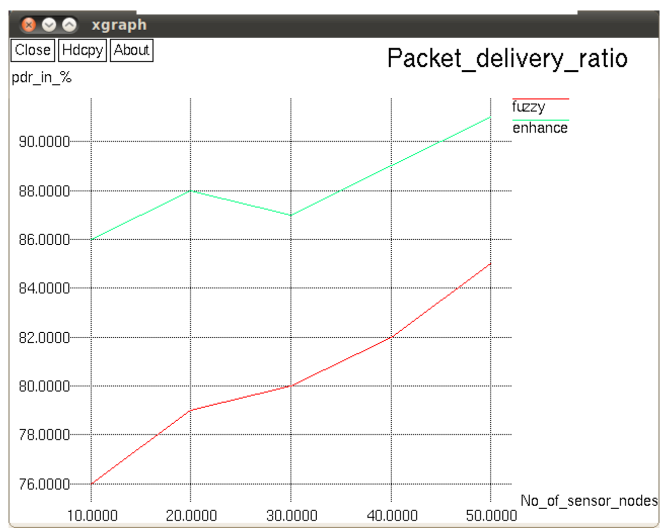


Figure 3 shows that Packet delivery ratio comparison between fuzzy based and proposed scheme in terms of percentage values. The result shows that the proposed system provides higher packet delivery ratio than the existing fuzzy techniques.

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4. Conclusion

In this paper, Sugeno-type Fuzzy Inference based clustering (SFIC) algorithm is proposed for prolonging the network lifetime by effectively reducing the energy consumption. Dynamic cluster formation is developed in which regression based threshold estimation is utilized to select Cluster Head. Then, Super Cluster Head is selected based on the Sugeno fuzzy inference rules. Then direct data transmission method is included for further reducing the energy loss from the network. Experiments are conducted and the performance result shows that, SFIC algorithm increases the network lifetime, packet delivery and end to end delay than the FLC algorithm.

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