Journal of Information & Computational Science 7: 3 (2010) 767–775
Available at http://www.joics.com

Improving on LEACH Protocol of Wireless Sensor Networks Using Fuzzy Logic

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Abstract

The Wireless Sensor Networks (WSN) consists of a large number of sensor nodes that are limited in energy, processing power and storage. The energy of nodes is the most important consideration among them because the lifetime of Wireless Sensor Networks is limited by the energy of the nodes. LEACH is one of the most famous clustering mechanisms; it elects a cluster head (CH) based on a probability model. This paper improves LEACH protocol using Fuzzy Logic (LEACH-FL), which takes battery level, distance and node density into consideration. The proposed method has been proved making a better selection by comparison simulations using Matlab.

Keywords: Wireless Sensor Networks; LEACH; Fuzzy Logic; LEACH-FL

1 Introduction

In general, the Wireless Sensor Networks consists of a large number of small and cheap sensor nodes that have very limited energy, processing power and storage. They usually monitor areas, collect data and report to the base station (BS). Due to the achievement in low-power digital circuit and wireless communication, many applications of the WSN are developed and already been used in habitat monitoring, military object and object tracking [1]. The energy consumption can be reduced by allowing only a portion of the nodes, which called cluster heads, to communicate with the base station. The data sent by each node is then collected by cluster heads and compressed. After that the aggregated data is transmitted to the base station. Although clustering can reduce energy consumption, it has some problems. The main problem is that energy consumption is concentrated on the cluster heads. In order to overcome this demerit, the issue in cluster routing of how to distribute the energy consumption must be solved. The representative solution is LEACH [2], which is a localized clustering method based on a probability model. The main idea of LEACH protocol is that all nodes are chosen to be the cluster heads periodically, and each period contains two stages. The first stage is construction of clusters, and the second stage

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March 2010

is data communication. Cluster heads are selected according to the probability of optimal cluster heads decided by the networks. After the selection of cluster heads, the clusters are constructed and the cluster heads communicate data with base station. Because LEACH is only depend on probability model, some cluster heads may be very close to each other and can be located in the edge of the WSN [3]. These in-efficient cluster heads could not maximize energy efficiency. Recently, a cluster head election method using fuzzy logic has been introduced by Gupta to overcome the defects of LEACH. They probed that the network lifetime can be efficiently prolonged by using fuzzy variables (concentration, energy and centrality) [4]. In the proposed method, a part of energy is spent to get the data of the three variables especially concentration and centrality. In this paper, a method based on LEACH using Fuzzy Logic to cluster heads selection is proposed based on three variables - battery level of node, node density and distance from base station, and this method will be introduced based on the assumption that the WSN can get their coordinate. Although this method has the same drawback as of Gupta's method, it presents a better result. For a cluster, the nodes selected by the base station are the nodes that have the higher chance to become the cluster heads using Fuzzy Logic based on their battery level, node density and distance. The remainder of this paper is structured as follows. Related work is discussed in section 2. In section 3 we introduce the proposed system model. In section 4, we show the simulations results of our method compared with those of LEACH. And finally, conclusions are given in section 5.

2 Related Work

The main idea of LEACH protocol is that all nodes are chosen to be the cluster heads periodically, and each period contains two stages with construction of clusters as the first stage and data communication as the second stage. The architecture of the model is shown in Figure 1.

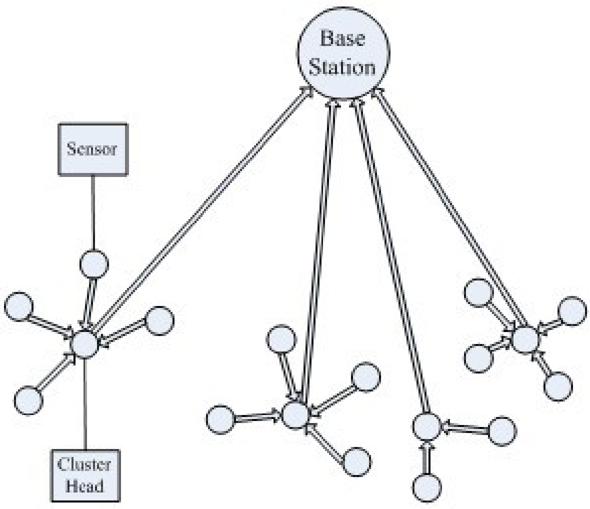

Fig. 1: WSN Architecture

Each node is selected to be the cluster heads according to the probability of optimal cluster heads decided by the networks. In each round, every node gets a random number between 0 and 1. If the number is less than the threshold values-T(n), the node becomes a CH for the current round [3]. T(n) is shown below:

$$T(x) = \begin{cases} \frac{\mathrm{P}}{1-\mathrm{P}\times(\mathrm{rmod}\frac{1}{\mathrm{P}})} & \text{if } \mathrm{n} \in \mathrm{G}, \\ 0 & \text{otherwise} . \end{cases} \tag{1}$$

The algorithm is based on the radio model used by LEACH. There are two different radio models proposed in [5]: The free space model and the multi-path fading channel model. When the distance between the transmitter and receiver is less than threshold value d_0, the algorithm adopts the free space model (d^2 power loss). Otherwise the algorithm adopts the multi-path fading channel model (d^4 power loss). So if the transmitter sends an l-bit message to the receiver up to a distance of d, the energy consumption of the transmitter and t receiver can be calculated by the following equations:

$$\mathrm{E_{Tx}(k, d)} = \{^{\mathrm{E_{elec}*k+\varepsilon_{\mathit{fs}}*k*d^2,d<d_0}}_{\mathrm{E_{elec}*k+\varepsilon_{\mathit{mp}}*k*d^4,d\geq d_0}} \tag{2}$$

$$\mathrm{E_{Rx}(k)} = \mathrm{E_{elec}} * \mathrm{k} \tag{3}$$

E_{Tx}(k,d) is the energy consumption of the transmitter who sends an k-bit message to the receiver up to a distance of d ; E_{Rx}(k) is the energy consumption of the receiver who receives an k - bit message; E_{elec} is the energy consumption of the wireless send-receive circuit; ϵ_{fs} and ϵ_{mp} represent the energy consumption factor of amplification in the two radio models. The most important part of the proposed method is Fuzzy Inference System (FIS) [5]. The FIS has four parts and the architecture of the model is shown in Figure 2.

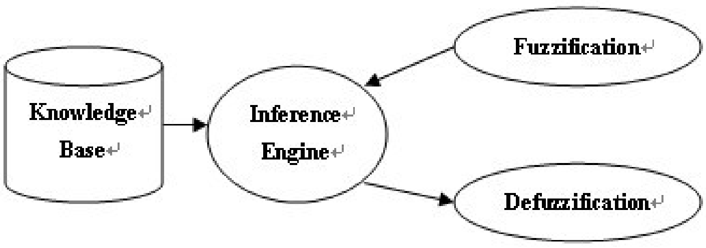

Fig. 2: FIS Architecture

1. Fuzzification module: transforms the system inputs, which are crisp numbers, into fuzzy sets. This is done by applying a fuzzification function.

2. Knowledge base: stores IF-THEN rules.

3. Inference engine: simulates the human reasoning process by making fuzzy inference on the inputs and IF-THEN rules.

4. Defuzzification module: transforms the fuzzy set obtained by the inference engine into a crisp value.

We use Mamdani's [5] method for the inference process of the proposed method. Mamdani's method is most commonly used in applications, due to its simple structure of 'min-max' operations. There are four steps to get the crisp value from the FIS system. The first step is to evaluate the antecedent for each rule. The second step is to obtain each rule's conclusion. The third step is to aggregate conclusions and the last step is defuzzification. LEACH-FL SYSTEM MODEL

3 LEACH-FL System Model

In proposed methods, we assume that nodes of WSN can get their coordinate. The LEACH-FL system has three parts, four fuzzification functions, an inference engine (conclude 27 rules) and a defuzzification module. The architecture of the model is shown in Figure 3 [6], but defuzzification module isn't shown in the figure because it just a formula and will be shown later.

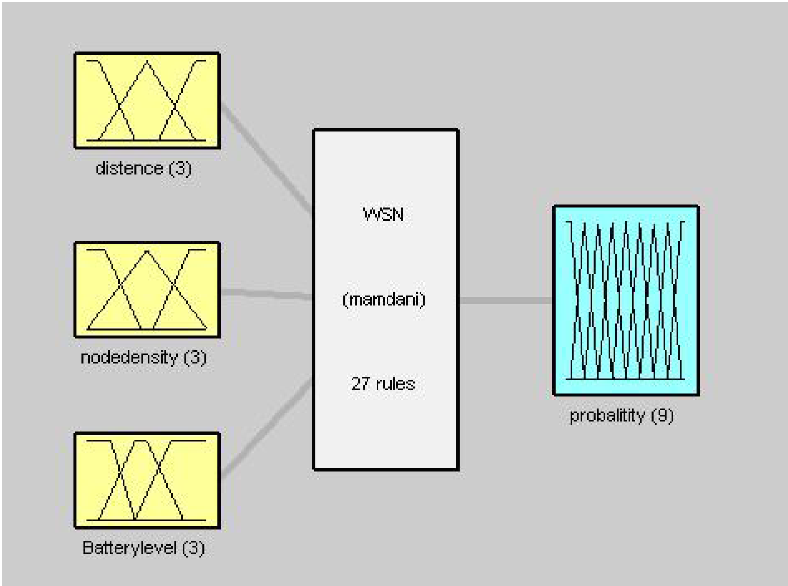

Fig. 3: LEACH-FL System Architecture

3.1 Fuzzification Module

Considering that three attributes of the nodes are needed to determine the cluster heads selection, we use three input functions to transforms the system inputs into fuzzy sets, which are distance, node density and battery level. Each of the input functions has three membership functions that show the different degree of the functions. The numbers after the membership functions show the degree of the membership function and also illustrate that the relationship among the input functions is more numerical, we will show that later. Table 1 gives the input functions.

Table 1: Input functions

input	membership		
distance	near(0)	medium(1)	far(2)
node density	sparsely(0)	medium(1)	densely(2)
battery level	low(0)	medium(1)	high(2)

The output function is composed of 9 membership functions. We use 9 functions instead of 7 functions of previously proposed system [4] [7], because the differences of importance of the inputs can be reflected more clearly. Table 2 gives the output functions. The four fuzzification functions (distance, node density, battery Level, and probability) are shown in Figure 4.

Table 2: Output functions

output	membership function
probability	very weak(0) weak(1) little weak(2) lower medium(3) medium(4) higher medium(5) little strong(6) strong(7) very strong(8)

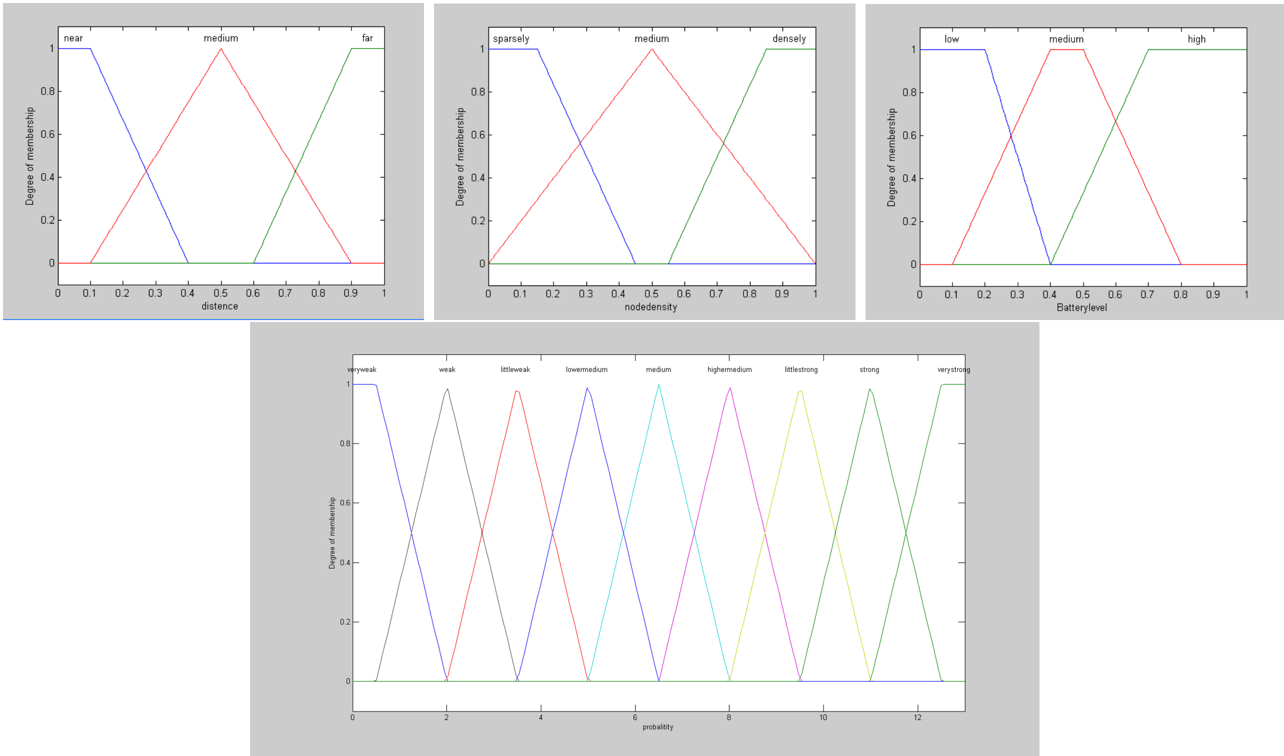

Fig. 4: Fuzzification Functions:(a)Distance(b)Node Density(c)Battery Level(d)Probability

3.2 Knowledge Base

In our system, we have 27 rules in the fuzzy inference. The form of the rules is: IF A and B and C THEN D. A, B, C and D represent battery level, node density, distance and probability respectively. The rules are based on the following formula.

$$\text{Probability} = \text{batterylevel} * 2 + \text{nodedensity} + (2 - \text{distance}) \tag{4}$$

The formula expounds the relationship among the input functions obviously. The battery level is the key for the probability of cluster heads selection. We show the rules in table 3.

3.3 Defuzzification Module

After aggregating the conclusions obtained by each rule, a defuzzification method is still needed to get the crisp value. One of the most popular defuzzification methods is the centroid, which returns the center of the area under the fuzzy set obtained aggregating conclusions. The centroid is shown in figure 5.

Table 3: Rules

battery level	node density	distance	probability
low(0)	sparsely(0)	far(2)	very weak(0)
low(0)	sparsely(0)	medium(1)	weak(1)
low(0)	sparsely(0)	near(0)	little weak(2)
low(0)	medium(1)	far(2)	weak(1)
low(0)	medium(1)	medium(1)	little weak(2)
low(0)	medium(1)	near(0)	lower medium(3)
low(0)	sparsely(0)	far(2)	little weak(2)
low(0)	sparsely(0)	medium(1)	lower medium(3)
low(0)	sparsely(0)	near(0)	medium(4)
medium(1)	sparsely(0)	far(2)	little weak(2)
medium(1)	sparsely(0)	medium(1)	lower medium(3)
medium(1)	sparsely(0)	near(0)	medium(4)
medium(1)	medium(1)	far(2)	lower medium(3)
medium(1)	medium(1)	medium(1)	medium(4)
medium(1)	medium(1)	near(0)	higher medium(5)
medium(1)	sparsely(0)	far(2)	medium(4)
medium(1)	sparsely(0)	medium(1)	higher medium(5)
medium(1)	sparsely(0)	near(0)	little strong(6)
high(2)	sparsely(0)	far(2)	medium(4)
high(2)	sparsely(0)	medium(1)	higher medium(5)
high(2)	sparsely(0)	near(0))	little strong(6)
high(2)	medium(1)	far(2)	higher medium(5)
high(2)	medium(1)	medium(1)	little strong(6)
high(2)	medium(1)	near(0)	strong(7)
high(2)	sparsely(0)	far(2)	little strong(6)
high(2)	sparsely(0)	medium(1)	strong(7)
high(2)	sparsely(0)	near(0)	very strong(8)

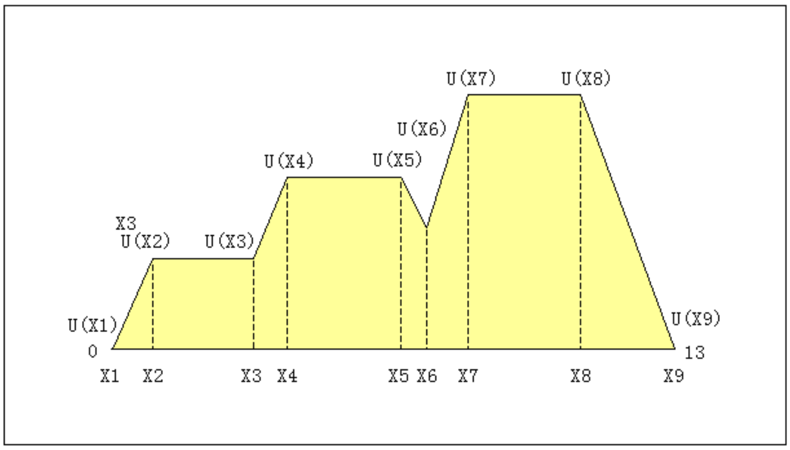

Fig. 5: Centroid

We use Formula G(i) to get the value of probability:

$$G(i) = \frac{\sum_{j=1}^{n} x_j \cdot u(x_j)}{\sum_{j=1}^{n} u(x_j)} \tag{5}$$

Each node of the WSN calculates a value G(i) through the above system. The computed result shows that the value of G(i) is betweens 0.665 and 12.2335. In LEACH protocol, every node gets a random number betweens 0 and 1, and the nodes that have a number less than the threshold values are selected to be the cluster heads. So we translate G(i) to F(i) using a linear method. In each round, if the F(i) of a node is less than the threshold values, the node is selected to be the cluster heads. F(i) is shown below:

$$F(i) = 1 - \frac{G(i) - 0.665}{12.2335 - 0.665} \tag{6}$$

4 Simulation Results

Simulations are performed in Matlab [6] to verify our methods. Figure 6 shows that the three attributes of the nodes have different effect on the probability of the nodes to be cluster nodes. First of all, with the increase of the battery level and node density, the probability of a node to be selected as a CH is increased. While with the increase of the distance between the node and the BS, the probability of a node to be selected as a CH is decreased. Second, the battery level plays a very important role in the selection of the cluster heads, because even the distance is far and the node density is low, the node of high battery level can still have a not-low probability. So, a node of low battery level will have a low probability obviously.

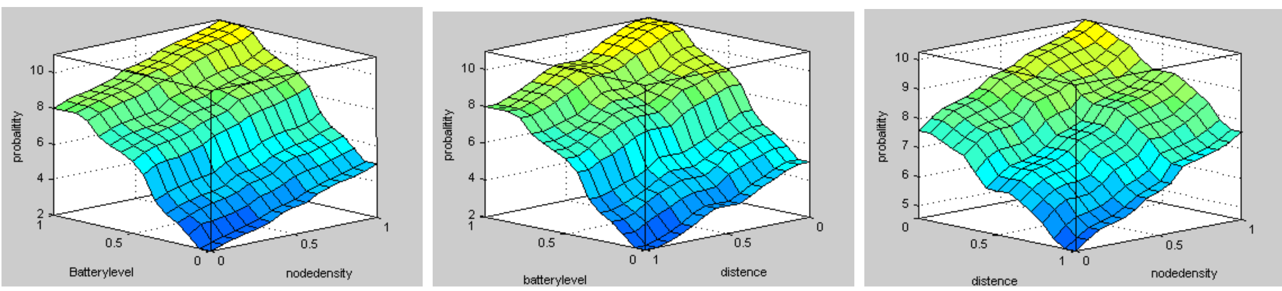

Fig. 6: Surface:(a)Node Density,Battery Level(b)Distance,Battery Level(c)Distance,Node Density

To compare with LEACH, the networks that have an area of 100*100 with 20 nodes are selected. The coordinate of the BS is (50,200) and the parameters are shown in table 4.

Table 4: Parameters

initial energy	0.5J	E_{elec}	50nJ / bit
ϵ_{fs}	10pJ /(bit*m^2)	ϵ_{mp}	0.0013pJ/(bit*m^4)

Figure 7(a) shows the energy consumption of the proposed system compared with that of LEACH. The increase rate of energy consumption of the proposed system is much lower than the rate of LEACH. Figure 7(b) shows the nodes alive of our system compared with the nodes alive of LEACH. Besides, both the dead time of the first node and the dead time of the last node of proposed system are later than those of LEACH. So WSN can get longer life and enjoy longer receiving of integral data by using the proposed method. Compare to LEACH, Gupta's methods [4] can make only about 1.8 times the number of living rounds, while our proposed method can make 2.2 3.8 times the number of living rounds.

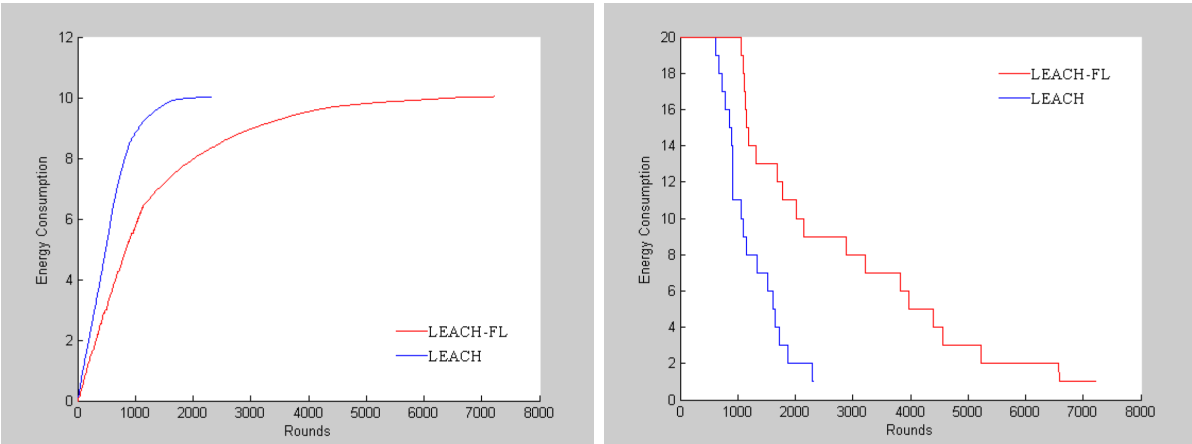

Fig. 7: (a)Energy Consumption(b)Nodes

Some networks have the environment of densely nodes, so we evaluate the proposed method for the networks that have an area of 100*100 with 200 nodes. The result shows better performance of the proposed method. Therefore, the proposed method is more suitable for the environment of densely nodes.

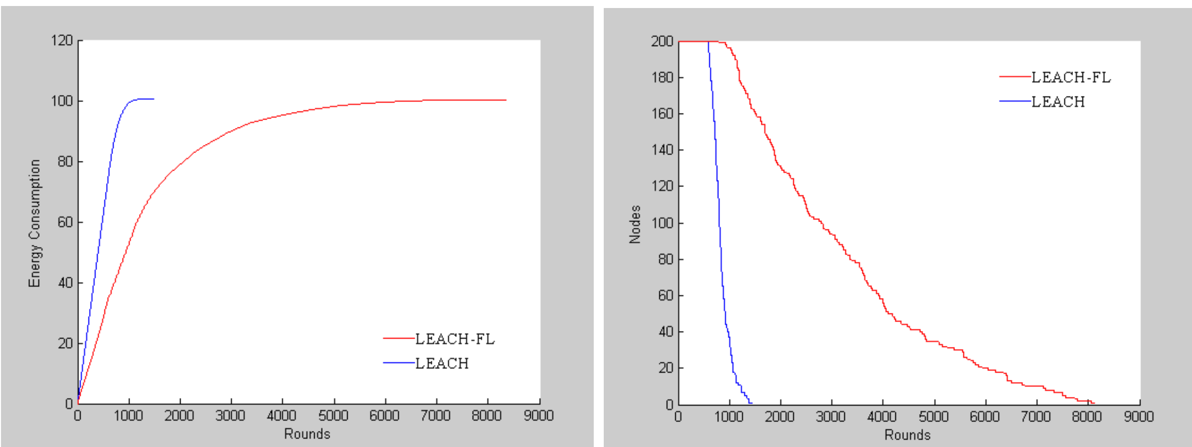

Fig. 8: (a)Energy Consumption(b)Nodes

5 Conclusion and Future Work

The energy is the most important factor in designing the protocol for WSN. LEACH is one of the most famous clustering mechanisms, it elects a cluster head based on probability model. However, LEACH is only depend on probability model, some cluster heads may be very close to each other and can be located in the edge of the WSN. These in-efficient cluster heads could not maximize the energy efficiency. A method has been built based on the improvement of LEACH by using fuzzy logic and choosing battery level, distance and node density to be the attributes of the cluster heads selection. Our method asks the nodes for more calculations and communications to get the data of the node density and the distance. The simulation result shows that the battery level plays a very important role in the selection of the cluster heads and our method makes a better decision of the cluster heads selection. Although we compared LEACH-FL with LEACH and Gupta's method, there are many protocols that have to be compared. We should consider more factors that can affect the lifetime of WSN. The fuzzification functions and rules need to be optimized by more simulations.

References

[1] C. Shen, C. Srisathapornphat, and C. Jaikaeo, Sensor Information Networking Architecture and applications, IEEE Personal Communications, pp. 52-59, Aug 2001

[2] Heinzelman, A. Chandrakasan and H. Balakrishnan, An application-specific protocol architecture for wireless microsensor networks, in IEEE Transactions on Wireless communications, pp. 660 - 670, Oct 2002

[3] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, Energy-efficient Communication Protocol for Wireless Microsensor Networks, Proceedings of 33rd Hawaii International Conference on System Sciences, Jan., 2000

[4] I. Gupta, D. Riordan and S. Sampalli, Cluster-head Election using Fuzzy Logic for Wireless Sensor Networks, Communication Networks and Services Rearch Conference, pp.255-260, May 2005

[5] http://www.dma.fi.upm.es

[6] http://www.mathworks.com/ Fuzzy Logic Toolbox user's guide

[7] J. Anno, L. Barolli, F. Xhafa, and A. Durresi, A Cluster Head Selection Method for Wireless Sensor Networks Based on Fuzzy logic, Proc. of IEEE TENCON-2007, CD-ROM, 4 pages, 2007