ISSN: 2229-6948(ONLINE)
DOI: 10.21917/ijct.2012.0091

FUZZY LOGIC BASED ENERGY EFFICIENT PROTOCOL IN WIRELESS SENSOR NETWORKS

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Abstract

Wireless sensor networks (WSNs) have been vastly developed due to the advances in microelectromechanical systems (MEMS) using WSN to study and monitor the environments towards climates changes. In environmental monitoring, sensors are randomly deployed over the interest area to periodically sense the physical environments for a few months or even a year. Therefore, to prolong the network lifetime with limited battery capacity becomes a challenging issue. Low energy adaptive cluster hierarchical (LEACH) is the common clustering protocol that aim to reduce the energy consumption by rotating the heavy workload cluster heads (CHs). The CHs election in LEACH is based on probability model which will lead to inefficient in energy consumption due to least desired CHs location in the network. In WSNs, the CHs location can directly influence the network energy consumption and further affect the network lifetime. In this paper, factors which will affect the network lifetime will be presented and the demonstration of fuzzy logic based CH selection conducted in base station (BS) will also be carried out. To select suitable CHs that will prolong the network first node dies (FND) round and consistent throughput to the BS, energy level and distance to the BS are selected as fuzzy inputs.

Keywords:

Wireless Sensor Network, Cluster Head, First Node Dies, Fuzzy Logic

1. INTRODUCTION

Wireless sensor network has been announced as one of the technologies that will change the world [1]. Hundreds or even thousands of smart wireless sensor nodes can form a huge yet intelligent WSN. Each sensor node is equipped with sensing unit, power unit, processing unit and communication unit as shown in Fig.1. The sensor node is powered by the power unit that may consist of a small battery. Sensor node can sense elements such as temperature, light intensity and water level from the physical environment by using suitable preloaded sensor unit. The analog signal given by the sensor unit will be converted into digital signal that is recognizable by the microcontroller unit based on the analog to digital converter (ADC) module. The sensed data will be further transmitted to the BS through the communication unit. Basically, the wireless sensor node has the ability to correspond among its peers rather than just directly communicate with the BS. Therefore, there are tons of possible communication methods to be considered in reducing the energy consumption while maintaining the successive information delivered to the end user.

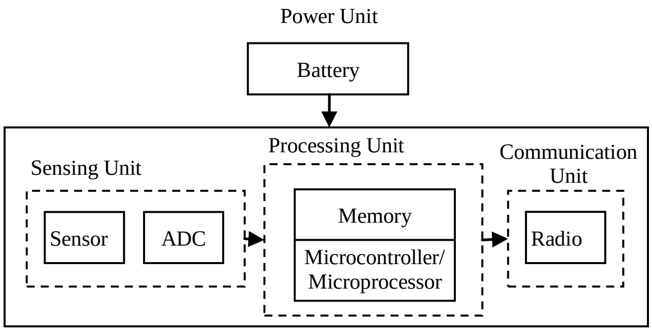

Fig.1. Sensor Node Structure

To fulfill the design objectives such as the sensor node size has to be compact for convenience usage, the design become difficult and challenging. The trade-offs for being compact in physical size are limited power source, limited computation power and small memory storage. Sensor node energy is the most important issue that affect the network lifetime. Due to the nodes are small in size and it may be deployed in hazardous areas, thus replacement of drained out battery become impractical and impossible. Therefore, to save energy and prolong the network lifetime by improving the routing algorithm is more practical. Furthermore, it is vital to reduce the energy consumption by proper control in wireless communication activity, since the energy cost to transmit one bit over 100 m is equal to energy consumed to execute 3000 instructions [2]. Cluster based hierarchical routing protocol is an energy-efficient routing protocol that is suitable for environmental monitoring. In the cluster, sensor nodes will be divided into a few groups and each consist one CH. The CH will collect data from member nodes in the same cluster and aggregate the collected data to be transmitted to the BS with reduced packet size. By implementing this protocol, it will significantly reduce the overall energy consumed and the network congestion by only allowing the CH to be communicating with the BS [3]-[4].

LEACH protocol is one of the common cluster routing protocols that aims to achieve the load balancing in sensor nodes by rotating the CH to prolong the network lifetime. Normally, in cluster routing protocol, energy consumption is concentrated on CHs which have to collect and aggregate the sensed data from member nodes and later forward the aggregated information to the BS [5]-[6]. In theory, LEACH protocol allows sensor nodes to elect itself as a CH based on the probability model. Every sensor nodes will become CH once in a cycle to evenly distribute the work loads. The disadvantage of LEACH protocol in CH election is that it only depends on the probability model to elect the CH without any sensor node parameters consideration, therefore it is possible that no CHs or too many are selected in a single round [7]. Furthermore, the elected CHs may be located near to each other and it leads to inefficient energy distribution [8].

In order to have an overview over the network for CH selection, CH selection decision is made in the BS. The author of LEACH proposed LEACH-C that utilizes centralized algorithm to elect the CHs in the BS using the simulated annealing algorithm [9]. Gupta proposed a CH selection algorithm that considers the sensor nodes status as selection criteria [10].

By considering three parameters which are the node remaining energy, the concentration and the centrality of sensor nodes, the fuzzy logic control will select the suitable CHs among the other sensor nodes. These CH selection mechanisms that are constructed in the BS require the sensor node status such as location (possible determined using a global positioning system (GPS) receiver) and the remaining energy. Basically, in order to use the algorithm, the centralized BS needs to know the sensor nodes location information. At the first round, location information will be transmitted to the BS and the algorithm assumes all sensor nodes are under minimal mobility constraint. GPS receivers consume large amounts of power since GPS is one of the communication radios. In this stage, it is too expensive in terms of price and energy cost to include the GPS in the sensor nodes for location purpose of the entire wireless sensor networks.

In short, this project aims to prolong the FND round and consistent throughput to the BS in every round. Furthermore, it does not need to know the location information of the sensor nodes. Centralized fuzzy logic based on the cluster heads selection mechanism in BS is proposed. Fuzzy logic control is used to manipulate the linguistic rules into mathematical form; it can perform fast and execute the real time decision with simplicity of the algorithm [11]. Moreover, the consideration of extra parameters in CH selection such as battery charging rate and data queue length can produce an optimized solution [12].

The paper is organized as follows: in the next section, overview of cluster based hierarchical routing protocol LEACH and fuzzy logic cluster based are demonstrated. Section 3 explains the system model followed by the analysis of the simulation results in section 4. Lastly, section 5 concludes the findings.

2. RELATED WORK

In this section, one of the cluster based hierarchical routing protocol which is LEACH protocol will be discussed. The discussion includes the fundamental theory of LEACH, the framework of the cluster formation and the disadvantages suffered by the LEACH protocol. In Section 2.2, cluster heads selection based on fuzzy logic control is illustrated. The illustration includes the basic block diagram of fuzzy logic centralized cluster heads selection model.

2.1 CLUSTER BASED HIERARCHICAL ROUTING PROTOCOL

Generally, in direct communication each sensor node has to transmit their sensed data to the BS which is located far away. The lifetime of the sensor node that is located further away from the BS will be much shorter. Cluster based hierarchical routing protocol can reduce the energy consumption by only allowing the selected CHs to transmit the aggregated data to the BS. CH aggregates the collected data from the cluster member to reduce the long range transmission count. In order to further reduce the energy consumption, the network will be split into few clusters to reduce the cluster size and hence reduce the energy consumption by the cluster members.

LEACH [2] is one of the clustering protocols that distribute the energy concentration in the same sensor node by rotating the CH. LEACH operates in rounds; each round consists of two phases which are the set-up phase and steady phase. In the set-up phase, it includes advertisement phase and cluster set-up phase while the steady phase includes the schedule creation and data transmission. During each round, the node independently generates a random number between 0 and 1.

If the generated number is less than the threshold value $T(n)$ which is defined by Eq.(1), the node will be elected as CH for the current round. Fig.2 shows the flowchart of the LEACH protocol and it will be used after cluster head selection procedure. As shown in Fig.1, if the sensor node is elected to be a CH, it will broadcast a message to its surroundings to inform the other sensor nodes as it had been elected as CH. Non-CH sensor node may receive few message from different CHs, which they will decide to join the nearest CH based on the RSS. After some period, CH will again broadcast the time division medium access (TDMA) to its cluster and the cluster members will transmit their sensed data to the CH according to the predefined time slot shown in TDMA.

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

The description of each symbol is: r is the round which already ended, p is the proportion of the nodes to CHs and G is a set of nodes which have never been CH in the last $1/p$ rounds.

Although the nature of LEACH protocol can distribute the heavy workload by rotating the CH, but the protocol faces some of the disadvantages as shown below:

- The elected CH may locate near to each other which results in uneven cluster formation.
- The number of elected CHs is not consistent in each round hence the BS will receive more or no data during each round.
- The elected CH may appear at the edge of the network and undesirable location.

The elected CH in LEACH protocol is based on probability model, therefore it can be observed that its disadvantages are mainly due to the consideration of local information [3]-[4]. Having the network overview to select suitable CH based on the critical parameters can improve the network lifetime.

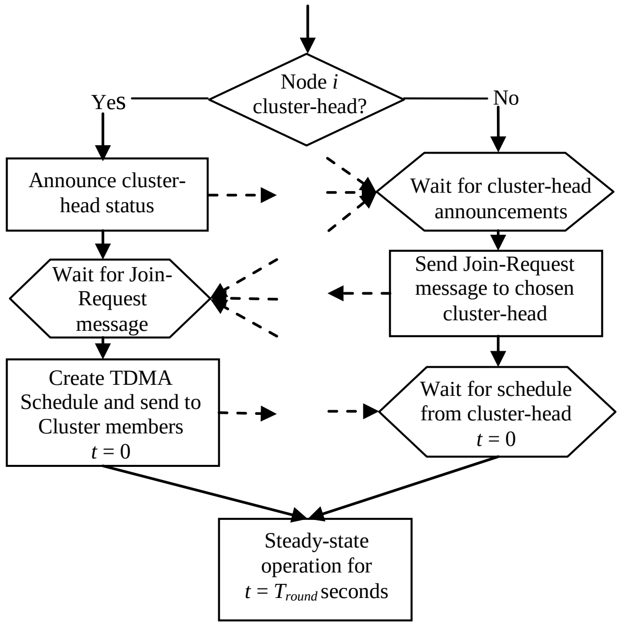

Fig.2. Flowchart of the LEACH Protocol

2.2 CLUSTER HEADS SELECTION USING FUZZY LOGIC CONTROL

The CHs selection algorithm using fuzzy logic control will be constructed in the BS that has the global view over the networks. The BS is more powerful than the sensor nodes in terms of computation power, sufficient memory, unlimited power supply and storage. Fig.3 shows the illustration of the centralized cluster selection model. As shown in Fig.3, the BS is loaded with the fuzzy logic control to compute desirable CHs candidates. By considering three fuzzy parameters which are energy, concentration and centrality, the network lifetime can be improved [10]. Energy level is available in each node, concentration is the number of neighbor nodes and centrality is a value based on how close the node to the cluster.

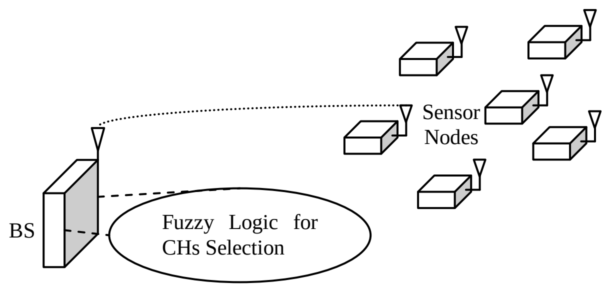

Fig.3. Centralized Cluster Selection Model

The two fuzzy inputs used in this project are:

- Sensor Node Energy – Remaining energy level in the sensor node.
- Distance to BS – The separate distance between the sensor node and the BS.

To obtain the sensor node remaining energy, sensor node can self measure the remaining energy via the ADC module in the microcontroller. The distance information can be obtained based on the received signal strength (RSS). In this work, the assumption of separate distance can be measured based on how RSS is made.

The inputs of fuzzy inference system (FIS) are the energy and the distance of a particular node to the BS. Based on the rule base, FIS will compute and decide the output which is the fitness of a node to become a CH. BS will select $p \times$ total number of nodes to become CHs based on their fitness. Sensor nodes will be listed in a table from highest to lowest according to their fitness. The table restores every single round to keep the information up-to-date. In short, the selected CH should be the best leader in every round.

3. SYSTEM MODEL

To study the effect of sensor nodes' distance on the sensor nodes' energy consumption, a basic linear topology model had been constructed as shown in Fig.4. BS represents the base station whereas node *A*, *B* and *C* are the sensor nodes. The relative distance between node *A* and BS is set as 7R whereas node *B* and *C* are located 6R and 5R away from the BS.

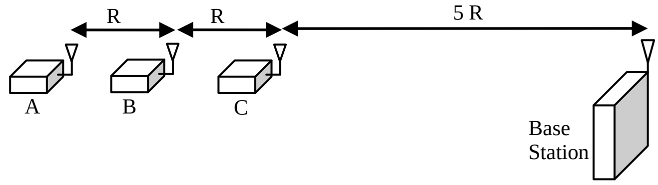

Fig.4. Basic Linear Model

In order to model the wireless network, some assumptions are used in the system as shown below.

- Each sensor nodes have enough power to transmit sensed data to reach the BS.
- The wide transmission range of BS is capable of using only a single broadcast to reach all the sensor nodes.
- The separate distance between sensor node and the BS can be measured based on the RSS.
- Sensor nodes are homogenous, with the similar nodes model and same energy resources.

3.1 RADIO ENERGY MODEL

Fig.3 shows the block diagram of transmitter and receiver in the radio energy model used for this project. The purpose of the radio model is to model the real communication activities in terms of energy consumption for sensor nodes. Based on the model shown in Fig.5, energy will be consumed during data transmission operation and the consumption is larger than data reception operation. The used radio model in this work is referred from [5]. The equation used to represent energy consumption during the transmission and reception for k bits message in the distance d between transmitter and receiver node is given by Eq.(2), where $E_{Tx-elec}$ is energy model of transmit electronic and E_{Tx-amp} is energy model of transmit amplifier.

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$

$$= \begin{cases} kE_{elec} + k\varepsilon_{fs}d^2 \ \ if \ \ d < d_0; \\ kE_{elec} + k\varepsilon_{mp}d^4 \ if \ \ d \geq d_0, \end{cases} \quad (2)$$

The separate distance, d_0 is the threshold for swapping amplification model, which can be calculated as $d_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$. In the reception module, to receive k-bit message, Eq.(2) is expended as in Eq.(3).

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

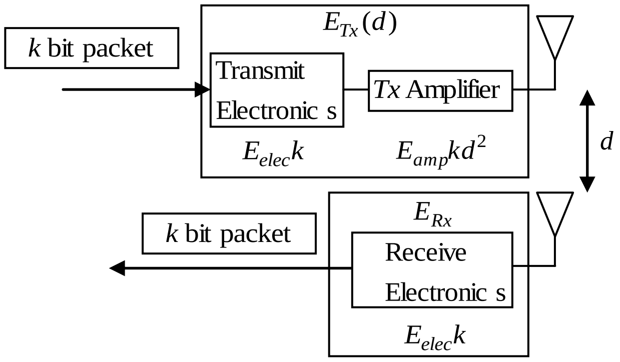

Fig.5. Radio Model Diagram

3.2 SIMULATION PARAMETERS

The simulation is carried out in MATLAB with the radio model parameters as shown in Table.1. The network topology and BS location are varied from each case which will be discussed later.

Table.1. Parameters of the Radio Model

Parameter	Value
Initial Energy, E_0	0.05J
Packet Size, k	4000bit
Energy of transceiver, E_{elec}	50nJ/bit
Energy of data aggregate, E_{DA}	5nJ/bit/message
Transmit amplifier (free space) ε_{fs}	10pJ/bit/m^2
Transmit amplifier (multi path) ε_{mp}	0.0013pJ/bit/m^4

3.3 CLUSTER HEADS SELECTION BASED ON DISTANCE

In wireless communication, distance is one of the factors that may affect the energy consumption as shown in Eq.(2). Distance d refers to the relative distance among the CH, member nodes and the BS. Eq.(4) illustrates communication activity where node A being selected as CH. Based on the modified linear topology as shown in Fig.4. Distance d_1, d_2 and d_3 in Eq.(4) represent the total transmit distance by each sensor nodes.

$$E_{Total} = 2n(E_{elec}k) + n(E_{elec}k + \varepsilon_{amp}k(d_1)^2) + n(E_{elec}k + \varepsilon_{amp}k(d_2)^2) + (E_{elec}k + \varepsilon_{amp}k(d_3)^2) \tag{4}$$

$$E_{Total} = 5n(E_{elec}k) + (E_{elec}k) + (nd_1{}^2 + nd_2{}^2 + d_3{}^2)(\varepsilon_{amp}k)$$

Basically, in the case of n equals to 1 and n represents the numbers of sensor nodes, if node C becomes the CH, the overall energy consumed is less than node B and node A being selected as CH. The reason is due to the fact that node C is located nearer to the BS, compared to the larger distance to BS of other member nodes. Therefore the nearest the CH to the BS, energy consumption is lesser. But the previous statements become invalid when n not equal to 1. It can be proved by the following cases where E_{Total} can be calculated based on Eq.(4).

Case Study 1: If A becomes CH, total energy consumption with n numbers of sensor nodes in B and in C.

$$E_{Total} = (5n+1)(E_{elec}k) + (5nR^2 + 49R^2)(\varepsilon_{amp}k)$$

Case Study 2: If B becomes CH, total energy consumption with n numbers of sensor nodes in A and in C.

$$E_{Total} = (5n+1)(E_{elec}k) + (2nR^2 + 36R^2)(\varepsilon_{amp}k)$$

Case Study 3: If C becomes CH, total energy consumption with n numbers of sensor nodes in A and in B.

$$E_{Total} = (5n+1)(E_{elec}k) + (5nR^2 + 25R^2)(\varepsilon_{amp}k)$$

Referring to Case Study 2 if node B becomes CH and $n = 5$, the overall energy consumption is less than Case 3, followed by Case 1. From these cases study, it can be observed that node B is more suitable to become CH compared to node C, since the n numbers of nodes from A and B spend more energy to transmit to node C. As a result, by selecting CH in the middle of linear topology will produce less energy consumption per rounds. According to the previous equations, CH B will show less energy consumption per rounds compared to CH A and C, but the tradeoff is FND occurs faster.

3.4 BALANCE IN ENERGY DISTRIBUTION

Based on the discussion carried out in Section 3.3, although proper CH selection with the consideration of separate distance can achieve minimum energy used in each round, however it will overload the CH and further lead to faster FND round. FND round can be prolonged by proper workload distribution to maintain the level of remaining energy in each node.

In this section, three protocols will be evaluated, namely direct communication, random CH selection protocol and energy constraint CH selection protocol. The evaluation is made using the same radio model and same network topology (BS located at x = 100 m and y = 160 m). Fig.6 shows the simulation results of the three protocols with 25 randomly deployed sensor nodes for the duration of 150 rounds.

From the results shown, it can be observed that FND round for energy constraints CH selection protocol is 40.0% longer than random CH selection protocol and 133.3% over direct communication protocol whereas random CH selection protocol is 66.7% longer than direct communication protocol. The reason of the direct protocol facing shortest network lifetime is mainly due to each sensor node has to transmit sensed data to the base station that is located far away. On the other hand, clustering protocols are outperforms the direct communication protocol.

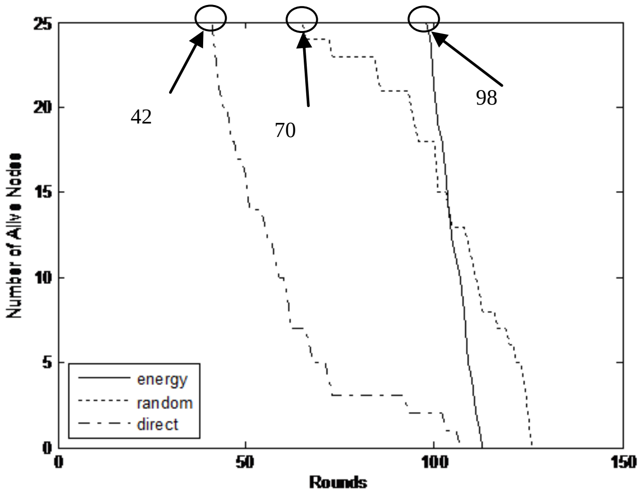

Fig.6. Basic Network Lifetime over Round

By only selecting one CH to transmit the sensed data to the BS in each round, it can significantly reduce the overall energy consumption compare to direct protocol. Since energy constraint protocol consider remaining energy as CH selection criteria, therefore the remaining energy of sensor node in the network will almost equal hence it will lead to longer network lifetime compared to random CH selection that work without any consideration. However, energy constraint protocol will not guarantee minimum energy consumption per round.

3.5 FUZZY LOGIC BASED CLUSTER HEADS SELECTION

There are pros and cons in using either energy or distance as the factor to elect the CH. Using fuzzy logic to consider both factors will improve the CH selection process. The optimum output can be obtained based on the fuzzy rule base system. Fuzzy inference technique via Mamdani method is used due to its simple structure. In Mamdani method, there are four important steps as shown below:

- Fuzzification: transforms the system inputs which are crisp values into fuzzy sets.
- Rule evaluation: refers to the fuzzified inputs and evaluate them to the antecedents of the fuzzy rules.
- Aggregate conclusions: the process of unification of the outputs of all rules.
- Defuzzication: transforms the fuzzy set obtained by the inference engine into a single crisp value.

Fig.7 shows the block diagram of the fuzzy logic control used in this work. Sensor node remaining energy and separate distance between BS and CH are the fuzzy inputs that go through fuzzification process. Fuzzy inference engine will manipulate the inputs from fuzzification based on the rules that set in the fuzzy rule base.

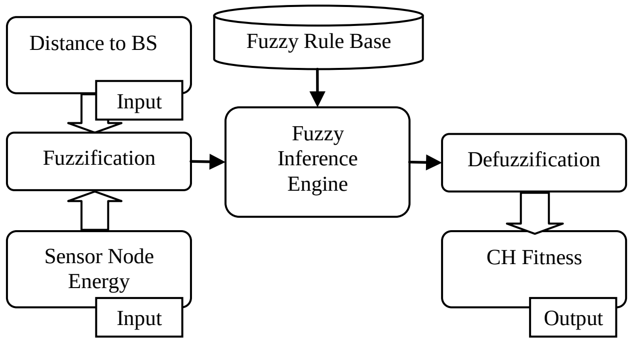

Fig.7. Block Diagram of The Fuzzy Logic Control

Finally, in the defuzzification module, the fuzzy set obtained from the inference engine needs to be transformed to the single crisp value. The common centre of area COA is used to calculate the crisp value using Eq.(5) where $\mu_A(x)$ refers to the membership function of the fuzzy sets:

$$fitness = \left(\int x.\mu_A(x)dx / \int xdx\right) \quad (5)$$

Membership functions of node's energy and membership function of node's distance are set for the simulation study. The linguistic variables used to represent the node distance are far, middle and near as shown in Fig.8. On the other hand, the linguistic variables used to represent the node's energy are divided into three levels; high, medium, and low as shown in Fig.9. The output representing the CH selection chances is named as fitness and it is divided into nine levels: very small, small, rather small, medium small, medium, medium large, rather large, large and very large as shown in Fig.10. Table.2 shows the fuzzy rule base that consists of $3^2 = 9$ rules.

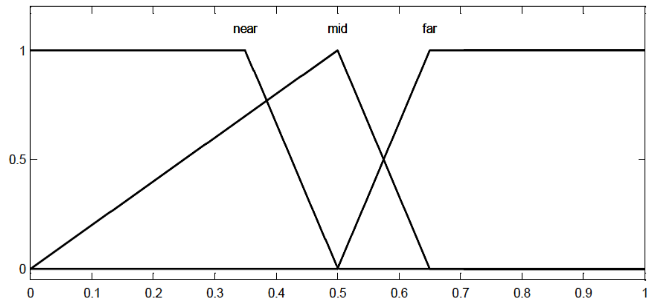

Fig.8. Membership Functions of Node Distance

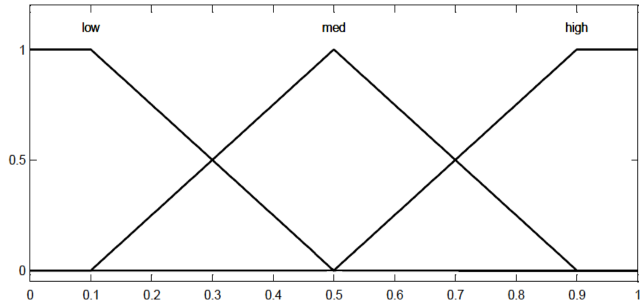

Fig.9. Membership Functions of Node Energy

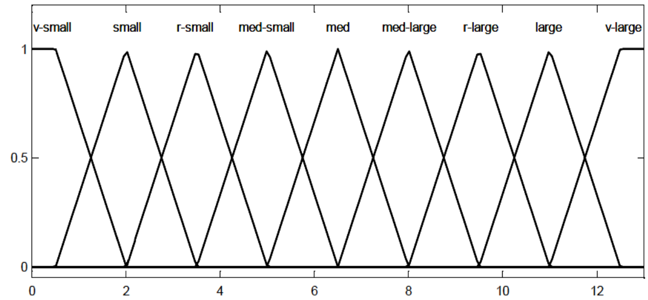

Fig.10. Membership Functions of CH Fitness

Table.2 shows the fuzzy rule base set in the fuzzy inference system (FIS). Referring to the distance's rule base, 'middle' is set to higher priority than 'near' because the CH in the 'middle' zone will perform better than the 'near' zone which has been explained in section 3. The example of rule can be expressed as if the remaining energy is 'low' and the separate distance is 'far' then the fitness to be selected as CH will be 'very small'. On the other hand, if the remaining energy is 'high' and the separate distance is 'middle', the fitness is considered 'very large'.

Table.2. Fuzzy Rule Base

Sl. No.	Energy	Distance	Fitness
1	low	Far	very small
2	low	Near	small
3	low	Middle	rather small
4	medium	Far	medium small
5	medium	Near	medium
6	medium	Middle	medium large
7	high	Far	rather large
8	high	Near	large
9	high	Middle	very large

In fuzzy logic based CH selection algorithm, BS loaded with fuzzy logic control will calculate the fitness for each node to become CH via FIS. The BS will select total number of CHs according to $p \times$ total number of nodes and p is the CH probability. The data transmission phase is similar to the LEACH steady state phase.

4. RESULTS AND DISCUSSIONS

The main difference between the LEACH and proposed protocol is the need of extra sensor node parameters as inputs into fuzzy logic control in order to select suitable CH. Therefore, an additional 24 bits of remaining energy and distance information are added to the data transmitted from member nodes to the CH. A total of 480 bits is added to the data transmitted from CHs to the BS as extra information for each cluster members. The simulation was carried out in MATLAB with the parameters show in Table.3.

Fig.11 shows the network lifetime comparison of LEACH protocol and proposed protocol for both 5% and 7% of CH number. It can be observed that the proposed fuzzy logic method performs better than the LEACH approach before FND in both 5% and 7% chosen as CHs cases. However, LEACH protocol performs better than the proposed method after 60% of total alive nodes. This is caused by the workload reduction in the CHs due to less cluster members survived and connected to the CH.

Table.3. Simulations Parameters

Parameter	Value
Topology size	$30 \times 100m^2$
BS Position	15m, 150m
Simulation Round	200
Number of Node, n	70

The improvement over LEACH protocol using the proposed fuzzy logic is because it used sensor node's remaining energy as one of the factor to be considered in selecting the CH. Therefore, the CH of fuzzy logic control will maintain the node energy by more appropriate CH selection. After FND, the number or remaining nodes decrease drastically as compared to the LEACH since the energy in the remaining nodes is almost equally and evenly less. Fig.12 shows the data received at the BS for the LEACH and proposed approaches in the case of 5% and 7% of chosen CH. Extra information for the proposed method is not considered into the throughput for fair comparison. Received data at the BS can be further enlarged by increasing the number of CH from 5% to 7%. It can be observed that the data received by the proposed approach are more than the LEACH in both cases. Appropriate number of CHs should be carefully decided to achieve the optimum value in data collection while prolonging the network lifetime. Using too many CHs will lead to additional overhead and cause the sensor nodes sacrifice faster without providing consistent and continuous significant information.

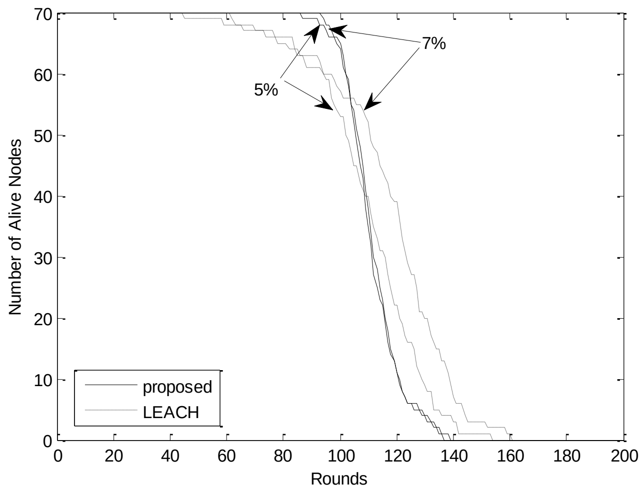

Fig.11. Network Lifetime Comparison over Round

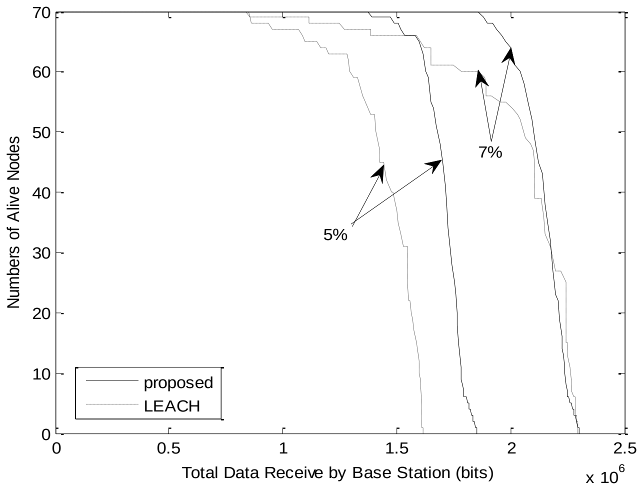

Fig.12. Data Received at the BS over Round

5. CONCLUSION

In conclusion, the proposed method with global knowledge of the networks achieved its objective to prolong the first node dies (FND) round and has also improved the throughput to the BS before FND. By increasing the number of CHs from 5% to 7% will increase the data received at BS while only slightly decrease in FND round. The proposed method that consider remaining energy and separate distance can be improved by adopting some intelligent algorithm to modify the shape of each fuzzy set to search for more optimum values.

ACKNOWLEDGMENT

The authors would like to acknowledge the financial assistance of the Research Acculturation Grant Scheme (RAGS), grant no. RAG0005-TK-1/2012 and scholarship under Ministry of Higher Education of Malaysia (MoHE), and Universiti Malaysia Sabah for providing Research Grant Schemes (SGPUMS), grant no. SLB0014-TK-1/2011.

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