Cluster-head Election in Wireless Sensor Networks Using Fuzzy Logic

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Abstract

A wireless sensor network consists of many inexpensive sensor nodes that can be used toconfidently extract data from the environment . Nodes are organized into clusters and in each cluster all non-cluster nodes transmit their data only to the cluster-head .The cluster-head transmits all received data to the base station .Because of energy limitation in sensor nodes and energy reduction in each data transmission, appropriate cluster-head election can significantly reduce energy consumption and enhance the life time of the network .In the proposed algorithm, a modified fuzzy logic approach is presented in order to improve the cluster-head election based on four descriptors energy, concentration, centrality and distance to base station .Cluster-head is elected by the base station in each round by calculating the chance each node has to elect as a cluster-head by considering descriptors .Network life time is evaluated based on first node dies metric, so energy depletion of one node causes the network to die .Simulation shows that theproposed algorithm can effectively increase the network life time .Sensor network is also simulated when sensor nodes move with random velocity in random direction in each round .Simulation shows that network life time is increased by considering this assumption in the proposed algorithm and can develop a better performance.

Keywords: Wireless sensor networks, Fuzzy logic, Cluster-head, Life time, First node die.

1. Introduction

Wireless sensor networks consist of many small inexpensive sensor nodes which enable sensing and data processing and can be connected via a wireless network [1-2]. These Wireless sensor networks present a generation of real-time systems for extracting data from the environment and decision-making from reliable monitoring [1]. These nodes can be self-organized in a clustered network [3-4]. Power, memory and computational capabilities are the important limitations WSNs may have. Some various applications of WSNs include data gathering in harsh and inhospitable environment, monitoring, surveillance and detection of chemical or biological agent threats where more traditional systems are infeasible [5]. For example, a sensor network can be used for detecting the presence of threats in a military conflict [2]. Sensor nodes can collect audio, seismic and other types of data and collaborate to perform a task [2]. All of the sensor nodes information should be collected and sent to a base station. We assume that all nodes are homogeneous in a WSN and each node enables sending data to the other nodes and to the base station [5].

A simple approach to accomplishing data gathering task is for each node to transmit its data directly to the base station. Since the base station is typically located far away, the energy consumption to transmit data to the base station from any node is high. So nodes die very quickly and, at last, cause a reduction in the network life time. Therefore, to reduce energy, an improved approach is to use as few transmissions as possible to the base station and to reduce the amount of data needed to be transmitted to the base station. Further, if all nodes deplete their energy level uniformly, then, the network can operate without losing any node for a long time [2]. So, nodes are organized in clusters and one node is elected in a cluster as a cluster-head. This cluster-head collects the other nodes data and transmits it to the base station. Also, data aggregation cause a reduction in the amount of transmissions, and, hence, reduce the energy consumption [2]. It combines one or more data packets from different sensor nodes to produce a single packet.

So, cluster-head election in wireless sensor network presents an important and efficient parameter to increase the life time of such networks [5].

A popular technique, called LEACH (Low Energy Adaptive Clustering Hierarchy)[3,5], is used in each round. LEACH is divided into two phases. Each round begins with

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a set-up phase. In this phase, cluster-head is elected randomly as a node which was not elected in previous rounds as a cluster-head. In the next phase, called steady-state phase, data are transmitted from the nodes to the cluster-head and then to the base station.

Nodes select themselves as cluster-head without the base station processing in LEACH [6], but LEACH-C uses a centralized algorithm to select the cluster-head by the base station [3]. The research shows that LEACH-C improves the performance by 20 percent to 40 percent, depending on network parameters, compared to LEACH in terms of the number of data collection rounds. This can be achieved before sensor nodes start to die [2].

All nodes have an equal amount of energy which is reduced by sending data in each round. Thus, the energy levels of nodes are not equal. So, the importance of parameter energy causes an association in cluster-head election phase with nodes with higher energy having more chance to become cluster-head than those with less energy [3].

Fuzzy logic is successfully used in various applied and theoretical domains. The most important advantage of fuzzy approach is that it is not necessary to have complete information and precise mathematical model of a system [7].

In this paper, a new fuzzy logic approach is used to improve the cluster-head election based on four input variables-energy, concentration, centrality and distance of node to the base station. Energy depletion of each node results in network death by FND [5]. So description of nodes variable should cause better cluster-head election and elects a node with sufficient amount of energy and appropriate situation to the low energy nodes.

Section 2 gives an overview of LEACH algorithm. In section 3, fuzzy logic is described to select the cluster-head. In section 4, the system model is described and energy consumption is introduced in section 5. In section 6, a proposed fuzzy algorithm is described for cluster-head election and simulation results are shown in section 7. Finally, section 8 concludes the paper.

2. LEACH Algorithm for Cluster-head Election in WSN

Cluster-head election in WSN has been evaluated in many studies. LEACH is a distributed algorithm where nodes make autonomous decisions without any centralized control and select the cluster-head [3-5, 8]. Each node i elects itself to be a cluster-head at the beginning of each round r with probability of p_i. Distributing the energy among all nodes requires each node to be a cluster-head once in $\frac{N}{K}$ rounds, if there are N nodes in the network and the expected number of cluster-head nodes for each round is k. then each node should choose to become a cluster-head in round r with probability:

$$P_i = \begin{cases} \dfrac{k}{N - k.(r \bmod \frac{N}{k})}; & C_i = 1 \\ 0 \quad ; & C_i = 0 \end{cases} \tag{1}$$

Where C_i is the indicator determining whether or not node i has been a cluster-head in the most recent $r \bmod N/K$ rounds.

$$C_i = \begin{cases} 1 & ;\ if\ node\ i\ is\ elected\ in\ the\ last\ (r \bmod N/k\ )round \\ 0 & ;else \end{cases} \tag{2}$$

Cluster-head election using LEACH has several disadvantages as follows [5]:

- If more than one node is elected to transmit data to the base station and each node probabilistically decides whether or not to become a cluster-head, there might be two cluster-heads are selected in close vicinity and cause to increase the overall energy depleted in the network.
- In this algorithm, cluster-head is elected with no consideration of remaining energy level in nodes, so electing a node with low level of energy cause to reduce the network life time.
- Each node has to processed data and cluster-head is also elected by nodes consumes CPU cycles of sensor nodes processor.

Nodes start with equal amounts of energy but they have different amounts of energy in the next rounds. So in the other model of LEACH, nodes with higher energy are more likely to become cluster-head than nodes with less energy and the probability of becoming cluster-head is set as a function of a node's energy level relative to the aggregate energy remaining in the network, rather than purely as a function of the number of times a node has been cluster-head[3]. Thus,

$$P_i = \min\{\frac{E_i}{E_{total}} k, 1\} \tag{3}$$

where

$$E_{total} = \sum_{i-1}^{N} E_i \tag{4}$$

3. Cluster-head Election Using Fuzzy Logic

Due to LEACH algorithm disadvantages, many studies have been conducted to use algorithms based on fuzzy logic and cluster-head election using these algorithms. In [9], cluster-head is elected using fuzzy logic and based on three parameters - distance of nodes to the centre of the cluster, remaining energy in nodes and degree of mobility. Cluster-head is elected once based on minimum distance to the centre of cluster and once based on energy, just in a

round. In [10], a fuzzy logic method is developed to select the manager and network's management. In [5], a fuzzy logic approach based on the fuzzy rule base to cluster-head election is used based on three descriptors; energy, concentration and centrality. In this algorithm, the descriptors are described as follows:
Energy: Energy level available in each node.

Concentration: Number of nodes present in the area of 20*20 meters with the node in the center. Centrality: Sum of the distance of other nodes to a node used to present other nodes locations relative to a node.

Anyway, it disregards the location of base station to elect cluster-head and also concentration and centrality just represent the geographical situation of the node and do not present the effect of elected cluster-head on nodes with low energy.

4. System Model

In this paper, cluster-head is elected in each round using fuzzy logic based on four descriptors; energy, concentration, centrality and distance of node to the base station. Geographical situation of nodes are assumed to be achieved by GPS (Global Positioning system) [10]. A WSN architecture is shown in Figure 1.

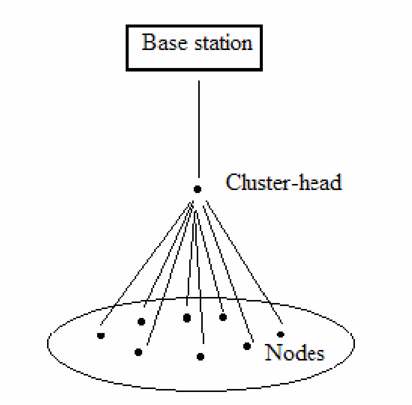

Fig. 1. WSN architecture [5].

Sensor network is present in two models. First, nodes situations are fixed in the network and in second model nodes are assumed mobile.

Cluster-head collects k bit messages from each node and compresses it to cn k bit message with $cn \leq 1$ as the compression coefficient [5].

Fuzzy cluster-head election scheme is divided into two phases. During set-up phase the cluster-head is elected by using fuzzy logic. In steady state phase the cluster-head collects the aggregated data, compresses it and then sends it to the base station.

5. Energy Consumption Model

Energy consumption model is shown in Figure 2. In this model, the transmitter consumes energy to run the radio electronics and power amplifier since data is sent from nodes to cluster-head. Also, the receiver consumes energy to run the radio electronics. This is because data is received in cluster-head. The following equation presents the energy consumption model for sending k bit data [2, 5, 8, 11]:

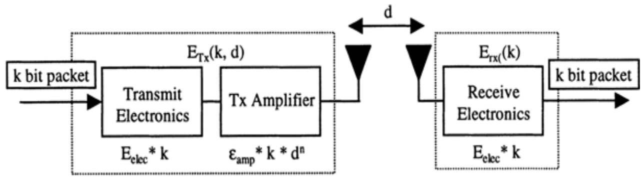

Fig. 2. Energy Consumption Model [3].

$$E_T(k, d) = E_{elec} . k + \varepsilon_{amp} . k . d^{\lambda} \quad (5)$$

$$E_R(k) = E_{elec} . k \quad (6)$$

Where $E_K (T, D)$ is the energy consumed to send k bit from a node to the cluster-head or from the cluster-head to the base station and $E_R (K)$ is the energy consumed by cluster-head to receive k bit data. In these equations, $\lambda = 2$ for sending data from non cluster-head nodes to the cluster-head and $\lambda = 2.5$ for sending data from cluster-head to the base station. $E_{elec}=50$ *nj/bit* is the energy dissipates to run the transmitter or receiver circuitry and $\varepsilon_{amp} = 100$ *pj/bit/m*^{2} is the energy dissipated by the transmission amplifier.

6. A Proposed Algorithm for Cluster-head Election

In this paper, a fuzzy system is proposed to elect the cluster-head node where input variables in each rounds are described as follows:

- **Energy:** energy level available in each node (E_1 ; $1 \leq i \leq N$).

- **Concentration:** summation of node's number present in the area of 20*20 meters with the node in the center which is considered a weight for these nodes. The initial energy level of nodes is assumed equal, but the difference between the amounts of energy for nodes is revealed in next rounds. So it is avoided by this weightening to elect the cluster-head which causes to be died the low energy nodes and reduces the network life time by FND. These weights are described as a relative of minimum amount of energy between nodes to energy of each node. So concentration can be described as follow:

$$Concen(j) = \sum_{k=1}^{n} \frac{E_{min}}{E_k} (x_i - 10 < x_k < x_j + 10)$$
$$\& \left(y_i - 10 < x_k < x_j + 10\right) \qquad ; j = 1, \ldots, N \qquad (7)$$

Where j is node number and n is the number of nodes present in the vicinity. E_{min} is the minimum amount of node's energy and E_K is the kth node's energy.

- **Centrality:** the sum of the squared distances of other nodes to a node with allocating a weight for each node. This weight which is described as a relative of minimum amount of energy to each node's energy causes to consider the amount of energy in nodes also the geographical situation of nodes. Centrality variable is described for each node in each round as follow:

$$Center(j) = \sum_{k=1}^{N} \frac{E_{min}}{E_k} \left(x_k - x_j\right)^2 + \left(y_k - y_j\right)^2 \quad ; j = 1,2, \ldots, N \qquad (8)$$

where N is the number of nodes.

- **Distance of node to the base station:** distance of each node to the base station described as follow:

$$Dist(j) = \sqrt{(x_j - x_{B.S})^2 + (y_j - y_{B.S})^2} \qquad (9)$$

where$(x_{B.S}, y_{B.S})$ is the base station location.

In this way, the effect of node's election as a cluster-head on the life of other nodes is considered. Applied fuzzy system consists of three sections as shown in Figure 3[7, 9].

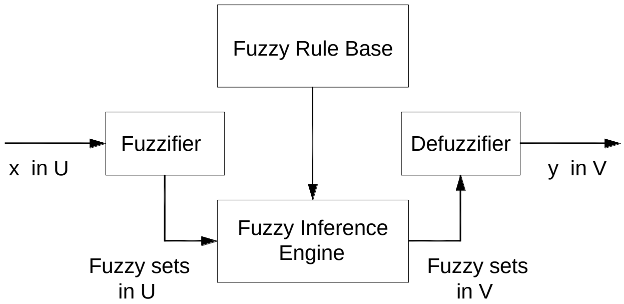

Fig. 3. Fuzzy system.

First, fuzzifier takes the input variables and determines the degree to which these inputs belong to each of the appropriate fuzzy sets [12]. The linguistic variables used to represent the node energy and concentration are divided into three levels: low, medium and high. There are three levels to represent the node centrality: close, adequate and far and three levels to represent distance of nodes to the base station: small, medium and long. The output represents the node cluster-head. Election chance was divided into seven levels: very small, small, rather small, medium, rather large, large and very large. Thus, 3^4 =81 rules are used for the fuzzy rule base [7]. The membership functions developed and their corresponding linguistic states are represented in Figures 4 - 7.

Then, the fuzzified inputs were applied to the antecedent of the fuzzy rules. It is then applied to the consequent membership function. Rule outputs are aggregated in a fuzzy inference engine, selected mamdani, to unify the outputs of all rules. The output of the fuzzy inference engine is fuzzy set chance and it is defuzzified in defuzzifier which calculates center of gravity of the fuzzy set aggregated output[5], [10].

$$chance = \frac{\int x \ \ \mu_A(x)dx}{\int \mu_A(x)dx} \qquad (10)$$

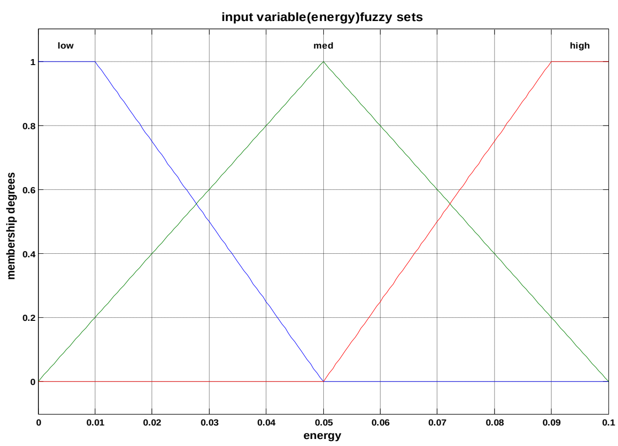

Fig. 4. Fuzzy set applied for variable energy.

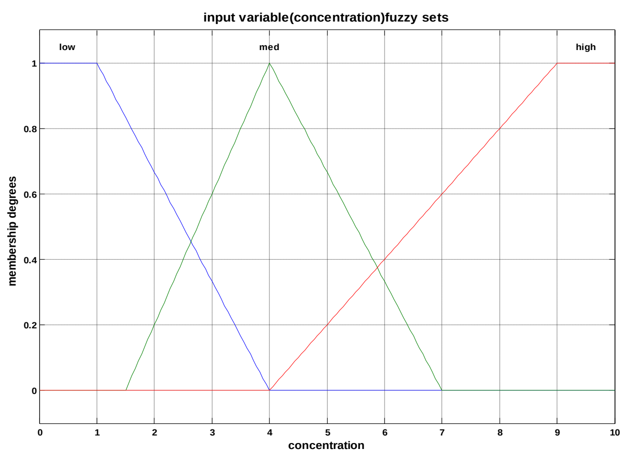

Fig. 5. Fuzzy set applied for variable concentration.

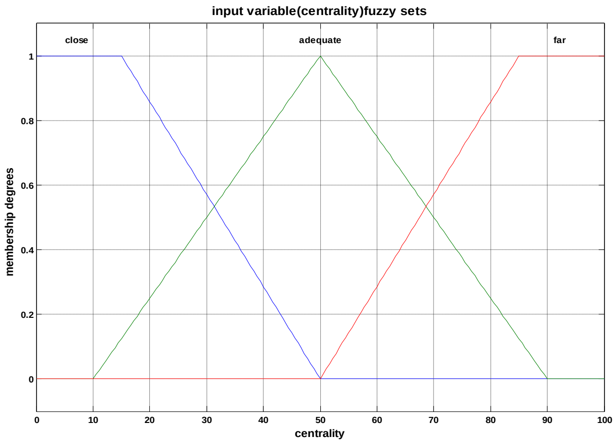

Fig. 6. Fuzzy set applied for variable centrality.

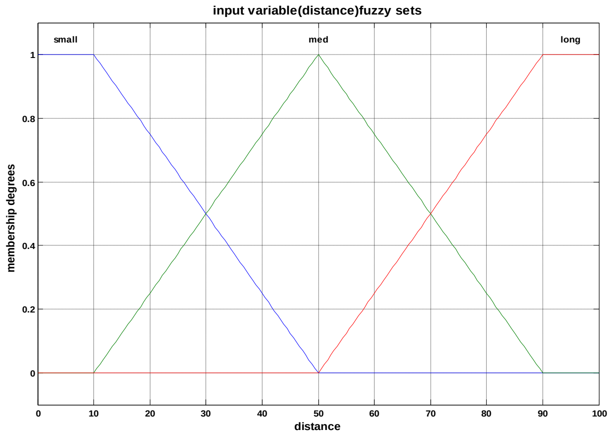

Fig.7. Fuzzy set applied for variable distance to the base station.

7. Simulation Results

The proposed algorithm is compared to the describe algorithm. The reference network consists of 150 nodes randomly distributed over an area of 150*150 meters. The base station is located at (200,50). Nodes have the initial value of energy equal to 0.1J at the beginning of the simulation and each node transmits 200 bit message, per round. Cluster-head compresses the collected data to 5% of its original size.

First, the LEACH algorithm is applied to select the cluster-head for the sensor network according to the equation (1), and then equation (3). Then, fuzzy algorithm is applied with three input variables, energy, concentration and centrality where only the geographical situation of nodes in variables concentration and centrality description are considered.

In the next stage, the fourth variable, distance of node to the base station is added to the fuzzy system input variables and in concentration and centrality description, also has been considered the effect of the selected node as cluster-head to energy retention of other nodes. In all algorithms, FND is used to determine the life time of the sensor network. Simulation results are illustrated in Figure 8.

Then, nodes are assumed to have random velocity in each round, so, two random numbers are chosen between [0-0.1] in each round and they are added to the x and y of node location. Each round is taken 100msec and so nodes have random velocities in each round. Network is also simulated drawing on this assumption and results are shown in Figure 9.

The results show that fuzzy algorithms have advantages in comparison to LEACH in fixed or mobile networks. Also, the second fuzzy algorithm increase the network life time more effectively, compared to the first fuzzy algorithm.

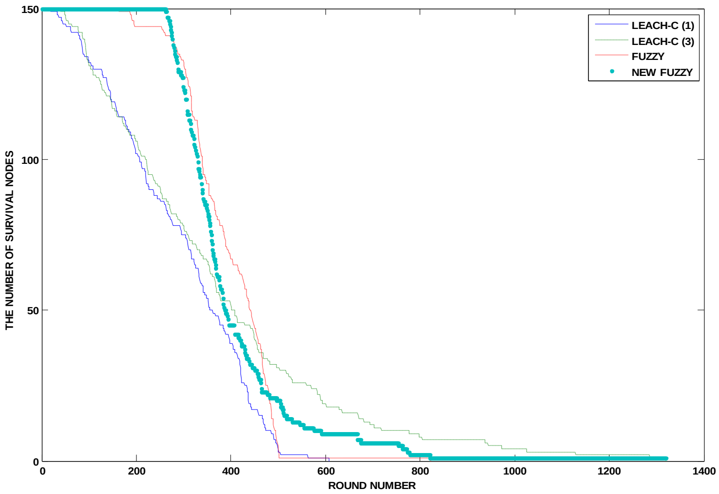

Fig. 8.compression of network life time by applying different cluster-head election algorithms with fixed nodes.

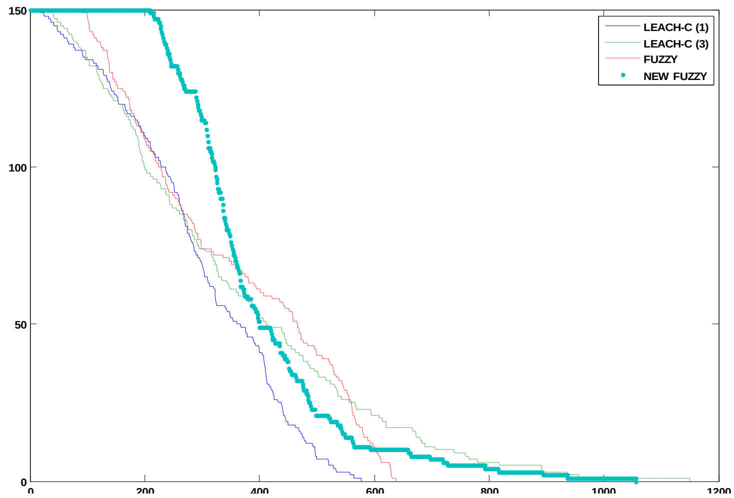

Fig. 9. Compression of network life time by applying different cluster-head election algorithms with mobile nodes.

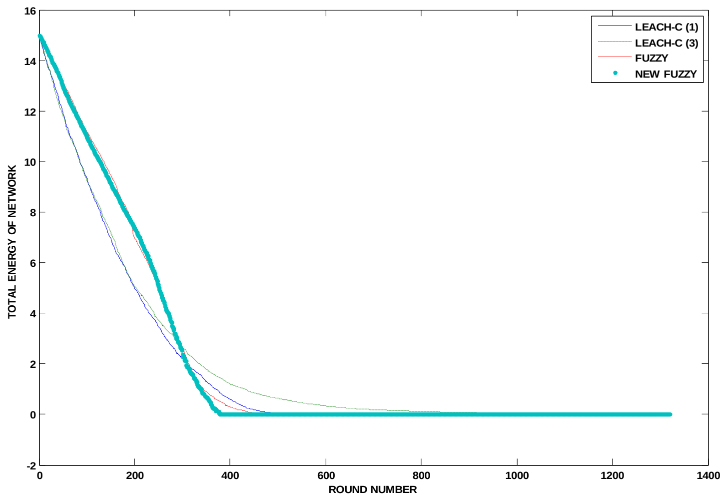

Fig. 10. Total energy available in the network by applying different cluster-head election algorithms with fixed nodes.

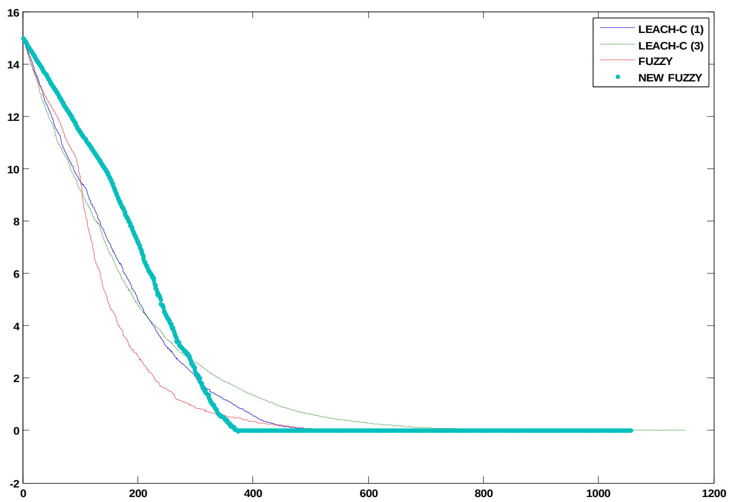

Fig. 11. Total energy available in the network by applying different cluster-head election algorithms with mobile nodes.

8. Conclusion

This paper discussed an algorithm for cluster-head election for wireless sensor networks. A fuzzy system is applied based on four input variables and elects cluster-head in each round by calculating the chance each node has to become the cluster-head and network life time is calculated by FND. The proposed algorithm is compared with the other algorithms. Simulations show that the proposed algorithm effectively increases the network life time in both fixed and mobile networks.

Further improvement in the network life time can be achieved by conducting further research on network characteristics and modifying the shape of the fuzzy sets or adding more appropriate input variables.

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