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Cluster Head Selection Using Fuzzy Logic and Chaotic Based Genetic Algorithm in Wireless Sensor Network

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ABSTRACT

Wireless sensor networks (WSNs) are composed of hundreds or thousands of sensor nodes in order to detect and transmit information from its surrounding environment. The sensor nodes have limited computation capability, limited power and small memory size. In these networks, sensor nodes are dependent on low power batteries to provide their energy. As energy is a challenging issue in these networks, clustering models are used to overcome this problem. In this paper, fuzzy logic and chaotic based genetic algorithms are combined to extend the lifetime of sensor nodes. In other words, fuzzy logic is proposed based on three variables - energy, density and centrality- to introduce the best nodes to base station as cluster head candidate. Then, the number and place of cluster heads are determined in base station by using genetic algorithm based on chaotic. Our Simulation results in the NS-2 show the longer network lifetime of the proposed algorithm than the LEACH, DEEC, SEDEEC and GFS protocols.
KEYWORDS:genetic algorithm; clustering, wireless sensor network, fuzzy logic, chaotic, lifetime.

1. INTRODUCTION

Wireless sensor networks are a new generation of recent networks with computational, energy and memory limitation [1]. The wireless sensor network includes hundreds or thousands of sensors that usually are scattered in an inaccessible environment. The main duty of these sensors is to collect information from surrounding environment and send it to base station [2-20].Each sensor node is composed of sensor, memory, computational and wireless communication unit with a limited board. Wireless sensor networks are used in army, hygiene, education, industry, agriculture and etc. [3-20]. In these networks, sensor nodes are dependent on low power batteries to provide their energy. Because these networks are used in dangerous and inaccessible environments, it is hard or even impossible to charge or change their energy source. Therefore, one of the main challenges of these wireless sensor networks is the sensors' low energy [4-21]. These networks efficiency depends on the lifetime of sensor nodes and network coverage. Therefore, it's important to optimize energy consumption and manage the consumption power of sensor nodes. Most of energy consumption in these networks is due to information transference inside the network .clustering is one of the common solutions to decrease the number of network's internal transference [5]. Fig. 1 shows clustering in wireless sensor network.

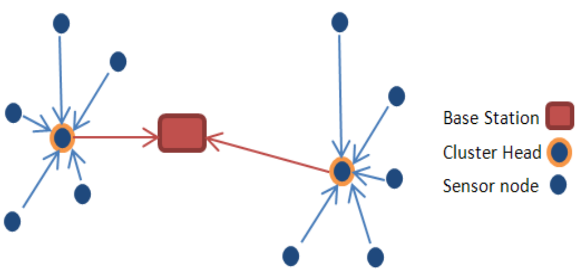

Fig. 1 Clustering in WSN

In clustering sensor nodes are divided into some clusters and one node is selected as cluster head in each cluster. Cluster heads receive data from other sensor nodes and send them to base station. Selecting a suitable cluster head decreases energy consumption to a great extent and as a result increases networks' lifetime [1, 2, 21]. In recent years, due attention has been paid to powerful methods such as: fuzzy logic, genetic algorithm and neural networks [6, 7, 8,9].

In LEACH protocol [10], cluster heads are chosen first and then the members of each cluster head are determined. Cluster members send the received data to cluster head according to TDMA scheduler. Cluster head combines the received data and sends it to base station. As this algorithm just uses local information, the number of cluster heads in each round is not fixed and it may

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be less or more than the optimized amount in one round. Also, each node should produce and compute a random number and a threshold level in every round.

ECS algorithm has improved LEACH method by changing probability. In probability function, energy parameter has been considered to choose cluster heads. Also reduction in search space has increased clustering speed [11].

In [13], in order to choose cluster heads, a two level fuzzy method is used that includes local level and global level. In local level, node's capability for being cluster head has been evaluated based on two parameters: energy and the number of neighbors. In global level three parameters have been considered: Centrality, closeness to base station and the distance between cluster heads.

The HEED protocol [13] is a distributed cluster based protocol that periodically selects cluster heads according to a hybrid of the node residual energy and a secondary parameter, such as node proximity to its neighbors or node degree. HEED favors nodes with high residual energy to become cluster heads and periodically executes re-clustering to achieve load balancing. The nodes that have been cluster heads will have a low probability of becoming cluster heads again, thus ensuring that all the nodes will carry the role of being a cluster head equally. HEED uses node degree as a fitness function if the requirement is to distribute the load among the cluster heads, the inverse of the node degree if the requirement is to create a dense cluster, or the mean of the minimum power levels required by all the nodes within the node's transmission range to reflect the communication cost within a cluster.

As a variation of HEED, time delay based clustering (TDC) is introduced in [14]. In TDC, all nodes compete to be CH until they hears ADV message, and then withdraw from the election process and subscribe to one of the elected cluster heads. As with HEED the announcement message is delayed, but with a slightly different delay mechanism. In HEED, the nodes are delayed by a simple iterations mechanism as discussed above. In TDC, three time delay schemes are studied: fully randomized, fixed slope, and steeping slope.

This paper is organized in 4 sections. In section 2 the proposed algorithm to extend the lifetime of sensor nodes is mentioned. Simulation and evaluation of the aforementioned algorithm are presented in section 3.section 4 is allocated to conclusion.

2 THE PROPOSED ALGORITHM

As in this paper a new idea is mentioned to increase the lifetime of wireless sensor network and combination of various algorithms are used to achieve our purposes, therefore, the Existing network is examined through fuzzy logic and chaotic based genetic algorithms from these aspects:

- The lifetime of network.
- The selection of cluster head in each round.
- The number of dead sensors after each round.

In this section, the hypotheses, the problem and the suggested algorithm are explained. The paper's hypotheses are:

- Sensors are fixed in their place.
- In any round, each sensor can just send or receive data.
- Sensing the environment and preparing the data of each sensor node in order to send it, is done independently.
- Each node sends its position and remaining energy to its cluster head in the form of control packets.
- Base station has enough knowledge about the position of network nodes.
- Each node is equipped to a GPS system and finds its place and geographical position.

Heinzelman's energy model [10] is used for sensor network. According to the radio energy dissipation model illustrated in Fig. 2, Consumed energy to send a message with k bits length in d distance is computed through the Eq. (1).

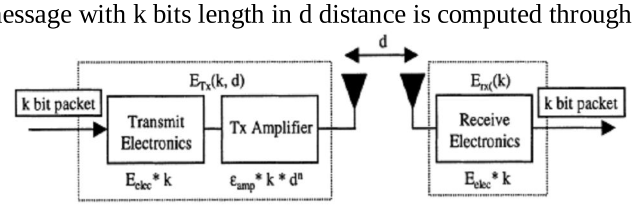


Fig. 2 Radio energy dissipation model

$$E_{TX}(k,d)=\begin{cases} k\times E_{elec}+k\times\varepsilon_{fs}\times d^{2}, if\ d\le d_0 \\ k\times E_{elec}+k\times\varepsilon_{mp}\times d^{4}, if\ d\ge d_0 \end{cases} \quad (1)$$

Where E_{elec} the energy dissipated per bit to run the transmitter or the receiver circuit, ε_{fs} and ε_{mp} depend on the transmitter amplifier model we use, and d the distance between the sender and the receiver. By equating the two expressions at $d = d_0$, we have: $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$

Each node's consumed energy to receive a *k* bit message is computed through the Eq. (2).

$$E_{TR} = k \times E_{elec} \qquad (2)$$

The distance between the two nodes that is shown with *d* variable is computed through the Eq. (3).

$$d = \sqrt{(X_A - X_B)^2 + (Y_A - Y_B)^2} \qquad (3)$$

In Eq. (3), (X_A, Y_B) is the position of node A in the network and (X_B, Y_B) is the position of node B in the network. Consequently, Euclid distance between two nodes has a square relation with the sent energy. In the proposed method, the same as LEACH algorithm, the period of network's activity is divided into some rounds and each round includes two phases: setup phase and steady state phase.

2.1 Setup Phase

In the first phase, cluster heads are selected and then the clusters ' members are determined. In this phase, each node calculates its chance parameter based there main characteristics through fuzzy logic: its energy, density and centrality in comparison with neighbors. Nodes with higher capability introduce themselves to base station as cluster head' candidate, so they prevent those nodes which are not capable of being cluster head from sending their information. The network uses nodes with different factor after being launched. Nodes that remaining energy in comparison with network's total energy is less than threshold level are recognized as dead nodes and can't participate in competition. In base station, cluster heads are determined among cluster head candidates using genetic algorithm. Also, the number of times in which a node is selected as cluster head is considered. Then, base station sends a message including cluster head's ID to each node. If a node's cluster head ID conforms to the node's ID, that node is a head a cluster. Base station creates a Time division multiple access table and this table is sent to cluster heads. TDMA table is used to time the data transfer of sensor nodes and also enables sensor nodes to turn off their radio antenna and save their energy until it's time for them.

2.2 Steady State Phase

In the second phase, cluster members send the received data to cluster head according to TDMA table and after receiving data, cluster heads compress and send them to base station.

2.3 Fuzzy Logic Control

A Fuzzy Inference System consists of four modules: fuzzifier, fuzzy inference engine, fuzzy rules base, defuzzifier. Fig. 3 shows a fuzzy logic controller.

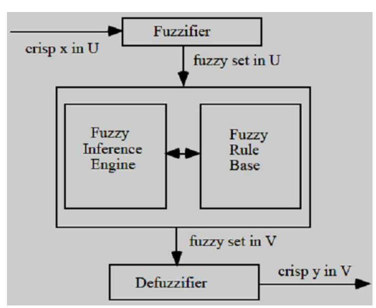


Fig. 3 Fuzzy Logic Controller

In fuzzifier, inputs with crisp value change into a fuzzy set and results are transferred to defuzzifier through fuzzy inference engine and fuzzy rules base. Defuzzifier changes a fuzzy set to crisp value. Models are interpreted according to fuzzy logic including the rules of if-then [15, 16]. In the proposed method, we have used the most commonly used fuzzy inference technique called Mamdani Method. Input parameters of fuzzy logic controller in the proposed method are:

- Node's energy: energy variable shows the remaining energy in proportion to the network's total energy.
- Node's density: density variable shows the number of a node's neighbors that their distance to the controlled sensor is less than *m*.

- Node's centrality: centrality variable shows how close a node is to a cluster.

In order to compute the number of neighbor's sensors in the beginning of network's activity, each sensor sends its ADV message to neighbor nodes in a definite radius; thus, each sensor calculates the number of its neighbors based on the energy of the received signal. ADV message is a message to introduce sensor in the network. In order to calculate the amount of centrality, each node computes its distance to those neighbors which exist in m radius and their sum shows the amount of centrality variable. Language variables for each of the inputs are:

Energy = (low, med, high)
Density = (low, med, high)
Centrality = (close, adeq, far)

The membership functions developed and their corresponding linguistic states are represented in Table 1 and Figs. (4)–(7).

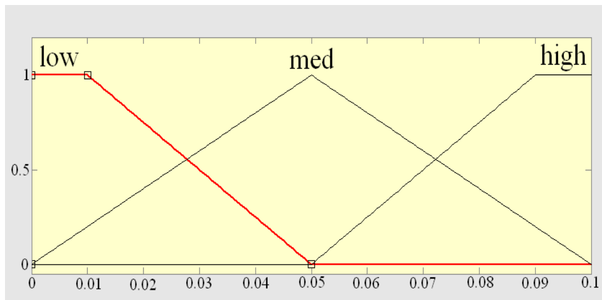


Fig. 4 Fuzzy set for fuzzy variable energy

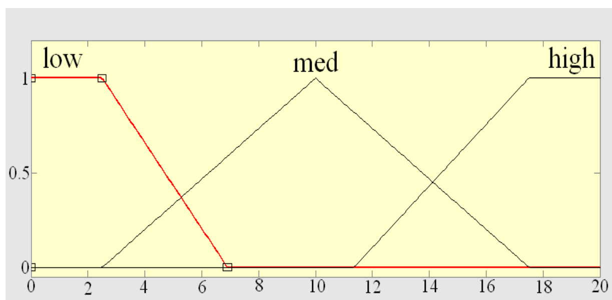


Fig. 5 Fuzzy set for fuzzy variable density

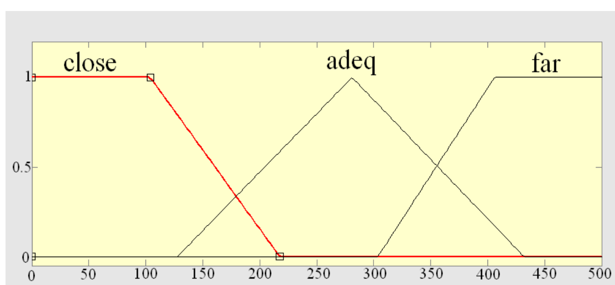


Fig. 6 Fuzzy set for fuzzy variable centerality

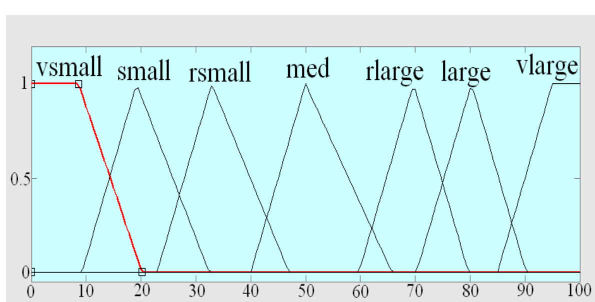


Fig. 7 Fuzzy set for fuzzy variable chance

Table 1 Fuzzy Rule Base

	Energy	Density	Centrality	OUTPUT(chance)
1	low	Low	close	Small
2	low	Low	adeq	Small
3	low	Low	far	Vsmall
4	low	Med	close	Small
5	low	Med	adeq	Small
6	low	Med	far	Small
7	low	High	close	Rsmall
8	low	High	adeq	Small
9	low	High	far	Vsmall
10	med	Low	close	Rlarg
11	med	Low	adeq	Med
12	med	Low	far	Small
13	med	Med	close	Large
14	med	Med	adeq	Med
15	med	Med	far	Rsmall
16	med	High	close	Large
17	med	High	adeq	Rlarge
18	med	High	far	Rsmall
19	high	Low	close	Rlarge
20	high	Low	adeq	Med
21	high	Low	far	Rsmall
22	high	Med	close	Large
23	high	Med	adeq	Rlarge
24	high	Med	far	Med
25	high	High	close	Vlarge
26	high	High	adeq	Rlarge
27	high	High	far	Med

2.4 Using genetic algorithm

Determining the number and place of cluster heads has always been a challenge. The dynamic nature of issue, due to the frequent changes in cluster heads in each round of network's activity, makes the issue more complex and as result modeling is not possible through math classic methods. Common clustering algorithms in other studies have benefited from heuristic methods. On the other hand, genetic algorithm is so flexible in solving dynamic issues. In this paper, genetic algorithm is used to determine the place of cluster heads in a way that the minimal amount of energy is consumed. Fitness Criterion is based on the minimal consumed energy from network nodes in each generation. In base station, the number of nodes that have introduced themselves as cluster head candidates determines the chromosome's length in genetic optimizing method. Each of this chromosome's genes recognizes some of the sensor network nodes. Chromosome's structure is defined as: $chrom = \{g_i \mid i = 1,2,3,...,l\}$,where l is the chromosome's length and g_i is the *i-th* gene.

After crossover operator, mutation happens in a way that a mutation may be created in a bit of one or some chromosomes. Finally, after crossover and mutation, base station selects the chromosome which has the networks least energy difference in proportion to the previous round and introduces the available nodes to network as cluster head and other nodes join to the nearest cluster head. Network's current energy in *k-th* round is shown with $E^{k}_{Network}$ .Fitness function is computed through Eq.(4) that should become minimum. In Eq. (4), | | symbol shows absolute value.

$$fitness = \left| E^{k}_{Network} - E^{k-1}_{Network} \right| \qquad (4)$$

In genetic algorithm, in random operation trend, primary population production, crossover and mutation operation, chaotic logistic mapping with *r=4* is used. This mapping is one dimensional and is shown by Eq. (5).

$$X_{n+1} = r \times X_n \times (1 - X_n) \qquad (5)$$

The following algorithm shows the stages of the proposed algorithm.

Step 1: Initial network;

Step 2: each node sends the position of itself in the network to its Neighbors.

While (all of node are alive) ***do***

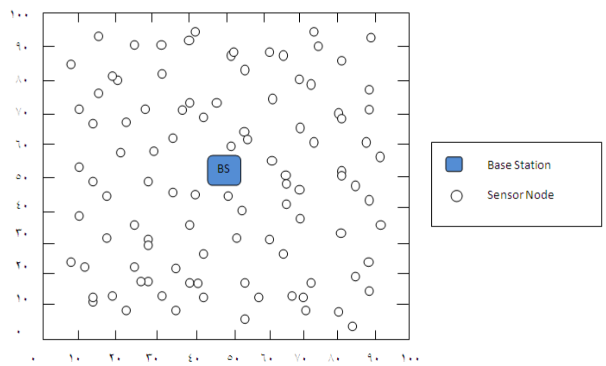
Step 3: each node calculates its chance parameter using fuzzy logic based on three descriptors - energy, density and centrality;

Step 4: each node that has more chance than its Neighbors, introduce itself as cluster Head candidate to the Base Station (BS);

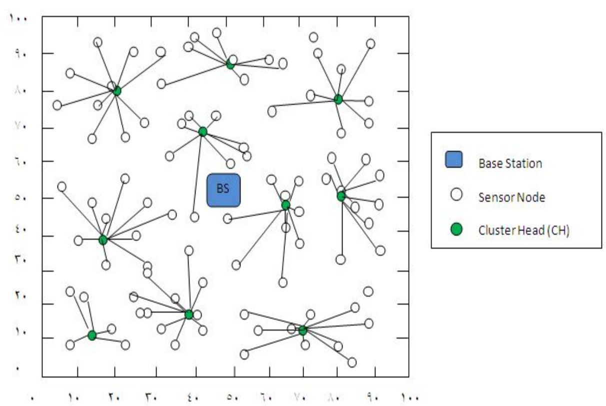
Step 5: in BS using Genetic algorithm based on chaotic, main cluster heads are determined;
Step 6: main cluster heads are introduced to all nodes in network;
Step 7: Each sensor node will join to the nearest CH;
Step 8: Each sensor node uses TDMA allocated to it to transmit data to the CH with a multiple- hop transmission;
Step 9: After all data has been received, the CH performs data fusion function by removing redundant data and compresses the data into a single packet. Then transmit it to the base station via single hops transmission.

3 SIMULATION AND RESULTS

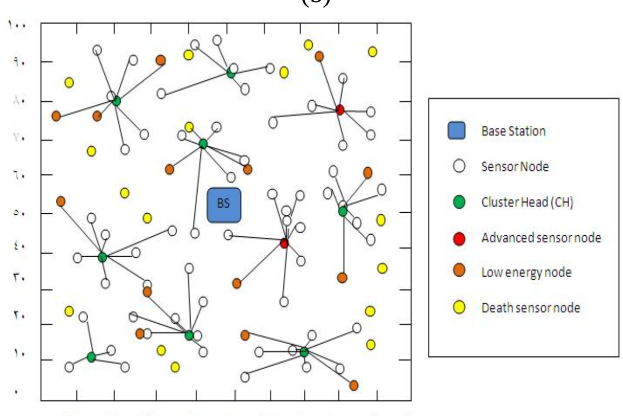
As the most important part of each paper is allocated to its results, this section examines this paper's results. Ns2 simulator is used to simulate the proposed algorithm. 100 sensor nodes are used in the simulation. Fig. 8 shows three snapshots of proposed WSN in simulation.



(a)



(b)



(c)

Fig. 8 Eoverview of proposed wireless sensor network (a) a snapshot of 100-node random network, (b) a snapshot of dynamic cluster structure in proposed algorithm, (c) a snapshot of WSN after 10% running

The parameter values used in the simulation are same as Table 2.

Table 2 The values of the simulation parameters

Parameters	Values
Network dimensions	100*100 m^2
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
d_0 (distance threshold)	87 m
E_{DA} (Energy aggregation Data)	5 nJ/bit/signal
Average of normal data packet size	4000 bits

3.1 Comparison of the proposed algorithm with fuzzy logic and genetic algorithm approach

As most of the presented methods are random ones, each of the methods are executed for five times and the average of achieved amounts in each simulation is used to examine the function of each method. In order to decrease the complexity and have a simpler comparison among the presented methods, one base station is used. In this section, the proposed algorithm is compared to the GFS algorithm [17] which works based on fuzzy logic and genetic algorithm from two aspects:

- The time of first sensor node’s death.
- The time of whole network’s death (the time in which sensor node’s energy is finished completely).

In this paper three scenarios are used to compare the efficiency of the suggested algorithm. Finally, the proposed algorithm leads to the lightest lifetime in sensor’s network.

- First scenario: In this scenario, the proposed algorithm is evaluated in the form of a heterogeneous network with three different nodes: An advanced node, a normal node and a node which is in a critical condition and has the lowest energy level.
- Second scenario: In this scenario, the proposed algorithm which is a heterogeneous network with clustering routing is considered in a fuzzy state in which each node determines its capability for being a cluster head based on fuzzy logic.
- Third scenario: In this scenario, in addition to a network with heterogeneous nodes and fuzzy logic, chaotic based genetic algorithm is proposed to choose the cluster head in base station. In this section, the number of generations is 100, the cross over probability is 0.6 and mutation probability is 0.1.

As the suggested algorithm works based on clustering, the most efficient route which has the highest energy and the least distance to base station is chosen and network’s stability increases too.

Fig. 9 shows the comparison of the proposed algorithm to the GFS algorithm in each of the three scenarios based on the time of first sensor node’s death.

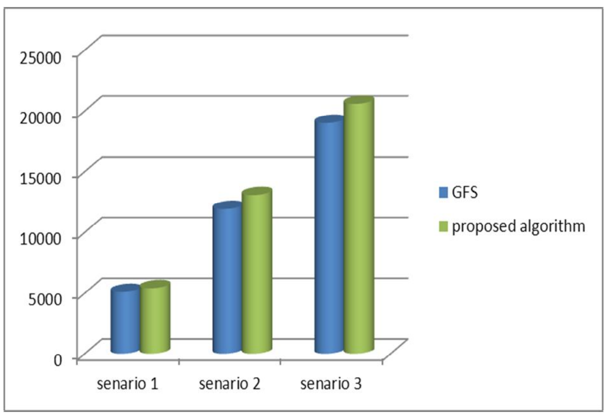


Fig. 9 The death time of the first node

Fig. 10 shows the time in which all nodes' energy is finished. As the proposed algorithm uses clustering, fuzzy logic and chaotic based genetic algorithm, sensor nodes use a lot of time to lose their energy.

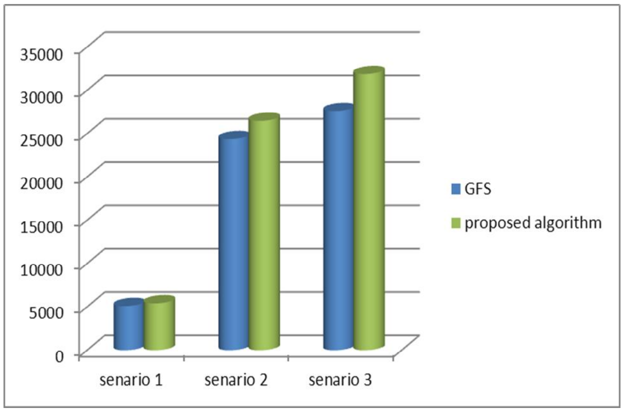


Fig. 10 The death time of total network

Table 3 shows that using chaotic logistic mapping in genetic algorithm in order to generation random number has better performance.

Table 3 The death time of first node

	Genetic Algorithm	Genetic Algorithm based on chaotic
The death time of first node	19216	20484

3.2 Evaluation Network Life-time in proposed algorithm

In this paper, network's lifetime was compared to LEACH ,DEEC [18] and SEDEEC [19] clustering algorithms and the results show that by using fuzzy logic and genetic algorithm, the proposed algorithm works better than LEACH ,DEEC and SEDEEC algorithms. Network's lifetime parameter shows the time in which the first sensor node consumes its energy and dies. When the sensor node spends more time to consume its total energy, the network's stability is more. In LEACH algorithm, all the nodes act without any distinguishing but in DEEC algorithm and the suggested algorithm, the initial energy and the beginning energy are computed simultaneously. Fig. 11 shows network's lifetime of proposed algorithm with comparison other algorithm.

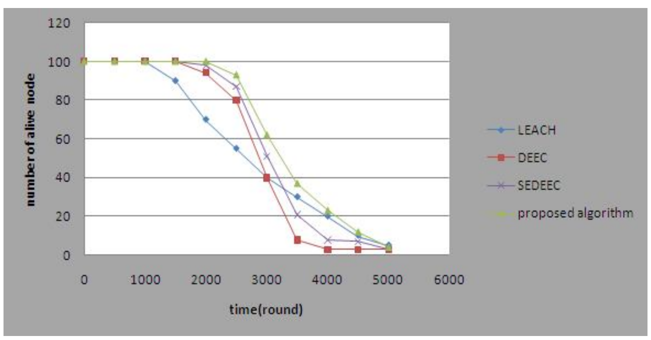


Fig. 11 comparison of network lifetime

Fig. 12 shows that when the amount of a and m increases, the node's stability increases too and it also shows the time in which the first node uses all its energy and dies. *m* shows the number of advanced nodes that their energy is n times more than the normal node's energy. When these numbers increase, the network's lifetime increases but network's management gets more complicated.

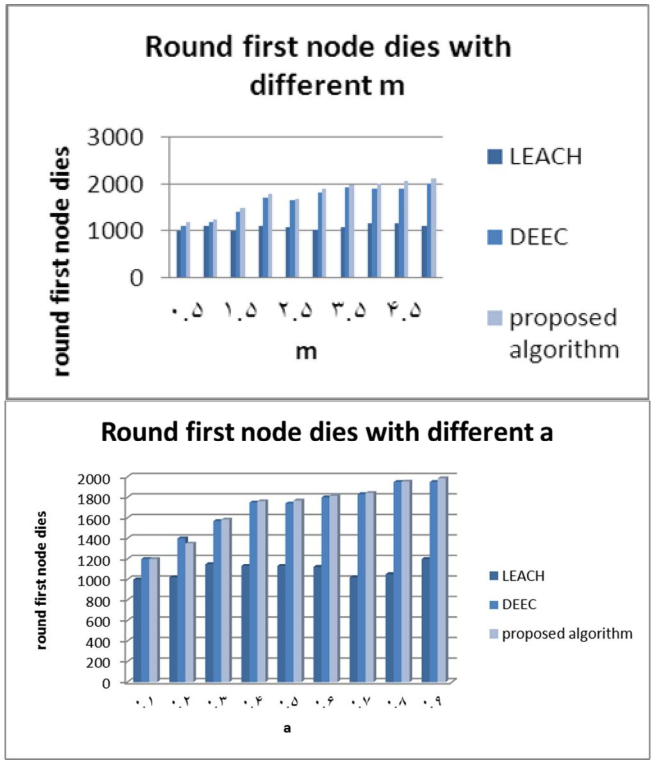


Fig. 12 The death time of first node with different m and a parameters

The second parameter is the number of received messages in base station. The results of Fig. 13 shows that the number of base station's received messages in the suggested algorithm is more so the network's lifetime increases until all the nodes consume their energy.

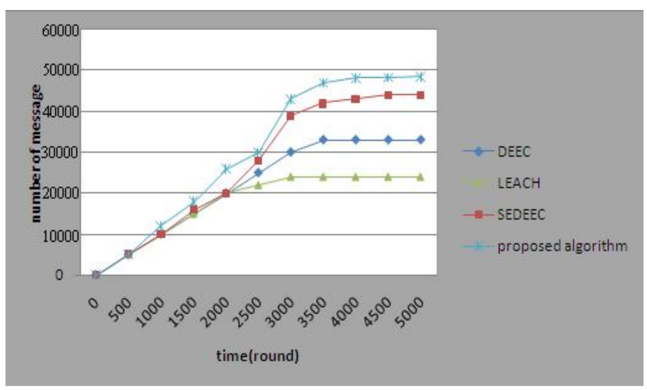


Fig. 13 Number of messages received in base station

4. Conclusion

In this paper, a new method which is based on fuzzy logic and genetic algorithm is represented to choose a cluster head in WSNs. Therefore, it is quicker and also more accurate to detect the node with higher energy and to select the cluster head. Moreover, this network has used nodes with heterogeneous characteristics. Some of the advantageous of heterogeneous nodes are: the long lifetime of networks, increase in network's reliability and decrease in data transference delay. In simulation, the suggested algorithm is compared to LEACH, EEC, SEDEEC and GFS algorithms.

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