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Improving energy consuming in WSN using mobile sink

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ABSTRACT

Wireless sensor networks (WSN) are consisted of many sensors which often are located in harsh and out-of-reach environments. One of the main challenges in WSNs is the limitation of theenergy consumption. One of applied methods for mitigating the energy consumption in these WSNs is to make use of the mobile sink in order to collect data of the sensor nodes from the network. In this research, a new method based on the Genetic Algorithm and fuzzy logic is proposed for reducing the WSN's energy consumption using the mobile sink. In proposed procedure, the suitable mobile sink's routing is determined using GA. GA functions based on stop stations position, stop time period and the coverage radius. The evaluation function in GA calculates the GA responses' quality with phasing the network's residual energy, amount of data collected and balance of energy consumption between network nodes. The simulation results indicate that the proposed method in different scenarios provides optimal performance in term of motion rout determination and increase in WSN lifetime relative to other existing methods.

Keyword:
wireless sensor networks (WSN), energy consumption, mobile sink, genetic algorithm (GA), fuzzy logic

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INTRODUCTION

Increasingly advances in electronic and telecommunication industries have caused that low energy consuming, smaller size and affordable sensor hardware were designed and developed in different applications. Such hardware (sensors) led to emergence and development of the networks called wireless sensor networks (WSN). A WSN can be consisted of hundreds or thousands sensor nodes. However, there are extensive researches on WSNs conducted; sensor nodes are still depending on small size batteries due to their number, being small and energy limitations. WSNs are often used in out-of-reach and hazardous environments; therefore, it is nearly impossible to recharge or change them in such environments. Optimization of the energy consumption and increasing the lifetime of the networks are among the most important parameters which play critical roles in WSN. One of the controversial and important challenges in WSN is lack of efficiently exploring the energy which reduces the network's lifetime. In majority of applications, sensor nodes face with limitations in term of their energy source. Therefore, there is a method needed for eliminating the energy waste in order to increase the networks' lifetime. The energylimitation along with large number of the sensor nodes causes many challenges in design and management of the WSN and energy in network protocols [1, 2, 3]. Considering that the energy limitation issue in WSN and optimization of the energy consumption in these networks are of significant importance; therefore, this issue has always been taken into consideration by researcher in this area. However, there are ambiguities in this area. So, it is necessary to conduct more researches on this issue and provide newer techniques to be able to provide better results than existing one. As a result, there have to be techniques for reducing the consumption in these networks. Employing concentrated algorithms in WSN applications are helpful in order to make use of the smart or non-smart optimal algorithms in network and change its parameters accurately during its running. In this section, this is assumed that all operations relevant to finding suitable rout are performed in a concentrated manner [4]. A GA-based method for reducing the energy consumption in WSNs is provided. On this basis, the network designer can determine the head-clusters and move the mobile sinks based on the head-clusters. This number is the chromosomes' length. Each gene in chromosomes is the ID of a number of network nodes whose energy is more than the mean network's energy. In [5] also a GA-based method is proposed. Based on the method proposed in [5], the chromosomes are defined in binary manner. GA needs a primary population of chromosomes for beginning; therefore, these chromosomes are produced randomly. Then, each of the chromosomes is evaluated based on criterion function. Since sensor networks performance depends highly on the network lifetime and network coverage, then taking into consideration the energy saving methods in sensor networks designing with long lifetime would be significantly critical [3]. In order to solve this problem, in this research, a mobile sinks-based method is proposed for energy consumption optimization. The goal of network's lifetime increase using the mobile sink is to design and displace of sinks for balancing the energy consumption in sensors and change the location of sinks in network environment.

Problem statement

As mentioned earlier, one of the major challenges in WSN which is controversial is lack of efficiently exploiting the energy which reduced the network's lifetime. In majority of applications, sensor nodes face with limitation of the energy source. Therefore, there is need for methods to eliminate the energy waste. This energy waste reduces the lifetime of network. One of the energy consumption reducing methods in WSN is mobile sink use. In WSN with working mobile sink(s) it is important how the mobile sink routs and how and based on which goal data are collected. For better explanation of this issue, an example is provided here. Figure 1 is an example of a WSN with mobile sink. In this network, there is only one mobile sink which is moving as a grid in determined positions and collects data sensed from sensor networks in certain station.

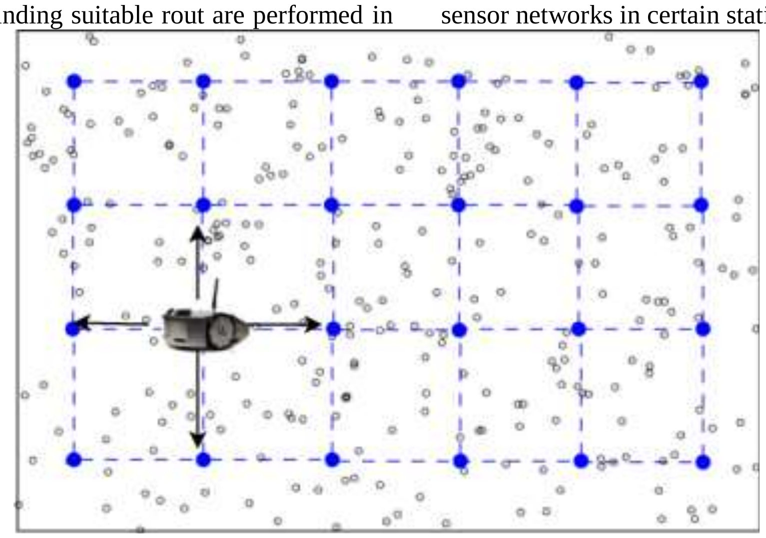

Figure1. En example of WSN with mobile sink

Considering above example, the main issue is that how and on which basis and order does the mobile sink move and select its path such that leads to reduction of network energy consumption reduction? Among the criteria involved in mobile sink routing include: sensor nodes density, sensor nodes residual energy, amount of collected data by sensor nodes, value and importance of a part of environment observed by the WSN and etc. These factors are of significant importance in WSN; because each factor is effective on network's energy consumption. But, how these (diverse) factors interact and balance and considering them in order to determine the best path for moving sing motion in network (best routing for mobile sink leading to network's lifetime) is a NP-Complete problem. Therefore, in this research a GA-based method and fuzzy logic are proposed for solving this problem in WSN using a mobile sink. All these factors are considered effective and lead to suitable and efficient routing.

The proposed network model

We assume that the head node (sink) exists and moves and has infinite energy (or changeable battery). Mobile sink has processing energy and can calculate its motion path. In fact, the proposed algorithm, functions in concentrated manner, i.e. the decisions are transferred to other sensors so that other sensors' data would be gathered. Also, it is assumed that the sink is aware of position of sensor nodes, amount of data gathered by the nodes and sensor nodes energy amount. In sensor network considered, it is assumed that the sensor nodes are in a fixed position and rarely their position is changed in environment. Also, these sensor nodes have limited energy and after they face with energy emptying, if the sensor nodes' energy is lacked, they would be destroyed. Moreover, it is assumed that the nodes are homogenous, i.e. they have similar processing energy and their primary energy levels are similar. Existing nodes in WSN are assumed to sense data periodically from the environment and make data ready for transmission. Indeed, we assume that data transmission from sensor nodes to sink in done in a level. That is, first sensor nodes can transmit the sensed data from environment to the sink, directly. In fact, it can be said that sensed data transmission is done in a phase and a level. Therefore, assumptions and network model considered here is a general network model which is considered in literatures. Generally, following characteristics are assumed in the WSN used:

- The sink is moving and system has only one mobile sink
- Sink moves as a grid
- Nodes are limited in energy and primarily they have similar power and energy
- Each node senses the data periodically and have always data ready for transmission
- System is uni-phase
- Nodes are able to measure the distance based on received signal energy
- Sink is aware about the information in sensors
- The sink's coverage range is adjustable and changeable in 3 levels.

The proposed method

In this section, the proposed method is explained in which the fuzzy logic and GA are used in order to reduce the WSN energy consumption using mobile sink.

Chromosomes coding in proposed method

Each chromosome (individual) provides an acceptable solution, but necessarily this is not an optimal solution. Considering the type of problem addressed in this study, chromosomes have to be defined in such a manner that 3 parameters are considered. They include:

- The order of sink motion in different stations
- Stop time period of sink in each station
- Coverage radius (rage) of sink in each station

Considering above 3 parameters, a 2-D array is used. 2-D array has 3 rows for each parameter and n columns. In fact, by n one means the number of stations in which the mobile sink can move. Figure 2 indicates how each chromosome is defined.

stations	S_1	S_2	S_3	...	S_n
stop time period	T_1	T_2	T_3	...	T_n
coverage range	R_r	R_r	R_r	...	R_r

Figure2. Chromosomes definition

In figure 2, first row is the stations. In this row, the values are permutation; i.e. no value can be iterated and each value (station) is only mentioned once in this row. Second row is the stop time period of station corresponding to the first row. This time period cannot be more than T_{max} ($T_m<T_{max}$). T_{max} is the maximum time determined as default for stop in each station by designer. Third row is also the station coverage range corresponding to first row. This range can be in 3 levels: low, medium and high. In r={1,2,3}, if r=1 then the coverage range is in low level, if r=2, then the range is medium in station and if r=3, then the sink's coverage range would be high. Figure 3 indicates 3 different levels the sink can have.

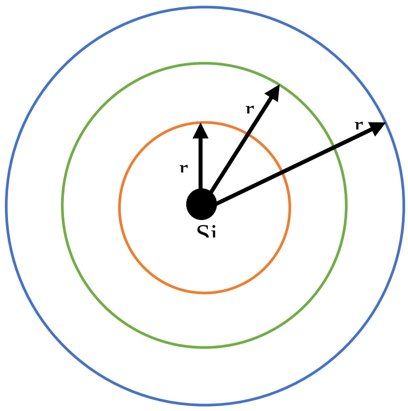

Figure3. 3 different levels the sink can have

When algorithm starts, all chromosomes are created randomly. The following rules have to be considered for chromosomes generation:

1. In chromosome, each element (gene) from row 1 can include the stations' number in permutation manner.
2. In second 2, sink's stop time in station m cannot be more than T_{max} ($T_m<T_{max}$).
3. In row 3 of chromosomes, each gene only can be 1, 2 or 3.

Fuzzy logic-based assessment function

The most important part of GA is how the criterion function is defined this has to be consistent with problem. In this research, criterion function for assessment of chromosomes uses 3 fuzzy parameters:

- Network's residual energy
- Amount of data collected by sink
- Nodes energy consumption balance

Making the network residual energy fuzzy

The fuzzy values for residual energy in network are considered such that previous period energy difference with next period is calculated and the fuzzy values are determined based on the least energy difference. In other words, fuzzy values between maximum energy difference and zero are considered and energy difference when approaching zero, the entire network would be in better situation in term of energy consumption. Therefore, the fuzzy rules would be changing relative to the previous and present network's energy difference. In order to calculate this difference between previous and present periods, the equation 1 is used where *k* is the k^{th} period or present one. The fuzzy value (f_F) for network's residual energy (for each chromosome) is obtained from equation 2. In this research there are 3 fuzzy states considered for network energy consumption. Based on fuzzy rules these 3 states are low, medium and high considered for network's residual energy.

$$E = |E_k - E_{k-1}| \quad (1)$$

$$f_E = \begin{cases} f_E = 1 & E < 1 \\ f_E = \frac{1}{E} & E \geq 1 \end{cases} \qquad 0 \leq f_E \leq 1 \quad (2)$$

Making the collected data fuzzy

The amount of data collected by sink is also significant. The main objective is to collect the highest amount of data with the least energy consumption. Therefore, the amount of collected data is considered as one of the parameters in chromosomes assessment. There are also 3 fuzzy states for the collected data. These are low collected data, medium collected data and high collected data. For calculating the fuzzy value related to collected data amount, the equation 3 is used where f_b is the fuzzy value obtained from data collected ($0 \leq f_D \leq 1$). Also, $data_i$is the amount of data collected in station *i* and *n* is the total number of the stations in which the mobile sink stops in order to collect data. The more obtained value from f_b is near 1, more data collected would be.

$$f_D = 1 - \frac{1}{\sum_{i=1}^{n} data_i} \quad (3)$$

Making energy consumption balance fuzzy

Network's energy consumption has to be distributed in balanced manner between network nodes. If there was no balance in energy consumption, in some part of network nodes may consume their energy quickly and would be destroyed which leads to loss of the network coverage. Therefore, mobile sink has to collect data in such a manner that it would not lead to loss of the energy consumption balance in network. So, this parameter is also the parameter for chromosomes fitness assessment. For this parameter, there are 3 fuzzy states (good, medium and bad energy balance) considered. Fuzzy values are also calculated for energy consumption balance in chromosomes from equation 4 where *N* is the entire number of network nodes. Also, *ave-_E*is the network entire nodes' residual mean energy and e_i is the residual energy in node *i*.

$$f_B = \frac{1}{\sum_{i=1}^{n} |ave\_E - e_i| / N} \quad (4)$$

After for each chromosome, 3 fuzzy parameters are calculated based on equations 2-4, based on fuzzy rule there would be a fitness value allocated to the chromosome. Accordingly, there are 9 states considered for the chromosome's fitness (e.g. very low, low, relatively low, medium-to-low, medium, medium-to-high, relatively good, good, very good).

Chromosomes synthesis

For chromosomes synthesis the one-point synthesis method is used. Based on the synthesis probability, chromosomes would be synthesized such that there is a random value generated corresponding to the chromosome's length and chromosomes would be synthesized based on the generated random value from the corresponding point to the random value.

Chromosomes' gene mutation

Every gene mutates based on the mutation probability. Here, the mutation performance is defined as each gene with mutation, would be assigned a random permissible value. In fact, the mutation operand follows the following rule for mutation:

- If a gene mutated in level 1, its position would be changed with other gene randomly.
- If a gene mutated in level 2, a random value less than T_{max} would be allocated to it.
- If a gene mutated in level 3, one of the values 1, 2 or 3 would be allocated to it, randomly.

Selecting chromosomes and final condition

For selecting the chromosomes, the Tournament method is used. This strategy is implemented in such a way that chromosomes in population are compared in pairs and among 2 chromosomes; the chromosome with higher quality would be selected. In fact, chromosomes in population are positioned randomly in an array whose start and end points are connected to each other (circular array). Fitness of each chromosome is compared to next one and the chromosome with higher fitness would be selected. In this research, there are 2 conditions considered for end of the GA, including:

- In G consequential generations, there was no improvement in chromosomes fitness.
- To reach the entire generations which was determined at the start of the GA.?

After the GA stops, the suitable mobile sink's motion would be obtained (optimal or sub-optimal) by which the mobile sink would collect the sensor nodes data in network.

Results

In order to test and validating the proposed algorithm, the MATLAB programming language was used. In order to assess results, the energy model of [6] is used. Equation 5 calculated the consumed energy for transmission of data. Also, the energy consumed for each node in order to receive data is calculated according to equation 6. In equation 5, *k* is the transmitted bit numbers and *d* is the distance. Therefore, for transmission of *k* bit to distance *d*, *Etx(k,d)*of energy is consumed and each node consumes *Erx(k)* of energy to receive *k* bit.

$$E_{tx}(k,x) = E_{elec} \times k + \varepsilon_{amp} + k \times d^2 \quad (5)$$

$$E_{rx}(k) = E_{elec} \times k \quad (6)$$

Where, $E_{elec}$and ε_{amp} are predefined constants (in simple word, in fact for clarifying the internal circuits of sensors for data transmission or receive as well as other required operations, the energy consumption is needed; therefore, this constant are considered for such operations).

Network model and considered scenarios

The network model considered in simulations is as follow:

- Nodes' energy is low
- Nodes are homogenous
- Each node during its lifetime has data to transmit
- Data transmission is in one stage (i.e. nodes send data directly to the base station)
- Nodes are capable to calculate the distance (based on signal energy)
- Base station has information of the nodes
- The base station is moving

In order to assess the proposed algorithm, there are 2 different scenarios considered. Similar scenarios with common ones in literatures in this line are selected. The number of nodes is considered varying in different scenarios and the network size is considered to be 100×100m. Based on literature reviews, majority of the networks are considered to be sized of 100×100m. Therefore, in this research also the network size is considered based on the literatures. The primary energy for each node in this scenario is similar and each node is considered to have 200J of energy. These values are considered for parameters: E_{elec}= *0.00001 J/bit*, ε_{amp}= *0.000002 J/bit.m*^{2}. Table 1 is the representation of different scenarios for simulations results assessment. The proposed method is compared with methods in [6, 7, 8] and the algorithm proposed in [6] (FLCP) is a fuzzy logic-based method with fixed base station. The algorithm, provided in [7] (MWST) is based on the tree routing for mobile sink and algorithm, in [8] (MILP) is a linear programming-based method in order to determine the suitable position of base station.

Table1. Values of different scenarios for experiments

Start point of sink motion	Nodes' energy (J)	Network size (m)	No. of nodes	Scenarios
۱۰۰	۲۰۰	۱۰۰ × ۱۰۰	۵۰	**Scenarios 1**
۱۰۰	۲۰۰	۱۰۰ × ۱۰۰	۱۰۰	**Scenarios 2**
۱۰۰	۲۰۰	۱۰۰ × ۱۰۰	۲۰۰	**Scenarios 3**
) ۵۰BSin center(	۲۰۰	۱۰۰ × ۱۰۰	۱۰۰	**Scenarios 4**
) ۵۰BSin center(	۲۰۰	۱۰۰ × ۱۰۰	۲۰۰	**Scenarios 5**

Simulation results

Assessment of the simulations results in term of network lifetime and live nodes number

In simulation, the network lifetime is considered based on the first node dies in network. Figure 4 demonstrates the result of the scenario 1. Considering the diagram in figure 4, proposed algorithm could increase the network's lifetime in comparison to other algorithms. Considering the results in proposed algorithm, the nodes die later than the other algorithms; therefore, the network's lifetime is better by the proposed algorithm as long as all nodes are alive. Based on data in table 4, nodes dying in FLCP are sooner than other algorithms. But, NWST and MILP can outperform the FLCP and increase the network's lifetime significantly. The proposed method in diagrams outperforms than other methods and in this algorithm, the nodes die later than other algorithms. Scenario 1 with nodes number=50 is simulated and the results obtained for nodes dying are indicated in figure 4.

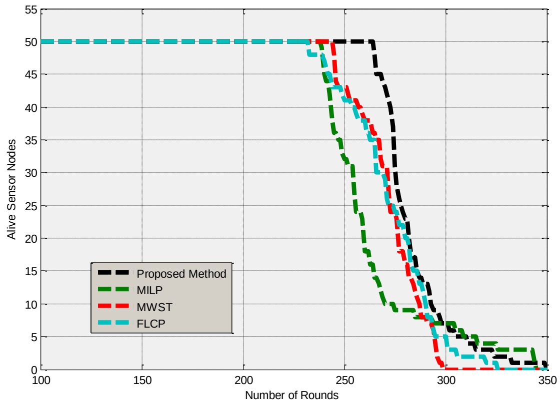

Figure4. Comparison between algorithm performances in term of live nodes number in scenario 1

The results obtained in scenario 2 are indicated in figure 5. As it is seen from diagram, proposed algorithm outperforms than others. In scenario 2, the nodes are more than the scenario 1 which is equal 100. What is seen in figure 5 is that in this scenario the nodes die later than 3 other algorithms and from this view, the network's lifetime would be increased.

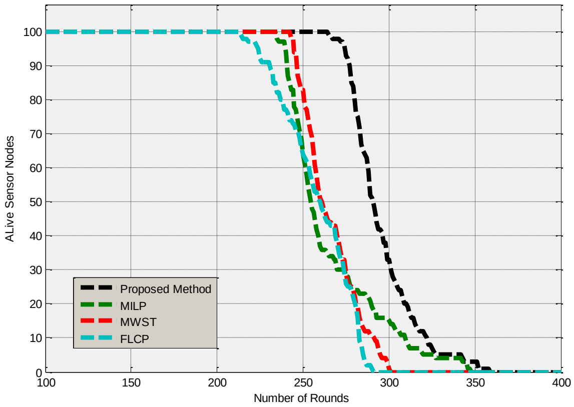

Figure5. Comparison between algorithm performances in term of live nodes number in scenario 2

The results of the scenario 3 are indicated in figure 6. In this scenario, the number of nodes is 200 which are two times more than the scenario 2. Considering the results obtained in this scenario indicated in figure 6 represents that in this scenario, the proposed algorithm could increase the lifetime of network and the nodes die later than other algorithms in this scenario. Considering different number of nodes in scenario 1, the results obtained indicate that proposed algorithm, in different scales can outperform others and so, it can be said that this algorithm is scalable and performs similarly in different scales.

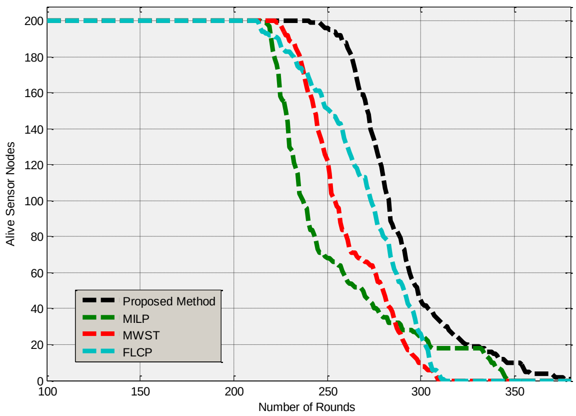

Figure6. Comparison between algorithm performances in term of live nodes number in scenario 3

In scenario 4, the base station's start point is considered to be from point 50; while in previous scenarios the base station's motion is started from point 100. Based on this condition, the results obtained from simulations in scenario 4 are indicated in figure 7. In this scenario, the nodes die later in proposed algorithm than other ones and it can be said that the proposed algorithm increase the network's lifetime.

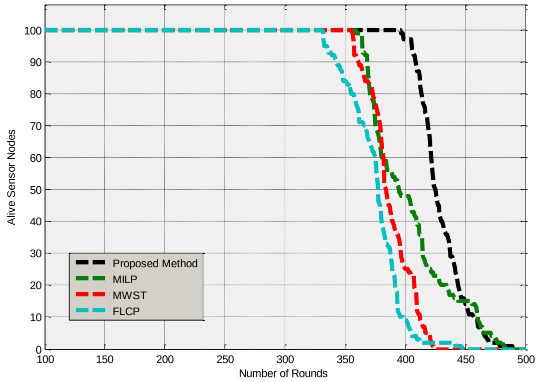

Figure7. Comparison between algorithm performances in term of live nodes number in scenario 4

In scenario five similar to scenario 4, the start point is from point 50, but number of nodes is two times more than nodes in scenario 4. The main objective of this scenario is to indicate that the proposed algorithm can outperform in different network sales and is not affected by the scale and extension of the network. Based on the results in figure 8, in scenario 5 also the proposed algorithm outperforms than others and increases the network's lifetime. In all 5 scenarios, FLCP which is based on fixed station is in last ranking and didn't perform better than others. Also, MILP and MWST provided similar results.

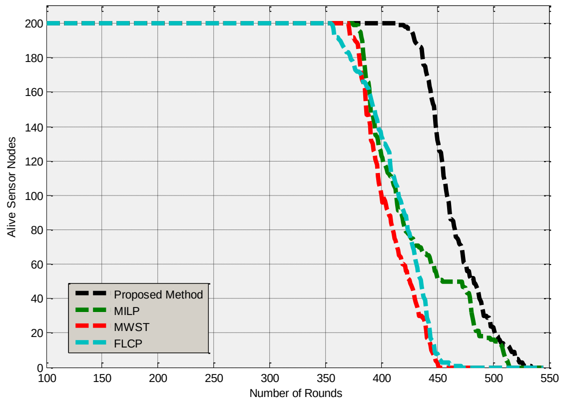

Figure8. Comparison between algorithm performances in term of live nodes number in scenario 5

Based on results obtained in 5 scenarios (in term of the network lifetime and live nodes) indicated in figures 5-9, it is observed that the proposed algorithm, can insure the network's lifetime and complete survival (coverage). The more network range is, better the network can monitor the environment. Therefore, nodes life in different periods causes that network's range would be in maximum level. This feature is of significant importance in important network's range-related applications. For example, in applications such as monitoring or routing in which the accurate data are needed, to delay the primary dying time is more important than the last node's death.

Results assessment in term of first node death, half of nodes' death and last node death

In this section, the results obtained from 3 standard criteria in WSN routing algorithm are assessed which are explained as follow:

- First node death: number of the round in which the network node stops working due to lack of energy
- Half nodes death: number of the round in which the half of nodes stop working due to lack of energy
- Last node death: number of the round in which the last node stops working due to lack of energy

The results obtained based on above criteria in 5 different scenarios are indicated in tables 2-6.

Table2. Comparison between results based on LND, FND and HND in scenario 1

Algorithm	FND	HND	LND
Proposed algorithm	۲۶۵	۲۷۸	۳۵۰
FLCP	۲۳۲	۲۷۲	۲۲۶
MWST	۲۴۴	۲۷۵	۲۹۹
MILP	۲۳۹	۲۵۸	۲۶۵

Table3. Comparison between results based on LND, FND and HND in scenario 2

Algorithm	FND	HND	LND
Proposed algorithm	۲۶۵	۲۹۱	۳۵۹
FLCP	۲۱۴	۲۶۰	۲۹۱
MWST	۲۴۳	۲۶۱	۳۰۱
MILP	۲۳۵	۲۵۵	۳۴۸

Table4. Comparison between results based on LND, FND and HND in scenario 3

Algorithm	FND	HND	LND
Proposed algorithm	۲۴۱	۲۸۳	۳۸۴
FLCP	۲۱۳	۲۷۴	۳۱۳
MWST	۲۲۳	۲۵۴	۳۱۰
MILP	۲۱۵	۲۳۷	۲۴۷

Table5. Comparison between results based on LND, FND and HND in scenario 4

Algorithm	FND	HND	LND
Proposed algorithm	۳۹۷	۴۲۵	۴۹۰
FLCP	۳۳۲	۳۷۸	۴۴۸
MWST	۳۵۶	۳۸۴	۴۲۵
MILP	۳۶۰	۳۹۵	۴۸۴

Table6. Comparison between results based on LND, FND and HND in scenario 5

Algorithm	FND	HND	LND
Proposed algorithm	۴۱۵	۴۵۹	۵۳۵
FLCP	۳۵۶	۴۱۶	۴۷۲
MWST	۳۷۱	۴۰۰	۴۵۲
MILP	۳۷۵	۴۱۴	۵۱۵

Based on the results obtained from LND, HND and FND, in all 5 scenarios, the time last for the first node to die in proposed algorithm, is better than other algorithms. Since in all 5 scenarios, the death time of the first node in propose algorithm is later than the first node death time in other algorithms. As well, half of nodes' death in proposed algorithm is better, since in all 5 scenarios, the HND is better once the proposed algorithm is used than other algorithms. In all 5 scenarios, the last node death time is later in proposed algorithm than FLCP, MWST and MILP and this indicates that the proposed algorithm not only delays the first node death, but also first node death would be delayed. Among 4 algorithms, FLCP has the worst performance; because first node death time in this algorithm is sooner than others. Thus, it is not desirable and doesn't have suitable network range. Also, last node death period in FLCP is sooner than proposed algorithm and MILP which indicates that the FLCP which uses the fixed station doesn't have suitable performance.

Result assessment according to mean energy consumption

In this section, the mean energy consumption is used as a basis for results assessment. Figure 9 indicates the mean energy consumption in entire network. Based on results obtained in figure 9, proposed algorithm has better mean energy consumption than other ones. In fact, the mean energy consumption reduction in proposed algorithm is of is of milder slope than other algorithms as well as the reduction of mean energy of entire network in this algorithm, is uniform. Whereas, in other algorithms (particularly FLCP) the mean energy consumption reduction is non-uniform and the energy is reduced more. Based on these results, in proposed algorithm the energy consumption is better than other 3 algorithms. Then, MILP reduces uniformly the energy consumption in network and them MWST and FLCP follow.

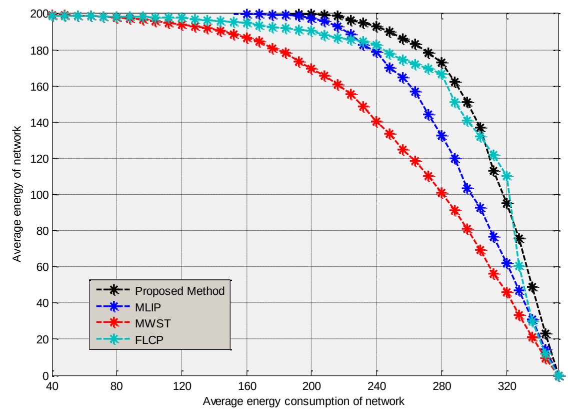

Figure9. Mean energy consumption of network in different algorithms

Based on the results of experiments, it is shown that generally the proposed algorithm outperforms the FLCP, MILP and MWST and this algorithm can increase the network's lifetime. This issue indicates that energy consumption in proposed method has been reduced. Moreover, the proposed method would improve the network's range considering that it has lower energy consumption and distributes the energy consumption more efficiently than other algorithms between nodes.

Conclusion

In this research, the proposed algorithm including GA and fuzzy logic was simulated. The simulations were conducted in 5 different scenarios and the results obtained based on the criteria such as number of live nodes in different time periods, FND, HND and LND and mean energy consumption were evaluated. The results of proposed algorithm were compared with FLCP, MILP and MWST. The results indicated that proposed algorithmoutperforms than other algorithms and optimized the energy consumption in entire network.

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