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Routing Optimization in Wireless Sensor Networks to Increase Network Life by Managing Network Energy

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Abstract: One of the important challenges in Wireless Sensor Networks is to proceed with data transmission in a way that tries to increase the network's life. One of the main issues is the reduction of latency in the node and energy in the sink nodes. Due to the limited energy of the nodes, data transmission has the largest share in energy consumption, so it is important to design a structure that has the least amount of energy in sending data to the base station. In this paper, we use fuzzy logic and the Mamdani method for clustering to solve the challenge and time-division multiplexing method to connect the nodes with the header. The proposed clustering is based on the use of the LEACH algorithm, that improves its capability, and reliability by fuzzy systems, and the particle optimization algorithm is used to optimize the path of the networks. The simulation results show that energy consumption decreases with an increasing number of cycles. For example, energy consumption reached 0.9 in the 2000 round and 0.1 in the 5000 round.

Keywords: Time- Division Multiplexing method, Fuzzy method, Routing, Energy.

Mathematics Subject Classification (2010): 16Y80, 91B32

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1. Introduction

Recent advances in electronics and wireless communications have enabled the design and manufacture of sensors with low power consumption, small size, reasonable price, and various applications. These small sensors, which can perform functions such as receiving various environmental information based on the type of sensor, processing and sending that information, have given rise to the idea of creating and expanding networks called Wireless Sensor Networks. A sensor network consists of a large number of sensor nodes that are widely distributed in an environment and collect information from the environment. The location of the sensor nodes is not necessarily predetermined, and is not clear. Such a feature allows us to leave them in dangerous or inaccessible places. Another unique feature of sensor networks is the ability to cooperate and coordinate between sensor nodes. Each sensor node has a processor on its board, and instead of sending all the raw information to the center or to the node that is responsible for processing and concluding the information, it first performs a series of basic and simple processes on the information it has obtained and then sends semi-processed data. Although each sensor alone has little capability, the combination of hundreds of small sensors offers new possibilities. The power of Wireless Sensor Networks lies in the ability to use a large number of small nodes that are self-assembled and can be used in a variety of applications such as simultaneous routing, environmental monitoring, monitoring the health of structures or equipment in a system. The range of wireless sensor networks is extensive, and has many applications, some of which are agricultural, medical, industrial, and military. In wireless sensor networks, unlike wired networks, on the one hand, the costs of network configuration and arrangement are reduced. On the other hand, instead of installing thousands of meters of wire, only small devices that are about the size of a coin should be installed and installed. It was connected wirelessly and with the help of waves (https://fa.wikipedia.org) and Junior et al.(2021).

Wireless Sensor Networks have many challenges such as energy efficiency, complexity, scalability, failure resistance, one of the most important of which is the management of energy consumption of nodes. Usually, the power supply of these nodes is not interchangeable and has a short life and try different methods to manage the amount of energy consumed by the nodes, which to solve this problem also consider the effect of the number of dead nodes. For this purpose, in this article, we have tried to consider the energy consumption by considering the number of nodes in the path where the data is to be sent step by step to reach the destination node, especially reducing the number of dead nodes. It can play an important role in this regard (https://fa.wikipedia.org).

The rest of the article is organized as follows: the second part is the related works, the third part is the theoretical foundations and the proposed solution, the fourth part is the simulation results, and the fifth part is the conclusion and future work.

2. Literature review

Data routing optimization in Wireless Sensor Networks is currently a very controversial issue. Therefore, many researchers have studied its dimensions. Here are some common examples of research background.

Huaung and Zhong (2010) proposed a particle optimization algorithm for IC design. Particle optimization based on artificial intelligence is a new evolutionary computational tool and has been successfully used in performance optimization, neural network design, classification, pattern recognition, signal processing, and robot technology.

Goścień (2019) has used a new algorithm for network routing. In this paper, the issue of allocating three types of single network currents, each segment, and multi-segment in the tensile optical network, is responsible for the security of the dedicated network path. In the following, this article uses two algorithms, particle optimization, and taboo search. The simulation results evaluate the efficiency of the algorithms and show that the proposed taboo search method is significantly better than other methods.

Hamela and Kathirvel (2018) have proposed a new routing model that includes an advanced intelligent mass distributor. Initially, with the MPR selection method, advanced path detection is performed. In this approach, parameters such as available bandwidth, queue occupancy, and life are considered as readiness nodes and the probability of incompatibility, power factor, and transport behavior as indicators of composite requirements. Unlike other energy models, this approach has less energy and is safer. The simulation results show that optimized continuous connection status routing with energy-saving and safety is better with other performance criteria such as energy consumption, residual time, grid life, and energy variance.

Khan et al. (2018) proposed a routing protocol without localization to minimize energy gaps. The proposed algorithm overcomes the interference when sending a data packet by setting a unique packet retention time for each sensor node. The formation of energy holes is reduced by the variable amplitude of the sensor nodes. Compared to conventional routing protocols, the proposed protocol does not require sensor node localization information, which is cumbersome and difficult. Because the nodes change their positions with the flow of water. The simulation results show the superior performance of the proposed design in terms of packets received at the final destination and end-to-end delay.

Wang et al. (2018) proposed a clustering-based routing protocol for dynamic networks to enable energy consumption and improve energy efficiency through clustering algorithms. The main idea is to periodically update the network topology and select a node with a higher degree and high residual energy as the head of the cluster to be responsible for collecting data and transmitting it. By moving the nodes, joining, and selecting the optimal clustering radius, the energy load of the entire network can be evenly distributed in each sensor node, which can significantly extend the life of the network. Extensive simulations show that dynamic networks have more energy than existing protocols.

Perez (2018) proposed a multi-objective optimization model to reduce node energy and path optimization. He also proposed a multiple location optimization algorithm for model optimization.

Yarinezhad and Sarabi (2018) presented a routing algorithm based on virtual network infrastructure and mobile. In the proposed algorithm, some nodes selected by the virtual infrastructure maintain the last position of the well. The simulation results show that the proposed algorithm performs better in terms of energy consumption and latency compared to similar algorithms.

Rahim et al. (2019) analyze the effects of node density and scalability on the performance of routing protocols. Two depth-based routing protocols and energy-efficient depth-based routing protocols have been used. The first is a non-cluster-based method that routes only using node depth, while the second is a location-less program that routes data from both the depth and residual energy of nodes uses.

Dong et al. (2016), in the RMER algorithm, suggest how to collect and send data to the well. Therefore, energy consumption can be significantly reduced, thus making it possible to increase grid life further.

Guolin et al. (2014) also used dynamic algorithms to route between network nodes.

Farooq and Pesch (2019) proposed an advanced routing protocol for low-power and low-loss networks (ERPLs). Highlights of ERPL include the following:

1) Peer-to-peer optimization and data transfer 2) No additional control message 3) Minimize source-to-destination routing. The results show that ERPL per-

forms better than standard RPL in communication and peer-to-peer transmission algorithms and their optimization.

Xing et al. (2019) address two important issues regarding multiple routing with network coding, namely load balance and transmission delay. The major problem is that the average bandwidth usage ratio and the average transmission latency are both minimized. To deal with this problem, they propose a multiple bee cloning algorithm that performs better than similar methods.

Dewan and Hansdah (2018) proposed a new algorithm that is suitable for peer-to-peer networks that require fast message transmission. Specifically addresses the issue of designing a communication network in a set of data centers located in different locations; It is geographically located and requires location information for applications. The design of the coverage network relies on the structure of social networks, which is found in evolutionary calculations to resemble a semi-structured network. The designed network is scalable and failure-resistant and can include arbitrary processing capacity nodes, network bandwidth, and storage.

Multimedia applications tend to generate high-volume network traffic, which leads to very high power consumption. To reduce energy, Genta et al. (2019) propose a routing algorithm that combines dynamic clustering, header selection, and multi-purpose routing algorithms for data communication to reduce energy consumption. The proposed algorithm uses the genetic algorithm of meta-exploration optimization to select the best path based on cost performance with minimum distance and minimum energy loss.

After reviewing some of the standard papers presented in the related works, in the next section, the theoretical foundations and proposed solutions will be presented.

3. Theorical Foundations and Proposed Solution

In this section, after reviewing, the theoretical foundations and definitions, the proposed solution is presented.

Theoretical foundations: First, briefly review fuzzy logic, Mamdani method, particle algorithm, and LEACH routing protocol. The fuzzy inference process includes membership functions, fuzzy operators, and one-condition rules. The type of fuzzy inference system used is Mamdani. In this method, the output membership functions of the fuzzy set must be non-fuzzy. This increases the efficiency of non-fuzzy. The proposed clustering is based on the use of the LEACH

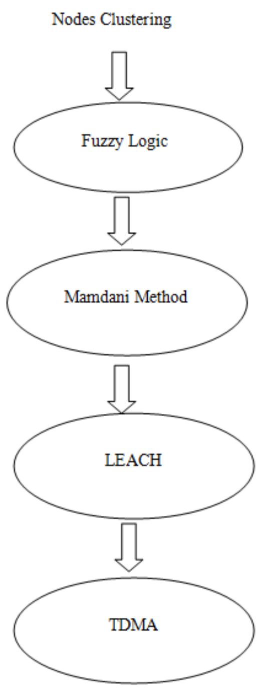

Figure 1: Sequence of steps performed
Figure

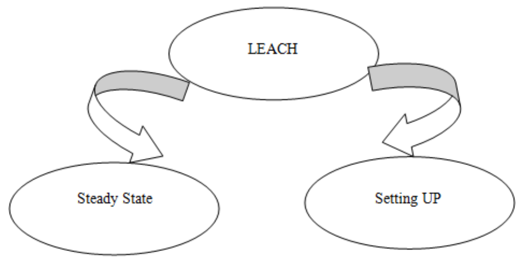

Figure 2: Steps of the LEACH algorithm

algorithm, the capability, and reliability of which have been improved by fuzzy systems. LEACH is a random selection clustering protocol that distributes energy load over network nodes, using cluster-based hierarchical routing. The purpose of this protocol is to reduce the power consumption of nodes to improve the life of the Wireless Sensor Network. In this algorithm, to consume balanced energy, the role of the eclipse rotates in each round between the nodes in the cluster. The connection of nodes with the header is done using the time-division multiplexing method Bennani and Zbakh (2019), Ali et al. (2019), Al-Zubaidi et al. (2019). Fig. 1 shows the sequence of steps, and Fig.2 shows the two main steps of the LEACH algorithm.

As shown in Fig. 2, the LEACH algorithm consists of two steps:

1) Startup stage 2) Steady-state stage.

In the start-up phase, clusters are formed, and in the steady-state phase, messages are sent to the header, which are sent to the base station after receiving and aggregating.

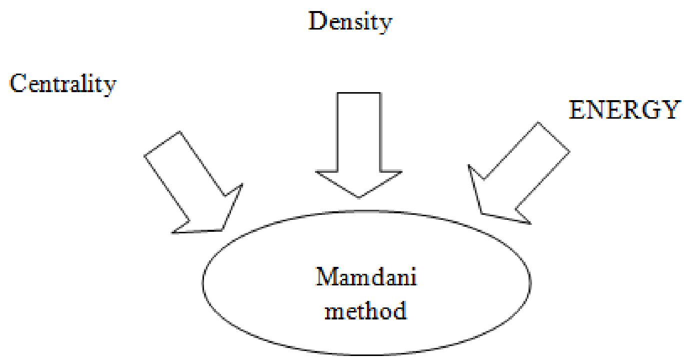

Figure 3: Mamdani method inputs

In the first round, a random value between 0 and 1 is considered for each node, and if this value is less than the set threshold for each node, this node is selected as the header. In this protocol, clusters of the same size are created. Due to the importance of energy-saving, not considering ”residual node energy” when selecting the cluster and randomly selecting the cluster at the beginning of each cycle will cause uneven energy consumption and network instability. In the proposed method, the probability of each node being the leader is calculated using a fuzzy system. Fig. 3 shows the inputs to the Mamdani method.

The fuzzy system used is the Mamdani type with three inputs ”energy”, ”density”, ”centrality”, and one output. To find the fuzzy output, finding the center of mass method, is used. Now the optimal particle swarm algorithm will help and has the ability to find the optimal policy line that can maximize the amount of mathematical hope for all states in the clusters. Fig. 4 shows a general chart of the proposed method.

The Particle Algorithm or PSO is a collective search algorithm modeled on the social behavior of flocks of birds. Initially, this algorithm was used to discover the patterns governing the simultaneous flight of birds and their sudden change of direction and optimal deformation of the handle. In PSO, particles flow in the search space. The displacement of particles in the search space is influenced by the experience and knowledge of themselves and their neighbors; so the other position of the particle mass affects how a particle is searched. Modeling this social behavior is the search process in which particles tend to successful areas. Particles learn from each other and move towards their best neighbors based on the

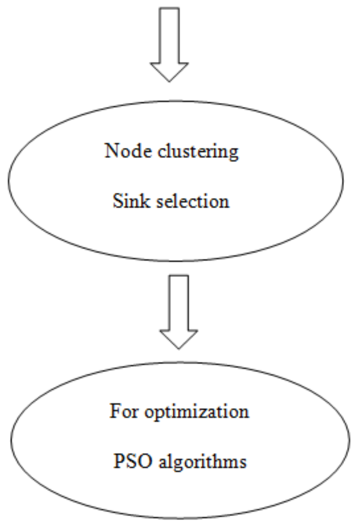

Figure 4: Outline of the proposed method

knowledge gained. This is present in its entire neighborhood. After an overview of the theoretical foundations, the proposed solution is presented.

3.1 Suggested solution:

In general, the steps of the proposed solution are as follows:

- Fuzzy logic: to reduce energy consumption
- Mamdani method: for clustering nodes
- Time-division multiplexing method: to maintain the connection of nodes with the thread
- LEACH routing algorithm or protocol: for clustering basics
- Particle algorithm or PSO: to optimize the network path

The eclipses in each round are selected by the base station taking into account the chance of each node to eclipse according to the three fuzzy descriptors mentioned. A central control algorithm in the base station produces better clutter because the base station has global network knowledge. In addition, base stations have many times more power than sensor nodes with enough memory, power, and space. The performance of the fuzzy scheme for selecting the head, as mentioned, consists of two start-up phases and a steady-state phase similar to LEACH Bennani and Zbakh (2019), Ali et al. (2019), Al-Zubaidi et al. (2019). In the setup phase, the heads of the clusters are determined using fuzzy knowledge processing, and then the cluster is organized. In the steady-state stage, the cluster heads collect the collected data and process the signal to compress the data into a single signal. This compressed signal is then sent to the base station. Expert knowledge is presented based on the following three descriptors:

- Node energy - the energy level in each node
- Node Density - The number of nodes in the vicinity
- Node Centrality - The value that classifies nodes into clusters based on how the node is centered.

The linguistic variables used to indicate node energy and node density are divided into three levels: low, medium, and high, and there are three levels to indicate node centrality: close, adequate, and far. Also, the result of obtaining the chance to select nodes at the node is divided into seven levels: very small, small, rather small, medium, rather large, large, and very large. The fuzzy rule base now contains rules such as the following: If the energy is high, the density is high, and the centrality is close, the node cluster is very likely to be selected. We used 27 rules for the fuzzy rule base. Mamdani fuzzy inference system has been proposed as the first attempt to control the combined steam and boiler engine by a set of language control rules obtained from experienced human operators. The particle algorithm plays an important role in optimizing the network path and uses the mentioned phases for this purpose.

- Random production of the initial population of particles: Random production of the initial population is simply the random determination of the initial location of the particles by distribution
- Uniform in solution space (search space). The random population stage of the initial population is present in almost all probabilistic optimization algorithms. However, in this algorithm, in addition to the initial random location of the particles, a value is also allocated for the initial velocity of the particles.
- Selecting the number of primary particles: We know that increasing the number of primary particles reduces the number of iterations required to

converge the algorithm. However, sometimes, it is observed that users of optimization algorithms think that this reduction in the number of iterations means a reduction in program execution time to achieve convergence, while such an idea is completely wrong. However, increasing the number of primary particles reduces the number of repetitions. But caused an increase in the number of particles .
The algorithm spends more time in the particle evaluation stage, which increases the execution time of the algorithm until the convergence is achieved, despite the reduction in the number of iterations. Therefore, increasing the number of particles cannot be used to reduce the execution time of the algorithm. There is another misconception that the number of particles can be reduced to reduce the execution time of the algorithm. There is also the notion that it takes time to evaluate the particles, but to get the algorithm to the optimal solution. The number of repetitions increases. (If we consider the convergence condition as not changing the cost of the best member in several consecutive repetitions) which ultimately means that the execution time of the program to achieve the optimal response is not reduced. It should also be noted that reducing the number of particles may cause them to get stuck in local minima, and the algorithm will not be able to reach the original minimum. If we consider the convergence condition as the number of iterations, although the execution time of the algorithm decreases with decreasing number of initial particles, but the obtained result will not be the optimal solution for the problem, because the algorithm is incompletely executed.
In short, the number of the initial population is determined by the problem. In general, the number of primary particles compromises the parameters involved in the problem. Experimentally, selecting an initial particle population of 20 to 30 particles is a good choice that works well for almost all test problems. You can also consider the number of particles a little more than necessary to have a little safety margin in the face of local minima.

- Evaluation of the objective function (calculation of cost or viability) of particles: In this step, we must evaluate each particle that represents a solution to the problem under study. The evaluation method will be different depending on the issue under consideration. For example, if it is possible to define a mathematical function for the purpose, by inserting the input parameters (derived from the particle position vector) in this mathematical function, the cost of this particle will be easily calculated. Note that each

particle contains complete information about the input parameters of the problem, which is extracted and placed in the target function.
Sometimes it is not possible to define a mathematical function to evaluate particles. This happens when we link the algorithm to another piece of software or use the algorithm for experimental data. In such cases, the information related to the input parameters of the software or test should be extracted from the particle position vector and placed in the software linked to the algorithm or applied in the relevant test. By running the software or performing experiments and observing and measuring the results, the cost of each particle will be determined.

- Record the best position for each particle (Pi, best) and the best position among all particles (Pj, best): In this step, according to the repetition number, two modes can be checked:

  If we are in the first iteration, according to equation (3.1) (t = 1), consider the current position of each particle as the best location found for that particle.

  $P_{i,best}=X_i(t)$,i=1,2,3,,d

$$Cost(P_{i,best}) = cost(X_j(t)) \tag{3.1}$$

  In other iterations, compare the cost obtained for the particles in step 2 with the amount of the best cost obtained for each particle. If this cost is less than the best-recorded cost for this particle, then the location and cost of this particle will replace the previous value. Otherwise, there will be no change in the location and the recorded cost for this particle. The particles are then optimized according to equation (3.2).

$$V_i(t) = w*V_i(t-1)+c_i*rand_1*(P_{i,best}-X_i(t-1))+c_2*rand_2*(P_{g,best}-X_i(t-1)) \tag{3.2}$$

  The coefficients w, c1, c2 are determined experimentally according to the problem. However, as a general rule, keep in mind that we must be less than one, because if greater than one is chosen, V (t) will constantly increase until it diverges. It can also be negative, but in the practical use of this algorithm, never consider these coefficients negative because negative w will cause oscillation in V (t). Selecting a small value for this coefficient w will also cause problems. The value of this coefficient is often considered positive in the PSO algorithm and in the range of 0.7 to 0.8. In the PSO

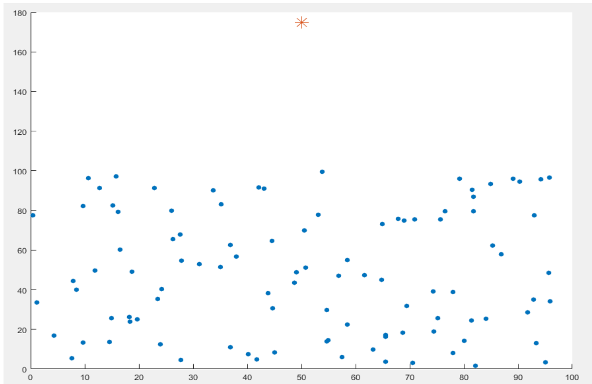

Figure 5: Distribution of nodes and Sink nodes in the simulated network

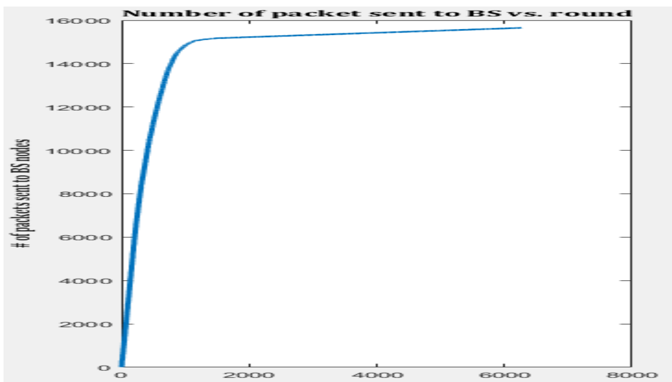

Figure 6: The number of packets sent to the base station in each round

algorithm, the values of these coefficients are often considered positive and in the range of 1.5 to 1.7.

- Convergence test: The convergence test in this algorithm is like other optimization algorithms. There are various methods to test the algorithm. For example, it is possible to determine a certain number of repetitions from the beginning and check at each stage whether the number of repetitions has reached the set value? If the number of iterations is less than the initial set value, then you must return to step 2, otherwise, the algorithm will end. Another method that is often used in algorithm convergence testing is that if in a few consecutive iterations, for example, 15 or 20 iterations do not change the cost of the best particle, then the algorithm ends; otherwise it must go to step 2.

After reviewing the explanations related to the performance of the proposed solution and the role of each of the theoretical foundations used in the following, we have a summary of this section.

Fuzzy logic and the Mamdani method are used for clustering nodes, and particle algorithm is considered to optimize the path of networks. The proposed clustering is based on the LEACH algorithm, whose capability and reliability have been improved by fuzzy systems. LEACH is a random selection-based clustering protocol that distributes energy loads over network nodes using cluster-based hierarchical routing. The purpose of this protocol is to reduce the energy consumption of nodes to improve the life of the wireless sensor network. In this algorithm, to consume balanced energy, the role of the eclipse rotates in each round between the nodes in the cluster. The connection of nodes with the header is done using the time-division multiplexing method. The next section presents the simulation results.

4. Simulation Results

The simulator used is MATLAB. The first criterion examined is comparing the number of dead nodes in each round. The results of measuring these parameters are presented in the form of diagrams and tables. The results show that the balanced energy consumption has caused the number of nodes that do not have the necessary energy to operate in the network to increase uniformly in each cycle. First, the hypotheses used in the simulation and the MATLAB environment are presented in the form of a table, and in this scenario, a working environment with dimensions of 100×100 square meters is considered. 100 nodes with an initial energy of 0.5 joules are randomly distributed in the medium, and the base station is located in the center with coordinates (175 and 50) as shown in Fig. 5 and is marked with a red star. The simulation parameters of this scenario can be seen in Table 1.

Fig.6 shows the number of packets sent to the base station in each round. The second criterion examined in this scenario is the comparison of the number of dead nodes in each round. The results of measuring this parameter are shown in Fig. 7, and the results show the fact that the balanced consumption of energy has caused that in each round, the number of nodes that do not have the necessary energy to operate in the network to the face will increase evenly (dead nodes). Fig. 8 shows a diagram of the energy consumption trend of nodes over the life

Table 1: Simulation parameters

parameters	**values**
Environment dimension	100*100
Base station specification	(50*175)
Nodes number	100
Data packet size	500 byte
First energy	0.5 J

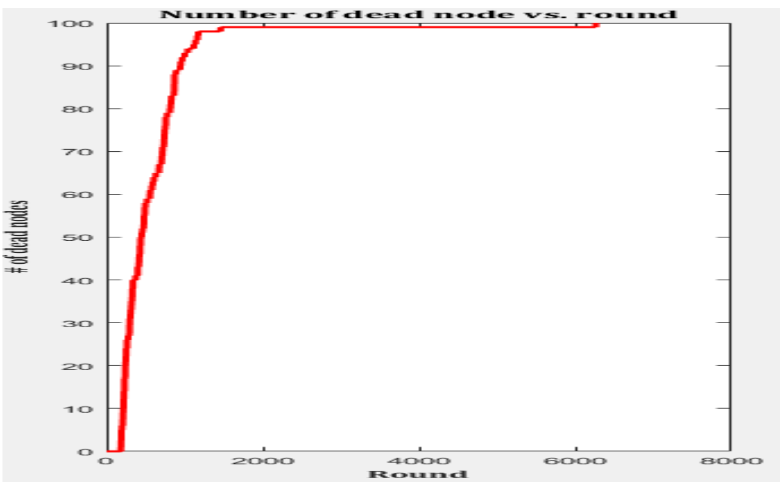

Figure 7: The number of dead nodes per round

of the network. According to the obtained results, the proposed algorithm has resulted in balanced energy consumption in each cycle.

Table 2 shows the statistical performance of the proposed method for different cycles.

According to the result of table 2, When the number of rounds increases, the amount of energy consumed decreases according to the number of dead nodes, and after a few rounds, the amount of energy consumed is equal to zero.

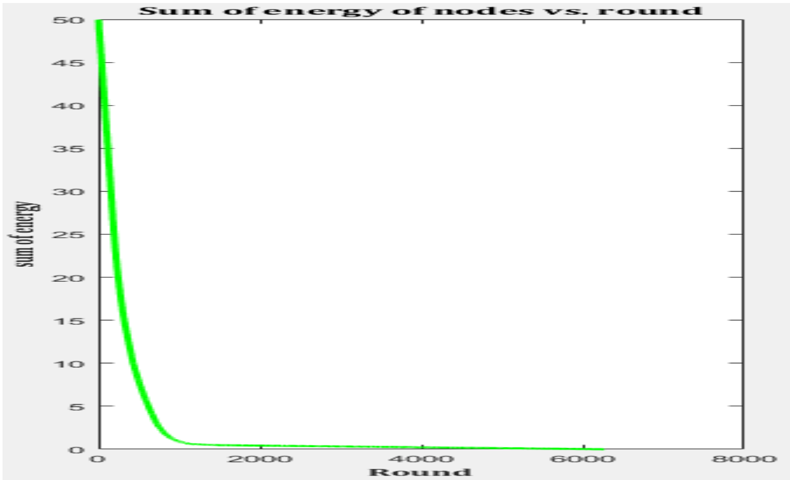

Figure 8: Energy consumption of nodes in each cycle round

Table 2: simulation result of proposed method

Nodes energy consumption of each round	**Number of dead nodes**	**Number of sending packets to base stations**	**Round**
50	0	0	0
48	0	453	100
47	3	766	150
-	7	1581	250
-	27	4012	500
1	73	13121	1000
1	99	14998	1500
0.9	99	15114	2000
0.5	99	15211	3000
0.2	99	15324	4000
0.1	99	15567	5000
0	88	15698	6000
0	0	-	7000

5. Conclusions

Our goal, in the beginning, was to use the fuzzy method to select the paths in which the most likely choice is the head or well. For this purpose, the Mamdani method has been used, which is one of the fuzzy methods. In fact, in order to get from one path to the other, fuzzy construction must take place. The proposed clustering is based on the use of the LEACH algorithm, whose capability and reliability have been improved by fuzzy systems. Then, after reaching the clusters, the particle optimization algorithm is used to select the nodes that have less energy. The choice must be made so that energy consumption is reduced by increasing the cycles and learning the path by the particle algorithm. In this article, as shown, we were able to achieve this. For future work, we can use other methods and protocols to see if the amount of grid energy is reduced compared to the methods presented, also can be used meta-heuristic algorithms such as spider algorithm for removing dead nodes. To do this, a router should be considered as records the statistics of its nodes in an instant and reduce the energy of the threads by using the optimizations.

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