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A fuzzy three-level clustering method for lifetime improvement of wireless sensor networks

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Abstract
One of the most important issues in wireless sensor networks (WSNs) is to reduce energy consumption and increase the network lifetime. Proper election of cluster head is one of the approaches to reduce energy consumption in the network. Among existing methods, low-energy adaptive cluster hierarchy (LEACH) is the most prevalent routing algorithm, in which the cluster head is elected based on a given threshold. In LEACH algorithm, only the cluster heads are allowed to send information to the base station (BS). In this paper, a novel routing protocol based on super cluster head election using fuzzy logic in three levels (SCHFTL) is proposed, in which a super cluster head is elected among the cluster heads. The super cluster head election is performed based on a fuzzy description in three levels using Mamdani inference engine. Effectiveness of the proposed SCHFTL routing protocol is verified through MATLAB simulations in terms of death, time of the first node and network lifetime compared with LEACH, cluster head election mechanism using fuzzy logic (CHEF) and fuzzy-based master cluster head election leach (F-MCHEL) protocols.

Keywords Wireless sensor networks (WSNs) · Clustering · Fuzzy logic · Super cluster head

1 Introduction

Recent advances in semiconductor, wireless technology and microelector mechanical systems (MEMS) have led to the ubiquitous deployment of wireless sensor networks (WSNs). WSN is a collection of large number of sensor nodes, communicating with one another through wireless links. Sensor nodes are distributed in an environment, and they gather information about temperature, humidity, pressure, vehicular movement and etc. There is wide range of application areas for WSNs, e.g., health, military, security and agricultural and industrial applications [1]. Despite ubiquity of these networks, there exist some challenges in designing them. One of the most important challenges is the routing problem. Since there are too many sensor nodes in the network and also the network structure is not predetermined, routing is not straightforward in WSNs [2]. In addition, energy and processing resources are limited in WSNs, due to the financial limitations [2]. That is to say, sensor nodes are supplied with batteries and limited processing capacity. Therefore, the energy consumption must be highly considered in designing the routing protocols [3, 4].

One of the most important scenarios in which WSNs are applicable is harsh and out-of-reach environments, such as battlefields. In these applications, it is not possible to resupply the sensor nodes with new batteries. Therefore, it is of great importance to reduce energy consumption by preventing data collision in these networks [1, 3]. To reduce energy consumption and increase the network lifetime, clustering-based routing protocols have been proposed, in which sensor nodes are divided into groups called clusters. In the clustering-based routing protocols, a node is elected as the cluster head and it collects information from all sensor nodes of that cluster. Then, each cluster head transmits the collected data to the base station (BS) to be processed [1]. In the clustering-based routing protocols, the number of

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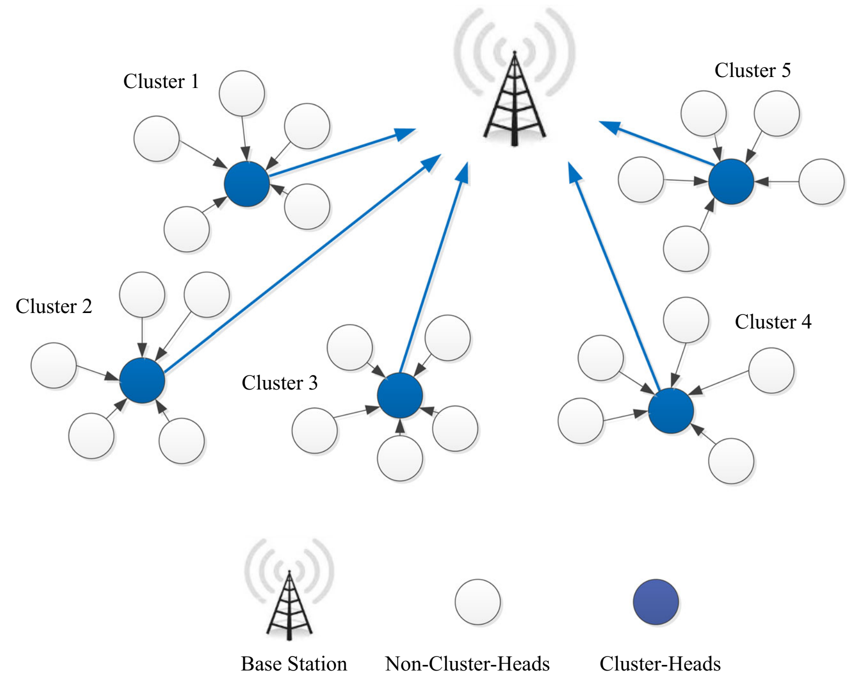


Fig. 1 Clustering-based data routing in WSN

messages that propagate through the network is reduced [5]. Figure 1 illustrates clustering-based data routing in a WSN.

Among existing methods, low-energy adaptive cluster hierarchy (LEACH) is a well-known clustering-based routing protocol, in which the cluster head is elected based on a given threshold. In LEACH, sensor nodes are randomly elected as cluster heads, such that the high energy consumption in communicating with the BS is distributed among all sensor nodes in the network [6]. In this algorithm, each node is elected as the cluster head with a given probability and the closest nodes to that cluster head are elected as the members of that cluster. The cluster head provides a time-based plan for its members and transmits the collected data to the BS. In the first step, the nodes compete in order to be elected as the cluster head. To this end, each node produces a random number between 0 and 1. If this number is less than the threshold $T(n)$, the node is elected as a cluster head. The threshold $T(n)$ is obtained by

$$T(n) = \begin{cases} \dfrac{P}{1-P(r \, mod(1/P))} & if \; n \in G \\ 0 & otherwise \end{cases} \tag{1}$$

where P is the desired probability to become a cluster head, r is the current round and G is the set of the sensor nodes which have not been elected as the cluster head in the recent $1/P$ rounds [6]. The cluster heads are elected randomly in this algorithm. In the next step, the nodes join to their closest cluster heads and create the clusters. Though LAECH is widely employed, it suffers from some drawbacks, such as dependency on the desired probability value. In addition, there is no guarantee to elect the ideal cluster heads. Cluster heads are elected randomly in this protocol, which may cause the cluster heads to be too close to each other and lead to high energy consumption. Moreover, cluster heads might be elected near the network borders causing an increase in energy consumption for sensor nodes to transmit data to cluster heads. Since LEACH uses single-hop routing, it is not applicable to the networks deployed in large environments. Furthermore, the idea of dynamic clustering brings extra overhead, which may reduce the gain in energy consumption [7]. A review on the existing clustering-based routing protocols is given as follows.

In [8], LEACH-centralized (LEACH-C) is presented, in which the BS elects the cluster heads using local information of each node, i.e., the location and remaining energy of each node. Therefore, the clustering is performed more efficiently. The main drawback of this clustering algorithm is that the BS must have a global knowledge of the location of all sensor nodes. Since the location information of each node is transmitted to the BS, the data overhead in the BS gets too high in this algorithm. In [9], a stable election protocol (SEP), which is an improved form of LEACH algorithm, is presented. The main goal of SEP is to take advantage of heterogeneous sensors in WSNs. This algorithm is similar to the LEACH algorithm except that the nodes are considered to have two different levels of energy (heterogeneous sensors). In this algorithm, it is assumed that the energy levels of some nodes are higher than other nodes, and the probability of nodes with higher energy levels to become a cluster head is higher. Performance of this clustering algorithm has been compared with LEACH under the same situation, and it has been concluded that SEP is able to improve the efficiency. But the main drawback of this algorithm and LEACH is that the cluster heads are elected without considering the changes in the energy level and locations of sensor nodes. These algorithms are designed statically, and they are not able to change according to topological modifications of the networks. In [10], quadrature-LEACH (Q-LEACH) for homogenous networks is proposed, which enhances stability period, network lifetime and throughput. Stability period is the time duration between death of first node and death of half of the nodes and is one of the most important metrics, especially in the dense WSNs [11]. In Q-LEACH, the network is partitioned into four quadrants, and hence, clusters formed within these subsectors are more deterministic compared to conventional LEACH. Such sort of partitioning leads to exact distribution of nodes in the environment, optimum definition of cluster head locations and lower energy consumption [10].

In [12], distributed energy-balanced unequal clustering routing protocol (DEBUC) is proposed which employs an unequal clustering mechanism and an inter-cluster multi-hop routing method. DEBUC divides all nodes into clusters of unequal size, such that the clusters closer to the BS have smaller size. DEBUC reduces and balances the energy consumption of the cluster heads, by adopting an energy-aware multi-hop routing method. In [13], a self-stabilizing robust clustering algorithm is proposed. The authors propose several enhancements in [13] to reduce the stabilization time and thus improve stability in a dynamic environment. In [14], detailed models are presented for rout maintenance operations of some widely used proactive routing protocols. Performance of the selected protocols are then analysed and compared using the proposed model. In [15], a new routing link metric is designed, and in [16], a new quality link metric called inverse expected transmission count (InvETX) is proposed. The main contribution of [16] is improvement of the optimized link state routing (OLSR) protocol in terms of optimized routing load and routing latency.

Too many researchers have tried to elect cluster heads that improve lifetime of the networks based on fuzzy logic. In [17], fuzzy-based master cluster head election leach protocol (F-MCHEL) has been proposed. In the proposed method, cluster heads are elected using two fuzzy descriptors, i.e., energy and proximity distance. In this protocol, only the master cluster head, which is elected out of the elected heads, can transmit information to the BS. In [18], the stability period of the proposed routing protocol in [9] has been increased based on fuzzy logic. The proposed method in [18] is called SEP fuzzy logic (SEP-FL), and it calculates the chance of each node to become a cluster head, in contrast to SEP which takes this parameter to elect the cluster head as a random value. In [19], two fuzzy-based systems are proposed for cluster head election with no excessive message exchanges. In [20], cluster head election mechanism using fuzzy logic (CHEF) is presented, in which the computational overhead is reduced and the network lifetime is extended. The operation of CHEF is localized, i.e., the BS does not elect cluster heads. This is the sensor nodes which elect cluster heads among themselves using the fuzzy logic. In [21], the cluster head selection protocol using fuzzy logic (CHUFL) is presented, in which the node's parameters, such as remaining energy, reachability from its neighbours and distance from BS are used as fuzzy input variables for cluster head election.

In [22], an adaptive fuzzy clustering algorithm is proposed based on mobile BS, in which a three-level fuzzy logic is utilized to elect the cluster heads. In the first level, the nodes are elected

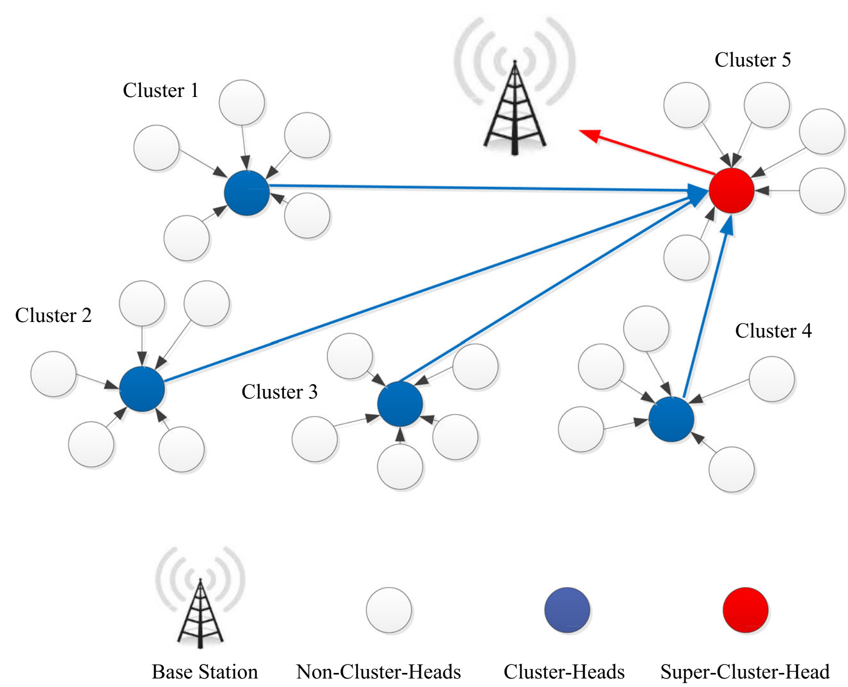


Fig. 2 SCHFTL clustering method

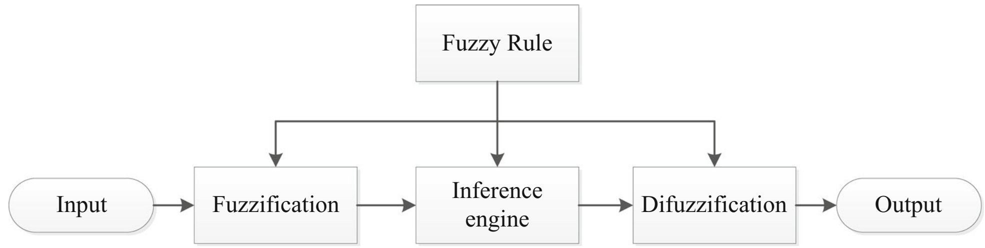


Fig. 3 Block diagram of fuzzy inference system

based on their remaining energy and density. In the second level, the best node cooperation is sought regarding the average energy consumption, and in the third level, the BS is moved based on energy of cluster heads and distance between cluster heads and the BS. In [23], a novel time synchronization algorithm named clustered consensus time synchronization (CCTS) is proposed for WSNs. CCTS is developed by incorporating the clustering technique in distributed consensus time synchronization (DCTS) algorithm to obtain faster convergence in the synchronization of nodes and better energy efficiency. Most of the proposed clustering algorithms do not consider the location of the BS, which may cause hot spot problem in multi-hop WSNs. To solve this problem, the fuzzy energy-aware unequal clustering algorithm (EAUCF) is designed in [24] by considering the BS location. In EAUCF, the cluster head radius is adjusted based on two parameters of nodes, i.e., their remaining energy and their distance from the BS. Therefore, the intra-cluster activity of the nodes, which are farther from the BS or have lower energy level, is decreased. In EAUCF, the fuzzy logic is used for handling the uncertainties in cluster head radius estimation.

In this paper, a novel routing protocol based on super cluster head selection using fuzzy logic in three levels (SCHFTL) is proposed. As discussed in previous paragraphs, many clustering-based routing protocols have been proposed to improve LEACH algorithm. However, in most of the proposed methods such as LEACH-C or Q-LEACH, the cluster heads are elected by the BS, which means the BS must receive state, location and remaining energy information from all sensor nodes through a global positioning system (GPS). Although LEACH-C and Q-LEACH enhance the network lifetime, they require extra cost for GPS. In some other methods such as SEP, the cluster heads are elected without considering the changes in the energy level and locations of sensor nodes. These algorithms are designed statically, and they are not able to change according to topological modifications of the networks. Therefore, some fuzzy-based routing protocols such as F-MCHEL and CHEF have been proposed to consider the changes in the energy level and locations of sensor nodes in the election of cluster heads. But, some other important parameters of nodes, i.e., communication quality, centrality, total delay and denial of service (DoS) attacks, have not been considered in these clustering-based routing protocols. Thus, the novel SCHFTL routing algorithm is proposed in this paper to improve the existing methods such as LEACH, CHEF and F-MCHEL, by taking into account these important parameters. In SCHFTL, only the super cluster head is responsible for sending information to the BS. Therefore, energy consumption and data overhead are reduced compared to LEACH and CHEF. In the proposed SCHFTL routing algorithm, the sensor nodes elect cluster heads among themselves, which means the BS does not need to receive information from sensor nodes through GPS. In SCHFTL, sensor nodes with priority to be a cluster head are elected in the first level. Then, in the second level, the cluster heads are elected based on different parameters, i.e., remaining energy, distance from the BS, communication quality, centrality, total delay and DoS attacks, to reduce energy consumption. Finally, in the third level, a super cluster head is elected out of the cluster heads using fuzzy descriptors.

The remainder of this paper is organized as follows. In Sect. 2, the system energy model is analysed. In Sect. 3, fuzzy inference modules and the SCHFTL algorithm are presented. Simulation results are provided in Sect. 4, and finally, the conclusions are drawn in Sect. 5.

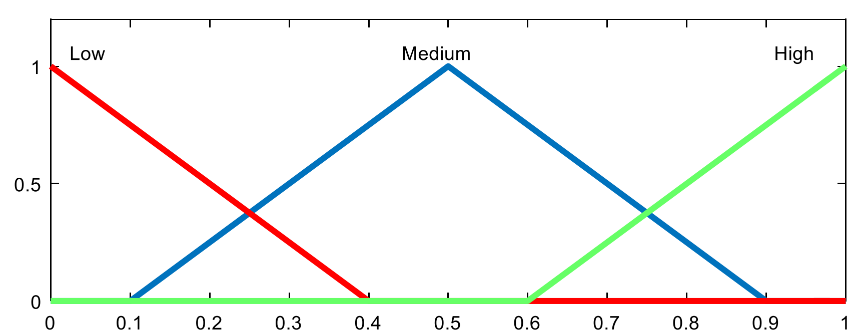


Fig. 4 Triangular fuzzy membership function

2 Energy consumption model

To analyse the energy consumption of the proposed SCHFTL routing algorithm, the same energy model of LEACH algorithm is employed. Therefore, the energy consumed in a transmitter to transmit an l-bit message is given by [8].

$$Etx = \begin{cases} l \times E_{elec} + l \times \epsilon_{fs} + d^2 & if\ d < d_0 \\ l \times E_{elec} + l \times \epsilon_{mp} + d^4 & if\ d \geq d_0 \end{cases} \quad (2)$$

where E_{elec} is the energy consumed to run the electronic circuits, ϵ_{fs} and ϵ_{mp} are the characteristics of the transmitter amplifier, d is the distance between the transmitter and the receiver and d_0 is a threshold.

3 The SCHFTL algorithm

Fuzzy logic is a promising decision making tool, which provides simple real-time solution even for problems with insufficient or missing information. Using fuzzy logic for designing routing protocols in WSN leads to network lifetime improvement and higher flexibility and scalability. Moreover, the data overhead problem in BS can be solved using fuzzy-based routing protocols. As mentioned before, cluster heads are elected randomly in LEACH protocol. Therefore, there is no guarantee to elect the ideal cluster heads. Too many cluster heads might be elected in some areas, and no cluster head might be elected in other areas, which lead to unbalanced energy consumption in the network. In addition, all cluster heads send information to the BS, which may cause data overhead. In F-MCHEL protocol, cluster heads are elected using two fuzzy descriptors, i.e., energy and proximity distance. To improve LEACH, CHEF and F-MCHEL, the three-level SCHFTL protocol is proposed in this section, by taking into account some important parameters, such as communication quality, centrality, total delay and denial of service (DoS) attacks, in the election of cluster heads. In the first level of SCHFTL, sensor nodes with priority to be a cluster head are elected based on a given threshold. Then in the second level, the cluster heads are elected based on different parameters to reduce energy consumption and total delay and increase the number of transmitted packets. In the third level of SCHFTL, a super cluster head is elected out of the cluster heads using fuzzy descriptors. In the proposed method, only the super cluster head is responsible for transmitting information to the BS. Therefore, the data overhead in BS is reduced compared to LEACH and CHEF. Moreover, more parameters are used as input of fuzzy inference system to choose the super cluster head, in the proposed SCHFTL protocol. Thus, the energy consumption and data overhead are both reduced compared to F-MCHEL and CHEF. The SCHFTL algorithm is represented in the following subsections.

Table 1 Fuzzy rule in the first phase

Remaining energy	Centrality	Chance
Low	Low	Lower very weak
Low	Medium	Very weak
Low	High	Weak
Medium	Low	Lower medium
Medium	Medium	Medium
Medium	High	Higher medium
High	Low	Strong
High	Medium	Very strong
High	High	Higher very strong

Table 2 Fuzzy rule in the second phase

Communication quality	Distance from the BS	Chance
Low	High	Lower very weak
Low	Medium	Very weak
Low	Low	Weak
Medium	High	Lower medium
Medium	Medium	Medium
Medium	Low	Higher medium
High	High	Strong
High	Medium	Very strong
High	Low	Higher very strong

3.1 System assumptions

The following assumptions are considered for developing the proposed SCHFTL routing protocol.

- The nodes are scattered randomly in the environment with static locations.

Table 3 Fuzzy rule in the third phase

Total delay	DoS attacks	Chance
High	High	Lower very weak
High	Medium	Very weak
High	Low	Weak
Medium	High	Lower medium
Medium	Medium	Medium
Medium	Low	Higher medium
Low	High	Strong
Low	Medium	Very strong
Low	Low	Higher very strong

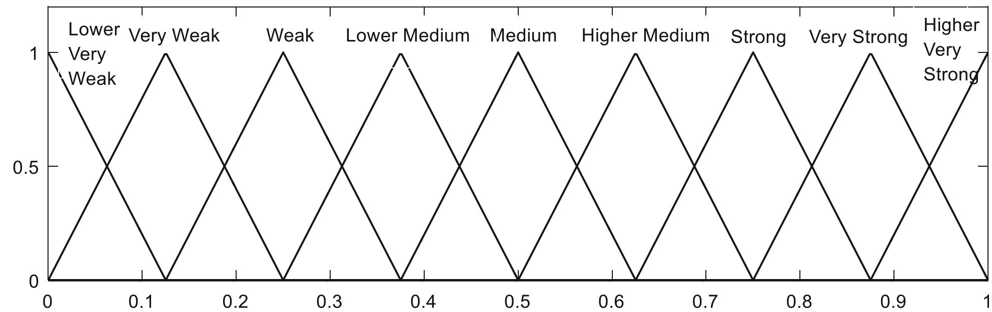


Fig. 5 Fuzzy membership functions for the output variable

- Three different scenarios have been considered, in which the BS is located at the centre, left and top-right corner of the environment.
- Two different scenarios have been considered for energy level of nodes. In homogeneous scenario, all nodes are assumed to have similar initial energy level. In heterogeneous scenario, different initial energy levels are assumed for nodes.
- The distance between the nodes and the BS is calculated based on the received signal strength (RSS).

3.2 System model

The proposed SCHFTL clustering method is based on the well-known LEACH algorithm. Each node produces a random number between 0 and 1. Then, these random numbers are compared with the threshold given by (1). If the random number is less than $T(n)$, the node has the priority to be elected as a cluster head. To reduce energy consumption and data overhead, a super cluster head is elected out of these cluster heads using fuzzy logic. Only the super cluster head is allowed to send data to the BS. Figure 2 illustrates the SCHFTL clustering method in a WSN consisting of non-cluster head nodes, cluster heads, super cluster head and the BS.

Table 4 Fuzzy rule in the third level

Remaining energy	Distance from the BS	Chance
Low	High	Lower very weak
Low	Medium	Very weak
Low	Low	Weak
Medium	High	Lower medium
Medium	Medium	Medium
Medium	Low	Higher medium
High	High	Strong
High	Medium	Very strong
High	Low	Higher very strong

3.3 Fuzzy inference system model

The fuzzy inference system is composed of four modules including fuzzification, fuzzy inference engine, fuzzy rules and defuzzification. The most common fuzzy method, i.e., Mamdani [25], is employed in this paper. Mamdani is a rule-oriented method and does not require complicated calculations. The block diagram of fuzzy inference system is shown in Fig. 3. In the fuzzification step, the inputs are converted to

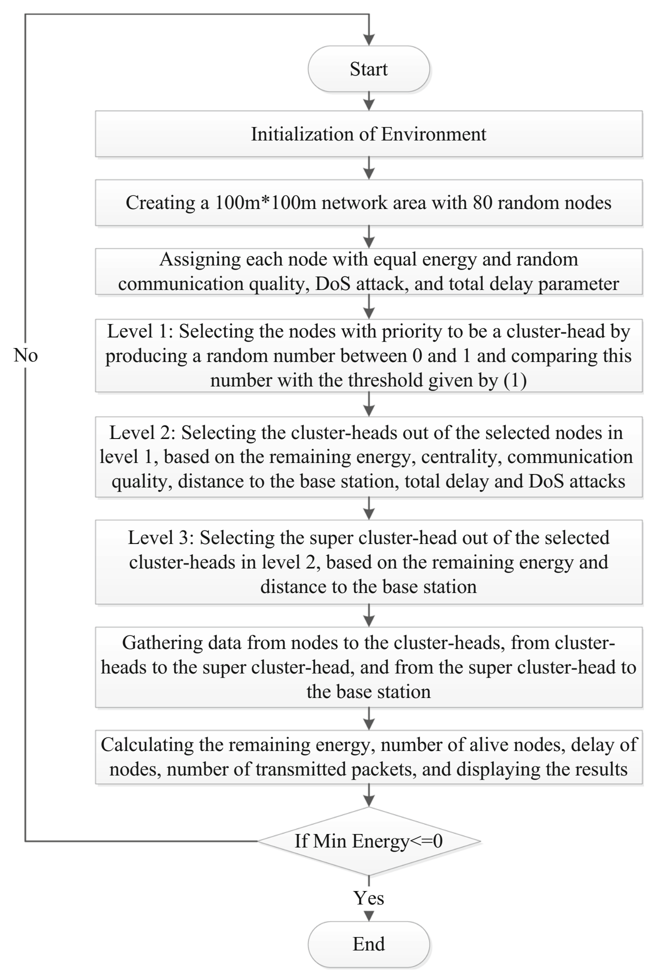


Fig. 6 Flow chart of simulating steps of the proposed SCHFTL protocol

Table 5 Simulation parameters [8]

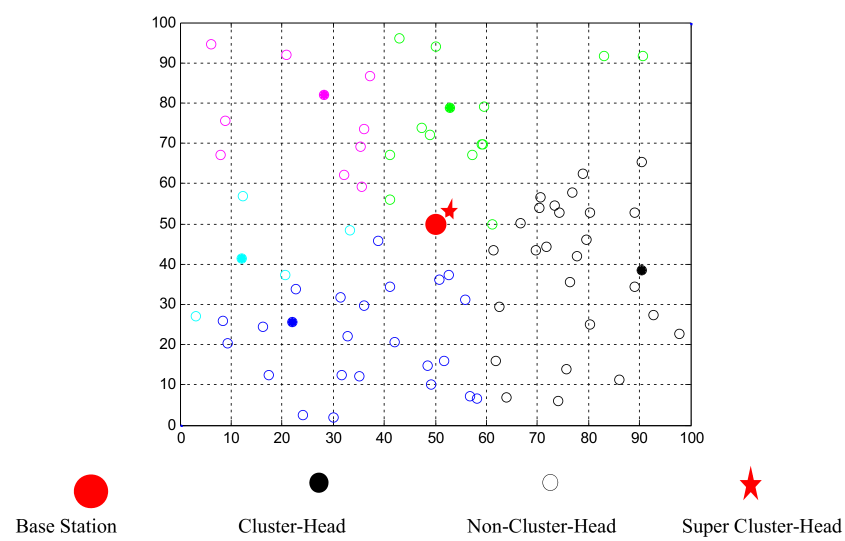
Parameter	Value
E_{elec}	50 nj/bit
ϵ_{fs}	10 $pj/bit/m^2$
ϵ_{mp}	0.0013 $pj/bit/m^4$
do	$\sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}}\ m$
l	1000 bit
Number of nodes	80

fuzzy quantities using fuzzy membership functions. Fuzzy rules are then applied by the (if and then) rules. Using the inputs and fuzzy rules, the fuzzy inference engine produces a result. Finally, in defuzzification step, results are converted to non-fuzzy results.

3.4 Fuzzification module for selecting cluster heads

After the first level, in which the nodes with priority to be cluster heads are selected, the second level is performed. In the second level of SCHFTL, Mamdani fuzzy inference technique and six fuzzy variables are employed to elect the cluster heads. The input and output membership functions are of triangle type between 0 and 1 as depicted in Fig. 4. Amounts of variables in each phase are low, medium and high. In the first phase, fuzzy inputs are the remaining energy and the centrality of cluster heads. The remaining energy is selected as a fuzzy input because cluster heads consume much more energy than non-cluster head nodes. Therefore, it is important to consider the remaining energy of nodes in cluster head election. The centrality parameter describes that how much the cluster head is at the centre of the cluster compared to other nodes. A higher centrality means that the cluster head is closer to the centre of the cluster, which results in a reduction in the energy consumption of non-cluster head nodes while sending data to the cluster head. The fuzzy sets that represent the first and second input variables, i.e., the remaining energy and centrality, are of triangular type as shown in Fig. 4. In the second phase, fuzzy inputs are the communication quality of nodes and their distance from the BS. If the node is closer to the BS, a lower energy consumption and faster data transmission are anticipated. Since each node has a communication quality based on the efficiency of its internal hardware, the communication quality of nodes is used as fuzzy input variable, to transmit data to the BS more efficiently. The fuzzy sets that represent the third and fourth input variables, i.e., communication quality of nodes and distance from the BS, are depicted in Fig. 4. In the third phase, fuzzy input variables are total delay and DoS attacks. Since the speed of transmitting data to the BS is of great importance, the total delay is considered as a fuzzy input in the proposed method. The total delay is defined as sum of each node's forwarding delay and queuing delay in the proposed SCHFTL routing protocol. The total delay of each node is defined by a random number. Moreover, WSNs are exposed to hostile attacks as other networks. These attacks result in service disruption and waste of batteries' energy. Motivated by this, DoS attacks are considered as a fuzzy input in the SCHFTL protocol. This parameter is defined by a random number between 0 and 1. The fuzzy sets that represent the fifth and sixth input variables, i.e., the total delay and DoS attacks, are depicted in Fig. 4. The chance of each cluster head to be elected as a super cluster head is then calculated, considering these six fuzzy inputs. It should be mentioned that these three phases are applied independently to all of the selected nodes from the first level. Then, results of

Fig. 7 The SCHFTL network model with its super cluster head



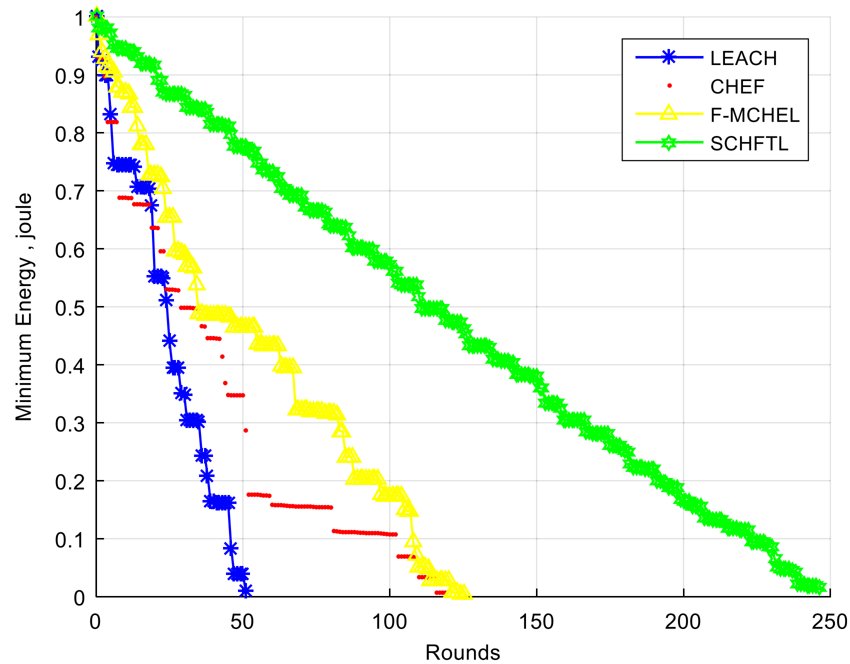


Fig. 8 Network lifetime for LEACH, F-MCHEL and the proposed SCHFTL

all three phases are multiplied to yield the overall priority of nodes. Therefore, the order of applying these three phases has no effect on the results. The fuzzy rules and the chance of being selected as a cluster head in the first, second and third phase are presented in Tables 1, 2 and 3. The output chance is composed of membership functions, i.e., lower very weak, very weak, weak, lower medium, medium, higher medium, strong, very strong and higher very strong. The fuzzy membership functions for output variable are depicted in Fig. 5.

3.5 Fuzzification module for selecting super cluster head

After the second level, in which the cluster heads are elected, a super cluster head is elected out of the cluster heads to reduce energy consumption in the network and data overhead in the BS. The super cluster head is similarly elected based on fuzzy logic. Two different parameters, i.e., the remaining energy of cluster heads and proximity distance (distances between

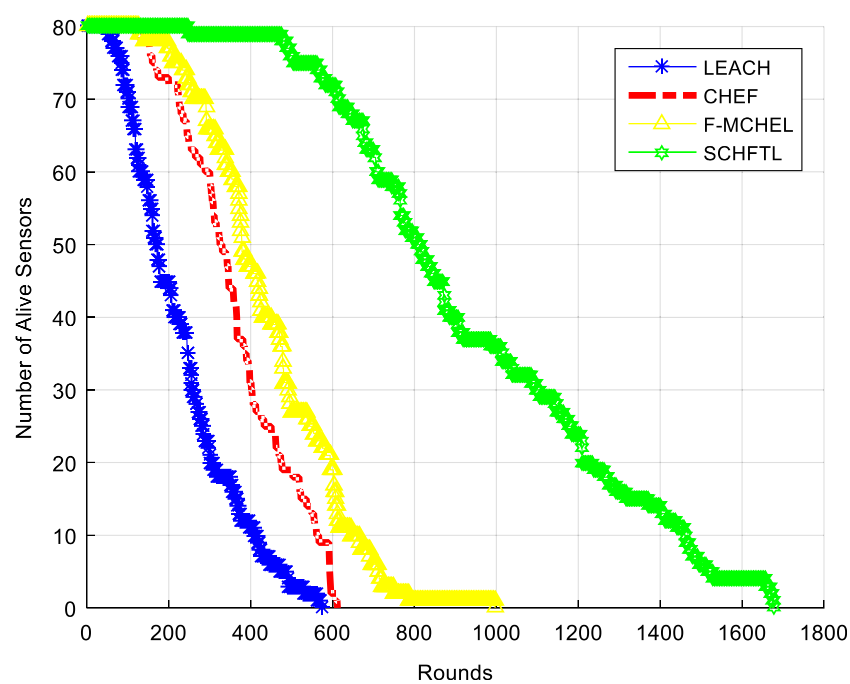


Fig. 9 Number of alive sensors for LEACH, F-MCHEL and the proposed SCHFTL

Table 6 Lifetime comparison

	Algorithm			
	LEACH	CHEF	F-MCHEL	SCHFTL
Death time of the first node (round)	49	119	121	247
Stability period (round)	181	247	317	660

Table 7 Comparison on minimum and maximum delay

	Algorithm			
	LEACH	CHEF	F-MCHEL	SCHFTL
Minimum delay (ms)	4	7.9	6.4	2.2
Maximum delay (ms)	40	40	31	11

cluster heads and the BS), are employed to determine the super cluster head. These two parameters are the input variables of the fuzzy inference system in the third level. The fuzzy sets that represent these input variables are of triangular type as depicted in Fig. 4. Moreover, the fuzzy rules and the chance of being selected as a super cluster head in the third level are presented in Table 4.

4 Results

To evaluate the effectiveness of the proposed SCHFTL algorithm, its performance is compared with those of LEACH, CHEF and F-MCHEL through MATLAB simulations. The flow chart containing different steps of simulating the proposed SCHFTL protocol is presented in Fig. 6.

4.1 Simulation settings

A WSN consisting of 80 nodes randomly located in an environment of size 100 m × 100 m is considered. Moreover, nodes are considered to have random communication quality. The simulation settings are provided in Table 5 [8]. Results of the simulations are presented at the following subsection.

4.2 Simulation results

In this section, simulation results are analysed. In Fig. 7, the SCHFTL network model with its super cluster head is shown. In the first experiment, the network lifetime is analysed. In this experiment, it is assumed that the BS is located at the centre of the environment and the network is homogeneous, i.e., nodes have similar initial energy level (1 *j*). Results of the first experiment are represented as follows. In Fig. 8, remaining energy of the nodes with lowest energy at each round is depicted for LEACH, CHEF, F-MCHEL and the proposed SCHFTL algorithm. It can be noticed that the proposed SCHFTL has the best performance, since the minimum remaining energy of the nodes in SCHFTL is higher than those of LEACH, CHEF and F-MCHEL. In Fig. 9, the number of alive sensors is depicted versus time. It is seen that nodes die latest, in the proposed SCHFTL algorithm. In Table 6, the death time of

Fig. 10 Comparison on total delay

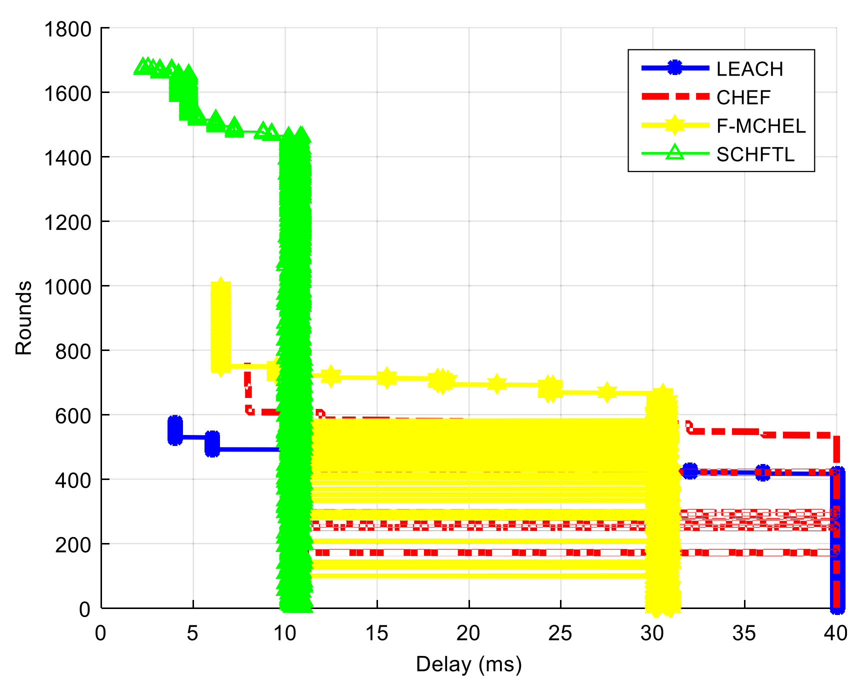


Table 8 Comparison on the number of received packets

	Algorithm			
	LEACH	CHEF	F-MCHEL	SCHFTL
Number of received packets	44,100	74,800	76,000	124,000

Table 9 Performance of SCHFTL for different BS locations

	BS location		
	(0, 50)	(100, 100)	(50, 50)
Death time of the first node (round)	201	235	247
Number of received packets	104,000	115,000	124,000

the first node in the SCHFTL algorithm is compared with the famous LEACH, CHEF and F-MCHEL algorithms. As is seen, the first node in the SCHFTL algorithm dies after 247 rounds. This is while in LEACH, CHEF and F-MCHEL algorithms, the time of the first nodes' death is 49, 119 and 121 rounds, respectively. Stability period of SCHFTL is also represented in Table 6 and compared with those of other routing protocols. Results of the comparison of this metric among the three algorithms indicate an improvement of 108% over F-MCHEL, 167% over CHEF and 264% over LEACH. Based on the aforementioned simulation results, it is deduced that the proposed SCHFTL algorithm has increased the network lifetime compared to LEACH, CHEF and F-MCHEL algorithms, significantly.

In the second experiment, data transmission delay in the BS is studied. Similar to the first experiment, it is assumed that the BS is located at the centre of the environment and the network is homogeneous. As mentioned before, the speed of transmitting data to the BS is of great importance. Therefore, the total delay, i.e., the sum of forwarding delay and queuing delay, is considered as a fuzzy input in the proposed SCHFTL algorithm. The forwarding delay is the time between the receiving of a data and the time of its transmission through the network [26]. The forwarding delay is determined by the network hardware and represents the time required by a router to process and forward data packets. The queuing delay is the time that a data packet waits in the queue to be transmitted by the router [27]. The total delay of each node is defined by a random number between 0 and 1, in the simulations. Total delay of each node is considered to be constant throughout the simulation time. In each round, the total delay of the cluster head and the total delay of all nodes in that cluster are gathered in the cluster head. The maximum of these delays is considered to be the total delay of the cluster and transmitted to the BS. Then, maximum of the total delays of all clusters is calculated in the BS as the total delay of that round. Since the total delay is considered as a fuzzy input in the proposed SCHFTL algorithm, nodes with lower delay are elected as cluster heads, which leads to a decrease in delay. Total delay of the proposed SCHFTL algorithm is compared with those of LEACH, CHEF and F-MCHEL in Fig. 10. Moreover, the minimum and maximum delays of the three algorithms are presented in Table 7. As is seen, the proposed SCHFTL algorithm has a 65% lower delay compared to F-MCHEL, 72% lower delay compared to CHEF and 45 to 72% lower delay compared to LEACH.

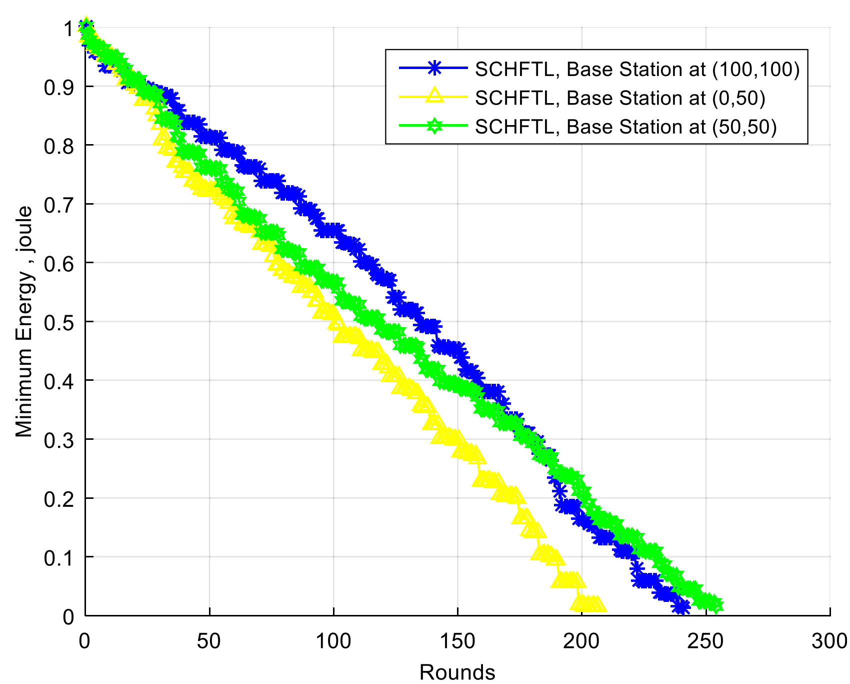


Fig. 11 Network lifetime for SCHFTL and different BS locations

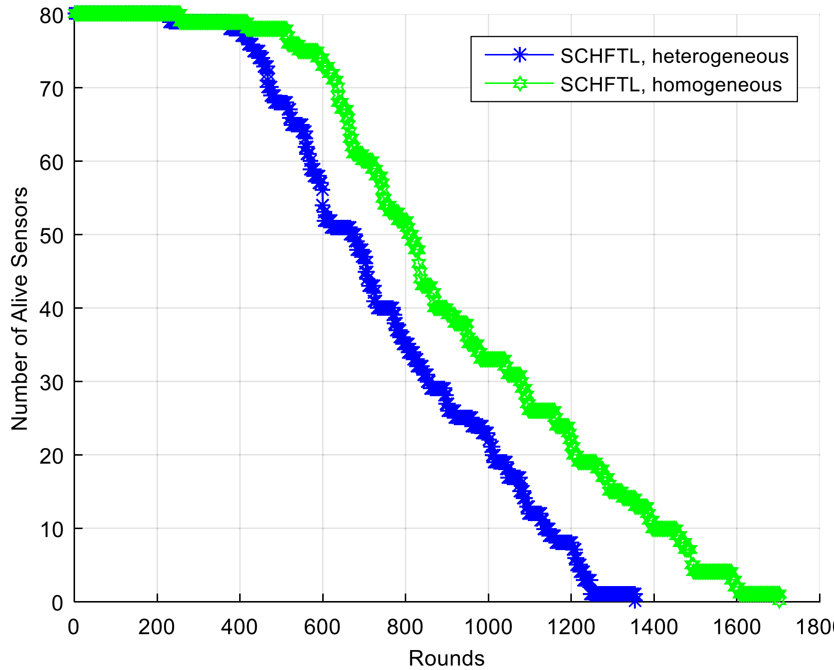


Fig. 12 Number of alive sensors for SCHFTL in heterogeneous and homogeneous networks

In the third experiment, performance of the proposed SCHFTL algorithm is analysed in terms of ability to transmit data packets to the BS. Similar to the previous experiments, it is assumed that the BS is located at the centre of the environment and the network is homogeneous. Higher number of transmitted packets means lower packet loss in the network. In all data transmission networks, some packets are lost due to different factors, such as low energy of cluster heads, hostile attacks, data overhead in the BS and low efficiency of cluster heads. In the simulations of the third experiment, the default number of sent packets is considered to be equal to the number of nodes, i.e., 80. Now, the aforementioned factors are all considered as the communication quality. The number of lost packets is then obtained based on the communication quality. Simulation results of this experiment are represented as follows. In Table 8, total number of received packets in the BS is represented. As is seen, the proposed SCHFTL algorithm has outperformed LEACH, CHEF and F-MCHEL algorithms in terms of received data packets. The proposed SCHFTL algorithm has achieved a 63% outperformance compared with F-MCHEL, 65% outperformance compared with CHEF and 181% outperformance compared with LEACH.

Table 10 Performance of SCHFTL in heterogeneous and homogeneous networks

	Network	
	Heterogeneous	Homogeneous
Death time of the first node (round)	223	247
Number of received packets	97,000	124,000

To evaluate impact of the base station location on the performance of the proposed SCHFTL algorithm, three different scenarios have been considered, in which the BS is located at the centre (50, 50), left (0, 50) and top-right corner (100, 100) of the environment. The network lifetime is analysed for SCHFTL and these different BS locations. Results of this comparison are depicted in Fig. 11 and Table 9. As is seen, the proposed SCHFTL algorithm has a better performance when the BS is located at the centre of the environment. This is because the distance between BS and super cluster head has a significant impact on energy consumption, according to (2). When the BS is located at the centre of the environment, the chance of the super cluster head to be closer to the BS is higher. Therefore, a reduced energy consumption is anticipated.

To evaluate impact of the initial energy level of nodes on the performance of the proposed SCHFTL algorithm, two different scenarios have been considered. In homogeneous scenario, all nodes are assumed to have similar initial energy level (1 *j*). In heterogeneous scenario, different initial energy levels between 0 *j* and 1 *j* are considered for different nodes. Results of this comparison are depicted in Fig. 12 and Table 10. As is seen, the proposed SCHFTL algorithm has a better performance when the network is homogeneous. This is a trivial result, since the initial energy level of some nodes is lower in heterogeneous scenario.

5 Conclusion

Reducing energy consumption in WSNs is of paramount importance, since it increases networks' lifetime. Clustering is an appropriate method to increase the network lifetime. Among existing clustering algorithms, LEACH is the most prevalent protocol. In a WSN with low energy consumption, data overhead in the BS is reduced. Data overhead is one of the most important reasons that decreases network lifetime and increases the possibility of data loss. When data overhead occurs, data packets collide with each other and some of them might get lost. So, the lost packets must be transmitted again. These retransmissions lead to energy loss in the nodes. So, a trustable algorithm for WSNs is required to control data overhead. In this paper, the novel SCHFTL clustering algorithm was proposed based on the fuzzy logic to reduce energy consumption in WSNs. By the appropriate selection of fuzzy variables, a super cluster head was elected out of the cluster heads. In the proposed SCHFTL, only the super cluster head is responsible for transmitting data to the BS. The proposed method avoids data overhead, data loss and data retransmission, which leads an increase in the network lifetime. Simulation results verified the outperformance of the proposed SCHFTL algorithm in comparison with LEACH, CHEF and F-MCHLE algorithms, in terms of network lifetime, death time of the first node, stability period, total delay and total number of received packets.

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