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Energy Efficient Clustering in Wireless SensorNetworks Using Fuzzy Approach to Improve LEACH Protocol

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ABSTRACT

The most important consideration in designing protocols for wireless sensor networks is the energy constraint of nodes because in most cases battery recharging is inconvenient or impossible. Therefore, many researches have been done to overcome this demerit. Clustering is one of the main approaches in designing scalable and energy-efficient protocols for wireless sensor networks. The cluster heads take the task of data aggregation and data routing to decrease the amount of communication and this prolongs the network lifetime. LEACH protocol is one of the famous of them. In this paper, we proposed a novel scheme to investigate the cluster, the Fuzzy Logic Cluster Leach Protocol (FUZZY-LEACH), which uses Fuzzy Logic Inference System (FIS) in the cluster process. We demonstrate that using multiple parameters in cluster reduces energy consumption. We compare our technique with the LEACH protocol to show that using a multi parameter FIS enhances the network lifetime significantly. Simulation results demonstrate that the network lifetime achieved by the proposed method could be increased by nearly 28.5% more than that obtained by LEACH protocol in A scenario, and by nearly 26.4% more than that LEACH protocol in B scenario.

Indexing terms/Keywords

wireless sensor networks; clustering; fuzzy logic; leach protocol; energy efficiency; network lifetime.

Academic Discipline And Sub-Disciplines

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1.INTRODUCTION

Recent advances in micro-electro-mechanical systems, digital electronics, and wireless communications have led to the emergence of wireless sensor networks (WSNs), which consist of a large number of sensing devices each capable of detecting, processing and transmitting environmental information. A single sensor node may only be equipped with limited computation and communication capabilities; however, nodes in a WSN, when properly configured, can collaboratively perform signal processing tasks to obtain information pertaining to remote and potentially dangerous areas in an untended and robust way. Applications for wireless sensors networks include battlefield surveillance, environ-mental monitoring, biological detection, smart spaces, industrial diagnostics, etc. [1]. Any WSN is deeply involved in and related to the monitored environment, and any change occurring to the surroundings will significantly influence its performance nevertheless, the network must be able to tolerate and 'survive' any change by implementing proper reactions and adaptation mechanisms sustaining communications for both sensed data and commands [2]. WSNs have themselves characteristics that make them different from other types of networks. One for example is that the applicability of the networks is related to energy supply of the nodes, so energy conservation is one of the most important challenges in these networks. In general, the applications of WSNs can be divided into two general groups: tracking and monitoring [3, 4]. WSNs are usually dispersed in harsh environments with limited access to human beings, are a like battlefields, forests, and special industrial and clinical fields. Therefore, it is essential that WSNs operate in a self-configured and autonomous mode with the capabilities to form a network in an ad hoc scheme. As WSNs are energy constrained and data transmission is the most energy consumer [5], there is a need to an architecture in which the transmission to a Base Station (BS) is as low as possible, and all the decisions are made in the node level. In WSNs, each sensor node receives a signal from a limited region. This signal is processed in that sensor node and the sensed data is generally transmitted to the observers (e.g. base stations). Sensor nodes consume energy while receiving, processing and transmitting data. In most of the cases, these sensor nodes are equipped with batteries which are not rechargeable. Therefore, energy efficiency is still a major design goal in WSNs [6]. In order to aggregate data through efficient network organization, nodes can be partitioned into a number of small groups, called clusters [6].In general, each cluster has a cluster head (CH) which coordinates the data gathering and aggregation process in a particular cluster. Clustering in WSNs guarantees basic performance achievement with a large number of sensor nodes [7, 8]. In other words, clustering improves the scalability of WSNs [9]. This is because clustering minimizes the need for central organization and promotes local decisions.

There has been a substantial amount of research on clustering protocols for WSNs. Most of the clustering protocols utilize two techniques, selecting CHs with more residual energy and rotating CHs periodically to balance energy consumption of the sensor nodes over the network [10]. These clustering algorithms do not take the location of the base station into consideration. This lack of consideration causes the hot spots problem in multi-hop WSNs. The CHs near the base station tend to die earlier, because they are in heavier relay traffic than the cluster-heads which are located relatively far from the base station.One of the most important algorithms which are suggested in the field of WSNs is the LEACH, an innovative implementation of clustering, aggregation, and dynamic scheduling, is introduced [11]. Despite these capabilities of the LEACH, it still has a weakness directed toward the selection of the optimal number of CH.

In this paper, we overcome the challenge of using fuzzy logic on the base station (BS) to determine the optimal number of CHs. Once this value is determined, it will be set throughout the network operational time. The proposed (FUZZY-LEACH) is introduced to make a further improvement in maximizing the lifetime of the WSNs. Therefore, the use of this algorithm will make it possible to determine the percentage of nodes that will be CHs, prior to network deployment, without the need to have a specialized equipped node with GPS and without need to transmit node location to the base station. The proposed approach uses the remaining energy, the distance to the cluster head of the sensor nodes, and the distance to the base station of the cluster head.

The rest of this paper is organized as follows. Related work (prior arts) and related concepts of designing the WSNs and applying the routing algorithms to extend the network lifetime are presented in part 2. In Part 3, the paper describes a brief background of Low Energy Adaptive Clustering Hierarchy Protocol and Fuzzy Approach. The routing model for the proposed routing method is presented in Part 4. Performance evaluation is proposed in Part 5. Finally, conclusion is presented in Part 6.

1.Background

The research of wireless sensor network clustering algorithm is of great importance to improve the network performance and also of great importance to practical application. There are several proposed clustering algorithms in the literature. The Low Energy Adaptive Clustering Hierarchy (LEACH) [11] protocol rotates the cluster-heads periodically in order to balance energy consumption. Cluster-heads are rotated in each round. The term round refers to the interval between two consecutive cluster formation process. LEACH is a distributed algorithm which makes local decisions to elect cluster-heads. If the cluster-heads that are selected do not change throughout the network's lifetime, then it is obvious that these static cluster-heads die earlier than the ordinary nodes. Therefore, LEACH includes randomized rotation of cluster head locations to evenly distribute the energy dissipation over the network [8]. LEACH also performs local data compression in cluster heads to decrease the amount of data that is forwarded to the base station.

The Gupta Fuzzy Protocol [12] uses the Fuzzy Logic approach to select CHs using three parameters: energy level, concentration, and centrality; each one divided into three levels. Mainly, this protocol has taken the LEACH protocol as a basis. The difference between the two protocols lies in the set-up stage where the BS needs to collect energy level and location information for each node, and evaluate them in the designed FIS to calculate the chance for each node to become a CH. The BS then chooses the node that has the maximum chance of becoming a CH. The CHEF protocol

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(Cluster Head Election mechanism using Fuzzy Logic in Wireless Sensor Networks) [13] is a similar approach to that of Gupta Fuzzy Protocol, but it performs cluster-head election does not need the BS to collect information from all nodes. Instead, the CHEF protocol uses a localized CH selection mechanism using Fuzzy Logic in a distributed manner. In the HEED (Hybrid Energy-Efficient Distributed Clustering) protocol, [6] remain energy as the first consideration when selecting cluster head nodes achieved to some extent cluster head's evenly distributed within the monitor region. Although consider the rest energy of nodes firstly when selecting cluster head nodes, in more complex environment, it seems not sufficient. In addition, such factors as nodes' geographical location information, computing ability are also vital. When all those nodes of which residual energy is numerous concentrated, then the formed cluster is not optimal; when each member node in cluster is far from cluster head node, more energy will be consumed, so the nodes' location in cluster should be taken into consideration. The Far-Zone LEACH protocol (FZ-LEACH) [14] is an improvement to the LEACH's to solve the problem of existence of the large clusters in the sensor networks, by forming Far- Zone that is a group of sensor nodes, which is placed at locations where their energies are less than a threshold. This improvement is well suited for scenarios where there exist large size clusters. LEACH presents some drawbacks, such as the election of cluster-head that not consider the state of sensor nodes in terms of energy, being a decision purely probabilistic and not aware of the energy levels. Thus, nodes can be selected and die quickly, leading to a possible disruption of communication with the sink, decreasing the lifetime of the network and unbalanced energy consumption.

In this paper, we use a fuzzy system with appropriate inputs to overcome the weakness of LEACH. The inputs that we consider in the fuzzy system are: Remaining Energy, Normalize Distance from sensor node to cluster head (node-CH), and Normalize Distance from cluster head to Base station (CH-BS). These parameters are not so closely related and can easily work with these heterogeneous parameters by using fuzzy logic. Also a fuzzy system does not need much computational complexity; consequently it is suitable for WSN. According to what was said, we proposed a distributed method and each node itself makes decision about being cluster head or not. This method must work in all environments and so doesn't need nodes coordinates. In this method by choosing suitable inputs for fuzzy system, is more efficient than the existence method and better cluster will be made.

1.Low Energy Adaptive Clustering Hierarchy Protocol and Fuzzy Approach

3.1Low Energy Adaptive Clustering Hierarchy Protocol (LEACH)

The first attempts in the area of clustering the nodes in WSNs is LEACH in (2000, 2002) by Heinzelman et al. [11], and [15]. The main idea behind LEACH is to rotate the CH role among all the nodes to achieve load balancing. In LEACH, the operational time is divided into some rounds and each round is divided into two phases: setup phase in which the clusters are formed and steady-state phase in which the data are directly transmitted to the BS by the CHs. The time line of operations in LEACH is depicted in Fig. 1.

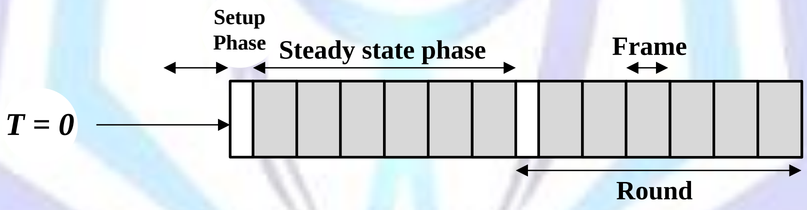


Fig.1. Timeline of operations in LEACH.

Note that the CH selection in LEACH is distributed with low overhead imposed by CH selection. LEACH uses a random approach for selecting the CHs and assures that all the nodes in the network get selected as CH for at least once in a predetermined epoch. The length of the epoch depends on the number of the nodes and clusters ($n/k\ round$). At the beginning of the CH selection phase, all the nodes generate a random number between 0 and1. Then each node compares its number withthreshold$T(n)$ as shown in Eq. (1)

$$T(n) = \begin{cases} \frac{p}{1-p\times\left(r \bmod \frac{1}{p}\right)} & if\ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

where p is the desirable percentage of the CHs, r is the current round, and G is the set of nodes that have not been selected as CHs in the last$1/p$ rounds. All the nodes in G compare their number with$T(n)$. If they found their number less than $T(n)$, elect themselves as CH and broadcast the *CH-ADV* message to all the nodes with in communication range R_c. If not, they join the nearest CH by sending the *Join-Req*message to the CH. Each node finds the nearest CH based on received strength signal indicator (RSSI). After cluster formation, the CHs aggregate the received data from the regular nodes and send them to the BS in a single-hop. LEACH utilizes TDMA protocol for gathering the data from regular nodes so that each regular node goes to sleep except in its time slot. Also, code division multiple access protocol is used in LEACH in order to avoid the collisions.

LEACH protocol is simple, it is distributed, generate slow overhead for CH selection, load is balanced, and the percentage of the CHs in the network is appropriate and can be defined; however, LEACH has some defects. The communication between the CHs and the BS is direct, so the power of the CHs, especially farther CHs to the BS, is deplete data faster rate and thus the

Network cannot be implemented in large scales. Also, since the CHs are selected randomly, two important problems emerge. First, the distribution of the CHs across the network is not performed properly. Second, the energy of the CHs is not considered in the CH selection so the nodes with low energy have may get elected as CHs. These problems encourage there searchers to improve the protocol.

3.1 Fuzzy Approach

The concept of fuzzy logic was introduced by Zadeh in the mid-1960s [16] as an extension of the concept of an ordinary fuzzy set. Since then, its applications have rapidly expanded in adaptive control systems and system identification. It has the advantages of easy implementation, robustness, and ability to approximate to any nonlinear mapping [17]. In fuzzy systems, the dynamic behavior of a system is characterized by a set of linguistic fuzzy rules based on the knowledge of a human expert, each of which is represented by a linguistic term such as "*small," "medium," or "large*." Fuzzy sets allow an object to be a partial member of a set. In Fig. 2, if X suggests a collection of objects denoted by x, usually X is referred to as the "*universe of discourse,*" and then a fuzzy set A in X is defined by a set of ordered pairs[18]:

$$A = \left\{ \left(\frac{x, \mu_A(x)}{x} \right) x \in X \right\} \tag{2}$$

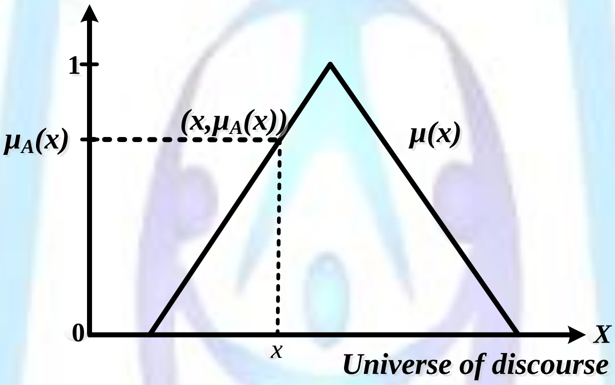


Fig.2. Membership functions from the pair$(x, \mu_A(x))$.

Where the function $\mu_A(x)$ is called membership function of the object $x$in A. This membership function represents a "*degree of belongingness*" for each object to a fuzzy set, and provides a mapping of objects to a continuous membership value in the interval [0...1]. When a membership value is close to the value 1 ($\mu_A(x)$→1) it means that input x belongs to the set A with a high degree, while small membership values ($\mu_A(x)$→0), indicate that set A does not suit input x very well. In fuzzy systems, the dynamic behavior of a system is characterized by a set of linguistic fuzzy rules based on the knowledge of a human expert. These rules are the heart of a fuzzy system and may be provided by experts or can be extracted from numerical data. In either case, the rules that we are interested in can be expressed as a collection of *IF-THEN* statements (IF *antecedents* THEN *consequents*). Antecedents and consequents of a fuzzy rule form the fuzzy input space and fuzzy output space respectively are defined by combinations of fuzzy sets. Considering a fuzzy system with p inputs and one output with M rules, then the L^{th} rule has the form [19]: R^L : *IF* $x_1$is F_1^L and … x_p is F_P^L THEN *y* is G^L where F_1^L … F_P^L and G^L denote the linguistic variables defined by fuzzy sets and $L = 1 \dots M$.

Fig. 3 shows the typical structure of a fuzzy system. It consists of four components namely; fuzzification, rule base, inference engine and defuzzification [16]. The processes of making crisp inputs are mapped to their fuzzy representation in the process called fuzzification. This involves application of membership functions such as triangular, trapezoidal, Gaussian etc. The inference engine process maps fuzzified inputs to the rule base to produce a fuzzy output. A consequent of the rule and its membership to the output sets are determined here. The defuzzification process converts the output of a fuzzy rule into crisp outputs by one of defuzzification strategies [18].

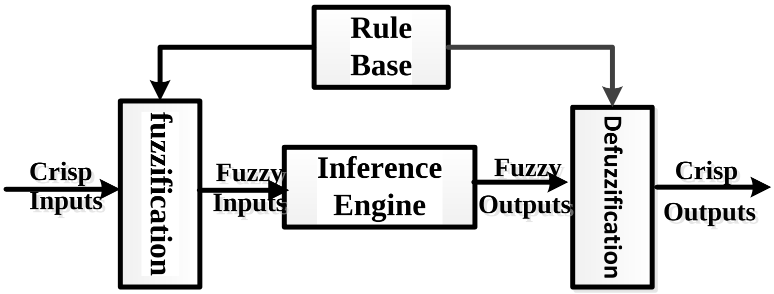


Fig.3. Typical structure of the fuzzy approach.

1.Proposed Method

4.1Implementation of LEACH protocol

Atypical application of a clustered WSN is presented in Fig. 4. As shown in this figure, the nodes in layer1 (the regular nodes) sense the field, generate the data, and send them to their associated CH. Then the CHs in the second layer receive these data, and after performing some processes like aggregation/fusion, transmit them to the BS in a multi-hop approach. Eventually the user receives the data from the BS through the Internet.

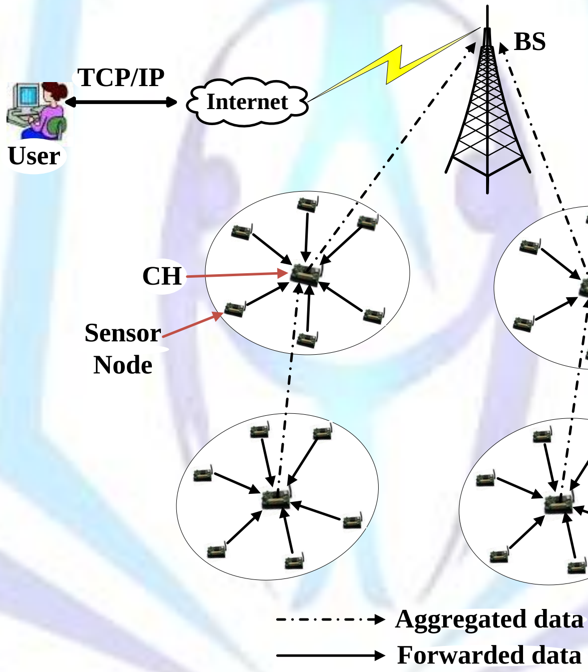


Fig.4. A typical clustered sensor network.

4.1.1Network model

In this paper, we consider a sensor network consisting of N sensor nodes deployed over a vast field to continuously monitor the environment. For a WSN we make some assumptions about the sensor nodes and the underlying network model:

- Sensor nodes are deployed randomly.
- All sensor nodes and the base station are stationary after the deployment phase.
- Nodes are capable of adjusting the transmission power according to the distance of the receiver nodes.
- The distance between nodes can be computed based on the received signal strength. Therefore, there is no need for sensor nodes to know their exact locations.
- All sensor nodes have the same amount of energy when they are initially deployed.
- The base station need not be located far away from the sensing region.
- All sensor nodes are identical.

4.1.1**Energy consumption model**

For the realistic, the first order radio model that will be used in LEACH [15], as a communication model between sensor nodes. Both the free space (d^2 power loss) and the multipath fading (d^4 power loss) channel models are used, depending on the distance between the transmitter and receiver. The energy consumption in transmitting a packet with k-bits over distance d. $E_{elec}$is the amount of energy consumption per bit to run the transmitter or receiver circuitry. E_{fs}, and E_{mp} is the amount of energy per bit dissipated in the RF amplifier according to the distance $d_0$which can be obtained from Eqs. (3), and (4) as below.

$$E_nT(k) = \begin{cases} k \times (E_{elec} + E_{fs} \times d^2) & ,if\ d \le d_0 \\ k \times (E_{elec} + E_{fs} \times d^4) & ,if\ d > d_0 \end{cases} \quad (3)$$

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mt}}} \quad (4)$$

The amount of energy consumption in receiving a packet with k bits can be calculated by Eq. (5).

$$E_nR(k) = k \times E_{elec} \quad (5)$$

The radio energy model parameters present details in fig.5, and Table 1.

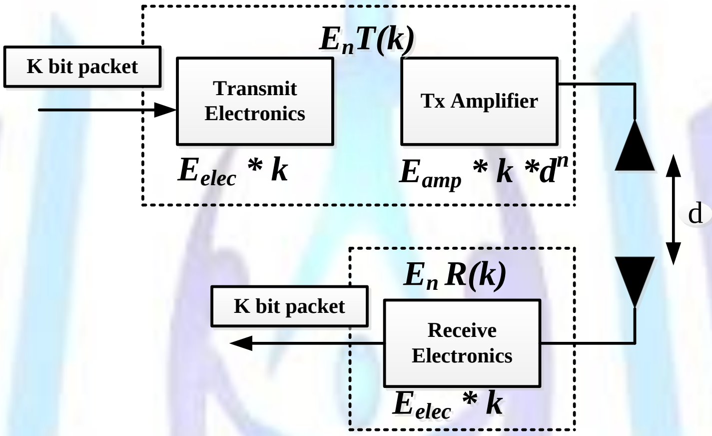


Fig.5. First order Radio model

Table 1. Parameters of the first radio model

Parameter	value
E_{elec}	$50\ nJ$
E_{fs}	$10\ pJ/bit/m^2$
E_{mp}	$0.0013 pJ/bit/m^4$

4.1 Implementation of Fuzzy Approach

In this Section, we focus on describing the major goal of fuzzy approach in LEACH protocol. Fuzzy approach is used to compute the fitness value of nodes to be cluster head, which depends on the remaining energy RE, D (node-CH), and D (CH-BS) as shown in figs. (6) and (7) respectively:

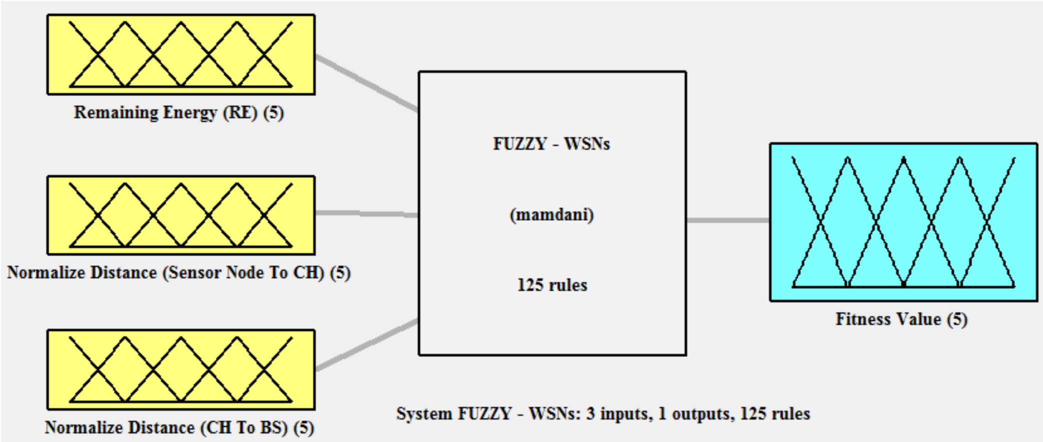


Fig.6. Fuzzy System Architecture

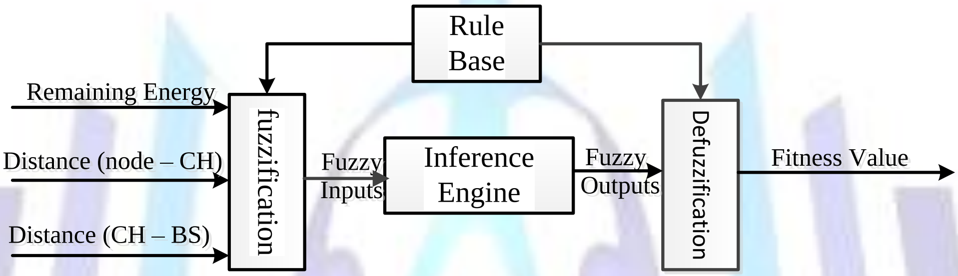


Fig. 7 Fuzzy structure with three inputs (remaining energy, normalize distance (node-CH), normalize distance (CH-BS) (sink), and one output of Fitness Value of CH.

Our method uses five membership functions for each input (RE), distance (node to CH), distance (CH to BS), and an output variable (Fitness value), as shown in Fig.8), with universal of discourse $[0 \ldots 5]$, $[0 \ldots 1]$, $[0 \ldots 1]$, and $[0 \ldots 1]$ respectively. For the fuzzy approach, the fuzzified values are processed by the inference engine, which consists of a rule base and various methods to inference the rules. Tables 2 - 6 shows the IF-THEN rules used in the proposed method, with a total number of $5^3 = 125$ for the fuzzy rule base. As an example, IF *RE* is *Very High* and *Distance to CH* is *Near* and *Distance to BS* is *Very Near* THEN *Fitness value* is Very Good. All these rules are processed in a parallel manner by a fuzzy inference engine. The defuzzification finds a single crisp output value from the solution fuzzy space. This value represents the fitness function value of node s which to be as cluster head. Practice defuzzification is done using centre-of-gravity method [20] given by:

$$fit(s) = \left(\sum_{k=1}^{n} U_k * c_k\right) \Big/ \sum_{k=1}^{n} U_k \qquad (6)$$

Where U_k is the output of rule base k, and c_k is the center of the output membership function.

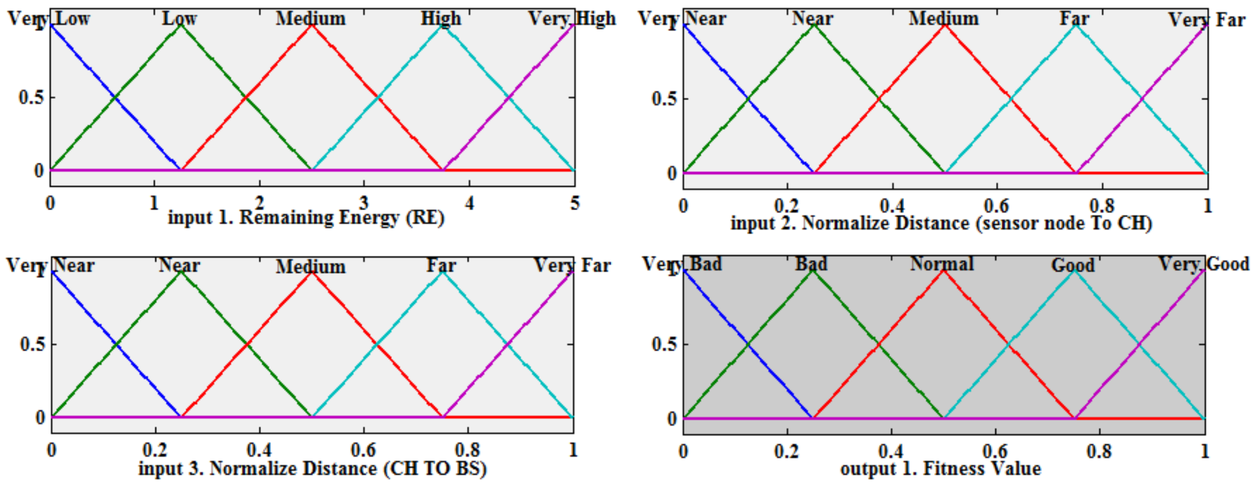


Fig. 8. Membership graph for three inputs (remaining energy (RE), normalize distance (node-CH), and normalize distance (CH-BS) and the output (fitness value).

Table 2.IF-THEN rules, where energy is very low.

D-(CH) / D- (BS)	V. Near	Near	Medium	Far	V. Far
V. Near	Normal	Bad	Bad	V. Bad	V. Bad
Near	Normal	Bad	V. Bad	V. Bad	V. Bad
Medium	Bad	V. Bad	V. Bad	V. Bad	V. Bad
Far	Bad	V. Bad	V. Bad	V. Bad	V. Bad
V. Far	V. Bad	V. Bad	V. Bad	V. Bad	V. Bad

Table 3.IF-THEN rules, where energy is low.

D-(CH) / D- (BS)	V. Near	Near	Medium	Far	V. Far
V. Near	Normal	Normal	Bad	Bad	V. Bad
Near	Normal	Bad	V. Bad	V. Bad	V. Bad
Medium	Normal	Bad	V. Bad	V. Bad	V. Bad
Far	Bad	V. Bad	V. Bad	V. Bad	V. Bad
V. Far	V. Bad	V. Bad	V. Bad	V. Bad	V. Bad

Table 4.IF-THEN rules, where energy is medium.

D-(CH) / D- (BS)	V. Near	Near	Medium	Far	V. Far
V. Near	Good	Good	Good	Normal	Normal
Near	Good	Good	Normal	Normal	Bad
Medium	Good	Good	Normal	Bad	Bad
Far	Normal	Normal	Normal	Bad	V. Bad
V. Far	Normal	Normal	Bad	V. Bad	V. Bad

Table 5.IF-THEN rules, where energy is high.

D-(CH) / D- (BS)	V. Near	Near	Medium	Far	V. Far
V. Near	V. Good	V. Good	Good	Normal	Normal
Near	V. Good	V. Good	Good	Bad	Normal
Medium	V. Good	V. Good	Good	Bad	Bad
Far	Good	Good	Normal	V. Bad	V. Bad
V. Far	Normal	Normal	Normal	V. Bad	V. Bad

Table 6.IF-THEN rules, where energy is very high.

D-(CH) / D- (BS)	V. Near	Near	Medium	Far	V. Far
V. Near	V. Good	V. Good	V. Good	Normal	Normal
Near	V. Good	V. Good	V. Good	Normal	Normal
Medium	V. Good	V. Good	Good	Normal	Bad
Far	V. Good	Good	Good	Bad	V. Bad
V. Far	Good	Good	Good	Bad	V. Bad

These four steps are used in fuzzy logic interface system (FIS) to calculate the fitness value for cluster Head as follows.

- Step 1: **Input of Crisp Value and Fuzzification**

First, we forward our inputs (crisp values), which represent our parameters: remaining energy of the CH, D(node-CH), and D(CH-BS), to our FIS. Depending on these three crisp numbers, we calculate the value of the membership function, which is the intersection point of the value of our parameters with the degree of the membership function.

- **Step 2: Rule Evaluation**

After the fuzzification step has been completed, we supply the membership values obtained to our IFTHEN rules to determine our new fuzzy output set. Our fuzzy IF-THEN rules have multiple inputs and the fuzzy operator (AND), which simply selects the minimum of our three membership values, is used to get a single number

- .**Step 3: Aggregation of the Rule Outputs**

The aggregation is a process of the union of all the outputs obtained from applying all rules ($5^3 = 125$ rules in our FIS model). Since we aggregate all our rules, we have used an OR Fuzzy Logic operator. The OR operator selects the maximum of our rule evaluation values to generate the new aggregate fuzzy set, which we use in the next step.

- **Step 4: Defuzzification**

The last step is de-fuzzification, where we obtain our fitness value. We have used the Mamdani technique to calculate the implication value, and the Centroid defuzzification method to find the CH election fitness value to form a cluster formation. Therefore, the Center of Gravity (COG) will be used in the centroid defuzzification, which we can compute from Eq. (6)

By applying the values we obtained from step 3 and calculating COG, we determine the fitness value for electing a CH to form a cluster. If two CHs have the same fitness value, to break the tie between them, we choose one closer to the BS. Then we use the distance to the CH.

1.PERFORMANCE EVALUATION

Using this network operation model allows the network lifetime metric to be measured in data collection rounds till the very first node runs out of energy. This metric is known as first node death (FND). It has been used extensively in literature [21-24].

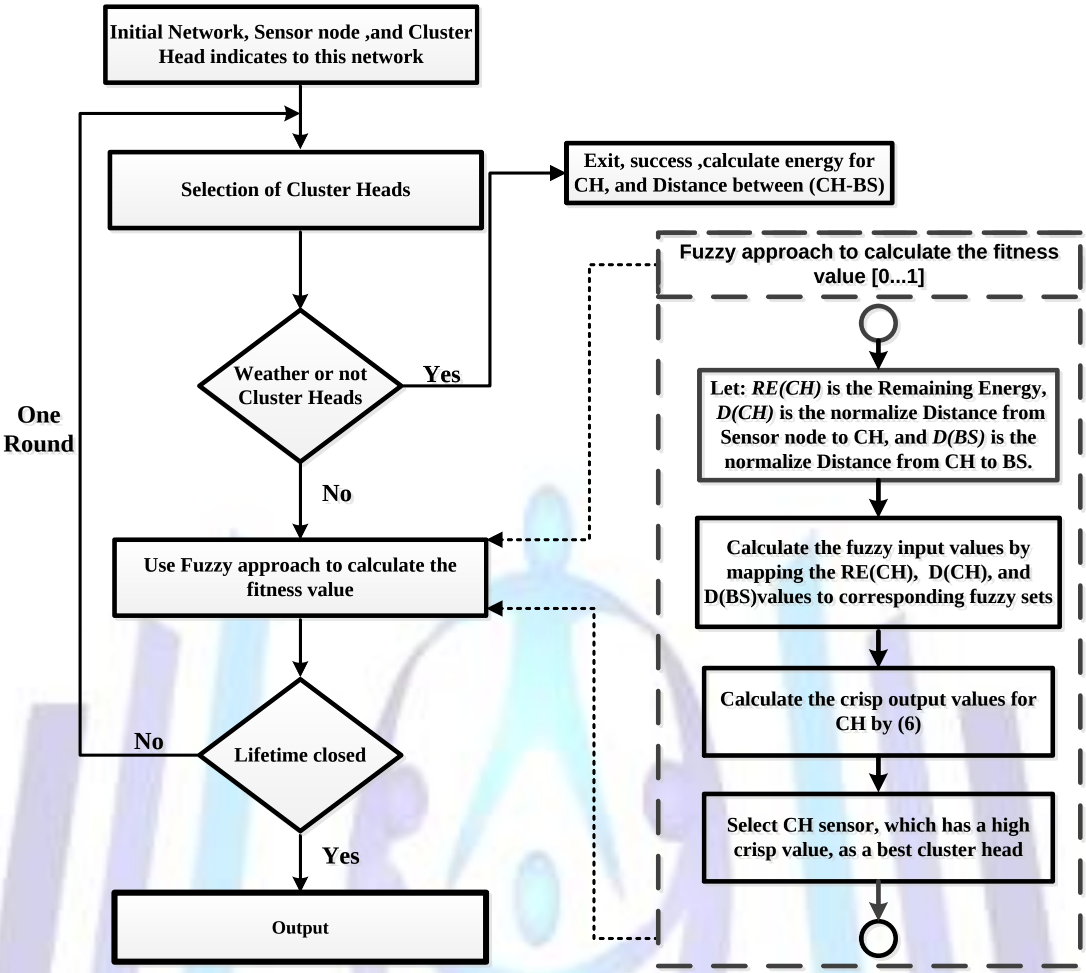


Fig.9. Flow chart of FUZZY – LEACH clustering.

5.1Simulation Setup

The simulations are carried out in MATLAB. 100 sensor nodes are randomly deployed in two different scenarios, *A* scenario ($\alpha = 3$, $P = 0.2$, $m = 0.3$) and *B* scenario($\alpha = 1$, $P = 0.1$, $m = 0.2$). Where α, m are constant values for heterogeneity percentage of nodes than are advanced, and P is an optimal Election Probability of a node to become cluster head. The two scenarios are distributed in the topographical area of dimension 100 m × 100 m. Both scenarios A and B have the sensed transmission limit of 30 m. The performance of the proposed method is tested in these two scenarios. There is only one data sink which located at (50 m, 50 m). All sensor nodes have the same initial energy 0.5J. The simulation was performed for 2000 rounds. We use a simplified model showed in fig.5 for the radio hardware energy dissipation. Table 7 presents the systems parameters in details.

Table 7.Simulation parameters.

Parameter			Value
Topographical Area (meters)			$(100m \times 100m)$
Sink location (meters)			$(50m \times 50m)$
Scenarios	A	α	3
		P	0.2
		m	0.3
		α	1

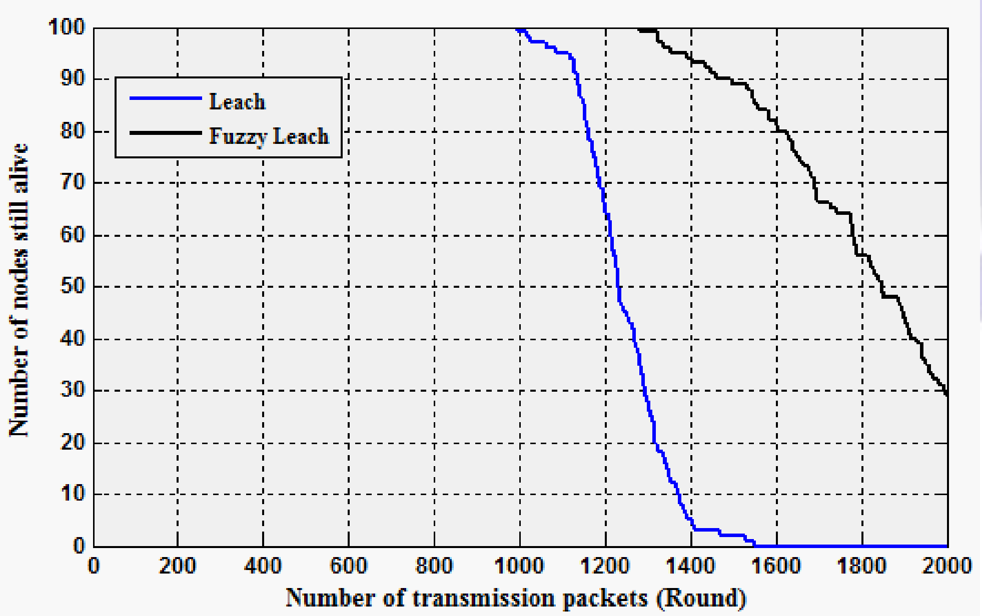
	B	P	0.1
		m	0.2
Number of nodes			100
Limit of transmission distance (meters)			30m
Initial energy of node			0.5J
Packet data size			4×10^3bits
No. of MFs (in each input and output variable)			5
No. of IF-THEN rules			125
No. of transmission packets (rounds)			2×10^3

5.2Simulation Results

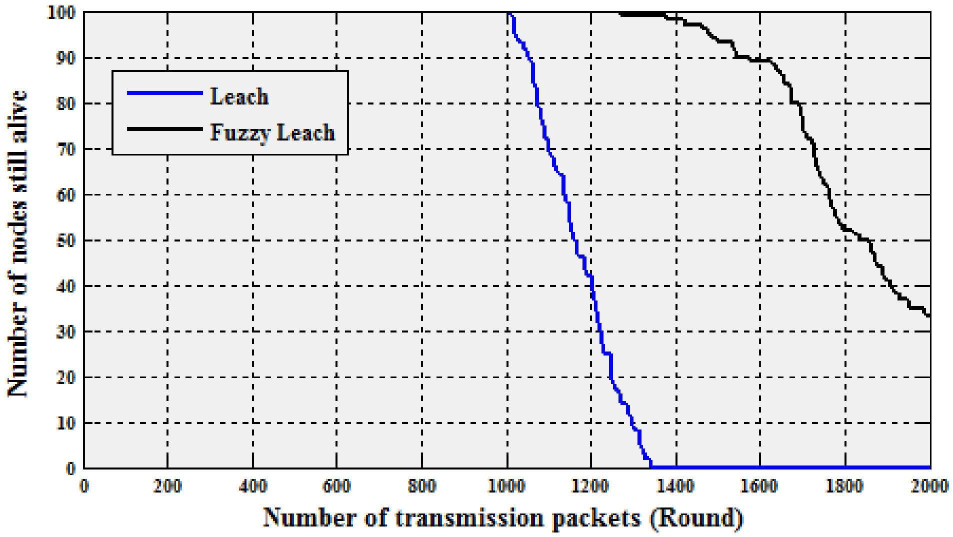
The number of alive nodes as a function of rounds by using the two different approaches for both scenarios A and B are shown in Fig.10(a) and 10(b), respectively. It can be seen that the proposed method outperforms Leach protocol in both scenarios $A$and B. When all packets are sent in scenario A, the network lifetime achieved by the proposed method increased by nearly 28.5% than that obtained by Leach protocol. Also in scenario B when all packets are sent, the network lifetime achieved by the proposed method is increased by nearly 26.4% than that obtained by Leach protocol.

Moreover in Fig.10(a) and 10(b), it can be seen that the number of alive nodes of the proposed method is always higher than that of Leach protocol. The different duration of time corresponding to the first dead node computed using the two different approaches in both scenarioss$A$ and B is listed in Table 8. Clearly, the time for the first node to die in the proposed method is much longer than the times for the first node to die in Leach protocol in both scenarios $A$and B.

From Fig. 10 and Table 8, it is clear that, the proposed method outperforms Leach protocol in terms of balancing energy consumption and maximization of network lifetime.



(a)



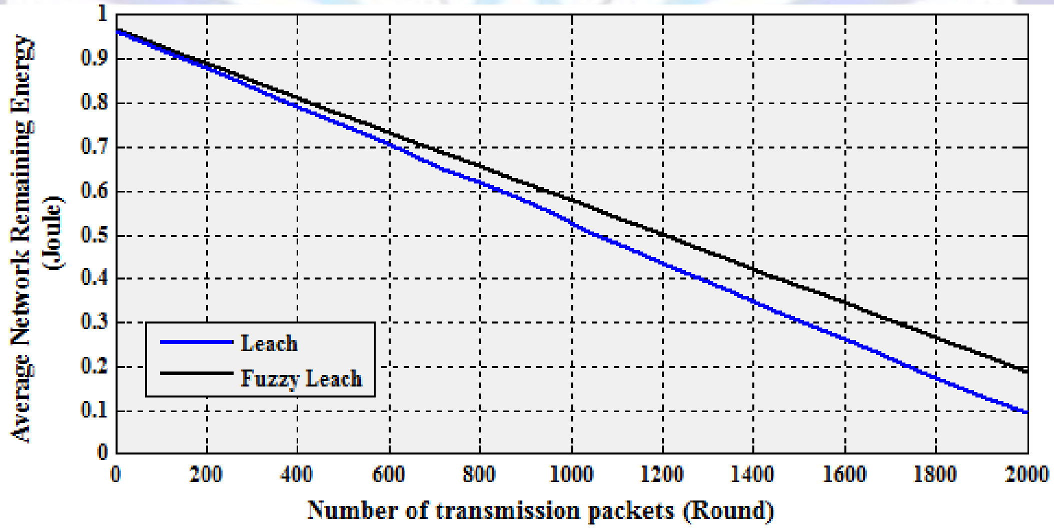
(b)

Fig. 10. Number of alive nodes as a function of rounds based on different approaches (Leach protocol, and proposed). (a) In scenario A. (b) In scenario B.

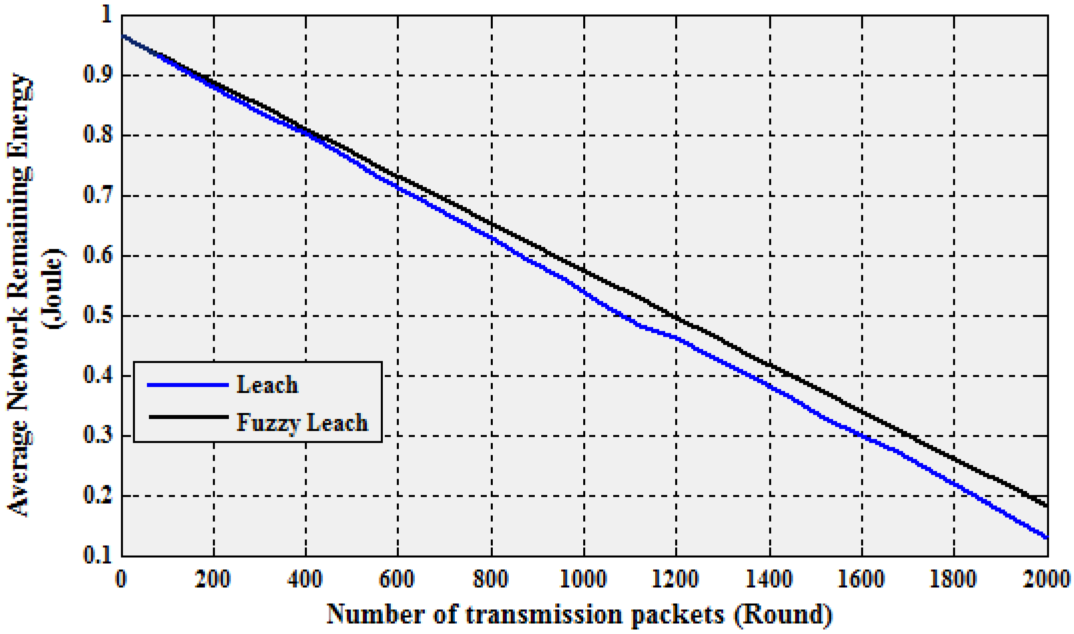
Table 8 .Number of rounds with the first dead node in both scenarios A and B

Approaches	Leach	Proposed
Lifetime of the first dead node (Rounds) in A area	995	1280
Lifetime of the first dead node (Rounds) in B area	1009	1273

Fig. 11(a) and 11(b) shows the average remaining energy of a WSN as a function of transmission rounds for the two approaches in scenarios A and B, respectively. As the round number increases in the two scenarios, the proposed method performs better than Leach protocol. This indicates that, better energy balance in a WSN is achieved by the proposed method in both scenarios Aand B.



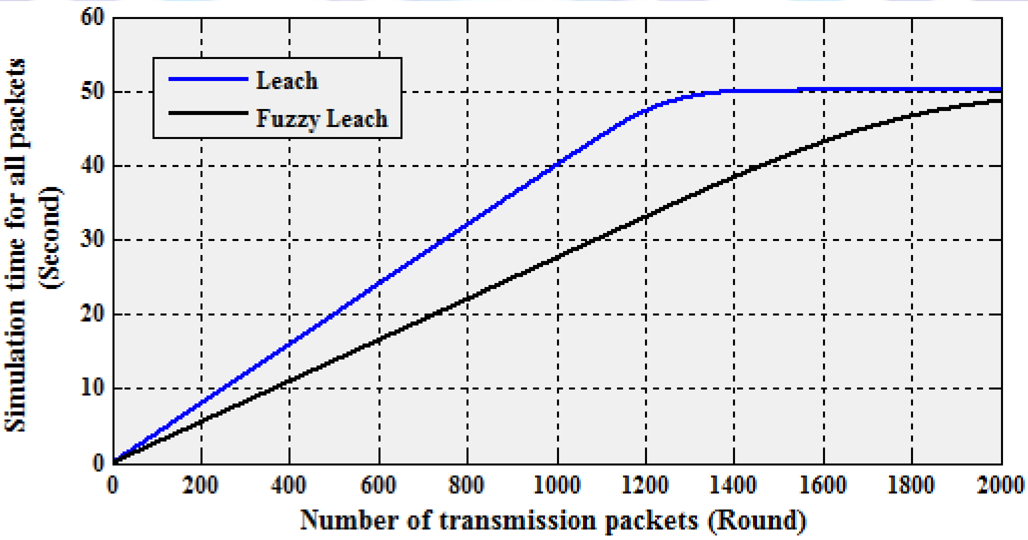
(a)



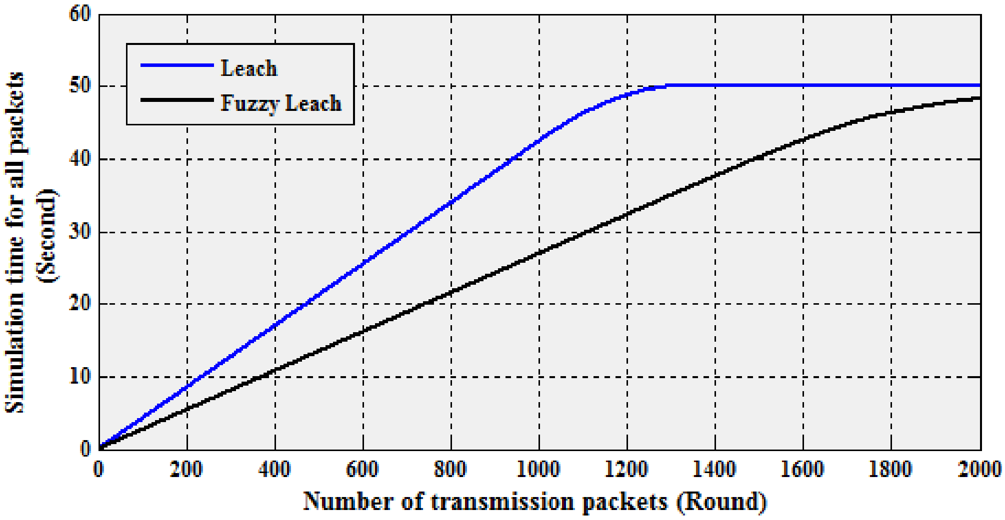
(b)

Fig. 11. Average network remaining energy as a function of transmission round. (a) In scenario A. (b) In scenario B.

The delay incurred in transmission of data packets is also a key parameter for certain applications. The comparison between two different approaches in scenarios A and B are shown in Fig. 12(a) and 12(b) respectively. It can be seen that, the proposed method has shortest delay compared to Leach protocol in the two scenarios. Shorter delay indicates both energy saving and efficient information transmission (especially secure and important ones). In other words, data packets are routed through different node-disjoint paths with multipath routing to avoid network congestion and prolong the network lifetime.



(a)



(b)

Fig. 12. Data transmission delay (simulation time for all packets) as a function of transmission round. (a) In scenario A. (b) In scenario B.

Note that above simulations are performed assuming that all the nodes are well maintained (i.e. stable with enough power) until the node dies. In real world, there may be certain situations that one even more of the sensors in the critical pathway become intermittent in the ability to function normally. Such behavior may add performance noise (fluctuations) into the WSN. As there are too many parameters to be considered, future investigations about such topics may be quite interesting and challenging.

1.CONCLUSION

In order to improve the energy efficiency and achieve the network load balance to LEACH protocol in WSNs, we have proposed a new clustering scheme based on fuzzy logic in this paper. Where each node determines its fitness value to become cluster-head candidate based on remaining energy, distance to cluster head from nodes and distance to base station from cluster heads. The performance of the proposed method is evaluated under the same criteria in two different scenarios. Simulation results demonstrate the effectiveness of the new approach with regards to enhancement of the lifetime of wireless sensor networks with randomly scattered nodes.

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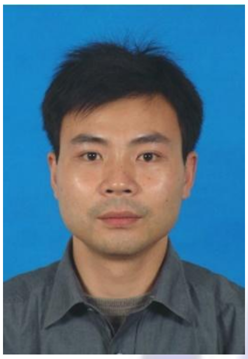

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