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Lifetime Prolonging for Clustered Heterogeneous Wireless Sensor Networks by SEP-FUZZY

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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 WSNs.In this paper, we proposed a novel scheme to investigate the cluster, the fuzzy logic cluster stable election protocol (SEP - FUZZY), which uses fuzzy logic inference system (FIS) in the cluster process. We compare our technique with two approaches (LEACH, and SEP) 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 27% more than that obtained by LEACH protocol, and by nearly 23% more than that obtained by Stable Election Protocol.

Keywords: *WSNs, clustering, fuzzy logic, SEP*

1. Introduction

A Wireless Sensor Network (WSN) is a combination of au-tonomous distributed sensors to monitor environmental of physical conditions and to pass the aggregated sensed data through the network to a main base station or sink.

In WSN, energy efficient communication is the subject of survival of a network. As a result, the researchers are mostly fo-cused towards energy efficient communication, energy manage-ment, and extending the network lifetime. Most of the time, study on Wireless Sensor Networks has assumed homogeneous nodes. But in reality, homogeneous nodes also have different levels of initial energy and depletion/drain rate. This leads to the research on heterogeneous networks where two or more types of nodes are considered and the more powerful sensor nodes act as cluster heads and handle resource-demanding tasks.

A Sensor Node is consisting of sensors, processor, transceiver and power units as showing in Figure 1. As we know that while de-signing a routing protocol a sensor node is limited energy supply, so available energy at that nodes must be a major constraint. For energy efficiency, extensibility of lifetime, scalability and perfor-mance, cluster based routing protocol enforces a structure out of different routing protocols.

In cluster based routing protocols, sensors are divided into different clusters after selecting some nodes as cluster heads among them, so that sensor nodes communicate information only to cluster heads and aggregate information to base station. Clustering is an efficient way to reduce energy consumption and extend the life time of the network, doing data aggregation and fusion in order to reduce the number of transmitted messages to the base station [1].

The rest of this paper is organized as follows. Related work (prior arts) and related concepts of designing the WSNs and apply-ing the routing algorithms to extend the network lifetime are pre-sented in part 2. In Part 3, the paper presents the routing model for the proposed routing method. Performance evaluation is proposed in Part 4. Finally, conclusion is presented in Part 5.

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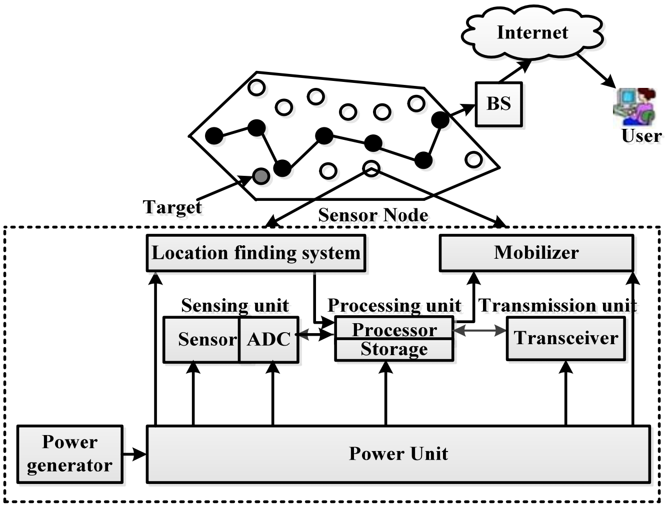

Figure 1. A typical Wireless Sensor Network

2. Related Work

The researches of wireless sensor network clustering algorithm are 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.

There are two categories of clustering schemes, those applied in homogeneous networks, referred to as homogeneous clustering schemes, and those applied in heterogeneous networks, referred to as heterogeneous clustering schemes. The most popular homogeneous clustering algorithms include low- energy adaptive clustering hierarchy (LEACH) [2] and power-efficient gathering in sensor information systems (PEGASIS) [3]. On the other hand, hybrid energy- efficient distributed clustering (HEED) [4], and distributed energy efficient clustering (DEEC) [5] are heterogeneous clustering algorithms.

The LEACH protocol selects CHs periodically and drains energy uniformly by role rotation. Each node makes a decision whether or not to be a CH according to a uniformly distributed probability. In PEGASIS, nodes will be organized to form a chain, which can be computed by each node or by the base station. The requirement of global knowledge of the network topology makes this method difficult to implement. HEED is a distributed clustering algorithm, which selects the CHs stochastically. The election probability of each node is correlative to the remaining energy. In heterogeneous environments, the low-energy nodes could own larger election probability than the high energy nodes in HEED. The heterogeneity of nodes in terms of their energy is considered in DEEC. DEEC has the merit of being a distributed clustering algorithm. However, the performance of homogeneous schemes is poor for heterogeneous networks because the low-energy nodes could have a higher probability of election than the high energy nodes [6].

Stable election protocol (SEP) studies the impact of heterogeneity, in terms of energy of the nodes. To elect the CHs, SEP uses a weighted probability method based on remaining energy in the nodes. This could prolong the stability period of the networks (stability is defined as the time from the beginning of the network Process until the first node dies). In SEP an adjustable percentage of the nodes have higher energy than the other nodes. Accordingly, a modified probability is defined to consider the residual energy of the nodes. Based on this probability, the length of used epoch in LEACH is increased. The authors' show that compared to LEACH, SEP can increase the stability period of the network.

Bala et al [7] considered deterministic-SEP (D-SEP), for electing cluster heads in a distributed style in two, three, and multi-level hierarchical wireless sensor networks. The significant improvement has been using D-SEP in comparison with SEP in terms of energy consumption, data transmission and network lifetime to Base station. D-SEP protocol goal is to enlarge the lifetime and stability of the network in the presence of heterogeneous nodes. Since cluster heads consume more energy than cluster members in receiving and sensing data from their component nodes, performing signal dispensation and transfer the aggregated data to next node or base station. D-SEP network lifetime is increased by 4.4 times over SEP. The results clearly show that the stability period of D-SEP is longer as compared to SEP. The authors in [8] proposed an enhanced SEP (E-SEP), it is three tire node protocols. E-SEP operates in a WSN under three-tier energy heterogeneity. E-SEP introduces additional nodes named intermediate nodes that act as a bridge between the normal and advanced nodes. The energy of the intermediate nodes is set between that of normal and advance nodes. The work in [9] proposed Distance based –SEP (DB-SEP), the DB-SEP has two parts, first on the nodes initial energy and secondly the selection of CH is distance based, the one close to the sink will have higher chance to become CH Clustering hierarchy is used to establish the network, in order to reduce the correlated data, the CH performs fusion function.

In this work, we propose a new protocol SEP-Fuzzy improves SEP protocol using Fuzzy Logic. In SEP, the election probabilities of cluster head are weighted by the initial energy of a node relative to that of other nodes in the network. SEP-FUZZY provides a longer stability period and a lower instability period and increases life time of nodes. We study the effect of our SEP-FUZZY protocol to heterogeneity parameters capturing energy imbalance in the network. 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.

3. Stable Election Protocol and Fuzzy Approach

3.1. Stable Election Protocol (SEP)

A. Network Model

In this section, we describe the SEP protocol. Assume that there are N sensor nodes. Nodes always have data to transmit to a base station, which is often far away from the sensing area. The network is organized into a clustered hierarchy where every cluster has a CH, responsible for executing fusion function to reduce correlated data produced by the sensor nodes within the same cluster. The CHs directly transmit the aggregated data to the base station. We suppose that the nodes are stationary.

SEP does not require energy knowledge sharing but is based on assigning weighted election probabilities of each node to become a CH according to their respective energy. By using this approach, SEP ensures that the CH is randomly selected based on the fraction of energy of each node. This also results in a uniform distribution of energy consumption.

In SEP, the election probabilities are weighted by the initial energy of a node relative to that of other nodes in the network. This prolongs the time interval before the death of the first node (stability period), which is crucial for many applications where the feedback from the sensor network must be reliable.

Let $\mathrm{E_0}$ be the initial energy of basic sensors, and m be the fraction of CHs, which own α times more energy than the normal ones. Thus, there are mN to CHs equipped with an initial energy of $(1-\alpha)\mathrm{E_0}$; and $(1-\mathrm{m})\mathrm{N}$, (basic sensors) with an initial energy of E_0. Thus, the total initial energy of the two level heterogeneous networks is:

$$\begin{aligned}\mathrm{E_{total}} &= \mathrm{N}\,(1-\mathrm{m})\mathrm{E_0} + \mathrm{mNE_0}(1+\alpha)\\ &= \mathrm{NE_0}(1+\alpha\,\mathrm{m}) \end{aligned} \quad (1)$$

So, the total energy of the system is increased by a factor of $(1+\alpha\mathrm{m})$.
Let $\mathrm{P_{adv}}$ be the weighted election probability of advance nodes.Optimum probability $(\mathrm{P_{opt}})$ of each node to become CH can be calculated by (2).

$$\mathrm{P_{adv}} = \frac{\mathrm{P_{opt}}}{1+\alpha\mathrm{m}} \times (1+\alpha) \quad (2)$$

The threshold is given by (3).

$$T(s) = \begin{cases} \frac{P_{adv}}{1 - P_{adv}\left[r.\mathrm{mod}\frac{1}{P_{adv}}\right]} & \text{if } s \in G \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

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 not the same amount of energy when they are initially deployed.
- The base station need not be located far away from the sensing region.

B. Energy Consumption Model

For the realistic, the first order radio model that will be used in LEACH [2], 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 (4), and (5) as below.

$$E_nT(k) = \begin{cases} k \times (E_{elec} + E_{fs} \times d^2) & , \text{if } d < d_0 \\ k \times (E_{elec} + E_{mp} \times d^4) & , \text{if } d \geq d_0 \end{cases} \quad (4)$$

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}} \quad (5)$$

The amount of energy consumption in receiving a packet with k bits can be calculated by (6).

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

The radio energy model parameters present details in Figure 2, and Table 1.

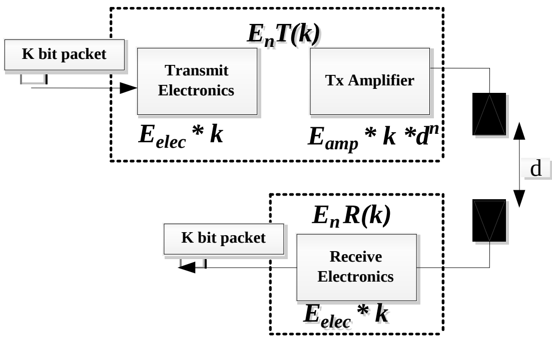

Figure 2. First order Radio model

Table 1. Parameters of the first radiomodel

Parameter	value
E_{elec}	$50\ nJ$
E_{fs}	$10\ pJ/bit/m^2$
E_{mp}	$100 pJ/bit/m^4$

3.2. Fuzzy Clustering Approach

The concept of fuzzy logic was introduced by Zadeh in the mid-1960s [10] 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 [11].

In Fuzzy Clustering model, when a basic sensor detects an event and wants to transmit its packets, it selects a best cluster head. To achieve this, we make use of fuzzy logic. The objective of fuzzy logic is therefore to calculate the optimal value of the best cluster head that depended which depends on the remaining energy RE, D (node-CH), and D (CH-BS) as shown in figures. (3) and (4) respectively.

Figure 3 and figure.4, shows the fuzzy logic with three input variables (RE, , D (node-CH), and D (CH-BS)), and an output (Fitness value), with universal of discourse [0. . .5], [0. . .1], [0. . .1], and [0. . .1], respectively. Fuzzy Clustering uses five membership functions for each input and an output variable, as shown in Figure 5.

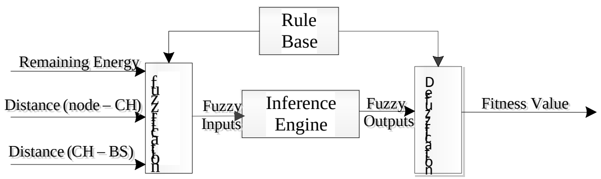

Figure 3. Fuzzy structure with three inputs RE, D(node-CH), D(CH-BS), and one output of Fitness Value of CH

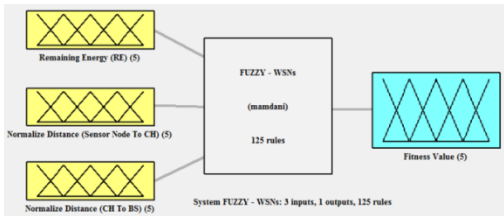

Figure 4. Fuzzy Clustering System Architecture

In Fuzzy Clustering, the fuzzified values are processed by the inference engine, which consists of a rule base and various methods to infer the rules. Tables 2–6 show the IF-THEN rules used in Fuzzy Clustering, with a total number of $5^3 = 125$ for the fuzzy rule base. As 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. At the end, the defuzzification finds a single crisp output value from the solution fuzzy space. This value represents the node cost. Practice defuzzification is carried out using center of gravity method given by (7) [12].

$$Fitnees\ value\ of\ CH = \sum_{k=1}^{n} U_k * c_k \Big/ \sum_{k=1}^{n} U_k \tag{7}$$

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

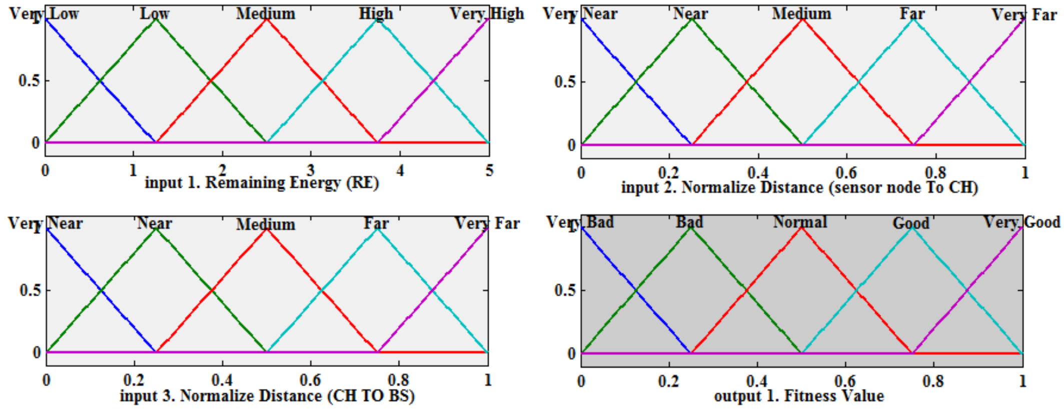

Figure 5. Membership graph for three inputs (remaining energy (RE), normalize distance (node-CH), and normalize Distance (CH-BS) and the output (fitness value).

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

4. 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 literatures [4, 13, 14, and 15]. Figure 6 shows the flow chart of the proposed method that is a improving SEP in heterogeneous WSNs by fuzzy approach.

4.1. Simulation Setup

Simulations are carried out in MATLAB R2011a (version 7.10) under Windows 10 (64 bits). The experiments are performed on a PC (Think Pad E431, China) with an Intel W Core™ i5 Processorrunning at 2.6 GHz and 4 GB of RAM.

For our proposed, 100 sensor nodes are randomly deployed in the area, this area assume that ($\propto$=3, P=0.2, m=0.3). Where $\propto$, 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 topographical area is distributed in the dimension 100 m × 100 m. this area has the sensed transmission limit of 30 m. The performance of the proposed method is tested in these in the area. There is only one data sink which located at (50 m, 50 m). The simulation was performed for 2000 rounds. We use a simplified model showed in figure 5 for the radio hardware energy dissipation. Table 7 presents the systems parameters in details.

Table 7. Simulation parameters

Parameter	Value
Topographical Area (meters)	$(100\text{m} \times 100\text{m})$
Sink location (meters)	$(50\text{m} \times 50\text{m})$
Number of nodes	100
Limit of transmission distance (meters)	30m
Initial energy of node	0.5J
Packet data size	4×10^3 bits
No. of MFs (in each input and output variable)	5
No. of IF-THEN rules	125
No. of transmission packets (rounds)	2×10^3

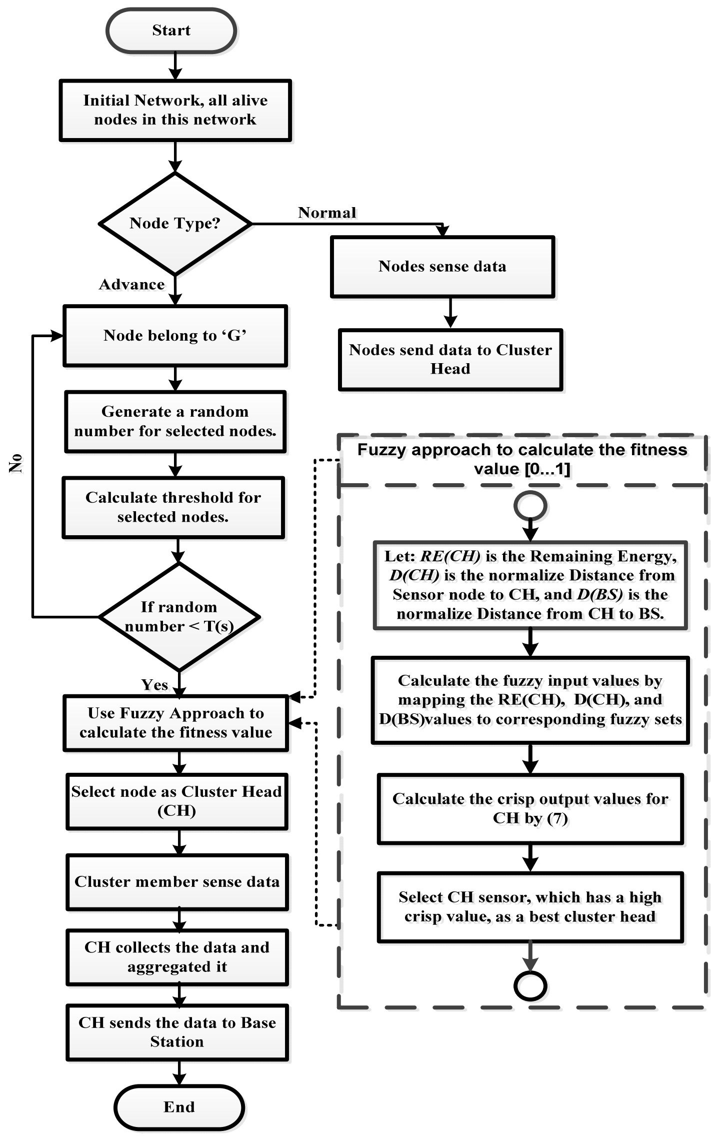

Figure 6. Flow chart of SEP - FUZZY clustering

4.2. Simulation Results

The number of alive nodes as a function of rounds by using the three different approaches for this area shown in Figure 7. It can be seen that the proposed method outperforms FUZZY_ SEP. the network lifetime achieved by the proposed method increased by nearly 27% than that obtained by Leach and also increased by nearly 23% than that obtained by SEP.

Moreover in Figure 7, it can be seen that the number of alive nodes of the proposed method is always higher than both LEACH and SEP. The different duration of time corresponding to the first dead node computed using the two different approaches are 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 and SEP. From Table 8 and Figure 7 it is clear that, the proposed method outperforms SEP in terms of balancing energy consumption and maximization of network lifetime.

Table 8. Number of rounds with the first dead node

Approaches	Leach	SEP	Proposed
Lifetime of the first dead node (Rounds) 186	519	911	

Figure 8 show the average remaining energy of a WSN as a function of transmission rounds for the three approaches. As the round number increases in the area, the proposed method performs better than both approaches (LEACH and SEP) protocols. This indicates that, better energy balance in a WSN is achieved by the proposed method.The delay incurred in transmission of data packets is also a key parameter for certain applications. The comparison between three different approaches is shown in Figure 9. It can be seen that, the proposed method has shortest delay compared to both Leach and SEP. 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.

Figure 10 show the comparison for network lifetime between three different approaches. It can be seen that, the proposed method more lifetime compared to both Leach and SEP.

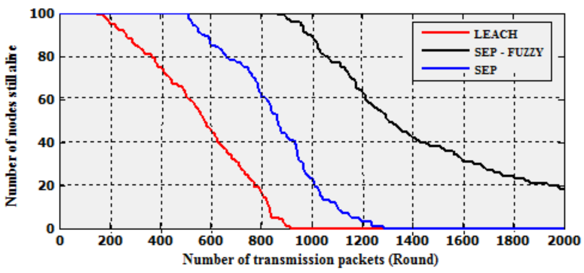

Figure 7. Number of alive nodes as a function of rounds based on different approaches (Leach, SEP, and proposed).

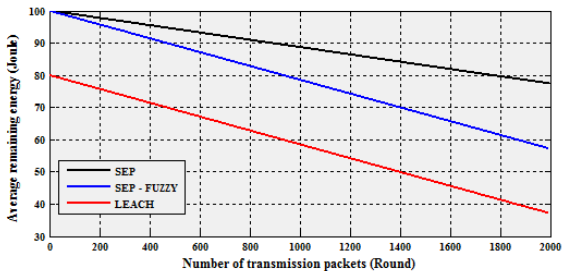

Figure 8. Average remaining energy as a function of transmission round based on different approaches (Leach, SEP, and proposed)

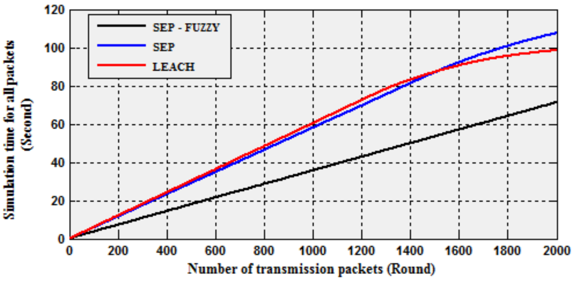

Figure 9. Data transmission delay (simulation time for all packets) as a function of transmission round based on different approaches (Leach, SEP, and proposed)

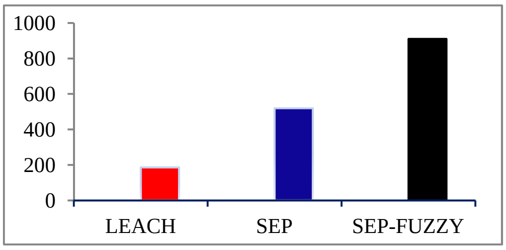

Figure 10. Lifetime comparison based on different approaches (Leach, SEP, and proposed)

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.

5. Conclusion

In order to improve the energy efficiency and achieve the network load balance to SEP 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 and compared with LEACH,SEP. 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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