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Pandian Vasant
Ivan Zelinka
Gerhard-Wilhelm Weber *Editors*

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Contents

A Fuzzy Based Clustering Approach to Prolong the Network Lifetime in Wireless Sensor Networks

Enaam A. Al-Hussain(✉) and Ghaida A. Al-Suhail

Department of Computer Engineering, University of Basrah, Basrah, Iraq
enaam.mansor@uobasrah.edu.iq

Abstract. The selection of cluster heads (CHs) in wireless sensor networks (WSNs) is still a crucial issue to reduce the consumed energy in each node and increase the network lifetime. Therefore, in this paper an energy-efficient modified LEACH protocol based on the fuzzy logic controller (FLC) is suggested to find the optimal number of CHs. The fuzzy chance is combined with the probability of CH selection in LEACH to produce a new selection criterion. The FLC system depends on two inputs of the residual energy of each node and the node distance from the base station (sink node). Accordingly, the modified clustering protocol can improve the network lifetime, decrease the consumed energy, and send more information than the original LEACH protocol. The proposed scheme is implemented using the Castalia simulator integrated with OMNET++, and the simulation results indicate that the suggested modified LEACH protocol achieves better energy consumption and network lifetime than utilizing the traditional LEACH.

Keywords: Cluster head · FIS · LEACH · Network lifetime · Castalia · OMNET++ · Wireless sensor networks

1 Introduction

Nowadays, the tremendous advancement of sensor equipment technology contributes to huge implementation capabilities in many fields, such as underwater monitoring, health monitoring, smart infrastructure monitoring, multimedia surveillance, Internet of Things (IoT), and other fields of use. Among these, in a targeted area environment, sensor devices are often distributed randomly over settings that can dynamically change. Information from such nodes may be sensed, processed, and sent to adjacent nodes and base station (BS). However, these sensors have many restricted features, such as limited memory, low computing, low processing, and most importantly, low power. As sensor nodes have limited resources, the clustering process mechanism is favored as an energy-efficient technique in WSNs. When networking is restricted to a few nodes, the strategy can conserve network energy. It would effectively extend the network's lifespan by minimizing the consumed energy using multi-hop transmission and data aggregation [1–5]. In particular, Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is one of the most well-known. protocol [6], which depend on

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adaptive clustering to utilize energy consumption. It can be considered as a benchmark of clustering routing protocol in WSNs and MANETs where the SNs in the network field are separated into clusters. Each cluster has one sensor node referred to as the leader node (or CH) and it is selected randomly. On the contrary, though energy from sensor nodes is retained by LEACH, its energy efficiency is still somewhat disadvantaged because of random, faster power drainage, particularly where smaller nodes per cluster are induced by the unequal distribution of nodes in clusters and time limit due to the use of the TDMA MAC Protocol [6–8]. To avoid the random selection of the CHs, and to find the optimum number of selected CHs and solve the complexities in the relation between the network lifetime and the other parameters of the sensor nodes, many approaches have been developed such as (i) Fuzzy Inference System (FIS) [9] (ii) Adaptive Neural-Network Fuzzy-System [10] (iii) Metaheuristic Intelligent Algorithms like swarm algorithms ABC and ACO, and flower-pollination [11–13]. Therefore, a new modified LEACH protocol via the fuzzy logic controller is obtainable in this paper, which efficiently improve the network lifespan and decrease the number of dead nodes during its rounds. The modified LEACH protocol aims to select the CHs based upon the Type1-Fuzzy Inference Method (T1-FIS). The CHs are chosen by considering two parameters (i) residual energy (REN) and (ii) the node's distance from the base station (DBS) based on the threshold significance. The rest of this paper will be structured as follows. Firstly, the related works are addressed in Sect. 2. In Sect. 3 the Modified LEACH protocol is described in detail. Section 4 displays and discusses the simulation results. Finally, in Sect. 5, the conclusion has been drawn.

2 Related Works

LEACH protocol is a routing protocol that utilizes a clustering technique to create random, adaptive, and self-configured clusters. In LEACH, all sensor nodes are combined into clusters, each of which has a Leader Node (or CH) who handles the TDMA schedule and send out the aggregated information to the BS. Since only CH sends the data to the BS, the network's energy consumption is significantly reduced. In each round of the LEACH protocol, the CH is elected at random, and the probability of being CH is proportional to the number of nodes. After several rounds, the chance of a low-and high-energy sensor node being as CH is the same, which contributes to an energy imbalance in CHs that exists in the whole structure; and consequently, the lifetime of the network is reduced [1, 2]. Though, to improve the LEACH protocol, and due to the complexity problem in the description of the relation between the network lifetime and the other parameters of the nodes, a FIS is one of the most well-known intelligent schemes that can be nominated to solve such problem. The reasons beyond are; it doesn't need precise system information and it is classified as a powerful tool in Artificial Intelligent (AI) methods that can build efficient solutions via the combination of many input data parameters and then provide the desired cost criterion. Many researches have been devoted to clustering parameters based on the fuzzy rules to determine and choose network CHs. For instance, Abidi, et al. [1] introduced a Fuzzy CH selection algorithm based on LEACH protocol using three input parameters:

Remaining Energy, Neighbours Alive, Distance from the BS to select CH. in [2], Ayati, M., et al. designed a three-level clustering method with numerous inputs at each level of clustering: remaining energy and centrality, transmission quality and distance from the BS, overall delay, and denial-of-service (DOS) attacks. Al Kashoash et al. [3] also proposed a FIS for CH selection based on two inputs: Residual Energy and Received Signal Strength (RSSI) value to increase network lifetime and packet transmission rate. The proposed algorithm demonstrated a significant increase in network lifetime up to the LEACH Protocol. The authors in [4–6] propose completely efficient solutions for balancing the energy depletion of the SNs and extending the life of the WSN. These methods make use of three fuzzy variables: node residual energy, distance to BS, and distance to CH. The simulation results demonstrate that, when compared to the LEACH protocol, the proposed algorithm significantly progresses energy efficiency and network lifetime of WSNs. Additionally, Lee et al. [7] suggested a clustering scheme for mobile sensor nodes that is utilize three inputs: residual energy, movement speed, and pause time. The issue of energy consumption in WSNs has remained a focus of research in recent years, and as a result, many current studies continue to work in this direction by developing efficient methods for increasing the network's efficiency. Such as the authors in [8–10], who employ the Fuzzy Clustering Algorithm to improve network reliability and lifespan. Additionally, that use Fuzzy Clustering Algorithm to enhance the network reliability and increase the Lifetime. Also, many Intelligent methods are suggested in terms of Adaptive Neural-Network Fuzzy-System, Meta-heuristic Intelligent Algorithms like swarm algorithms ABC and ACO, and flower-pollination [11–14]. Additionally, Balaji et al. [15] recommended a multi-hop data packet exchange, with the data packets eventually being sent to the BS. When packets are transmitted from the source sensor to the BS via the CH, they are transmitted using fuzzy logic type1 with three parameters. Which correctly predicts the nodes with a high degree of confidence and is close to the BS. On the other hand, in [16], the selection of the fuzzy logic cluster head is based on three inputs: remaining energy, node density, and distance to the BS (sink). Due to the fact that WSNs suffer from a number of issues related to energy consumption and network scalability as a result of their complexity and nonlinear behavior, some recent research has focused on automating the construction and optimization of the rule base table in a FIS. For example, Tran et al. [17] improve energy efficiency in large-scale sensor networks by using energy-based multihop clustering in conjunction with the Dijkstra algorithm to determine the shortest path. Meanwhile, Fanian et al. [18] propose a Fuzzy Multi-hop Cluster based routing Protocol and an intelligent scheme called the Shuffled Frog Leaping Algorithm for improving the rule base table in a FIS. Additionally, the authors in [19, 20] suggest that an energy-efficiency and reliability-based cluster head selection scheme would be an ideal way to improve the overall accomplishment of WSNs.

3 Modified LEACH Protocol Design

In this section, a selection approach for cluster heads (CHs) using the Fuzzy Inference Scheme is suggested to improve network lifetime and reduce the energy consumption of the LEACH protocol in WSNs. The organization of this section is introduced as follows: (i) Network model assumptions are stated first, (ii) the details about the design of the fuzzy logic controller are presented, and (iii) finally the operation of the suggested protocol is given.

3.1 Network Model

The criteria required to describe the network model based on the proposed Fuzzy LEACH protocol are considered as follows:

1. N Sensor Nodes are considered uniformly disseminated on M X M interesting area, and all the nodes and BS are stationary (non-mobile).
2. All SNs have the capability to sense, aggregate, and forward the data to the BS (i.e., acts as a sink node).
3. In the network, the nodes are non-chargeable and are homogeneous in initial energy terms.
4. The Sink Node (BS) is situated in the central of the network field. It is often assumed that the communication links to the other nodes are symmetrical. So that the data rate and energy consumption of any two nodes are symmetrical in terms of packet transmission.
5. The nodes are operated in power control mode, based on the receiving distance from the SN.
6. At the Sink node (BS), the selected CH nodes would not be selected again in any new round of selection.
7. In each round of the Set-Up phase, the cluster heads are still selected randomly but with extra fuzzy logic criteria to enhance the CHs selection process of the LEACH protocol.

3.2 Design of Fuzzy Logic Controller (FLC)

There are commonly four key steps in the FLC [14]:

1. **Fuzzification:** Convert the crisp values of each input variable to fuzzy values in the form of membership functions. Triangular, Trapezoidal, and Gaussian membership functions are the most well-known types of MFs, but to avoid discontinuities in the input domain, the Gaussian membership function is proposed, which is defined as in Eq. 1:

$$f(x, \sigma, c) = \exp\left(\frac{-(x-c)^2}{2\sigma^2}\right). \tag{1}$$

   where, c is the mean, and σ is the standard deviation.
2. **Rule evaluation:** Apply step 1 output to the fuzzy rule to evaluate the fuzzy output. A typical rule of the Mamdani fuzzy model is used due to their widespread acceptance
   Rn: if x1 is X1 and x2 is X2 then Y is y.
3. **Aggregation:** It is integrating each rule's outputs into a single fuzzy set. Many aggregation methods can be used such as (i) max(maximum), (ii) sum (sum of the rules o/p sets), and (iii) proper (probabilistic or).

4. **Defuzzification:** transform fuzzy set values to a single crisp number. Many types of defuzzification methods are found, the weighted average method and centroid method, or what is sometimes called (center of the area) are the most popular methods for defuzzification.

Figure 1 demonstrates a fuzzy inference system for selecting CHs. in this model, the Fuzzy Logic Controller (FLC) is assessed using two parameters: Residual Energy and node distance to Base Station; and it can produce the output parameter namely the fuzzy chance. Later, to improve the cluster head selection, a fuzzy chance and LEACH probability criterion can be combined to produce a new chance in finding these CHs.

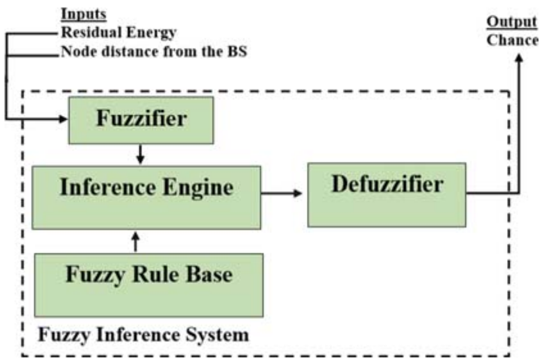

Fig. 1. The fuzzy inference system for the CHs selection

In our proposal, we used the Mamdani approach as a FIS because of its simplicity. The rule of the Fuzzy Logic Controller (FLC) is to measure the probability of CH selection based on two input descriptors as shown in Table 2: (i) Residual Energy (REN) and (ii) the distance between each node and the Base Station (DBS). Thus, this controller is designed with two designated inputs (REN and DBS) and one output (chance). The first one is the residual energy (REN). The second input is the distance to the base station (DBS). Consequently, the linguistic variables and the fuzzy logic rule base are shown in Tables 1 and 2.

Table 1. Inputs/output linguistic variables.

Parameter	Linguistic variable
Residual energy (REN)	Low, Medium, High
Distance to BS (DBS)	Close, Average, Far
Chance	VL, L, M, H, VH

Table 2. Fuzzy rules.

Residual energy (REN)	Distance to BS (DBS)	Chance
Low	Close	M
Low	Average	L
Low	Far	VL
Medium	Close	H
Medium	Average	M
Medium	Far	L
High	Close	VH
High	Average	H
High	Far	M

In the FLC system, the Gaussian membership functions are employed rather than triangular or trapezoidal membership functions to represent linguistic variables and in order to avoid the discontinuities if the input MFs do not cover each input domain completely. Figure 2 depicts the membership functions of REN, and the membership functions of DBS respectively.

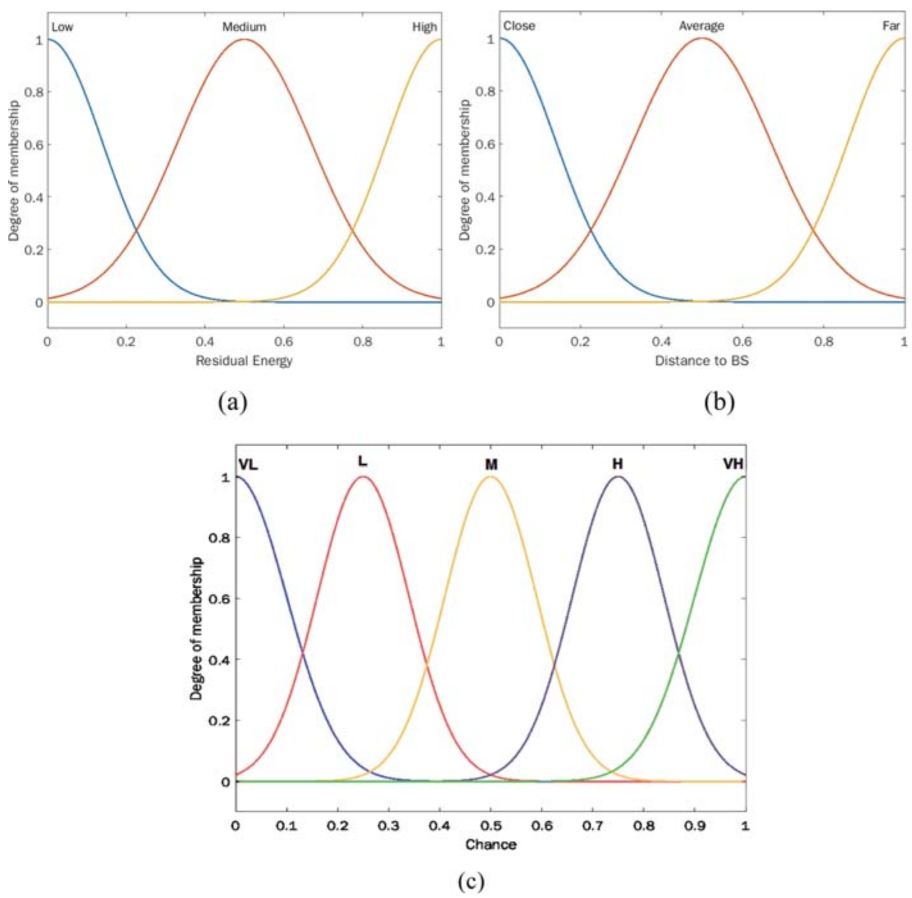

Fig. 2. Fuzzy inference system of proposed algorithm (a) MFs of input variable REN, (b) MFs of input variable DBS, and (c) MFs of output variable chance.

On contrary, the fuzzy inference system (FIS) is simulated using the Xfuzzy tool which is a development environment that combines many powerful tools to design and tuning the parameters of a fuzzy system. Also, there is an excellent ability to generate a C++ code for this system that can be integrated with the Castalia simulator as in Fig. 3.

Which demonstrates the simple architecture for Modified Leach protocol using Xfuzzy tools and Castalia simulator that integrating with OMNET++. The graphical user interface of Xfuzzy shows the specifications by means of drop-down structures so that the complete system or any rule bases can be select as the active specification by few stages: (i) Description stage: select a preliminary description of the system by using two tools (xfedit and xfpkg) that assist in the description of fuzzy systems. (ii) Verification stage: study the behavior of the fuzzy system under development value of the various internal variables for the input values of the given range. (iii)Tuning stage: adjusting the different MFs. (iv) Synthesis stage: generate a system representation that could be used externally such as xfcpp, that used to develop a C++ description.

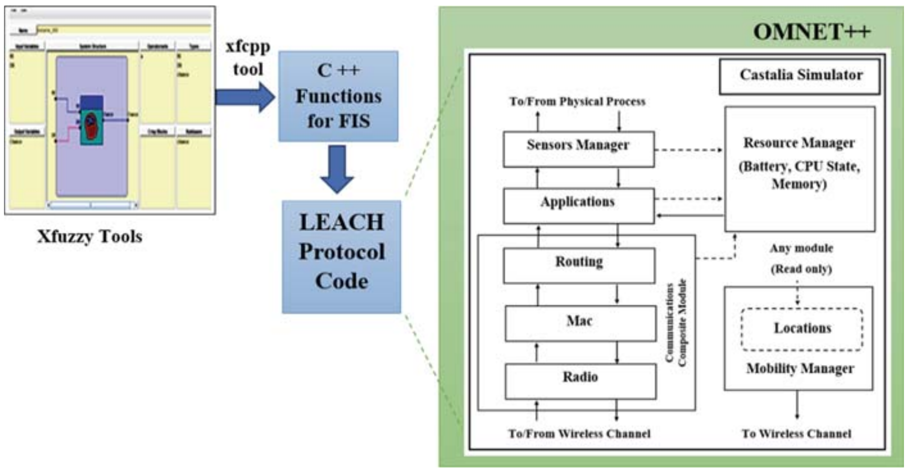

Fig. 3. Simple architecture for modified leach protocol using xfuzzy tools and OMNET++/castalia simulator.

3.3 Operation of the Modified LEACH Protocol

In this subsection, we use the proposed CHs selection algorithm using T1-FIS depending on Residual Energy (REN) and the Distance from the BS (DBS) of each node (DBS). This algorithm performs its operation at rounds based on LEACH protocol according to specific and defined criteria. Thereby, each round starts with the following steps of the proposed fuzzy-based algorithm:

Proposed Fuzzy-Based Algorithm:

Step1: The BS Sends a request for ID, Residual Energy, Distance to Sink for each sensor node in the network and waits for a response from the sensor nodes.
Step2: Define REN & DBS as Inputs to FIS to produce a fuzzy chance.
Step3: Select CH based on the Chance Produced from FIS and the threshold equation of the LEACH Protocol according to the following criteria:
If rand (0,1) < *Threshold value of the LEACH* & Chance >= Fuzzy threshold(q) then the node is selected as a CH *Otherwise*, the node is selected as a CM.

T(*n*) represents the threshold value of LEACH protocol which is modified by adding *(E_s / Emax)* to avoid the random selection of the CHs in the set-up phase, and defined as in Eq. 2:

$$T_{new}\,(n) = p\left(\frac{1}{1-p\,(r \bmod \frac{1}{p})} + \frac{Es}{E_{max}}\right) \quad (2)$$

Step 4: Once the CHs are elected, each CH sends advertisement (ADV) messages to all sensor nodes to join it.
Step 5: Based on the RSSI, the sensor nodes join it CHs.
Step 6: Each CH makes a TDMA schedule based on the number of CMs, and each SN sends its data packet within its time slot.
Step 7: Each CH aggregates the data from its CMs and sends it to the sink.

4 Simulation Results

Now, this section discusses the performance assessment of the Modified LEACH in Sect. 3, using Castalia simulator and OMNET++. The proposed algorithm is examined when the network of our simulations consists of 100 SNs spread uniformly over an area of 100 × 100 m^2. We consider the location of the base station to be in the location (50, 50). The initial energy of all nodes is expected to be 3 J. The obtained results are compared with the original LEACH protocol. The environmental network parameters utilized in the simulation are expressed in Table 3.

Table 3. Simulation parameters.

Parameters	Value	Parameters	Value
Network size	100 ×100 m^2	Initial energy	3 J
No. of nodes	100	Simulation time	300 s
No. of clusters	5	Round time	20 s
Location of BS	50 × 50 m	Packet header size	25 Bytes
Node distribution	Random	Data packet size	2000 Bytes
Energy model	Battery	Bandwidth	1 Mbps

Figure 4 illustrates First Node Dead (FND), Half Node Dead (HND), and Last Node Dead (LND). The results demonstrate that Modified LEACH outperforms the original leach protocol by about 50.94%, 14.1667%, and 13.259% in standings of FND, HND, and LND respectively.

Meanwhile, Fig. 5, and Fig. 6 present energy consumption of the nodes, and total number of alive nodes is measured in relation to the number of network communication rounds to evaluate the proposed protocols. The results show that the Modified LEACH consumes less energy than and Traditional LEACH in terms of consumed energy, and the number of alive nodes per round by about 13.69%, and 15.29% at the first 100 s.

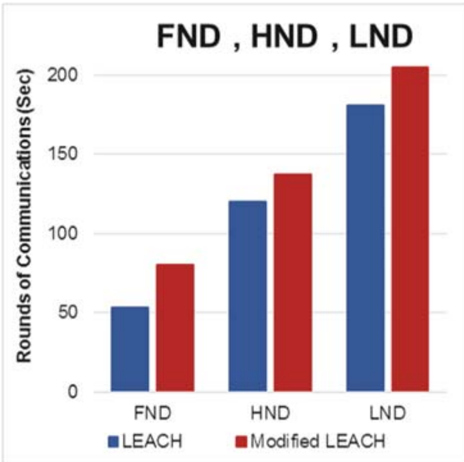

Fig. 4. FND, HND, and LND.

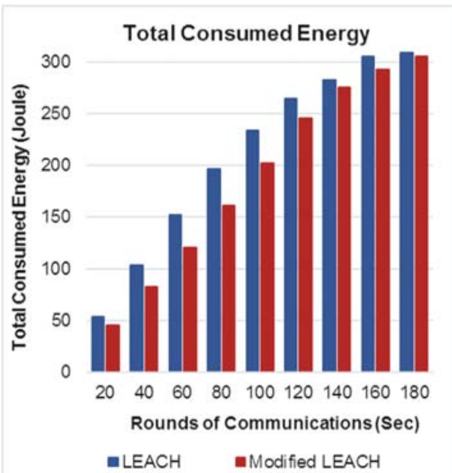

Fig. 5. Total energy consumption.

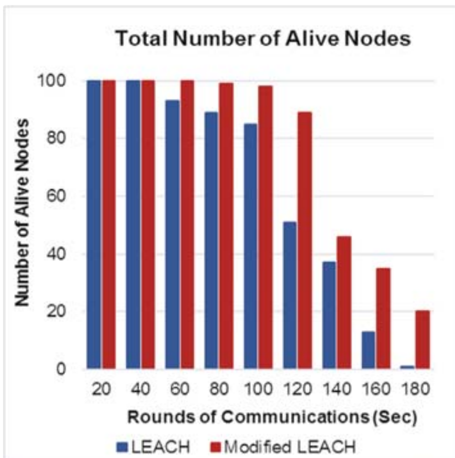

Fig. 6. Total no. of alive nodes.

5 Conclusions

Due to the increase and expansion of WSN applications, particularly in the last few years, it has become important to find an effective solution to WSN challenges. Energy savings was one of the primary challenges confronting these networks. In this paper, a CH selection scheme is proposed using Fuzzy-Logic system (T1-FIS). It depends on Residual Energy and Node Distance from BS in order to maximize the network lifetime and decrease the energy consumption per sensor node. The modified LEACH Protocol is developed and simulated in Castalia (v3.2) and OMNET++ (v4.6). The results showed that the modified protocol can successfully decrease the energy consumption and increase the network lifespan compared to the original LEACH and other existing Fuzzy-based LEACH proposals. For future work, the proposed scheme can involve different parameters in the design of fuzzy inference system like the centrality, SNR, RSSI, and packet size. Moreover, one of Artificial Intelligent algorithms (AI) such as GA, PSO, ABC, and FPA is also eligible to optimize the QoS accomplishment of the LEACH protocol.

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