Energy-Efficient Fuzzy Inference System Cluster Head selection in Wireless Sensor Networks

I Nasurulla[1] and R Kaniezhil[2]

[1]Periyar University, Salem, Tamilnadu – 636 011, India.

[2]MIT College of Arts and Science for Women Musiri, Thiruchirappalli, Tamilnadu, India.
Email: nasrumca@gmail.com[1], kaniezhil@yahoo.co.in[2]

Abstract

Energy consumption is an essential element to consider in the context of wireless sensor networks (WSNs). Many sensor nodes are available today, and they mostly use energy to send data over great distances. WSNs have a limited amount of energy to work with. This trait creates a significant barrier for routing protocol designers. As a result, many designers and researchers focus on WSN architectures and algorithms that enable energy-efficient operation. The clustering algorithm is one of the most often used algorithms in this area. As a result, various routing protocols based on clustering algorithms have been suggested for WSNs, with cluster heads (CHs) selection and cluster creation as the functionalities of these protocols. The selection of CHs, on the other hand, is one of the most critical concerns. This research presents a new routing strategy called Energy-efficient fuzzy inference system cluster head (EEFIS-CH), which improves the LEACH protocol. This method seeks to minimize energy consumption in terms of network lifespan extension by utilizing three fuzzy factors. Residual energy predicted efficiency and proximity to the base station are the three criteria. In comparison to LEACH and LEACH-ERE routing protocols, simulation findings suggest that the EEFIS-CH strategy produces better outcomes.

Keywords - *Cluster Head; LEACH; LEACH-ERE; Fuzzy Inference System; Wireless Sensor Networks; Energy-Efficient.*

I. INTRODUCTION

One of the technologies that will revolutionize the world has been identified as the wireless sensor network [1]. Hundreds of thousands of smart wireless sensor nodes can be combined to make a massive but intelligent WSN. As seen in Fig. 1. Each sensor node is outfitted with a sensing unit, a power unit, a processing unit, and a communication unit. The power unit, which could be a tiny battery, supplies electricity to the sensor node. By employing a suitable preloaded sensor unit, sensor nodes can sense temperature, light intensity, and water level from the physical environment. Based on the analog to digital converter (ADC) module, The sensor unit's analog signal will be transformed into a digital signal that the microcontroller unit will recognize. The data collected will be transferred to the BS via the communication unit. In other words, rather than communicating directly with the BS, the wireless sensor node can connect with its peers. As a result, numerous communication strategies reduce energy usage while retaining information sent to the enduser.

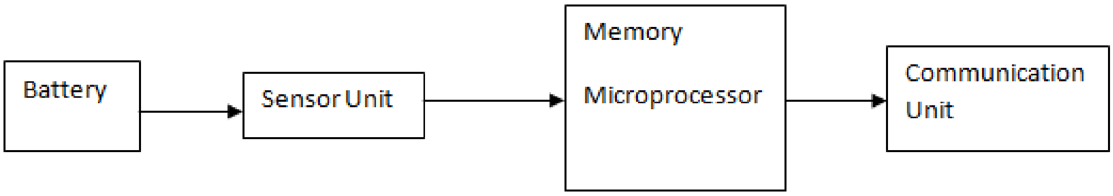

Fig 1. Sensor Node Structure

The design becomes complicated and challenging to meet design criteria, such as the sensor node size having to be compact for ease of use. Limited power supply, limited computing capability, and minimal memory storage are the trade-offs for being compact in physical size. The most critical factor affecting network longevity is sensor node energy. Because the nodes are small and maybe deployed in hazardous regions, replacing a depleted battery is impractical and impossible. As a result, enhancing the routing algorithm to save energy and extend the network lifetime is more practical. Furthermore, Because the energy cost of transmitting one bit across 100 meters is equal to the energy cost of executing 3000 instructions, it is critical to limit energy consumption in wireless communication activity through efficient regulation. The clusterbased hierarchical routing protocol is a low-energy routing technique that can be used for environmental monitoring. Sensor nodes in the cluster will be grouped into a few groups, each including one CH. The CH will collect data from member nodes in the same cluster and combine the information before sending it to the BS in smaller packets. By putting this process in place, only permitting the CH to communicate with the BS will dramatically reduce total energy consumption and network congestion [3][4]. LEACH is a common cluster routing protocol that tries to perform load balancing in sensor nodes by rotating the CH to extend the network lifetime. Normally, energy consumption in cluster routing protocols is concentrated on CHs, which must collect and aggregate sensed data from member nodes before forwarding the aggregated data to the BS[5]-[6]. In theory, the LEACH protocol allows sensor nodes to choose themselves as a CH using a probability model. To evenly spread the job demands, each sensor node will become CH once in a cycle. The downside of the LEACH protocol in CH election is that it relies solely on a probability model to elect the CH without considering any sensor node parameters. Hence no CHs or too many may be chosen in a single round [7]. Furthermore, the elected CHs may be close to one another, resulting in poor energy distribution [8]. The BS makes the CH selection choice to have an overview of the network for CH selection. LEACH-C was proposed by the creator of LEACH, which uses a centralized approach to elect the CHs in the BS using the simulated annealing technique [9]. Includes an addition to the energy efficiency depending on residual energy, projected efficiency, and proximity to BS. Furthermore, based on these criteria, each node determines its likelihood of becoming a CH. The probability of a node is calculated using a Fuzzy Inference System. The remainder of the paper is arranged in the following manner. The related work is described in Section 2. In Section 3, the network model is described. In Section 4, the proposed EEFIS-CH technique is described. In section 5, we offer our simulation results as well as an analysis of the proposed approach. Finally, Section 6 brings this paper to a close. Many protocols and approaches to routing based on the clustering algorithm have been proposed in recent years for wireless sensor networks (WSNs); many of them based on the LEACH algorithm attempt to solve the problems found in the clustering algorithm, specifically the cluster heads (CHs) selection. This section gives you an overview of fuzzy.

II. Overview of the Fuzzy Logic Methodology

Professor Lotfi Zadeh proposed the fuzzy logic technique [10], [11] to handle problems that are difficult to answer using classical logic theory, not only as a control methodology but also as processing data based on approving membership in small sets rather than membership in clusters. This strategy is effective [12][13]. Figure 2 depicts the four aspects of fuzzy logic operation: fuzzification, IF-THEN rules basis, Fuzzy Inference System (FIS), and efuzzification. Inputs A and B, for example, are turned into fuzzy linguistic sets by employing membership functions. The role of rule base evaluation is to determine IF-THEN rules and apply them to the input.

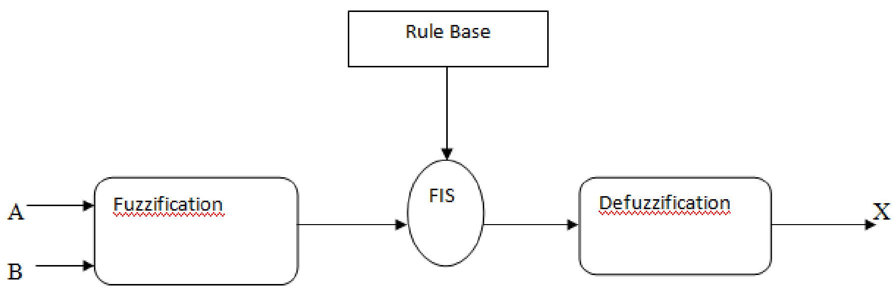

Fig 2. Operation of fuzzy logic

III. LEACH PROTOCOL

The LEACH (Low Energy Adaptive Clustering Hierarchy) protocol [5],[9] is a hierarchical system in which cluster heads are selected at random. The set-up phase and steady-state phase of the LEACH procedure are both important. Cluster heads (CHs) are selected, and clusters are formed during the set-up state phase. Cluster heads (CHs) selection and cluster formation are part of the set-up state phase. Sensing and transmitting sensed data to the base station (BS) via CHs are part of the steady state phase. Each sensor node generates a random number between 0 and 1 at the start of each round's setup phase to determine whether it will become a CH or not for the current round.

$$T(n)=\begin{cases} \dfrac{p}{1-p*(r \bmod \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

If the number generated by the sensor node is less than T(n), the sensor node is designated as a CH for the current round. Equation T(n) defines the threshold T(n) (1) Where r denotes the current round, G is the set of nodes that have not been a CH in the previous 1/p rounds, and p=k/n denotes the expected number of CHs in the round, and n the number of nodes in the network field, and p=k/n denotes the expected number of CHs in the round.

A. LEACH-FL Protocol

The LEACH methodology is being improved. To increase the performance of the LEACH protocol, it is proposed to use Fuzzy Logic (LEACH-FL) [14]. This protocol takes three fuzzy descriptors into account: energy level, node density, and distance between the CH and the BS. With a set-up stage and steady-state stage, this approach is similar to the Gupta protocol.

$$G(i) = \frac{\sum_{j=1}^{n} x_j . u(x_j)}{\sum_{j=1}^{n} u(x_j)}$$

B. LEACH-ERE Protocol

In [15], Jin-Sheyan Lee et al. present the LEACH-ERE technique for homogenous WSN. This fuzzy logic-based solution for homogeneous WSNs has been developed based on the LEACH architecture in addition to energy prediction. This approach has two arguments (sensor node residual energy, sensor node expected residual energy)for calculating the probability value. Using the centre of area (COA) technique, each sensor node in the WSN calculates a value of chance. The sensor node with the most residual energy and expected residual energy has a higher probability of becoming CH. In all sensor nodes, there are 18 fuzzy if-then rules defined. Other protocols, such as LEACH and CHEF, do not produce the same results as the LEACH-ERE method. However, the distance between CHs and base stations and the distance between sensor nodes and CHs are ignored, resulting in uneven energy usage. Also, even if the distance between this specific CH and the BS is enormous, each sensor node chooses a certain CH. As a result of the increased energy consumption, the network lifetime of WSNs decreases.

C. SYSTEM MODEL

Figure 3 depicts the basic system model used in this paper. The detected data is sent from each node to the cluster's CH. The CH compiles the data collected and sends it to the BS. Algorithm clustering is used in this operation. In addition, we make the following assumptions:

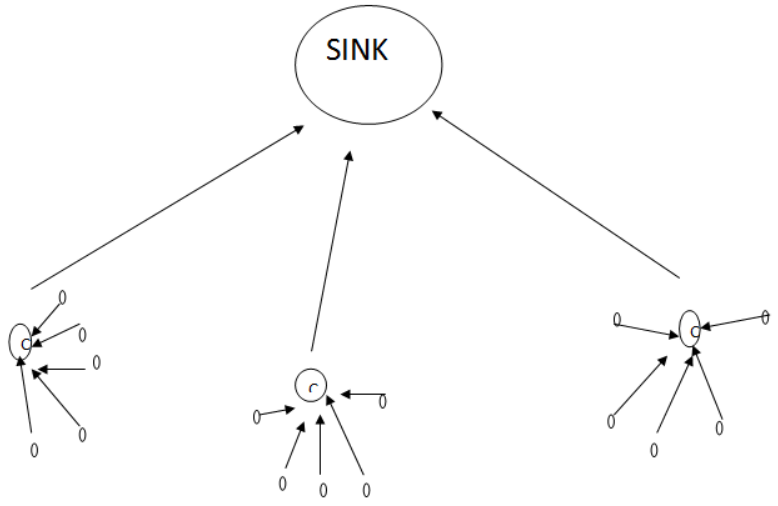

Fig- 3. System Model

The network is homogeneous, and all nodes have the same energy resources.

- •The CH is in charge of data compression and aggregation.
- •The wireless radio signal power may be used to determine the distance between nodes, then between CHs and BS.
- •After deployment, all nodes, and the BS remain stationary.

D. Expected Efficiency

The expected efficiency ratio between each node's expected residual energy and the cluster's expected average energy. The estimated residual energy in [11] has been used in principle to model the expected efficiency in this research. Expected residual energy is defined as the energy left over after a node has completed its function, such as being the cluster's head for around. After the CH is chosen and the cluster is formed, the steady-state phase is divided into frames, during which cluster members communicate their sensed data to the CH during their assigned transmission slot. Each CH receives the sensed data from all cluster members within a frame. The CH will combine the sensed data into a single packet and send it to the BS. The predicted energy consumption is calculated as follows:

$$E_{exp\,Consumed}(l, d_{toBS}, n) = N_{frame} * (E_{T_x}(l, d_{toBS}) + n * (E_{R_x}(l) + l * E_{DA}))$$

4. EEFIS-CHPROPOSED APPROACH

We introduce the EEFIS-CH strategy in this part, which leverages the Fuzzy Inference System (FIS) to increase network lifetime and reduce energy usage in WSNs. In a similar way to the LEACH, our suggested method selects CHs in each round. Algorithm 1 represents the pseudo-code for the proposed technique. Every round, each node estimates the chance using the three fuzzy factors of remaining energy, predicted efficiency, and proximity to BS. If a node's maximum chance is less than a predetermined threshold T, the node is considered inactive (n), which is the probability of becoming a CH candidate. For the current round, the sensor node becomes a CH. After the CHs have been selected, each CH sends a CSMA-MAC advertisement message throughout the network to alert the remaining nodes that it is a CH. Following this, the node joins the CH based on the strongest signal strength advertisement message. Depending on the slot in the TDMA schedule, each CH waits to receive sensed data from cluster members once all the CHs have been picked and the clusters have been arranged. After that, the CHs compile the sensed data into a signal packet and send it to the BS. In EEFL-CH, we applied the strategy of using the most frequencies. The Mamdani technique is what it's called. We also employed fuzzy inference systems (FIS) to calculate the probability of each node. As shown in Fig. 3, there are three input variables for FIS.[8],[14],[16].

•The difference between each node's original and used energy is called residual energy.
•Expected Efficiency is the proportion of each node's expected residual energy to the cluster's expected average energy.

•The distance between the node and the base station is called "closeness to BS."

The likelihood of the node being CH, also known as chance, is one of the output variables.

The maximum chance indicates that the node has a higher possibility of being a CH in the current round.

Algorithm 1- Proposed Algorithm of EEFIS-CH

T(u): a threshold value to become a CH candidate, chance(n): the chance value of the node a to be a CH, r: round number

/* for every round */

1. Each node n calculates chance value based on Residual Energy, Expected Efficiency and Closeness to BS.

2. Select CHs in each round based on the maximum chance value.

3. if Max(chance(n)) <= T(n)

CH(u)T<-n;

end if

1. Formation of clusters based on received strength signal.

/'* for each nodes */

1. Cluster members send sensed data to their CH.

/* end of for */

1. BS collects the information from CHs.

/*end of rounds*

5. SIMULATION

In this section, we use MATLAB to evaluate the performance of the EEFL-CH technique. We used WSNs with n=100 nodes randomly spread in a network field of 100m2 to the model suggested EEFL-CH, LEACH, and LEACH-ERE, with a probability of becoming CH of 0.1. The base station is situated in the middle of the sensing field. In terms of network lifetime and residual energy, the EEFIS-CH technique was compared to LEACH and LEACH-ERE. The total number of nodes living vs. the number of rounds, with each node receiving 0.5J of energy at the start. We can see that the nodes in the LEACH protocol die faster than those in the LEACH-ERE and EEFIS-CH protocols. In comparison to LEACH and LEACH-ERE, the results reveal an increase in network lifetime. Our technique is more stable than existing clustering algorithm-based routing protocols (LEACH and LEACHERE). Depicts the residual energy, which shows the accumulated energy dissipation on the round.

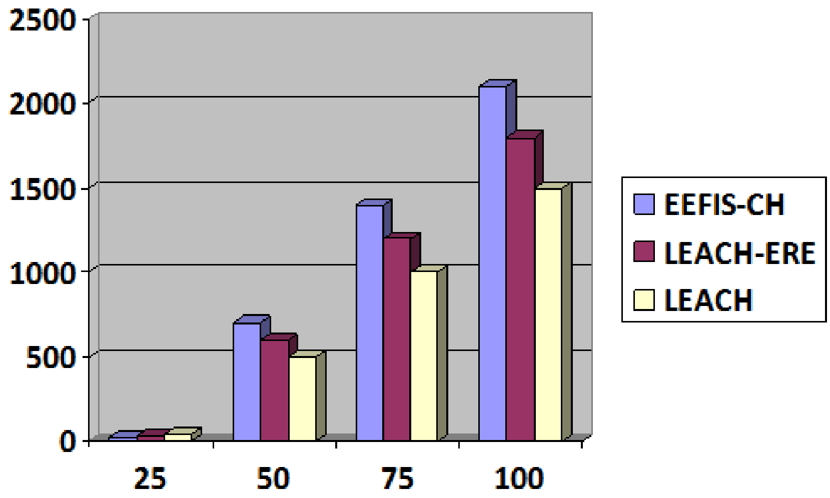

Fig 4. Node death percentage per number of rounds

The EEFL-CH method has higher residual energy than the LEACH and LEACH-ERE protocols. This is due to the CH's power regulation and the possibility of selecting a CH that considers the residual energy of each node, expected efficiency, and proximity to the BS, allowing the network's total energy dissipation to be reduced. In fig. 4, the number of rounds for 1 percent, 25%, 50%, and 100% node death is shown for EEFL-CH, LEACH-ERE, and LEACH, respectively. It is evident that the EEFL-CH strategy might outperform the LEACHERE and LEACH throughout the network's operation. In the LEACH protocol, the network's energy depletion occurs quickly. In comparison to the LEACH and LEACH-ERE protocols, as illustrated in fig.4, we can conclude that our suggested technique has better characteristics regarding network lifespan extension.

6. CONCLUSION

Many clustering algorithm-based routing protocols have been proposed to improve the energy efficiency of WSNs. LEACH is one of the earliest protocols for homogeneous WSNs based on a clustering method. The LEACH algorithm does not consider energy usage while selecting CHs; instead, it relies solely on a predetermined probability. In this research, we offer EEFL-CH, a new fuzzy logic-based technique for WSNs. The suggested approach aims to increase the network lifetime and reduce energy usage in WSNs. We focused on CHs selection procedure to achieve this goal of our proposed approach. The CHS is chosen using the EEFIS-CH technique, which considers residual energy, predicted efficiency, and the nodes' proximity to the BS. We infer from the simulation findings that the proposed EEFISCH is more energy-efficient and effective in optimizing the network lifetime of the entire network and achieving superior performance.

Compared to the LEACH and LEACH-ERE procedures in this regard. To select CHs, the suggested EEFL-CH method considered residual energy, predicted efficiency, and node proximity to the BS in this work. Because there are a variety of factors that can influence the network lifetime of WSNs, including cluster formation. A future objective for this research is to combine the proposed EEFL-CH with one of the fuzzy logic-based systems for CHs selection to lengthen the network lifetime and reduce total energy consumption.

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