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Fuzzy Rule-Based Clustering Algorithm for Energy Efficiency in WSN

Harish Thakur[1], Dr. Anita Ganpati[2]
[1]Research Scholar, [2]Professor, Dept of Computer Science, Himachal Pradesh University, Shimla, India

Abstract: Wireless Sensor Networks (WSNs) have gained much attention in public and research communities due to their incredible capabilities and ever-growing range of applications. The WSN is equipped with a specialized transducer that adds sensing services to IoT. This equipment is limited to battery and resource capacity, which introduces many challenges to academia and industry. Many recent wireless sensor networks (WSN) routing protocols are enhancements to address specific issues with the low-energy adaptive clustering hierarchy (LEACH) protocol. Low Energy Adaptive Clustering Hierarchy (LEACH) algorithm compensates for the energy flow in CH by probabilistically rotating the position between nodes with energy above the specified threshold. The selection of CH in WSN is NP-Hard as the optimal data aggregation with efficient energy efficiency cannot be resolved in polynomial time. Since the performance of LEACH deteriorates sharply with increasing network size, the challenge for new WSN protocols is to extend the network lifespan while maintaining high scalability. This paper introduces a fuzzy logic-based energy-efficient scalable routing algorithm (F-EESRA). The goal of the proposed algorithm is to extend the network lifespan despite an increase in network size. This paper compares F-EESRA against EESRA WSN routing protocol in terms of network performance. EESRA uses multi-hop transmissions for intra-cluster communications to implement the proposed work. The simulation results show that F-EESRA outperforms the fuzzy protocol in terms of energy efficiency on large-scale WSNs.
Keywords: Wireless sensor networks, Clustering, Routing, Energy efficiency, LEACH

I. INTRODUCTION

Wireless Sensor Networks (WSNs) have recently gained popularity due to their potential to improve life quality through monitoring, automation, and a few more applications. The WSN is made up of numerous tiny processors. Sensor nodes are the name for these tiny computers. Signal processing, routing protocols, data management, and other factors should be considered while developing, implementing, and operating a sensor network [1]. The four fundamental parts of a sensor network are an assembly of localized sensors, connectivity to another system, intelligence gathering at a hub, or data collection and mining capabilities. WSN stands out from other networks due to the features like a single sensor has limited resources. Also, nodes are not connected in advance; the only supposition is that each node will recognize its neighbor. Moreover, sensor nodes only forward data after sensing. There is no other regulation practiced.

The WSN is a communication network that detects information, gathers it from a specific region, and transmits it to the main area. A system needs to be capable, secure, user-friendly, and reliable. The WSN is useful for monitoring farms and forests, as well as for military purposes [2]. Applications for wireless sensor networks improve the environment. The fundamental layout of the wireless sensor network is shown in Figure 1. The Base Station and Sensor Network are the two primary elements of a WSN network. The sensor node can collect information & communicate via a network. The base station is usually believed to as simply a component that collects information from numerous nodes. To share knowledge, a WSN Application & BS are connected to the Web. Sensors are often placed randomly in a pre-determined region and broadcast the collected data via the internet to a BS in another location.

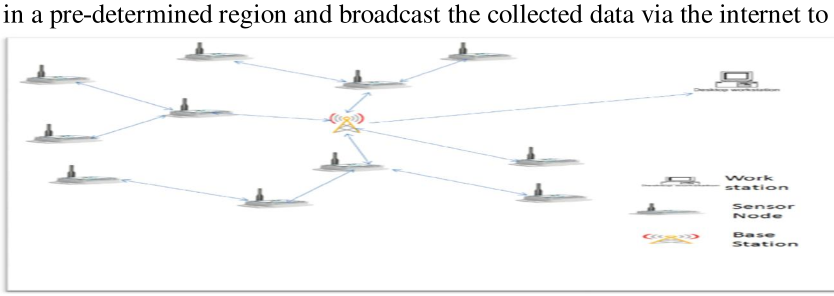

Figure 1: Arrangement of Wireless Sensor Network [3]

The rest of this article is structured as follows. Section II describes the Clustering and routing approach. Section III presents the Fuzzy logic. Section IV represents the literature survey. Section V shows the proposed Work. Section VI shows the results. Section VII gives the conclusion of the proposed work.

A. *Clustering & Routing*

The enormous number of nodes, low available data rates, and various resource constraints have limited the usability of generic ad-hoc routing protocols in WSNs. One of the methods by which we can enhance the lifespan of WSNs while minimizing energy consumption is clustering and routing the data to the base station.

B. *Clustering Protocols*

To maximize the network lifespan and overcome limited battery capacity, WSN clustering protocols tend to support resource awareness and adaptivity [4]. Clustering algorithms act as a communication protocol that groups the sensors and uses the least amount of energy. The nodes of the sensor are divided into clusters. Every cluster has one head of the cluster and also some members of nodes. Member nodes transmit their sensed data to their respective heads of clusters. CH collects, and aggregates all of the data and then transmits it to the BS. Each CH depreciates a high rate of energy compared with normal sensor nodes. When the distance between the node and BS is more clustering helps in saving energy, where the node forwards the data to either the cluster head (CH) or relay node without sending it directly to the Base Station. The data aggregation at CH before sending it to BS helps achieve data redundancy and improve network lifetime by handling congestion, avoiding long-distance communication, and making possible load balancing between the available routes towards the corresponding destinations.

Some of the clustering algorithms are LEACH, HEED, SEP, K-Means, Fuzzy C-Means, etc. Clustering may also aid in increasing system scalability. As a result of the use of cluster heads, the data-gathering process is enhanced, as well as the lifetime is increased as a result. However, because of the additional tasks that each CH must complete, their energy is depleted quicker than that of the neighboring sensors. When a cluster head's batteries run out, a replacement CH must be selected among the rest of the cluster's sensors to continue with the head's functions. The cluster heads might well be chosen at random or according to predetermined parameters such as residual energy, node distance, signal intensity, or connection [5].

C. *Routing Protocols*

Based on the network structure, WSN routing can be classified as flat-based routing, hierarchical-based routing, or location-based routing. A flat routing architecture allows sensor nodes to perform identical roles in the routing process. Flat-based routing frequently assigns comparable responsibilities or abilities to all nodes. Hence, all sensor nodes are set to forward the sensed packets directly to base stations. With hierarchical routing, though, network nodes can play a number of responsibilities. A hierarchal routing architecture segments the sensor nodes into clusters. Within a cluster, nodes are differentiated according to the tasks performed. In a typical two-layer hierarchy structure, low-level nodes (i.e. cluster members (CM)) are responsible for sensing data from the environment and forwarding the data to their respective cluster head (CH), while high-level nodes (i.e. cluster heads) are responsible for compressing and transmitting the gathered data to the base stations [6]. As a result, cluster heads can conserve energy by doing some data analysis and compression. In location-based routing, the positions of sensors are used to transmit data through the network. A scheduling algorithm is said to be adaptive if particular system properties can be altered to adjust to existing network conditions and available power levels. Furthermore, these methods can be categorized as multipath-based, query-based, negotiation-based, Quality of Service based, or coherent-dependent routing techniques, depending on how they operate. Routing techniques are categorized as proactive, reactive, or hybrid protocols, depending on how the origin determines a route to the destination [7].

D. *Fuzzy Logic*

The CH selection model can be formulated as a multi-objective optimization problem in general, such as a resource allocation problem with input data, necessary outputs, objective function optimization, as well as constraint satisfaction. Since every sensor in the network could be a CH, selecting one is a combinatorial challenge. Optimized cluster-based routing and Cluster Head selection methodology may assist in accomplishing Quality of Service requirements. However, optimizing the Cluster Head selection to achieve QoS-based energy efficiency is an NP-hard problem [8]. Yet, it can still be optimized through meta-heuristics techniques that include crucial factors for the selection of Cluster Head in constructing the fitness function. While forming so, the meta-heuristic method is applied to achieve an optimal solution on the grounds of its characteristics.

With further research on WSN, the researchers propose the Bio-inspired meta-heuristic algorithm to improve the energy efficiency and life cycle of WSN, such as ant colony optimization, particle swarm optimization, artificial bee colony optimization, Grey Wolf Optimizer (GWO), and fuzzy logic to name a few.

Fuzzy control is a technique for incorporating human-like thoughts into a control system. It is not intended to provide accurate reasoning, but it is intended to provide acceptable reasoning. It can mimic human deductive reasoning, which is the process by which people infer conclusions from what they know. With the help of fuzzy logic, any uncertainties can be easily dealt with [9]. Unlike classical or digital logic, which operates on discrete values of 0 or 1 (true or false), fuzzy logic control systems analyze analog input values in terms of logical variables with continuous values among 0 and 1. A generic fuzzy logic control has 3 phases: input, processing, and output. Figure 2 below shows the schematic representation of a generic fuzzy logic control system and its complete work.

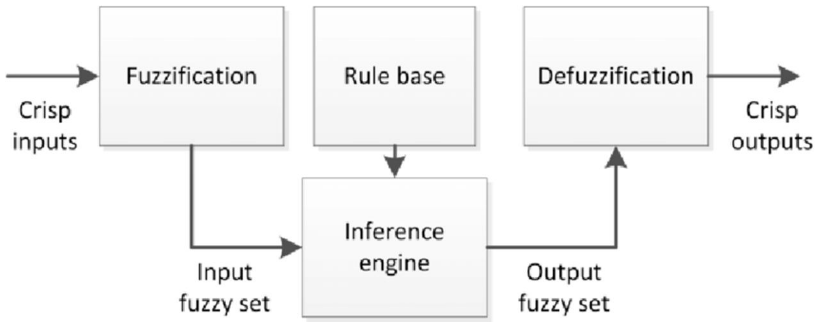

Figure 2: Fuzzy logic control system [10]

First, the crisp input data are transformed into fuzzy inputs by fuzzifier in the input stage using the defined fuzzy sets and associated membership functions. The fuzzy output signals are then inferred by the inference engine based on the fuzzy inputs in the processing step. The fuzzy outputs are then inferred by the inference engine in the processing stage using fuzzy inputs and linguistic rules from the fuzzy rule base. The fuzzy rule base is a collection of IF-THEN statements that the ore process knowledge of human operators. Finally, the defuzzifier generates crisp outputs by converting fuzzy outputs based on defined membership functions, which are used as control outputs.

II. LITERATURE SURVEY

Within this section, we will discuss previous work concerning the LEACH clustering protocol and EESRA routing protocol. Much has been achieved by the researchers to increase the energy efficiency of wireless sensor networks through the LEACH protocol and its variants.

Elsmany et al [11] proposed the scalable routing protocol is presented as an energy-efficient clustering and hierarchical routing algorithm. The suggested method's objective is to extend network life expectancy despite the increasing size of the network. The algorithm utilizes a 3-layer hierarchy to reduce CH load and randomize CH selection. Furthermore, to use hybrid WSN MAC protocol, EESRA employs multi-hop broadcasting for intra-cluster communications. This study examined EESRA and other WSN routing protocols in terms of network performance as network scale changes. The simulation findings demonstrate that EESRA outshines the benchmarked procedures on large-scale WSNs in aspects of load balancing and energy efficiency.

Veena et al [12] In this paper suggested a grey wolf optimization-based CH selection technique for WSNs that takes into account different factors such as node energy level, node degree, sink proximity, intra-cluster proximity, and priority aspect. This paper also addresses routing via QoS-aware transmitter node selection for effective and dependable inter-cluster routing from CHs to BS. The proposed technique is designed to simulate and evaluate using QoS parameters like remaining energy, stability period, throughput, a lifetime of the network, and delay. The proposed methods improve general network performance by 10.00%, 23.75%, and 54.54% for ESO, GECR, and LEACH, respectively. As a result, the study concludes that the protocol is well-suited for designing WSNs in IoT applications.

Deepika et al [13] in this paper suggests an efficient technique for selecting CHs in WSNs to increase network life expectancy. Grey wolf optimizer was used to complete this task. The general GWO has been altered in this paper to serve the defined objective of CH selection in WSNs. The suggested formulation's optimal solution takes into account the average intra-cluster length, sink proximity, remaining energy, and CH balancing component. Simulations are run under various conditions.

When the proposed protocol, i.e., GWO-C protocol, is compared to clustering protocols, results show the hat proposed procedure outperforms in terms of energy usage, throughput, and network longevity. The proposed protocol creates clusters that are both energy efficient and scalable.

Daneshmand et al [14] proposed concentrated on an efficient CH selection scheme that rotates CH location among greater energy nodes and others. In contrast to the LEACH protocol, Simulation analysis shows that the updated version outperforms, with a 60% advancement in output a and 64% increase in residual energy. More CH selection variables can be added by considering a network with mobile nodes that frequently change location. The developed framework can also be evaluated with different practical scenarios for a WSN-based IoT framework.

Pham et al. [15] in this paper suggest WSN has become widely used due to its importance in the Ithe of the era. They provide a network for encoding, transmission, and sharing of sensory data in a variety of IoT systems. Aside from their advantages, WSNs must overcome a number of challenges, such as network finiteness and insecurity to unforeseen natural conditions. LEACH is a common approach for elongating the network's presence by choosing a CH based on a probabilistic model. This paper proposes a modified LEACH clustering method to accommodate undefined network parameters.

Abdul Wasay et al [16] the proposed Implemented nodes are resource constrained, like electricity, storage resources, resources, and so on. A robust routing protocol is required to keep a long network. In this paper, researchers proposed a technique based on hybrid optimization methods for enhancing network life span and performance through a routing algorithm in energy-efficient IoT assistance. A new set of hybrid methods is adjusted to clustering and repositioned for distribution among SN using CH in the center position. An innovative method for extending grid life and reducing energy consumption is proposed. The proposed routing protocol takes into account residual energy in some nodes when determining the center location. The results of the simulation would be examined and compared to LEACH, LEACH-C, GEEC, and actual EECRP. The proposed scheme outperforms the current program.

Anurag Shukla et al. [17] The suggested efficiency of WSN in IoT is determined by the deployment method and protocol used to route the system. A scalable and Energy-Efficient Routing Protocol was presented. SEEP employs a multi-hop hierarchical routing algorithm to save energy. To accomplish a scalable and energy-efficient system, SEEP employs a multi-level clustering design. The proposed sub-area technique divides the network region in SEEP into various areas. Network size reduces to avoid communication over vast distances, and no. of places in the network increases. A reduction in region width boosts the number of groups towards BS, while a decline in area-wise each location reduces the number of clusters. Every group promotes the Relay Node and Cluster Head for some of the best nodes. BS receives multi-hop knowledge sensed via local RN and CH from standard nodes. To extend the network's life, the Suggestion Protocol also creates a link between distance and energy. To make the proposed implementation of random walking points and routes for mobile nodes in simulation more authentic for the basic application of WSN-based IoT, static and mobile circumstances were taken into account. SEEP has been tested for its effectiveness against LEACH, M-LEACH, EA-CRP, TDEEC, DEEC, SEP, and MIEEPB.

Lin et al [18] proposed the implemented a new energy-efficient clustering approach aimed at increasing WSN energy performance by minimizing and balancing its consumption. The authors proposed a lemma about the dual-CH mechanism for generating power overhead during CH rotation and an on-cooperative strategy for controlling energy usage among CH. With the suggested protocol, a non-cooperative match layout was presented with the goal of regulating energy usage towards CH, and now the Energy-efficient Clustering approach merged Game theory or Dual method was suggested, which took energy efficiency in both intra and inter-cluster interaction into consideration. Based on the reviewers, results show that ECGD can improve energy efficiency while also extending the device's life cycle.

Al-Mhiqani et al [19] proposed a three-section IEECP has been to prolong the life of WSN-based IoT. It is specifically motivated to find the best possible cluster set for overlapping balanced groups. The balanced-static clusters are formed by modifying the FCM algorithm and method for reducing and aligning SN's power usage. Finally, in ideal regions, CHs are selected by rotating the CH function between cluster members using an inventive CH selection-rotation approach that incorporates a back-off timing method for CH selection with a rotation method for CH rotation. The results show that IEECP outperforms current best practices.

III. RESEARCH METHODOLOGY

Existing work selects the cluster head based on LEACH. As per this, the nodes the randomly elected as cluster heads without considering their parameters. Such an approach can poorly elect the cluster heads. This will impact the lifetime of the network. Another drawback in existing work is related to the selection of cluster congregation nodes which are elected based on remaining energy only. This might elect the farther nodes as well which will consume more energy in the data transmission process.

To overcome these research gaps, The research work will focus on the optimal selection of cluster heads as existing work has elected the cluster heads randomly according to LEACH clustering protocol; such a random head selection process leads to the selection of unsuitable nodes for the role of cluster head. Therefore, in the proposed work the cluster heads will be selected using fuzzy rules. The parameters that will be used as input to the fuzzy box will be:

1) Remaining energy of the node
2) Distance from the base station
3) Distance from the neighboring nodes

The output of the fuzzy will be the optimal node that has higher values of remaining energy, and a lower distance from the base station as well as the neighboring nodes.

The next step is the formation of clusters by the cluster heads. In this process, the head nodes broadcast an advertisement packet to the nearby nodes. The nodes which receive the packet join the cluster head to which the distance is minimum. Once the clusters have been formed, the next step is the selection of cluster congregation nodes from the cluster members. For this process, the existing scheme focused on the residual energy of the nodes. The node having the highest residual energy has been elected as the cluster congregator node. These nodes will be selected according to their residual energy and their distance from the cluster members.

The last step is the data aggregation and data forwarding phase. In this phase, the first cluster congregator nodes will aggregate data from cluster members. This data will be forwarded to the cluster head. At this step, we will make use of the differential compression technique will be used to compress the data packet size. This compressed data will be then forwarded to the base station.

IV. RESULTS AND DISCUSSION

Both planned and actual work were simulated using MATLAB. The simulation made use of a 100-square-meter network with 100 randomly placed nodes. Four different scenarios were simulated using a network of 100 nodes that were dispersed randomly. The effectiveness of the network is analyzed using average Residual Energy usage, no. of alive and dead nodes, and throughput.

1) *A number of Alive Nodes:* This was used to compute the device's energy usage for each round. The suggested technique has [100,300, 500, 700, 900, 1100, 1300, 1500] rounds in total. With the rise in the number of rounds, the sensor node depletes its resources and ultimately dies. This gives a complete scenario for maximizing the network lifetime, which is fairly due to the assignment of different power levels for different modes of communication within the network.

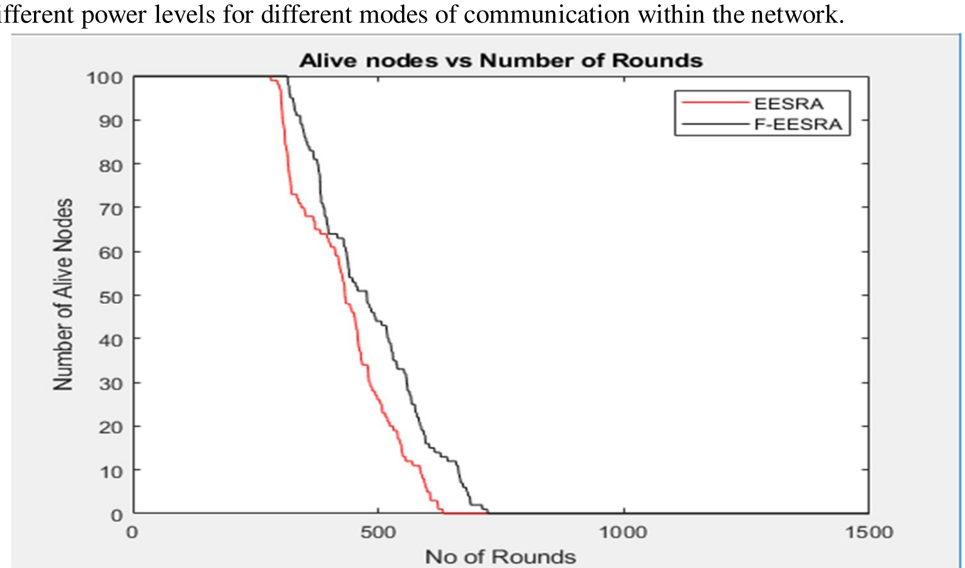

Figure 5.1: No. of Alive Nodes

Table 5.1: Comparison of Alive Nodes

Technique	Number of Rounds
EESRA	600
F-EESRA	700

Figure 5.1 demonstrate that for the existing work first node got dead immediately on the 600th round and for the proposed work first node got dead on the 700th round. So, it is clear that network stability is better in the proposed work because the cluster head is selected properly by using the proposed fuzzy rules approach.

2) *Number of Dead Nodes:* No. of dead nodes was used to calculate the device's energy consumption for each cycle. The suggested technique has [100,300, 500, 700, 900, 1100, 1300, 1500] round in total.

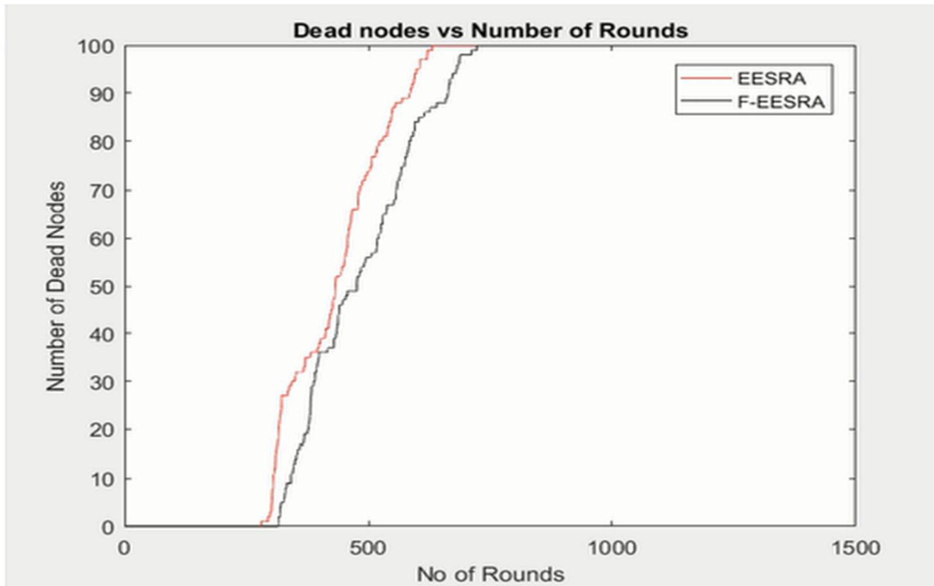

Figure 5.2: No. of Dead Nodes

Figure 5.2 demonstrates that for existing work network got dead on the 300th round and for proposed work network got dead on the 330th round. CH selection in the new scheme is based on the fuzzy rules approach in which the fitness function of the node is computed depending on the energy and distance of the node with respect to BS. So, it is clear that network lifetime is better in the proposed fuzzy rules-based approach than the existing one.

Table 5.2: Comparison of Dead Nodes

Technique	Number of Rounds
EESRA	300
F-EESRA	330

3) *Throughput:* The amount of successful data transfer in the network is referred to as throughput. The formula mentioned earlier is used in this situation to calculate throughput estimates:

$$\text{Throughput} = \frac{\text{Total No.of packets successfully transferred}}{Total\ Number\ of\ packets\ transferred}$$

The improvement in throughput is due to a decrease in the number of data transmission along the with secure substitution of CH that retains energy at a global level with dual control for different modes of transmission. Efficient efficiency gives better the algorithm.
From Fig 5.3, the throughput for a proposed F-EESRA algorithm increased the total number of packets successfully transferred is 4.8×10^4 which is more than the existing algorithm EESRA where packets transferred is 4.2×10^4 because if alive nonexistent in the network for a long period it provides better throughput.

Table 5.4 Comparison of Throughput

Technique	Number of Round
EESRA	$4.2*10^4$
F-EESRA	$4.8*10^4$

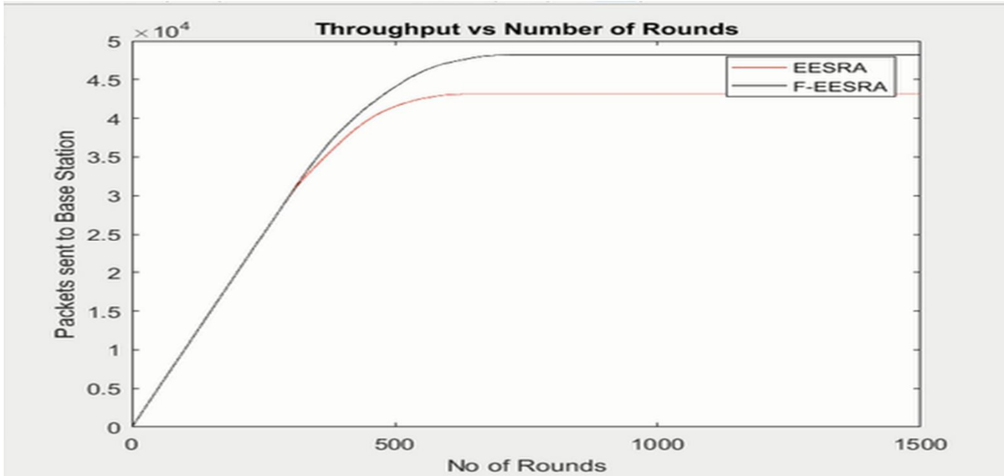

Figure 5.3: Throughput

4) *Average Residual Energy:* Energy is the primary resource used by WSN nodes, and this determines how long the network will last. Figure 5.4 shows that the average RE for the current EESRA approach is steeper than for the proposed method, indicating that steeper decreases indicate a higher rate of energy depletion.

Table 5.5 Comparison of Average Residual Energy

Technique	Number of Round
EESRA	600
F-EESRA	700

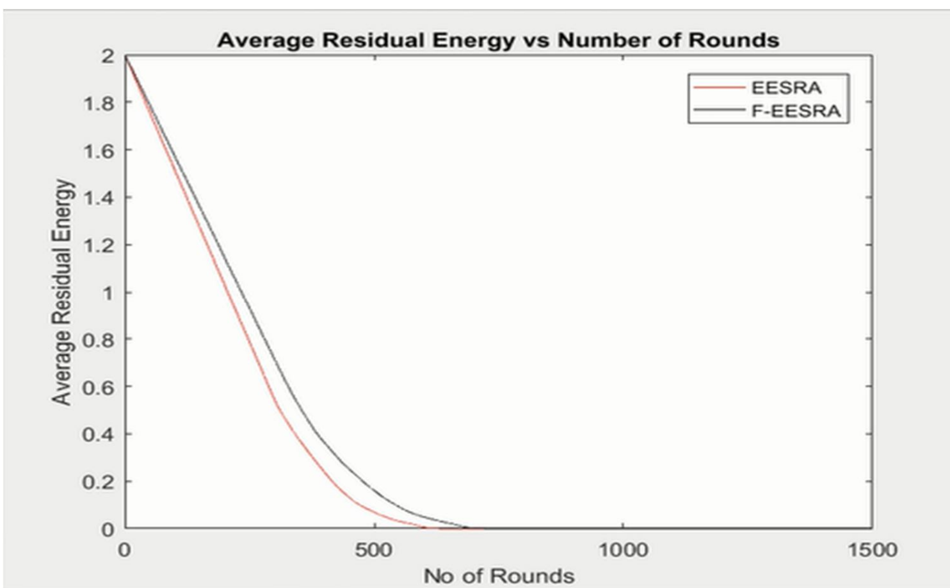

Figure 5.4: Average Residual Energy

Above mention tables clearly show that the proposed F-EESRA algorithm improves the values for all four parameters like Residual energy, throughput, no. of alive nodes, and dead nodes because the concept of a single path will not be used as it will increase load over the cluster heads forming the path. Additionally, the stress on the CH building the route is increased because only one route is used. The cluster heads will forward the data to the base station via the neighboring cluster head or directly to the base station as compared to existing techniques. Previously, the CH would either send data directly to BS or through another CH that was close by.

V. CONCLUSION

It is quite difficult to develop an energy-efficient WSN protocol. The cluster-based routing protocol is a unique method for improving the quality of a sensor network that aids in choosing CH and data transmission. In the proposed work, the relay cluster head that will transmit data to the base station is found using the fuzzy logic control system. The research looks at routing algorithms like EESRA and F-EESRA that prioritize the best CH selection. The ultimate goals of these algorithms are energy consumption reduction and network life optimization. In order to compare the two techniques' performance, a number of alive and nodes, network throughput, and average residual energy are taken into consideration. The proposed F-EESRA has greater throughput values and reserves more energy. We can conclude that the suggested plan is superior to the current approach. The suggested approach can also be assessed using a range of real-world WSN-based IoT scenarios.

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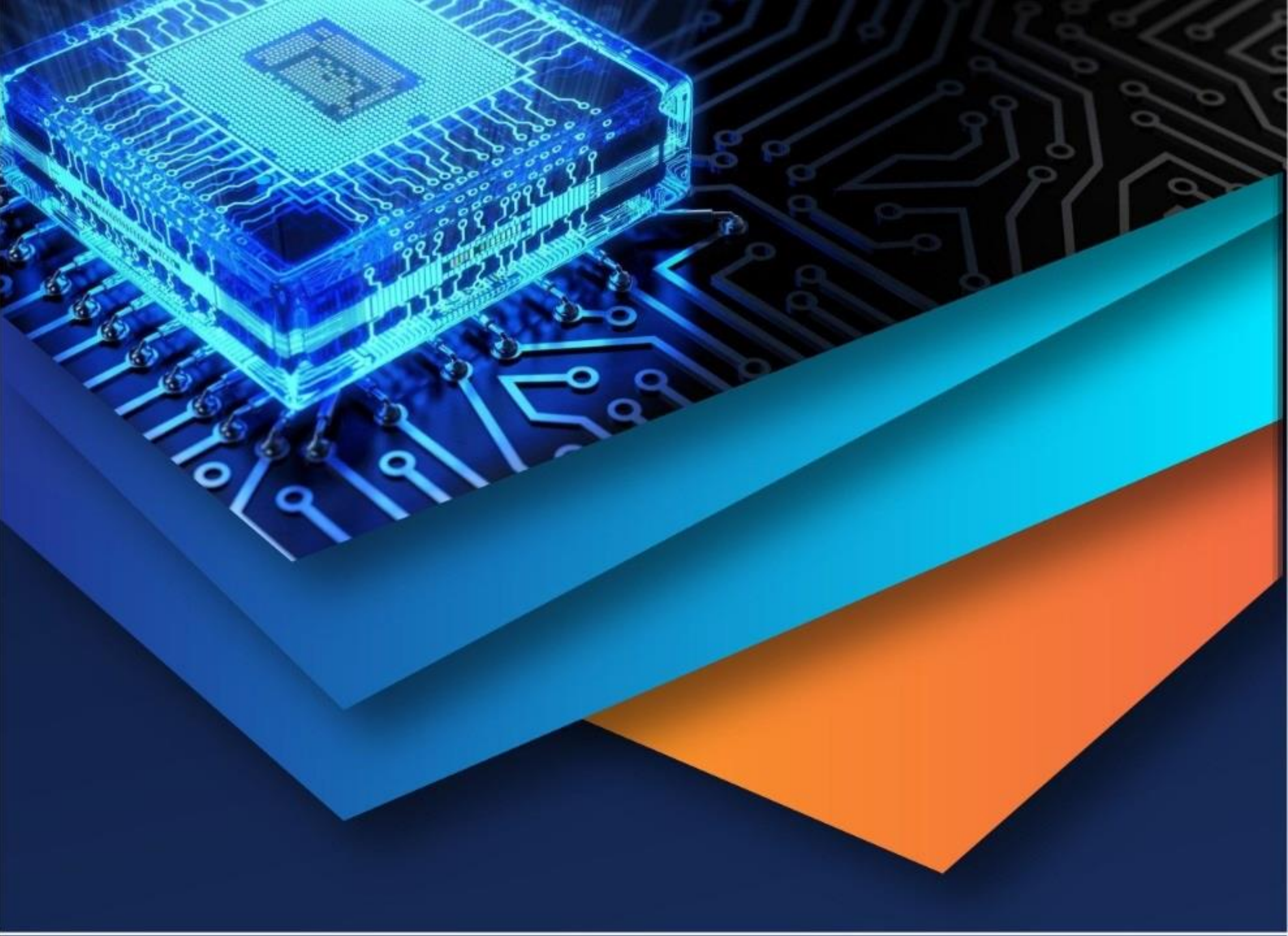

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