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Original Article

Energy-Efficient Adaptive Routing Algorithm Based on Fuzzy Inference System using Zone-Based Clustering of Wireless Sensor Network

Annie Sujith[1], Kamalesh V. N. [2], Srinivasa H. P [2], Suresh S. [3]

[1,2]*Department of CSE, T. John Institute of Technology, Karnataka, India*
[3]*Department of CSE, P. A. College of Engineering and Technology, Tamil Nadu, India*

[1]annie.jithu@gmail.com

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Abstract **-** *Sensor nodes in Wireless Sensor Networks (WSN) have limited resources. Therefore establishing an energy-efficient routing strategy is a major difficulty. For WSN, the suggested algorithm presents an energy-efficient adaptive routing strategy based on the Fuzzy Inference System (FIS) and zone-wise clustering (EEARZC). It introduces a new routing trust mechanism. Using a FIS to choose which Cluster Head to transmit from among the willing candidates, EEARZC discovers the best path to the Sink Node. Increased packet delivery rate, efficient energy utilization in nodes, and increased network lifetime are all benefits of EEARZC. The suggested technique is compared for several situations using metrics such as the first node dying, half of the nodes dying, the last node dying, the number of live nodes, total remaining energy, and the quantity of data received at Sink Node. Compared to previous techniques, simulation findings demonstrate that EEARZC provides greater performance.*

Keywords **-** *Routing, Energy efficiency, Fuzzy inference system, Zone, Fuzzy rules, Wireless sensor network.*

1. Introduction

Wireless Sensor Networks face energy restrictions as the sensor nodes have finite energy. Sensor Nodes plus a Sink Node make up a WSN. These nodes are mostly utilized in regions where human access is restricted. It can collect and evaluate data in adverse environments without the need for human interaction, which is useful for industrial applications [1], military applications [2], environmental research [3], etc. As a result, data availability and network longevity are important challenges that must be addressed. Environmental characteristics such as pressure, stress, humidity, vibration, and temperature are monitored by the nodes in a WSN. The sensor nodes can also keep track of a human's body vitals, such as blood pressure and pulse rate [4]. As a result, the types of sensors in the nodes are determined by the network's tasks. A Wireless Sensor Network may have thousands of nodes, each of which transmits data to the destination using a direct or multi-hop transmission. The intermediary nodes are utilized to transfer data to the destination multi-hop. Each sensor node can be a forwarder for transmitting data to a Sink Node. Traditional routing techniques are not relevant to WSN since assigning global ids to numerous nodes deployed in WSN is impossible [5]. WSN also has limited storage, energy, and processing resources. Sensor nodes that are in the proximity of the destination Node use more electricity. As a result, they ultimately deplete, resulting in a hot spot problem and a decrease in network longevity. The nodes are battery-operated, and mostly, the battery is not replaceable or rechargeable. Hence it is critical to build an energy-efficient routing method.

Much of the recent research in Wireless Sensor Networks has focused on finding strategies to reduce energy use. Numerous routing techniques have been created that attempt to conserve power and increase the lifespan of networks. The purpose of any routing method is to discover a path from a specific node or an event-producing node to the destination. It is difficult to build an appropriate routing system for a WSN since it is an application-oriented network with restricted resources. Researchers have developed some grid-based approaches in the past. For extending the network's lifetime, Logambigai et al. [6] presented a routing strategy that employs Grid-based uneven clustering and fuzzy logic. The Grid coordinator uses fuzzy rules in this technique to establish an efficient path to the destination by decreasing the number of hops. LPGCRA is a grid-based clustering and routing method proposed by Liu et al. [7]. This approach picks C.H. from nodes with the greatest remaining energy to avoid premature sensor node death. As a result, the hot spot issue is no longer an issue in LPGCRA. However, because the cluster member nodes are sometimes far from the chosen C.H. in this technique, more energy is consumed in transmitting their collected information to the C.H. Furthermore, the selected C.H.s send the collected data of their clusters directly to the destination, causing the C.H.s' energy to be rapidly depleted.

The Clustering Technique, frequently used in WSNs, is an energy-efficient way to increase scalability. The network is partitioned into numerous clusters using this method. One sensor is designated as the C.H. in each Cluster, with the remaining nodes forming its members. The sensor nodes keep an eye on their surroundings and communicate the information they gather to their C.H.s. After aggregation, the C.H. analyses the acquired data and sends it to the destination in a singular or multiple hop ways. The clustering technique allows for more efficient data collecting and aggregation, as well as a reduction in the amount of energy used to forward data to the destination node. This research provides an Adaptive Routing Algorithm for a WSN based on a FIS, which uses the Zone-Based Clustering Scheme [8] from our earlier work. To run, a fuzzy inference engine requires less processing power and resources. It offers an accurate result even if the supplied data is obscure, confusing, or imprecise. As a result, approaches based on fuzzy logic are suited for use in WSN sensor nodes with limited resources. Equal-sized zones are established in the network using the Zone-based clustering approach [8] presented in our earlier work. A Zone Monitor is assigned to each zone. After that, Cluster Heads are picked for each zone. The remaining sensor nodes in each zone create clusters by joining one of the zone's selected C.H.s as a cluster member. For improving energy utilization in sensor nodes in WSN, this clustering strategy uses unequal clustering in the sensing field and uniform clustering and uniform cluster head distribution inside a zone. The suggested routing algorithm's main goal is to discover the best way to deliver data to the Sink Node from these clusters.

The proposed Routing Algorithm 1 can be broken down into three parts:

Algorithm 1A: Sending the "RelayRequest" packet and reception of the response message "AcceptReq" from all the willing neighbour Cluster Heads.

(1) Whenever any Cluster Head wishes to transmit to the Sink the aggregated data of its Cluster, it sends a "RelayRequest" packet to all the neighbouring Cluster Heads.
(2) A neighbouring Cluster Head receiving the "RelayRequest" packet will send a response message "AcceptReq" only if it is willing to act as a relay device for this request.

Algorithm 1B: Using the Fuzzy Inference System for selecting one neighbouring Cluster Head for the Next hop.

(1) From amongst the willing neighbour Cluster Heads, the requesting Cluster Head will select one neighbour Cluster Head for relaying based on the output of the FIS.

Algorithm 1C: Using Zone Monitors as backup relay devices.

(1) If none of the neighbouring Cluster Heads respond, the C.H. will forward the data to its Zone Monitor. The Zone Monitor will forward this multi-hop data to the Sink Node using neighbouring Zone Monitors or Cluster Heads.

EEARZC introduces a new trust mechanism for WSN routing that reduces packet loss and retransmissions, resulting in energy savings in sensor nodes. It also assists in determining the optimum route to the Sink Node. The network's efficiency is improved by using Zone Monitors as backup relay devices. The benefits of EEARZC include a higher packet delivery rate, more efficient energy utilization, and a longer network lifetime.

The remaining paper is laid out as mentioned here: Section 2 summarises the literature review relevant to the suggested methodology. Section 3 describes the suggested algorithm. Section 4, the evaluation and comparison of EEARZC to other algorithms. Section 5 presents the conclusion and future enhancements.

2. Related Work

One of the first hierarchical routing algorithms was suggested by Heinzelman et al. [9], who introduced a Communication Protocol called LEACH that made efficient usage of power in sensor networks. A CH is randomly chosen depending on a probability, and surrounding sensors join the Cluster of the most near C.H. However, in this technique, more C.H.s may be selected than are required, resulting in increased energy usage. Furthermore, in LEACH, the elected C.H.s may not be evenly distributed throughout the network; as a result, a few nodes located further away from their C.H.s must broadcast data over a longer distance, resulting in increased energy consumption.

Mazumdar and Om [10] suggested a fuzzy logic-dependent distributed uneven clustering method called DFCR. The clustering method creates groups of varying sizes for the hot spot problem. The radius of each Cluster is deduced by utilizing a fuzzy logic technique. The C.H.s are chosen depending on the nodes' space, destination, and energy. A virtual network is formed for connection with the Base Station, with C.H.s passing their collected information to the Base Station through other C.H.s. A cost function is used to choose the routing path, which greatly increases the path's cost if the next node's residual power is low, compelling it to pick another route with a node with more residual energy.

Al-Kiyumi et al. [11] introduced a Fuzzy Logic dependant energy-aware distributed routing system that employs the shortest path with the lowest cost function. This method employs fuzzy logic during network routing to calculate the probability of a relay. The input variables for the fuzzy logic are the energy needed for transmission and the energy drained rate.
For implementing distributed unequal clustering in WSNs, Hamidzadeh et al. [12] developed an uneven cluster-radius technique dependent on node density. The cluster radius, which determines whether WSN clustering is equal or unequal, can be fixed or variable. It is divided into two phases: the election of C.H.s and the joining of Members. The member-join phase is based on an evaluation function,

and the Cluster Heads are determined using a global and local search.

Balakrishnan et al. [13] created FLECH, a hierarchical clustering approach based on fuzzy logic that selects the cluster head using criteria including its remaining power, spacing from the Sink Node, and node centrality. The strength of this algorithm is that it uses a weighted and probabilistic technique to determine cluster heads. On the other hand, this technique performs clustering in each round, resulting in faster energy depletion in sensor nodes.
Huang et al. [14] presented a multi-hop and grid-based method to lower the energy burden surrounding Sink Node and balance energy consumption. For the election process of nodes, this algorithm considers aspects such as node residual energy, location of the node, and network area levels. The Cluster Heads' workload is also lowered by introducing communication nodes that elect C.H.s and transport data among clusters using multi-hop routing.

Agrawal et al. [15] presented an unequal clustering strategy based on FUCA's fuzzy logic to increase the network's lifetime. In this approach, selecting C.H.s is based on the remaining power of nodes, their distance from the Sink, and node density. Rank and competition radius are the two fuzzy output variables. The disadvantage of the system is that the nodes far from the Base Station use more energy due to single-hop transmission. Another disadvantage is the random selection of primary Cluster Heads.

Tamandani et al. [16] introduced a routing scheme dependent on fuzzy logic. The space between nodes and the Sink, battery level of nodes, and density of nodes are the fuzzy input variables utilized, in addition to the typical threshold values used in SEP. These extra fuzzy input variables are utilized to improve the SEP protocol's existing Cluster Head election process and the network's throughput and longevity.

Hassan et al. [17] suggested a zone-based clustering method for reducing transmission distances between communicating nodes within and outside the Cluster. A CH is chosen from a zone by comparing the remaining energies of the zone's sensor nodes. Restricting the space between Cluster Head and its members decreases energy waste in sensor nodes.

Tanwar et al. [18] presented a heterogeneous and multiple-level pathfinding strategy for WSNs, efficiently using power. All nodes are classified as normal or advanced depending on their residual energy. Cluster Heads are chosen based on weighted probability to avoid energy holes in this method. The network longevity and stability improved as a result of the simulations.
The routing algorithm proposed by Z.A. Khan et al. [19] divides a sensing area into rectangular clusters. After that, the clusters are put together to form zones. The method determines the most efficient number of C.H.s in the sensing area for data transfer between C.H.s and the Base station.

A. M. Ortiz et al. [20] devised a routing method that uses energy effectively in nodes and uniform load balancing to extend the network's lifetime. This approach assigns roles based on fuzzy logic during route creation and maintenance.

EAFCA is an energy-aware fuzzy clustering technique suggested by Akila et al. [21]. A Cluster Head is chosen in a cluster using this approach, which considers node residual energy, competing for node 2-hop coverage, and mean distance to 1-hop neighbours. While the competition radius is two hops, EAFCA leverages multi-hop data transfer to the C.H. inside each Cluster. However, in this method, clustering is done in each cycle, reducing the network's lifetime and increasing the number of control messages sent between nodes. The selected Cluster Head sends the aggregated data from all its cluster members to the Base Station.

Manjeshwar et al. [22] suggested a routing algorithm called TEEN in which the collected information is not sent often to the Sink, although the sensing function occurs continually. TEEN reduces communications as compared to LEACH. However, it is not ideal for applications that need regular updates.

To lower transmission costs, Heinzelman et al. [23] and Latiff et al. [24] proposed a scheme that reduced the spacing of nodes within clusters. For effective packet transmissions, Rahmanian et al. [25] reduced the spacing of nodes within clusters and the spacing between C.H. to Sink.

Despite the recent WSN research, establishing a more energy-efficient routing technique remains a major difficulty. As a result, this study proposes an Adaptive Routing Algorithm that aids in efficiently using energy in nodes while extending the network's lifetime.

3. Materials and Methods

The proposed power-efficient adaptive routing algorithm that uses FIS is explained in this section. It is based on our prior work on the underlying Wireless Sensor Network and leverages the Zone-Based Clustering technique [8]. Consider a 400 X 400 m2 field divided into 100 X 100 m2 zones, as shown in Figure 1. A Zone Monitor and Cluster Heads are chosen inside each zone, and clusters are formed using the Zone-based clustering algorithm [8]. The suggested routing algorithm's main goal is to discover the best way to deliver data from these clusters to the Sink Node.

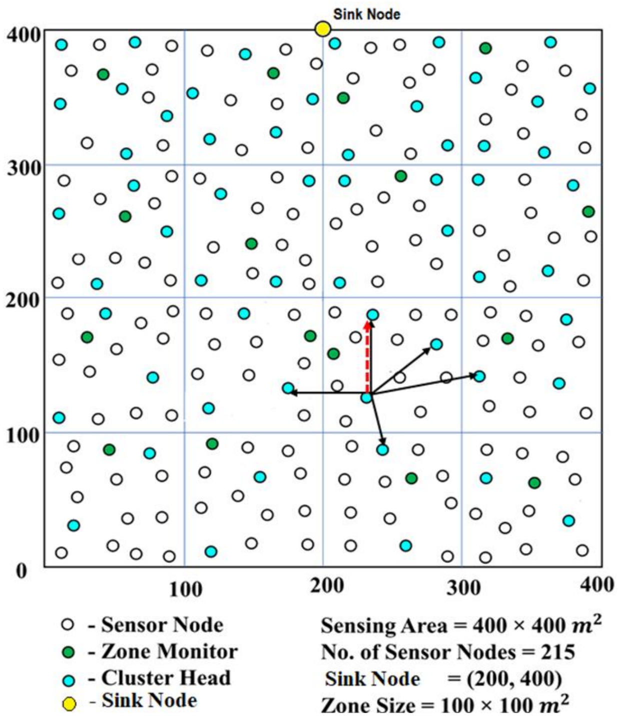

Fig. 1 "RelayRequest" packet sent by a Cluster Head to all neighbouring CHs

The assumptions in the suggested work are as given below:

1. The nodes are deployed in an x×x region.
2. The sensors and the Sink are stationary.
3. The Sink is present outside, at the edge of the sensing field.
4. The Sink and the sensor nodes are location-aware.
5. Each sensor node has bidirectional communication links with the neighboring sensor nodes.
6. The sensing region's size must be specified beforehand.
7. The Sink Node's location coordinates must be provided initially.
8. Sensor Nodes use power control to adjust their transmission power.

The workflow of the suggested Routing Algorithm 1 is depicted in Figure 2. The suggested Algorithm 1 can be broken down into three parts. Let us see each part in detail.

3.1. Algorithm 1A: Sending the "Relayrequest" packet and reception of the response message "Acceptreq."

All nodes in a Wireless Sensor Network may not be cooperative or trustworthy. When data packets are sent to such non-cooperative nodes, packets are dropped, and packet retransmissions are required, wasting energy in sensor nodes. Various routing techniques have been suggested in the past that employ variables like nearby node remaining power, the number of hops to reach the Sink, and so on to select the next node for relaying the message. An adjacent node with a good amount of remaining energy and the quickest path to the Sink Node may not always be the best next node for relaying the data. Due to receiving data from other cluster heads, it may already be overburdened. Assume the Cluster Head sends data to a neighbouring node that refuses to operate as a relay. Owing to excessive traffic, there may be a considerable delay in passing the information to the next-hop node, or packets may be missed due to buffer overflow, resulting in energy waste in the sensor nodes. In the Zone-Based Clustering method [8], Cluster Heads with half of their residual energy exhausted will stop operating as a relay device after sending a 'NoRelay' notification message to their Zone Monitor. They will, however, continue to serve as Cluster Heads, gathering and delivering data for their Cluster. These Cluster Heads are refusing to relay data packets to the Sink Node. Other considerations to consider while choosing the next node include bandwidth availability, congestion state, and willingness to operate as a relay device. The suggested Routing Algorithm determines the best next node for relaying from among the adjacent Cluster Heads.

The following Algorithm 1A presents the first part of the proposed Routing Algorithm 1.

Algorithm 1A

Step 1: Anytime a C.H. wishes to transfer the data of its Cluster to the Sink, it sends a "RelayRequest" message to all the neighbouring Cluster Heads.

Step 2: A neighbouring Cluster Head receiving the "RelayRequest" packet will send back a response message "AcceptReq" only if it is willing to act as a relay device for this request.

Step 3: The response message "AcceptReq" from a willing Cluster Head will contain the following information about the C.H. itself:

- Residual Energy
- Distance from the Sink Node.
- Its location coordinates
- Capability Factor

Step 4: The requesting Cluster Head might receive response messages from multiple neighbouring Cluster Heads.

Step 5: One neighbour, C.H., is selected for the relay of packets from amongst the candidates based on the output of the FIS given by Algorithm 1 B.

Step 6: The requesting Cluster Head will send the aggregate data to this selected neighbouring C.H. for the Next-hop.

The data is routed through the first routing algorithm until it reaches the Sink. If a C.H. wants to relay the collected information from its Cluster to a Sink in the proposed system, it must first send a "RelayRequest" packet to all of its adjacent Cluster Heads, as shown in Figure 1. Only cooperative nodes will send an "AcceptReq" response message, including information about the Cluster Head, such as its remaining power, space from the Sink Node, position coordinates, and Capability Factor. A Cluster Head's Capability Factor is a quantity between zero and one. Candidate C.H. sends this number based on the conditions it is experiencing, such as traffic volume, available bandwidth, and congestion state. Using the Capability Factor as one of the FIS's fuzzy inputs aids in making good routing decisions.

E.g.,
(1) If a Cluster Head has a low value for Capability Factor as 0.2, it indicates that it is not a good choice for selecting a Relay device as it already has congestion and low bandwidth availability whereas
(2) A Cluster Head with a Capability Factor of 0.9 is a good choice and can forward the data without delay.

3.2. Algorithm 1B: Selecting the Next Hop Node for relaying data using the Fuzzy Inference System

The suggested Routing Algorithm uses a Fuzzy Inference System to pick which Cluster Head to select for relaying as the Next Hop Cluster Head from among the nearby candidate's Cluster Heads, resulting in an optimal routing to the Base Station. The red dashed line in Figure 1 represents data transfer to the specified Next Hop Cluster Head.

The following Algorithm 1B presents the second part of the proposed Routing Algorithm 1.

Algorithm 1B
Step 1: For selecting one neighbor node from amongst the candidates, the following four Fuzzy Inputs are given to the inference system for each candidate node:

- The remaining energy of the candidate node
- Distance of the candidate from Sink
- Distance of requesting node to the candidate node.
- Candidate node's Capability Factor

Step 2: The output of the FIS is the choice of the Next Hop node for relaying the data.

The candidate node's remaining energy, its distance from the Sink Node, the distance of requesting node to the candidate node, and the candidate node's Capability Factor are the four Fuzzy Inputs offered to this inference system. The Fuzzy Inference System's output is the selection of a selected nearby node for relaying data from the candidates. Table 1 displays the range of fuzzy input for the sensing field depicted in Figure 1.

Table 1. Fuzzy input and corresponding ranges

Fuzzy Input Variable	Input Range	Fuzzy Variable
Residual Power of candidate nodes	0.0 – 0.2 0.1 – 0.4 0.3 – 0.6 0.5 – 0.8 0.7 – 1.0	Low Medium Low Adequate Medium-High High
Distance of candidate node from Sink Node	0 – 80 40 – 160 120 – 240 200 – 320 Greater than 280	Short Medium Short Medium Medium Large Large
Distance of requesting node to the candidate node	0 – 40 20 – 80 60 – 120 100 – 160 Greater than 140	Closer Medium Closer Medium Medium Distant Distant
Candidate node's Capability Factor	0.0 – 0.2 0.1 – 0.4 0.3 – 0.6 0.5 – 0.8 0.7 – 1.0	Low Average Low Average Average More More

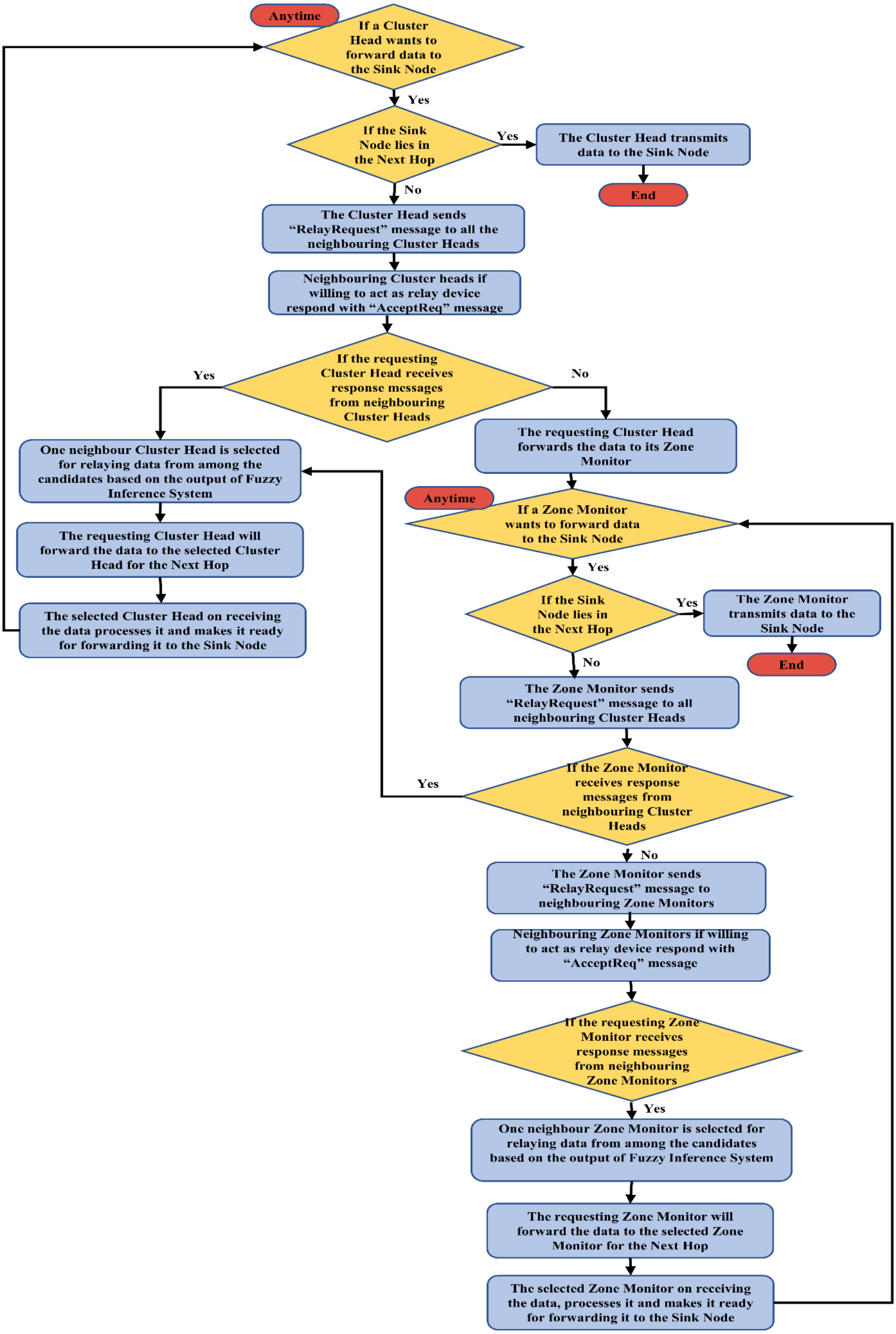

Fig. 2 Workflow of the proposed Routing Algorithm 1

The fuzzy input variables and their language counterparts utilized to determine the Next Hop node are shown below:

(1) The residual energy of candidate node – (Low, Medium Low, Adequate, Medium High, High)
(2) Distance of candidate node from Sink Node – (Short, Medium Short, Medium, Medium-Large, Large)
(3) Distance of requesting node to the candidate node – (Closer, Medium Closer, Medium, Medium Distant, Distant)
(4) Candidate node's Capability Factor – (Low, Average Low, Average, Average More, More)

The triangle membership function is employed for intermediate fuzzy values, whereas the trapezoidal membership function is used for fuzzy boundary values.

The variable, Residual Power of the candidate nodes and the corresponding linguistic values utilized are seen in Figure 3. In this set, the values used are Low, Medium Low, Adequate, Medium High, and High.

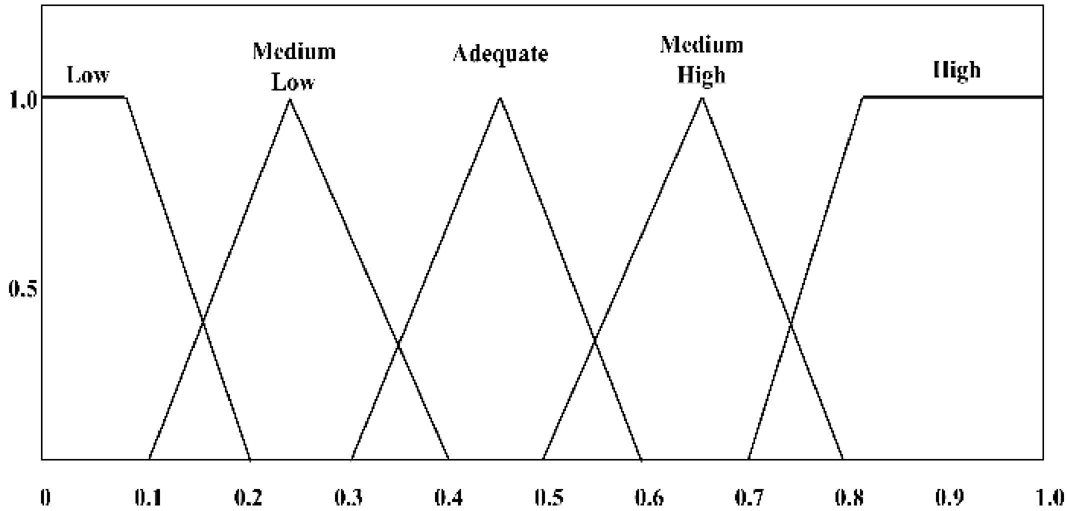

Fig. 3 Fuzzy Set for the input Residual Power of candidate nodes

The variable, distance of the candidates from the Sink, and the corresponding linguistic values utilized are shown in Figure 4. In this set, the values used are Short, Medium Short, Medium, Medium-Large, and Large.

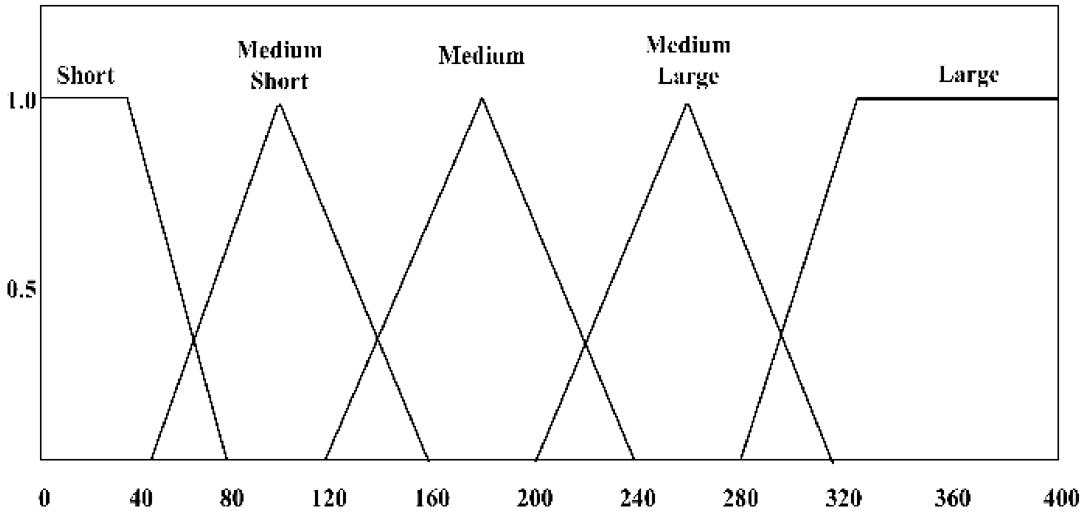

Fig. 4 Fuzzy Set for the input Distance of candidate nodes from Sink

The variable, distance of requesting node and candidate node, and the corresponding linguistic values utilized are seen in Figure 5. In this set, the values used are Closer, Medium Closer, Medium, Medium Distant, and Distant.

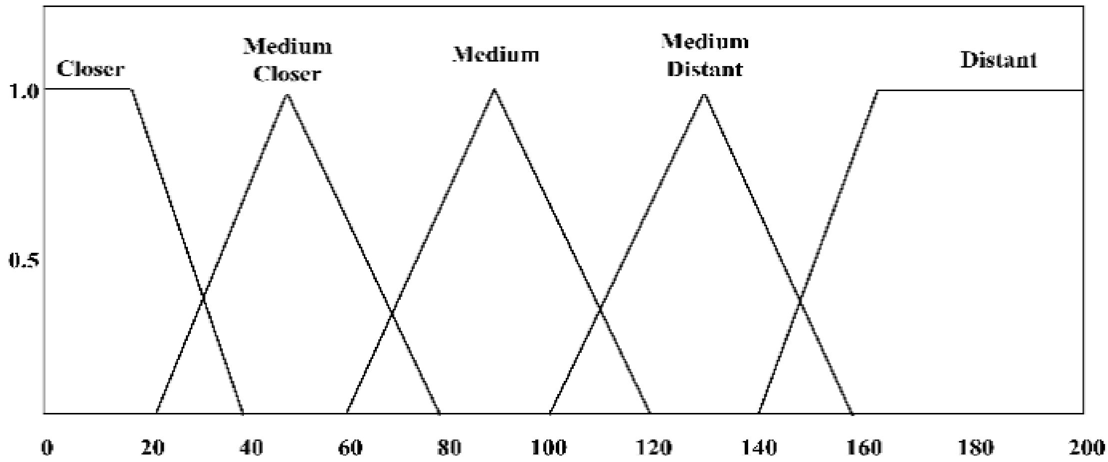

Fig. 5 Fuzzy Set for the input Distance of requesting node and candidate node

The variable, the Candidate node's Capability Factor, and the corresponding linguistic values utilized are seen in Figure 6. In this fuzzy set, the values used are Low, Average Low, Average, Average More, and More.

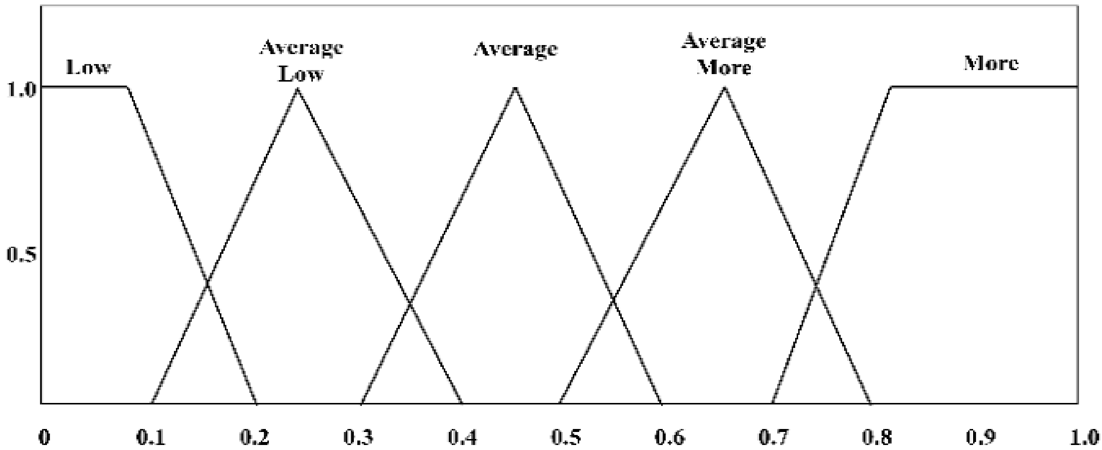

Fig. 6 Fuzzy Set for the input Candidate node's Capability Factor

The variable, NextHopNode_Choice, and the corresponding values utilized are seen in Figure 7. For the output variable NextHopNode_Choice the values used are Most Likely, More Likely, Likely, Medium Likely, Medium Lesser Likely, Less Likely, Lesser Likely, and Least Likely.

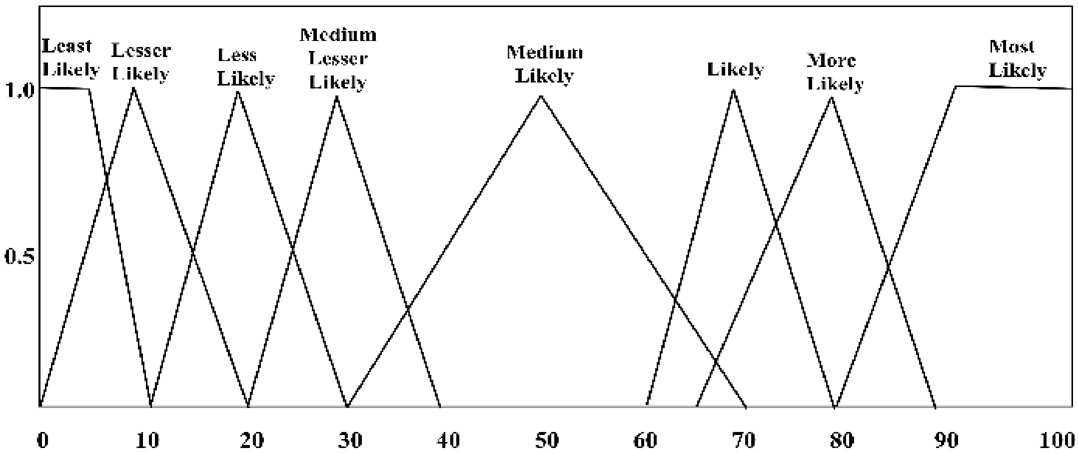

Fig. 7 Fuzzy Set for the output NextHopNode_Choice

In the suggested approach, the Mamdani inferencing technique is employed for fuzzy logic, and the COA technique is employed for defuzzification. This defuzzification technique gives a crisp value as output. Table 2 shows the fuzzy criteria for the Next Hop CH Choice.

Table 2. Fuzzy rules for Next Hop CH Choice

CH Current Energy	Dist. Between CH and Sink	Dist. Between requesting CH & Candidate CH	CH Capability Factor	Next Hop CH Choice
Less	Distant	Distant	Low	Least Likely
Less	Distant	Distant	Average	Least Likely
Less	Distant	Distant	High	Lesser Likely
Less	Distant	Medium	Low	Least Likely
Less	Distant	Medium	Average	Less Likely
Less	Distant	Medium	High	Less Likely
Less	Distant	Close	Low	Lesser Likely
Less	Distant	Close	Average	Less Likely
Less	Distant	Close	High	Less Likely
Less	Medium	Distant	Low	Least Likely
Less	Medium	Distant	Average	Least Likely
Less	Medium	Distant	High	Less Likely
Less	Medium	Medium	Low	Lesser Likely
Less	Medium	Medium	Average	Lesser Likely
Less	Medium	Medium	High	Less Likely
Less	Medium	Close	Low	Less Likely
Less	Medium	Close	Average	Less Likely
Less	Medium	Close	High	Less Likely
Less	Close	Distant	Low	Lesser Likely
Less	Close	Distant	Average	Lesser Likely
Less	Close	Distant	High	Less Likely
Less	Close	Medium	Low	Lesser Likely
Less	Close	Medium	Average	Less Likely
Less	Close	Medium	High	Less Likely
Less	Close	Close	Low	Lesser Likely
Less	Close	Close	Average	Likely
Less	Close	Close	High	Likely
Medium	Distant	Distant	Low	Least Likely
Medium	Distant	Distant	Average	Lesser Likely
Medium	Distant	Distant	High	Lesser Likely
Medium	Distant	Medium	Low	Lesser Likely
Medium	Distant	Medium	Average	Likely
Medium	Distant	Medium	High	Likely
Medium	Distant	Close	Low	Likely
Medium	Distant	Close	Average	More Likely
Medium	Distant	Close	High	More Likely
Medium	Medium	Distant	Low	Lesser Likely
Medium	Medium	Distant	Average	Medium Lesser Likely
Medium	Medium	Distant	High	Medium Likely
Medium	Medium	Medium	Low	Medium Likely

Medium	Medium	Medium	Average	More Likely
Medium	Medium	Medium	High	More Likely
Medium	Medium	Close	Low	Likely
Medium	Medium	Close	Average	More Likely
Medium	Medium	Close	High	More Likely
Medium	Close	Distant	Low	Lesser Likely
Medium	Close	Distant	Average	Lesser Likely
Medium	Close	Distant	High	Medium Likely
Medium	Close	Medium	Low	Medium Lesser Likely
Medium	Close	Medium	Average	Medium Likely
Medium	Close	Medium	High	More Likely
Medium	Close	Close	Low	Medium Likely
Medium	Close	Close	Average	More Likely
Medium	Close	Close	High	Most Likely
High	Distant	Distant	Low	Least Likely
High	Distant	Distant	Average	Lesser Likely
High	Distant	Distant	High	Less Likely
High	Distant	Medium	Low	Lesser Likely
High	Distant	Medium	Average	Likely
High	Distant	Medium	High	Likely
High	Distant	Close	Low	Medium Lesser Likely
High	Distant	Close	Average	More Likely
High	Distant	Close	High	Most Likely
High	Medium	Distant	Low	Lesser Likely
High	Medium	Distant	Average	Lesser Likely
High	Medium	Distant	High	Medium Lesser Likely
High	Medium	Medium	Low	Medium Lesser Likely
High	Medium	Medium	Average	Likely
High	Medium	Medium	High	More Likely
High	Medium	Close	Low	Likely
High	Medium	Close	Average	More Likely
High	Medium	Close	High	Most Likely
High	Close	Distant	Low	Least Likely
High	Close	Distant	Average	Lesser Likely
High	Close	Distant	High	Less Likely
High	Close	Medium	Low	Lesser Likely
High	Close	Medium	Average	More Likely
High	Close	Medium	High	Most Likely
High	Close	Close	Low	More Likely
High	Close	Close	Average	Most Likely
High	Close	Close	High	Most Likely

3.3. Algorithm 1C: Using Zone Monitors as backup relay devices

If the requesting Cluster Head does not get a response message "AcceptReq" from any of the neighbouring Cluster Heads, its Zone Monitor will act as a backup relay device. This circumstance could arise, for example, if the network is currently experiencing excessive traffic due to an event. Data packets are less likely to be dropped when the Zone Monitor, which is present in each zone, is used as a backup relay device. Another situation is when the network is entering its dying stage, and many sensor nodes are dead. The Zone Monitors also pitch in and help relay data when the network is stressed to maximize usage of the remaining available resources and extend network lifetime. Thus, using the Zone Monitors as backup relay devices improve network efficiency, saves energy in nodes by minimizing packet drops and retransmissions, and extends network lifetime.

The following Algorithm 1C presents the third part of the proposed Routing Algorithm 1.

Algorithm 1C

Step 1: If the requesting Cluster Head does not get a response message "AcceptReq" from any neighboring Cluster Heads, it will forward the data to its Zone Monitor for relaying.

Step 2: Anytime a Zone Monitor receives data for forwarding it to the Sink node, the Zone Monitor will first try to forward this data through the neighboring Cluster Heads by sending a "RelayRequest" packet to them.

Step 3: A neighboring Cluster Head receiving the "RelayRequest" packet will send back a response message "AcceptReq" only if it is willing to act as a relay device for this request.

Step 4: The requesting Zone Monitor might receive response messages from multiple neighboring Cluster Heads.

Step 5: One neighbor, C.H., is selected for relaying from amongst the candidates based on the output of the FIS given by Algorithm 1 B.

Step 6: If none of the neighboring Cluster Heads are responding, the Zone Monitor will forward the data using adjacent Zone Monitors by sending a "RelayRequest" message.

Step 7: A neighboring Zone Monitor receiving the "RelayRequest" message will send back a response message "AcceptReq" only if it is willing to act as a relay device for this request.

Step 8: The requesting Zone Monitor might receive response messages from multiple neighboring Zone Monitors.

Step 9: One neighbor Zone Monitor is selected for the relay of data from amongst the candidates based on the output of the FIS given by Algorithm 1B.

Step 10: The requesting Zone Monitor will forward the aggregate data to this selected neighboring Zone Monitor for the Next-hop.

4. Results and Discussion

The suggested approach, EEARZC, is simulated using Matlab. Experiments are conducted for various densities with the nodes dispersed randomly and uniformly in a 400 X 400 m2 area. To compare EEARZC to existing approaches, the measures of cumulative energy usage and network longevity are used. Table 3 lists the network simulation parameters.

Table 3. Network Simulation Parameters

Parameters	Values
Area	400 X 400 m^2
Sensor Nodes	150 - 350
Location of Sink Node	(200, 400) m
Nodes' Initial Energy	1.0 J
Eelec	50 nJ/bit
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
Packet Size	4000 bits

Figure 8 shows an area of 400 × 400 m^2. The sensing area of 400 X 400 m^2 is divided into 100 x 100 m^2 zones of equal size. The Sink Node's location coordinates at the sensing area's edge are (200 × 400) m.

The proposed EEARZC algorithm is compared against DFCR [10], DEFL [11], and LEACH [9]. The experiment is repeated more than 2000 times in each run. EEARZC outperforms the other algorithms in the comparison, according to the results. It is evaluated at network densities of 150 and 250 to demonstrate and validate the proposed work's behavior. Figure 9–12 compares the achieved average lifetime of EEARZC with LEACH, DEFL, and DFCR. These graphs show that EEARZC has a longer average network lifetime for various network densities.

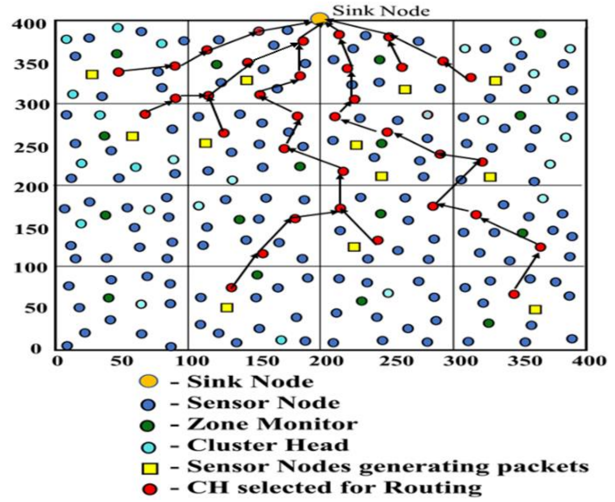

Fig. 8 Simulation of proposed Routing algorithm using Zone-Based Clustering

Figure 9 shows that for a network with 150 nodes, in terms of the FND metric, EEARZC performs better than DFCR by about 54%, DEFL by nearly 142%, and LEACH by almost 466%. Also, for a network with 250 nodes, in terms of the FND metric, EEARZC performs better than DFCR by about 46%, DEFL by almost 123%, and LEACH by nearly 533%. Similarly, for a network with 350 nodes, in terms of the FND metric, EEARZC performs better than DFCR by about 50%, DEFL by almost 136%, and LEACH by nearly 542%.

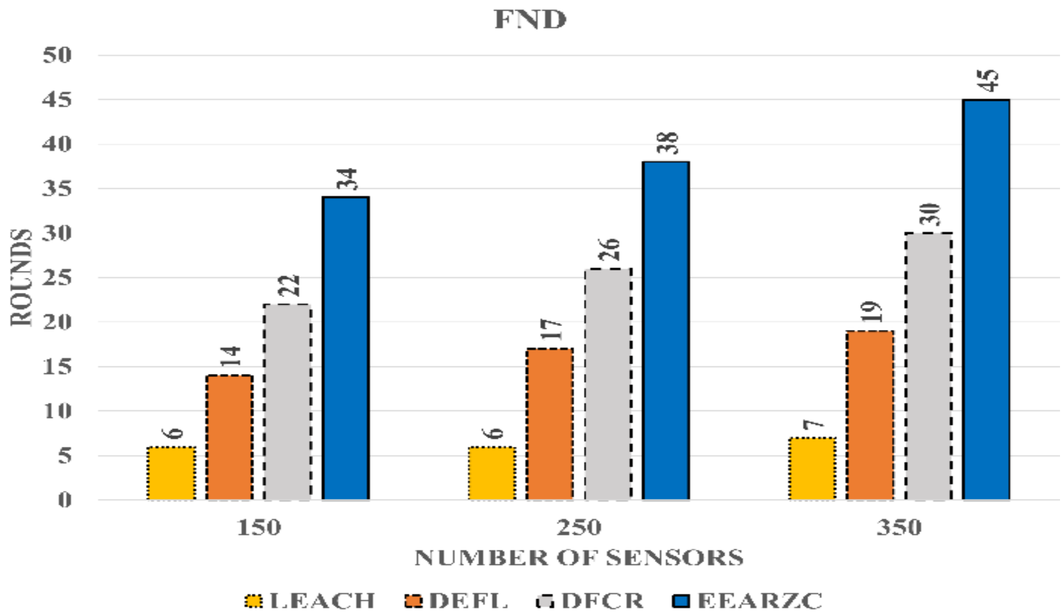

Fig. 9 Comparison of First Node Dies (FND)

Figure 10 shows that for a network with 150 nodes, in terms of the HND metric, EEARZC performs better than DFCR by about 80%, DEFL by nearly 217%, and LEACH by almost 728%. Also, for a network with 250 nodes, in terms of the HND metric, EEARZC performs better than DFCR by about 80%, DEFL by almost 223%, and LEACH by nearly 783%. Similarly, for a network with 350 nodes, in terms of the HND metric, EEARZC performs better than DFCR by about 82%, DEFL by nearly 169%, and LEACH by almost 767%.

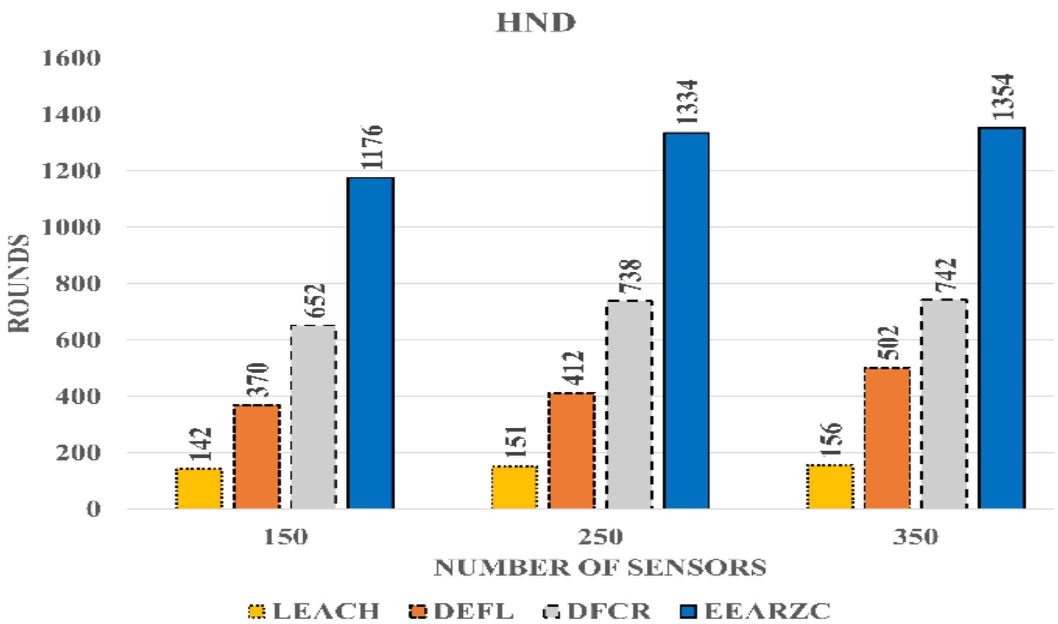

Fig. 10 Comparison of Half Nodes Die (HND)

Figure 11 shows that for a network with 150 nodes, in terms of the LND metric, EEARZC performs better than DFCR by about 10%, DEFL by about 34%, and LEACH by about 78%. Also, for a network with 250 nodes, in terms of the LND metric, EEARZC performs better than DFCR by about 19%, LEACH by about 77%, and DEFL by about 33%. Similarly, for a network with 350 nodes, in terms of the LND metric, EEARZC performs better than DFCR by about 19%, DEFL by about 34%, and LEACH by about 79%.

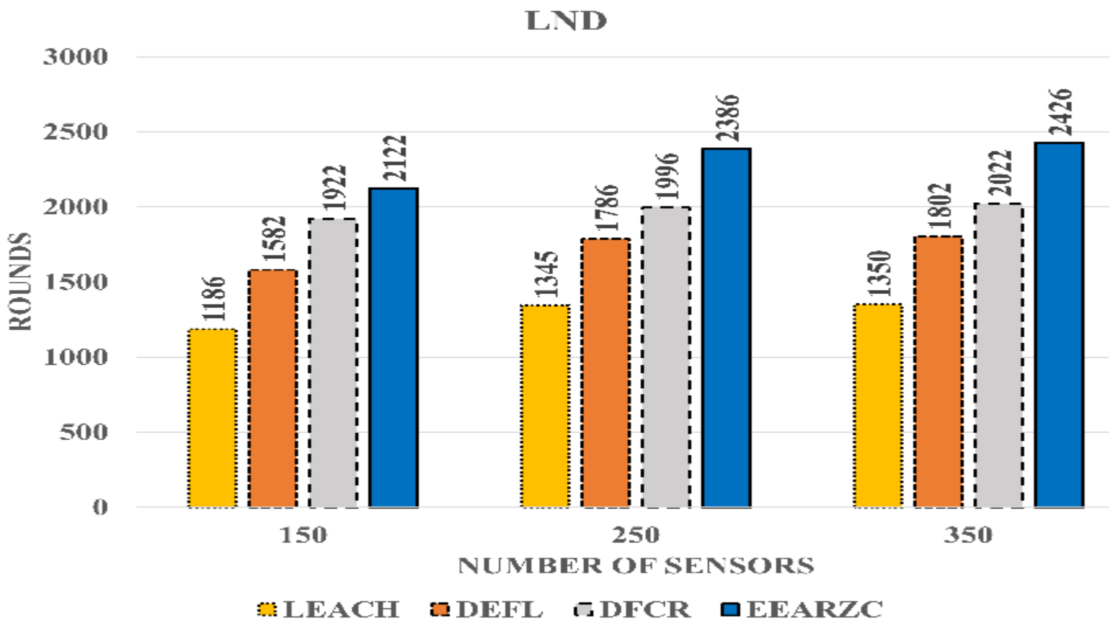

Fig. 11 Comparison of Last Node Dies (LND)

Figure 12 shows the overall improvement achieved for the network's lifetime by EEARZC against LEACH, DEFL, and DFCR for different network densities. Figures 9 - 12 show that EEARZC performs better than DFCR, DEFL, and LEACH.

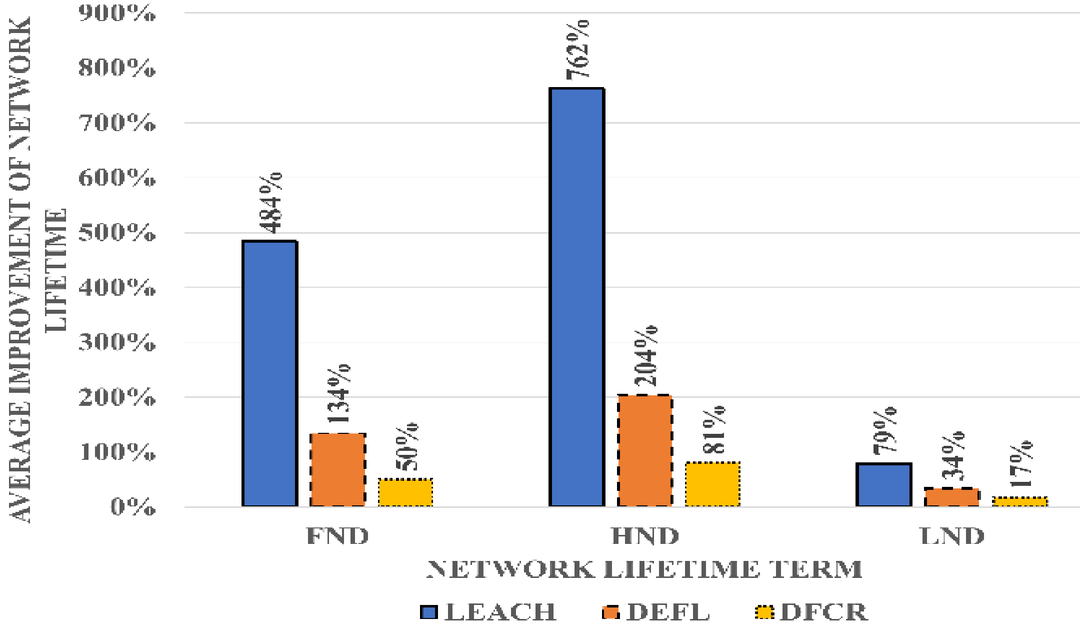

Fig. 12 Average improvement percentage of EEARZC over other schemes for network lifetime metrics

Figure 13 plots the number of live sensors versus rounds for a WSN density of 250 nodes for the different algorithms. After 1200 rounds, 49 nodes are active in the DFCR algorithm, 33 alive nodes in DEFL, and 12 alive nodes in LEACH. However, a greater number of 134 nodes are alive in EEARZC. Based on the Alive Nodes metric, at 1200 rounds, for a network with 250 nodes, EEARZC performs better than DFCR by about 173%, DEFL by nearly 306%, and LEACH by about 1016%.

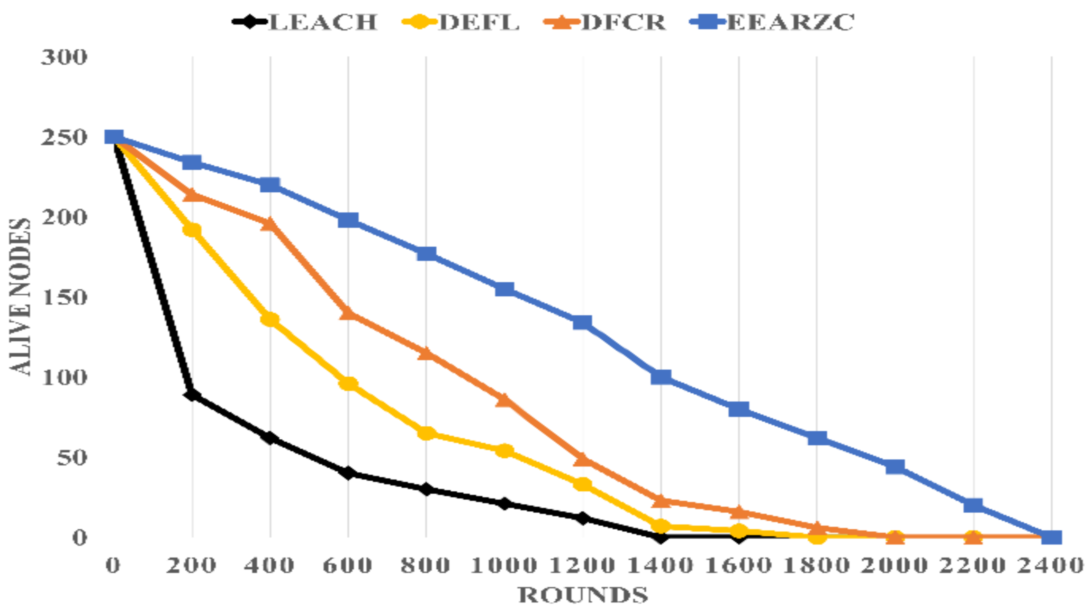

Fig. 13 Number of Alive Nodes vs. Number of Rounds

Figure 14 depicts the number of packets arriving at the Sink Node for a density of 250 nodes. Compared to DFCR, DEFL, and LEACH, in EEARZC more significant quantity of data arrives at the Sink. Based on the Packet Delivery Rate metric (PDR), at 1000 rounds for a network with 250 nodes, EEARZC performs better than DFCR by about 29%, DEFL by about 79%, LEACH by almost 230%.

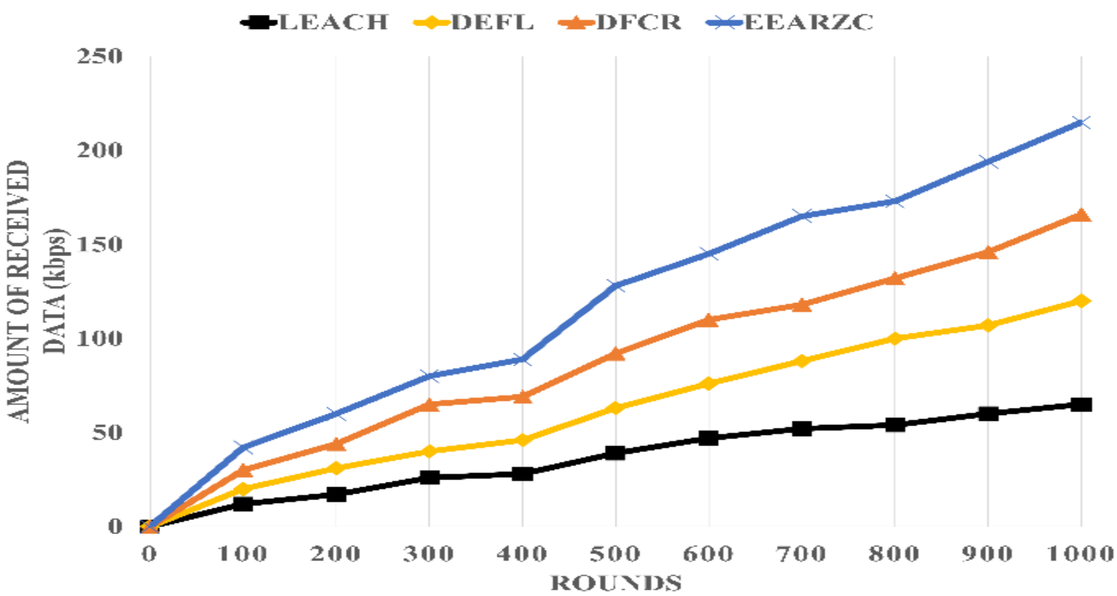

Fig. 14 Quantity of Packets received at the Sink

Figure 15 presents the percentage of aggregate residual power per round for the different methods. This figure shows that EEARZC saves more energy than the other algorithms.

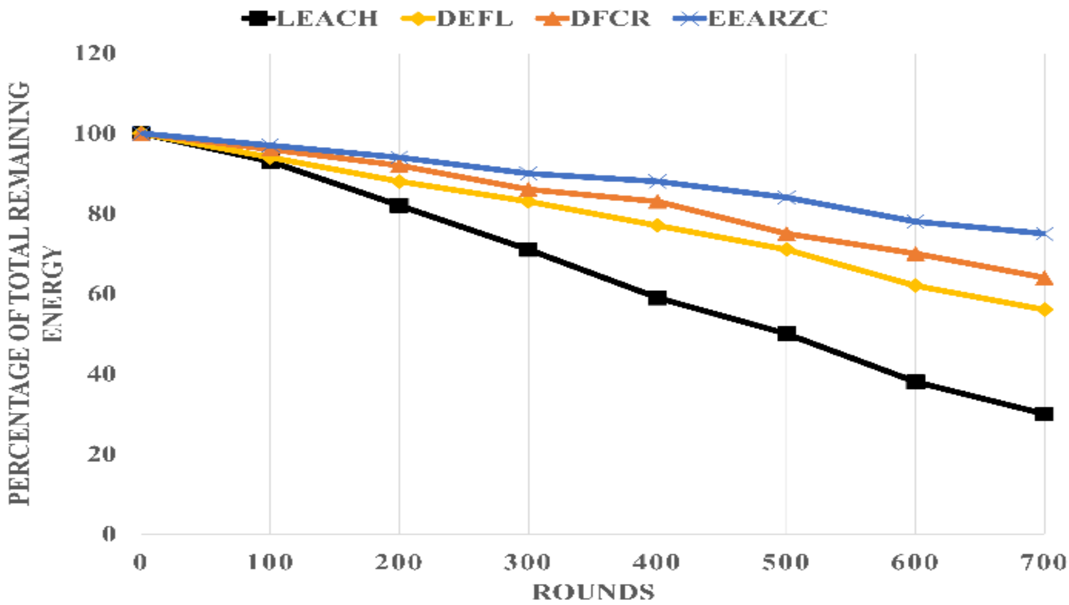

Fig. 15 Percentage of total residual energy per round

EEARZC improves performance because control messages are exchanged by the Cluster Head to confirm that the node is cooperative before transferring data to the Next Hop Node. Using FIS assists in determining the most effective method for forwarding packets to the Sink. By reducing packet drops and subsequent retransmissions, utilizing the zone Monitors as backup relay devices improve network efficiency and conserve energy in nodes. Energy conservation in sensor nodes, increased network lifetime, efficient energy utilization, and improved packet delivery rate are all advantages of EEARZC.

5. Conclusion

Some nodes in a Wireless Sensor Network may be hesitant or non-cooperating because they do not wish to operate as a relay device for transmitting data to the Sink. When packets are forwarded to non-cooperative nodes, packets are dropped and retransmitted, wasting energy in sensor nodes. As a result, in EEARZC, a Cluster Head must first send a "RelayRequest" packet to all of its adjacent Cluster Heads before forwarding the aggregated data of its Cluster to the Sink Node. Only willing Cluster Heads will respond with the message "AcceptReq" after adding the message information about itself that the Fuzzy Inference System needs to make routing decisions. As a result, the proposed algorithm establishes a trust mechanism for routing in WSN, reducing packet loss and retransmissions. EEARZC additionally determines the best path to the Sink Node by employing a FIS to determine which Cluster Head to choose from among these willing candidate Cluster Heads for relaying the Next Hop Cluster Head. The remaining power of the candidate, the candidate node's distance to the Sink Node, the distance of requesting node from the candidate, and the candidate node's Capability Factor are all considerations taken into account when making this decision. The Capability Factor of a node is determined by the amount of traffic, bandwidth availability, and congestion condition. The Fuzzy Inference System's output is the selection of a selected nearby node for relaying data from the candidates. The Zone Monitors are employed as backup relay devices, which increases the efficiency of WSN. Energy conservation in sensor nodes, increased packet delivery rate, efficient energy utilization, and a longer network lifetime are advantages. Matlab simulations were used to assess EEARZC. It has been discovered that EEARZC outperforms other related approaches. Application-oriented networks are Wireless Sensor Networks. As a result, more parameters can be included in the future when computing the value for the Capability factor, depending on the application requirement. In WSNs, the suggested routing algorithm EEARZC can be improved to incorporate mobile sensor nodes.

Abbreviations

The following abbreviations are used in this manuscript:

B.S.	Base Station
DFCR	Distributed Fuzzy Logic based Algorithm
CH	Cluster Head
FIS	Fuzzy Inference System
SN	Sensor Node
EEARZC	Energy-Efficient Adaptive Routing Algorithm using Zone-Based Clustering and FIS
DEFL	Distributed Energy-aware Fuzzy Logic Algorithm
WSN	Wireless Sensor Network

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