Energy Efficient Routing Protocol for IoT Networks Using Ns2 Simulation

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Abstract—Limited power, poor memory, and low computing capabilities make the Internet of Things (IoT) devices resource restricted. Extending the network lifetime is one of the critical objectives in IoT. When it comes to preserving energy in a smart city, routing is one of the most critical factors. Designing an energy-efficient routing protocol boosts energy utilization to a significant extent. Networks with Reduced Power and Loss, the Energy Aware Routing Protocol for the IoT, decreases network traffic and extends network lifespan. As a result, routing variables such as load, remaining energy, and predicted transmission count identify the optimum parent for data transfer. The data traffic is dispersed throughout the network because it considers the load routing measure during route construction. As a result, it enhances network lifetime and achieves a high packet delivery ratio.

Index Terms—Fuzzy logic, energy efficiency, IoT, mobility, routing protocols

I. Introduction

The Internet of Things (IoT) has garnered a growing amount of attention from the academic community. In its early stages, it has the potential to address a wide variety of issues. The Internet serves as a network's communication infrastructure for transferring resources from one platform to another. The MIT Auto-ID Lab came up with the term "Internet of Things" in 1999. Over one billion different devices are now connected to the Internet, giving them the ability to observe and collect information without the assistance of a person. [1]. They estimated that billions of Internet-connected IoT devices would be online by 2020. When it comes to improving human life, the IoT plays a significant role [2].

A. IoT Architecture

Many physical devices can be connected to the Internet through the Internet of Things. As a result, having a constant design is essential to store all the data in this case correctly. In IoT, many researchers have suggested numerous layered architecture models for the Internet of Things. However, none of them has been to meet all the architectural requirements. Internet of Things architecture has three layers: perception, application, and networking. The sensors are first deployed at the perception layer, where they will generate and send data to the network layer using wireless devices. Finally, the user reads the sensor information in the application layer, coupled to the network layer through the network interface [3].

Therefore, the Internet of Things (IoT) has been built using a five-layered architecture in different applications. Perception, network, middleware, application, and business layer are all components of the Internet of Things. For instance, As seen in Fig. 1. the diagrammatic description of layer IoT architecture.

- *Perception Layer:* During the perception layer, the sensor devices are implanted with a physical item, which receives a physical signal, a biological signal, or a chemical signal and creates an electrical signal as an output. Thermal sensors (temperature, heat flow, and so on), magnetic sensors (magnetic flux density, moment, and so on), electrical sensors, and other types of sensors are commonly classified as follows: (current, voltage, inductance, etc.), mechanical, chemical, and optical sensors can measure things like length, flow, force, acceleration, and more (light intensity, polarization, etc.). Finally, a wireless medium sends the data packets from the sensors to the network layer. [4].

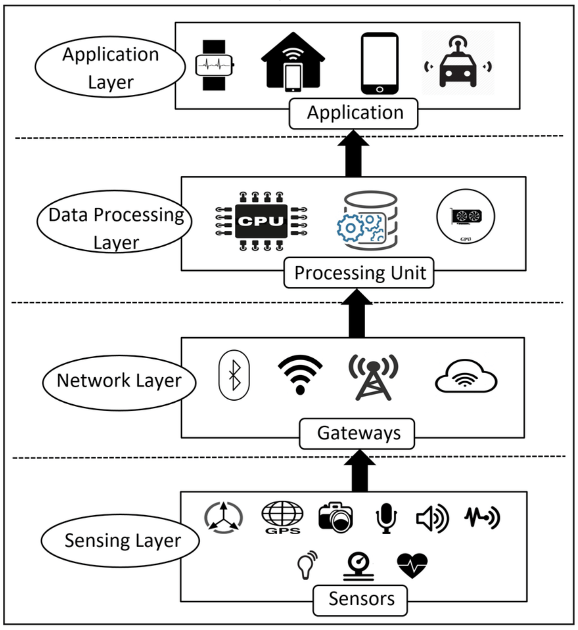

Fig. 1. Layer IoT architecture.

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- *Network Layer:* It ensures safe communication between the middleware and the network's physical layer. Because of the requirements, data transmission can occur either by wired or wireless means. The network layer carries out the routing procedure between the participant and the destination node. Fiber optic and coaxial cable are the two most used types of wired communication. [5]. Wi-Fi, infrared, UMTS, 3G, 4G, Bluetooth, Zigbee, and other wireless communication technologies today.
- Middleware Layer: This layer facilitates services to various heterogeneous objects connected to the IoT network. It gathers the sensor reading from the network layer and stores the information in the local database or cloud storage. Subsequently, it automatically takes the received information's decision according to the user's needs [6].
- *Application Layer:* Using information from the linked devices, it offers services in response to user requests. It sends the request to the service layer in the form of a query. The service layer then delivers the information to the appropriate user. Moreover, it provides services and meets the requirements of users or customers. One of the most often used application protocols on the Internet of Things is the Constrained Application Protocol (CoAP), which minimizes communication bandwidth and computing time.[7].
- *Business Layer:* The overall management of the IoT is maintained through the business layer. It constructs the business model, charts and graphs through the data obtained from the application layer. The business model helps to provide the future move of business strategy and an easy way to improve organizational growth. It also compares each layer output with the probable output for enhancing the quality of services to the user [8].

B. *Internet of Things*

The Internet connects all computers globally, including IoT gadgets, a global wide-area network. The method involves using switches and servers to connect two computers. Private or open organizations, academic institutions and government structures are part of the Internet's global trade system [9]. IP is considered a primary component and communication backbone of the Internet Protocol (IP). The IoT presents a system of physical objects, 'things' developed with sensors, programs, and various advancements to communicate and market knowledge and different web-based gadgets and frames. For example, simple home appliances and furniture have been transformed into "smart" gadgets that can be monitored and controlled via the Internet. IoT devices are designed to be used by individuals at home or in the workplace. Consumer, enterprise, and industrial IoT devices can all be grouped. Although consumer IoT devices such as watches and phones are essential, the weather and traffic control systems are crucial components of the Industrial IoT chains (see Fig. 2).

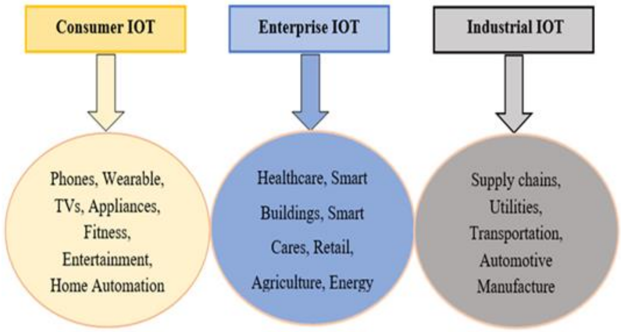

Fig. 2. Classification of IoT devices

C. *Routing Issues and Challenges in IoT*

- Because of their low power, processing speed, and memory capacity, Internet of Things (IoT) devices are typically resource restricted. Extending the network lifetime has become one of the primary objectives in IoT. Therefore, the energy-efficient technique is developed in IoT networks during data communication to reduce energy utilization in the network [10]. Designing an effective routing protocol has undergone many challenging factors affecting the whole network performance. To achieve effective network communication, the routing protocol considers these issues. Fig. 3 shows the limitations of IoT routing.
- Energy Efficiency: The nodes are autonomously deployed and powered by the battery in the network. Therefore, energy conservation is mandatory to enhance the network's lifetime. The routing protocol plays an essential role in energy conservation. The efficient route selection process conserves the energy during data packet transmission, increasing the network lifetime.
- Deployment of Nodes: the deployment of nodes on the Internet of Things can be either planned or spontaneous. The nodes are deployed manually in the deterministic approach, transmitting the data on the pre-determined route. On the other hand, the nodes are deployed randomly in a self-organizing approach and create an ad-hoc infrastructure to transfer the data.
- Data Reporting Model: It is based on IoT applications. It is categorized into four types (Hybrid and Event-Driven models are also possible). Periodic data monitoring applications use the time-driven model to periodically transfer sensor data to the sink node. The query-driven and event-driven model is suitable for time-critical applications. The node sends the data to the sink node when a sudden change occurs in the sensor data. The hybrid model combines the reporting models for the data transfer.
- Coverage Area: In IoT, there is a communication range in the physical environment for each sensor node. The coverage area is one of the significant factors in designing an IoT routing protocol.
- Fault Tolerance: Fault tolerance plays a vital role in data transfer. Suppose sudden node failure occurs due to battery drain or any physical damage. It affects the

entire network performance. In such cases, there is a need to reconstruct the route with immediate effect to avoid packet loss in networks.

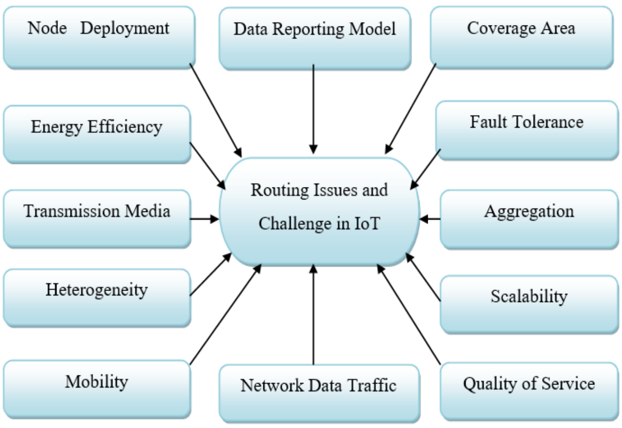

Fig. 3. Routing challenges in IoT.

The rest of the paper is structured as follows: Section II will present a review of some of the past works related to our work, Section III presents the proposed energy efficiency enhancement scheme, Section IV will present the results of the simulation, and finally, we will conclude our work in Section V and present future scope.

II. Literature Review

The IoT devices have limited resources, and most of the devices are connected to the battery powered. One of the essential factors in IoT applications is energy conservation. The power failure of a node affects the Neighbor nodes in the transfer of data packets. As a result, the whole network performance degrades employing packet delivery ratio and latency. Many recent research works have contributed to developing energy-aware routing protocols to extend the network's lifetime.

[11] presented an objective function (LB-OF) for RPL, which balances the traffic burden among the network nodes. The traffic load is calculated depending on each parent's number of child nodes available. In DODAG, each node receives the traffic information through a DIO message. The participant node opts for a parent node with fewer child nodes for data transfer. COOJA simulator was used to simulate the scenario in question. A comparison between the efficiency of the LB-RPL and MHROF-RPL has been made.

To summarize: It allows for an extended network lifespan and reduces bottlenecks on intermediate nodes. However, LB-RPL is not provided with reliability in all the cases. Moreover, it does not consider the energy metric during route establishment.

Researchers [12] have suggested a sigma routing metric for RPL. The existing objective functions based RPL protocol cannot support the large-scale networks. It is noted that network size rises as a hop count increases. As a result, the bottleneck problem is brought closer to the DODAG's core. The suggested goal function uses the ETX (expected transmission count) value's standard deviation to choose the best data transfer parent. An excellent solution to the problem. COOJA simulator is used for the simulation. It compares the efficiency of sigma based RPL to normal RPL and MRHOF. The results show that the sigma metric based RPL prolongs the network and reduces the power consumption and Delay among the network nodes. However, sigma metric based RPL cannot control the data traffic. During route establishment, it does not take the load metric into account.

This research [13] developed the drizzle approach to maintain route information. Regular RPL has difficulty with a trickle timer, which solves the problem. Each node's probability value is assigned using the Drizzle Trickle Timer, suppressing the control message. As a result, it increases the network's performance during route selection and upkeep. Furthermore, the drizzle algorithm shortens the convergence time by skipping the listen-only period, allowing faster convergence. COOJA is used to simulate the situation. According to the simulation results, drizzle-RPL is compared to RPL and MHROFRPL in several network scenarios. According to this study, the drizzle-RPL provides improved performance metrics regarding control overhead, E2E Delay, and convergence time. However, packet loss increases due to data collisions and hidden terminal difficulties.

[14] has proposed a route and service discovery-based routing protocol (DiRPL) in LLN. The DiRPL supports features such as a large coverage area and automatically diagnosing and repairing the fault in the topology. The DiRPL uses the handshake mechanism to find the parent node in the DODAG. COOJA simulator is used to assess DiRPL's performance. Wiimote mote is installed in the network region in this scenario. The simulation result shows that DiRPL takes more time to transmit the data when a hop count increases gradually.

IETF has standardized the routing protocol as RPL. In the most recent few years, researchers have put in a significant effort to enhance RPL performance. Still, several challenges remain to improve network lifetime and provide mobility capabilities in RPL.

[17] proposed an energy effective routing scheme based on a modified leach protocol in an industrial system for connected objects. She found that cluster operations on routing protocols can dynamically positively change energy consumption.

[18] worked on surveying the state of the art routing algorithms applied to wireless sensor networks and the Internet of things. The survey included papers with high contributions to the energy efficiency problems in wireless communications.

[19] worked on services for various heterogeneous objects connected to the IoT network. It gathers the sensor reading from the network layer and stores the information in the local database or cloud storage. Subsequently, it takes the decision automatically from the received information according to the user's needs.

III. Proposed System

Energy-aware RPL (routing protocol for low energy networks) leverages ETX (expected transmission packet count), RER (real-time energy efficiency), and Load routing metrics for DODAG parent selection in its fuzzy logic-based protocol. Energy-aware RPL based on Fuzzy Logic, the routing metric RER is an attribute of maximizing; ETX and Load are minimization properties. The average weighted method does not apply to these routing metrics for parent selection. This protocol's proposed design applies fuzzy logic to routing metrics. In the DODAG, a new Objective Function (OF) for selecting a preferred parent node examines the quality of the parent node. Therefore, it is necessary to employ fuzzy logic-based energy-aware RPL protocol to transfer information from participants to the DODAG root. This study proposed a fuzzy logic-based Internet of Things protocol called FLEA-RPL. In the DODAG, route selection is determined by link and node metrics. To consider the load, ETX, and RER factors and choose the route that will result in the least amount of wasted energy. Fuzzy logic is utilized. As a result, distributing network traffic across multiple connections lessens the amount of data lost in a packet loss. The first study aims to extend FLEA-network RPL's life for IoT. ETX, load and RER routing characteristics are used to identify the best parent for data transmission. Parent changes, latency, power consumption, and delivery ratio assess FLEA-RPL performance. FLEA-RPL extends a node's life by delivering more packets than conventional routing protocols. The simulation results confirm that FLEA-RPL increases the node expiration time by achieving a higher packet delivery ratio when compared with existing routing protocols.

A. Objective Function

When determining the quality of the parent node, FLEX takes advantage of fuzzy reasoning based on routing metrics. RER, ETX, and Load are all ambiguous inputs, and the ambiguous output variable is the parent's quality. Generally, it conducts the fuzzification and defuzzification for route selection.

B. Routing Metrics

- **Residual Energy:** It shows the remaining energy of the network's RPL routers. The residual energy of node x is given in Eq.1.

$$RER_{(x)} = \frac{Initial\_Energy - Spent\_Energy}{Initial\_Energy} \quad (1)$$

- **Load:** Traffic load is the quantity of network data that flows throughout the network at a given time. The objective function of load balancing is to distribute the network's traffic burden evenly among the nodes. Therefore, it adapts the amount of traffic according to the number of connected nodes [15]. There are two ways to determine how much traffic passes through a node in the DODAG tree.

$$Load(P_q, DODAG_{root}) = \sum_{x=1}^{n} Load(x) \quad (2)$$

X and n are the number of nodes in a route P with q Queuing Delay of traffic and the number of single nodes in a path P. Node x's traffic load is determined using Eq.3. Where *m* and *n* are child nodes of x and the total number of nodes in x, respectively.

$$Load_{(x)} = \sum_{m=1}^{n} child\_count(m) \quad (3)$$

- ***Expected Transmission Count:***

1. This information determines how well a participant is connected to the DODAG root. In addition, data broadcast and retransmission numbers are calculated to determine whether the DODAG root may be successfully reached.

2. Link ETX**:** use this tool to determine how good connectivity is between two nodes in a DODAG. It shows how many data packets have been successfully delivered to the recipient. The reversed data transfer shows the sender's acknowledgement transmission count. The link ETX of node *x* is calculated in Eq. 4.

$$ETX_{(x)} = \frac{1}{FD \times RD} \quad (4)$$

Forward and backward data transmission are denoted by FD and RD, respectively.

3. Route ETX: It assesses how well a path connects a participant node to the DODAG root. Eq.5 calculates the route ETX of path P from the source q to the DODAG root.

$$ETX(P_q, DODAG_{root}) = \sum_{x=1}^{n} ETX_{(x)} \quad (5)$$

where x and n are the set of nodes in a path P and the total number of sensor nodes in a path P, respectively.

C. Fuzzification

As the name suggests, it represents sharp input as fuzziness. When the DODAG generates the link and node information, that is what is crisp. As can be seen, the two most important terms to keep in mind when working with fuzzy logic are operands and membership function.

- ***Linguistic Variable:*** Fuzzy logic relies heavily on the language variable. An additional variable that may be expressed in terms of words or phrases is included. The linguistic variables of input and output routing metrics are given in Table I.

- ***Membership Function:*** Assists in assessing linguistic factors using membership functions. When it comes to the fuzzy input and output variables, FLEA-RPL (Fuzzy logic Energy Efficiency - Routing Protocol for Low-Power and Lossy Networks) has used the trapezoidal and triangle membership functions, respectively [10].

There are three scalar parameters in the triangle curve, each with an objective value membership function., h1, i1, and j1. The parameters h1 and j1 are the triangle's legs, and i1 represents the triangle's apex.

TABLE I: VARIABLES IN LINGUISTICS

Routing Metrics	Variables in linguistics
RER	Average and Full, Low
Load	Regular and Heavy, Light
Neighbor Quality	Excellent-very good- Good- Low good-Bad- Low bad- and Awful
ETX	Average and Long, Short

In Eq. 6, the triangle membership function is shown in its most generic form.

$$\mu_{c2}(y) = \begin{cases} 0 \; y < h_1 \\ \frac{y-h_1}{i_1-h_1} \quad h_1 < y < i_1 \\ 1 \; i_1 < y \le j_1 \\ \frac{j_1-y}{j_1-k_1} \quad j_1 < y \le k_1 \\ 0 \;\; k_1 \ge y \end{cases} \tag{6}$$

Real-value membership function of vector y, the trapezoidal curve, comprises four scalar parameters, *h2*, *i2*, *j2*, and K2, all real numbers. As seen in Eq. 7, a trapezoidal membership function has the following general representation:

$$\mu_{c2}(y) = \begin{cases} 0 \; y < h_2 \\ \frac{y-h_2}{i_2-h_2} \quad h_2 < y < i_2 \\ 1 \; i_2 < y \le j_2 \\ \frac{j_2-y}{j_2-k_2} \quad j_2 < y \le k_2 \\ 0 \;\; k_2 \ge y \end{cases} \tag{7}$$

The membership function of load represents the traffic load in the network nodes. The linguistic variable traffic load can be heavy, regular, and light. The linguistic variable *Light* of membership function *Load* can be represented in Eq. 8.

$$\mu_{c2}(y) = \begin{cases} 1 \;\; if \; Load \le 3 \\ \frac{Load-3}{6-3} \quad 3 < Load < 6 \\ 0 \;\; if \; Load \ge 6 \end{cases} \tag{8}$$

It is possible to express membership functions for additional traffic load variables. For example, ETX, RER, and Neighbor node quality may alternatively be expressed using the membership function. Fig. 4 illustrates the load's membership function.

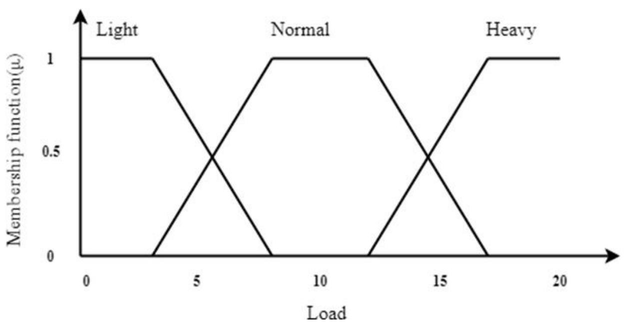

Fig. 4. Load's member function.

From 0 to 1, the RER value membership scale is available. Using the FLEA- RPL, the best parent node is chosen. RER membership is shown in Fig. 5.

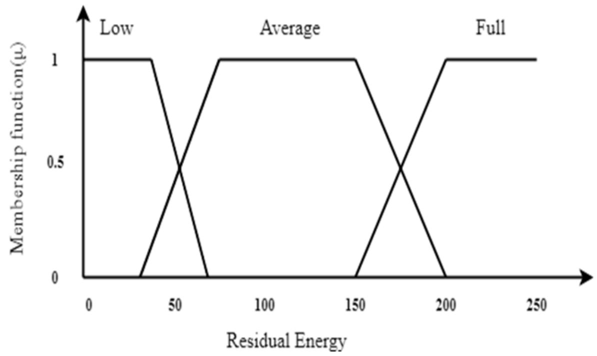

Fig. 5. RER's role in membership.

Each of the ETX and membership values are in the range of zero to one. Fig. 5 shows how ETX's membership functions work. Neighbor's quality of membership function ranges from 0 to 100. [12]. The fuzzy output variable has the following language variables: outstanding, very good, good, low-good, bad, low-bad, and horrible. Fig. 6 shows the quality of the Neighbors.

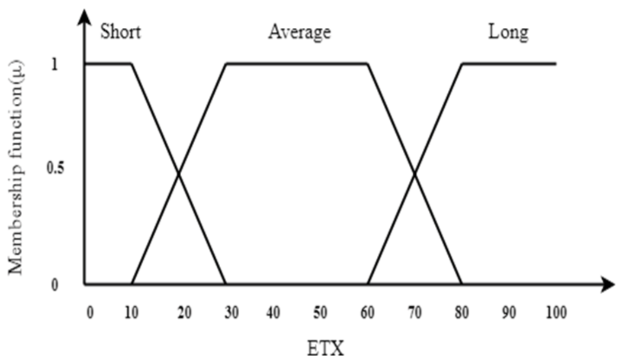

Fig. 6. ETX has a membership function.

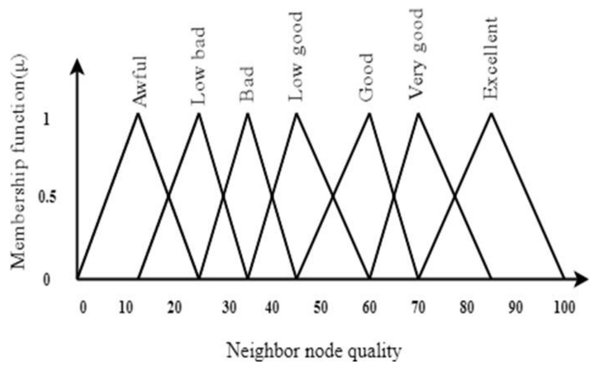

Fig. 7. Neighbor quality is a member function of membership.

D. Rule of the Fuzzy

There are three fluffy information sources in FLEA-RPL: the RER, ETX, Load, and the Neighbor hub's nature. Each information variable participates, so the fluffy rule base has 27 principles. Hub is not entirely set in stone by the consequence of the three-participation work. The application needs to change the fluffy information factors and the fluffy principles. Mamdani's model is well-known, and it makes use of a shaky foundation for derivation. FLEA-fluffy RPL's standards are evaluated using the If-Then rule. In the context of the organization, it provides results. Table II shows the fluffier components.

TABLE II: RULE OF THE FUZZY

S. No	ETX	Residual Power	Load	Neighbouring Quality
1	Short	Full	Light	Excellent
2	Average	Full	Light	Very good
3	Long	Full	Light	Good
4	Short	Low	Light	Good
5	Average	Low	Light	Bad
6	Long	Low	Light	Low bad
7	Short	Average	Light	Very good
8	Average	Average	Light	Good
9	Short	Average	Light	Good
10	Short	Full	Normal	Very good
11	Average	Full	Normal	Good
12	Long	Full	Normal	Bad
13	Short	Low	Normal	Bad
14	Average	Low	Normal	Low bad
15	Average	Low	Normal	Bad
16	Short	Average	Normal	Good
17	Average	Average	Normal	Low good
18	Long	Average	Normal	Low bad
19	Short	Full	Heavy	Good
20	Average	Full	Heavy	Bad
21	Long	Full	Heavy	Good
22	Short	Low	Heavy	Low bad
23	Average	Low	Heavy	Bad
24	Long	Low	Heavy	Awful
25	Short	Average	Heavy	Bad
26	Average	Average	Heavy	Low bad
27	Long	Average	Heavy	Bad

E. Defuzzification

One of the significant tasks in a fluffy surmising framework is defuzzification. A value of 0 to 100 may be found here. In FLEA-RPL, defuzzification is executed with a traditional weighted method, which can be written as Eq.9 in math.

$$S = \frac{\sum_{j=1}^{N} W_j \times \mu_c(W_j)}{\sum_{j=1}^{N} \mu_c(W_j)} \quad (9)$$

where S addresses the new set worth, c is a fluffy district. N shows a complete number of fluffy principles, µc is a predicate truth worth of space W, and Wj is an area worth of specific rule j. such as the favored parent has the measurements data of Load, RER, and ETX, and its qualities are 2, 175, and 10 separately. The membership values of linguistic variables are 0.5, 0.5, 1, and 1 for Light, Normal, Full, and Short, respectively. In the fuzzification process, FLEA-RPL generates two rules. Rules 1 and 4 coordinate with the fluffy rule base for the above model. The result of the principles is Excellent. The result worth of both the guidelines is 0.5. Also, the idea of Neighbor values is 70 and 86 for the enlistment of Very incredible and Excellent independently. The defuzzification is still up in the air in Eq.10.

$$S = \frac{(0.5\times70+0.5\times86)}{(0.5+0.5)} = 78 \quad (10)$$

Similarly, FLEA-RPL ascertains the nature of the favored parent. Then, the member hub picks the parent hub with the most excellent fresh worth.

F. Rank Calculation

In DODAG, the member hub x ascertains the position esteem from the position of the standard Ent hub and its rank Increase. Min Hop Rank Increase and advancement are considered to calculate rank-increasing significance. The minimum rise in Hop rank is an intrinsic value, naturally 256. The position computation is given in Eq. 11 and Eq.12.

$$rank(x) = rank(parentNode) + rankIncrease \quad (11)$$

$$rankIncrease = step + minHopRankIncrease \quad (12)$$

G. Parent Selection Process

In FLEA-RPL, the route can be established in two different ways. In the first one, the participant willingly passes the DIS message to the root of the DODAG. Second, the DODAG regularly transmits the DIO message to their Neighbors. The proposed protocol performs the parent selection by applying the fuzzy logic for data transfer. The parent selection mechanism is shown in Fig. 8. The DODAG starts the trickle timer (*I*) to maintain the topology among the network nodes. The initial counter value *C* is assigned 0. The trickle timer interval ranges from I_{min} *to* I_{max}. In RPL, the standard I_{min} and I_{max} values are 12 ms and 10 ms, respectively. When taking part in a lean break, users respond to the parent node DODAG.

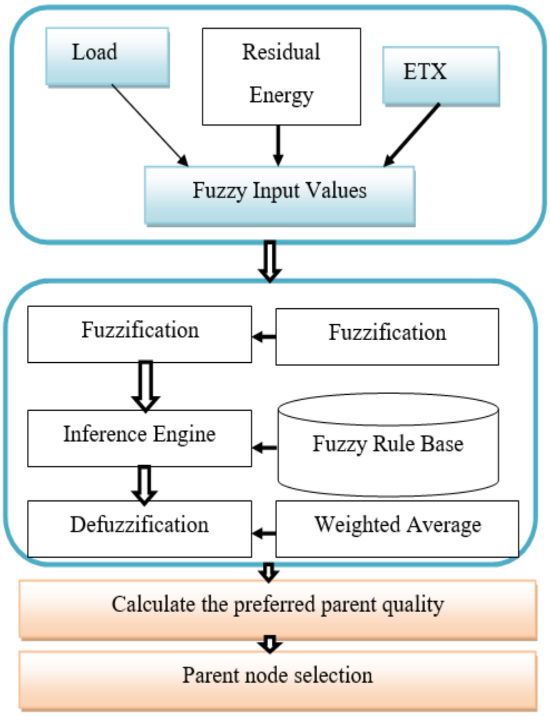

Fig. 8. The mechanism for choosing a parent

Algorithm Parent Selection Algorithm

```
Input: parentNodeList
Output: bestPreferredParentNode
procedure PARENT SELECTION
    begin:
    bestParentNodeRank=∞
    for preferredParentNodeId ∈ parentNodeList do
        rank(particpant)=rank(parentNode)+rankIncrease;
        rankIncrease=step + minHopRankIncrease
        Create linguistic variable and membership of Load,ETX and RER
        Make fuzzy rule base
        Evaluate the generated rules with fuzzy rule base
        Perform the defuzzification process
            step=(Σ_{j=1}^{N} W_j×μ_c(W_j)) / (Σ_{j=1}^{N} μ_c(W_j))
        if bestParentNodeRank > preferredParentNodeRank then
            bestParentNodeRank=preferredParentRank
        end if
    end for
    while preferredParentNodeRank == bestParentNodeRank do
        participantNodeId=preferredParentNodeId
    end while
    Return bestPreferredParentNode
end procedure
```

H. Simulation Setup

To assess FLEA-RPL protocol performance, Network Simulator was used. We randomly place the mote Sky on the network region (600 m by 600m) to create the mote Sky. The simulation consists of a DODAG root node with a hundred RPL routers. Simulated data transmission rates of 1, 6, and 10 packets per minute are used in three scenarios. It is the average values that are provided as the simulation outcomes. As shown in Table III, the simulation settings and parameters are listed.

TABLE III: CONFIGURATION AND PARAMETERS FOR THE SIMULATION

Simulation Parameter	Values
Simulator	Network Simulator (NS2)
OS	Contiki 2.7
Network area	600 × 600 m2
Full battery	1500 mA
Radio environment	Unit disk graph medium
Simulation duration	1 Hour
Data packet timer	60 sec
Routing protocol	RPL
Number of nodes	RPL routers =100 DODAG root =1
Size of Packets transmitted	Data Simulated transmission rates of 1, 6, and 10 packets per minute are used in three scenarios.
DIO interval doubling	10
Node type	sky mote
Minimum DIO interval	12
RPL parameter	minHopRankIncrease=256
MAC / Adaptation layer	Contiki MAC/ 6LowPAN

I. Performance Metrics

The following metrics evaluate the performance of FLEA-RPL.

- Residual Energy: It displays the node's energy content.
- When a packet fails to reach its destination, it is referred to as a “packet loss ratio.
- E2E Delay measures the average time needed to successfully transmit data from the origin to the destination.
- In this case, the number of times a parent changes during the simulation are shown by this field.

IV. RESULTS AND DISCUSSION

The simulation is used to judge the efficacy of FLEA-RPL. Control overhead, E2E Delay, residual energy, power usage, and PLR are analyzed. RPL and MRHOF RPL are utilized as benchmarks for the FLEA-RPL comparison.

A. NS2 Results

The nodes in the Energy-aware RPL based on fuzzy logic are freely relocated. In other words, the topology of this network is dynamic. Routing protocols determine the best path for data packets from the source node to the destination node. A routing protocol is required when the shortest time and route are found. This paper presents a model employing a flexible logic approach to evaluate and compare two routing protocols based on delay and throughput outputs (a fuzzy system with four outputs). A simulator was used to perform an in-depth analysis of two protocols to demonstrate the effectiveness and genuine nature of the embedded system. The simple option to see how well the embedded system operated was to compare its simulation results to those of the NS-2 program. (See Fig. 9)

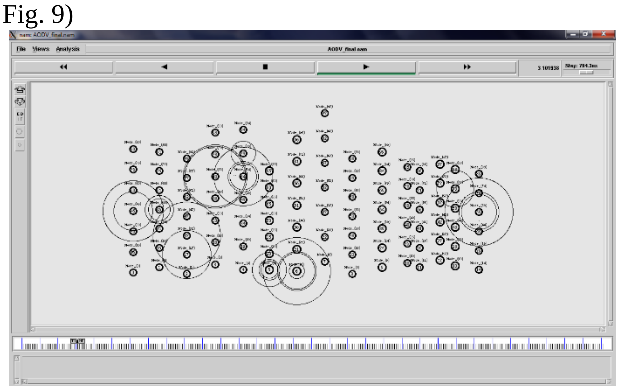

Fig. 9. NS2 Simulation of energy-aware RPL based on fuzzy logic.

B. Scenario 1: One Packet of Data is Sent and Received Every Minute

A packet-per-minute transfer rate illustrates the parent change values of several RPL protocols (see Fig. 10). FLEA-RPL parent change value is observed and compared to regular RPL, FL-RPL, and MRHOF-RPL in order to determine the network's stability. It is estimated that the parent change values of the four types of RPLs are 0.28 for conventional RPLs, 0.25 for FL-RPLs and 0.17% for FLEA-RPLs. FLEA-parent RPL's change value is minimal compared to RPL, MRHOF-RPL, and FL-parent RPL's change value. For the most part, it relates to the parent node's selection taking into account the load metric. Consequently, the DODAG is the appropriate parent for FLEA-RPL, allowing the network a longer lifespan.

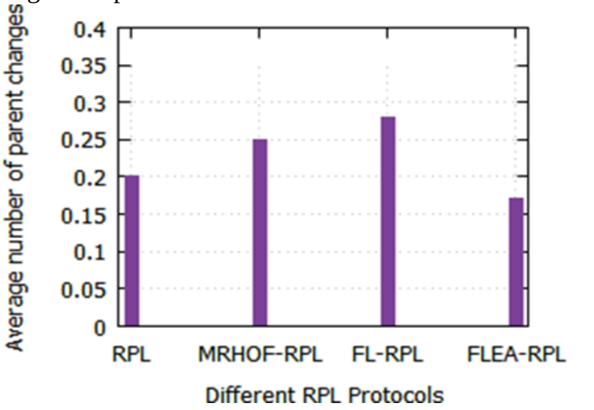

Fig. 10. Instances when the parent change value differ depending on the RPL protocol.

It is shown in Fig. 11 how many hops it takes to get from A to B on an average basis.

As a result, the conventional RPL, FL-RPL, MRHOF-RPL, and FLEA-RPL have a latency of 3, 8, 3, 7, and 2, respectively, seconds. The FLEA-RPL is faster than other protocols such as conventional RPL, FL-RPL, and MRHOF-RPL. Because of the network traffic diversification during parent selection, this occurs.

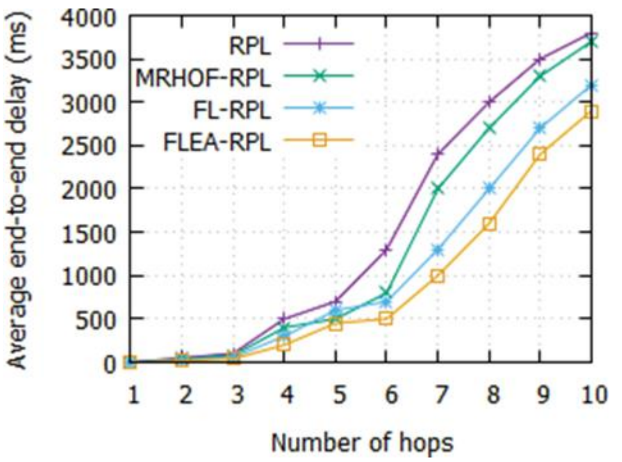

Fig. 11. E2E delay versus number of hops.

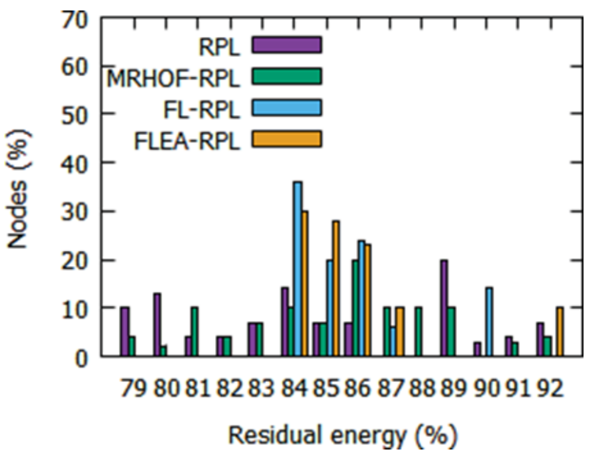

Fig. 12. Residual energy of network nodes.

Fig. 12 depicts residual energy network nodes with a one-packet-per-minute data transmission rate. In FLEA-RPL, it is found that 90% of organization hubs' excess energy ranges between 84% and 87 % around. The rest 10% of the organization hubs have remaining energy, around 90% to 92% Bug RPL showed higher organization lifetime and remaining energy than normal RPL, FL-RPL and MRHOF-RPL.

Fig. 13 portrays the connection between bundle misfortune proportion, organization size, and information move rate. Considering the number of bounces for the parent determination exclusively, RPL has a high parcel misfortune proportion. MRHOF-RPL thinks about the ETX metric for the parent choice. The battery, hence, drains rashly, driving in high bundle misfortune. 100 hubs in a 100-hub network have parcel misfortune proportions of 6%, 4%, 5.8%, and 3.8%.

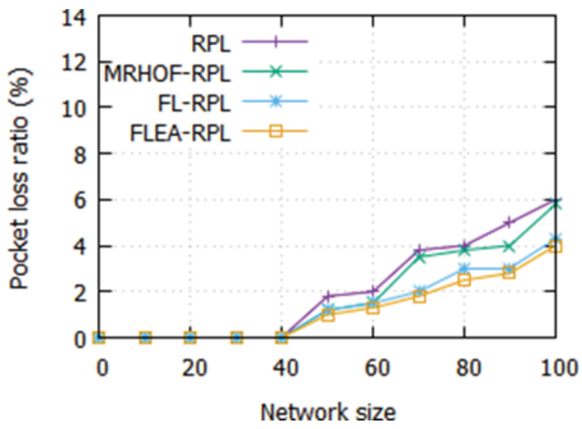

Fig. 13. Packet loss ratio versus network size.

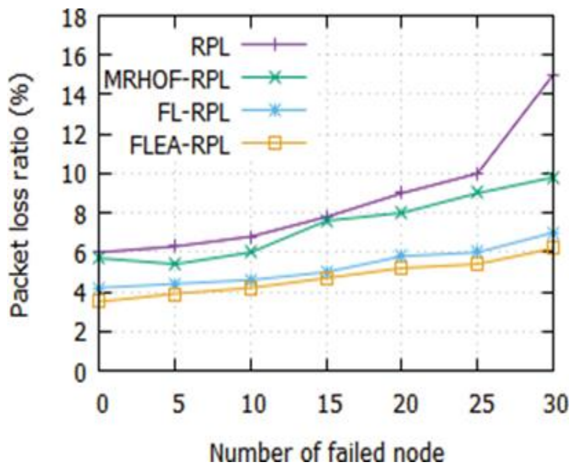

Fig. 14. In the event of a node failure, the typical packet loss ratio.

Fig. 14 portrays the bundle misfortune that happens when hubs fall flat. The quantity of hubs that have bombed fluctuates from 0 to 30. It is seen that there is an expansion in bundle misfortune as it expands the bombed hubs. Looking at RPL, FL-RPL, and MRHOF-RPL for a bombed hub size of 30, FLEA-RPL decreased bundle misfortune proportion by 11%, 2% %, and 4%. ETX and RER were considered together with the traffic load while making the parent decision. As the number of node failures, there exists a chance for the DODAG root to fail because of the transmission of control packets for route formation.

C. *Scenario 2: Six Packets Per Minute is the Data Transfer Rate*

Fig. 15 portrays the parent change values for various RPL conventions. To survey the organization's security, Standard RPL, FL-RPL, and MRHOF-RPL seem the same, but bug RPL is shown differently. Only MRHOF-RPL, FL-RPL, and FLEA-RPL have parent change values of 0.3, 0.4, and 0.35. Interestingly, with RPL, FL-RPL, and MRHOF-RPL, FLEA-parent RPL's change regard is the most insignificant. This problem has emerged due to using a load metric while selecting the parent node.

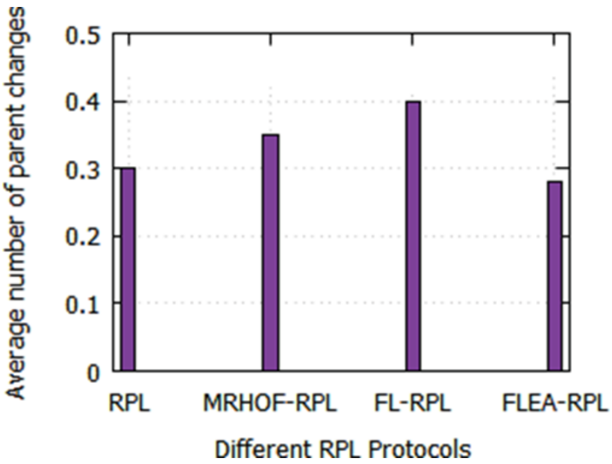

Fig. 15. The average number of parents who make a change when using various RPL protocols.

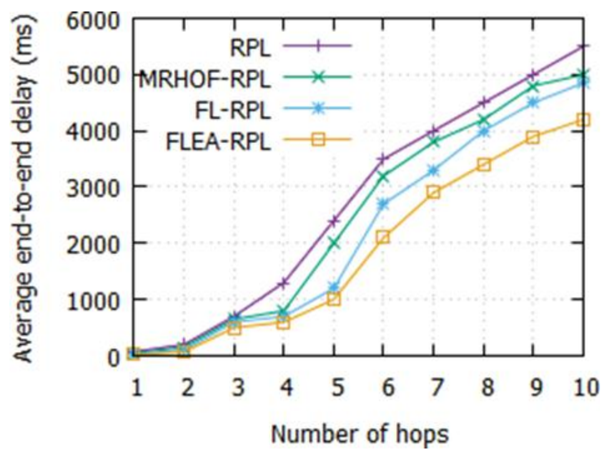

Fig. 16. The Relationship Between E2E Delay and the Number of Hops.

As the number of hops increases, the average E2E latency decreases. For example, normal RPL, FL-RPL, and FLEA-RPL all have a 5.5-second delay. However, compared to other protocols, FLEA-RPL takes less time than standard RPL, FL-RPL and MRHOF-RPL, according to the study's findings. Because of the network traffic diversification during parent selection, this occurs as depicted in Fig. 16.

Fig. 17 outlines the network hub leftover energy with an information move pace of six parcels each moment. For example, in FLEA-RPL, it is noticed that 90% of organization hubs lingering energy ranges somewhere in the range of 62% and 66% around. The rest, 10% of the organization hubs, has remaining energy, around 70% to 72.

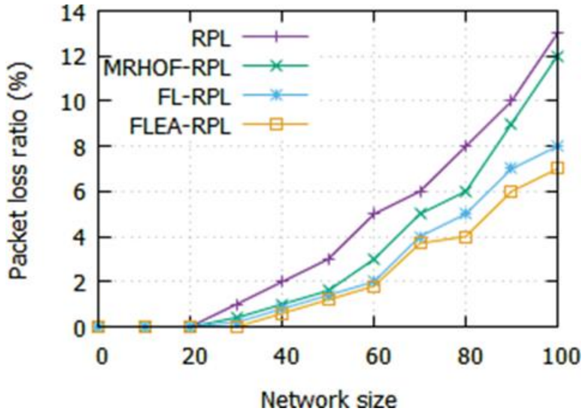

Fig. 17. Network Nodes' Remaining Power

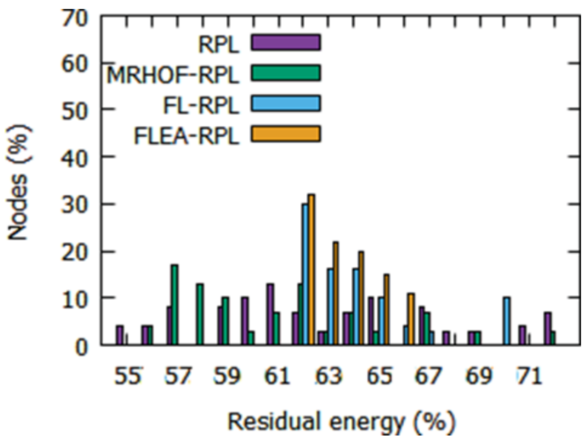

Fig. 18. Packet loss ratio versus network size.

According to Fig. 18, RPL, FL-RPL, FLEA-RPL, and MRHOF-RPL packet loss increases with network size and data transfer rate. From 0 to 30 nodes have failed. PLR increases with the number of faulty nodes, according to the study. Because RPL does not consider link quality when selecting a parent, packet loss is significant. While choosing a parent, MRHOF-RPL just thinks about the connection quality. Therefore, the battery runs out too early, bringing about a considerable parcel misfortune for an organization size of 100 hubs.

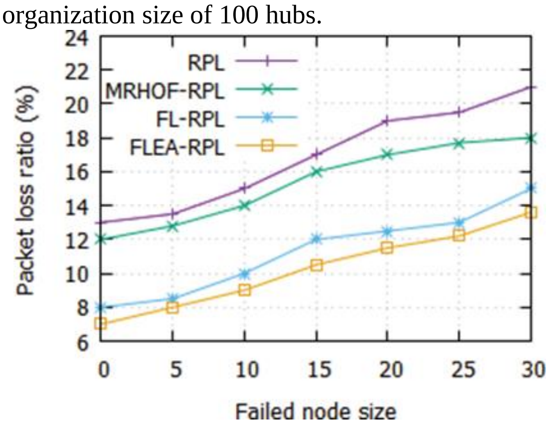

Fig. 19. In the event of a node failure, the average packet loss ratio

Six packets are exchanged every minute., Fig. 19 shows the packet loss when there are failing nodes. It is possible to have 0 to 30 nodes fail. As the quantity of dangerous hubs increments, so does bundle misfortune, as indicated by the exploration. Because RPL does not consider interface quality while choosing a parent, there is a bundle of misfortune. Bug RPL has separately decreased the bundle misfortune proportion by 7%, 2%, and 4%.

V. Conclusion and Future Work

This study proposed the FLEA-RPL IoT protocol based on fuzzy logic. Route selection in the DODAG is based on both link and node metrics. The load, ETX, and RER factors are combined using fuzzy logic to determine the best data transmission, parent. It also reduces packet loss by spreading network data traffic across multiple connections. The Network Simulator was used to conduct the performance analysis. The simulation results show that FLEA-RPL performed better than RPL, FL-RPL, and MRHOF-RPL. A few directing conventions are proposed in this examination in future work to extend the life expectancy of the IoT organization. However, the proposed work can be reached later and is currently being examined.

• In the current work, a single sink node is used to collect network data. However, multiple sink nodes can be deployed in an IoT network to increase network lifetime, which is considered for future work extension.

• Future work will focus on the performance of the EM-RPL in a real-time environment. In addition, the mobility of sink and sensor nodes is considered for EM-RPL in mobile robot applications. In the future, investigating sink mobility could be a difficult task.

• The EM-RPL establishes the network route using a static trickle timer. The dynamic trickle timer can decrease control overhead, which can be thought of as future work.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Ali Saadoon Ahmed has collected the data to prepare the contributions and solve the problem. Also, proposed the algorithms to implemented in this research; Sefer Kurnaz has modified the paper organization and proofread the English language.

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