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Research Article

Energy-Aware Routing Protocol with Fuzzy Logic in Industrial Internet of Things with Blockchain Technology

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It is the expansion and use of the Industrial Internet of Things (IIoT) in various industrial sectors and applications that are referred to as the Industrial Internet of Things (IIoT). The Industrial Internet of Things includes industrial applications such as robots, medical devices, and software-defined manufacturing processes. In terms of energy conservation, routing is extremely essential. The creation of an energy effectual steering procedure leads to a substantial rise in energy consumption. To minimize network traffic and increase network life, the article presented an Industrial IoT Fuzzy Logic Energy-Aware Routing Protocol (FLEA-RPL), which decreases network traffic as well as improves network life. The most suitable parent for data transfer is selected based on, among other things, the routing parameters charge, residual energy, and expected transmission count. Since the load routing metric is taken into consideration during the construction of the route, the data traffic is spread across the network. This increases network's lifetime while maintaining a high packet delivery ratio. The proposed work proposes a Multilayer Energy-Aware Aware RPL (MCEA-RPL) cluster for the Internet of Things to decrease network data traffic while increasing the lifetime of the network. It is split into three phases, each including the creation of network rings, intraring divisions, and intercluster routing. First and foremost, the virtual ring is created in the network. Secondly, each ring forms an identical cluster and chooses the CH node. Finally, it is responsible for the maintenance and performance of the DODAG. Data transfer from the lesser sheet to the DODAG root is known as data transfer. By using Blockchain technology, the lifetime of a network may be extended by reducing the number of identical data package transfers. This article offers Enhanced Mobility Support RPL (EM-RPL) in Industrial IoT which enhances mobility support with blockchain and spreads system generation. It comprises two processes: a collection of the parental static node and selection of the parent moving node. The static parent selection method uses routing metrics load and residual energy to identify the parent that is most suited for data transfer. Two phases of mobile parent selection must be distinguished: data transmission and route rediscovery. The mobile node utilizes furious logic to compute the hand-off value of the metric packet errors ratio and the signal strength indication received from the base station. If the hand-off value exceeds the threshold limit, the DODAG route has to be changed to work correctly. The EM-RPL thus increases the package delivery rate by reducing the amount of route interruption caused by mobility, while offering an efficient handling mechanism.

1. Introduction

The Internet of Things (IoT) has garnered a portion of courtesy from academics in recent years. It is one of the most promising skills because it provides a host of solutions to problems in a wide range of fields. With its capacity to transfer information from one platform to another worldwide, the Internet is the backbone of a network's communication. Kevin Ashton invented the phrase "Internet of Things" at the MIT Auto-ID Laboratory in 1999. One billion gadgets are connected to the Internet, and any device may sense, collect, and send information from one device to another without someone interacting [1]. By 2020, the Cisco Internet of Things (IoT) team anticipates the Internet to connect billions of IoT devices. The Internet of Things is improving human lives, which include monitoring of public health, building automation, logistics, connected cars, intelligent city development (including the smart grid), intelligent homes, smart retail, intelligent farming, and other applications (e.g., [2]).

1.1. Structural Design of Industrial Internet of Things. The Industrial Internet of Things (IoT) can connect many physical items to the Internet. A consistent architecture is needed to store all the information in this instance as efficiently as feasible. Many academics have proposed many architecture models for the Internet of Things; however, none of them have yet fulfilled all architectural criteria. The architecture of the Internet of Things consists of three sheets: the perception layer, the application layer, and the network layer. Initially, sensors are placed at the perception layer to produce and transmit data via wireless devices into the network layer. Finally, the sensor information is read by the user via the network interface [3] in the application layer which is connected to the network layer. The Internet of Things (IoT) was generally developed in various applications utilizing a five-layered architecture. The Internet of Things is composed of conception, networks, middleware, applications, and business layers.

The Industrial Internet of Things strategies is frequently constrained to resources due to their low influence, incomplete computing power, and partial memory size. The lifespan of the network was one of the most significant objectives of the Internet of Things. As a result, energy-efficient methods are being developed in data transmission in IoT networks in demand to reduce the liveliness ingesting of the system and consequently network expenses (B. Ghaleb et al.) [4]. Many challenging factors in the creation of an effective routing protocol have been examined, all of which may affect network's overall performance. The routing protocol considers these challenges to create effective network communication. The IoT routing challenges are illustrated in Figure 1.

Efficient energy design: since the battery independently distributes and drives the nodes in the network, the network is highly dependable. As a consequence, energy conservation is needed to extend the usable lifespan of the system. The routing protocol is extremely useful when it comes to energy conservation. Energy may be saved during data packet transfer and the network lifetime can also be increased by using an efficient technique of road selection. When it originates to the Internet of Things, node deployment is contingent on the necessities of a specific application, whether it is deterministic or self-arranging. Data reporting model: it may be classified into four kinds: query-driven model, time-driven prototypical, event-driven prototypical, and hybrid prototypical. This model is based on Internet of Things applications. Regular data surveillance applications utilize the time-driven paradigm to regularly send sensor data to the sink node. The query-driven and event-driven models will assist time-critical applications [5]. A quick change in sensor data causes data to be sent from the source node to the sink node. The hybrid approach uses a combination of reporting methods and other variables for data transfer.

Physical environment communication range: each sensor node has a range of communication in the physical world on the Internet of Things. One of the most essential concerns when designing an Internet of Things routing system is the coverage area. Fault tolerance is important in data transmission because it enables continuous data flow. If a node emerges from nowhere, a battery depletion or other physical harm may lead to a failure. It affects network's overall operation. In such circumstances, the route must be reconstructed as quickly as feasible, to avoid network packet losses. Scalability is an essential need for big networks and a necessity for all networks. The routing protocol must thus be able to enable network scalability.

A method used to gather and aggregate data packets from different sensor nodes through an aggregate function is called the aggregate acquisition and aggregation of functions. This lowers the number of data transfers in the network. In time-constrained applications, the sensor node's requirement quickly sends information to the sink so that the quality of the service must always be good. In any other scenario, the application Internet of Things will not meet the required requirements and standards. As a consequence, one of the most essential things to consider while developing a routing protocol is the service quality (QoS) offered to consumers. The network data traffic is a measurement of the number of network data packets flowing across the network at any time. The routing protocol supports two-way data transmission. The pattern of traffic on the Internet of Things is different from the application. Mobility: mobility support is one of the hardest tasks on the Internet of Things. It is mainly due to system's wireless nature and the fact that the route may frequently be interrupted due to mobility. Therefore, it is necessary to redevelop the route in such a scenario.

Heterogeneity: depending on the application they are utilized, the responsibilities and capabilities of the sensor nodes vary. The variety of the nodes may provide technical challenges during the routing procedure. Some applications, for instance, employ a combination of different sensors to keep an eye on the surroundings.

To transmit sensor data wirelessly from one source node to extra, the sensor node uses infrared or radio frequency transmission as a communication medium to connect with other nodes. Multiple route propagation, high error rates,

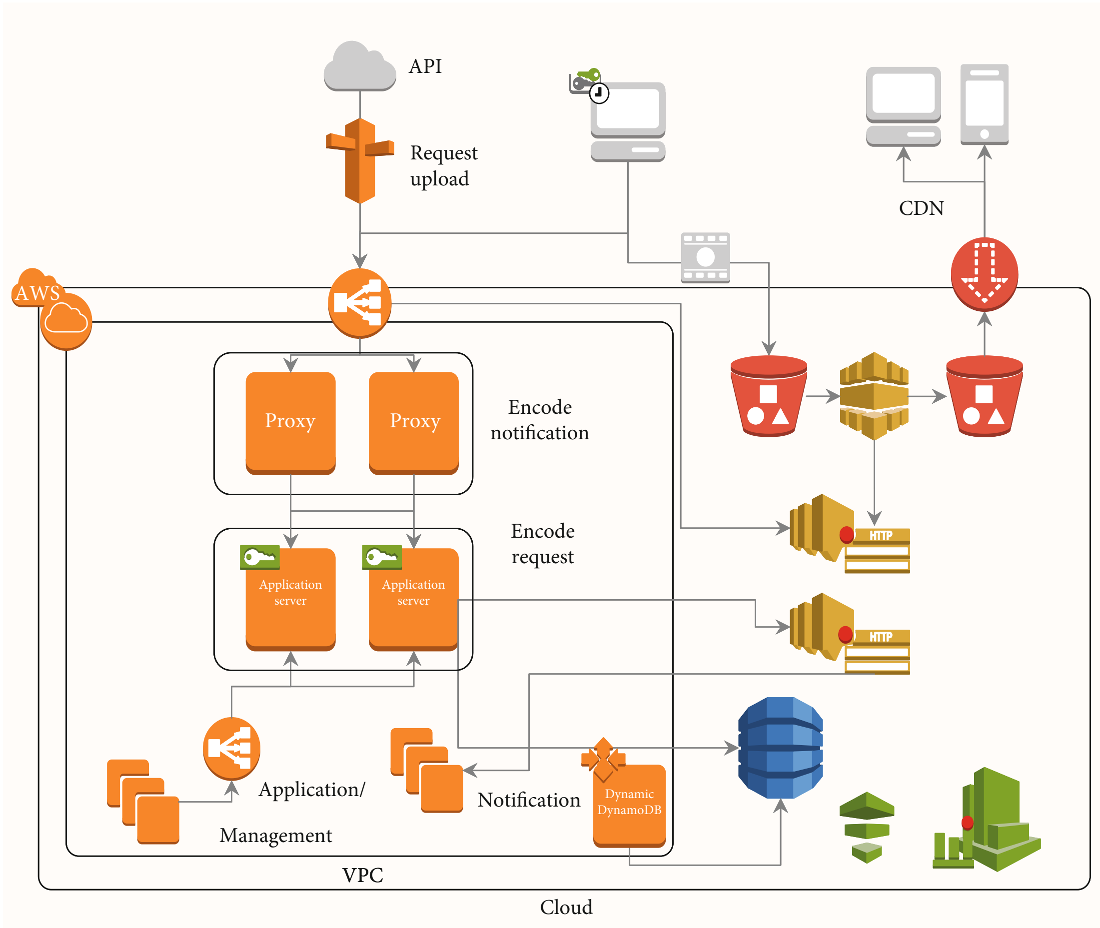

Figure 1: Workflow of in IIoT.

reflection, and fading are all problems linked with these two transmission techniques. The Internet of Things devices is extremely resource-restricted since they are battery-driven. Energy is one of the most critical concerns for applications on the Internet of Things. Because of the multihop network topology and a large amount of data traffic near the sink node, the energy is drained faster by nodes closer to the sinking node. This affects network's overall performance and operation. The routing metric hop count is used by traditional routing protocols for the creation of the DODAG. As it constantly uses the same path for data transmission, it causes an early energy loss at the nodes along that path, leading to path breaks. Routing factors such as residual energy (RER), loading, anticipated transmission count (ETX), and connection quality have thus to be taken into consideration throughout the whole construction phase. As a consequence, a routing protocol is needed, which uses calculation techniques of different routing metrics, based on the request needs. On the Internet of Things, data are sent via nodes to the sink node in a multihop way. All neighboring nodes may redundantly transmit the same data to the sink node, which results in an increased traffic load and wasteful use of energy. Energy conservation on the nodes is necessary, and this may be done by minimizing redundant data transfer. The clustering technique is the most effective means of decreasing energy usage at network nodes in the above-stated situation. The data packet is transmitted to the CH node by the cluster nodes. Once information is acknowledged from the CM nodes, the aggregate node transmits it to the processing sink node. As a consequence, clustering may assist conserve energy by dropping the number of statistics packets transferred from the source node to the sink node. Path breaks will arise because of node mobility. To continue with data transmission, the routing protocol must thus relearn the path. The interruption of the route has a greater impact on the performance of the routing protocol than on network performance. The mobility issue of the node has to be addressed. The routing protocol must contain a better hand-off mechanism to minimize the frequency of route interruptions caused by mobility, to identify an alternate method of continuing the transmission of information. Extending network's life span and enhancing mobility assistance is a tough task on the Internet of Things. Protocols that address the above-mentioned problems, in particular, are in great demand. Therefore, the following are the objectives of the project: this research is aimed at creating an energy-efficient protocol to route the Internet of Things by diversifying network traffic and minimizing overhead control messages. The purpose of this article is to propose a cluster-based Internet of the Things routing protocol to reduce network data traffic and to enhance the mobility support of nodes throughout the Internet of Things. Section 2 includes literature survey. Section 3 represents the methodology, whereas Section 4 represents the experimental results, and conclusion ends with Section 5.

2. Review of the Literature

It is intended for use in Small Control and Reduction System (LLN) and selects, among other factors, the most suitable parent to transport information packages from source to sink nodes. The Internet of Things devices usually has less power, less memory, and less capacity for processing. The IETF has standardized the RPL to satisfy the Long-Term Network (LLN) ([2]) requirements. RPL generates a DODAG to be used to convey participant data containers to the origin of the DODAG, controlled by the participant. Each sink node has a distinct DODAG that is kept. DODAG form refers to the first node as the DODAG root, the second node level to the leaf node, and the other nodes to the middle nodes. In the DODAG representation, the edge which corresponds to the DODAG root upwards is called an upward road, and vice versa, the edge which correlates with the DODAG root downwards. It contains the DODAG rank, RPLInstanceID, DODAG version number, and DODAGID, all needed for the RPL network topology [6].

The RPLInstanceID identifies all DODAGs in the network with the same objective function and organizes them under a single-instance number. The DODAGID provides the DODAG with the unique identification to find it on the network. If the DODAG detects a new route, the version number changes to reflect the change. The distance between the member and the DODAG origin is abundant. The participant node chooses the optimal parent for data transmission from the available choices using the neutral purpose. The neutral purpose is calculated based on the routing data and intended to minimize road costs in the network. Every node in RPL may have either a storage mode or a nonstorage mode, depending on its purpose. During storage, the node receives and transmits information to its parent node. If the node does not store data, it transmits the data to its parent node. The RPL supports traffic patterns such as multipoint, point-to-point, and multipoint traffic patterns. The RPL uses the trickling timer to minimize the overhead control during the route construction process. You may specify predefined time intervals from 1 to 1,000,000 seconds with the trickling timer. It includes three parameters, connexion redundancy inspection, minimal intervals, and maximum intervals, indicated by K, $I_{\min}$, and $I_{\max}$. To begin with, the counter C value is set to zero. Whenever the sweeping timer gets a continuous transmission for the length of the sweeping interval specified in DODAG, the counter C value is increased until the supplied K value is reached. In addition, for several reasons, the DODAG root fails, including energy depletion, network congestion, node failure, and other problems.

A. Hassan et al. [7] presented an energy-conscious routing method to prolong the lifetime of LLNs. The inadequate selection of paths leads to early battery depletion and a bottleneck problem near the origin of DODAG. It selects the optimal DODAG parent based on routing [8] factors such as the Battery Depletion Index (BDI) and the Energy Relationships (RER). The simulation is conducted using the COOJA simulator. It is worth noting that the proposed energy-conscious routing increases the lifetime of the LLN while at the same time reducing the delay about RPL, ETX-RPL, and MRHOF-RPL. However, since the connection measurements during the route building process are not taken into consideration, the energy-conscious RPL proposed increases the packet loss ratio.

The dynamic and efficient parent selection technique for LLN RPL has been introduced, according to W. B. Heinzelman et al. [9]. It uses the metrics load and RER to decide which parent is most suited to data transfer. In addition, the construction of topology in the MAC layer is changed as a consequence of this protocol. As a consequence, the traffic load spreads throughout the network. The results indicate that network stability is increased while network traffic is distributed equally among nodes inside the LLN network. The reproduction is showed using COOJA. The efficiency of the dynamic parent collection RPL is significantly greater compared to traditional RPL. It extends the lifetime of the LLN and decreases the latency at a similar period. Bhandari et al. have proposed an RPL procedure for IoT monitoring applications [9] and is called the Congestion Aware RPL (CA-RPL). It focuses mostly on congestion across the nodes of the network, as the name suggests. It proposed a new parent selection mechanism in RPL which takes into consideration congestion. It uses the multicriteria decision-making technique to decrease congestion throughout the network (MCDM). For data transmission, ETX, RER, neighborhood index, and queue use routing characteristics are used to identify which parent is the one that is most suitable for data transmission. The simulation is conducted using the COOJA simulator.

M. S. Tomar et al. [10] have developed a novel target function for multiway ad hoc low-power networks that improve network longevity. The first objective function searches for the shortest route for data transmission by utilizing latency, buffer occupancy, bandwidth, and ETX routing parameters to find the shortest route. The second objective function uses the greedy approach to choose the parent most suitable for information transmission. The simulation is conducted using the COOJA simulator. It has been noted that the overall performance of the network also increases when the number of gateways rises. It also shows that the greedy approach is better than the end-to-end strategy since it does not take into consideration the obligation cycle when choosing a parent. The metrics buffer occupancy and delay values, however, operate on the level of the node and their values change often.

The context-aware and load-balanced routing protocol (CL-RPL) for the Internet of Things have already been developed by Iova et al. [11]. The rapid data flow of LLN adds to the problem of early battery depletion, which our approach addresses. With the use of queue metrics and RER, a context-aware objective function was proposed for the parent selection which was dependent on the context of the choice. The reproduction is led using the COOJA simulator. The efficacy of CL-RPL is evaluated and opposed to standard RPL. It increases the overall network performance about lifetime and end-to-end latency. However, it may lead to higher packet loss under certain network conditions.

S. Izquierdo et al. [12] created an energy-conscious Internet of Things RPL. Two proposed objective functions have been identified, particularly the parent energy objective function (PEOF1) and the parent energy target function (PEOF2) (PEOF2). Both goal functions take into consideration the ETX and RER routing metrics for parent selection. The PEOF1 objective function uses RER to choose the parent best suitable for the transmission of data packets. The objective function PEOF2 uses the RER to identify the path between participating nodes and the DODAG root. The simulation is conducted using the Contiki COOJA 2.7 simulator. To evaluate its performance, it benefits from the symmetrical and asymmetrical features of the proposed procedure. It is worth noting that the PEOF2 is much better than the V. Karagiannis et al. [13] proposed a multipath selection approach for cache-based use in the RPL. However, the comparison of performance is done just with PEOF and PEOF2. Energy consumption is a key problem in low-power and loss networks. Many research initiatives are aimed at reducing the quantity of energy used by the grid. The energy equalization routing method and cache usage algorithm should be used to choose the most efficient data transmission path. The simulation is conducted using the COOJA simulator. Compared to RPL, the proposed multirouting protocol minimizes energy use while increasing reliability at the same time. On the other side, the node extremely rapidly depletes the energy supply when it is close to the sink.

R. Khan et al. [14], LLN proposed an expanded Kalman-based RPL filtering (EKFRPL). RPL does not offer mobility function support. Because of these network performance restrictions, existing routing methods are affected by problems such as slow response and poor overall network performance. EKF-RPL is proposed as a solution since it enables more mobility while prolonging the generation of the system. The simulation is done using the COOJA simulation program. The EKF-RPL presentation is assessed using together with the exact model and the reproduction. The findings are promising if the efficiency of EKF is compared with the efficiency of existing mobility aid techniques [15]. It has been shown that EKF-RPL provides better performance based on energy usage, responsiveness, control overhead, and packet loss. On the other hand, EKF-RPL does not take into consideration network latency and scalability.

The cheap data and accountancy blockchain concepts in the industrial sector may stimulate the creation of new technologies that will allow companies and individuals to create cryptocurrencies and accounting programs that revolutionize their respective areas of expertise. In general, the blockchain will offer companies and individuals a safer and more reliable alternative to conventional shipping and delivery techniques. The blockchain will allow companies to retain shipping data across many devices in the logistics sector while preventing them from being held by criminals. As it allows supply shift to function more efficiently and with more trust, blockchain technology has the potential to increase logistics interoperability. Individuals profit from the blockchain because it monitors what and where they have spent their money, ensures that their credentials are safe, and gives them a feeling of security that is not accessible via analog methods [16]. The safety of industrial control systems (ICS) in the IIoT is a major problem [17]. The inherent security of blockchain may make industrial control systems (ICS) more resistant to manipulation on the Internet of Things (IoT), but blockchain can open the door to a variety of cyber security options that might affect entire eighth ecosystems. For example, the blockchain can ensure that the whole ecosystem is secure from the start and irreversible. Because IIoT is a large network that connects a large number of strategies, the IIoT is susceptible to a large number of vulnerabilities. The number of vulnerabilities will increase quickly as more devices are connected to IIoT. In the meanwhile, cryptographic algorithms are limited in life before they become inoperable, which means, if hackers learn and adapt to more advanced hacking methods, even the safest algorithms may be jeopardized. Many devices have limited resources in the IIoT, which is another reason (e.g., smart sensors, microcontrollers, etc.)

Blockchain nodes may often be split into two types: complete (FN) and lightweight (LN):

(i) Full node, capable of downloading and verifying all of blocks and transactions, and • Light node, with just a few blocks and transactions to be verified. FN may serve as a mining node, which implies the blockchain can be generated

Lightweight node (LN): due to the restricted available resources, LN can only store and analyze part of the data on a blockchain. In the Internet of Things, lightweight intelligent devices (sensors) may operate as an LN, offering fresh transactions spread among nodes and eventually incorporated as a block in the blockchain.

3. Industrial Internet of Things with Routing Protocol That Is Based on Fuzzy Logic

RER routing measurement has a FLEA-RPL maximization property while ETX and Load have the same minimizing property. The average weighted method for parent selection does not apply to these routing characteristics since they are too complex. This results in the usage of the fuzzy logic of the proposed protocol to calculate routing metrics [18]. In particular, it provides a new objective function (OF) for parent selection which measures the quality of the DODAG hierarchical parental node designated. FLEA-RPL implements the OF to select the best suitable DODAG parent node from which data from participants to DODAG root may be sent. FLEA-RPL is a routing protocol in which utilizes fuzzy logic for routing metrics to assess the parent node quality. There are three fluid input variables, RER, ETX, and Load, and one fluid output variable, the quality of life of the parent. Generally, it is responsible for fluctuating and defuzzing data for the selection of routes.

The quantity of network data that passes through the network during a particular period is called traffic load, and the goal load balancing function is responsible for spreading the load amongst the nodes within the network. It modifies the traffic load to reflect children's numbers [19]. The traffic load on this track is calculated on the P path between the source node q and DODAG root in

$$\underline{\text{Load}}\ \text{Pqg DoDAG root}) = \sum_{x=1}^{Z} \text{Load}(x), \tag{1}$$

where x and n are a single node in a path P and a total number of nodes in a path P respectively. The traffic load of particular node x is calculated in

$$\text{Load}(x) = \underset{m=1}{\textbf{child}\_\text{count}}(m), \tag{2}$$

where m and n are the number of nodes in x that are children of x and the total number of nodes in x, respectively.

3.1. Estimated Number of Transmissions. The quality of the path between the participant and the DODAG root is determined. It estimates the number of transmissions and transmissions required to reach the DODAG root node successfully. ETX connection: this statistic evaluates the quality of the connection between the two DODAG nodes. The quantity of data packets received successfully by the recipient is indicated by the transmission of forwarding information. The reverse data delivery indication shows the number of accreditations received by the sender.

The data supply shall be specified by letter FD, whereas the data supply shall be indicated by letter RD. Route ETX: this measure assesses the route quality among a member node and the root node of DODAG. According to Equation (3), the path ETX P may be calculated from the source q to the DODAG root.

$$\text{ETX}(x) = \frac{1}{\text{FD} \times} |\text{RD}, \tag{3}$$

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

3.2. Fuzzification. It shows the sharp input as a fuzzy input. The required inputs are the DODAG link and node information. The main words language variable and membership function are presented below in futile logic.

3.3. Linguistic Variable. The language variable plays a crucial role in futile logic. It is a variable that stores the value separate from the numbers in terms of words or phrases. Table 1 provides the language variables for input and output routing metrics.

3.4. Membership Function. The language variable plays a crucial role in futile logic. It is a variable that stores the value separate from the numbers in terms of words or phrases. Table 1 provides the language variables for input and output routing metrics, h_1, i_1, and j_1. The parameters h_1 and j_1 are the base of the

Table 1: Linguistic variables.

Routing metrics	Linguistic variables
Load	Light, normal, and heavy
RER	Low, average, and full
ETX	Short, average, and long
Neighbor quality	Awful, very bad, bad, very good, good, excellent

$$\mu_{c1}(z) = \begin{cases} 0, & z \le h_1, \\ \dfrac{Z - h_1}{i_1 - h_1}, & h_1 < z \le i_1, \\ \dfrac{j_1 - z}{j_1 - i_1}, & i_1 < z < j_1, \\ 0, & j_1 \ge z. \end{cases} \tag{4}$$

The trapezoidal curve is a true value vector y, including four scalars, h_2, i_2, j_2, and k_2 parameters. The parameters h_2 and k_2 are both little and upper curve limits. Similarly, the i_2 and j_2 parameters represent both lower and higher support limits. The trapezoidal function is often represented

$$\mu_{c2}(y) = \begin{cases} 0, & y \le h_2, \\ \dfrac{y - h_2}{i_2 - h_2}, & h_2 < z < i2, \\ 1, & i_2 < z \le j_2, \\ \dfrac{j_2 - y}{j_2 - k_2}, & j_2 < z < k_2, \\ 0, & k_2 \ge z, \end{cases} \tag{5}$$

$$\text{Light (Load)} = \begin{cases} 1, & \text{if Load} \le 2, \\ \dfrac{\text{Load} - 3}{6 - 3}, & 3 < \text{Load} < 5, \\ 0, & \text{if Load} \ge 5. \end{cases} \tag{6}$$

The load membership function is the load in the network nodes. The traffic load may be expressed by the linguistic variable as heavy, normal, and light Z. Latib et al. [20]. The language variable membership function light load may be seen in Equation (6). Likewise, the membership function for additional linguistic variables of traffic load may be expressed. The membership function may also be expressed for the other ETX, RER, and neighboring node quality measures. The load membership feature is illustrated in Figure 2. The RER membership shows the current energy in the RPL router.

The membership of RER value ranges between 0 and 1. The FLEA-RPL selects the parent node with maximum residual energy. The RER membership is depicted in Figure 3.

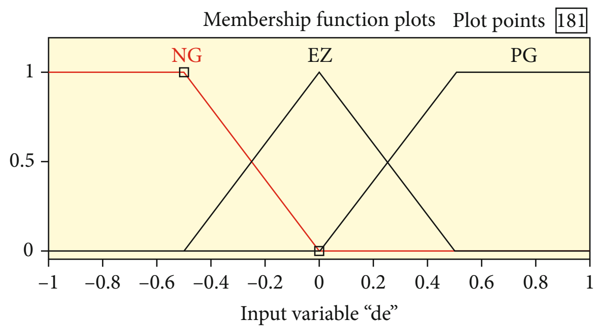

Figure 2: Membership function of load.

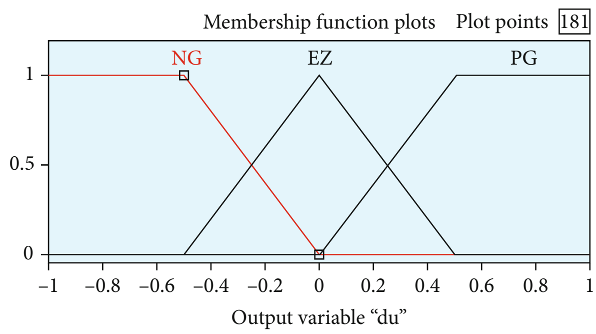

Figure 3: Membership function of RER.

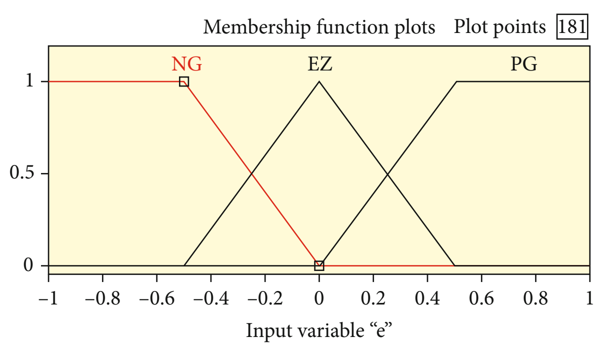

Figure 4: Membership function of ETX.

ETX's membership function represents the link quality between the participant and the DODAG root. The linguistic variables of the fuzzy output variable are excellent, very good, good, low good, bad, low bad, and awful S. Izquierdo et al. [12]. The membership of neighbor quality is shown in Figure 4.

Figure 5 represents the neighborhood quality of the membership function.

3.5. Fuzzy Rule. It is a combination of input and output fuzzy variables [21]. In FLEA-RPL, the fuzzy inputs are RER, ETX, and Load, and the fuzzy output is the quality of the neighbor node. The fuzzy rule base contains twenty-seven rules, as there are three input fuzzy variables [22] and membership functions for each input variable. The output of the three-membership function determines the quality of the neighbor node. The fuzzy input variables and fuzzy rules are adjusted according to the application requirements [23]. Mamdani model is a popular and commonly used fuzzy inference system [12]. It evaluates the fuzzy rules of FLEA-RPL using the If-Then rule. It provides the results according to the network conditions. Table 2 demonstrates the fuzzy rules.

3.6. Defuzzification. Defuzzification is one of the significant processes in a fuzzy inference system [24], which converts the fuzzy output into a single crisp value. Its value ranges from 0 to 100. In FLEA-RPL, the weighted average method is used for defuzzification, and its representation is given in

$$S = \frac{\sum_{j=1}^{N} W_j \times \mu_c(W_j)}{\sum_{j=1}^{N} \mu_c(W_j)}, \tag{7}$$

where S represents the crisp set value and c is a fuzzy region. N indicates the total number of fuzzy rules, μ_c is a predicate truth value of domain W, and W_j is a domain value of particular rule j.For example, the parent preferred contains Load, RER, and ETX metrics, and their values are 2, 175, and 10. Language variables for FLEA-RPL are Light and Standard for Load, Full for RER, and Short for ETX. For Light, Normal, Full, and Short, the membership values are 0.5, 0.5, 1, and 1 for the language variables. FLEA-RPL produces two rules in the fuzzification process [25]. For the example above, rules 1 and 4 match the fuzzy rule base [25]. The output of the rules is excellent. Both rules have an output value of 0.5. The qualitative value of neighboring values is 70 and 86 correspondingly for the membership of the Very Good and Excellent. The value of fuzzification is determined in

$$S = \frac{(0.5 \times 70 + 0.5 \times 86)}{(0.5 + 0.5)} = 78. \tag{8}$$

Likewise, FLEA-RPL calculates the quality of the preferred parent. Finally, the participant node chooses the parent node with the maximum crisp value [25]. In DODAG, the participant node x calculates the rank value from the rank of the parent node and its *rank increase*. The *rank increase* value is computed from the *step* and *minHopRankIncrease*. The *step* value is calculated using the objective function. The *minHopRankIncrease* is an inbuilt value, which is 256 by default. The rank calculation is given in

$$\text{rank}\ (x) = \text{rank}\ (\text{parentNode}) + \text{rankIncrease}, \tag{9}$$

$$\text{rankIncrease} = \text{step} + \text{minHopRankIncrease}. \tag{10}$$

The route may be created in FLEA-RPL in two distinct methods. First, the participant deliberately transmits the DIS message to the DODAG root. Secondly, the DODAG sends the DIO message periodically to its neighbors. To transmit data, the suggested protocol conducts parent selection using fuzzy logic [26]. The method for selecting the parent is illustrated in Figure 6. To maintain the topology across network nodes [26], the DODAG begins the trickle timer (I). The starting counter value C is 0. The time interval of the

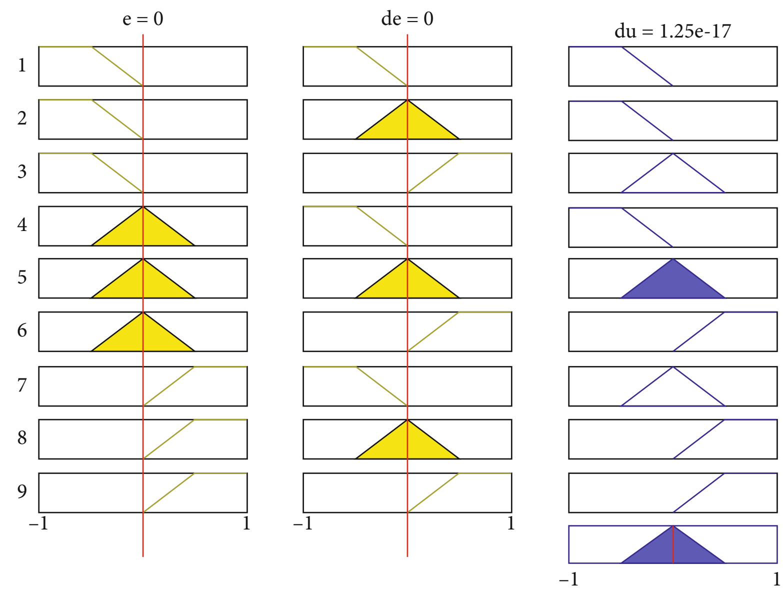

Figure 5: Membership function of neighbor quality.

Table 2: Fuzzy rules.

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

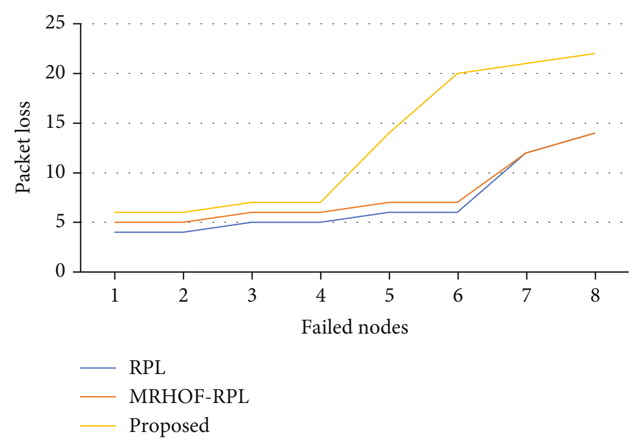

Figure 6: Average packet loss ratio in the node failure scenario.

trickle timer is from I_{min} to I_{max}. In RPL, the standard values of I_{min} and I_{max} are 12 ms and 10 ms. The participant delivers the response message to its parent node at the DODAG within the trickle interval. Finally, the parent node delivers its appropriate participant the DAO-ACK message [27]. The parent selection pseudocode is provided in the algorithm. Figure 7 represents the Optimization Algorithm Flowchart. The Optimization algorithm decides the best features in the system.

The DODAG is first created in the intercluster routing [28]. The CH node chooses the optimum data transmission cluster parent node. The DIOC message is sent to all CM nodes in the cluster. The CH node waits till the answers from the CM nodes come to an end. Once the answer has been received, the CH node transmits the CH-ACK message to the appropriate CM nodes in the cluster. MCEA-RPL retains the CH node during upward routing in two states: the original parent and the suboptimal parent. The suboptimal parent gathers data from all CM nodes and aggregates it.

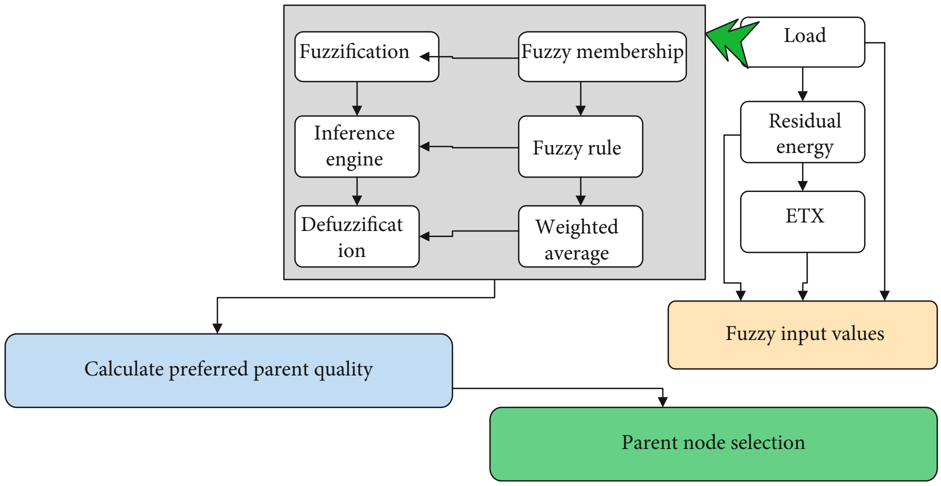

Figure 7: Parent selection mechanism.

```
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
      if bestParentNodeRank > preferredParentNodeRank then
        bestParentNodeRank=preferredParentRank
      end if
  end for
  while preferredParentNodeRank == bestParentNodeRank do
      participantNodeId=preferredParentNodeId
  end while
  Return bestPreferredParentNode
end procedure
```

Algorithm 1: Parent selection algorithm.

The initial optimal parent transmits the data to the ideal CH parent node in the upper ring. Parent's suboptimal parent is provided with the DIOC control message. In the chosen field, the DIOC message contains the parent information. During parent selection, a suboptimal parent selects the best CH parent for data transmission via the ETX and RER parameters. Fuzzy Inference System (FIS) is an important part of the fuzzy logic system which is used to map input and output values using fuzzy logic [29]. In FIS, the key operations are fusing, inference engine, fusing rules, and defusing.

4. Experimental Results and Analysis

4.1. Simulation Setup. The Leistung Using a COOJA network simulator, FLEA-RPL protocols have been tested and compared with common RPL, FL-RPL, and MRHOF-RPL protocols. The Tmote Sky is installed randomly in the network region (600 m/600 m). A DODAG root node with hundred RPL routers is included in the replication. The simulation is carried out in three situations with a transmission rate of data of one, six, and ten packets per minute [30]. The findings indicate the average values received from the simulation. Table 3 illustrates the setup and parameters of the simulation.

4.2. Performance Metrics. The following measurements [31] assess FLEA-RPL performance.

Rest of energy: it indicates how much energy the node has.

Packet loss ratio: defined as the proportion among the entire and the source number of failed packets and the total number of data packets.

Table 3: Simulation setting and parameters.

Parameters used for simulation	Values
OS	Contiki 2.7
Number of nodes	100 RPL routers and 1 DODAG root
Data packet timer	60 sec
Simulation duration	1 hour
MAC/adaptation layer	ContikiMAC/6LowPAN
Full battery	1500 mA
Network area	$600 \times 600\ m^2$
Radio environment	Unit disk graph medium
Simulator	COOJA
Minimum DIO interval	12
Node type	Tmote sky
DIO interval doubling	10
Routing protocol	RPL

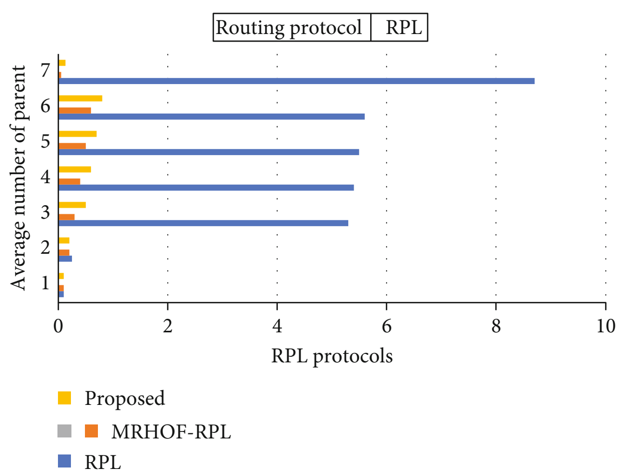

Figure 8: Various RPL protocols with parental changes in data.

End-to-end delay: this is an average period to correctly transmit the information from source to destination.

Parent change number: indicates how many times parent changes occur throughout the simulation.

4.3. Performance Evaluation Results. The performance of FLEA-RPL is evaluated via simulation. Control overhead, latency from end to end, residual power, power consumption, and packet loss ratio are the assessment parameters. The FLEA-RPL is compared with the current known RPL and MRHOF-RPL routing protocols [32].

Scenario 1: data transfer rate within a minute

Figure 8 shows parental change values for different RPL protocols with one packet a minute transmission rate. The parental modification value of FLEA-RPL is recorded to evaluate the network stability and is compared to the conventional RPL, FL-RPL, and MRHOF-RPL. Standard RPL, FL-RPL, MRHOF-RPL, and FLEA-RPL changes parent values are 0.2, 0.28, 0.25, and 0.17 correspondingly. The parent change value in FLEA-RPL is low compared with RPL,

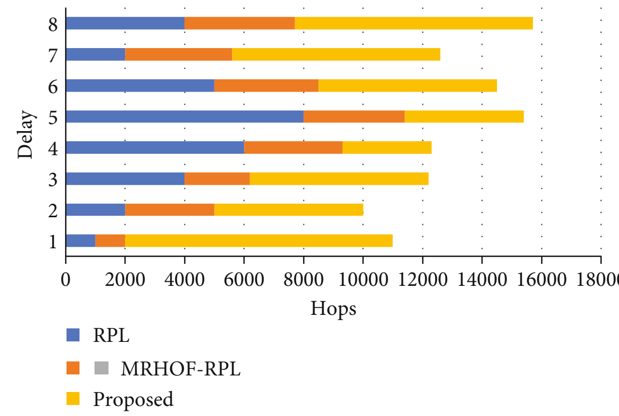

Figure 9: End-to-end delay versus number of hops.

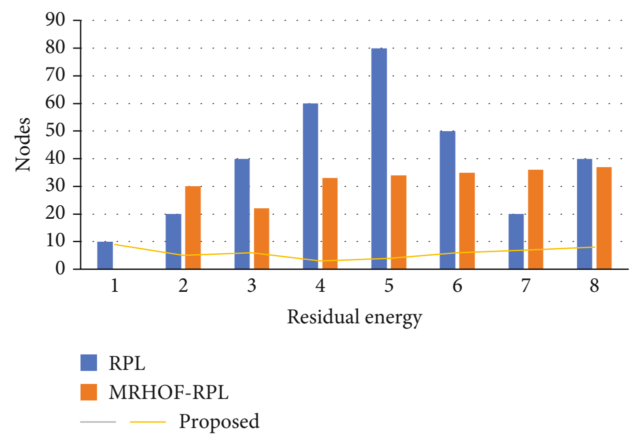

Figure 10: Residual energy of network nodes.

MRHOF-RPL, and FL-RPL. It is primarily related to the load metric for the selection of the parent node. FLEA-RPL thus chooses the finest parent in the DODAG and extends network's lifespan.

Figure 8 shows the average hops end-to-end latency. The RPL, FL-RPL, MRHOF-RPL, and FLEA-RPL standards are 3.8, 3.2, 3.7, and 2.9 seconds. The result indicates that the FLEA-RPL requires less time than other RPL, FL-RPL, and MRHOF-RPL protocol standards. The diversification of network traffic across the network during parent selection.

Figure 9 shows the network node residual energy with a data transmission rate of one packet a minute. FLEA-RPL shows that 90% of network nodes have residual energy ranging from about 84% to 87%. The remaining 10% of the network nodes contain residual energy between 90% and 92%. In comparison to conventional RPL, FL-RPL, and MRHOF-RPL, FLEA-RPL exhibits improved network life and residual energy. Due to RER consideration, the optimum parent selection to transmit data to the root of DODAG is selected.

Figure 10 illustrates the RPL, FL-RPL, FLEA-RPL, and MRHOF-RPL packet loss ratio by changing one packet per minute by network size with data transmission rate. The percentage of the packet loss in RPL is large, given the number of hops for parent selection alone [32]. For parent

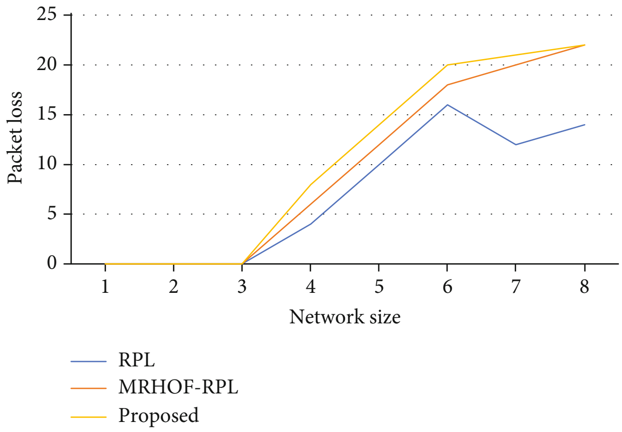

Figure 11: Ratio of network size and packet delivery.

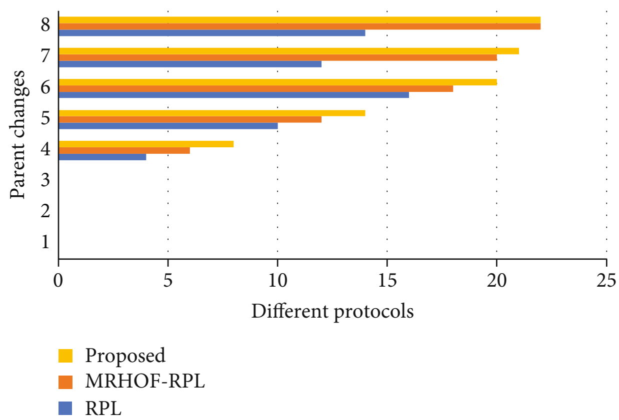

Figure 12: Average number of data concerning various RPL protocol.

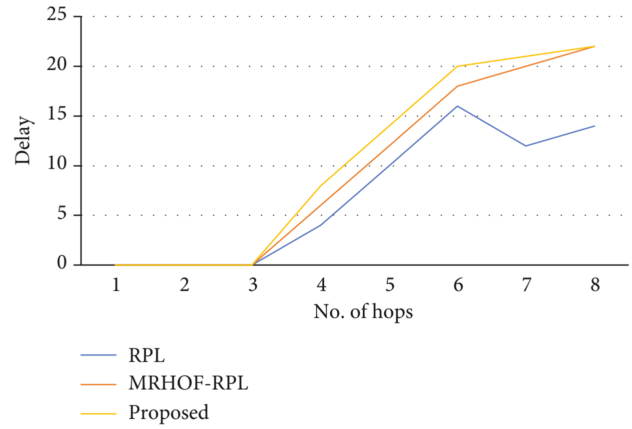

Figure 13: End-to-end delay versus number of hops.

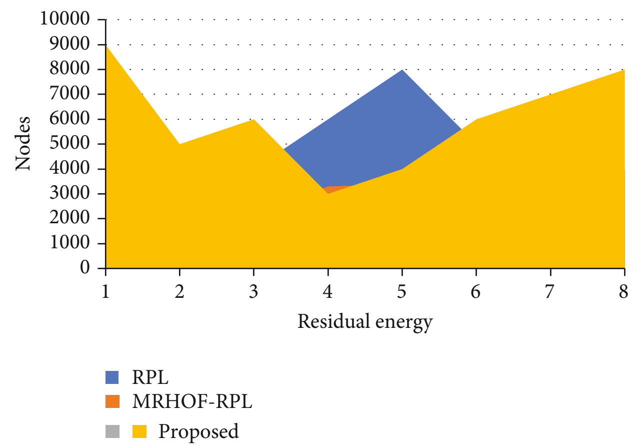

Figure 14: Residual energy of network nodes.

selection, MRHOF-RPL solely considers the ETX measure. The battery is thus prematurely depleted and causes a significant loss of packets. For a network size of 100 nodes, the conventional RPL, FL-RPL, MRHOF RPL, and FLEA-RPL packet loss ratios are 6%, 4%, 5.8%, and 3.8%, respectively. It is experimental that the loss of packets rises with the increased amount of nodes.

Figure 11 demonstrates the loss of packets when nodes fail. The number of nodes that have failed ranges from 0 to 30. It is found that the data loss rises when the failing nodes are increased [33]. FLEA-RPL decreased a packet loss ratio of 11% to 2 and 4%, respectively, for a failed node size of 30 compared with RPL, FL-RPL, and MRHOF-RPL. It is due to the traffic burden in conjunction with ETX and RER for choosing parents. As a result of the number of node failures, the DODAG root may fail because of the exchange of control packets for the route setup.

Scenario 2: data transfer rate with a limited number of data

Figure 6 depicts the parent alteration values of various RPL protocols. To assess the network stability, the parental change value of FLEA-RPL is noted, and its value is likened with standard RPL, FL-RPL, and MRHOF-RPL. The parent change values of standard RPL, FL-RPL, MRHOF-RPL, and FLEA-RPL are 0.3, 0.4, 0.35, and 0.28, respectively. It is observed that the parent change value in FLEA-RPL is low compared to RPL, FL-RPL, and MRHOF-RPL. Figure 12 represents the average number of data concern. It is mainly due to the consideration of the load metric for the parent node selection.

The above Figure 13 depicts the regular end-to-end delay in the number of hops. The end-to-end interruption of standard RPL, FL-RPL, MRHOF-RPL, and FLEA-RPL is 5.5, 5, 4.8, and 4.2 seconds, respectively. The results show that FLEA-RPL takes less delay compared to other protocols standard RPL, FL-RPL, and MRHOF-RPL. It is due to the diversification of network traffic during the parent selection across the network. Figure 14 illustrates network node residual energy with a data transfer rate of six packets per minute. In FLEA-RPL, it is noted that 90% of the network node's residual energy ranges between 62% and 66% approximately. The rest 10% of the network nodes have residual energy around 70% to 72%. FLEA-RPL shows increased network lifetime and residual energy compared to the standard RPL, FL-RPL, and MRHOF-RPL.

The above Figure 14 depicts the packet loss of RPL, FL-RPL, FLEA-RPL, and MRHOF- RPL by varying the network size with the data transfer rate of six packets per minute. The

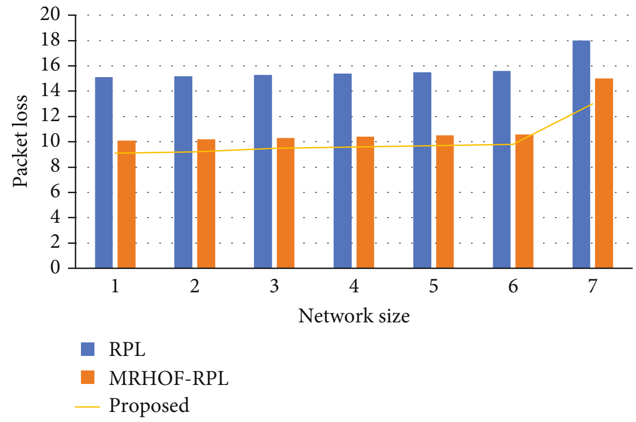

Figure 15: Packet loss in the network.

number of failed nodes varies from 0 to 30. It is observed that there is an increase in packet loss, as the number of faulty nodes increases. As RPL does not consider the link quality metric for the parent selection, it results in high packet loss. MRHOF-RPL considers only the link quality for the parent selection. Hence, the battery depletes early, resulting in high packet loss. For a network size of 100 nodes, the packet loss ratio of standard RPL, FL-RPL, MRHOF-RPL, and FLEA-RPL is 13%, 8%, 12%, and 7%, respectively.

Figure 15 depicts the packet damage in the occurrence of failed nodes, by the transfer rate of six packets per minute. The number of failed nodes varies from 0 to 30. It is observed that there is an increase in data damage, as the number of faulty nodes increases. As RPL does not reflect the link value metric for the parent collection, it results in high packet loss. For a failed node size of 30, FLEA-RPL has reduced the packet loss ratio by 7%, 2%, and 4%, respectively, compared to RPL, FL-RPL, and MRHOF-RPL. It is due to the consideration of traffic load along with ETX for the parent selection [34].

Scenario 3: transmission of data within a certain period

Figure 16 depicts the parent alteration values of various RPL protocols with the transfer rate of ten packets per minute. To assess the network stability [35], the parent change value of FLEA-RPL is noted, and it is compared with standard RPL, FL-RPL, and MRHOF-RPL. The parent change values of standard RPL, FL-RPL, MRHOF-RPL, and FLEA-RPL are 0.4, 0.5, 0.45, and 0.35, respectively. It is observed that the parent change value in FLEA-RPL is low compared to RPL, FL-RPL, and MRHOF-RPL. It is due to the consideration of the load metric for the parent node selection. Thus, FLEA-RPL chooses the optimal parent in the DODAG, and it prolongs the network lifetime.

Figure 17 depicts the end-to-end delay corresponding to the number of hop counts. The latency of standard RPL, FL-RPL, MRHOF-RPL, and FLEA-RPL are 6.5, 6, 5.5, and 5 seconds, respectively. The result shows that the FLEA-RPL takes a smaller amount of interruption compared to other protocols standard RPL, FL-RPL, and MRHOF-RPL. It is due to the diversification of network traffic during the parent selection across the network.

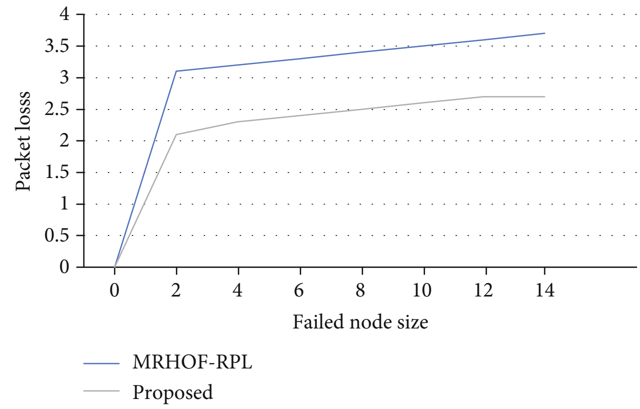

Figure 16: Node failure scenario with lesser packet loss.

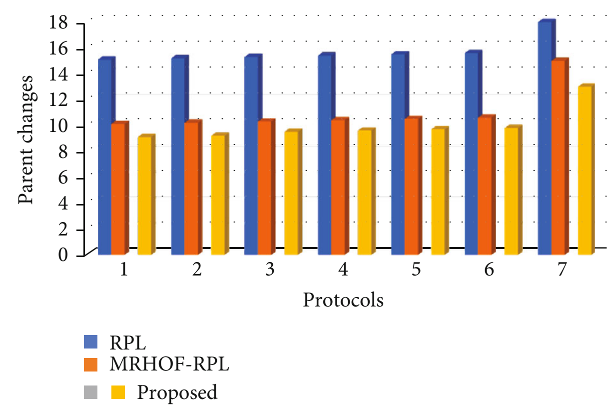

Figure 17: Comparison with different scenarios in the system.

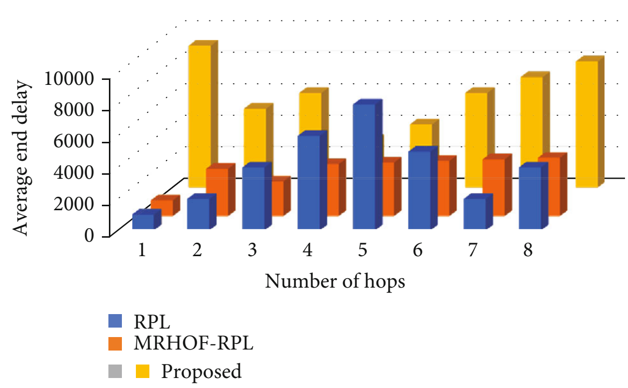

Figure 18: Delay time between the nodes.

Figure 18 shows the residual energy of network nodes when data is transferred at a rate of ten packets per minute, as shown in the example above. There are several interesting findings in FLEA-RPL, such as the fact that the total residual energy of network nodes varies between 51 percent and 56 percent. When compared to the conventional RPL, FL-RPL, and MRHOF-RPL, the FLEA-RPL exhibits increased network lifespan and residual energy, respectively. It is because of the evaluation of RER that the optimum parent selection for data transfer to the DODAG root has been determined for data transmission.

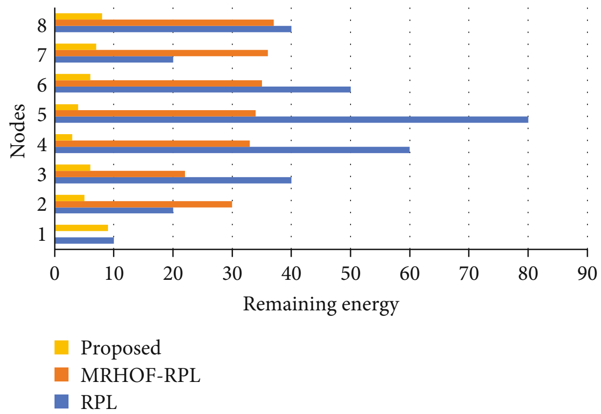

FIGURE 19: Network nodes residual energy.

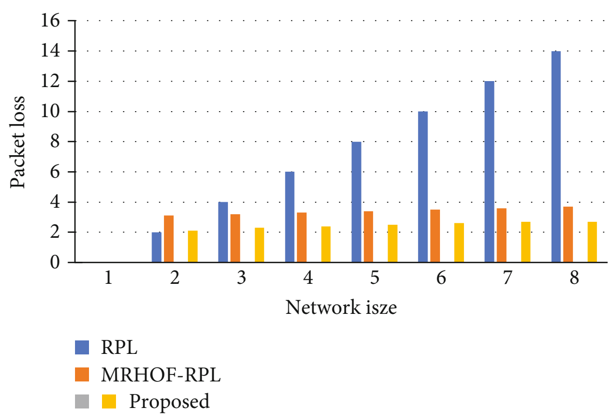

FIGURE 20: Ratio between packets and the network within the system.

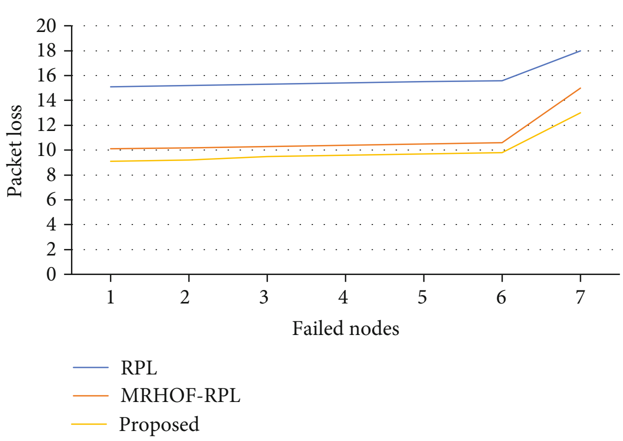

FIGURE 21: Ratio between packet loss and attempted nodes in the protocol.

Figure 19 depicts the packet loss ratio of RPL, FL-RPL, MRHOF-RPL, and FLEA-RPL as a function of network size for the four types of RPL. Packet loss ratios of conventional RPL, FL-RPL, MRHOF-RPL, and FLEA-RPL are 17 percent, 16 percent, 13 percent, and 10 percent for networks with 100 nodes, respectively, according to the packet loss ratio table.

As the number of network nodes grows, it has been found that the amount of packet loss increases as a result. It is due to the evaluation of traffic load, as well as ETX, while making the decision on which parent to use.

Figure 20 depicts the device packet loss in the attendance of failed nodes. The number of failed nodes varies from 0 to 30. It is observed that there is an increase in packet loss, as the number of faulty nodes increases. As RPL does not consider the link quality metric for the parent selection, it results in high packet loss. For a failed node size of 30, FLEA-RPL has reduced the packet loss ratio by 15%, 8%, and 10%, respectively, compared to RPL, FL-RPL, and MRHOF-RPL. Figure 21 represents the packet loss and the attempted nodes in the routing protocol.

5. Conclusion

Because the Industrial Internet of Things devices are energizing, it is essential to route the liveliness on the nodes. The research effort aims to address the Internet of Things routing protocol issues. This is why an enhancement is being made to the standard RPL routing protocol. A Fuzzy Logic-based Energy-Aware RPL (FLEA-RPL) protocol is first and primarily proposed for the Internet of Things. To choose the most suitable route for data transfer, it utilizes a flushing logic for ETX, Load, and RER indicators. The results of the simulation show that it increases the lifetime of the network to a certain extent. Second, the Internet of Things (IoT) Multilayer Energy-Aware RPL (MCEA-RPL) protocol is recommended. The network is organized into clusters of the same size. It then combines fluid logic with the RER and ETX routing parameters to find the greatest way for data transfer. The information is gathered via the cluster head node, then the aggregated data is sent to the sink node. The results of the simulation suggest that as indicated in the table, MCEA-RPL extends network life compared to existing routing protocols. Thirdly, the Internet of Things Enhanced Mobility Support RPL (EM-RPL) protocol is proposed. For the calculation of the hand-off value, the fuzzy logic is applied to the RSSI and PER metrics. If the hand-off value goes above the threshold limit, the system immediately starts to look for an alternate path to avoid the issue. As a consequence, it reduces the number of route breaks caused by movement and the quantity of data transfer. As a result of the simulation results, it is evident that EM-RPL improves network node mobility. Many routing techniques are proposed in this research to prolong the Internet of Things network life. However, as explained shortly below, the proposed work may be extended in the future. A limited number of sink nodes are used in the present research to collect information from the network, which simplifies the architecture.

Data Availability

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

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