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Fuzzy Logic based Object Function to Enhance the Quality of Service in Internet of Things

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Abstract: Internet of Things (IoT) is a developing field, which more number of smart devices are connected together in the resource constrained environment. The routing technique provides an intelligent path between the sender and sink node. Routing Protocol for Low Power Lossy (RPL) Network is the standardized routing protocol in the IoT environment. It has some limitation especially while choosing the best parent among the multiple nodes. By default in RPL, there are two standard objective functions, Minimum Rank with Hysteresis Objective Function (MRHOF) and Objective Function Zero (OF0) which have single metric to select the best parent node. Our Proposed method involves Fuzzy Logic based Objective Functions (FLOF) which includes the four metrics such as Hop count, Energy, Signal Strength and ETX for the selection of the best parent in order improve the reliability. The Performance has analyzed by using Contiki 3.0 Cooja simulation tool. The results obtained from this research work prove that there is an enormous impact in the Quality of Service (QoS) parameters such as packet delivery ratio, throughput, latency and energy consumption with incorporation of FLOF.

Keywords: *Fuzzy Logic, RPL, Routing, QoS, Contiki, Energy, Parent Node.*

1. Introduction

IoT refers to the most recent development in wireless communications technology that allows for the interconnection of various "smart" items, including sensors and actuators. All devices that make up the Internet of Things are linked through a global network, and they exchange data via the internet, in which each device has its own unique address. It refers to a system of interconnected computing devices that share data over the web despite limited resources. Abdmeziem, M.R et.al (2016) IoT is mainly focused on two aspects, one is Network oriented IoT and other one is Generic Objects are connected to a framework. The heterogeneous objects are available in huge number in today environments for the communications. The IoT defines as Internet oriented and things oriented perspectives for the research. It provides an innovation for the Information Communication Technologies (ICT). In order to minimize the human interaction between the devices, internet of things play a vital role in the today's world. IoT technology has come over a period of time, the recent update in IoT has involve in the various aspects of technologies in practical implementation. The manufacturer are using the technology to make the IoT environment with the low cost and low sensor. The consistent sensors make the technology more affordable. The data transfer between the smart devices are connected via sensors and further transfer to the cloud via internet. The IoT is the collection of technologies that enables the connectivity between the devices that are used to make decisions rapidly. When designing a routing system for a wireless network, the goal should be to make the network last longer. The life of the network is extended by using as little energy as possible.

Its primary goal is to make it easier for networks to communicate under limited conditions, such as those seen in the IoT. A dynamic architecture, intermittent connectivity, and low-power devices with limited processing capabilities are the main characteristics of these networks. Directed Acyclic Graphs (DODAGs) are the building blocks of RPL and are used to represent the paths that devices take when communicating with one another.

When it comes to maintaining and updating routing information, the protocol takes a proactive approach. Aghaei, A et.al (2021) Devices periodically broadcast DODAG Information Objects (DIOs), which update the network's structure and available routes. The routing information is kept up-to-date and ready to be used at all times by this proactive approach Manikanthan & Padmapriya (2022). Furthermore, RPL enables reactive routing methods, which enable devices to find routes on the fly in reaction to dynamic network conditions. The fact that RPL can handle the various communication patterns seen in IoT applications including various traffic pattern only adds to its flexibility. Smart homes, industrial automation, and environmental monitoring are just a few of the many applications that can benefit from RPL's adaptability. Loop avoidance and rank-based path selection are built into RPL to tackle the problems of limited devices and rocky connections. Devices inside the DODAG are given ranks by the protocol, which allows for efficient parent selection and loop-free routing. Almusaylim et.al (2020) The Standard objective functions OF0 and MRHOF which used a single metric for select a best parent node, which leads to poor performance.

The modern computer relies on "true or false" (1 or 0) Boolean logic, but fuzzy logic proposes an alternative based on "degrees of truth" that can be used to computing. In the 1960s, Lotfi Zadeh of Berkeley University was the first to propose the concept of fuzzy logic. By adding uncertain and changing variables to the decision-making process, Lamaazi, H. and Benamar (2018). RPL's architecture can benefit from fuzzy logic, which in turn improves path selection. The possible structure of it is as follows: As a method of processing variables, fuzzy logic permits the processing of several potential truth values by means of a single variable. By taking into account all relevant data and determining the optimal course of action based on the input, fuzzy logic is able to solve the problem of selecting the nearby node.

The contribution of the paper is to identify the optimal parent node. Considering the information provided, the primary

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contributions of this research can be succinctly outlined as follows:

• Analyzing and emphasizing the limitations of widely utilized RPL OFs and alternative RPL-based protocols that rely on fuzzy logic for combining measurements.

• Introducing an innovative enhancement to RPL by utilizing a novel combination of link and node metrics, including ETX, Hop Count, Signal Strength, and Energy.

• Employing a new fuzzy logic approach to integrate the four specified input metrics and generate an optimized output for neighbor quality, specifically for parent selection.

• Extensive simulation experiments will be conducted to assess the efficacy of the proposed protocol.

This evaluation will consider energy consumption, packet delivery ratio, latency and throughput. The effectiveness of the protocol will be demonstrated by comparing it with existing works.

2. Literature Survey

Durai.S (2021) enhanced MEQA-RPL that works especially well with IoT networks that have mobile nodes. To find the next preferred parent (PP) for mobile nodes, the process uses the measured several metrics. We test how well MEQA-RPL works by running a lot of scenarios in Contiki Cooja and comparing it to regular RPL and MRPL. Overall, the results show that MEQA-RPL works better than regular. The protocol supports mobility well, keeps signalling costs low, and can be used in a variety of bigger situations. This software, MEQA-RPL, was created to help IoT networks deal with the problems that mobile nodes cause by improving route planning, lowering energy use, and raising quality of service for mobile nodes. The main problem the authors are having is coming up with a routing system that works well with IoT networks that have mobile nodes. This protocol is made to correctly predict paths, use as little energy as possible, and make service better for mobile nodes.

Darabkh et al. (2022) created a novel OF for a number of IoT areas that help connect wireless devices that are limited in resources .The authors use fuzziness and they look at the membership function for each measure as well as a route evaluation rule. The study also looks at simulation results that show how FL-HELR-OF stacks up against other protocols that are similar. The OF makes IoT applications work better by increasing the number of packets delivered, lowering delay, using less energy, and lowering the average hop count. The authors need to come up with a good routing system for networks that meets the needs of users and applications and gets around the problems with current Objective Functions (OFs), which use a lot of power and don't work reliably. They also want to fix the problems with RPL systems' storage and computing.

Savva et al. (2023) test a Fuzzy Logic-based FLIDS to identify IoT network jamming threats. It involves 60 topologies, sink places, and jammer types and a random IoT node placement to test the concept. Contiki OS and Cooja simulator examine FLIDS under varied inputs, topologies, and jammer situations. The technique correctly recognises most attacks in a distributed fashion, with reactive jammers averaging 96.407% accuracy. The research compares FLIDS to other approaches and shows that it can recall 100% of deceptive jammers using only two metrics.

Gopila and Rukmani (2021) devised a Fuzzy Supervised Learning technique for RPL path selection that takes node mobility into account. An optimised objective function employing multi-metrics, fuzzy logic, and supervised learning predicts the quality node. For dependable data delivery, the system predicts the appropriate parent node using remaining energy, signal strength, and queue length. The ANN classifier achieved 93% accuracy in testing, surpassing Naive Bayes and Decision Tree. The results show that the proposed FSS mechanism accurately assesses node quality, improving real-time IoT dependability, energy usage, and latency. The authors' key challenges are node mobility, network stability due to the exponential rise in devices linked to the network, big data management, QoS, and IoT application security.

Gaddour et al. (2014) introduced a novel OF for the RPL routing protocol that combines metrics. Fuzzy logic evaluates neighbour nodes and chooses the best parent for routing. OF-FL significantly improves network performance, supporting numerous parallel applications with opposing requirements. The authors' key problem is designing a new RPL routing protocol goal function that can incorporate various critical routing metrics to find the optimum way to the root while meeting application requirements.

Sankar. S. and Srinivasan. P. (2018) suggested a FLEA-RPL to make networks last longer. Fuzzy logic is used to figure out the quality of parent nodes based on routing metrics. The study also talks about work that needs to be done in the future, like making it possible for nodes in LLN to move around and using the protocol in real-time settings. The authors' biggest task was to find the best way to extend the lifetime while taking into account limitations like limited memory, energy, and data processing power.

Kuwelkar and Virani (2021) created a novel approach for the RPL protocol in IoT networks. Quality is calculated by integrating Residual Energy, Delay, and ETX using Fuzzy Logic. This Quality measure chooses the best parent node for root data forwarding. Under duress, RPL-FZ consumes 8% less power than MRHOF and OF0 and has a 7% greater Packet Delivery Ratio (PDR). RPL-FZ has 8% less latency than other objective functions. Simulations under different network densities and data transmission speeds informed the technique and results. The challenges which have special needs due to limited processing, memory, and battery-powered sensor nodes. Traditional routing protocols are unsuitable for IoT networks.

Sanaboina, C.S. and Sanaboina, P. (2019) proposed a fuzzy logic-based solution to improve the RPL in the IoT to reduce energy consumption. Simulations and assessments are done using COOJA. To save electricity, the fuzzy logic controller integrates Network Size, Mobility Speed, and Imin. Fuzzy logic-based networks use 50% less power than default networks. The fuzzy logic-based approach reduces transmit power, conserving energy in IoT networks, according to simulations.

The RPL routing system should be changed so that low-power, lossy sensor networks that are both fixed and mobile can provide better quality of service. This was suggested by Gaddour et al. (2015). It also shows Co-RPL, an extension of RPL that lets you move and fixes the time it takes to change shapes. Of-FL and Co-RPL cut down on lost bits and network latency much more than the standard specification, as shown by performance studies. Models and real-world tests are used to look at the pros and cons. They also look at Co-RPL and RPL side by side and discover that Co-RPL works better in mobile WiFi networks. The writers had the most trouble with low-power features, severe and lossy situations, and the low computing and storing power of low-power wireless sensor networks. These networks have trouble connecting and talking to each other. The authors had the most trouble with low-power features, harsh and lossy conditions, and the fact that low-power wireless sensor networks don't have a lot of computing or storage power.

A cluster routing protocol called FC-RPL uses fuzzy sets to improve the lifetime of low power and lossy networks (LLN) for Internet of Things applications, according to Sankar and Srinivasan (2019). The process includes clustering, head selection, and parent selection. Clusters are created via Euclidean distance and fuzzy sets for residual energy, neighbours, and centrality. The cluster leader is chosen this way. Data is transported by the cluster head node choosing the best DODAG parent node. FC-RPL enhances packet delivery ratio by 2% to 6% and network durability by 15% to 25%, according to simulations. Due to the restricted power, memory, and compute of nodes, authors struggle to extend the longevity of low power and lossy networks (LLN).

To address the resource limitations of networks, Saaidah et al. (2019) suggested an RPL goal function is to use of fuzzy logic, a new RPL objective function (OF) is generated by combining metrics for nodes and links, such as RSSI, RE, and TH. With three input and one output language variable, OFRRT_FUZZY finds the optimum path using fuzzy inference process (FIP). Cooja and Contiki OS are used to test the method in simulations. After comparing OF0 with MRHOF, OFRRT-FUZZY comes out on top in terms of average latency, packet delivery ratio, overhead, and power usage. With the use of fuzzy logic, a new RPL objective function (OF) is generated by combining metrics for nodes and links, such as RSSI, RE, and TH. With three input and one output language variable, OFRRT_FUZZY finds the optimum path using fuzzy inference process (FIP). Their main concern is with LLNs, or low power and lossy networks, which have low memory capacities, short battery lives, and limited energy. The inefficiency of OSPF for LLNs is caused by these restrictions. In order to deal with resource constraints.

FL-HELR-OF, an RPL objective function for IoT networks, was introduced by Darabkh et al. (2022) to overcome the limitations of single and composite metric-based objective functions Fuzzy logic integrates hop count, energy use, latency, and signal intensity. Authors' modified RPL protocol uses cross-layer routing and PHY/MAC. Many simulations assess several metrics. The suggested protocol's network dependability, energy efficiency, and real-time transmission serve many IoT applications. Limited single and composite metric-based objective functions for IoT networks are the authors' key challenge. Not supporting many IoT apps increases network longevity for some but degrades performance for most. A fuzzy logic and metrics-based RPL aim function will overcome these issues.

Aljarrah (2017) explored using a novel approach to improve IoT network performance. The method uses a unique model with metrics. These metrics are node, channel, and link-oriented. IEEE 802.15.4 on OMNeT++ simulator evaluates the proposed RPL protocol. Enhanced Bidirectional Multicast RPL Forwarding (EBMRF) suppresses duplicate multicast packets. For IoT networks, the RPL protocol provides efficient unicast and multicast forwarding. Due to the limits of single fuzzy logic systems, the authors designed a multi-fuzzy model to improve earlier research answers. This multi-fuzzy model uses node-, channel-, and link-oriented metrics.

Mehbodniya et al. (2022) proposed an IIoT Fuzzy Logic Energy-Aware Routing Protocol (FLEA-RP) that makes use of blockchain technology to lessen the load on networks and increase their lifespan. An energy-efficient IoT is built using a fuzzy logic framework. This protocol diversifies network traffic and minimises overhead control messages. In the COOJA network simulator, FLEA-RP is compared against RPL, FL-RPL, and MRHOF-RPL. The findings demonstrate that the FLEA-RP protocol improves reliability, energy consumption, end-to-end latency, and lifespan. In order to decrease qos parameters and network expenses, manage mobility issues, and increase the network's lifespan, the authors are tasked with designing energy-efficient data transmission methods for IoT networks.

3. Proposed Methodology

The multi-metric technique to developing an optimal objective function uses link and node measurements. A unique method uses fuzzy logic and the best parent selection to pick the best data transmission path. Figure 1 shows node selection metrics.

Fuzzification is the process by which a precise input value is converted into a fuzzy set or array. Applying Fuzzy Logic in protocols for routing can enhance their performance. In Fuzzy logic, two crucial terms are linguistic variable and membership functions. In Figure 3.1 shows the Fuzzy logic metrics of FLOF which is used for selecting the best node.

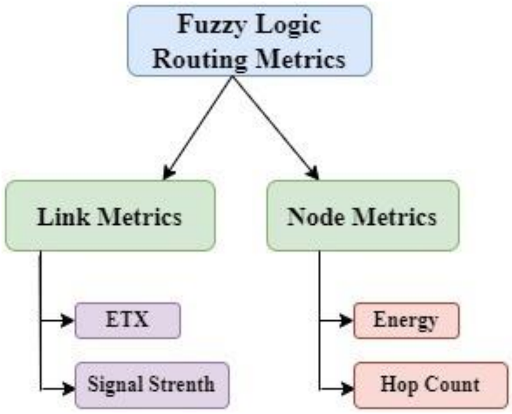

Fig. 3.1. Fuzzy Logic Metrics

Hop Count Metric:

It is a metric that quantifies the network devices, such as routers, that a data packet needs to pass through in order to go from its source to its destination. Each "hop" denotes the action of a singular equipment transmitting the packet to the subsequent device along the path. RPL employs hop count as a key indicator for determining the most efficient path for forwarding data.

Energy:

Energy metrics are essential tools for monitoring and optimising energy usage in many systems, such as wireless networks, mobile devices, and even buildings. These indicators offer useful insights into the utilisation of energy and illuminate possible areas for enhancement.

ETX:

The Expected Transmission Count (ETX) is a key metric of connection quality in RPL and calculate the average packet delivery transmissions.

Signal Strength:

The signal strength measure is essential in wireless networks as it serves as a significant indicator of the quality and performance of the connection. Within the framework of RPL it delivers useful perspectives for enhancing data transfer and network effectiveness.

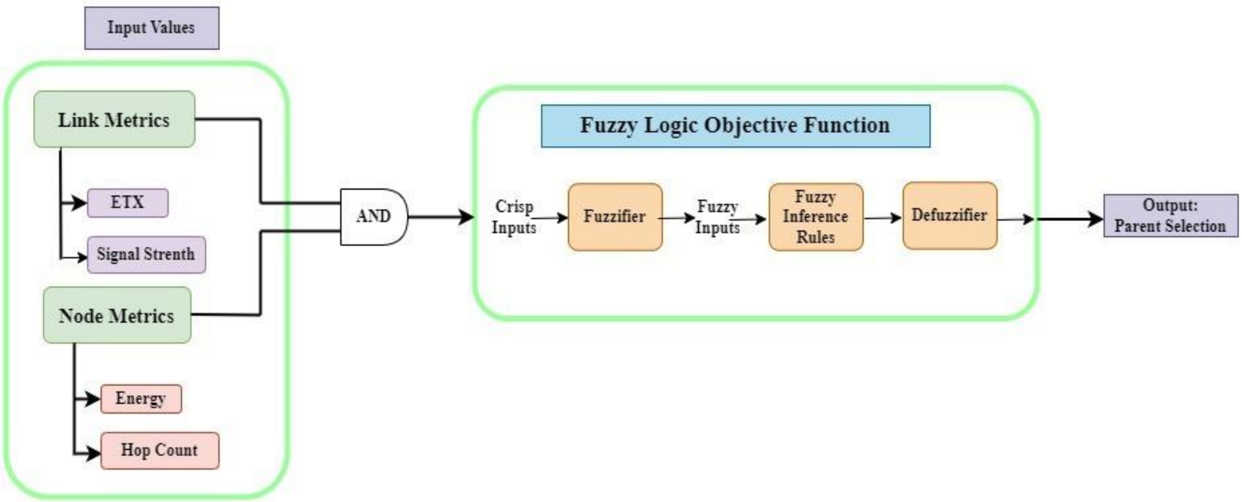

Fig. 3.2. FLOF-Fuzzy Logic Based Objective Function

In Figure 3.2 the proposed framework of FLOF is depicted. Design membership functions that meet two conditions: Each membership function must overlap with its nearest neighbours. The sum of all applicable fuzzy set membership values for any input variable should be 1 or close to it.

Input Variables:

- ETX: Fuzzy sets: Very Low, Low, Medium, High, Very High
- Hop_Count: Fuzzy sets: Very Short, Short, Medium, Long, Very Long
- Signal_Strength: Fuzzy sets: Very Weak, Weak, Medium, Strong, Very Strong
- Energy: Fuzzy sets: Very Low, Low, Medium, High, Very High

Output Variable:

Parent Selection: Fuzzy sets: Not Recommended, Low Priority, Medium Priority, High Priority, Very High Priority.

Rules:

1. IF ETX is Very Low AND Hop_Count is Very Short AND Signal_Strength is Very Short AND energy is Very High THEN Parent_Selection is Very High Priority.
2. IF ETX is Low AND Hop_Count is Short AND Signal_Strength is Short AND energy is High THEN Parent_Selection is High Priority.
3. IF ETX is Medium AND Hop_Count is Medium AND Signal_Strength is Medium AND energy is Medium THEN Parent_Selection is Medium Priority.
4. IF ETX is High AND Hop_Count is Low AND Signal_Strength is Weak AND energy is Low THEN Parent_Selection is Low Priority.
5. IF ETX is Very High OR Hop_Count is VeryLow OR Signal_Strength is VeryWeak OR energy is VeryLow THEN Parent_Selection is Not Recommended.

Table 1. Fuzzy Rules

ETX	Hop Count	Signal_ Strength	Energy	Parent Selection Output metric
Very Low	Very Short	Very Short	Very High	Very High Priority
Low	Short	Short	High	High Priority
Medium	Medium	Medium	Medium	Medium Priority
High	Low	Weak	Low	Low Priority
Very High	Very Short	Very Weak	Very Low	Not Recommended

Based on the rules above, the best parent node has selected and its optimized. The Maximum priority node has been choose and its transfer the packets to the nearby node, the process is repeated until it reach the destination.

4. Simulation Results

An analysis has been conducted on the performance of the FLOF algorithm in evaluation with other OF. The examination focused on the packet delivery ratio and average energy consumption. The simulation was performed using the Contiki 3.0 with Cooja simulator, with the simulation settings indicated in Table 2.

Table 2. Simulation Settings in Cooja

Simulation Parameters	Values
OS	Contiki 3.0
Network Simulator	Cooja
RPL OF	OF0,MRHOF,FLOF
Radio Medium	Unit Disk Graph Medium (UDGM)
Sky Nodes	25,50,75,100
Loss Models	Distance Loss
Deployment area	100*100
Transmission	50
Reception ratio	50
Mote	Sky mote
Interval doublings	8

Interval Imin	12
k	3
Network Layer	RPL
End to End	UDP
Simulation Time	1200s

Power Consumption:

The power consumption of a node when it is in each of the system's four states: CPU, LPM, TX, and RX. Mill watts (mw) are the units of measurement for power. The formulas provided below are used to calculate it

$$\text{Power of a Node (mw)} = \text{CPU Power} + \text{LPM Power} + \text{Listen Power Transmit Power}$$

where,

CPU Power: Average CPU power consumption.

LPM Power: Average power consumption while in Low-Power Mode (LPM).

Listen Power: Average power consumption while listening for packets.

Transmit Power: Average power consumption while transmitting packets.

The Figure 4.1 shows the average power consumption of the nodes for the three objective functions with various nodes.FLOF have minimum power when compare with other two objective functions.

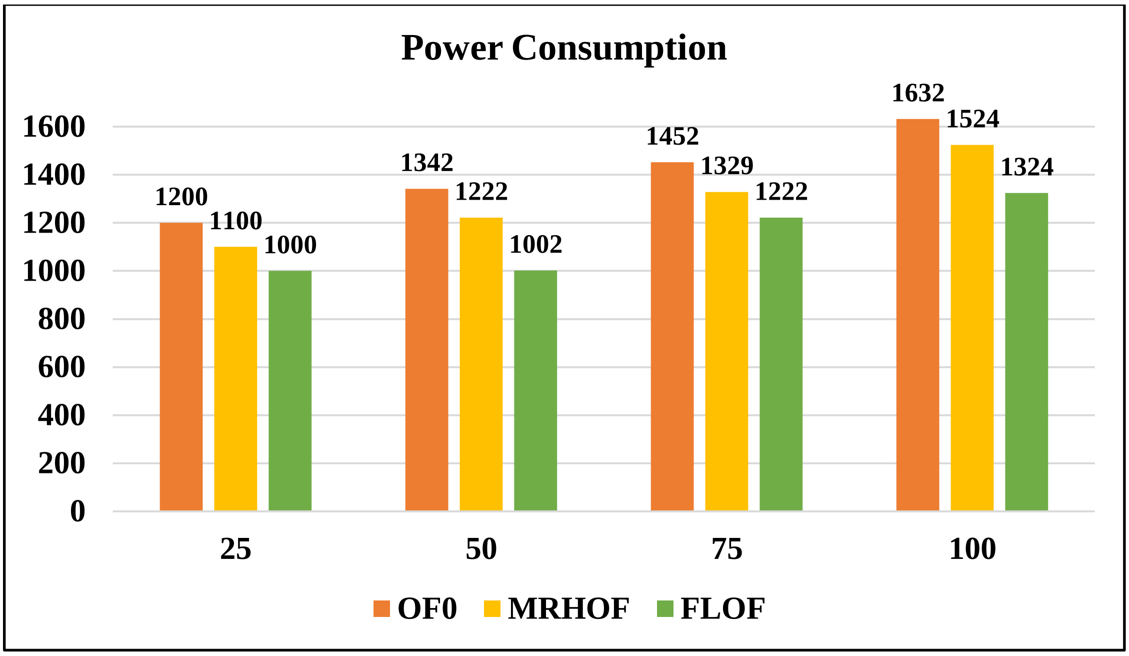

Fig. 4.1. Average Power Consumption

Packet Delivery Ratio

The ratio of effectively delivered packets to the number of packets sent within the network. It is a metric used to assess the effectiveness of the routing protocol in terms of reliable packet delivery. High PDR values indicate a more efficient and reliable communication in the network, while lower values may suggest packet losses and potential challenges in data transmission. The Figure 4.2 shows the Packet Delivery Ratio for the three objective functions with various nodes.FLOF have minimum PDR when compare with other two objective functions.

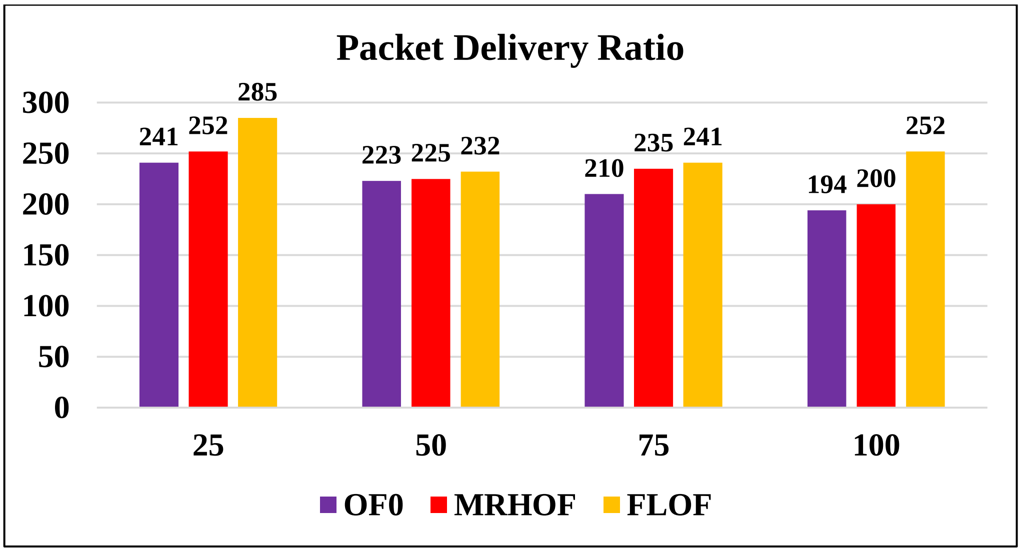

Fig. 4.2. Packet Delivery Ratio

Latency

Latency refers to the time delay experienced in the transmission of data between two points in a system. It includes processing, transmission, and propagation times to transport information from source to destination. Latency is a crucial metric in computing and communication systems, and it is often measured in milliseconds (ms). The Figure 3 shows the Latency for the three objective functions with various nodes.FLOF have minimum latency when compare with other two objective functions.

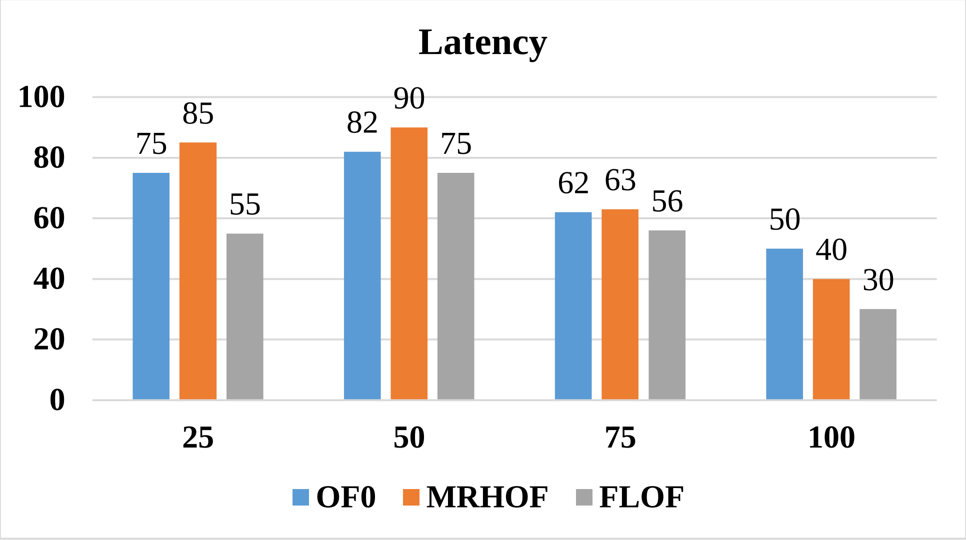

Fig. 4.3. Latency

Throughput:

Throughput quantifies the speed at which data is effectively transmitted across a network or processed by a system during a specified period. The term refers to the precise quantity of data that is successfully transmitted, without taking into account any additional data or repeated transmissions. The Figure 4.4 shows the throughput for the three objective functions with various nodes. FLOF have maximum throughput compare with other two objective functions.

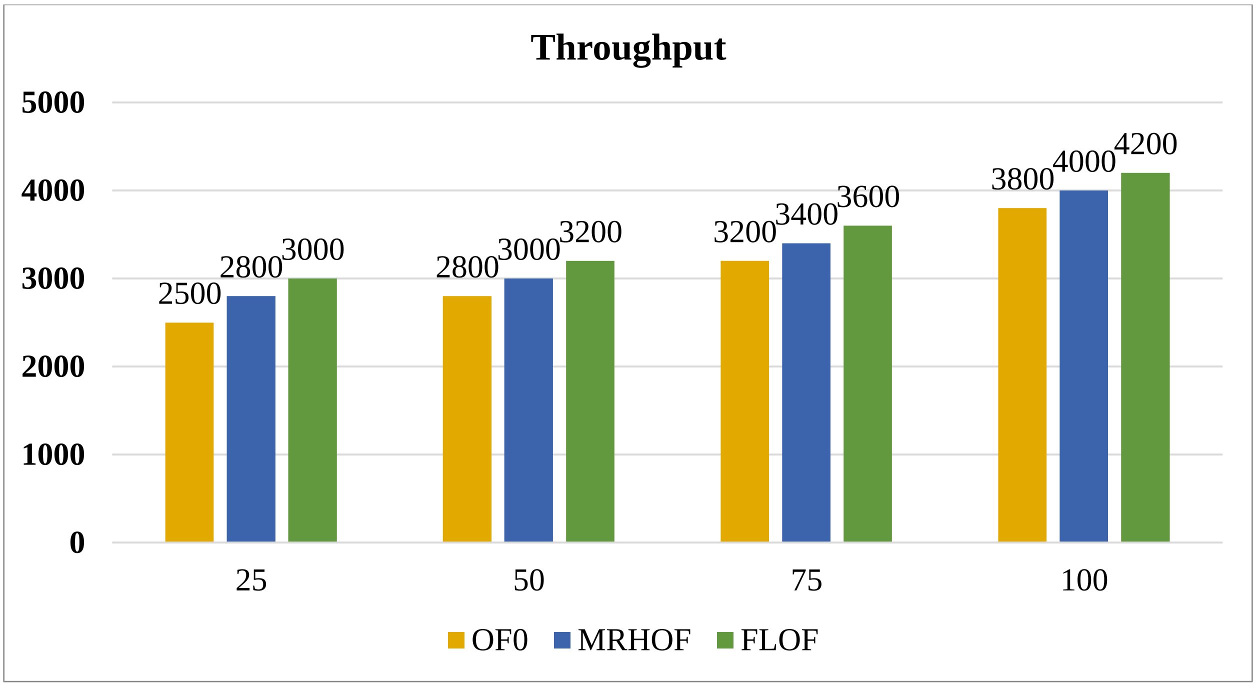

Fig. 4.4. Throughput

5. Conclusion

In this research, we proposed FLOF where the node wishes to communicate with the root via the parent node. Out of its multiple parents, it selects the highest-quality one. Fuzzy logic is applied for the selection of parent by considering these routing metrics such as energy, ETX, hop count, and signal intensity to determine the quality of the parent node. The parent node chosen for data transfer is the one with the highest quality value among the proposed parents. Simulations show that FLOF outperforms MRHOF and OF0 in packet delivery ratio and network longevity. In future, Fuzzy logic based RPL routing will be used in real time environment.

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