

Multi-objective fuzzy-based RPL routing for enhanced QoS in IoMT video data transmission

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Abstract

The internet of multimedia things (IoMT) is an emerging field experiencing significant global growth and popularity. It supports the implementation of various multimedia content-based applications, notably wireless multimedia sensor networks (WMSNs). The standard internet protocol version 6 (IPv6) routing protocol for low-power and lossy networks (RPL) is utilized for broadcasting both scalar internet of things (IoT) and IoMT data traffic. This research introduced an efficient fuzzy-based routing strategy for IoMT applications, aimed at selecting the optimal routing path for video broadcasts. The study emphasizes the quality of experience (QoE) and quality of service (QoS) during video data transmission. The performance of the proposed multi-objective fuzzy-based routing is evaluated against existing approaches, focusing on energy consumption, delay, and throughput. The efficacy of the proposed RPL protocol, along with other state-of-the-art RPL protocols, is assessed across varying node counts. At 20 nodes, the proposed RPL protocol demonstrates superior performance, achieving an energy consumption of 0.089 mJ, a network throughput of 0.79 Kbps, and a delay of 0.090 seconds. Other performance metrics, such as the structural similarity index measure (SSIM) and the peak signal-to-noise ratio (PSNR), are recorded at 97.23 and 35.45, respectively, highlighting the effectiveness of the proposed methodology.

Keywords

Internet of multimedia things, Quality of experience, Quality of service, Routing protocol, Wireless multimedia sensor networks.

1.Introduction

Smart environments such as internet of multimedia things (IoMT) have led to significant variation in data streams. Recently, visual sensors are becoming very prevalent, for example, mobile phones and closed-circuit television (CCTV) cameras develop greater amounts of unstructured data streams [1–3]. Moreover, with the development of multimedia devices, a wide range of IoMT applications are utilized for the transmission of data streams [4, 5]. A network having diverse range of applications provides stronger support compared to the internet of things (IoT) environment because of the development of multimedia information in the network.

IoMT applications such as video-on-demand and video conferencing face greater challenges in assuring many quality of service (QoS) concerns like bandwidth, delay and packet loss rate [6–8]. Delivering a video stream is a significant challenge particularly in terms of mitigating data loss, as the latter is characterized by large packet sizes sent by the media access control (MAC) and physical layer (PL) [9, 10]. The inability of a communication protocol to differentiate among various types of packets, circulating inside a network, is another issue that worsens the QoS. Scalar data and video data must be adequately distinguished if the QoS criteria is to be fully met for the majority of applications [11,12].

Additionally, it is majorly revealed that networks are known to be subjected to few constraints like bandwidth limitation, minimum processing units and power utilization, leading to a decrease in the quality

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of the communication [13–15]. IoT systems are established on low-power and lossy networks (LLNs), and obtain unnatural resources which provides flexibility to any routing protocol for use in limited-resource applications.

Routing protocol for low power and lossy networks (RPL) is the consistent routing protocol for IoT, as described by the internet engineering task force (IETF) routing group for LLN [16]. RPL is an efficient distance vector routing protocol (DVRP) that arranges a network into a tree structure known as a destination-oriented acyclic graph (DODAG). In RPL, every node chooses its parent based on particular routing strategies [17]. The routing protocol is distinguished by its flexibility to select random impartial function as per the application's concerns. However, the transmission of video using the RPL network leads to very high energy consumption and transmission delay [18]. Hence, selection of an optimal routing path plays a significant part in transmitting a video sequence with minimum energy usage and delay [19, 20]. However, the existing researches do not consider the issues related to energy utilization and time delay, and that is why these issues serve as the motivation for this research. In this research, an effective routing is developed, which helps in the process of selecting optimal routing path using the proposed fuzzy-based RPL protocol.

The primary contributions of this research are as follows:

1. This study introduces an effective multi-objective fuzzy-based routing approach system to detect the optimal path for transmitting video data in the IoMT medium.
2. The fuzzy-based approach considers both QoS metrics and quality of experience (QoE) metrics by allotting conditions as low, medium, and high. These three conditions prioritize the path based on the quality of the video.
3. The proposed fuzzy-based approach utilizes a mechanism to select the optimal path which minimizes the delay while transmitting data packets.

The remainder of the paper is organized as follows: Section 2 details the related works based on routing in IoMT, and section 3 presents the proposed method. The results obtained while evaluating the proposed approach are represented in section 4, section 5 presents the discussion and finally, section 6 describes the conclusion.

2.Related works

In this section, the recent researches based on routing in IoMT are described. Shahbakhsh et al. [21] suggested a multi-instance variant of RPL for creating a novel routing strategy, to improve the quality of compressed video. The suggested system had two types of frames with various priorities that were delivered based on the corresponding instances of node disjoint (ND) and link disjoint (LD). With a low energy consumption rate, the suggested system effectively differentiated between prioritized and non-prioritized video frames. However, the suggested system failed to impose a higher priority on QoS.

Bouacheria et al. [22] introduced an improved version of RPL known as multi-instance RPL (MI-RPL). This routing protocol was suggested to overcome the restrictions that existed depending on the RPL storing mode. The MI-RPL diminished the total control messages by prohibiting the insignificant messages when a new node was needed to join the saturated node. Thus, the suggested protocol diminished the network overhead and helped to minimize energy usage while transmitting data. However, the suggested approach was not valid for larger networks.

Bouzebib and Hadj [23] introduced the multi-path routing protocol for low power and lossy networks (MP-RPL) which was an advanced form of RPL used for developing multiple end-to-end paths with several qualities according to the measurements of radio link quality. The intention behind suggesting this approach was to enhance the quality of video delivery in IoMT. This framework constructed paths while considering video characteristics along with feasibility and acceptance of QoS, in the applications related to multimedia. However, the suggested approach was not flexible enough to take into account the precedence level of each packet, which affected the delivery process of video.

Bidai [24] introduced an improved version of RPL known as free bandwidth of RPL (FreeBW-RPL) where data was significantly distributed in many multimedia devices. The suggested routing protocol introduced an objective function (OF) that evaluated every individual layer of the sensor network. Moreover, QoS routing challenge was opted for, while selecting the route to evaluate the efficiency of FreeBW-RPL in the applications related to multimedia. Nonetheless, the suggested protocol overlapped with other packets when the routing path became congested.

Bouzebiba and Lehsaini [25] introduced a disjoint multipath RPL protocol to provide QoS in IoMT. The suggested multipath protocol offered enhanced available bandwidth to suitably adopt itself for higher number of applications. Moreover, the suggested framework utilized a precedence-based minimum complexity encoding-based plan that collected images from video data. The suggested framework replicated the highest priority data in more than one path. The replication of high-priority packets helped to achieve the highest performance. Nonetheless, the rate of distortion of the suggested framework was high which also enhanced the complexity.

Kettouche et al. [26] introduced a distributed scheme for an energy-efficient target recognition based on energy efficiency in IoMT. The suggested approach detected an activity of significance before performing communication based on shape-based description which helped to enhance the network lifespan. The suggested framework focused on specification and design, thereby helping to develop a routing protocol based on a low energy consumption scheme. Nevertheless, the suggested framework did not examine the multi-objective fitness functions.

Alsabhan et al. [27] developed a variability of trust-based technique. The hierarchical trust-based approach called CTrust-RPL was suggested to estimate the node based on progressing activities. To preserve computing, storage, and energy sources at node level, the complex trust-related computations were sent to the controller present in the larger layer. To address increasing strains of dispersed IoT and security added probable assaults, C-Trust technique required a distributed and accessible trust-based technique.

Ul et al. [28] developed LLN with RPL to offer an energy efficient routing. The suggested framework considered multi-OF which included packet energy correlation index (PECI). The correlation offered by Peci provided information related to the node's ability to manage the waiting time of packets.

Jaisooraj and Madhu [29] proposed an energy-efficient and mobility optimization-based RPL framework to achieve a stable and reliable protocol. An mRPL-based firefly optimization algorithm was introduced to improve the performance of end-to-end delay, packet delivery ratio (PDR), and power consumption. Low energy and limited resources were the limitations of this work which needed attention while building mobility management networks. For

further research, the number of mobile nodes was increased for real-time applications used in internet protocol version 6 (IPv6) over low-power wireless personal area networks (6LoWPAN) with network security.

Manikannan and Nagarajan [30] presented metric-based RPL trustworthiness scheme (MRTS) that included trust evaluation for secure routing topology. Creation of this scheme addressed the lack of reliable security measures in RPL. Many simulations demonstrated that MRTS was effective in terms of throughput, energy usage, nodes' rank changes, and PDR. The study claimed that MRTS was usable as a strategy for the repeated Prisoner's Dilemma which showed its cooperative execution characteristic. MRTS needed to meet more necessities like mobility, and its functionalities were tested against various frame rates.

Djedjig et al. [31] introduced parental change control routing protocol for low power and lossy networks (PCC-RPL) that prohibited the unsolicited parent changes by using trust-based concepts. In PCC-RPL, the parents monitored the activity of children and when the malicious behavior was noticed by parents, the trust level on the children node was diminished. The suggested approach offered better throughput and minimal energy consumption which was considered as the significant parameter in RPL routing.

Pishdar et al. [32] introduced dynamic RPL routing in IoT with an effective topology management. The dynamic RPL offered an effective support in a distributed manner to achieve high network performance and stability. Moreover, the RPL of helped in the process of selecting optimal route with high network performance and stability. Yet, the topology was varied when it was used to defend the security attacks.

Alsukayti [33] introduced energy efficient RPL protocol in the IoT environment. The RPL protocol introduced in this research effectively minimized the control overhead and helped to enhance the efficiency. Yet, a significant power loss occurred for larger scale of sensor networks. Prabhavathi and Balakrishna [34] introduced a dual context-based routing and load balancing RPL protocol in IoT networks. Initially, the grid section was performed where the network area was split to various levels on un-uniform grids. The selected grid was used in the process of classifying the data which was received from the Adam deep neural network (ADNN) which offered an optimal routing

performance. But the parent relied only on the single node which diminished the routing efficiency while selecting the optimal path.

Kumar and Hariharan [35] introduced energy and delay aware data aggregation routing protocol in IoT. The suggested approach comprised of two processes which were selection of parent and data aggregation. The process of selecting parent relied on residual energy which helped to select the optimal parent for transmitting the data. The data aggregation utilized compressed sensing wherein the parent node was combined with the data packets to select the optimal routing path. Sennan et al. [36] introduced ranking-based RPL protocol for multipoint data communication in IoT network. The OF for multimodal sensor data were introduced on the basis of ranking RPL. The introduced RPL enhanced the throughput and minimized the loss in terms of energy and delay. This enhanced the throughput and minimized the loss for parent selection also. However, the suggested protocol was not suitable for multimedia data transmission.

Refaee et al. [37] introduced a fuzzy dynamic trust-based RPL with butterfly ant optimization algorithm (FDT-RPL+BAOA) for optimized routing protocol. By integrating FDT-RPL+BAOA for LLN enhanced the data transmission security. The FDT-RPL+BAOA was highly effective in removing error rates and was adaptive to sudden changes in the network topology. Still, the energy consumption of the FDT-RPL+BAOA was higher due to the instability of the nodes while transmitting the information.

Wang et al. [38] developed a reliable and effective routing mechanism based on deep learning with service customization (DL-SC) for IPv6 network. The initial module applied neural network to learn difficult function and it rapidly output in win-win customized strategies according to user demands. Then, IPV6 neighbor unreachable detection (NUD) was taken as link status to discriminate service performance. The suggested protocol enhanced the construction of tree by prohibiting the transmission of packets. Still the suggested protocol consumed more energy while transmitting nodes with lower ranks.

Idrees and Witwit [39] introduced cooperative and feedback-based trustable energy-efficient routing protocol (CFTEERP). The suggested protocol

evaluated the local trust value and the global trust value for every individual node with the help of attribute nodes and k-means estimation procedures. CFTEERP utilized the nearest secure node instead of selecting just the nearest nodes, for routing data. This helped to enhance the network lifespan. In spite of this, the introduced routing protocol was incapable of handling the neighbor-based routing. Ghanbari et al. [40] introduced a new lightweight routing protocol for IoMT-based LLN using fuzzy-logic method. The developed IoMT-based fuzzy RPL was developed to enhance the performance of routing. The metrics used were, receiving signal strength indicator (RSSI), and hop count, to create a fuzzy interface system in the network for preserving energy. However, its required different topology when applied for defending the security attacks.

It is hence seen that the limitations faced by the existing approaches are mainly energy consumption and delay, which are due to inappropriate selection of routing path for transmitting video data. So, this research develops an effective routing approach using a multi-objective fuzzy-based technique.

3.Methods

Multi-objective fuzzy-based routing for transmission of video data in IoMT applications

An effective multi-objective fuzzy-based routing approach was proposed which enhances the routing functionality to select the optimal routing path for the transmission of video in applications related to IoMT. The research focuses on both the QoS and QoE during video data transmission to evaluate the user's experience. The QoE metrics of peak signal-to-noise ratio (PSNR) and structural similarity index measure (SSIM) are considered along with the QoS metrics of energy consumption, throughput and delay. The process involved in the selection of optimal routing path to transmit the video sequence is diagrammatically depicted in *Figure 1*.

3.1RPL

The RPL [41] is a kind of DVRP performed for LLN. This protocol helps to support point to multi-point traffic patterns and offers an overall structure for the routing process. The network topology is organized using the DODAG, where each path is rooted with individual points that play as sink nodes [42, 43].

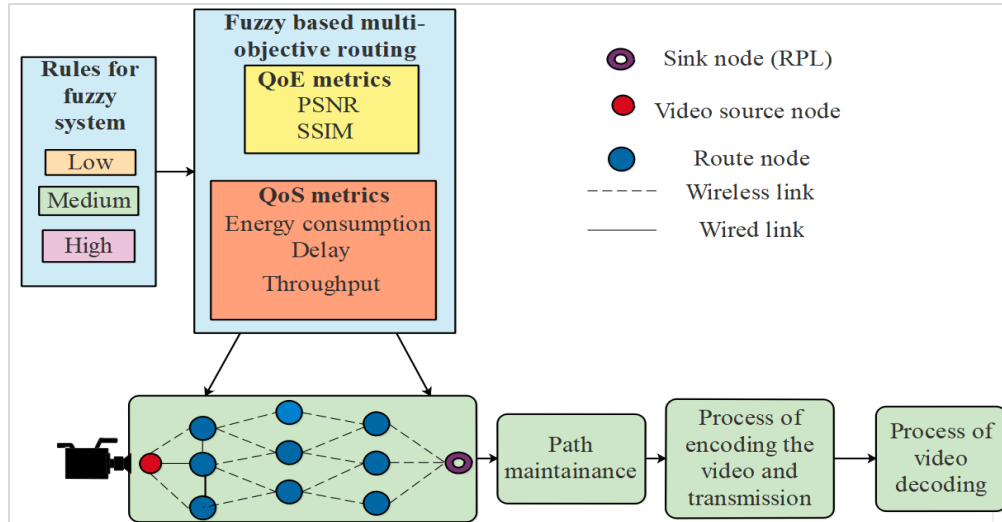


Figure 1 The process involved in the selection of a routing path for video data transmission

The new types of internet control message protocol version 6 (ICMPv6) are described as DODAG tree that are entrenched according to the message types as:

- (i)Directed acyclic graph (DAG) destination information object (DIO) - It is controlled between root and child nodes for topology design.
- (ii)Destination advertisement object (DAO) - It is controlled between the child node and root to contribute and substitute a routing table.
- (iii)DODAG Information solicitation - It is managed between node and network to request DIO.
- (iv)Destination advertisement object acknowledgement (DAO-ACK) - It is controlled in reply to messages through DAO.

RPL pursues certain values for topology maintenance and detecting the routing path.

- RPL instance ID: It is utilized to indicate the existence of one or more topologies of DODAG, which are autonomously improved from the number of OF.
- DODAGID: It is depicted as an indispensable value which includes every single DODAG tree. It is integrated with a value known as RPL Instance ID which supports for the creation of an integrated DODAG in the network.
- DODAG version number: A specified value indicates the different topology in DODAG. Additionally, a specified value is integrated with DODAGID, while the RPL Instance ID supports for the analysis of DODAG version.
- RANK: A specified parameter indicates the location of node-to-node presented in a root. The rank is a significant value that depicts the distance root of the node.

3.2System model

Wireless multimedia sensor network (WMSN) [44] is based on IoMT and consists of N number of sensor nodes with various roles and communication links. This research considers the multi-point to point (MP2P) traffic [45] scheme between WMSN and its individual root nodes. The source node captures the video sequence and transmits it to the sink node through a single interface. All the video packets from the source node are received at the destination node, and then reconstruction takes place. This research is based on RPL routing to develop a number of routes to the root node by considering QoE and QoS.

3.3Multi-objective fuzzy-based routing path selection

The data is obtained from WMSN and the multi-objective fuzzy-based system allows a specified value for each sensor node before the stage of deployment. The suggested approach detects the high-quality paths to transmit the video which satisfies the aforementioned QoS metrics and QoE. The suggested approach utilizes minimum rank with hysteresis objective function (MRHOF) based on estimated transmission count (ETC) routing to select the number of paths alongside avoiding the traffic during the time of video transmission. This strategy of an effective routing path selection is deployed with the help of the proposed fuzzy rule-based approach. The proposed approach has the ability to adapt to variations in network topology, mobility of nodes and traffic pattern. The proposed fuzzy logic approach dynamically adapts itself to the routing path to accommodate node mobility and reconstruct the routing table. Secondly, the suggested approach is

scalable to make decisions in selecting routing path for the IoMT network. The fluctuations in the IoMT network lead to variations. So, the proposed fuzzy logic method is utilized to adapt itself to the factors like network congestion and QoS.

The suggested approach is highly capable of handling multiple number of criteria and helps in effective scaling, thereby accommodating itself with the diversified needs. The multi-objective routing path approach considers the high throughput path to transmit the data packets with minimum delay. However, ETC does not consider the balance among nodes, thereby resulting in more energy consumption. So, the proposed fuzzy-based approach considers QoS/QoE as a major concern by prioritizing the paths as low, medium, and high. The hysteresis mechanism is utilized to select the optimal path which minimizes the delay while transmitting data packets. The ETC is evaluated based on the Equation 1 as follows:

$$ETC = 1/(Df \times Dr) \quad (1)$$

Wherein the probability of forward delivery ratio is known as Df and the probability of reverse delivery ratio is referred to as Dr .

3.3.1 Parent selection based on the priority levels using fuzzy logic

According to the fuzzy-based RPL technique, the routing path is prioritized as low, medium, and high, which is comparable to the stages involved in DODAG creation. When choosing the parent node using a ranking approach, the variations such as node connectivity, signal strength and delay are carried out. Based on this criteria, the suitable parent nodes are selected to make sure efficient and reliable data transmission. In the native RPL, a DODAG topology

is initially constructed before the data is transmitted over the network. As a result, in this initial stage, the root relays a DIO message to nearby nodes. Various important details including node rank, OF and metrics are included in this message. Initially, a node receives a DIO which extends the address of the sender to its parent report and determines its rank by DIO. The highest membership value for the membership function of the set of different values is shown in Equation 2:

$$\begin{aligned} Max_{\mu_{low}x} &= 0; Max_{\mu_{medium}x} = \\ 0.5; Max_{\mu_{high}x} &= 1; \end{aligned} \quad (2)$$

The node must delete every node in the parents' inventory which defies a tedious rank order if it is already a member of DODAG; however, the currently obtained DIO improves its rank in DODAG with respect to ignoring the routing loops. If a node is set up to play as a router in either scenario, it sends a DIO containing modified rank data to its neighbors. This procedure is repeated at every router until every node in a network joins the DODAG to create a topology with a tree structure. Each node that has joined DODAG chooses from a list of all of its parents. The parent that transfers traffic to DODAG's root most frequently, is chosen. To ensure convergence and loop-free operation, the recommended parent is typically a neighbor, which broadcasts the lowest rank value. Of course, each node's desired parent determines the default path. The fuzzy-based RPL routing works under three conditions, low, medium and high. The frame count from 5 to 7 is considered low, 8 to 10 is considered medium, and 11 to 12 are high. The precedence levels based on the number of frames are diagrammatically depicted in Figure 2.

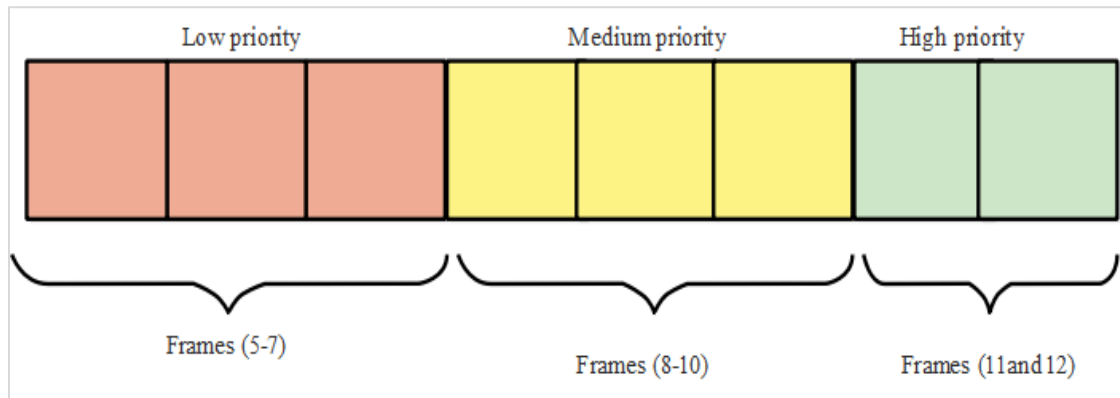


Figure 2 Priority levels based on the number of frames

The proposed fuzzy-based approach prioritizes the videos into three levels. The video data is transmitted

to the nodes based on the priorities (i.e. quality of the video). At first, the highest priority frames (11,12) are considered that are then followed by the frames with

medium priority (i.e. 8-10) and finally, the frames with the least priority (i.e. 5-7) are considered. The priority levels are allotted by the proposed fuzzy-based approach by considering the QoS parameters of energy consumption, delay and throughput. Furthermore, the QoE metrics, PSNR and SSIM are considered for defining the effectiveness of video transmission to the destination node. The weighted sum approach is utilized to optimize the multi-objective functionalities, and to solve the issues such as high energy consumption and high delay, by choosing the scalar weights which is based on Equation 3.

$$U = \sum_{i=1}^k w_i F_i(x) \quad (3)$$

The selected weights are represented as w_i , and F_i is the sum of fitness functions considered for evaluation (i.e. $F_i = \text{energy consumption} + \text{delay} + \text{throughput}$).

Whenever all the weights are positive, minimizing the Equation 3 offers sufficient condition to optimize the multiple objectives considered in this research. Three end-to-end paths, P_l , P_m and P_h are introduced at the time of the DODAG process. The nodes that pass through the path P_h are referred to as highly prioritized nodes, which are the most preferred parents. In the same way, nodes of path P_m are selected as the medium prioritized nodes, which are the second most preferred parents, while P_l nodes are selected as the least prioritized nodes, and are chosen as the third preferred parents. The algorithm of multi-objective fuzzy-based approach utilized in selecting the routing path is described as follows:

Algorithm 1

Input: Node N , Parent Node PN and Sender Node parent

Output: Selected parent N

- 1 Setup the topology, rank and RPL
- 2 Generate a membership function for RPL
- 3 Generate the fuzzy rule
- 4 Transform the input value to a fuzzy value based on preferred node
- 5 Integrate the fuzzy-based rules for frame selection
- 6 Perform de-fuzzification to transform fuzzy values to individual values to select best parent

3.4 Maintenance of the routing path

The P_l , P_m or P_h nodes are those that make up the developed routing path. Any deviation from the parent's chosen path leads to path modification. Therefore, the trickling method is used to maintain the routing path, thereby eliminating the transmission of DIO messages among nodes. The trickling algorithm

is used to balance dissemination of routing information while diminishing its impact on routing performance. The trickling approach is utilized in sending periodic update at increasing intervals. The router sends immediate updates and these updates are maintained for longer time interval. This gradual rise of time interval helps to prohibit the insignificant congestion. In this research, DIO transmission is scheduled using the trickling method. When a network condition is constant, a timer allows DIO intervals to rapidly increase and converge to maximum intervals. When a network experiences any inconsistencies (such as changes in parent, rank, etc.), a crawl timer is altered to its less interval, causing a more continual DIO broadcast to rapidly resolve the issue. As a result, this mostly impacts the bandwidth and power usage. To maintain the stability of the constructed paths and reduce the number of trickles, the timer resets, so as to save energy and extend the lifetime of the network, which is crucial to limit changes in the preferred parents. Here's a clearer version of the sentence:

3.5 Encoding and transmitting the video

After the construction of a multi-objective fuzzy system for optimal route selection, the node that is placed at the source transmits the video traffic over multi-paths. At first, the video codec is selected based on the efficiency of compression and computational complexity. The compression efficiency and computational resources are balanced on the IoMT devices. The lower resolution and lower frame rates minimize the size of data and energy consumption for IoMT devices. The energy efficiency is a significant factor in IoMT networks that helps to prolong the battery capability and optimize the utilized resources. At first, the node is located at the source which undergoes a different pre-transmission process through the SenseVid tool. Three types of routing paths are considered namely, P_l (with least priority), P_m (with medium priority), and P_h (with high priority). Among the three routing paths, the path P_h is selected as the most preferred path which retains the quality of data packets.

3.6 Decoding and evaluation

The video packets received at DODAG [46] root is recorded at the receiver node or destination node, and the decoding is performed to evaluate the QoE metrics, PSNR and SSIM. Every individual node present in the DODAG helps to handle the video packet. The video packet is routed with the help of P_h , then the next hop corresponds to the alternative routing paths of P_l and P_m .

4.Results

In this section, the results attained while estimating the proposed fuzzy-based RPL approach and detecting the optimal routing path, are discussed. The metrics based on QoS and QoE are considered to evaluate the robustness and efficiency of the proposed approach. QoS metrics of energy consumption per node (%), network throughput (kbps), and delay are considered. The QoE metrics namely, PSNR and SSIM are considered for the estimation of the efficiency of the proposed approach. The proposed approach is implemented in the system having Intel i7 processor, 8 GB of random-access memory and Windows 10 operating system. The evaluation of the system is performed in the Python environment. The performance metrics based on QoS considered in this research are represented as follows:

Energy consumption (%): It is defined as the energy used by every node in a DODAG structure. It is computed by the sum of energy which is considered while transmitting the data and energy consumption per node. Equation 4 is used to evaluate the energy consumption.

$$EC = \sum(T_{state} \times I_{state} \times V) \quad (4)$$

Wherein, the power consumed by a node is denoted as I_{state} , the voltage supplied to each node is depicted as V and the time taken while the node is transmitted is denoted as T_{state} .

Throughput: The network throughput is defined as the ratio among all video packet sizes effectively obtained at a sink node, and the time needed to transfer an entire video.

Delay: Delay time is the duration among changes at the source point and their reception at the destination point within a system.

The performance metrics based on QoE considered in this research are represented as follows:

PSNR: It is described as the ratio among maximum probable values of the signal and power distortion which impacts the depiction quality. Equation 5 is utilized to evaluate the PSNR. The MSE is evaluated using the Equation 6.

$$PSNR = 20 \times \log_{10}(MAX) - 10 \times \log_{10}(MSE) \quad (5)$$

$$MSE = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} O(i,j) - D(i,j)^2 \quad (6)$$

SSIM: It is used to define the quality of the images based on the similarity between the original data and the received data. The SSIM is evaluated using the Equation 7.

$$SSIM = \frac{(2\mu_x\mu_y+c_1)(2\sigma_{xy}+c_2)}{(\mu_x^2+\mu_y^2+c_1)(\sigma_x^2+\sigma_y^2+c_2)} \quad (7)$$

Wherein the matrix of the original frame of the video is denoted as O and the data of the degraded image is denoted as D . An index of the row of the frame as well as the number of rows in a pixel are depicted as i and m , respectively. The number of columns in the pixels and index of the column are represented as n and j , respectively. The pixel sample means of x and y are represented as μ_x and μ_y . The variance of x is represented as σ_x^2 and the variance of y is represented as σ_y^2 . The c_1 and c_2 are co-variances and the dynamic range of the pixel values is represented as L . The simulation parameters of the proposed framework are presented in Table 1. Moreover, the RPL protocol is based on DODAG ID, OF and trickle parameter.

Table 1 Simulation parameters

Parameter	Values
Type of mote	Sky mote
Routing protocol	RPL
Video source node	1
Frame frequency capture	1 fps
Range of communication	50 m

4.1Performance analysis

In this section, the proposed multi-objective fuzzy-based routing performance is evaluated against the existing approaches based on energy consumption, delay and throughput. The efficiency of the proposed RPL protocol is evaluated along with prior state-of-the-art RPL protocols for different numbers of nodes. Figure 3 represents the graphical representation of the estimation of energy consumption. It depicts the results attained while estimating the fuzzy-based RPL approach with an existing one for the different number of nodes.

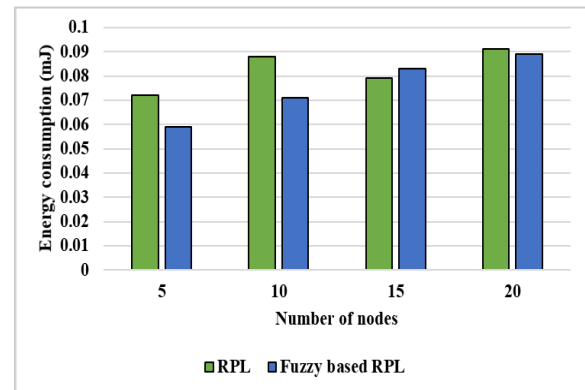


Figure 3 Evaluation of energy consumption

The results are evaluated for different numbers of nodes ranging from 5 to 20 for existing RPL and fuzzy-based RPL protocols. The obtained results depict that the fuzzy-based RPL exhibits better results as compared to existing approaches. For instance, when the node count is 5, the energy consumption of RPL is 0.072 mJ, whereas the proposed approach consumes only 0.059 mJ. These results show that the proposed approach consumes minimal energy while transmitting data packets from source to the destination. Secondly, the performance is evaluated based on the assessment of network throughput by considering the number of data packets that are effectively transmitted from source to the destination node. The outcomes from *Figure 4* display the graphical representation for the analysis of network throughput. It shows that the proposed approach achieves good throughput of 0.76 kbps when the total count of nodes is 5, whereas the throughput of the existing RPL protocol for 5 nodes is 0.75 Kbps. The proposed approach detects an optimal route for transmitting data packets from the source node to the destination node.

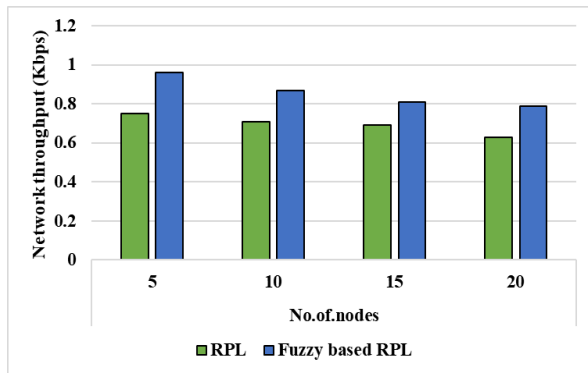


Figure 4 Evaluation of network throughput

Thirdly, the evaluation is performed considering delay time, which refers to the period of time taken to transmit data packets from source node to destination node, within a network. The results are assessed for different node counts from 5 to 20. *Table 2* demonstrates the results attained while analysing the

proposed fuzzy-based RPL approach with the existing RPL protocol with respect to delay time.

Table 2 Comparison of state of art RPL with the proposed approach for delay

Methods	Delay (ms)			
	No. of nodes			
	5	10	15	20
RPL	0.075	0.088	0.093	0.098
Fuzzy-based RPL	0.069	0.081	0.089	0.090

The outcomes attained from *Table 2* prove that the fuzzy-based RPL approach reaches lesser delay time of 0.069 for 5 nodes, whereas the existing RPL attains a delay time of 0.075 ms for the same number of nodes. The superior throughput and selection of optimal path to transfer data packets, help to achieve minimum delay.

4.2 Evaluation of SSIM and PSNR

The proposed approach's performance is analyzed by considering QoE metrics of SSIM and PSNR. The results obtained from *Table 3* exhibit the results of SSIM and PSNR given by the proposed fuzzy-based RPL approach when compared with the existing RPL.

Table 3 Evaluation of SSIM and PSNR

Methods	SSIM	PSNR (dB)
RPL	93.78	30.86
Fuzzy-based RPL	97.23	35.45

The results attained from *Table 3* prove that the fuzzy-based RPL approach obtains superior SSIM of 97.23 and PSNR of 35.45 dB. The prioritization of the routing path and sending data packets accordingly results in proper selection of an optimal routing path and effective transmission of data packets by the proposed fuzzy-based approach, due to which it gains better performances than the existing RPL approach.

4.3 Evaluation of energy efficiency

Here, efficiencies of the fuzzy-based RPL as well as the traditional RPL protocols are evaluated based on varying time periods. *Table 4* presents the outcome for energy efficiency based on different time periods.

Table 4 Evaluation based on energy efficiency

Method	Metric	Time (Sec)					
		50	100	150	200	250	300
RPL	Energy consumption	800	1500	1900	2400	2900	3300
Fuzzy-based RPL	(mW)	500	700	1200	1600	2000	2400

The outcomes in *Table 4* exhibit that the proposed approach consumes minimal amount of energy when compared to the traditional RPL routing. The energy consumption of the proposed method for 50 seconds is 500 mW, whereas the traditional RPL protocol consumes energy of 800 mW.

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4.4 Comparative analysis

The proposed method's performance is determined alongside the existing approaches' performances, and these approaches are, MI-RPL [22] and MP-RPL [24]. The MI-RPL is used as the comparative method to estimate the efficiency of the proposed approach based on SSIM for various frame rates of 3, 11 and 8. Similarly, the proposed approach performance is analyzed with MP-RPL as the comparative method, based on the different frame rates of 5 and 6. *Table 5* displays the results obtained while estimating the proposed approach and MI-RPL for different frame rates from 3, 11 and 8.

Table 5 Comparison of the proposed approach with the existing one for the frame rate of 3, 11 and 8

Methods	SSIM		
	No. of Frames		
	3	11	8
MI-RPL [22]	0.92	0.91	0.65
Fuzzy-based RPL	0.95	0.93	0.76

Secondly, the performance of the proposed approach is related with MP-RPL for different frames 5 and 6. *Table 6* shows the results achieved while determining the proposed approach with MP-RPL for various frame rates of 5 and 6. The results displayed in *Tables 5* and *6* show that the proposed approach achieves more preferable results in terms of SSIM for different frame rates. The MI-RPL consumes low energy, while the suggested system effectively differentiates between the prioritized and non-prioritized video frames. However, the suggested system fails to impose a higher priority on the QoS. Next, the efficiency of fuzzy-based RPL approach is estimated by overhead based on the size of the network and simulation time. The evaluation of the proposed approach is performed with Mm-RPL [23], while *Table 7* depicts the outcomes based on overhead for the size of the network.

Table 6 Comparison of the proposed approach with the existing one for frame rates of 5 and 6

Methods	SSIM	
	No. of Frames	
	5	6
MP-RPL [24]	0.92	0.89
Fuzzy-based RPL	0.96	0.91

Table 7 Overhead vs size of the network

Methods	Metric	Number of nodes			
		5	10	15	20
Mm-RPL [23]	Overhead	180	1100	2000	2750
Fuzzy-based RPL	(Packets)	130	580	950	1250

In a similar way, the efficiency of the proposed fuzzy-based RPL protocol is evaluated based on the simulation time. *Table 8* exhibits the outcomes based on the overhead vs simulation time.

Table 8 Overhead vs Simulation time

Methods	Metric	Time (sec)				
		250	500	750	950	1200
Mm-RPL [23]	Overhead (Packets)	1800	2200	4000	5500	6100
Fuzzy-based RPL		1200	1800	2500	3600	4500

The experimental outcomes through *Tables 7* and *8* prove that the suggested approach attains minimal overhead for both network size and simulation time. For instance, the overhead of the proposed approach at the simulation time of 250 seconds is 1200 packets, whereas the overhead of existing Mm-RPL is 1800 packets. Thus, the proposed fuzzy-based RPL proves its efficiency in terms of overhead.

5. Discussion

This section presents the experimental outcomes achieved by the suggested framework along with the advantages and its drawbacks. The efficiency of the suggested approach is assessed in terms of SSIM and PSNR. The efficacies of suggested framework, MI-RPL, and MP-RPL, are assessed at varying frame rates. The existing MI-RPL is assessed using various number of frames ranging from 3, 11 and 8. The SSIM of the suggested framework with frame rate of 3 is 0.95, whereas that of the MI-RPL is 0.92. In a similar way, the SSIM of the suggested model for framerate of 5 is 0.96, whereas the existing MP-RPL achieves an SSIM of 0.92. Thus, the comparative evaluation exhibits the effectiveness of the suggested model over the existing techniques. The multi-objective fuzzy-based approach selects the optimal routing path to transmit the video sequence with better throughput and minimalized delay. The proposed fuzzy-based approach utilizes hysteresis mechanism to select the optimal path which minimizes delay while transmitting the data packets. It has the capability to adapt variations in network topology, mobility of nodes and traffic pattern. It dynamically adapts itself to routing path for accommodate node mobility and reconstruct routing table. Moreover, it is scalable to make decisions in selecting routing path for IoMT network.

The proposed multi-objective fuzzy approach has a set of rules, which increases the algorithm's complexity. In addition to this, the capability of the suggested

fuzzy-based approach is diminished under varying network conditions. The IoMT applications require additional power that results in the consumption of more resources and minimalizes the overall efficiency.

A complete list of abbreviations is listed in *Appendix I*.

6.Conclusion

For the benefit of IoMT applications, this research provides an efficient fuzzy-based routing strategy to choose the best routing path for video transmission. The research focuses on QoS and QoE during the transmission of video data. The performance of the proposed multi-objective fuzzy-based routing is evaluated with existing approaches based on energy consumption, delay, and throughput. This research considers the MP2P traffic pattern of WMSN for an individual root node. The transmission node captures the video sequence and transmits it to the sink node through a single interface. All video packets from the source node are received at the destination node, wherein these are then reconstructed. In this research, RPL routing is utilized to develop multiple routes to the root node concerning QoE and QoS. The effective routing path selection is performed with the help of the proposed fuzzy rule-based approach. The suggested approach considers high throughput path to transmit the data packets with minimum delay. In future, the efficiency of the suggested model can be evaluated in real-time IoMT applications.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Data availability

None.

Author's contribution statement

Harisha K.S.: conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing. **Parameshachari B.D.:** writing—review and editing, supervision and project administration.

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Appendix I

S. No.	Abbreviation	Description
1	ADNN	Adam Deep Neural Network
2	CCTV	Closed-Circuit Television
3	CFTEERP	Cooperative and Feedback-Based Trustable Energy-Efficient Routing Protocol
4	DAG	Directed Acyclic Graph
5	DAO	Destination Advertisement Object
6	DAO-ACK	Destination Advertisement Object Acknowledgement
7	DIO	Destination Information Object
8	DODAG	Destination-Oriented Acyclic Graph
9	DVRP	Distance Vector Routing Protocol
10	ETC	Estimated Transmission Count
11	FSR	Fisheye State Routing
12	FreeBW-RPL	Free Bandwidth of RPL
13	ICMPv6	Internet Control Message Protocol version 6
14	IETF	Internet Engineering Task Force
15	IoMT	Internet of Multimedia Things
16	IoT	Internet of Things
17	IPv6	Internet Protocol Version 6
18	LLN	Low-power and Lossy Networks
19	LD	Link Disjoint
20	MAC	Media Access Control
21	MI-RPL	Multi-Instance Routing Protocol for Low Power and Lossy Networks
22	MP2P	Multi-Point to Point
23	MP-RPL	Multi-Path Routing Protocol for Low Power and Lossy Networks
24	MRHOF	Minimum Rank with Hysteresis Objective Function
25	MRTS	Metric-based RPL Trustworthiness Scheme
26	ND	Node Disjoint
27	OF	Objective Function
28	PCC-RPL	Parental Change Control Routing Protocol for Low Power and Lossy Networks
29	PDR	Packet Delivery Ratio
30	PECI	Packet Energy Correlation Index
31	PL	Physical Layer
32	PSNR	Peak Signal-to-Noise Ratio
33	QoE	Quality of Experience
34	QoS	Quality of Service
35	RPL	Routing Protocol for Low Power and Lossy Networks
36	RSSI	Receiving Signal Strength Indicator
37	SSIM	Structural Similarity Index Measure
38	WMSN	Wireless Multimedia Sensor Networks
39	6LoWPAN	IPv6 over Low-Power Wireless Personal Area Networks