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An Enhanced QoS-Aware Multipath Routing Protocol for Real-time IoT Applications in MANETs

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Abstract: Recent transmission of large volumes of data through mobile ad hoc networks (MANETs) has resulted in degraded Quality of Service (QoS) due to factors such as packet loss, delay, and packet drop in multipath routing. To address this issue, a traffic-aware Enhanced QoS-Aware Multipath Routing Protocol (EQMRP) has been proposed for real-time IoT applications in MANETs. EQMRP efficiently switches between multiple paths and monitors traffic conditions to maintain an optimal data transmission rate. The proposed method considers different delay sensitivity levels and link expiration time (LTE) to maintain QoS in each path. Through IoT application data analysis, EQMRP maintains QoS in each path more efficiently than conventional methods. The proposed method has been simulated and validated using MATLAB, and the performance analysis shows that EQMRP achieves a higher packet delivery ratio, lower delay, and reduced packet drop compared to conventional methods. In conclusion, the traffic-aware EQMRP protocol offers a significant improvement in QoS for real-time IoT applications in MANETs.

Keywords: Quality of Service (QoS); Internet of Things (IoT); Link Expiration Time (LET); Mobile Ad hoc Network (MANET)

1 Introduction

Mobile Ad hoc Networks (MANETs) are wireless mobile nodes that transmit data without a centralized infrastructure. However, this makes it challenging to ensure Quality of Service (QoS) due to limited power and bandwidth, changing topology, and real-time applications [1].

QoS support is critical in wireless and mobile networking with jitter, packet delivery ratio, throughput, and end-to-end latency being important considerations [2, 3]. Conventional routing protocols, such as table-driven and demand-based, have limitations in addressing MANET challenges [4]. For example, table-based techniques like OLSR add significant overhead even when there is no real traffic, while on-demand protocols like Ad hoc On-Demand Distance Vector (AODV) cause delays and overburden some intermediary nodes due to frequent data processing [5].

To address these challenges, the proposed QoS-aware routing protocol monitors traffic conditions and efficiently switches operations. It identifies and sends high-priority real-time application data across low-latency MANET paths, considers different delay sensitivity levels and link expiration time, and selects the optimal path that meets QoS requirements while minimizing network bandwidth and battery consumption. The proposed protocol is evaluated through simulations, and the results demonstrate its effectiveness in improving QoS metrics compared to conventional methods [6]. In conclusion, the proposed QoS-aware routing protocol can contribute to the development of efficient and reliable MANETs for real-time applications. The research in this area is crucial for addressing the challenges of wireless and mobile networking settings and enabling the seamless communication of mobile devices. The proposed protocol can also serve as a benchmark for future research in this area.

Figure 1 shows the fundamental block diagram of a MANET using IoT, which highlights the key components of the network and their interactions. The figure provides a visual representation of the network architecture and can help readers better understand the proposed QoS-aware routing protocol.

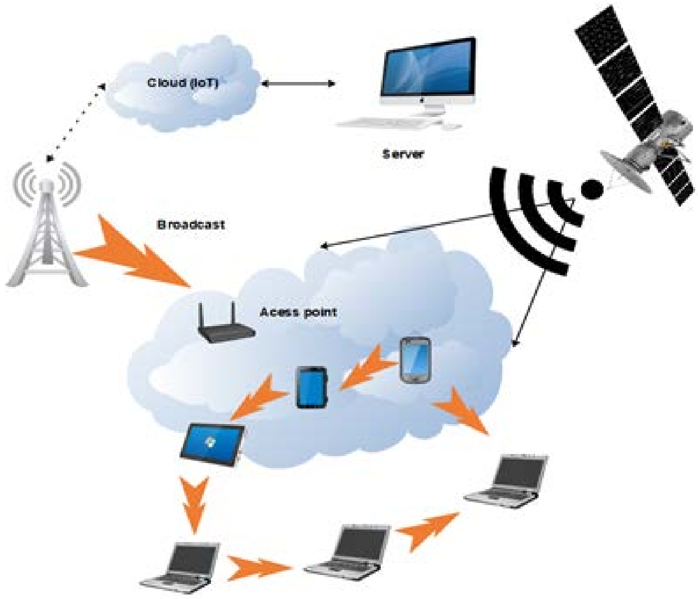

Figure 1. The fundament block diagram of MANET using IoT

2 Methodology

2.1 Related Works

Several techniques have been investigated to improve Quality of Service (QoS) in Mobile Ad hoc Networks (MANETs), with a focus on supporting real-time applications and services. One such technique is the Priority-Aware Dynamic Source Routing (PA-DSR) protocol proposed by Biswas and Dasgupta [7]. This protocol assigns priority based on data rates to improve QoS for routing. Simulation results showed that the proposed PA-DSR protocol outperformed the conventional DSR protocol in terms of throughput, packet delivery ratio (PDR), and end-to-end delay for five unique connections. Noorul et al. [8] conducted performance analysis research to study the impact of different routing protocols on Quality of Service (QoS) for Voice over IP (VoIP) applications over Mobile Ad hoc Networks (MANETs). The routing protocols investigated included AODV, TORA, OLSR, and GRP, while different queuing choices such as FIFO, PQ, and WFQ were also analyzed [9, 10]. Their results showed that Jitter delay, packet delay in transit, and wireless LAN media access response time and throughput of 802.11 g technology at 54 Mbps are important factors that affect the quality of VoIP conversations. Khan et al. [11] proposed a smart routing method to connect an IoT service and its real-world data flow, aimed at improving the routing protocol in the context of the Internet of Things (IoT). Their proposed method can be used for urgent data services such as environmental monitoring using real-time data. The authors developed a new way to incorporate MANET overlays and construct them collectively over MANET to improve IoT urban data. Their proposed method can dynamically identify and send high-priority real-time application data across low-latency MANET paths. Sharma [12] presented TCP/IP traffic shaping techniques for real-time congestion control in the network model. They used a real-time token bucket to determine the number of buffer sizes and bucket sizes based on the result of the flow. Their results showed that the recommended solutions worked better in a congested traffic environment.

Mallikarjunaswamy et al. [13] proposed a mobility measure that accounts for the complicated network mobility situation in Mobile Ad hoc Networks (MANETs). Their proposed metric can handle new link breakages and/or link additions and is well-suited for mobile nodes that exhibit a non-zero pattern of Poisson distribution. The authors suggest that their proposed metric can enhance both the objective and subjective measures of network productivity and effectiveness.

This study proposes an Enhanced QoS-Aware Multipath Routing Protocol (EQMRP) for real-time Internet of Things (IoT) applications in Mobile Ad hoc Networks (MANETs), building upon previous works. The proposed method employs traffic condition monitoring and efficient switching operations, considers different delay sensitivity levels and link expiration time, and dynamically identifies and sends high-priority real-time application data across low-latency MANET paths. Simulation results show that EQMRP achieves a higher packet delivery ratio, lower delay, and reduced packet drop compared to conventional methods. These findings suggest that EQMRP can be an effective solution for improving Quality of Service (QoS) in real-time IoT applications in MANETs.

3 Proposed Methodology

3.1 Overview

As part of this work, a disjoint multipath routing mechanism has been introduced for the transmission of various Internet of Things (IoT) traffic classes, aimed at ensuring reliable and efficient data transmission. A queuing system model has been formulated based on traffic priorities, which is dependent on packet loss and delay. The traffic classes have been classified into four categories: loss-sensitive, critical (delay and loss-sensitive), delay-sensitive, and normal (delay-and-loss insensitive) [14–16]. This classification enables the routing protocol to prioritize the transmission of high-priority traffic, such as critical and delay-sensitive traffic, over low-priority traffic, such as normal traffic.

To enable the selection of discontinuous pathways, packets with varying priority must be sent through on-demand routing [17, 18]. In this study, the identified paths are grouped into four categories, namely normal, critical, delay-sensitive, and loss-sensitive, based on their total delay and link-expiration time (LET). The total end-to-end latency of a path is determined by the sum of all intermediate hop delays. To facilitate the routing process, each node maintains and updates a path table that contains the fields of path ID and the accumulated values of delay and LET towards the destination [19–21].

3.2 Estimation of Metrics

3.2.1 Node Link Expiration Time (LET)

The link expiration time between two nodes refers to the duration of time that the nodes are connected within a fixed network range R [22–24]. Using the motion parameters of two nodes, the duration of time for which these two nodes remain connected can be calculated. Let (x_i, y_i) and (x_j, y_j) denote the coordinates of nodes n_i and n_j respectively. Let V_i and V_j denote their speeds along the directions D_i and D_j. The time duration between n_i and n_j is derived by using the Eq. (1) and Eq. (2).

$$LET = \left(-(ab+cd) + \sqrt{a^2+c^2}\right) r^2 - (ab-bc)^2\Big) / \left(a^2+c^2\right) \tag{1}$$

In this case, $a = V_i \cos D_i - V_i \cos D_i;\quad b = x_i - x_j; C = V_i \sin D_i - V_j \sin D_j; d = y_i - y_j.$

3.2.2 End-to-End Delay (EED)

End-to-end delay of a route is the summation of all the link delays in the entire path. It is represented as,

$$\mathrm{EED}(\mathrm{Path}(a,b)) = \sum_{(L_{i,j} \in \mathrm{path}(a,b))} \mathrm{Delay}\left(L_{i,j}\right) \tag{2}$$

3.3 Categorizing Traffic Classes

The traffic classes are categorized as follows:

• Delay Sensitive: Time-critical monitoring techniques like distributed control systems are covered in this category, which includes intra-frames (I) in a video stream. A great deal of attention is paid to this specific topic [25–27].

• Loss Sensitive: Monitoring data, such as temperature readings or snapshot images recorded from several points of view, must be transmitted in a precise time period to the operator, but is also loss sensitive. A bi-directional frame(b) and a predictor frame make up this class (p).

• Normal (Delay and Loss-insensitive): Essential monitoring data may be included in this class, which may necessitate offline processing.

• Storage videos, environmental data from scalar sensors, and snapshot multimedia material that's not time-critical are all instances of crucial media. This class is considered the least significant [28–31].

3.4 Queuing System Model for Disjoint Multipath Routing

Figure 2 illustrates the queuing system model based on node-disjoint multipath routing, incorporating the four traffic classes: loss-sensitive, critical (delay and loss-sensitive), delay-sensitive, and normal (delay-and-loss insensitive) [31–33]. Nodes are capable of transmitting real-time traffic of multiple traffic classes, which are received through a receiving buffer queue cache for dissimilar types of inward traffic. To ensure efficient transmission, a priority scheduler is employed to direct the packets to the sending buffer queue in a suitable order based on the priorities of the real-time packets as illustrated in Table 1.

A scheduler is employed to manage the packets in the sender buffer queue and transmit them through the route based on the situation of every disjoint path. At every relay node along the disjoint route, a queuing model is utilized in conjunction with priority to send real-time packets of varying priorities [34, 35].

Table 1. Traffic classes with multiple priorities

Traffic Classes	Traffic Priority (TP)
Delay Sensitive	High
Loss Sensitive	Middle
Normal (Delay and Loss-insensitive)	Low
Critical (Delay and Loss-sensitive)	Lowest

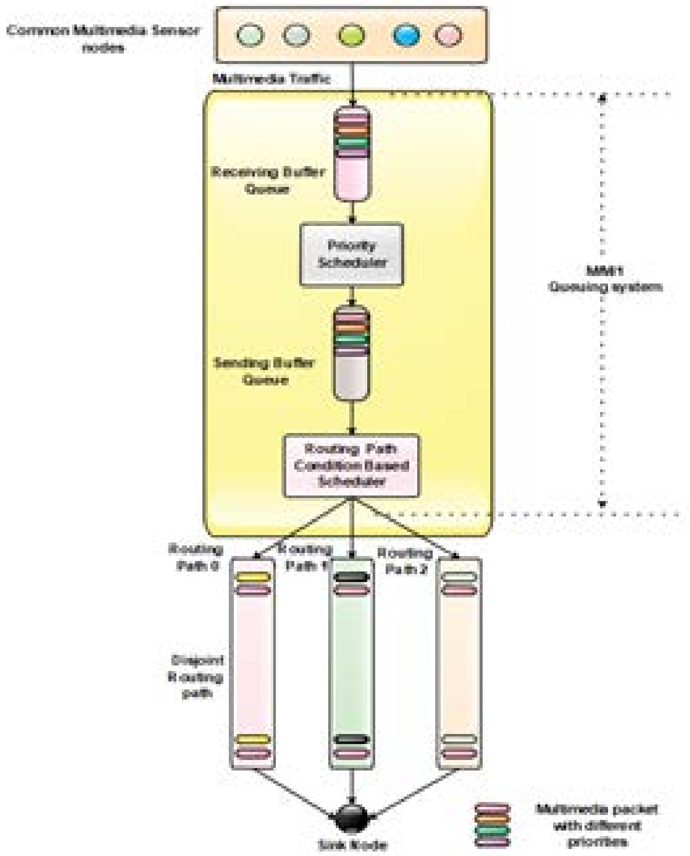

Figure 2. The queuing system model based on node-disjoint multipath routing

The selected traffic control scheme employs a priority scheduler to send the packets of various traffic classes based on their required priorities. Inbound real-time data packets are cached at the receiver buffer, and a classifier is used to monitor the class of the inbound packet and route it to the appropriate queue. In every transmission window, the scheduler determines the sequence of packets in the sender buffer queue based on their available priorities [36, 37].

3.5 On Demand Multipath Routing

During on demand routing, disjoint paths are chosen so that packets with different priorities are transmitted based on their conditions.

The steps involved in this process are as follows:

1) Each node analyses the nodes based on its delay and link expiration time.

2) Ni sends a request message (RO_REQ) requesting routing.

3) Each node upon receiving the RO_REQ message, verifies its node cache.

4) When it identifies a suitable node with minimum delay and maximum LET, it initiates the routing process.

5) The discovered paths are categorized as Critical, Loss sensitive, Normal, and delay sensitive, based on which the appropriate traffic class is chosen for transmission.

6) The end-to-end delay of a path is derived by the composition of the delays of its intermediate hops [38–40].

7) Each node is able to maintain and update a path table that contains the fields of path id and the accumulated values of delay and LET towards the destination. Figure 3 shows the disjoint multipath routing [41, 42].

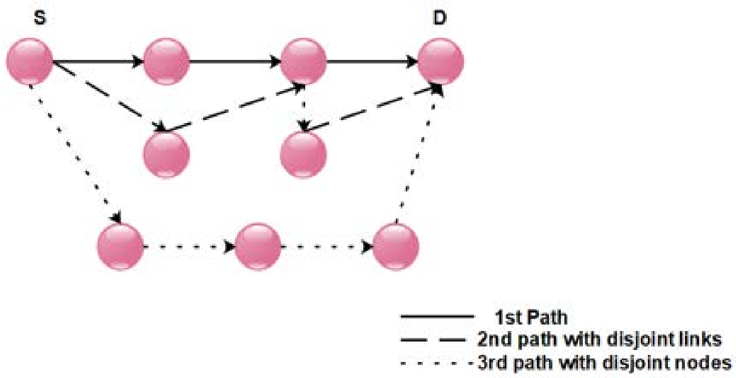

Figure 3. Disjoint multipath routing

For each path, P_i between the source S and destination D, EEDi and LETi are computed and compared with the predefined threshold values EEDth and LETth.

1. If EED $>$ EEDth, in this case the path will be taken as delay sensitive.
2. If LET $>$ LETth in this case the path will be taken as delay sensitive loss sensitive.
3. If EED $>$ EEDth and LET $>$ LETth, in this case the path will be taken as delay sensitive delay and loss sensitive that is it will be considering a critical path [43–45].
4. Otherwise, the path is considered as delay and loss insensitive i.e., normal path. The classified paths with priority as shown in Table 2.

Table 2. Classified paths with priorities

Traffic Classes	Path Priority (PP)
Class Sensitive to Delay	1
Class Sensitive to Loss	2
Class Sensitive to Delay as well as Loss-sensitive	3
Delay and loss insensitive	4

The following Algorithm 1 illustrates the steps involved in EQMRP.

Algorithm 1 EQMRP

for each incoming traffic flow F_j $j = 1, 2, \ldots \mathrm{m}$ (Where m is represented the number of nodes)
  Assign priority $\mathrm{TP_i}$ as per its category
  for each $\{S_i, \mathrm{D}_i\}$ pair
    Determine the path set $\{\mathrm{PS}\}$
    for each path $\mathrm{p_i} \in \mathrm{PS}$,
      Determine LET and EED using Eq. (1) and (2)
      Classify the path and assign priority $\mathrm{PP_i}$ as per Table 3.
      end for
    end for
  if $(\mathrm{TP_j} = \mathrm{High})$
    Assign p_i with $\mathrm{PP}_i = 1$
  else if $(\mathrm{TP_j} = \mathrm{Medium}\ )$
    Assign p_i with $\mathrm{PP}_i = 2$
  else if $(\mathrm{TP}_j = \mathrm{Low}\ )$
    Assign p_i with $\mathrm{PP}_i = 3$
  else if $(\mathrm{TP}_j = \mathrm{Lowest}\ )$
    Assign p_i with $\mathrm{PP}_i = 4$
  end if
end for

4 Experimental Results

The proposed Enhanced QoS-Aware Multipath Routing Protocol (EQMRP) has been implemented in MATLAB, and its performance has been compared with the RTA-AODV [46–49] and traditional AODV routing protocols. The performance metrics evaluated in the study include end-to-end delay, packet delivery ratio, average packet drop, and average residual energy. These metrics enable the comparison of the proposed EQMRP protocol with existing routing protocols in terms of Quality of Service (QoS), network efficiency, and energy consumption.

4.1 Experimental Settings

The performance analysis of the proposed Enhanced QoS-Aware Multipath Routing Protocol (EQMRP) and conventional routing methods has been carried out, with respect to several parameters as shown in Table 3. The comparison is based on the evaluation of end-to-end delay, packet delivery ratio, packet drop, and residual energy. In this section, the results of varying nodes for the real-time traffic scenario are presented [50–52].

Table 3. Simulation settings

Particulars	Range
Number of Nodes	50 to 250
a Size of the Topology	$500\ \mathrm{m}X500\mathrm{m}$
MAC Protocol	IEEE 802.11b
Simulation Time	100 seconds
Traffic Types	Exponential, Video (for real-time), CBR (for non-real-time)
Traffic Rate	$250\mathrm{Kbps}$
Propagation Model	Two Ray Ground
Antenna model	Omni Antenna
Initial Energy	10 Joules
Transmission Power	0.660
Receiving Power	0.395

4.2 Results for Real-time Traffic

Table 4 and Figure 4 show the results of end-to-end delay obtained for all the protocols for the real-time traffic scenario [53, 54].

Figure 4 illustrates the comparison of delay between the proposed Enhanced QoS-Aware Multipath Routing Protocol (EQMRP) and the RTA-AODV and AODV protocols [55, 56]. The results show that the delay of EQMRP is 0.8% less than RTA-AODV and 1.2% less than AODV, indicating its superiority in reducing end-to-end delay [55, 56]. Table 5 and Figure 5 demonstrate the results of packet delivery ratio obtained for all the protocols in the real-time traffic scenario. Figure 6 shows that the packet delivery ratio of EQMRP is 0.98% higher than RTA-AODV and 1.45% higher than AODV, indicating its superiority in improving the packet delivery ratio. Table 6 and Figure 6 present the results of packet drop measured for all the protocols in the real-time traffic scenario [57–59].

Table 4. Results of end-to-end delay (Real-time)

Nodes	EQMRP (sec)	RTA-AODV (sec)	AODV (sec)
50	0.239	0.667	0.870
100	0.371	0.801	1.118
150	0.481	0.974	1.349
200	0.729	1.001	1.412
250	1.016	1.278	1.638

Table 5. Results of packet delivery ratio (Real-time)

Nodes	EQMRP	RTA-AODV	AODV
50	0.9778	0.9453	0.9053
100	0.9716	0.9446	0.8246
150	0.9689	0.9411	0.8111
200	0.9612	0.9372	0.7932
250	0.9545	0.9107	0.7717

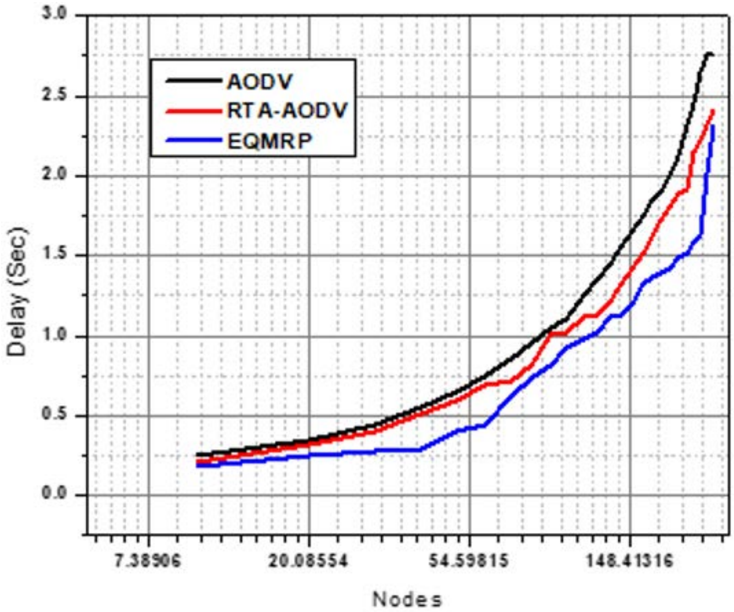

Figure 4. End-to-end delay (Real-time)

Table 6. Results of packet drop (Real-time)

Nodes	EQMRP	RTA-AODV	AODV
50	1457	2886	4286
100	2403	4947	6177
150	5023	7213	8043
200	6744	7995	10125
250	6818	8401	11494

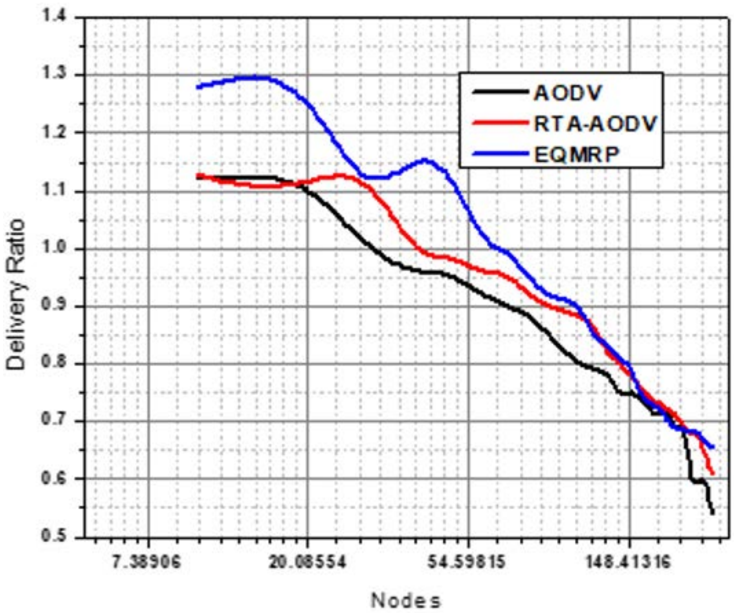

Figure 5. PDR - packet delivery ratio (Real-time)

Figure 6 illustrates the comparison of packet drops between the proposed Enhanced QoS-Aware Multipath Routing Protocol (EQMRP) and the RTA-AODV and AODV protocols. The results indicate that the packet drops of EQMRP are 0.75% less than RTA-AODV and 1.16% less than AODV, indicating its effectiveness in reducing packet loss and improving network reliability. Table 7 and Figure 7 present the results of average residual energy measured for all the protocols in the real-time traffic scenario [60–62].

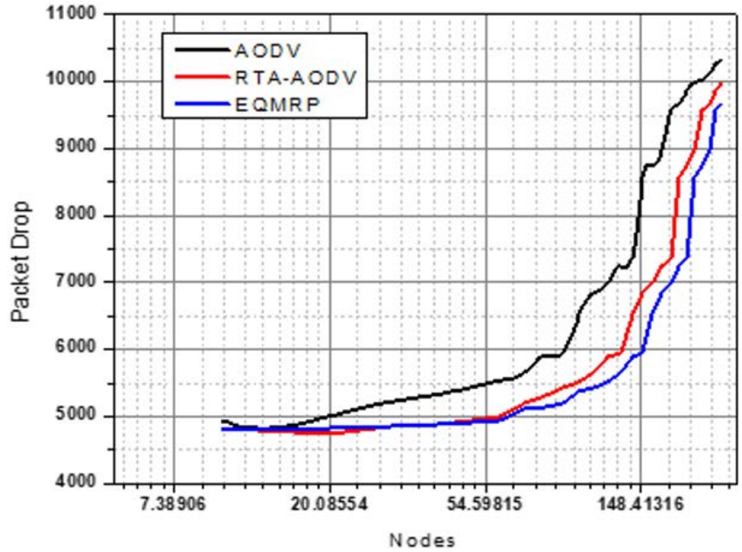

Figure 6. Average packet drop (Real-time)

Table 7. Results of residual energy (Real-time)

Nodes	EQMRP (Joules)	RTA-AODV (Joules)	AODV (Joules)
50	6.51	5.84	4.92
100	6.35	5.81	4.76
150	6.31	5.76	4.56
200	6.30	5.75	4.45
250	6.29	5.73	4.37

Figure 7 shows that the residual energy of EQMRP 1.16% higher than RTA-AODV and 1.05% higher than AODV.

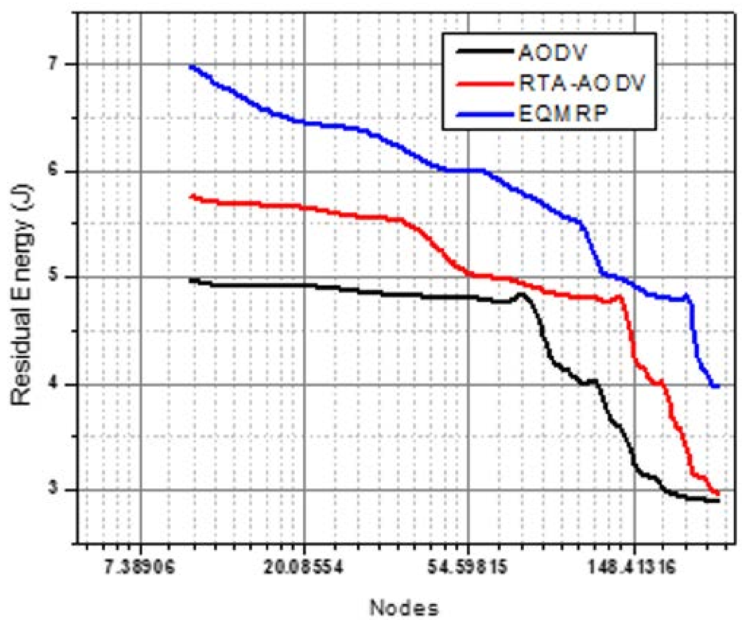

Figure 7. Residual energy (Real-time)

5 Conclusion

This paper proposes a method for controlling traffic in multi-path routing for the transmission of various Internet of Things (IoT) traffic classes with real-time applications. The proposed method is implemented using IoT to ensure dynamic and secured data sharing of real-time application data. The proposed method employs a disjoint multipath routing approach for transmitting various IoT traffic classes to ensure reliable and efficient data transmission. During on-demand routing, disjoint routes are selected to ensure packets with multiple priorities are transmitted according to the state. The discovered paths are grouped as Normal, Critical, Loss-sensitive, and Delay-sensitive, in accordance with the appropriate traffic class chosen for transmission. The proposed Enhanced QoS-Aware Multipath Routing Protocol (EQMRP) reduces the end-to-end delay with respect to node iterations. According to the simulation results, the proposed method demonstrates better performance compared to AODV (1.2%) and RTA-AODV (0.8%). The proposed method also shows better performance compared to conventional methods AODV (1.45%) and RTA-AODV (0.98%) with respect to packet delivery ratio and reduces packet drop compared to conventional methods AODV (1.16%) and RTA-AODV (0.75%). Moreover, the proposed method enhances residual energy compared to conventional methods AODV (1.05%) and RTA-AODV (0.85%). The proposed protocol has been simulated and validated using MATLAB. Simulation analysis shows that the proposed method exhibits better performance compared to conventional methods.

Future scope: The customer's trust is increased when the file gets communicated with multipath routing and with increased parallel operation without loss of information. at the same time, it will be capable to store in multi-cloud without any obstacles using this proposed method.

Limitations: In 6G communication technologies, the application will be sharing the data in 10000 Gb/s speed which requires high speed encryption and decryption process. The proposed method experiences attenuation and loss of information.

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7 Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

8 Conflicts of Interest

The authors declare that they have no conflicts of interest.

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