National Journal of Antennas and Propagation, ISSN: 2582-2659 Vol. 8, No. 2, 2026 (pp.205-217)
WWW.ANTENNAJOURNAL.COM

Research Article

An Intelligent QoS-Driven Energy-Efficient Routing Protocol for Improving Stability and Lifetime of MANETs

Chithirai Pon Selvan[1], S.D.Vijayakumar[2*], R. Praveenkumar[3], K.Sumathi[4], G Sekar[5], A Satheesh Kumar[6], P. Karunakaran[7]

[1]*Director of Research, Head of School - Science and Engineering, Curtin University, Dubai*
[2]*Assistant Professor, Department of Artificial Intelligence and Data Science, Nandha Engineering College, Erode, Tamilnadu, India.*
[3]*Associate Professor, Department of Electronics and Communication Engineering,Nandha Engineering College, Erode, Tamilnadu, India.*
[4]*Associate Professor ,Department of Information Technology,Kangeyam Institute of Technology, Kangeyam, Tirupur, Tamilnadu, India.*
[5]*Associate Professor , Department of Electronics and Communication Engineering, VSB College of Engineering Technical Campus, Coimbatore, Tamilnadu, India.*
[6]*Assistant Professor , Department of Computer Science and Engineering, Nandha Engineering College, Erode, Tamilnadu, India.*
[7]*Professor ,Department of Artificial Intelligence and Data Science, Nandha Engineering College, Erode, Tamil Nadu, India.*

KEYWORDS:

Mobile Adhoc Networks,
Routing,
Energy Efficiency,
Quality of Service,
Stability

ARTICLE HISTORY:

Received: 17.12.2025
Revised: 21.01.2026
Accepted: 13.02.2026

DOI:
https://doi.org/10.31838/NJAP/08.02.17

ABSTRACT

Mobile Ad hoc Networks (MANETs) are characterized by their dynamic topologies, infrastructureless communication, and energy-limited mobile nodes. These features together form a complex of challenges for route stability and lifetime. Frequent topological changes and energy limitations cause frequent route discoveries, leading to increased latency, high control overhead, and poor Quality of Service (QoS). Traditional routing protocols cannot combine QoS demands with energy awareness of nodes, resulting in route instability and short-lived communication sessions. In this scenario, to overcome the above-mentioned limitations, this paper proposes an Intelligent QoS-Driven Energy-Efficient Routing Protocol (Q-EERP) to improve route stability and extend the lifetime of MANETs. The proposed protocol simultaneously considers node and link parameters during route discovery and maintenance to ensure the establishment of stable routes. An improved HELLO message exchange scheme is introduced to carry additional information from the transmitter, including residual energy and coordinate values for distance computation, to enable dynamic neighbor discovery and energy-efficient routing. Simultaneous observation of neighbor status helps to avoid the selection of energy-exhausted and unstable neighbors in active routes, which reduces the occurrence of route failures. The performance of the proposed protocol is tested using simulations with the Network Simulator 2 (NS-2), with varying node speed and pause time to simulate real-world mobility scenarios. Simulation results show that Q-EERP has an average end-to-end delay of 25.11 ms, a packet delivery ratio of 85%, a throughput of 817.95 kBps, a control overhead of 2.64%, and a normalized routing overhead of 37.12%. The results of the simulation experiment show a significant improvement in the network throughput and packet delivery ratio, as well as a decrease in the end-to-end delay and routing overhead. All these factors contribute to the improved stability of the network in a highly dynamic MANET environment.

Author's e-mail: pon.selvan@curtindubai.ac.ae, mail2vijay.sd@gmail.com, rpraveenster@gmail.com, thirusumathi83@gmail.com, gsekarganesh@gmail.com, satheeshkumar.a@gmail.com, karuna.dr@gmail.com

Author's Orcid id: 0000000192953340 , 0009-0002-1997-1707, 0009-0008-5129-9096, 0000 0001 8726 4495, 0000-0001-8885-7700, 0009-0008-8182-0946, 0009-0007-9583-5041

How to cite this article: Selvan CP et al, An Intelligent QoS-Driven Energy-Efficient Routing Protocol for Improving Stability and Lifetime of MANETs, National Journal of Antennas and Propagation, Vol. 8, No. 2, 2026 (pp. 205-217).

1. INTRODUCTION

Mobile Ad-hoc Networks (MANETs) have been extensively used in different scenarios, like disaster relief, healthcare units, video conferencing, and military applications, where the transmission of audio and video information is very likely [1]. The Evolution of the Internet of Things (IoT) has increased the usage of MANETs, where smart devices are used as nodes of the network [2]. The high demand for services related to multimedia transmission requires quality of service with better efficiency [3]. The provision of QoS in MANETs is difficult due to resource management and planning by a central controller, external disturbances, and internal failures such as link failures, battery drain, sudden congestion, high link utilization, and process faults. Mobility of nodes causes dynamic variations in the network topology, which further affects the connection stability [4].

Mobile nodes have limited battery power; when the battery of a node drains, the effect of the disruption affects the corresponding link as well as the overall network topology. Network management is required to maintain compliance with standards of communication quality, especially in the presence of resource limitations such as bandwidth, delay, and power. These issues may cause increased latency and packet loss and may also cause a decrease in throughput. There is a great need for research and development of new routing techniques in MANETs that can efficiently adapt to dynamic changes and resource limitations. Routing techniques can be broadly identified into reactive and proactive techniques.Proactive Routing algorithms constantly update route information and are more appropriate for smaller and less dynamic networks. Destination-Sequenced Distance-Vector Routing (DSDV) [5] and Optimized Link State Routing Protocol (OLSR) [6] have shorter route discovery times and use Hello messages and topological control messages during route discovery. Reactive routing algorithms are more appropriate for large and highly dynamic networks, where routes are established on demand. Standards such as Ad-hoc On-demand Distance Vector (AODV) [7], Dynamic Source Routing (DSR) [8], and Temporally Ordered Routing Algorithm (TORA) require periodic updates to route information for neighboring nodes.

Of the protocols listed, AODV has received considerable attention in the academic community because of its efficient routing performance. A single route is discovered and maintained based on the route discovery process [9]. However, the route discovery process involves considerable overhead of control messages and focuses on route optimization, which may neglect the evaluation of node and link status [10]. This paper presents an optimized routing mechanism that takes into consideration nodes and connections during route discovery to improve energy efficiency and QoS. The use of a Link Quality Estimation Model is suggested to improve route reliability by evaluating the status of communication channels. Network topology optimization through Node Degree analysis may also improve load balancing. Future node status prediction using Node Condition Prediction allows proactive route modification, thus improving overall performance and system robustness.

The primary contributions of the present work are as follows:

- Introduction of the QoS-aware Energy-Efficient Routing Protocol (Q-EERP), which tries to make optimal routing decisions based on QoS parameters and dynamic residual energy values of nodes.
- Q-EERP uses Received Signal Strength Indicator (RSSI) values and dynamic node parameters such as energy depletion rate and node density to improve link quality and routing.
- Q-EERP performs better than other existing solutions by minimizing end-to-end delay, maximizing the success rate of packet delivery, and reducing the overhead of routing control messages.

The proposed Intelligent QoS-Driven Energy-Efficient Routing Protocol (Q-EERP) is described as intelligent because of its adaptive decision-making process, which considers multiple parameters instead of traditional shortest path methods. The intelligence of the proposed protocol is evident from its ability to simultaneously consider node-level parameters like residual energy and node stability, as well as link-level QoS parameters like delay and transmission reliability. Moreover, the proposed protocol also refreshes the neighborinformation continuously using an improved HELLO message mechanism that carries residual energy and location information, which helps in real-time distance calculation and energy-efficient path computation. Based on the continuously monitored parameters, the proposed Q-EERP protocol selectively includes stable and energy-rich nodes in the routing paths and prunes unreliable and energy-depleted routes proactively before actual failures.This proactive and context-aware routing strategy minimizes unnecessary path rerouting, balances energy consumption among nodes, and maximizes overall network lifetime. Therefore, the proposed protocol is intelligent due to its adaptive learning capabilities from network dynamics, multi-criteria optimization, and predictive route stability management, as opposed to traditional or reactive routing strategies.

The subsequent sections are organized as follows: Section 2 discusses the literature survey of state-of-the-art routing protocols proposed to enhance service quality. Section 3 suggests that the Q-EERP enhances QoS, especially in MANET. The simulation analysis and performance comparison with existing models are done in section 4. Section 5 achieves the research with conclusions and future scope of the study.

2. LITERATURE SURVEY

In the past decade, there has been a growing need to construct smart urban infrastructures and Intelligentmobility solutions, leading to the proposal of routing standards prioritizing QoS for multimedia services. Some of these protocols are outlined below:

The QoS-aware routing technique suggested in [11] is the multi-rate-backup method. This method enhancesthe investigated procedures to uplift the efficiency of QoS-aware routing in MANETs in the existence of movement, shadowing with variable linkSignaltoInterferenceNoise Ratio (SINR). The study explores the combined benefits of the existing procedures and proposes utilizing multiple backup path methods.

Eiza et al. introduced a graph-based routing algorithm called Evolving Graph-Reliable AODV (EG-RAODV) [12]. This method enhances the conventional AODV procedure. It is designed to choose accurate routes supporting QoS for vehicle interaction in a Vehicular Adhoc Network (VANET). The research aims to employ the dynamic graph theory to represent a VANET signaling graph on a roadway.

Rajadurai et al. introduced a multicast routing algorithm called Multicast AODV with Backup Branches (MAODV-BB) [13]. This method enhances the effectiveness of the previous AODV procedure. This study combines the benefits of the tree's framework with the mesh architecture to efficiently upgrade briefer tree branches and create a multiple-cast tree with standby sections.

Jain et al. introduced routing algorithm for cross layer calledthe Cross-Layer Decision Based Routing Protocol (CLD-BRP) [14]. This method enhanced the multimedia’s Quality of service services on the Internet of Vehicles (IoV). This study aims to derive routing metrics from several levels, namely the data rate measurement from the physical tier and the traffic measurement from the network tier. These measurements will be included in a cost structure to determine the QoS and select routes accordingly.

Chen et al. introduced a Quality-of-service aware multicast routing algorithm called Bandwidth and Coding-basedMulticast Routing Protocol (BCMRP), designed explicitly for MANET [15]. This study aims to establish the criteria for identifying node which is Adhoc in nature, as a coding host. Next, BCMRP estimates the bandwidth usage of each encoding host. This study introduces a routing expense function that considers the residual capacity measure of neighboring nodes while making decisions.

Chen et al. introduced a multicast routing method namedthe Delay-Sensitive Multicast (DSM) protocol [16]. This protocol was designed to facilitate QoS in real-time multimodal MANET applications. This study primarily employs a technique to estimate the delay period of neighboring nodes within a single hop. This study presents the DSM routing procedure built on a multicast tree to guarantee the end-to-end delay duration.

Agarwal et al. introduced a routing method that utilizes Fuzzy Petri Nets and Ant System [17]. The technique aims to govern the maximumeffective path for MANET. This study primarily utilizes the fuzzy synchronized Petri net, especially a change in fuzzy which is synchronized , to simulate the function related to decision making. Subsequently, the ant method is employed to determine the most efficient path.

Ahirwar et al. introduced a hybrid multi-metric optimized routing algorithm named M-Lion-Whale [18]. This method was designed specifically for protected routing in MANET. The investigate aims to integrate the Lion Algorithm (LA) into the Whale Optimization Algorithm (WOA) to create a new algorithm called M-Lion-Whale. This study presents a fitness parameter with five factors, energy, location, connection lifespan, latency, and trust, to determine the ideal route and assist QoS in decision-making.

Lal et al. introduced a QoS-aware routing algorithm, Retransmission Dual-Busy-Tone Multiple Access (RDBTMA) [19]. This method enhances the current Dual-Busy-Tone Multiple Access method, increasing efficiency and supporting QoS in Manets. This study examines the busy signals, CTS/RTS communication exchanges, and rapid retransmission mechanism to handle packet collisions.

Ghafoor et al. introduced a novel routing protocol named Beaconless Traffic-Aware Geographical Routing Protocol (BTA-GRP) designed explicitly for MANET in smart cities [20]. This method enhances geographic-based routing systems. This study considers traffic volume, location, and orientation while determining the routing expense function to find an appropriate route.

Guo et al. introduced the Bayesian Receiver Forwarding Decision (BRFD) system as a novel routing structure to integrate Named Data Networks (NDN) into VANET, creating the NDN-VANET network architecture [21]. The objective is to design a receiver-forwarding decision-making process that uses the Bayesian decision principle, considering the present state of the network. This design has a back-off technique to mitigate broadcasting storm problems caused by interest messages in NDN-VANET.

Xu et al. introduced a novel routing procedure named Packet Probability-based Routing(PPR), designed specifically for three-dimensional VANET situations [22]. The main aim of this work is to improve the dependability of communication links. This study develops a prototype for estimating the likelihood of packet receipt. Based on this framework, a routing decision-making process is implemented using a multi-objective optimizing issue to identify the connection with the greatest packet reception likelihood.

Mokhtari et al. introduced a novel AI-based method which utilizes Unmanned Aerial Vehicle (UAV) assistance to enhance the efficiency and security of urban VANET [23]. This workprovides two subordinate protocols for routing information and detecting malicious vehicles. The first sub-protocolis designed to route packets among vehicles with the assistance of UAVs. The second sub-protocolis designed to route packets among UAVs.[24] Behuraet al. undertakes an extensive analysis of 118 VANET routing protocols, comparing them with QualityofService parameters such as Security of the network, reliability access, delay element latency and scalability proposes a clustering model based on coalition-game theory. It also foresees the application of edge computing, 5G, and machine learning for enhancing vehicular networks in the future.[25]Abdullah et al. proposes HEER, a multi-criteria hybrid routing protocol for WBANs that optimizes residual energy, energy drain rate, energy harvesting, distance, and priority to increase packet delivery ratio, throughput, energy efficiency, and system lifetime in comparison to ERRS, AMCRP, and TAHT.

[26] Sefatiet al. describes a secure hybrid WSN routing architecture that integrates Q-learning, Reinforcement Learningwith trust-aware anomaly detection, ensuring scalable, energy-efficient, and attack-secure communication.[27]Vijayakumar, S. D et al. describes an energy-efficient Air Quality Clustering protocol for MANET-based WSNs, achieving 92% classification accuracy, 320-hour lifetime, 1% packet loss, and 30% energy savings with solar-assisted optimization.[28]M. Siraj et al. designs a mobile agent-based, quality-aware cooperative routing strategy for heterogeneous IoT networks, optimizing mobility, energy, and resource constraints to improve load balancing, reliability, and security.

The literature review is a systematic study of modern routing protocols, with a focus on their strengths and weaknesses. The relevance of Q-EERP, a dynamic and efficient routing protocol, is highlighted as crucial to the challenges posed by the changing conditions of the network. The proposed Q-EERP system combines a QoS-aware energy model with real-time analysis of node conditions, using adaptive methods to improve energy efficiency and route stability. Unlike conventional routing protocols, Q-EERP proposes an energy-aware framework that considers the power status of nodes and the residual energy ratio in the routing decision process. The combination of the two provides a comprehensive solution to the energy and quality-of-service (QoS) challenges. The system employs a cross-layer technique to estimate the quality of links using the RSSI and path stability measurements. This improves routing efficiency compared to current approaches that frequently depend on static or less dynamic models.

3. Proposed QoS-aware Routing Protocol for MANET

This section encompasses the Energy Model used in the route-finding operation, parameters for optimizing routing by emphasizing node and link quality estimate models, and the architecture of the Q-EERP protocol, which includes the procedures of path discovery, reply, maintenance, and route formation. This research aims to ensure the development of energy-efficient routes, accurately measure the efficiency of nodes and links, and opt the best pathways based on QoS metrics to enhance battery capacity in erratic network conditions.

3.1 Energy Model

Due to the limited battery capacity in MANETs, the primary focus is building energy-efficient routes. Therefore, the routing procedure must create an energy-efficient route, considering both the endpoints' power utilization and residual battery life. This research introduces the energy model utilized in the route-finding procedure of the suggested Q-EERP method. The energy modeling adopts a node-level methodology but with simplifications to reduce routing overhead.

The residual energy of individual MANET device is determined through the energy element, which is the quotient of the residual energy and the beginning node's energy. An ad hoc node becomes an intermediary node of a legitimate route whose energyfactor is higher than or equivalent to a given threshold value, $TV_E (0 \leq TV_E \leq 1)$. The energy ratio ($E_x^{res}$) of a node at any given time t is calculated using the following method.The remaining power of node n_x, $E_x^{res}(t)$at period t is calculated as:

$$E_x^{res}(t) = E_x^0 - C_x(t) \qquad (1)$$

Where E_x^0 represents the starting power and $C_x(t)$is the power spent by node n_x at period t, calculated using the following parameters.

- The transmitted energy$TE_{xy}(t)$refers to the amount of energy used by node n_x while packet transmission to node n_y.
- The remaining energy$RE_{xy}(t)$refers to the amount of power used by node $n_x$while packet is received from node n_y.

- The energy needed by node $n_x$for transmitting a packet to node n_y is denoted as $RL_{xy}(t)$.
- Power consumption ϕ of a node throughout periods of inactivity, sleep, and movement. Therefore, the calculation of the overall power used $C_x(t)$by a node $n_x$at period t is as follows:

$$C_x(t) = TE_{xy}(t) + RE_{xy}(t) + RL_{xy}(t) + \phi \quad (2)$$

The power needed to transmit a packet, denoted as $RL_{xy}(t)$, is calculated as follows:

$$RL_{xy}(t) = TE_{xy}(t) + RE_{xy}(t) + \delta \quad (3)$$

δ represents the amount of power used forthe packet arrival. The function $C_x(t)$that now expressed as:

$$C_x(t) = 2\left(TE_{xy}(t) + RE_{xy}(t)\right) + \delta \quad (4)$$

The power needed for sending messages from node n_x to node n_y in period t, denoted as $TE_{xy}(t)$,is determined by the power usage c_{xy} per bit transfer and the information rate d_{xy} from node n_x to node n_y. The calculation for $TE_{xy}(t)$is as follows:

$$TE_{xy}(t) = c_{xy}d_{xy} \quad (5)$$

The $RE_{xy}(t)$ by node n_x for receiving a packet from node $n_y$in period t is calculated as

$$RE_{xy}(t) = \varepsilon d_{xy} \quad (6)$$

Where ε represents the uniform power consumption required for receiving a single bit across all nodes. The following expressioncalculates the cost of power usage per bit transfer, denoted as c_{xy}.

$$c_{xy} = \alpha\beta'\left(l_{xy}\right)^n \quad (7)$$

The parameter α, n (1 < n ≤ 4), and l_{xy} represent the network's spacing independent variable, path loss indicator, and the separation between nodes n_x and n_y, accordingly. The factor β'represents the length dependence term and accounts for the nodes' comparative movement. The projection for $\beta'$is calculated as:

$$\beta' = \beta * \frac{l_{xy}^m}{l_{xy}^0} \quad (8)$$

The variable l_{xy}^0 represents the starting distance among the nodes n_x and n_y, whereas l_{xy}^m represents the mean length moved among the nodes throughout the measured time frame. The variable β is associated with the spatial separation of the nodes.

The energyratio of a node is calculated as follows:

$$EF_x(t) = \frac{E_x^{res}(t)}{E_x^0} \quad (9)$$

The energy ratio $EF_x(t)$ is crucial in calculating the ability of a node. It is equivalent to a threshold level to determine whether a path is legitimate during the path discovery procedure. The ability of a node n in the set N is represented by $C(n)$, where $C(n)$ is a value between 0 and 1. The ability is calculated by combining the subsequent properties of the node:

- ResidualPower, $P(n) = EF_x(n)$
- Memory consumption, $Mu(n)$
- Central Processing Unit (CPU)consumption, $Cu(n)$
- Network utilization, $Nu(n)$

The Capacity $C(n)$ of a specific node n is calculated as follows:

$$C(n) = w_P P_{(n)} + w_M Mu(n) + w_C Cu(n) + w_U Nu(n) \quad (10)$$

Where w_P, w_{Mu}, w_{Cu}, and w_{Nu} represent the weights allocated to each node variablefor residual power, memory, CPU, and network. These weights are allocated in a manner that:

$$w_P + w_{Mu} + w_{Cu} + w_{Nu} = 1 \quad (11)$$

From the capacity of a node, energy ratio can be obtained. This is useful in analyzing the different energy usage with respect to time and helps to get the node's energy, which is residual in nature. The corefocus of the research is to mitigate energy usage, hence obtain higher residual energy level.

3.2 Parameters for Efficient Routing

This subsection will cover the key characteristics used to assess the total quality of a path in a MANET, focusing on the two primary elements: nodes and connections.

3.2.1 Node condition prediction

The prime function of MANETdevices is to facilitate the transmission of data messages. Batteries power these mobile nodes. Therefore, it is necessary to include power consumption prediction during routing. Every node expends power during four distinct states: transmission, reception, idle, and sleeping. The transmission stage consumes the most energy. Additional parameters, like the node level and the quantity of packets it forwards, are used to forecast its behavior in servicing. To assess the quality of a node, several characteristics are considered, including the pace at which energy is depleted, the current power level of the node,the energy consumption rate, and the number of messages sent. The following variables are briefly given below.

- Energy drain rate

The power depletion rate refers to the speed at which a MANET device consumes power. If the device exclusively handles arriving packets based on its remaining power, a significant amount of traffic is sent towards it. Another thing to consider is that if the consumption rate of a device with significant remaining energy is substantial, it experiences a rapid decrease in MANET lifetime, leading to its premature shutdown.

- Energy level

The greater energy level of a node indicates a better route. The estimation is calculated by dividing the starting power $E_0$by the present residual power E_∞, as given below:

$$E_L = \frac{E_0}{E_\infty} \qquad (12)$$

Mobile nodes function as routers, forwarding data packages. The processing capabilities of a node are assessed by the number of packets it handles. A node will be deemed more authenticQoS if it processes more packets.

- Degree of a node θ_n

The node density denotes the nodes countnear a particulardevice, N_x. A device with a greater level suggests that in the event of a connection being broken, it would be simpler to discover an alternative route. It guarantees fewer hops for the transfer of data packages. Therefore, the total quality of a node N_x is evaluated based on four variables: the level of the node θ_n, its power drain ratio $E_{d/t}$, power level E_0, and the amount of data packages P_d sent. The different weights w_1, w_2, w_3 and $w_4$are allocated to every element in a way that satisfies the equation $w_1 + w_2 + w_3 + w_4 = 1$. The reliability of the specific node, where x ranges from 1 to n, is estimated as

$$N_q = \theta_n w_1 + E_{d/t} w_2 + P_d w_3 + E_0 w_4 \qquad (13)$$

The overall aggregate cost of the performance of the nodes (ON_q) along the route is determined by adding up the predicted performance of each contributing node, as shown below.

$$ON_q = \sum_{x=0}^{N-1} N_q \qquad (14)$$

3.2.2 Link Quality Estimation Model

The suggested Q-EERP technique employs a cross-layered method to assess connection quality, primarily relying on the RSSI obtained from the bottom layer.

RSSI quantifies the level of signal quality received by the recipient. The Q-EERP method calculates the mean of the three most recent signals obtained or RSSI quantities, formally denoted as S_m. The RSSI rating needs details on the channel's standard. It indicates whether the obtained signal strength is sufficient for transmitting data packages. Additional factors considered in the assessment of link quality include R_{th}, which represents the minimum signal strength required for receiving it, $N_{s,c}$, which denotes the amount of hopping from the initial node to the present node and the cumulative quality of connections OL_{qx-1} included in the Routing Request (RREQ) package. The amount of Overall Aggregate Link performance OL_{qx} up to the present node N_x is calculated as

$$OL_{qx} = \frac{OL_{qx-1} + S_m + R_{th}}{N_{s,c}} \qquad (15)$$

Based on the link performance, the better link is selected for routing, in addition to higher residual energy containing nodes.

3.3 Q-EERP protocol design

3.3.1 Path discovery process

The primary objective of Q-EERP path discovery is to identify all routing pathways that possess enough communication capabilities. During this procedure, the target node executes an alternate route selection method to acquire the required path based on the data given by the intermediate node about connected resources.

During the first stage of path exploration, the origin node creates the RREQ package, which is structured as seen in Fig. 1. The structure introduces additional fields to hold data, such as power, capacity, and queue size, as opposed to the RREQ structure of AODV.

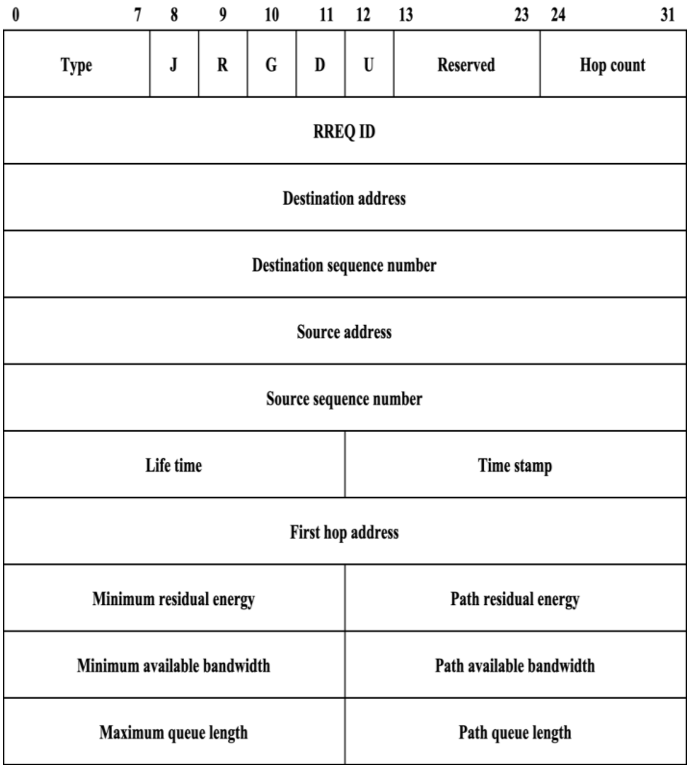


Fig. 1. RREQ Format

Upon getting an RREQ, the intermediary device must update the power, capacity, and queue size parameters in the RREQ field of Q-EERP and then transmit the updated RREQ to its immediate neighbor. Fig. 2 illustrates the intermediary node's handling process of the RREQ.

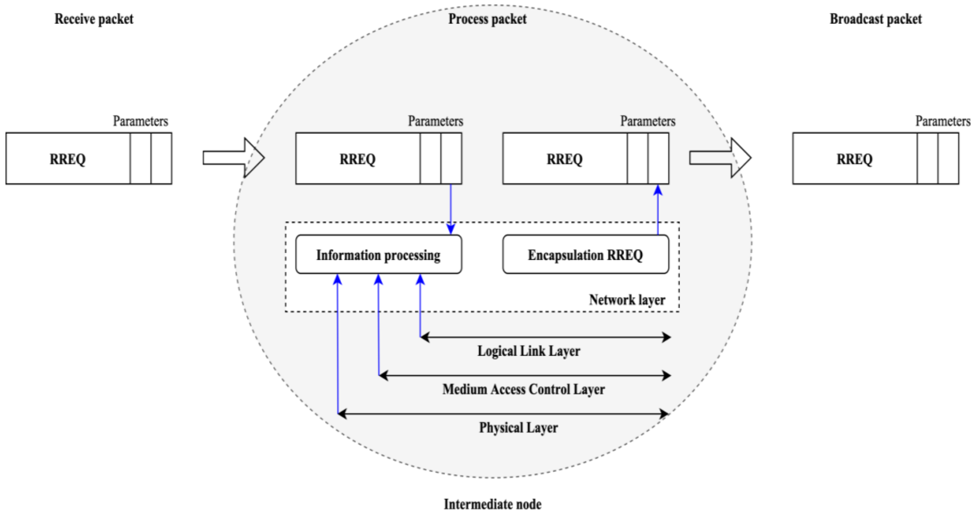


Fig. 2. Packet processing of RREQ

Upon receiving the initial RREQ, the target node promptly starts the timer. Once the timeout expires, the other option selection method retrieves the RREQ data to compute the cost value of the route.

3.3.2 Pathreply process

During the reply route procedure, every intermediary node computes the steady-state likelihood of the route taken by the Routing Reply (RREP) package. The entire procedure concludes at the original node. Fig. 3 displays the package structure for RREP. The packet structure of RREP includes an additional feature called Path Stability Condition (PSC), which is not included in AODV.

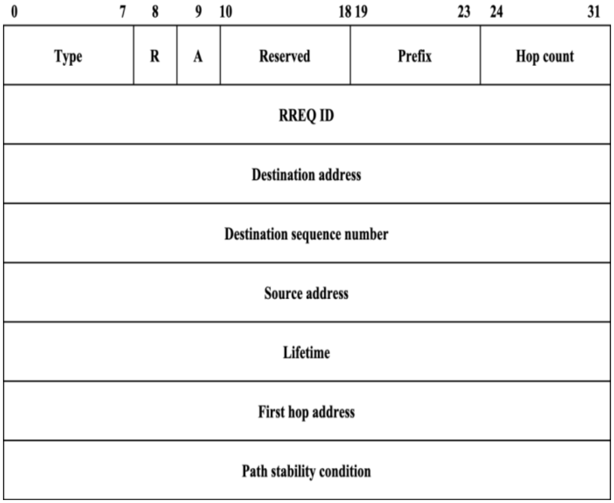


Fig. 3. RREP format

In the RREP message format, an extra field called path stability condition is added to check the link quality. Once the originating node has determined the constant likelihood of each route, the primary path-choosing method will organize all possible paths in an ordered manner based on their stable probabilities. The process will then choose the best route as the designated route for data communication based on the QoS.

3.3.3 Path maintenance process

A topology shift tracking and input system is included in routing management to mitigate lost packets and retransmission resulting from network interruptions. Within this system, the node along the route is responsible for monitoring the likelihood of a stable connection with the next-hop node. When this likelihood drops below a particular level, the node transmits a Link Abnormal State Warning (LASW) message to the original node. The LASWforwarded by the device node includes identification number for the associated node that forms the unbalanced connection.

When a middle node gets a route request, reply, and LASW, the routing modifies the rule of Q-EERPand is triggered to update the routing database. Upon receiving the route reply, the middle node will consist of the route item to the originating node in the reversing route table and then transmit the route request again. Upon receiving the route reply, the node will include the path entry to the forwarding route database for the target node and search for the reversing route to transmit the route reply. When the intermediary node gets LASW, it removes the path item associated with the poor QoS link and searches for an alternate route to keep transmitting LASW.

3.4 Route establishment process

The route discovering procedure is triggered when an origin node S must send a data message to a target node D, but D has no routing details in its database. The origin node starts the path discovery procedure by transmitting path request control messages to neighboring nodes.

In this suggested Q-EERP approach, two additional fields, namely accumulating node performance and accumulating link performance, are included in the route request packet. These data are included alongside the standard routing data, which provides source location, target sequence number, and hop count.

- Each intermediary node gets the route request signal and computes the node condition and channel QoS health accordingly. The predicted values are then inserted into the corresponding fields of the path reply data.
- The revised path reply data is sent to additional nodes, while the intermediary node rejects duplicated route reply messages.
- When the primaryroute reply packet attains the destination, the target's node buffer examines and stores the accumulated node and connection quality values along the route R_x. Afterward, the targeted node patiently awaits the arrival of an additional route reply message within a specific time frame to search for a more optimal route.
- When the packet arrives before the expiry duration, its retained values (representing the state of nodes and connections) are contrasted with the elements of the currently arrived route reply message. If the subsequent route reply signal for path R_y has a superior cumulative cost, regarding nodes or connections, compared to the prior one, the present message will be considered for further analysis.

The whole procedure for Q-EERP to enhance QoS in MANETis also shown in Fig.4.

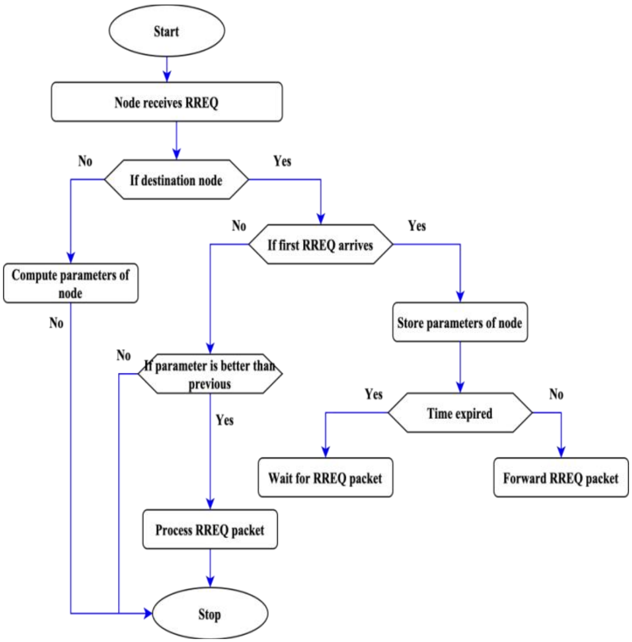


Fig. 4. Q-EERP routing process

The procedure carries out the following stages:

- Setup phase

Every node computes its Optimality Function (OF) during this stage by considering longevity, traffic quantity, and transmission dependability. These details are obtained from the surrounding area's data and are stored in its routing table.The first stage is to find and construct a path.

If no route is available to the destination, the source node begins finding a path by sending a path exploring request package (P_{req}) to its immediate neighbors. Intermediate nodes transmit this P_{req} message again, according to the OF of the neighboring node is one hop away, as maintained in its routing database until the target node is found. After obtaining a P_{req} package, the recipient node transmits a Path Exploration Response (P_{rep}) package as a response using the reversed route of the P_{req} message. The procedure concludes when the source node gets the P_{req} message is from the target node.

- Data forwarding stage

When the route discovery process concludes, the source getsmultiple pathways from the starting point to the target. The research assesses each path to determine the ideal route among many options to determine which is most suited for forwarding the information.

- Path maintaining stage

During this stage, updation of the routing table happens, with information on lifespan, dependability, and traffic concentration after completing a round.
The complete process of the Q-EERP routing algorithm is given below:

```
Input – Nodes, links, source, destination
Output – optimum path
Data – Lifetime, Reliability, Traffic intensity
Compute routing table for all nodes
Find path from source to destination
If path exists
    Evaluate selection criteria for best path
    Select the highest score & transmit the data
Else
    Compute path discovery & establishment
        Send path discovery request to next hop nodes
        Select highest score node as next hop
        Update the data in discovery request packet
        If node is destination
            Send path discovery reply
        Else
Send path discovery request to next hop nodes
        Evaluate selection criteria for best path
        Select the highest score & transmit the data
        Compute path data & update values in
```

```
routing table
End
```

The Q-EERP routing algorithm inputs nodes, connections, sources, and destinations to calculate the most efficient route, considering longevity, dependability, and traffic intensity characteristics. The algorithm then calculates the routing tables for each node and later selects a route from the source to the destination node. Once a viable route has been selected, an analysis of the criteria for selection is carried out to identify the best route, and data transfer is done based on the selected route. In the case where a route has not been discovered, a path discovery process is started by sending queries to the next-hop nodes. This process includes updates of information, selection of the node with the highest QoS value, and changes to the routing tables. The approach therefore encourages efficient data transfer and optimal network management in dynamic MANETs.

The Q-EERP framework is proposed to improve energy efficiency and ensure strong connectivity in Mobile Ad Hoc Networks (MANETs). The proposed protocol is most suited to critical applications such as vehicular communication networks, disaster response networks, and military communication networks, where reliable routing and efficient energy use are of utmost importance. In addition, the dynamic route selection approach integrated into the framework helps to improve performance in dynamic environments with varying resource availability and network heterogeneity.

4.Simulation results and analysis

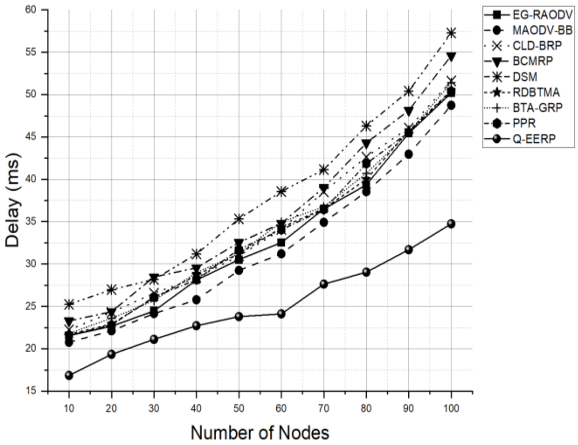
The simulation of the idealised Q-EERP is performed using Network Simulator 2 (NS-2). The initial energy of each node is set to 100 watts. The size of the network is changed from 10 to 100 nodes, and the nodes are randomly dispersed in a 1000 × 1000 m area to test the performance of MANET nodes at varying densities. The speed of the node is set to 2.5 m/s, and the Constant Bit Rate (CBR) traffic is set to 15 kb/s.

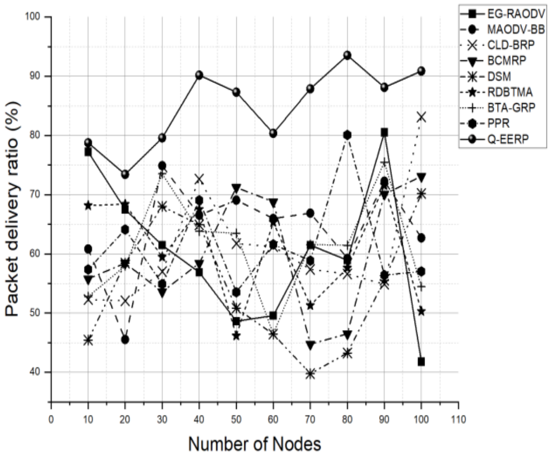
The results of the scenarios include several output criteria, which are given as follows:

- The delay of the end to end node, sometimes known as latency, indicates the period it takes to send all data messages, measured in ms.
- The Packet Delivery Ratio is computed as the amount of data messages correctly reaching their intended target compared to the overall number of data messages transmitted and measured in %.
- Throughput is computed as the aggregate data collected by all nodes during a specific period and measured in kBps.
- Control overhead refers to the number of path request packets (hello, route request, reply, and error) sent across the network throughout the path discovery procedure and measured in percentage.
- Normalizing routing overhead refers to the proportion of path request messages to the entire quantity of data messages that arrive at the target and is measured in %.
- Residual energy refers to the remaining energy at a node after some period. It is measured in Jules (J).

  The performance of the proposed algorithm is appraised using different node density and node mobility conditions.

4.1 Node density vs. metrics





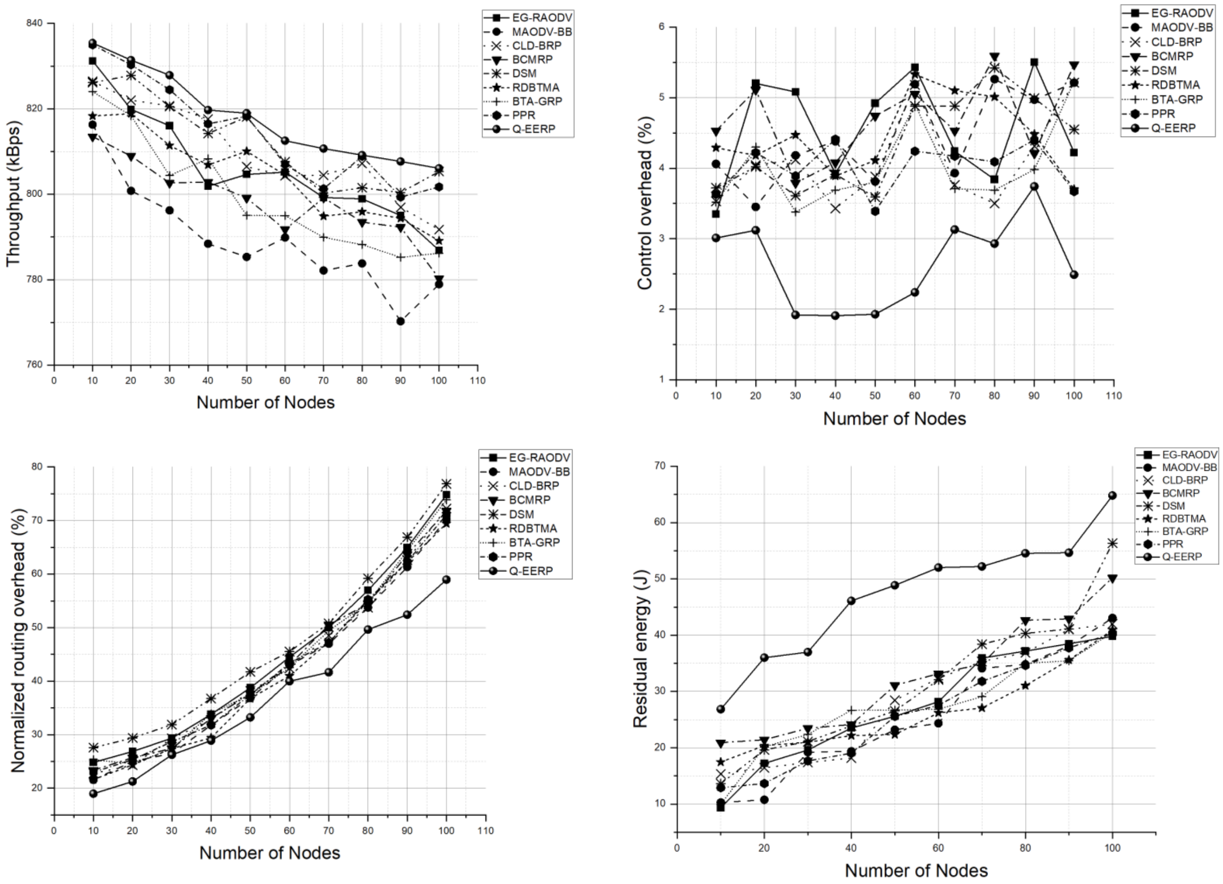
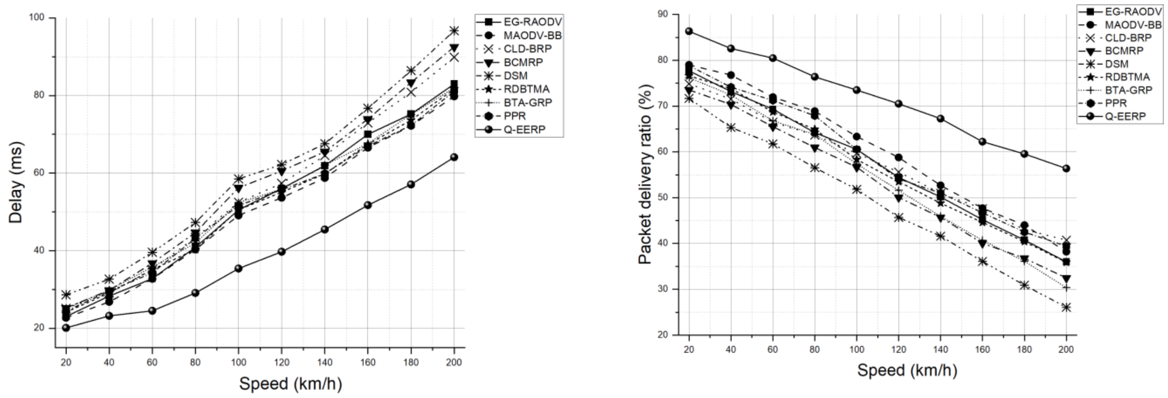


Fig. 5. Performance analysis over different node densities (a). Delay, (b). Packet delivery ratio, (c). Throughput, (d). Control overhead, (e). Normalized routing overhead, and (f). Residual energy

Figures 5(a) to 5(f) show the performance comparison of different routing algorithms based on varying node densities. The Q-EERP protocol provides an average delay of 25.11 ms, a packet delivery ratio of 85%, a throughput of 817.95 kBps, a control overhead of 2.64%, and a normalized routing overhead of 37.12%. The average residual energy is 26.85 J. With the increase in node density, the Q-EERP protocol remains highly efficient by handling increased traffic through its adaptive routing and energy-saving mechanisms. Compared to other protocols, Q-EERP shows a large improvement in packet delivery ratio, which increases by 30%. It also shows a significant reduction in control overhead, which reduces by 40%, thereby showing improved efficiency. The ability of the protocol to dynamically adjust routing paths based on the quality of connections and node energy further reduces delays and overheads, thereby leading to improved performance. The network, therefore, remains stable and efficient at high node densities because of the routers' ability to make decisions based on RSSI, QoS, and residual node energy.

4.2 Node speed vs. metrics



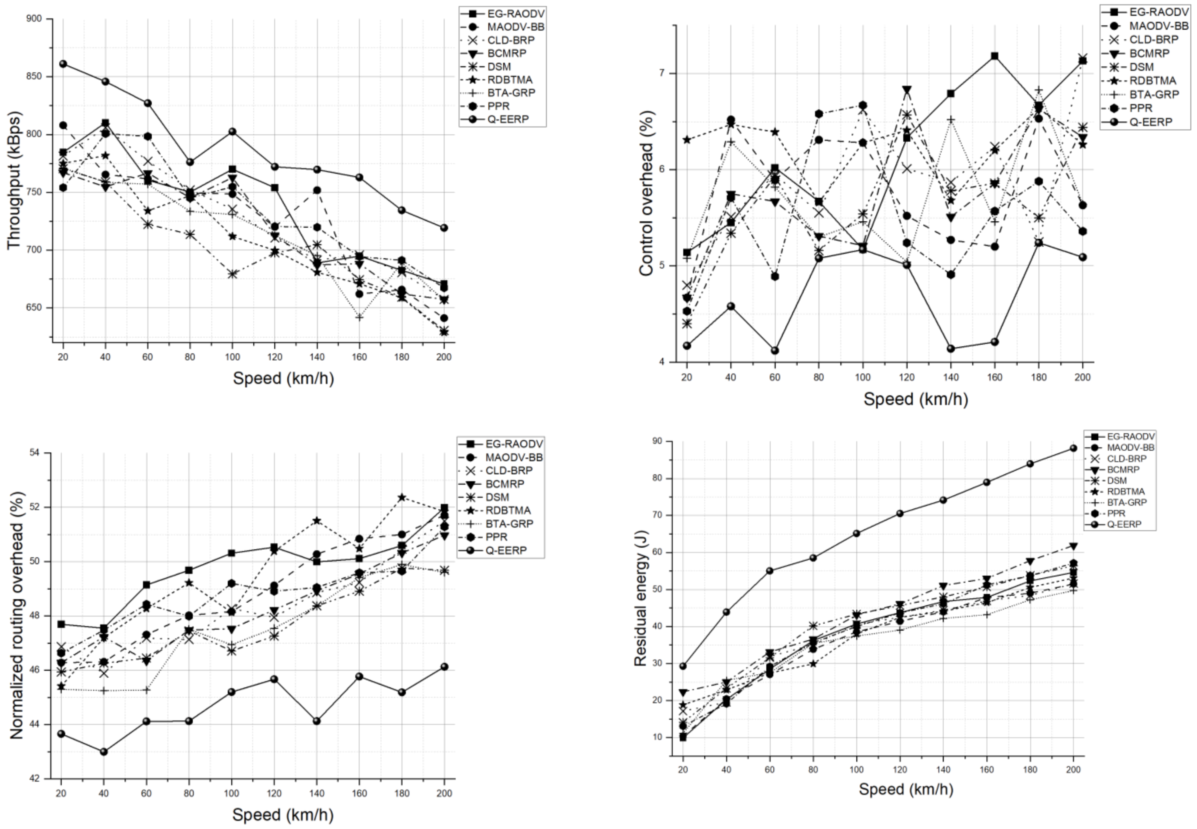


Fig. 6. Performance analysis over differentnode mobilities (a). Delay, (b). Packet delivery ratio, (c). Throughput, (d). Control overhead, (e). Normalized routing overhead, and (f). Residual energy

Figures 6(a) to 6(f) illustrate the performance comparison of various routing algorithms based on the mobility of various nodes. The Q-EERP protocol provides the best performance in all respects because of its adaptive routing and energy conservation capabilities. Specifically, the system provides an average latency of 39.03 ms, packet delivery ratio of 71.52%, throughput of 787.11 kBps, control overhead of 4.68%, normalized routing overhead of 44.7%, and residual energy of 64.77 J. The latency reduction and packet delivery ratio enhancement of up to 35% can be ascribed to the optimized route discovery and minimum retransmission of Q-EERP. Moreover, the system provides a throughput enhancement of up to 15% compared to other protocols, which is because of the optimal data management and 20% lower overhead related to other protocols. The proposed protocol provides better performance by efficiently managing traffic and optimizing energy consumption, thereby providing stable and reliable network performance even at higher node speeds, where other protocols experience higher latency and packet loss.

The proposed Q-EERP method has better performance capabilities in terms of different node densities and mobility. This is achieved by using a routing mechanism that thoroughly and efficiently analyzes the quality of nodes and links. The adaptive route selection mechanism of the proposed protocol, which considers the RSSI, QoS, and residual energy of nodes, ensures optimal route identification and maintenance. This leads to enhanced battery life, lower control overhead, and better packet delivery ratio, which provide stable and efficient network performance in dynamic networks.

5. CONCLUSION AND FUTURE SCOPE

This work contributes to the area of routing stability in Mobile Ad Hoc Networks (MANETs) by developing and implementing the proposed QoS-aware Energy-Efficient Routing Protocol (Q-EERP). The proposed protocol jointly evaluates the performance parameters at the node and link levels to guarantee stable and sustainable path routing. In the route maintenance process, the performance status of neighboring nodes is continuously evaluated using a modified HELLO messaging system. The improved control packet includes supplementary information specific to the transmitter, such as residual energy values and geographical coordinates, which support precise distance measurement and energy-efficient neighbor assessment. This makes it possible to proactively remove unstable and energy-exhausted nodes from active routing paths, thus preventing early route failures. Performance evaluation was carried out using the Network Simulator 2 (NS-2) simulation software, with the mobility of nodes represented by the speed and pause time variables. The simulation outcome shows that Q-EERP has an average end-to-end delay of 25.11 ms, a packet delivery ratio of 85%, a throughput of 817.95 kBps, a control overhead of 2.64%, and a normalized routing overhead of 37.12%. These results clearly show that the proposed protocol improves the reliability and throughput of data packet delivery while significantly reducing the end-to-end delay and routing overhead compared to existing solutions. Real-time experimentation was not considered due to the high cost, complexity, and maintenance issues involved in implementing the proposed protocol in a hardware setup. Simulation-based validation allows for controlled experimentation with varied mobility conditions that are hard to recreate in a real-world setting. Future research will be directed at implementing and validating Q-EERP in a controlled experimental testbed to evaluate the practical feasibility and scalability of the proposed protocol in a real-world setting.

REFERENCES

1. Kaisar, S., Kamruzzaman, J., Karmakar, G., & Rashid, M. M. (2022). Decentralized content sharing in mobile ad-hoc networks: A survey. Digital Communications and Networks.
2. Singh, P., Khari, M., & Vimal, S. (2022). EESSMT: an energy efficient hybrid scheme for securing mobile ad hoc networks using IoT. Wireless Personal Communications, 126(3), 2149-2173.
3. Goyal, P., Rishiwal, V., & Negi, A. (2023). A comprehensive survey on QoS for video transmission in heterogeneous mobile ad hoc network. Transactions on Emerging Telecommunications Technologies, 34(7), e4775.
4. Xie, J., & Murase, T. (2020). Multiple user cooperative mobility in mobile ad hoc networks: An interaction position game. IEEE Access, 8, 126297-126314.
5. Kanani, P., Patil, N., Shelke, V., Salot, K., Nanavati, A., Damodaran, N., & Desai, S. (2023). Improving QoS of DSDV protocol to deliver a successful collision avoidance message in case of an emergency in VANET. Soft Computing, 1-11.
6. Jain, R. (2022). Ant colony inspired energy efficient OLSR (AC-OLSR) routing protocol in MANETS. Wireless Personal Communications, 124(4), 3307-3320.
7. Saini, T. K., & Sharma, S. C. (2020). Recent advancements, review analysis, and extensions of the AODV with the illustration of the applied concept. Ad Hoc Networks, 103, 102148.
8. Almazok, S. A., & Bilgehan, B. (2020). A novel dynamic source routing (DSR) protocol based on minimum execution time scheduling and moth flame optimization (MET-MFO). EURASIP Journal on Wireless Communications and Networking, 2020, 1-26.
9. Angurala, M., Bala, M., & Bamber, S. S. (2020). Performance analysis of modified AODV routing protocol with lifetime extension of wireless sensor networks. IEEE Access, 8, 10606-10613.
10. Bamhdi, A. M. (2020). Efficient dynamic-power AODV routing protocol based on node density. Computer Standards & Interfaces, 70, 103406.
11. Chen, Z., Zhou, W., Wu, S., & Cheng, L. (2020). An adaptive on-demand multipath routing protocol with QoS support for high-speed MANET. IEEE Access, 8, 44760-44773.
12. Eiza, M. H., & Ni, Q. (2013). An evolving graph-based reliable routing scheme for VANETs. IEEE transactions on vehicular technology, 62(4), 1493-1504.
13. Rajadurai, S. J. G., Veerappan, J., & Ramasamy, K. (2017). Optimization of multicast ad hoc on-demand routing protocol based on genetic algorithm with backup paths in MANET. Wireless Personal Communications, 94, 2095-2124.
14. Jain, B., Brar, G., Malhotra, J., Rani, S., & Ahmed, S. H. (2018). A cross layer protocol for traffic management in Social Internet of Vehicles. Future Generation computer systems, 82, 707-714.
15. Chen, Y. H., Wu, E. H. K., Lin, C. H., & Chen, G. H. (2017). Bandwidth-satisfied and coding-aware multicast protocol in MANETs. IEEE Transactions on Mobile Computing, 17(8), 1778-1790.
16. Chen, Y. H., Hu, C. C., Wu, E. H. K., Chuang, S. M., & Chen, G. H. (2017). A delay-sensitive multicast protocol for network capacity enhancement in multirate MANETs. IEEE Systems Journal, 12(1), 926-937.
17. Agarwal, P., Gupta, R., & Alam, M. A. (2023). Sprouting Tree for Physiological Stress Assessment Using Fuzzy Petri Net. Current Psychiatry Research and Reviews Formerly: Current Psychiatry Reviews, 19(3), 314-324.
18. Ahirwar, G. K., Agarwal, R., & Pandey, A. (2023). An Extensive Review on QoS Enhancement in MANET Using Meta-Heuristic Algorithms. Wireless Personal Communications, 131(2), 1089-1114.
19. Lal, C., Laxmi, V., Gaur, M. S., & Ko, S. B. (2015). Bandwidth-aware routing and admission control for efficient video streaming over MANETs. Wireless Networks, 21, 95-114.
20. Ghafoor, K. Z., Abu Bakar, K., Lloret, J., Khokhar, R. H., & Lee, K. C. (2013). Intelligent beaconless geographical forwarding for urban vehicular environments. Wireless networks, 19, 345-362.
21. Guo, X., Chen, Y., Cao, L., Zhang, D., & Jiang, Y. (2020). A receiver-forwarding decision scheme based on Bayesian for NDN-VANET. China Communications, 17(8), 106-120.
22. Xu, C., Xiong, Z., Kong, X., Zhao, G., & Yu, S. (2019). A packet reception probability-based reliable routing protocol for 3D VANET. IEEE Wireless Communications Letters, 9(4), 495-498.
23. Mokhtari, S., Nouri, N., Abouei, J., Avokh, A., &Plataniotis, K. N. (2022). Relaying data with joint optimization of energy and delay in cluster-based UAV-assisted VANETs. IEEE Internet of Things Journal, 9(23), 24541-24559.
24. Behura, A., Kumar, A. & Jain, P.K. A comparative performance analysis of vehicular routing protocols in intelligent transportation systems. *Telecommun Syst* **88**, 26 (2025). https://doi.org/10.1007/s11235-024-01243-1
25. Abdullah, A.M. Hybrid energy-efficient routing protocol for extended network lifetime in wireless body area networks. *J Supercomput* **82**, 130 (2026). https://doi.org/10.1007/s11227-026-08277-z
26. Sefati, S.S.; Sefati, S.T.; Nazir, S.; Zareh Farkhady, R.; Obreja, S.G. Federated Reinforcement Learning with Hybrid Optimization for Secure and Reliable Data Transmission in Wireless Sensor Networks

(WSNs). *Mathematics* **2025**, *13*, 3196. https://doi.org/10.3390/math13193196

27. Vijayakumar, S. D., and S. Anbu Karuppusamy. "Energy optimized air quality monitoring with AQC-MANET for real time pollutant detection and analysis." *GLOBAL NEST JOURNAL* 27.9 (2025).
28. M. Siraj, M. Altamimi and Z. Ahmad Abbasi, "Mobile Secured IoT Sensors-Driven Network Using Efficient QoS Management," in *IEEE Access*, vol. 12, pp. 180471-180480, 2024, doi: 10.1109/ACCESS.2024.3509692.