International Journal of Computer Information Systems and Industrial Management Applications
ISSN 2150-7988 Volume 18(18s) 2026 pp. 367-382
https://doi.org/10.70917/ijcisim-2026-4876
Article

Link Capacity Aware Load Balanced and Energy Efficient Multipath Routing for MANETs (EMRD-LB)

Aradhana Saxena[1], Nitika Vats[2]

[1]SAGE University, Indore, Madhya Pradesh, India.
Email: saxena.aradhna@gmail.com
[2]SAGE University, Indore, Madhya Pradesh, India.
Email: Nitika.doohan@gmail.com
Corresponding Author:Aradhana Saxena

Abstract: Mobile nodes are continuously moving in the network and form the link to transfer the information between source and destination. All the mobile nodes have limited bandwidth and limited battery power. Energy is the primary source required for route establishment and data transfer to all the interconnected nodes. If the nodes have a limited amount of energy, it means immediate action is required to switch to the other node or re-establish the route for proper data transfer. In this research, a novel energy-efficient multipath routing for load balancing (EMRD-LB) is capable of improving the routing performance. The EMRD-LB approach is efficiently utilizing the energy of nodes and link capacity to avoid congestion from the network. This method enhances data flow and extends the operational lifespan of the network nodes. By dynamically adjusting the routing paths based on current energy levels, the system ensures optimal performance even under varying load conditions. The load balancing is required to reduce the packet dropping and control the extra load by reducing the data rate and buffer management. The proposed scheme is also capable of reducing overhead, which is typically increased due to data retransmissions and delays in acknowledgement packets. Flooding of overhead packets increases bandwidth consumption and delays in data forwarding. The performance of EMRD-LB is compared with QMR, AOMDV, and MMEE, and the performance of the proposed scheme is better. The EMRD-LB reduces delay, reduces packets dropping and improves data receiving.
Keywords: -MANET, Energy, Load balancing, link capacity, Routing

1. Introduction:

Mobile ad hoc networks (MANETs) are self-organizing wireless networks formed by mobile nodes that communicate without fixed infrastructure or centralized controller, which makes routing both essential and difficult because link break frequently, limited bandwidth and nodes run on constrained batteries. Classical single-path reactive protocols such as AODV, TORA and DSR discover one “best” route on demand, but this single route often becomes congested or fails when node mobility is very high, causing packet loss, increased delay and faster energy depletion along heavily used processing capacity of nodes. Multipath routing was introduced to address these limitations by maintaining several alternative routes between a source and destination to improve reliability, support load sharing and reduce route discovery overhead however many existing multipath schemes do not explicitly account for instantaneous link capacity, traffic load and node energy in a unified way, so some paths still turn into bottleneck while others remains underutilized.

The proposed link capacity aware load balancing and energy efficient multipath routing for MANETs (EMRD-LB) targets this gap by combining cross-layer link capacity estimation with energy-aware, balanced load route selection. In EMRD-LB information from the MAC and physical layers (such as channel utilization, queue length, signal quality) is used to estimate the effective available bandwidth of each wireless link, while residual energy and drain rate at nodes are monitored to avoid overusing low-energy devices. During rote discovery, multiple candidate paths are collected and each path is evaluated with a multi-objective score that jointly considers its bottleneck link capacity, energy profile, load distribution and predicted stability, so that the protocol can select a small set of high-quality multipath routes and assign traffic weights to them rather than relying on a single best path. By dynamically splitting traffic across these capacity-aware and energy-conscious paths and continuously adapting the weights based on congestion and energy feedback, EMRD-LB aims to increase packet delivery ratio, lower end-to-end delay, reduce routing overhead and extend network lifetime compared with conventional AODV-based and existing multipath energy aware schemes.

2. Literature Review

In this section describe existing work to control congestion, energy ware and load balancing technique in brief which associate key feature, performance metrics, advantage and limitation and challenges. These works helps to develop proposed system which able to overcome the limitation and existing challenges to fulfill requirement of research.

Research on routing in Mobile Ad Hoc Networks (MANETs) has evolved significantly from conventional on-demand routing toward multipath, energy-aware, load-balanced, QoS-aware, optimization-based, and intelligent routing mechanisms. One of the foundational approaches was the Dynamic Source Routing (DSR) protocol, which employed on-demand route discovery and route caching to support communication in dynamically changing networks [1]. Although DSR offered relatively low routing overhead and rapid adaptation, its dependence on route-cache information resulted in scalability and stale-route problems in highly mobile networks. Cross-Layered Multipath AODV (CM-AODV) subsequently incorporated signal-quality information and cross-layer parameters into route selection, improving path reliability by considering link-quality and SNR-related characteristics [2]. However, cross-layer interaction introduced additional implementation complexity.

A comprehensive survey of multipath routing protocols emphasized the importance of reliability, delay, energy efficiency, and routing overhead in MANET environments [3]. The survey demonstrated that multipath routing can improve fault tolerance by maintaining alternative routes, but it also highlighted the additional overhead associated with maintaining multiple paths. Node-disjoint multipath routing considering link and node stability further addressed this issue by incorporating Link Expiration Time (LET), drain rate, bandwidth, and node stability into route selection [4]. Such mechanisms can improve network lifetime and reliability by avoiding unstable or energy-depleted nodes; however, discovering node-disjoint paths may require considerable control overhead.

Load balancing became an important research direction as increasing traffic concentration on selected nodes caused congestion, energy depletion, and reduced network lifetime. A survey of load-balancing techniques in MANETs analyzed clustering, traffic distribution, energy consumption, and network lifetime as important factors for maintaining QoS [5]. The study demonstrated that effective traffic distribution can prevent individual nodes from becoming bottlenecks, although the wide diversity of load-balancing strategies makes the development of a unified adaptive solution challenging. Location-aware routing using a Genetic Algorithm (LOCA-GAMNET) subsequently incorporated node location, gateway selection, and mobility parameters into the routing process [6]. The genetic optimization mechanism improved packet delivery and reduced packet loss, but its effectiveness depended on the availability and accuracy of location information and introduced additional computational requirements.

QoS-aware routing further extended multipath routing by considering application-specific requirements. A QoS-aware multipath threshold routing mechanism employed bandwidth and delay thresholds together with traffic information to select appropriate routes [7]. This approach improved QoS for traffic-sensitive applications, but the selection of appropriate threshold values remained difficult because network conditions change continuously. Efficient Multipath AODV (EMAODV) attempted to improve route discovery by incorporating TTL-related mechanisms, reducing unnecessary flooding, and improving relay/forward decisions [8]. Although the approach reduced congestion and improved routing efficiency, TTL adjustment increased route-discovery complexity.

Energy efficiency subsequently became a major objective in MANET routing because mobile nodes operate under limited battery resources. The Energy-Aware Multipath Routing Scheme based on PSO (EMPSO) integrated Particle Swarm Optimization with a Continuous-Time Recurrent Neural Network (CTRNN) to identify optimized loop-free routes based on transmission cost and energy considerations [9]. The optimization capability improved routing decisions, but CTRNN training and PSO processing introduced additional computational overhead. A node-disjoint multipath routing protocol further focused on complete path separation to prevent bottlenecks at common intermediate nodes and improve fault tolerance [10]. Although node-disjoint paths provide improved resilience, their discovery and maintenance can increase routing overhead, particularly in highly dynamic networks.

Efficient load-balancing routing techniques subsequently attempted to jointly improve QoS and network lifetime by distributing traffic more effectively across available nodes [11]. Such approaches improved PDR, throughput, and delay characteristics, but maintaining an appropriate load distribution under rapid topology changes remained challenging. A stable multipath routing strategy proposed in 2017 combined residual energy, Link Expiration Time, and load-balancing information during route selection [12]. This approach represented an important step toward jointly considering energy, link stability, and traffic distribution. Nevertheless, its dependence on conventional stability metrics limited its ability to predict future link failures or dynamically anticipate congestion.

Secure multipath routing was also investigated to improve the robustness of MANET communication. AODV-SMR used non-intersecting paths to reduce the effect of path failures and improve packet delivery [13]. The use of non-overlapping paths enhanced fault tolerance, but path establishment and maintenance became more complicated. HDF-based optimal path selection was subsequently applied to multipath wireless sensor networks using AOMDV and an HDF-based path evaluation mechanism [14]. The approach attempted to select the optimal route from multiple available paths according to route-quality characteristics. Although this improved path selection, the accuracy of route-quality prediction could decrease when network conditions changed rapidly.

Optimization-based cross-layer approaches gained further attention around 2020. EECRP-PSO integrated PSO with cross-layer information to optimize routing and MAC-layer parameters while reducing energy consumption and improving PDR [15]. The approach demonstrated improvements in delay and energy-related performance; however, cross-layer implementation and metaheuristic optimization increased system complexity. This limitation suggests that routing algorithms should provide optimization benefits without imposing excessive computational and communication requirements on resource-constrained nodes.

Cluster-based and multipath routing approaches continued to develop in 2021. A multipath cluster-based routing protocol employed traffic distribution, congestion reduction, and an analytical delay model to improve reliability and load balancing [16]. The approach provided useful traffic-management capabilities, although analytical models often rely on simplifying assumptions that may not accurately represent highly dynamic MANET environments. Performance evaluation of AOMDV further demonstrated the benefits of multiple reverse and link-disjoint paths for maintaining fault tolerance and reducing packet loss [17]. However, duplicate RREQ processing and multipath maintenance can produce considerable control overhead.

In 2022, hybrid metaheuristic optimization was introduced to further improve multipath routing. The SM-CSBO approach combined Cuckoo Search and Butterfly Optimization to address multiple objectives involving QoS, energy efficiency, and reliable transmission [18]. Its superior performance compared with several conventional optimization approaches demonstrated the potential of hybrid optimization. Nevertheless, combining multiple metaheuristic algorithms can increase computational complexity and processing time, making lightweight implementation an important consideration.

Recent research has moved toward predictive and machine-learning-based routing. A bio-inspired and machine-learning-driven multipath routing framework combined ACO, ETX, LSTM, and Random Forest techniques to predict link reliability and support intelligent routing decisions [19]. The integration of machine learning enabled predictive routing rather than relying exclusively on current network conditions. However, model training, computational requirements, and adaptation to changing network patterns remain significant challenges. More recently, the

Intermediate Node Traffic Sharing Model (INTSM) introduced dynamic traffic sharing and predictive analysis for MANET route discovery, with the objective of reducing packet delay and congestion while improving throughput [20]. Although the approach demonstrated promising improvements, its assumption of relatively predictable traffic patterns may restrict performance under highly unpredictable network conditions.

Overall, the literature demonstrates a clear transition from conventional reactive routing [1]–[4] to load balancing and QoS-aware routing [5]–[8], followed by energy-aware and optimization-based routing [9]–[15], and finally intelligent, predictive, and adaptive routing [16]–[20]. Despite this progress, most existing approaches focus on one or a limited combination of routing factors, such as energy, link stability, congestion, QoS, or predictive link quality. Optimization-based approaches may introduce high computational overhead, while machine-learning-based approaches require training resources and may not adapt efficiently to rapidly changing network conditions. Therefore, a research gap remains for an adaptive and lightweight multipath routing protocol capable of jointly considering residual energy, link stability, congestion/load distribution, route reliability, packet delivery, delay, and network lifetime. This motivates the development of the proposed Energy-aware Multipath Routing with Dynamic Load Balancing (EMRD-LB) protocol.

Table 1. Comparison of Five Most Relevant Studies

Ref.	Year	Approach / Protocol	Key Features	Performance Focus	Major Advantage	Limitation
[9]	2015	EMPSO	PSO + CTRNN, energy-aware multipath, loop-free routes	PDR, energy, hop count, overhead	Energy-efficient route optimization	High computational/training overhead
[12]	2017	Stable Multipath Routing	Residual energy, LET, load balancing	PDR, delay, energy consumption	Combines stability and energy with load balancing	Limited predictive capability
[15]	2020	EECRP-PSO	PSO, cross-layer optimization, MAC information	PDR, energy, delay, overhead	Effective energy and delay optimization	Cross-layer and PSO complexity
[18]	2022	SM-CSBO	Cuckoo Search + Butterfly Optimization	PDR, routing/control overhead, QoS	Strong multi-objective optimization	High computational complexity
[19]	2023	ML-Driven Multipath Routing	ACO, ETX, LSTM, Random Forest	Link prediction, throughput	Predictive and intelligent routing	Training time and resource requirements

3. Proposed Work:

Ad hoc communication is adopted in many applications to improvise services related to data transmission and reliability. This research adopts a simulation-based experimental methodology to design, implement, and evaluate a link capacity-aware, load-balanced, energy-efficient multipath routing for mobile ad hoc networks (MANETs). The proposed (EMRD-LB) approach enhances traditional multipath routing by making it aware of link capacity, traffic distribution, and remaining energy during route discovery and data transmission. To develop and adopt the proposed strategy, the methodology consists of four major phases.

1. System Model and Assumption
2. Link Capacity Estimation
3. Energy Estimation
4. Data Forwarding and Load Balancing

3.1 System Model and Assumption

Consider a mobile ad hoc network as G = (V, E), where V = {v1, v2, v3,…vn} is the set of mobile nodes in the network and E represents bidirectional wireless links. The nodes are configured by initial energy, transmission range R, node mobility as a random waypoint model, symmetric links (meaning if node vi can hear vj, then vj can hear vi), MAC protocol RTS/CTS mechanism to handle the hidden terminal problem, physical and MAC layers available to the network layer, and a routing protocol for route decisions. These assumptions are useful for deploying the network and implementing it under network simulation 2. Collectively, the nodes form a dynamic topology that enables multipoint communication between the source and destination, with multiple paths available simultaneously; however, this topology frequently changes, which is crucial for maintaining stability in the network. The proposed EMRD-LB uses the concept of signal strength and location-based service to predict the direction of the destination and somehow increase the network stability of communication. In this methodology, our objective is to balance network load and provide efficient energy-based routing, which requires the key concept of identifying each node's load dependency parameters, such as link capacity, queue utilization, available channel bandwidth, incoming and outgoing data flow rate, and getting the mobile node load on the other side to achieve energy efficiency. To achieve this, we gather details about each node's current energy, the energy depletion rate per data packet, and the estimated energy consumption and lifetime of the node, which are essential for determining the node's status and prioritizing timely route changes based on its remaining lifetime. The overall proposed system provides congestion-free and balanced-load communication to mobile ad hoc networks.

3.2 Link Capacity Estimation

In the mobile ad hoc network channel bandwidth is very limited because the number of available channels is shared by multiple users. In the ad hoc network channel contention is very high due to frequent changes in the topology and routing table. In ad hoc communication, measuring link capacity is crucial due to dynamically shared nodes sharing the common channel and changing network topology. In the proposed EMRD-LB routing, link capacity estimation depends on bandwidth, channel, MAC contention, queue occupancy, and transmission time, which are formalized in eq (1) to eq (11).

The available bandwidth on link (i, j) is estimated as:

$B_{ij}^{avail} = B_{ij}^{max} - B_{ij}^{used}$ …………………..(1)

Where

B_{ij}^{max}= maximum channel capacity of 802.11b standard

B_{ij}^{avail} = Bandwidth consumed by existing flow

The available link capacity LCij between nodes I and j is calculated as:

$LC_{ij} = B \times \left(1 - C_{ij}\right) \times \left(1 - Q_{ij}\right)$………………(2)

Where

B= Nominal channel bandwidth

C_{ij} = Channel contention

Q_{ij} = Queue utilization

The available bandwidth and link capacity are less than the predefined threshold, so they are excluded from route formation.

The channel utilization is also measured to identify the availability of the channel, which is calculated as follows:

$$U_{ij} = \frac{T_{busy}}{T_{max}} \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where the time channel is sensed as busy and is the maximum window size.

In the communication duration of transmission time is also important because it identifies how long data is carried by the medium, which helps to estimate the time taken for data from source to receiver. The proposed system is able to estimate the transmission time, which helps to identify the channel busyness of the shared channel and the expected contention time for new transmitter nodes. The expected transmission time (ETT) combines link capacity and packet loss to evaluate as follows between the i and j nodes:

$$ETT_{ij} = \frac{P_s}{B_{ij}^{avail}} \times \frac{1}{1 - f_{ij}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where

P_s= Size of packet (bytes)

f_{ij}= forwarded data delivery ratio on link (i , j)

3.3 Energy Estimation

Mobile ad hoc network devices have limited battery power and without that energy, it is not possible to provide communication between nodes. The overall network formation depends on the battery so that our objective is to minimize the energy consumption via proper route selection and unwanted message flooding. In this section our objective is to predict the lifetime of a node in communication.

The total energy consumption for node vi

$$E_i^{consume} = E_i^t + E_i^r + E_i^i + E_i^s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where E_i^t = Transmission energy, E_i^r= reception energy, E_i^i= idle energy, and E_i^s= sensing energy.

The residual energy $E_i^{residual}$ is calculated as:

$$E_i^{residual} = E_i^{initial} - E_i^{consume} \quad ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,(6)$$

The node life time predict as

$$T_i^{lt} = \frac{E^{residual}}{E_i^{consume\_rate}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Where $E_i^{consume\_rate}$ = is average energy consumption per unit time.

3.4 Data Forwarding and Load Balancing

The proposed routing system uses the multipath routing mechanism, which is enhanced through the above methodology and guaranteed for efficient and reliable route discovery from source to destination. The multipath route selection is based on node disjoint paths and evaluated as minimum link capacity, average residual energy, and hop count. The route discovery process is initiated by the source node and broadcasts RREQ with a path capacity vector, accumulated energy cost, and bottleneck link capacity, which is received at intermediate nodes, and calculates the local link capacity between Cij and neighbor Nj node, updates the bottleneck link capacity and energy cost, and recalculates the load variance based on queue length and forwards RREQ if the packet is not duplicated. Finally, the destination receives multiple RREQs from disjoint paths and computes the path score by eq (8). The destination node selects the top k paths with the highest scores and sends RREP back along each selected path; the source node maintains an active path table with metrics that are updated from time to time.

$$Score(p) = \alpha \times C_{min}(p) + \beta \times \frac{1}{E_{drain}(p)} + \gamma \times \frac{1}{\sigma^2(p)} + \delta \times S(p) \ldots\ldots\ldots\ldots\ldots(8)$$

Where

$C_{min}(p)$= Minimum link capacity on path p (0-1)

$E_{drain}(p)$= Maximum energy drain rate on path p

$\sigma^2(p)$= Variance of queue lengths on path p

S(p)= path stability score (0-1)

The eq(8) is used to find the paths, and the source node starts data transmission, where the proposed system applies the dynamic load balancing mechanism, minimizes network congestion, and improves efficiency. To balance the network load, calculate each path's dynamic weight and then normalize it; after that, select the path with probability and finally update statistics and if congestion is detected, then immediately trigger a load balancing alert message to redistribute the traffic across all available paths. The dynamic weight is calculated by eq(9) and the normalized weight by eq(10).

$$Score(p) = \alpha \times C_{min}(p) + \beta \times \frac{1}{E_{drain}(p)} + \gamma \times \frac{1}{\sigma^2(p)} \ldots\ldots\ldots\ldots\ldots\ldots(9)$$

Normalized weight calculates as:

$$w_i' = \frac{w_i}{\Sigma \quad (w_j)} \ldots\ldots\ldots\ldots\ldots(10)$$

The congestion threshold calculate by eq(11)

$$Threshold = \mu_{queue} + 2\sigma_{queue} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

Where μ_{queue} and σ_{queue} are mean and standard deviation of queue length across all paths.

Finally load balancing factor LBF:

$$LBF = \frac{\sigma^2 queue}{\pi^2 queue} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(12)$$

The proposed EMRD-LB routing provides reliable and congestion-free communication, which is more adaptable for mobile ad hoc network communication as compared to existing routing strategies.

4. EMRD-LB Functional Architecture

This diagram 1 illustrates the five-layer structure for the link estimation and load balancing process for mobile ad hoc networks; it shows how information flows from the lower layers (MAC and physical) through processing modules to produce the key metrics used in path selection. This is a comprehensive architecture diagram of a five-layer structure that has information sources, processing modules, a core engine, an output decision, and data plane operation. Each layer transforms raw measurements into more abstract metrics used for routing, load balancing, and energy optimization. The architecture collects cross-layer metrics capacity, quality, load, and energy from MAC, physical, network, and energy layers. These metrics are processed by the channel monitor, quality estimator, capacity calculator, and energy monitor to produce normalized link-level metrics. The EMRD-LB core engine estimates path capacity, computes a multi-objective score per path and selects primary and backup multipath to perform dynamic load balancing. The data plane uses these decisions for forwarding and maintenance with feedback loops enabling real-time adaptation.

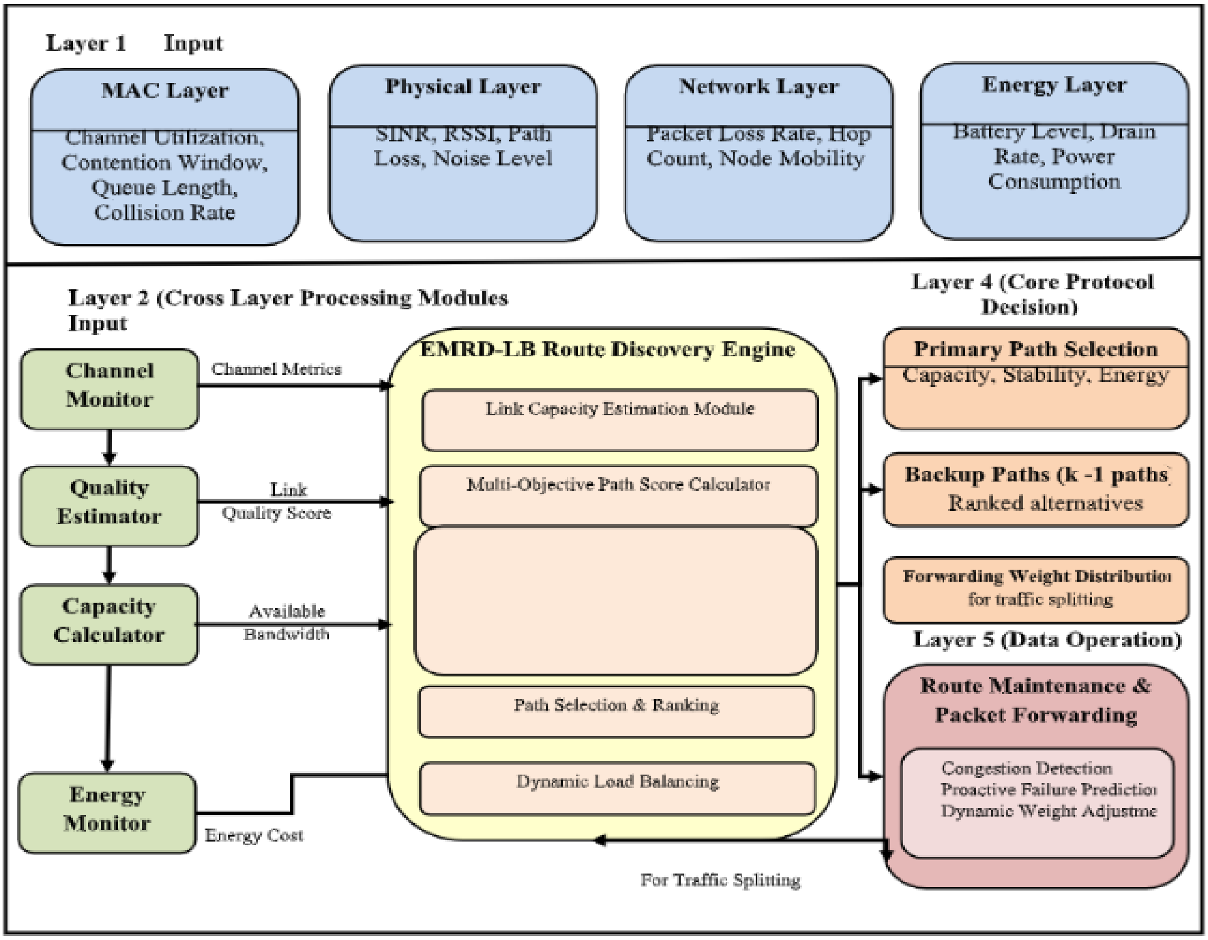

Figure 1: EMRD-LB Protocol Architecture

5. Proposed Algorithm:

In this section, describe the proposed algorithm to discover routes and data forwarding using link capacity and energy-aware routing, which is capable of balancing network loads and providing congestion-free communication. The basic idea behind the routing procedure is to be aware of the energy of each node, load, signal strength routing, and link capacity to select a route. In the next phase, start data sending from the selected route and update the weight vector as formalized in the algorithm and detect the congestion if it occurs; otherwise, the selected path is ready to continue data sending.

Algorithm: EMRD-LB

Input:

N: Mobile node,

S: Source node

D: Destination Node

Cij: link capacity

Ql: Queue length

Plost: Packet loss rate

El: Energy level

Pc: Power consumption

Rp: AOMDV

LV: load variance

EDR: energy drain rate

Ψ: radio range 5502m

Output: average NRL, delay, PDR, Drop, ARE, AEC, Data receiving

Procedure 1: Route Discover

Source S broadcast RREQ(Rp, S, D)

For each Ni ∈ M

Configure Plost = 0, El, Pc for Ni

If Ni in Ψ **than**

Calculate local Cij

Update bottleneck link capacity = min (current, Cij)

Append Cij to path capacity vector

Update EDR = max(drain_rate, Ni.drain_rate)

Recalculate LV based on Ql

If RREQ not duplicate **than**

Forward RREQ to next hop

D waits for Δt to receive multiple RREQs

For each received RREQ r:

Compute path Score(r)

D select path and ranked

Send RREP to S by selected path

S maintain active path table

Else

Stop forwarding

End if

Else

D not found or unreachable route

End if

End for

Procedure 2: Data Forwarding

Input:

pkt: data packet

P: active path set {P1, P2, ……Pk}

Output: path selection for pkt

Procedure:

For each path Pi ∈ P

Calculate dynamic weight

Normalized weight calculates as:

$$w_i' = \frac{w_i}{\sum \quad (w_j)}$$

If w_i' > avg(w_i') **than**

Select path's

If Qi > threshold **than**

Network is congested

wi wi – δ(0<δ<1)

trigger load balancing alert

Else

Start data forwarding to D

End if

Else

Not selected

End if

End for

6. Simulation Parameters & Results

The performance of all the approaches is measured on the same simulation parameters. The simulation parameters are mentioned in table 1. The Network Simulator version 2 (ns-2) is used for the simulation. The different node density is considered under the same simulation area. This ensures a fair comparison between the various methodologies employed. Additionally, the results will answer questions about how node density impacts overall network performance and efficiency. The packet size is considered 512 Bytes and the simulation time is 100 sec in all node density scenarios.

Table 1 Simulation Parameters

Simulation Area	1000m X 1000m
Number of Nodes	25, 50, 75, 100
Node Movement	Random Uniform Distribution
Node Speed	0-20 m/n
Traffic Type	CBR, UDP
Packet Size	512 Byte
Network Protocol	QMR, AOMDV, MMEE, EMRD-LB
Channel Type	Wireless Phy
Radio Range	550m2
Simulation Time	100s

6.1 Average Normal Routing Load & Delay Analysis

In the dynamic network, successful data transfer and data receiving are not straightforward tasks. The nodes' movement and direction are not easy to predict. The possibility of congestion in the network is more likely to enhance the packet dropping. The proper load balancing scheme is required to control the congestion and handle the load efficiently in a dynamic network. In this graph 2, compare the average normal routing load (Avg. NRL) and average delay (Avg. Delay) performance of novel EMRD-LB with MMEE, QMR, and AOMDV. The EMRD-LB shows 2% less overhead from AOMDV. In the case of average delay performance, AOMDV and EMRD-LB are in line. The average delay of QMR is high due to the complex communication among the nodes for reliable data transfer. The performance of the proposed scheme is capable of enhancing the data packets received with lower delay and overhead.

Figure 2: Average NRL and Delay Analysis

6.2 Heatmap Performance Analysis

A heat map is the geographical distribution of data values by different colors. In the figure 3 shows a heat map which is the visualization tool for representing the performance of QMR, MMEE, AOMDV, and EMRD-LB. The color code represents the strong and weak performance of the approaches. The performance of the proposed scheme is better due to the proper handling of the congestion in the network. The effective load balancing technique minimizes the packet loss and reduces overhead in the network. The AOMDV approach performance is better but not able to efficiently utilize the energy resource for routing. The higher number of data packets received means the proposed scheme is able to handle the congestion properly and provides better performance. The performance score of EMRD-LB is the highest as compared to all approaches.

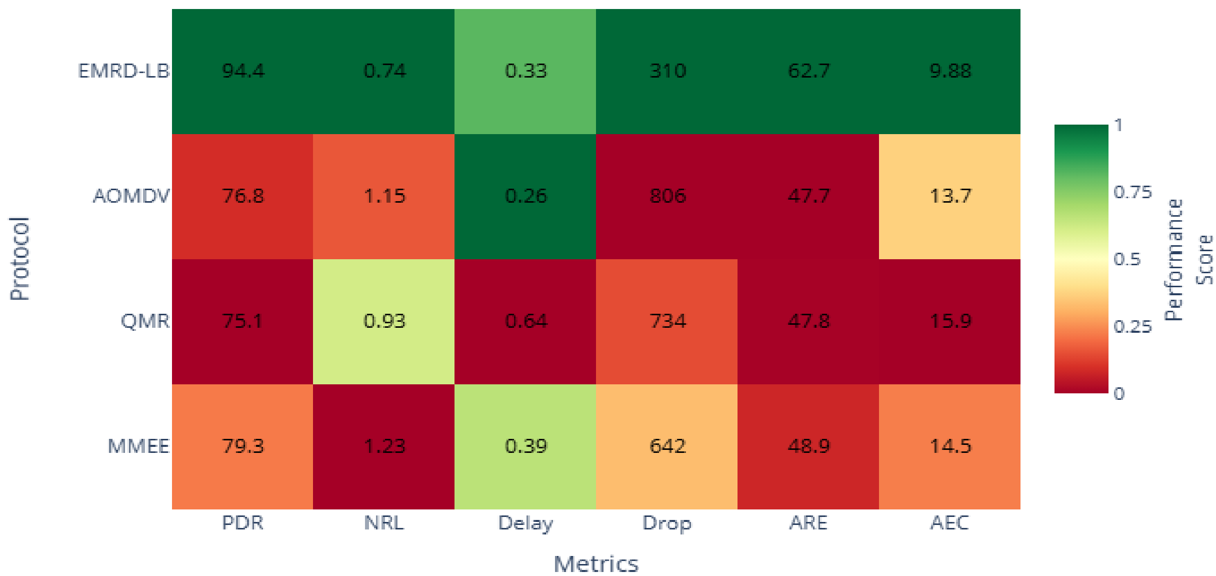

Figure 3: Heatmap Performance Analysis

6.3 Average Performance Across All Scenarios

The performance metrics considered for all approaches are same and the performance of all is mentioned in table 2. The AOMDV is the previous approach whose performance is better than the other two approaches. In the given table the novel EMRD-LB performance is better than AOMDV because it properly balances the load and reduces the wastage of energy in retransmission. The average PDR of EMRD-LB is 10% more as compared to AOMDV, the average NRL is 2% less and the average ARE is 20% more. The delay performance of AOMDV and EMRD-LB is almost equal. The novel approach is able to handle the congestion properly and enhance the energy utilization.

Table 2 Average Performance of all scenarios

Protocol	**Avg PDR (%)**	**Avg NRL**	**Avg Delay (s)**	**Avg Drop**	**Avg ARE**	**Avg AEC**
MMEE	81.09	2.82	0.27	757.75	34.09	31.46
QMR	79.56	2.47	0.45	885.75	35.15	29.32
AOMDV	81.58	2.37	0.21	830.25	31.01	30.63
EMRD-LB	92.18	2.29	0.22	341.50	46.06	23.66

6.4 Normalized Multi-Metric Radar Chart

The overhead in the network is required to properly handle the exchange of data between the sender and the receiver. In the MANET connection establishment is not basic because of the movement of nodes. The sender sends the connection establishment packets to the receiver, who then confirms receipt to the sender. In this graph, 4 measure the overhead performance of MMEE, QMR, AOMDV, and the novel EMRD-LB approach. The performance of EMRD-LB is better because of strong link establishment and proper load handling in the network. The performance of all the approaches is measured in 100 seconds of simulation time. The novel approach is showing higher efficiency, low drop, low NRL, and a very slightly high delay in the network. The proper channel utilization of a wireless link shows less drop and negligible retransmission of data packets between sender and receiver. This indicates that the scheme can sustain a stable connection even under varying conditions. Additionally, the results suggest that employing approach for load balancing could further enhance network performance and minimize overhead.

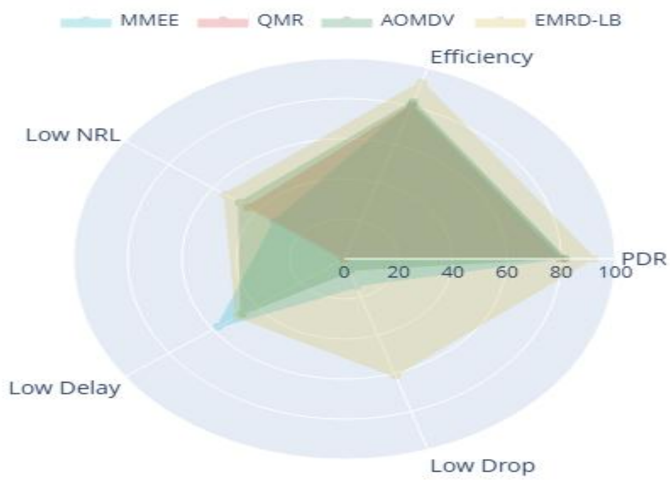

Figure 4: Normlized Multi-metric redar Chart Analysis

6.5 Percentage of Data Receives Distribution

The protocol can significantly increase the number of packets successfully delivered to their intended destinations by enhancing the routing approach and distributing the load across various routes. In the process of determining the overall data-receiving percentage of the network and developing reliable links, the effectiveness of the multipath protocol is an important factor to consider. The described technique provides an efficient solution to congestion issues in dynamic networks. In the figure 5 shows the packet-receiving network yields superior results in the suggested EMRD-LB. Improvements in routing performance and congestion management are achieved by the EMRD-LB technique, which ultimately leads to improved bandwidth utilization as compared to AOMDV, QMR, and MMEE. The novel approach demonstrates a 10% higher Packet Delivery Ratio (PDR) compared to AOMDV, and it is expected to perform even better against other methods.

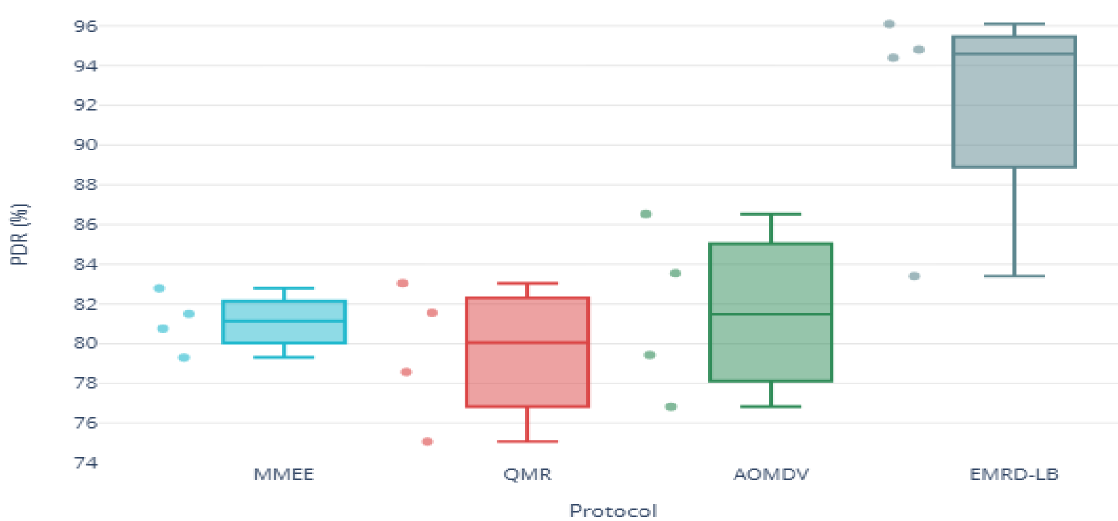

Figure 5: Data Receiving Percentage Analysis

6.6 Average Drop Count

The data dropping is the common in the network due to resource un-availability, destination not available, heavy traffic or congestion and improper load balancing. In the figure 6 compared to the QMR, TA-AOMDV, and MMEE strategies that were previously used in MANET, the unique EMRD-LB load balancing method delivered a lower number of average dropped data. Each and every module's performance is simulated using the same simulator and same simulation time consider for all scenarios. The EMRD-LB is displaying less data dropping and less overhead in the network. Increasing congestion on the network indicates that it is utilizing the limited bandwidth and processing capability of mobile nodes, which is a consequence of the network's increasing congestion. The averahe dropping of EMRD-LB is only 300packets but AOMDV is 700 packets (minimum) and rest of them are more than 700packets. According to the measurements of performance, the EMRD-LB has superior performance in dynamic networks as compared to other schemes.

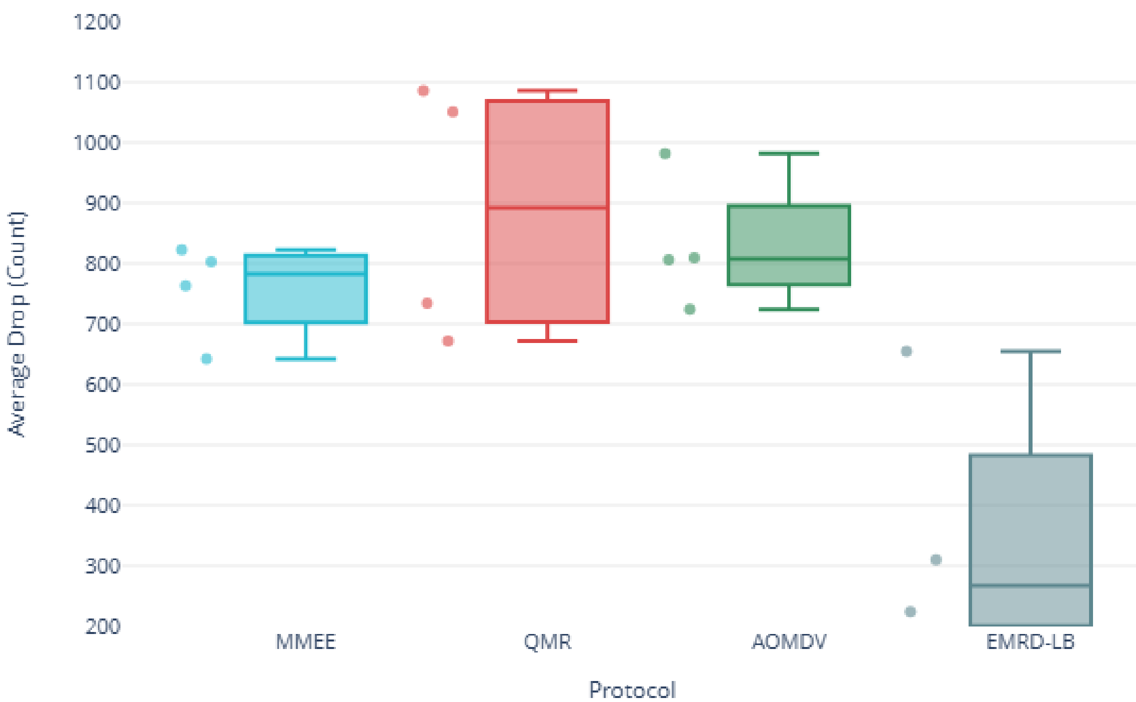

Figure 6: Average Drop Count Analysis

6.7 Performance Rankings

The better performance of the approach in the dynamic network determines its ranking. If the performance is higher, that means the ranking is higher. In previous approaches, the ranking of the AOMDV protocol was higher compared to others because it handled the load properly in the network. The ranking of all the previous approaches with novel EMRD-LB w.r.t. performance metrics is mentioned in table 3. The proposed EMRD-LB approach is able to handle the load and utilizes the energy of nodes properly, which enhances network lifetime. The ranking is one of EMRD-LB in PDR, NRL, and Drop, but in the delay ranking, it is two. The routing performance is showing less packet dropping and overhead in the network. These improvements indicate that EMRD-LB optimizes resource utilization and ensures a more reliable communication process.

Table 3 Performance Ranking Analysis

Metric	Rank 1	Rank 2	Rank 3	Rank 4
PDR (↑)	**EMRD-LB (92.18%)**	AOMDV (81.58%)	MMEE (81.09%)	QMR (79.56%)
NRL (↓)	**EMRD-LB (2.29)**	AOMDV (2.37)	QMR (2.47)	MMEE (2.82)
Delay (↓)	AOMDV (0.21s)	**EMRD-LB (0.22s)**	MMEE (0.27s)	QMR (0.45s)
Drop (↓)	**EMRD-LB (341.5)**	MMEE (757.75)	AOMDV (830.25)	QMR (885.75)
Metric	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**

7. Conclusion and Future work

In a MANET, the primary source of energy is essential for setting up routes and transferring data to the nodes involved in routing. Therefore, in the instance that the nodes possess a lower quantity of energy, it is necessary to choose the other node that possesses an adequate quantity of energy in order to transmit the data to the receiver in the MANET. Nodes have limited amount of bandwidth and battery power is available at each of the nodes. The occurrence of congestion in the network is a typical problem that can be attributed to heavy traffic on a specific path or the breakage of a corresponding link. In this research proposes an EMRD-LB is a novel energy-efficient multipath routing for load balancing to reduce congestion and balance the load in the network. The performance of proposed RMRD-LM is compared with QMR, MMEE and AOMDV. To avoid network congestion, the EMRD-LB strategy makes effective use of the connection capacity as well as the energy that is contained within nodes. The data flow is improved by this strategy, and the network nodes are able to function for a longer period of time. Although the load conditions are always changing, the system is able to maintain its ideal performance by dynamically altering the routing paths based on the current energy levels. It is necessary to implement load balancing to lessen the number of dropped packets and to handle the additional load by lowering the data rate and practicing buffer management. In the comparison of results AOMDV performance is better than QMR, MMEE. The EMRD-LB showing 2% less average overhead as compared to AOMDV. The average overhead of rest of two even more. Same as data receiving is 8% more as compared to AOMDV and QMR, MMEE receiving is more than 10% less. Same as the average dropping and average delay performance is also better than previous approaches.

In the MANET, nodes are incapable of maintaining the record of the location of other nodes. The location record with routing protocol can enhance the routing performance. In the future, propose the location-based approach to improve energy utilization and reduce the overhead of re-route establishment.

REFERENCES

1. Tanaya Roy and Sandip Roy, “Atypical Stable Multipath Routing Strategy in MANaET”, International Journal of Computer Applications (0975 – 8887) International Conference on Emerging Trends in Informatics and Communication.
2. Jeyaraj D, Yesudhasan J, Aliar AAS. Developing multi-path routing protocol in MANET using hybrid SM-CSBO based on novel multi-objective function. Int J Commun Syst. 2023; 36(4)
3. Mahdi Abdulkader Salem and Raghav Yadav. “Efficient Load Balancing Routing Technique for Mobile Ad Hoc Networks”. International Journal of Advanced Computer Science and Applications (IJACSA) 7.5 (2016).
4. Rani Sahu, Neetu Sahu, Vinay Sahu, “Revolutionizing MANET Route Discovery with INTSM: An Innovative Load Balancing Approach”, American Journal of Electrical and Computer Engineering (Volume 8, Issue 2), 2024.
5. Mohammed Tarique, Kemal E. Tepe, Sasan Adibi, Shervin Erfani, “Survey of multipath routing protocols for mobile ad hoc networks”, Journal of Network and Computer Applications, Volume 32, Issue 6, 2009, Pages 1125-1143
6. D. Maheshwari, R. Nedunchezhian . Load Balancing in Mobile Ad Hoc Networks: A Survey. International Journal of Computer Applications. 59, 16 (December 2012), 44-49.
7. M. A. Mahdi, T. C. Wan, A. Mahdi, M. A. G. Hazber, and B. A. Mohammed, “A Multipath Cluster-Based Routing Protocol For Mobile Ad Hoc Networks”, Eng. Technol. Appl. Sci. Res., vol. 11, no. 5, pp. 7635–7640, Oct. 2021.
8. J. Harshdeep, D. Rijutha and W. Nan, “Design and Implementation of An Efficient Multipath AODV Routing Algorithm for MANETs“, IEEE, 2019,

9. N. Geetha, “Performance Evaluation of Multipath Routing Protocol (AOMDV) In Mobile Ad Hoc Networks”, ICCAP 2021, December 07-08, Chennai, India, 2021
10. K. A. Darabkh, M. A. Al-Shurman, and A. H. Yahya, “Developing secure multipath routing protocol (AODV-SMR) for MANETs,” International Journal of Computer Networks & Communications (IJCNC), vol. 9, no. 4, pp. 1–18, Jul. 2017.
11. Pekka Savola, “DSR: Dynamic Source Routing”, CSC/FUNET, Helsinki University of Technology, 2001.
12. U. D. Prasan, Gorti. Satyanarayana Murty, Ch. Ramesh, S. Vishnu Murty, “Routing by HDF Based Optimal Path Selection in Multipath WSNs”, International Journal of Recent Technology and Engineering (IJRTE), Volume-8 Issue-3, September 2019.
13. A. H. Mohsen and M. H. Ahmed, “Cross-layer design for QoS-aware multipath routing in mobile ad hoc networks,” Computer Communications, vol. 31, no. 14, pp. 3224–3239, 2008.
14. Shuchita Upadhayaya and Charu Gandhi, “Node Disjoint Multipath Routing Considering Link and Node Stability protocol: A characteristic Evaluation”, IJCSI International Journal of Computer Science Issues, Vol. 7, Issue 1, No. 2, January 2010.
15. Kodavayur Sankar Shivakumar, Venkannagouda C. Patil, “An optimal energy efficient cross-layer routing in MANETs”, Sustainable Computing: Informatics and Systems, Volume 28, 2020.
16. M. Ali, B. G. Stewart, A. Shahrabi, A. Vallavaraj . QoS Aware Multipath Threshold Routing for Mobile Ad hoc Networks. International Journal of Applied Information Systems. 7, 1 (April 2014), 8-15.
17. Y. Harold Robinson, M. Rajaram, “Energy-Aware Multipath Routing Scheme Based on Particle Swarm Optimization in Mobile Ad Hoc Networks”, 2015.
18. S. Munawara Banu, M. Mohamed Surputheen , M. Rajakumar, “Bio-Inspired and Machine Learning-Driven Multipath Routing Protocol for MANETs Using Predictive Link Analytics”, The Scientific Temper (2025) Vol. 16 (10).
19. S. Sharma and S. Sharma, “Location Aware Routing for MANET using Genetic Algorithm (LOCA-GAMNET),” International Journal of Wireless & Mobile Networks, vol. 4, no. 4, pp. 121–135, 2012.
20. Y. Yu and M. Liang, "A Node-Disjoint Multipath Routing Protocol in MANETs," 2015 International Conference on Computer Science and Mechanical Automation (CSMA), Hangzhou, China, 2015, pp. 108-112