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Efficient Routing in MANETs by Optimizing Packet Loss

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ABSTRACT

In self-forming Mobile Ad Hoc Networks (MANETs), the work introduces dynamic routing for heterogeneous nodes in an infrastructure-limited environment. Military, healthcare, and disaster recovery applications require efficient communication on these networks. Further, multi-hop MANET communication requires reducing packet loss due to energy limits and buffer overflow. The proposed routing mechanism selects energy-efficient, uncongested intermediary nodes and dynamically optimized routes for communication depending on packet loss likelihood. It greatly lowers packet loss, improving network reliability. Our mechanism outperforms energy-aware, buffer-aware, and reactive protocols in network lifetime and packet delivery. We quantify these improvements to verify our mechanism's effectiveness. The proposed mechanism makes MANETs a reliable solution for important applications by proactively optimizing routes to reduce packet loss.

1. INTRODUCTION

MANETs embody self-configuring and self-maintaining networks comprised of heterogeneous mobile devices (nodes) forming a dynamic network structure. Operating as peer-to-peer, multi-hop, and infrastructure-less networks, MANETs are indispensable across various applications like emergency services, disaster recovery, military operations, conferences, and educational institutions. The vitality of these applications underscores the absolute requirement for efficient data communication, given the substantial implications of data loss on performance [1].

Within these networks, the role of a routing protocol is pivotal in enabling effective communication between network elements. Developing a robust routing protocol within the context of MANETs presents challenges due to the dynamic topology, heterogeneity, and mobility intrinsic to such networks. Numerous routing protocols have been devised to align with MANET characteristics, employing proactive, reactive, and hybrid design concepts to address their inherent challenges [2]. However, conventional approaches often assume uniform and cooperative behavior among network nodes, an assumption that does not hold in adversarial environments like MANETs [3].

Considering the peer-to-peer multi-hop nature of MANET communication, relay nodes serve as intermediaries, forwarding packets from source to destination, an action necessitating energy and buffer resources [4]. Consequently, optimizing energy and buffer utilization becomes imperative to mitigate packet loss and enhance overall network performance. As packet dropping in mobile ad hoc networks (MANETs) significantly impacts network reliability by causing incomplete data delivery, undermines throughput due to retransmissions and inefficient resource utilization, increases energy consumption through the need for additional transmissions, introduces latency and delay that hampers real-time applications, and varies in its effect based on the tolerance of different applications to packet loss.

While existing energy and buffer-efficient routing protocols exist, these often allocate specific communication paths based on factors like higher energy nodes, minimal energy consumption routes, low retransmission paths, or routes with ample buffer capacity. Yet, this approach can inadvertently lead to packet drops at certain nodes. Specifically, nodes along routes experiencing high energy traffic or bearing low transmission energy could become bottlenecks, ultimately affecting overall network performance [5].

Many energy and buffer-efficient routing methods allocate communication paths based on parameters like greater energy nodes, low energy consumption routes, low retransmission paths, or routes with high buffer capacity. These techniques can cause packet drops at some nodes, especially along high-energy traffic or low-energy transmission paths. Nodes can create bottlenecks, decreasing MANET performance [6]. The work addresses this difficulty by identifying energy-efficient and congestion-resilient MANET intermediate nodes to reduce packet loss. This strategy could enhance network lifespan and improve packet delivery, making MANETs a more reliable mission-critical option. We use dynamic route optimization and adaptive relay node selection to reduce packet loss due to energy limits and buffer overflow, improving network performance.

This paper is organized into six sections, each addressing a critical aspect of designing and optimizing routing protocols for MANETs. The next sections cover related work. Further section describes the routing mechanism for reducing packet loss due to buffer overflow and energy restrictions. Simulation experiments are conducted, and several graphs are presented to visualize the performance of the proposed mechanism in the next section. The paper concludes by highlighting the contributions, strengths, and limitations of the proposed mechanism and suggesting areas for future work.

2. LITERATURE REVIEW

Mobile Ad Hoc Networks (MANETs) are dynamic, self-organizing networks of mobile devices needed for ad-hoc, infrastructure-less communication. MANET performance depends on energy management and buffer capacity. Due to their impact on communication performance, MANET routing protocols must balance energy consumption reduction with node energy levels. Node buffer space helps packet processing, speeding transmission and reducing latency. Insufficient buffer capacity can cause packet discarding, reducing network speed and packet forwarding. Energy-efficient routing protocols must be developed to improve MANET performance that simultaneously monitors buffer space.

Buffer space in nodes is crucial to MANET transmission. Packet loss from buffer overflow degrades network performance. MANETs cannot use congestion control measures like wired and wireless networks. This requires early congestion detection and control methods. Routing protocols guide traffic to node buffers to reduce packet loss due to buffer capacity. Leading MANET routing protocols emphasize non-control congestion. However, computing and monitoring node buffer average queue size and packet waiting times is more proactive. Effective in controlling congestion, MANETs' dynamic nature makes congestion avoidance difficult, stressing the necessity for mitigation methods [7-9].

MANETs' finite node energy contributes to intermediary node packet losses. The main purpose of MANET routing is to find the best paths between communication units. The restricted battery capacity and operational challenges of recharging or replacing batteries during network operations present considerable energy-related challenges. Energy-efficient routing solutions are needed to meet communication goals including reduced route formation latency, packet loss, and throughput [10]. The literature describes path selection algorithms for dependability, energy efficiency, and higher-energy nodes. However, these protocols generally fail to handle bottleneck nodes in multi-link routing networks, causing packet losses due to increasing traffic and energy consumption [11].

Existing solutions fail to manage node buffer capacity and congestion. Some non-control congestion protocols do not actively compute and monitor important metrics in node buffers, allowing congestion-related packet loss. In energy-efficient routing, current methods for path selection for dependability, energy efficiency, and higher-energy nodes do not address bottleneck nodes in multi-link routing networks [12, 13]. Insufficient mitigation exists for packet drops owing to high traffic loads at specific nodes. Lack of an integrated approach that incorporates energy restrictions and buffer capacity leads to inferior performance. The suggested protocol, which optimizes node selection along routing paths, provides a more cohesive solution to MANETs' buffer overflow and energy resource constraints.

Current techniques' shortcomings affect MANET performance greatly. Poor buffer management can cause packet loss and network performance, decreasing data transmission dependability. Energy-related issues including improper path selection and bottleneck nodes can increase energy usage and shorten network longevity. These implications emphasize the need for a comprehensive solution beyond current guidelines.

In light of these challenges, this study aims to optimize the selection of intermediary nodes along routing paths to avoid packet drops arising from buffer overflow or constrained energy resources. This is achieved through a routing protocol design that minimizes packet loss by determining routing paths based on optimized packet drop probability values associated with buffer overflow and energy drain. The proposed protocol employs the following mechanisms:

(1) Selection of Nodes to Prevent Buffer Overflow-Induced Packet Drops: Intermediate nodes are chosen for routing based on computed packet drop probabilities aligned with their residual buffer space.

(2) Selection of Nodes to Prevent Energy-Related Packet Drops: Routing paths are constructed using intermediate nodes with lower probabilities of packet loss due to energy drain.

(3) Computation of Optimized Routing Paths: The protocol calculates routes between communicating entities while optimizing for packet drop probabilities linked to buffer overflow and energy drain within intermediate nodes.

This innovative protocol addresses the dual challenges of buffer overflow and constrained energy in MANETs, potentially revolutionizing network performance and extending network lifespan.

3. THE PROBABILITY OF A PACKET BEING DROPPED DUE TO INSUFFICIENT BUFFER SIZE IN MANETS

In Mobile Ad Hoc Networks (MANETs), understanding the chance of a packet being missed due to insufficient buffer size optimizes network performance. This chance depends on buffer size, packet processing time, incoming and outgoing packet rates, and wireless link duty cycle. Imagine a MANET intermediate node with a finite buffer. Nodes process packets exponentially and receive them Poisson-distributed. The goal is a probabilistic approach to estimate packet drop probability while the outgoing buffer is full. MANET network engineers need this model to predict and minimize packet loss from insufficient buffer size. Understanding these probabilities helps MANETs build more reliable and efficient communication protocols, improving network stability and performance.

To determine the probability of a packet being dropped in a mobile ad hoc network (MANET) due to insufficient buffer size, several parameters come into play, including the node's buffer size, average packet processing time, rates of incoming and outgoing packets, the duty cycle of the wireless link, and buffer slot availability. Let's consider an intermediate node in a MANET with a finite buffer. This node processes packets according to an exponential distribution and receives packets following a Poisson distribution [14]. The following attributes describe this node: B, the outgoing buffer size; Tp, the average packet processing time; Q, the total number of packets in the outgoing buffer; R, the incoming packet rate; and D, the departing packet rate, influenced by the average transmission time of a packet and the availability of the outgoing link. When Q equals B, indicating that the outgoing buffer is full and a packet will be discarded due to insufficient buffer size, a probabilistic model can be expressed as follows:

$$P_{buffer} = P(Q \;=\; B) \tag{1}$$

Here, P_{buffer} signifies the probability of a packet being dropped due to insufficient buffer size. This probability can be computed by multiplying the likelihood that the rate of departing packets (D) is greater than or equal to the rate of incoming packets (R), denoted as $P(D \;>=\; R)$, with the conditional probability that the buffer is full ($P(Q = B \mid D >= R)$).

$$P_{buffer} \;=\; P(D \;>=\; R) \;*\; P(Q \;=\; B \mid D \;>=\; R) \tag{2}$$

The probability $P(D \;>=\; R)$ indicates that the buffer is not filling up faster than it's being emptied, which can be calculated as the complement of $P(D \;<\; R)$:

$$P(D \;>=\; R) = 1 \;-\; P(D \;<\; R) \tag{3}$$

where, $P(D \;<\; R)$ can be calculated using Little's Law [15], representing the chance that the rate of departing packets is less than the rate of incoming packets:

$$P(D \;<\; R) = R \;* \frac{(Tp \;+\; Tt)}{B} \tag{4}$$

where,

$$Tt \;=\; L \,/\, (d \;*\; \min(R, C)) \tag{5}$$

where, L represents the packet length and min(R, C) indicates the effective transmission rate, accounting for the link's duty cycle [16], where C and R represent the capacity and data transfer rate of the wireless communication channel, respectively. To calculate the probability that the buffer is not filling up faster than it's being emptied, Eq. (4) is utilized.

The final equation to determine the probability that the rate of departing packets is greater than or equal to the rate of incoming packets is given by following Eq. (6), i.e., the equation to calculate $P(D \;>=\; R)$ is given by

$$\begin{aligned} &P(D \;>=\; R) \\ &= \left(1 - (d \;*\; \min\,(R, C) \right. \\ &\left. * \left(\frac{Tp \;+\; L \,/\, (d \;*\; \min\,(R, C)))}{B}\right)\right) \end{aligned} \tag{6}$$

The second part of Eq. (2) i.e., $P(Q = B \mid D >= R)$, reflects the conditional chance that the buffer is full, given that the rate of packets leaving the network is greater than or equal to the rate of packets entering the network. This is computed as

$$P(Q \;=\; B \mid D \;>=\; R) \;=\; P(Q \;-\; D \;=\; B \;-\; R) \tag{7}$$

where, $P(Q$ - D = B - $R)$ is the probability that the buffer occupancy is equal to B - R, indicating that B - R packets must leave the buffer before it is full. Using the binomial coefficient method, one can determine the likelihood that buffer occupancy is equal to B - R.

$$C(Q \;-\; d \;*\; \min(R, C), B \;-\; d \;*\; \min(R, C)) \tag{8}$$

The binomial coefficient $C(n, k)$ represents the number of possibilities to select k items from n items [17], Eq. (8) describes the number of methods to select $B - d * \min(R, C)$ packets from a pool of $Q - d * \min(R, C)$ packets that must leave the buffer before it becomes full. The likelihood that the buffer has $B - d * \min(R, C)$ vacant slots is expressed by Eq. (9), as P_{free} is the probability that any individual slot is free. It is crucial to assess the likelihood of the buffer occupancy state aligning with the condition where B - R packets must exit the buffer to prevent overflow. This intricate process involves the application of the binomial coefficient, denoted as $C(n,k)$, which signifies the number of ways to select k items from a set of n items. The formula presented as Eq. (8) elucidates the number of feasible combinations to choose $B \;-\; d \;*\; \min(R, C)$ packets from a pool of $Q \;-\; d \;*\; \min(R, C)$ packets, which must exit the buffer to avert overflow.

$$P_{free}^{(B-(d\,*\min(R,C)))} \tag{9}$$

The likelihood that the remaining $Q - B + d * min(R, C)$ buffer slots are filled is computed by Eq. (10)

$$1 - P_{free}^{(Q-B-(d\,*\min(R,C)))} \tag{10}$$

Final Eq. (11) to compute the P_{buffer} i.e. is the probability of a packet being dropped due to insufficient buffer.

$$\begin{aligned} P_{buffer} = &\left(1 - (d \;*\; \min\,(R, C) \right. \\ &\left. * \left(\frac{Tp \;+\; L \,/\, (d \;*\; min(R, C)))}{B}\right)\right) \\ &* \Big(C(Q - (d \;*\; min(R, C), B - (d \\ &* \;\min\,(R, C))\Big) * P_{free}^{(B-(d\,*\min(R,C)))} \\ &* \left(1 - P_{free}^{(Q-B-(d\,*\min(R,C)))}\right) \end{aligned} \tag{11}$$

4. THE PACKET LOSS PROBABILITY DUE TO ENERGY DRAIN IN A MOBILE AD HOC NETWORK

Optimizing Mobile Ad Hoc Networks (MANETs) requires understanding energy drain-induced packet loss. Transmission power, reception power, signal-to-noise ratio, and route loss are estimated. To determine the likelihood that a packet will be dropped in a mobile ad hoc network (MANET) due to energy drain, we need to consider various parameters such as transmission power, receiving power, signal-to-noise ratio, and path loss. Consider an intermediate MANETs node with a finite energy, with transmitting power, receiving power, and energy drain rate are P_t, P_r and E_d respectively. The Estimation of the probability of packet loss due to energy drain (P_{E_d}) in a mobile ad hoc network is computed as follows.

$$SNR_r = \left(\frac{P_t}{P_r}\right)^2 \qquad (12)$$

Eq. (12) represents the signal-to-noise ratio (SNR) at the receiver, which is essential for evaluating energy drain-induced packet loss probability. A higher SNR leads to a lower packet loss probability due to energy drain. As the SNR, which quantifies the strength of the transmitted signal relative to the background noise, increases, the probability of packet loss due to energy drain diminishes.

$$\text{Path loss} = \left(\frac{d}{D_0}\right)^{-alpha} \qquad (13)$$

Eq. (13) shows the path loss between the nodes that are sending and nodes that are receiving in a mobile ad hoc network, representing signal weakening as it travels from the transmitter to the receiver. Path loss is the weakening of the signal as it travels from the transmitter to the receiver through the environment. The path loss model shows how the signal strength is affected by distance, obstacles, and other things in the environment. In this equation, d is the distance between the sending and receiving nodes, and D_0 is a reference distance used in the path loss model. The accurate estimation of D_0 is essential; we assume that specific techniques employed to compute D_0 fall outside the scope of our current research focus. The exponent alpha shows how fast the signal gets weaker as you move away from it. A higher alpha value means that the signal weakens faster over distance, which is usually the case when there are more obstacles or other things in the way. By raising $\frac{d}{D_0}$ to the power of negative alpha, the equation models how the signal weakens. Eq. (13) is used to calculate the probability of packet loss due to energy drain in the MANET.

$$1 - \left(\left(\frac{P_t}{P_r}\right)^2 * \left(\frac{d}{D_0}\right)^{-alpha}\right) \qquad (14)$$

Eq. (14) represents the probability of successful packet delivery. The term $\left(\frac{P_t}{P_r}\right)^2 * \left(\frac{d}{D_0}\right)^{-alpha}$ is the signal-to-noise ratio (SNR) and represents the ratio of the transmitted signal power to the received noise power. A higher SNR indicates a stronger and more reliable signal, which increases the probability of successful packet delivery. Subtracting the SNR from 1 gives the probability of unsuccessful packet delivery, i.e., the probability of packet loss due to noise, interference.

$$Total\ noise\ power = (R * L * E_d * T_d + Sigma^2) \qquad (15)$$

where, $R * L$ represents the processing load of the node in terms of the number of bits per second that can be processed, and $E_d * T_d$ represents total energy consumed by the node over the duration of the transmission, and $Sigma^2$ represents the background noise power. Eq. (15) used to optimise the energy efficiency of a wireless node by adjusting transmission parameters such as the data rate, transmission power, and processing load to achieve a desired level of noise power while minimising energy consumption.

$$E(P) = \frac{E_p}{(R * L * E_d * T_d + Sigma^2)} \qquad (16)$$

Eq. (16) reflects the energy consumed by the node to send a single packet as a percentage of the node's available energy.

$$(1 - ((P\_t/P\_r)\hat{}2 * (d/D\_0)\hat{}(-alpha)))^{E(P)} \qquad (17)$$

Eq. (17) denotes the likelihood that a single packet transmission will not suffer packet loss due to energy drain. The term $1 - (P\_t/P\_r)\hat{}2 * (d/D\_0)$ represents the probability that the packet will not be lost due to signal attenuation and interference. Raising this probability to the power $E(P)$ gives the probability that a single packet transmission will not experience packet loss due to both energy drain, attenuation and interference. If Eq. (17) subtracted from 1 to give the overall probability of packet loss due to energy drain P_{E_d}, and it represent in Eq. (18)

$$P_{E_d} = 1 - (1 - ((P\_t/P\_r)\hat{}2 * (d/D\_0)\hat{}(-alpha)))^{E(P)} \qquad (18)$$

This detailed estimation model illuminates MANET packet loss probability dynamics, particularly energy drain. These equations show that mobile ad hoc networks need a holistic approach to energy resource management to enable reliable and efficient communication.

5. EFFICIENT ROUTING IN MANETS BY SELECTING NON-CONGESTED NEIGHBOURS AND ROUTE WITH GREATER PACKET PROCESSING CAPABILITIES

When a source node wants to send a packet to a destination node, it broadcasts a route request message. Every intermediate node that receives the route request message calculates the packet drop probability due to buffer overflow and energy drain. Each intermediate node adds its own calculation to the message and rebroadcasts the message to its neighbors. When the destination node receives the route request message, it computes the combined value of packet drop probability due to buffer overflow and energy drain for each intermediate node listed in the message. The destination node finalizes those nodes whose combined value is less and sends a route reply message to the source node with the finalized route information. The source node then sends the packet to the destination node using the finalized route information.

MANETs need effective route selection for optimal communication. Intermediate nodes collaborate to find the optimum path for a packet based on packet drop probability owing to buffer overflow (P_{buffer}) and energy drain (P_{E_d}). The destination node is crucial to route completion and source node response.

To calculate a combined rank for each node based on the values of P_{buffer} and P_{E_d}, destination node uses a weighted sum approach to compute the combined rank by assigned weight to P_{buffer} and P_{E_d} are α and β respectively. The weights are assigned based on their relative importance for the application and network performance metric. Destination node uses the min-max normalization method to compute the combined rank of P_{buffer} and P_{E_d}.

The destination node initially computes the normalized value values of P_{buffer} and P_{E_d}.

$$P_{buffer_{nrm}} = \left(P_{buffer} - P_{buffer_{nin}}\right) \Big/ \left(P_{buffer_{max}} - P_{buffer_{nin}}\right) \tag{19}$$

$$P_{E_{d_{nrm}}} = \left(P_{E_d} - P_{E_{d_{nin}}}\right) \Big/ \left(P_{E_{d_{max}}} - P_{E_{d_{nin}}}\right) \tag{20}$$

The combined rank is computed by following equation

$$R_{\left(P_{buffer}, P_{E_d}\right)} = \alpha P_{buffer_{nrm}} + \beta P_{E_{d_{nrm}}} \tag{21}$$

The lower values $R_{\left(P_{buffer}, P_{E_d}\right)}$ indicates the node performance is better in terms of energy and buffer. Destination selects the nodes with the lowest combined rank up to the threshold that satisfies the desired network performance and application requirements. Algorithm-1 shows the procedure to compute the combined value of packet drop probability due to buffer overflow and energy drain

Algorithm-1

Input: - nodes: a list of nodes, each with P_{buffer}, P_{E_d}, α and β

Output:- selected_nodes: a list of k nodes with the lowest combined ranks

1. Normalize the values of P_{buffer}, P_{E_d} for each node using the min-max normalization algorithm.

For each node i:

$$P_{buffer_{nrm}} = \left(P_{buffer} - P_{buffer_{nin}}\right) \Big/ \left(P_{buffer_{max}} - P_{buffer_{nin}}\right)$$

$$P_{E_{d_{nrm}}} = \left(P_{E_d} - P_{E_{d_{nin}}}\right) \Big/ \left(P_{E_{d_{max}}} - P_{E_{d_{nin}}}\right)$$

2. For each node i, calculate its combined rank using the following steps:

$$R_{\left(P_{buffer}, P_{E_d}\right)} = \alpha P_{buffer_{nrm}} + \beta P_{E_{d_{nrm}}}$$

3. Sort the nodes in ascending order of their combined ranks.

sorted_nodes = sort(nodes, Threshold=γ, node: $R_{\left(P_{buffer}, P_{E_d}\right)}[node]$)

4. Select the first k nodes with the lowest combined ranks.

selected_nodes = sorted_nodes[:k]

5. Return the selected nodes.

Algorithm Steps:

1. **Route Request Broadcasting:**
- Source nodes broadcast a route request message to initiate the route discovery process.
- Intermediate nodes calculate their individual P_{buffer} and P_{E_d} values, incorporating local buffer and energy considerations.

2. **Message Propagation:**
- Intermediate nodes append their P_{buffer} and P_{E_d} calculations to the route request message.
- The modified message is rebroadcasted to neighboring nodes.

3. **Destination Node Processing:**
- Upon receiving the route request, the destination node computes the combined rank for each intermediate node.
- The combined rank is calculated using a weighted sum approach, with weights α and β assigned based on their relative importance.

4. **Normalization:**
- Normalization of P_{buffer} and P_{E_d} values is performed using min-max normalization for each intermediate node.
- $P_{buffer_{nrm}} = \left(P_{buffer} - P_{buffer_{nin}}\right) \Big/ \left(P_{buffer_{max}} - P_{buffer_{nin}}\right)$
- $P_{E_{d_{nrm}}} = \left(P_{E_d} - P_{E_{d_{nin}}}\right) \Big/ \left(P_{E_{d_{max}}} - P_{E_{d_{nin}}}\right)$

5. **Combined Rank Calculation:**
- The combined rank for each node is then computed using the normalized values.

$$R_{\left(P_{buffer}, P_{E_d}\right)} = \alpha P_{buffer_{nrm}} + \beta P_{E_{d_{nrm}}}$$

6. **Node Selection:**
- Nodes are sorted in ascending order of their combined ranks.
- The destination node selects nodes with the lowest combined ranks, up to a threshold γ that satisfies network performance and application requirements.

7. **Route Reply:**
- The destination node sends a route reply message to the source node with the finalized route information.

Analysis and Design Choices:

Weighted Sum Approach: Weighted sums let you prioritize P_buffer and P_(E_d) by application and performance indicators.

Min-Max Normalization: Scaling values to a common range facilitates fair comparisons.

The threshold γ balances network efficiency and performance by controlling the number of selected nodes.

Communication from Source to Destination: The algorithm optimizes energy and buffer efficiency by include those nodes with the lowest combined ranks in the final path.

Overall, this approach improves MANET route selection by dynamically addressing buffer and energy restrictions. Intermediate nodes collaborate to evaluate and forward route requests, creating a robust and flexible routing mechanism.

The min-max normalization method plays a pivotal role in computing combined ranks based on packet drop probabilities associated with buffer overflow and energy drain, ensuring consistent and impartial scaling of probability values across diverse network nodes. This method follows a structured approach encompassing the definition of a normalization range, computation of minimum and maximum probabilities, normalization of individual probabilities, and subsequent weighted aggregation. The resultant composite values drive the ranking of nodes' performance, fostering equitable evaluation and precision. The method's inherent capability to preserve relative relationships among probabilities eliminates scale discrepancies. This strategic incorporation enriches the precision of route selection, bolsters overall reliability, and empowers informed decision-making through comprehensive evaluations of buffer overflow and energy drain probabilities.

6. SIMULATION ENVIRONMENT

The simulation environment [18, 19] comprises 100 nodes distributed randomly across a 1000x1000 square area, with uniform transmission ranges. Each node is initially assigned 100 Joules of energy. Energy expenditure during packet transmission and reception is computed considering node distance, packet size, and transmission power, with real-time updates reflecting energy usage. Buffer sizes are capped at 10 packets per node, and a drop-tail queuing policy discards packets when the buffer is full. This design choice impacts packet retention and loss dynamics. Packet drop probability calculation in the simulation considers both buffer occupancy and residual energy levels of each node. Uniform transmission ranges are employed, ensuring consistent communication capabilities across nodes. The specific range value is not provided but is assumed to be uniform for all nodes. The simulation parameters considered to evaluate the performance are shown in Table 1.

Table 1. Performance evaluation metrics

Network Parameters	Value
Radio Area	100-300 m
Noses	100
Simulation Time	100 s
Mobility	10-40 M/s
Routing	Distance Vector, Energy,Buffer aware, Proposed
Communication	Two Ray Ground
Energy	100 j
Traffic	CBR
Communication Area	1000 m×1000 m

The conventional Ad Hoc On-Demand Distance Vector (AODV) [20] routing protocol is adapted to incorporate packet drop probability calculation and route request/reply messages. Upon receiving a route request, nodes append packet drop probability to the message before relaying it. The destination node calculates the combined packet drop probability for listed intermediate nodes and selects those with lower combined values. A route reply message with optimized routing information is sent to the source node. Performance assessment metrics include packet delivery ratio, end-to-end delay, energy consumption, and throughput. The simulation spans 1000 seconds, employs a CBR traffic generator, and maintains a fixed packet size with adjustable packet rates to simulate varying traffic loads. Network performance is benchmarked against original AODV, buffer-aware routing, and energy-aware routing protocols. Various scenarios evaluate and compare network performance.

The conventional Ad Hoc On-Demand Distance Vector (AODV) routing protocol is adapted to integrate packet drop probability calculations and route request/reply messages. When a route request is received, nodes append packet drop probability to the message before relaying it. The destination node computes the combined packet drop probability for listed intermediate nodes and selects those with lower combined values. This adaptation enables a comparative assessment of the proposed algorithm against the baseline AODV protocol.

6.1 Performance results

Self-forming and adaptive Mobile Ad Hoc Networks (MANETs) can reduce packet loss from buffer overflow and energy constraints using the suggested routing algorithm. The technique outperforms protocols by proactively selecting energy-efficient, uncongested intermediary nodes. The method uses buffer occupancy, energy levels, and packet processing rates to predict packet loss. Comprehensive simulation experiments show that the Proposed protocol outperforms Reactive, AODV, and R_Aware protocols. Figures 1-3 indicate its ability to sustain high packet delivery fractions, minimal communication latency, and energy efficiency, especially under heavy traffic. The mechanism's reliability is shown by the continuous packet delivery fraction (Figure 4). Overall, the Proposed protocol is a reliable solution for mission-critical applications due to its increased packet delivery ratios, lower end-to-end latency, and enhanced energy efficiency in dynamic MANET scenarios.

The results of the proposed routing mechanism for self-forming and adaptable MANETs exhibit strong potential. The mechanism aims to minimize packet loss due to buffer overflow and energy restrictions by selecting intermediary nodes that are energy-efficient and uncongested. These results are derived from comprehensive simulation experiments.

In order to figure out how likely it is that a packet will be dropped, the suggested method takes into account a number of important factors. These factors include how full the node's memory is, how much energy it has, and how its packet processing rate changes over time. The chance that a packet will be dropped is based on how likely it is that the buffer will overflow and the energy will run out during the transmission process. At each node, certain parameters are used to figure out this likelihood. These factors include the size of the buffer, the average time it takes to process a packet, the rate at which packets come in and go out, the duty cycle of the wireless link, and the number of free buffer slots. Using these parameters, the mechanism figures out how likely it is that a packet will be lost due to not enough buffer room or a power drain. By adding these calculated probabilities to route request messages, neighboring nodes can make more informed choices during route discovery. This makes path selection in mobile ad hoc networks more efficient and reliable.

Figure 1 illustrates extensive testing of four routing protocols—Reactive, AODV, Resource-Aware (R_Aware), and the Proposed protocol—in a mobile ad hoc network (MANET) under various traffic situations. The Proposed protocol maintains high packet delivery fractions over time, demonstrating its ability to assure reliable data transfer despite network congestion. However, the AODV and R_Aware protocols maintain comparable packet delivery fractions under heavy traffic, demonstrating their communication efficiency. However, the Reactive protocol's extraordinary packet delivery fraction of 99.01% consistently over time intervals, found in a non-traffic condition, provides vital insight into its baseline performance. The Proposed protocol's ability to manage congestion-related issues and packet loss during high-traffic loads makes it a strong contender for improving MANET reliability and performance.

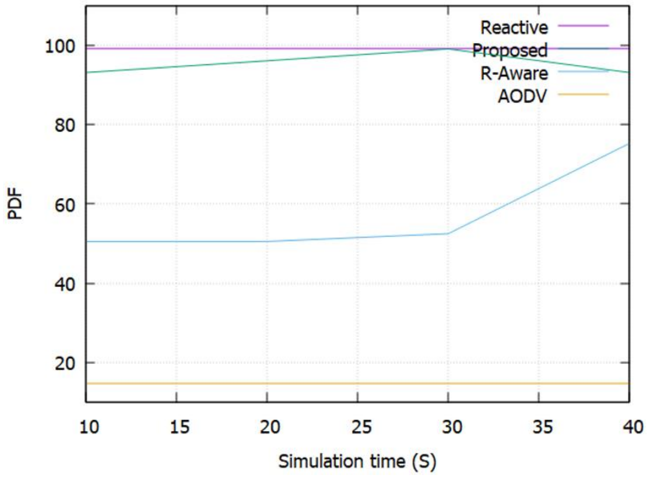

Figure 1. Performance comparison of packet delivery ratio over simulation time for the proposed, existing energy and buffer-aware, reactive routing

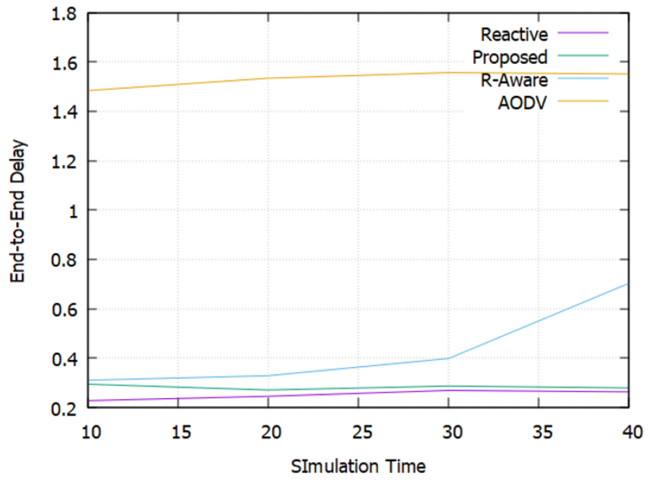

Figure 2. Performance comparison of end-to-end delay over simulation time for the proposed, existing energy and buffer aware, reactive routing

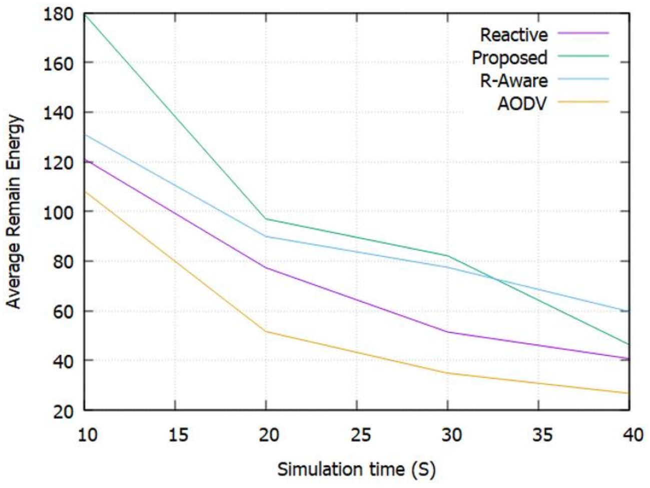

Figure 3. Performance comparison of energy consumption over simulation time for the proposed work, existing energy and buffer-aware, reactive routing

Figure 2 depicts delay performance throughout different simulation timeframes. Notably, the Proposed protocol maintains low latency throughout time intervals with exceptional efficiency. The Proposed protocol's delay numbers (0.270713 to 0.294228 seconds) demonstrate its ability to transmit data quickly even in dynamic network situations. While the AODV and R_Aware protocols have comparable delay patterns, they appear to manage communication latency well. Consider the Reactive protocol's outstanding delay performance, consistently at low values (0.227599 to 0.269343 seconds) even in non-traffic conditions. These findings demonstrate the Proposed protocol's ability to reduce communication delays, making it a promising MANET performance solution in low-latency scenarios.

Figure 3 analysis average leftover energy levels throughout different simulation times. The Proposed approach reliably maintains greater average remaining energy levels throughout time. The proposed protocol's energy preservation values (46.2662 to 179.711) demonstrate its ability to sustainably manage and conserve energy resources in dynamically difficult network circumstances. However, the AODV and R_Aware protocols show similar energy preservation tendencies, showing they may communicate efficiently. Reactive procedure consistently conserves higher energy levels (59.6497 to 131.182) even in non-traffic scenarios. These findings highlight the Proposed protocol's potential to improve network longevity by conserving energy resources, making it a prospective MANET energy efficiency path.

Figure 4 showcases the relationship between simulation time and average packet delivery fraction. The constant packet delivery fraction over time indicates the consistent performance of the proposed mechanism.

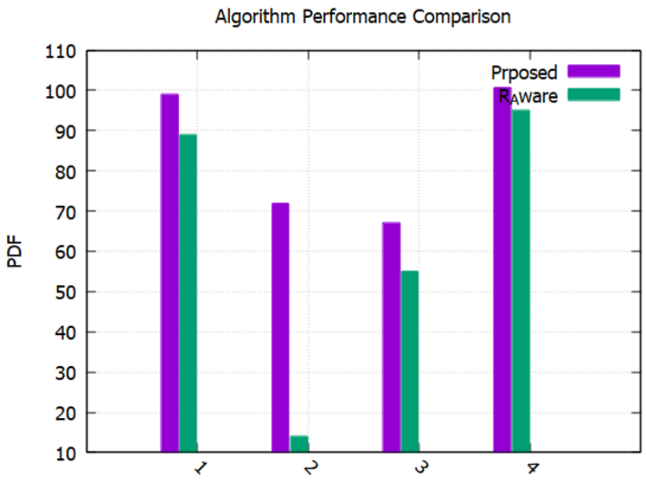

Figure 4. Performance comparison of packet delivery Fraction over simulation time for the proposed work and resource-aware routing protocols

The simulation results clearly show that the Proposed protocol outperforms Reactive, AODV, and Resource-Aware (R_Aware) routing algorithms in a variety of dynamic mobile ad hoc network scenarios. Note that the Proposed protocol routinely achieves high packet delivery fractions, fast data transfer, and better energy conservation than its competitors. Its resilience under heavy traffic, minimum communication delays, and good energy management demonstrate its potential to improve MANET efficiency, dependability, and durability in actual scenarios. Collectively, these results affirm the superiority of the proposed routing mechanism over existing energy-aware, buffer-aware, and reactive protocols. The mechanism yields higher packet delivery ratios, reduced end-to-end delays, and improved energy efficiency. This positions the proposed mechanism as a robust choice for various mission-critical applications.

7. CONCLUSION

The Work addresses the challenges in Mobile Ad Hoc Networks (MANETs), specifically focusing on mitigating packet loss due to buffer overflow and energy constraints. The proposed routing mechanism strategically selects intermediary nodes based on energy efficiency and congestion levels, demonstrating superior performance in simulation experiments compared to existing protocols. Key strengths of the approach lie in its adaptability to self-forming MANETs with peer-to-peer and heterogeneous nodes, effectively minimizing packet loss. The mechanism's effectiveness is evident in high packet delivery ratios, low end-to-end delays, and efficient energy consumption. However, limitations include limited exploration of mobility patterns' impact, scalability considerations, and the absence of real-world experimentation. Future research directions should delve into these aspects, exploring dynamic energy models, security considerations, and QoS support. Despite these challenges, the study provides valuable insights into routing protocols for MANETs, showcasing potential improvements in network longevity and packet delivery efficiency for critical applications.

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