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SIMPLIFIED ROUTING FOR MOBILE AD HOC NETWORKS USING A COMBINED RESOURCE METRIC

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ABSTRACT

Mobile Ad Hoc Networks are autonomous, infrastructure-less networks consisting of wireless mobile devices. Within the network, “the sender communicates with the receiver only if it is in radio communication range of one another; otherwise, it must communicate through intermediate nodes. To enable reliable communication, cooperation among intermediate nodes and the use of their resources are essential; otherwise, packets are dropped. The primary reasons for these drops are “battery drain,” “full buffers,” and “high traffic at the intermediate nodes.” These packet drops are unintentional. This paper proposes a simplified routing method to address undesirable packet drops by planning routes that avoid congestion and maximize resource utilization at nodes. These routes are determined based on each intermediate node's remaining power, available memory, and current traffic levels. Performance evaluation of this protocol is conducted on a simulated network and compared with other standard reactive methods, accounting for uniform traffic distribution. The simulation results show that this protocol can significantly reduce undesirable packet drops and increase successful transmissions, ensuring a reliable communication system for critical applications, including disaster relief operations and healthcare systems.

Keywords: *Mobile Ad Hoc Networks, Packet Drops, Routing, energy, buffer, Packet Delivery.*

1. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) are wireless networks in which nodes, such as mobile phones or sensors, communicate directly with one another without relying on a fixed infrastructure. It enables multi-hop communication by passing data through multiple intermediate nodes to reach its destination [1]. The characteristics and flexibility of networks make them ideal for sensitive and critical applications such as disaster relief, medical monitoring, and environmental tracking, where fast, reliable data transfer is crucial [2].

However, during communication, intermediate nodes unintentionally drop packets due to limited battery power, overloaded data buffers, and excessive network traffic. This packet drop negatively impacts network performance and the application's objective [3]. This problem, often overlooked in existing literature, presents challenges for applications that require dependable communication.

Packet drops in MANETs occur primarily for two reasons: intentional drops resulting from malicious behaviour, and unintentional drops when nodes run out of power, their storage fills up, or network traffic overwhelms them [4]. In the literature, various routing mechanisms have been designed to mitigate packet-dropping problems, but they also have limitations. Standard routing methods, such as the reactive distance vector protocol, choose paths based on the shortest

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distance, assuming all nodes have sufficient resources [5]. This leads to the formation of unreliable paths and causes unintentional packet drops [6]. Other protocols compute routes based on the residual resource status of intermediate nodes, but struggle with changing traffic patterns, leading to frequent data loss in busy networks [7]. Similarly, methods such as CACK [8], which verify data delivery, require excessive computational power, making them impractical for resource-limited devices [9].

To address these issues, this work proposes a novel, simplified routing method that selects reliable paths based on three key factors: remaining battery, available storage, and current traffic levels. Unlike existing methods that focus on only one factor, our approach employs two intelligent techniques: one predicts network congestion to prevent storage overload, and the other efficiently manages resources to handle data more effectively. By avoiding unreliable nodes, our method extends network performance and outperforms existing reactive routing (AODV) [10] and other existing solutions. It ensures robust communication for critical applications, such as disaster recovery and medical monitoring.

2. RELATED WORK

MANETs are wireless networks in which nodes, such as smartphones or sensors, act as both senders and relays to share data without a central coordinator. These nodes often lose data packets due to low battery, full storage, and heavy network traffic. This reduces network reliability and performance. While many studies have explored routing methods for MANETs, few tackle data packet loss caused by all three issues: low power, full storage, and high traffic. This section reviews existing methods and their limitations compared to our new approach.

Traditional MANET routing methods (reactive and proactive distance vector) choose paths based on the shortest distance or maximum sequence numbers. Reactive methods, such as AODV [10], find routes only when needed, whereas proactive methods maintain updated routing lists [11]. These methods assume nodes have sufficient resources, so they often select unreliable nodes along the routing path, resulting in packet loss under dynamic network conditions and during bursty traffic. This makes them unsuitable for critical and sensitive applications such as medical monitoring and environmental tracking, where reliable communication is crucial.

Energy is a significant issue in MANETs [25], as nodes consume substantial power (800–1200 mW) to send and receive packets [12]. Energy-aware routing protocols select a low-power-consuming path or nodes with higher energy, but fail to consider storage limits and traffic levels. This leads to network overload, resulting in packet loss during high-traffic periods [13].

Buffer overflow is another common cause of packet loss in dynamic networks, such as MANETs. Thus, the intermediate nodes' buffer is another consideration factor regarding packet loss. Existing protocols are based on RED [14,15], which monitors congestion after it has started, leading to packet drops during traffic spikes. Other protocols based on residual buffer status could also not find an issue in advance. Protocols based on traffic sharing distribute network traffic across multiple intermediate nodes but fail to address unintentional packet drops.

CACK is one of the effective malicious and intentional packet drops mitigation mechanisms compared to other mechanisms, such as credit and reputation. However, CACK presents overhead and neglects unintentional packet drops. Other, strictly security-focused packet mitigation mechanisms [16-18] mitigate only malicious nodes and malicious packet-dropping nodes. Moreover, they operate reactively to packet drops, imposing significant cryptographic overhead and resulting in poor network performance. Another intentional packet drop mitigation is the Credit-Based mechanism, which encourages node cooperation by assigning credits; however, it fails to mitigate unintentional packet dropping [19].

Recent work has improved the above routing mechanisms, but they still cannot completely eliminate unintended packet drops. A trust- and link-failure-prediction-based routing protocol was proposed by Benakappa and Kiran [20], but it did not address the problem of intentional dropping behavior caused by storage congestion and traffic. Mohammad and Abdul employ an energy- and buffer-aware protocol; however, it does not account for traffic management and congestion prediction [21]. Nizamuddin et al. use probability-based energy and buffer models to prevent packet drops; however, these are reactive patches [22]. Mohammad et al. combine energy and buffer with security to alleviate malicious and system failure packet drops; however, their performance is not satisfactory under dynamic network conditions [23]. CC et al.'s EBR is applicable to vehicular networks with energy and storage, but it does not account for traffic management or proactive planning [24].

Hence, in such situations, simple routing schemes are proposed to address packet loss caused by the network-layer paradigm in MANET. It computes paths using a minimal-congested, most resource–utilized routing path approach. The routing metric used in the algorithm is the "residual status-based weight" (Rs), which accounts for the remaining battery, available storage, and the current load of intermediate nodes to calculate the route. Better yet, it is proactive, predicting congestion and pre-allocating resources rather than having to react. This routing metric is adapted to the current reactive protocol, allowing it to select nodes with resources and, foremost, reliability.

3. NOVELTY AND CONTRIBUTION

In this paper, we describe a novel and straightforward routing algorithm for MANETs. It aims to mitigate unintentional packet drops, even when the reasons for packet dropping are unknown. It is a generalization of our prior work and is more advanced than the state of the art. Unlike earlier work, which considers only energy, storage, or traffic for utility aggregation, this work simultaneously finds all three. We highlight three key innovations.

The existing packet drop mitigation techniques studied so far have been optimized for at most one resource constraint or one network failure at a time. Recent work, RER-SK [13], only considered the battery, whereas RRARM [7] considered both the buffer and the battery. This work considers various sources of non-deterministic packet loss, including remaining battery capacity, storage availability, and network traffic. It is practical to determine an appropriate routing path among nodes.

Existing works adopt a reactive approach to alleviate bursty packet drops. They sit and wait until the middle nodes become overloaded or exhausted before they activate mitigation. Instead, the novel approach aims to avoid unintentional packet drops, i.e., to incentivize a scheduling policy based on predictions of the storage infrastructure's load in an overloaded or drained state. This creates reliable routing paths. Earlier works aimed to maximize either the battery or palimpsest life, but not both. The effective scheduling approach is to address these two drawbacks simultaneously, which is employed in our scheme. This allows the middle nodes an opportunity to process as much of the packet (as possible) using on-board memory.

The contribution is the combination of traffic hints and proactive congestion prediction with intelligent resource scheduling. Unlike the latter, which is static (a hardcoded set of rules with no learning from traffic), existing mechanisms have been incorporated into the proposed mechanism, which is dynamic and can effectively learn network dynamics. In this paper, a simple, novel routing heuristic for MANETs is proposed to mitigate packet loss caused by accidental drops. It is an extension of our earlier work and is superior to existing ones. It differs from existing works, which focus on energy, storage, and traffic separately. We highlight three key innovations:

Most mechanisms for preventing packet drops do not account for multiple resource constraints or network failures. RER-SK considers only battery capacity, while RRARM considers both energy and storage. The work, unlike the above-discussed approach, considers all factors that can lead to accidental drops in packer battery life, available storage space, and network traffic. This reduces the computational cost of finding an optimal path between message-exchange endpoints.

Predicting Problems Before They Happen. So far, only reactive approaches have been suggested in the literature to minimize unwanted drops. They sit in wait for those intermediaries to become overloaded or swamped, and then they hit them with mitigation. Instead, the proposed approach mitigates unintended packet loss by anticipating packet drops on nodes ahead of time, based on estimations of storage states for buffering and full nodes. This creates reliable routing paths.

Smart Resource Management. Previous systems could optimize battery or storage size, but not both simultaneously. The resultant substantive scheduling algorithm is then applied to effectively overcome both drawbacks. This allows intermediate nodes to process more packets, given the resources available to them. The novelty of our work lies in the disjunctive combination of traffic-aware, proactive congestion prediction and smart resource scheduling. Unlike existing schemes, which are based solely on a static set of rules (unchanging with traffic patterns), our scheme is dynamic and adapts to changes in topology.

It provides a more valid alternative to CACK and similar protocols that generate unnecessary messages and continually consume node resources. Hence, our method will result in lower lost messages, faster data exchange, and a more robust network. Thus, the proposed approach is most

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relevant in mission-critical applications, such as disaster management or remote medical care, where real-time responses are required during emergencies to save lives. TABLE 1 presents comparisons between the existing and other MANET routing protocols, demonstrating contributions to unified resource management, proactive congestion prediction, and dual-constraint optimization.

Table 1: Comparison Of The MANET Routing Protocols In Terms Of Metric, Resource Handling Ability, And Their Limitations

Protocol	**Metric Used**	**Congestion Handling**	**Resource Optimization**	**Traffic Load Integration**	**Key Limitation**
AODV [10]	Hop count	None	None	No	Does not consider resource limitations; computes unreliable routes
EBR [24]	Energy, buffer	Reactive, fixed thresholds	None	No	No traffic integration, reactive
RRARM [21]	Energy, buffer	Reactive, RED thresholds	Single constraint	No	No traffic integration and proactive congestion handling
RER-SK [13]	Energy	None	Single constraint	No	Restricted to energy, no buffer and traffic taken into account
CACK [8]	Acknowledgment	Reactive, malicious focus	None	No	High complexity, leaves out accidental drops
Benakappa & Kiran [20]	Energy, trust	Reactive, link failure prediction	None	No	Ignores buffer and traffic constraints
Nizamuddin et al. [22]	Energy, buffer	Reactive, probabilistic	None	Partial	Lacks dynamic optimization
Mohammad et al. [23]	Energy, buffer	Reactive, security focus	Single constraint	No	Limited stability in dynamic traffic
Proposed	Residual Status (Rs)	Proactive (queue analysis)	Dual constraint (dynamic programming)	Yes	None; holistically addresses energy, buffer, and traffic

4. METHODOLOGY

A. Problem Definition

MANETs are wireless networks composed of nodes without a central coordinator. Nodes communicate directly if they are within communication range; otherwise, they rely on intermediate nodes. The network is particularly well-suited for sensitive tasks such as disaster relief, medical monitoring, and environmental tracking. These operations require fast, reliable, and energy-efficient communication. But devices frequently lose data due to low battery, full storage, or poor network connections. This results in reduced network performance, particularly in busy, dynamic environments.

Typical routing mechanisms, such as AODV, select the path with the minimum distance. They assume that all nodes have sufficient resources and often choose unreliable routing paths. This results in more unintentional packet loss. Other solutions that focus solely on energy, buffering, and delivery confirmation (such as those in CACK [7]) address

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only one cause of unintentional packet drops and require excessive computational power. They fail to address unintentional packet drops caused by battery depletion, storage overflow, and burst traffic. The proposed protocol addresses this problem by simultaneously considering all three aspects of unintentional packet dropping, thereby mitigating packet loss and enhancing the reliability of MANETs.

B. *Objective*

To mitigate unintentional data loss caused by limited device resources, our work aims to achieve three goals:

1. Compute the minimum-congested and maximum resource-utilized routing path with the intermediate node's battery life, available storage, and current traffic
2. Design a monitoring system to track device storage and prevent congestion by analyzing network traffic trends.
3. Propose a smart scheduling algorithm that takes into account the remaining battery of the node and buffer constraints, such that packets can be better processed at the node.

Satisfying the above goals creates a uniform system that reduces the risk of data loss due to energy outages, full storage, and traffic burstiness, thereby making MANETs more reliable for mission-critical applications.

C. *Proposed Work*

A simple routing protocol is explained for MANETs by introducing a new routing metric, "Residual status," (R_s). in this section. This addresses the remaining energy (E_{res}), buffer residual (B_t), and traffic load (T_r) to mitigate unintentional drops due to resource scarcity. The routing protocols consist of two simple algorithms: a history-based congestion prediction algorithm and `knapsack through dynamic programming' used to maximize the packet processing capacity subject to energy and buffer constraints. The protocol is designed to ensure reliable routing by selecting a path free of congestion, energy drain, and overloaded nodes.

D. *RESIDUAL STATUS OF NODE METRIC*

The novel routing metric (R_s) ensure that only those intermediate nodes with sufficient resources participate in routing, thereby mitigating packet loss due to a lack of resources. The $R_s$metric is computed by an equation. (1).

$$R_s = w_1 . \frac{E_{res}}{E_{max}} + w_2 . \left(1 - \frac{Q_s}{B_t}\right) + w_3 . \left(1 - \frac{T_r}{T_{max}}\right) \quad (1)$$

Where $E_{res}\ and\ E_{max}$ are residual and maximum energy, Q_s is the current queue length, B_t is the maximum buffer capacity in bytes, T_r is the current traffic load, and T_{max} is the maximum traffic rate. The weighting constant $w_1, w_2, w_3 \epsilon [0,1]$ by satisfying $w_1 + w_2 + w_3 = 1$ balance the contributions of energy, buffer, and traffic status. High value of R_s implies that the node has a low risk of buffer overflow and sufficient energy to process packets without depletion. Thus, nodes with $R_s \geq R_{max} = 0.8$ are prioritized for routing, while nodes with $R_s < R_{min} = 0.2$ are excluded for routing to mitigate packet drops. Where, R_{max} is the threshold for high-priority nodes to ensure robust packet forwarding, minimizing drop risks, and R_{min} is the minimum threshold to exclude resource-constrained nodes. Thus, nodes in the network are categorized based on R_s thresholds with $High = 3$, $Medium = 2$, and $Low = 1$. Numerical priority levels of the node for routing are shown in the equation (2).

$$P(n_i) = \begin{cases} 3, & R_s \geq R_{max} \\ 2, & R_{min} \leq R_s < R_{max} \\ 1, & R_s < R_{min} \ldots \end{cases} \ldots (2)$$

Additional metrics include normalized components, which are explained as follows;

$$E_{norm} = \frac{E_{res}}{E_{max}}, \qquad B_{norm} = 1 - \frac{Q_s}{B_t},$$
$$T_{norm} = \frac{T_r}{T_{max}}$$

Risk factors for depletion $(D_e = 1 - E_{norm})$, overflow $\left(O_b = \frac{Q_s}{B_t}\right)$ and overload $\left(O_t = \frac{T_r}{T_{max}}\right)$ combine into a reliability factor $R_f = W_e . D_e + W_b . O_b + W_t . O_t$, the weighting constant w_e, $w_b, w_t \epsilon [0,1]$ by

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satisfying $w_e + w_b + w_t = 1$. Low R_f values indicate reliable nodes, i.e., with $R_f \leq 0.3$ for inclusion. Prioritize the route selection by following the equation, i.e. (3).

$$P(n_i) = \begin{cases} 3, & R_s \geq 0.8 \\ 2, & 0.2 < R_f < 0.8 \\ 1, & R_s < 0.2 \end{cases} \quad \ldots\ldots (3)$$

Furthermore, network-wide averages and variances inform the load-balancing process.

E. Stochastic Queue Analysis for Buffer Overflow Prevention

The algorithm predicts buffer overflow by eliminating nodes prone to congestion, a major cause of dropped packets in MANETs. The dynamics of the queue, including waiting times, queue lengths, and overflow probabilities, are simulated using a model based on queueing theory. The Schematic is augmented with a congestion indicator to distinguish packets that cannot be forwarded, thereby providing information on the delay of packet transmission. The RED mechanism aims to preserve QoS while keeping the buffer overflow loss small enough for delay-sensitive applications.

Buffer overflow is a significant source of unintentional packet losses in MANETs, particularly under high traffic loads. The analysis model combines stochastic queueing-based congestion prediction with buffer occupancy and traffic load. The algorithm calculates the waiting time $W_b(t) = Q_b(t)/\mu$ to determine overflow risk, enabling proactive exclusion of congested nodes. Queue length $Q_b(t) = min(\lambda(t).t, B_t)$, where $\lambda(t) = \lambda_0.(1 + \alpha.T_r)$ adjusts the arrival rate $(\lambda_0 = 10 \text{ packets/s}, \alpha = 0.5)$ for traffic. Traffic intensity $\rho = \lambda(t)/\mu < 1$ ensures stability $(\mu = 20\ packets/s)$. A node is at risk if $W_b(t) \geq 2$.TTL $(TTL = 200ms\ per\ ITU\ G.114)$, $Q_b(t) = B_t$, or overflow probability $P_{ov} = 1 - e^{-\lambda(t).W_b(t)} \geq 0.9$.

Algorithm 1: Stochastic Queue Analysis for Buffer Overflow Prevention

Require: Buffer capacity B_t = 512 KB, TTL = 200 ms, arrival rate $\lambda_0 = 10$ packets/s, service rate μ = 20 packets/s, time t, traffic T_r, scaling $\alpha = 0.5$

Ensure: Node suitability (True/False)

1: Compute $\lambda(t) = \lambda_0.(1 + \alpha.T_r)$
2: Compute $\rho = \lambda(t)/\mu$
3: if $\rho < 1$ then
4: Compute $Q_b(t) = min(\lambda(t).t, B_t)$
5: else
6: $Q_b(t) = B_t$
7: end if
8: Compute $W_b(t) = Q_b(t)/\mu$
9: Compute $P_{ov} = 1 - e^{-\lambda(t).W_b(t)}$
10: if $W_b(t) \geq 2 \cdot$ TTL or $Q_b(t) = B_t$ or $P_{ov} \geq 0.9$ then
11: $C_r = 1$
12: return False
13: else
14: $C_r = 0$
15: return True
16: end if

F. Knapsack-Based Dynamic Programming for Information Processing Optimization

The target of this algorithm is to maximize the information processing capacity (SK) of a node with energy (E_{res}) and buffer (B_t) constraints, which leads to maximizing data throughput while minimizing packet drop. For completing the processing of n packets with sizes $\{S(P_1), S(P_2), S(P_3) \ldots\ldots S(P_n)\}$ and energy costs $\{e(P_1), e(P_2), e(P_3) \ldots\ldots e(P_n)\}$, by a node having residual energy E_{res} and buffer B_t, an algorithm determines a subset of chosen packets to be offloaded based on a criterion that balances the processed data against fulfilling both power constraints. It is not possible to process a fraction of the packets, as in integer optimization. The proposed scheme adopts a 2D knapsack algorithm to produce the optimal packet schedule, thereby significantly enhancing network lifetime and robustness in resource-constrained MANETs.

Packet forwarding is interrupted on one hand, and packets must be unavoidably dropped due to the energy- and buffer-limited capacities on the other. For this purpose, the protocol employs a knapsack-based dynamic programming algorithm to achieve the maximum information processing capacity $SK = \sum_{i \in T} s(P_i)$ under E_{res} and B_t, where T is the selected packet subset. It defines the information processing capacity as the total data a node processes by summing the sizes of packets chosen in subset T.The total energy cost for processing a packet P_i is computed by summing energies for receiving (e_r), processing (e_p), and transmitting (e_t), shown in equation (4)

$$e(P_i) = e_r(P_i) + e_p(P_i) + e_t(P_i) \ldots\ldots\ldots (4)$$

Where,

$$e_r(P_i) = A_u . s(P_i)/r \quad (A_u = 300\ mW, r = 2Mbps)$$

$$e_p(P_i) = c.s(P_i)\ (c = 0.1\ mj/byte),$$

$$e_t(P_i) = P_{u,v}(s(P_i)/r)\ \ (P_{u,v} = 600\ mW)$$

Optimizes packet processing using a knapsack approach by selecting the maximum data processed for packets 1 to i within energy (e) and buffer (b) constraints, which is computed by following the equation (5)

$$V[i,e,b] = \max(V[i-1,e,b], s(P_i) + V[i-1, e-e(P_i), b-s(P_i)]) \ldots (5)$$

$$\forall\ if\ e(P_i) \le e\ and\ s(P_i) \le b$$

The above constraint imposes resource bounds on packet processing by limiting energy and buffer consumption per packet. Packet energy efficiency ratio is perceptible in the form of the Packet size to Energy cost ratio, and the higher this ratio, the more efficient the packet will be, thereby enhancing the network lifetime based on Eq. (6) below.

$$\eta_e = s(P_i)/e(P_i) \ldots\ldots\ldots (6)$$

Algorithm 2 Knapsack-Based Information Processing Optimization

Require: Packets n, E_{res} = 10 J, B_t = 512 KB, costs $e(P_i)$, sizes $s(P_i)$

Ensure: Optimal packet schedule

```
Initialize V[0..n, 0..E_res, 0..B_t] = 0,
   Keep[0..n, 0..E_res, 0..B_t]= 0
   for i = 1 to n do
     for e = 0 to E_res do
       for b = 0 to B_t do
         Compute η_e = s(P_i)/e(P_i)
         if e(P_i) ≤ e and s(P_i) ≤ b then
            if V[i − 1, e − e(P_i), b − s(P_i)] + s(P_i) > V[i − 1, e, b]   then
              V[i, e, b] → V[i − 1, e − e(P_i), b − s(P_i)] + s(P_i)
              Keep[i, e, b] → 1
            else
              V[i, e, b] → V[i − 1, e, b]
              Keep[i, e, b] → 0
  end if
         else
           V[i, e, b] → V[i − 1, e, b]
  Keep[i, e, b] → 0
         end if
       end for
     end for
end for
return Schedule based on Keep
```

G. Integration with AODV

The proposed protocol enhances the existing reactive AODV routing protocol's routing metric, hop count, with Rs, ensuring resource-aware routing that prioritizes nodes with sufficient energy and buffer space and low traffic. It modifies route discovery and maintenance to incorporate constraints, minimizing packet drops in dynamic MANETs.

During discovery, the source broadcasts RREQ with cumulative $R_s(R_s^{cum} = 0)$. Each intermediate node computes its individual R_s value, which integrates residual energy, buffer capacity, and traffic load, using Algorithm 1 to predict congestion by assessing queue length Q_s and traffic load T_r, and Algorithm 2 to optimize packet processing within energy $E_{res}$and buffer B_t constraints. If the node finds $R_s > R_{max}$, update $R_s^{cum} += R_s(N_i)$ and forward the packet further. If it finds $R_s < R_{min}$ then it is discarded. Destination selects the optimal path by choosing the route with the highest R_s^{cum} by $P^* = arg\ max_p(R_s^{cum}(P))$, ensuring $\forall N_i \in P, R_s(N_i)) \ge R_{min}$. Path cost $C_P = \sum_{N_i \in P} \frac{1}{P(N_i)}$ quantifies path cost based on priorities by summing inverse priorities (High = 3, Medium = 2, Low = 1). For maintenance protocol monitors

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$$R_s = w_1 . \frac{E_{res}}{E_{max}} + w_2 . \left(1 - \frac{Q_s}{B_t}\right) + w_3 . \left(1 - \frac{T_r}{T_{max}}\right),$$

if it finds $R_s < R_{min}$ broadcasts RERR and rediscover. Beacon messages update R_s.

Algorithm 3 Resource-Aware AODV Routing

Require: Source S, destination D, thresholds R_{max}=0.8, R_{min}= 0.2
Ensure: Optimal path
S broadcasts RREQ with cumulative $R_s^{cum} \leftarrow 0$
for each intermediate node N_i **do**
  Compute R_s using Algorithm 1 and Algorithm 2
  if $R_s \geq R_{max}$ **then**
  Update RREQ cumulative $R_s^{cum} + \leftarrow R_s(N_i)$
  Forward RREQ to neighbours
  else if $R_s < R_{min}$ **then**
  Discard RREQ
  end if
end for
D selects path $P^* = arg\ max_p\left(R_s^{cum}(P)\right)$
D sends RREP along selected path
for each node in path **do**
  Monitor $R_s(t)$ periodically
  if $R_s < R_{min}$ **then**
  Broadcast RERR
  Initiate new route discovery
  end if
end for
Maintain route with periodic R_s updates via beacon messages
return Selected path

5. PERFORMANCE ANALYSIS

To evaluate the effectiveness of the proposed protocol in preventing unintentional packet drops, we analyze three intermediate nodes in a multi-hop MANET and compare their routing performance with three reactive protocols: standard distance vector-based AODV, energy-aware routing, and buffer-aware routing. The analysis assumes constant bit rate (CBR) traffic (packet size = 512 bytes) with a packet time-to-live (TTL = 200 ms) per ITU G.114 recommendations. We consider three single-hop paths from source S to destination D, each via one intermediate node (Node 1, Node 2, or Node 3), to evaluate path selection based on each protocol's routing metric, and the network is shown in Figure 1.

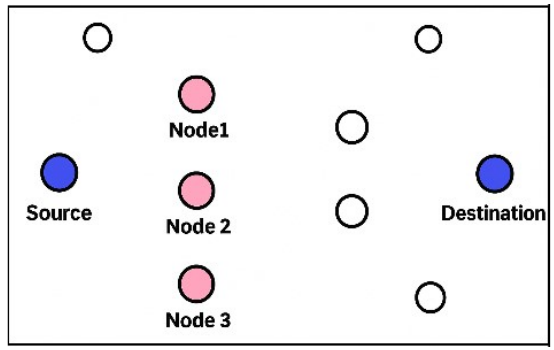

Figure 1: Network Topology Illustrating Source (S), Destination (D), And Three Intermediate Nodes (Node 1, Node 2, Node 3) In A Multi-Hop MANET. The Proposed Residual Status (Rs) Metric Selects Node 1 For Routing By Optimizing Residual Energy, Buffer Capacity, And Traffic Load.

The performance is evaluated using the network simulator NS-2 with 200 heterogeneous nodes in a 1000m × 1000m area, using the 802.11 MAC. We computed the route and compared it with AODV, energy-aware routing, and buffer-aware route computation. The simulation node attributes for three intermediate nodes are shown in Table 2, and the Packet characteristics are shown in Table 3.

Table 2: Characteristics Of Three Intermediate Devices (Node 1, Node 2, Node 3) In A Manets Simulation With Remaining Battery Power (E_{res}, In Joules, J), Maximum Battery Capacity (E_{max}, In J), Storage Capacity For Data (B_t,

In Kilobytes, KB), Current Data Stored (Q_s, In Bytes, B), Current Network Traffic (T_r, In Packets Per Second, P/S), Maximum Traffic Capacity (T_{max}, In P/S), And Data Processing Rate (μ, In P/S). These Attributes Help Evaluate Each Device's Ability To Reliably Relay Data In The Network.

Node	Remaining Battery (E_{res}, J)	Max Battery (E_{max}, J)	Storage Capacity (B_t, KB)	Current Data Stored (Q_s, B)	Current Traffic (T_r, p/s)	Max Traffic (T_{max}, p/s)	Processing Rate (μ, p/s)
1	5	20	5120	5120	20	100	20
2	6	20	3584	3584	30	100	20
3	7	20	2560	2560	25	100	20

Table 3: Energy Costs For Different Data Packet Types (Small, Medium, Large) In Manets Simulation: Packet Size (P_Size, In Bytes), Energy Used To Receive A Packet ($e_r(P_i)$, In Millijoules, Mj), Energy Used To Process A Packet ($e_p(P_i)$, In Mj), Energy Used To Transmit A Packet ($e_t(P_i)$, In Mj), And Total Energy Cost Per Packet ($e(P_i)$, In Mj). These Costs Help Assess How Much Battery Power Devices Need To Handle Data, Impacting Network Reliability For Applications Like Disaster Relief Or Medical Monitoring.

Packet Type	Packet Size (P_Size, bytes)	Receiving Energy ($e_r(P_i)$, mJ)	Processing Energy ($e_p(P_i)$, mJ)	Transmitting Energy ($e_t(P_i)$, mJ)	Total Energy Cost ($e(P_i)$, mJ)
Small	512	0.13	0.05	0.15	0.33
Medium	1024	0.26	0.1	0.31	0.67
Large	2048	0.51	0.2	0.61	1.32

Table 4: Computed Metrics For Intermediate Nodes (Node 1, Node 2, Node 3) In The MANET Simulation, Including Arrival Rate (Λ), Traffic Intensity (Ρ), Queue Length (Q_b), Waiting Time (W_b), Overflow Probability (P_{ov}), And Residual Status (R_s), With Routing Protocol Selections, Also Shows Which Routing Protocols (Proposed, Buffer-Aware, Distance Vector, Energy-Aware) Select Each Node Based On These Metrics, Indicating Their Suitability For Reliable Data Transfer.

Node	Data Arrival Rate (λ, p/s)	Traffic Intensity(ρ, unitless)	Stored Data(Q_b, bytes)	Waiting Time (W_b, ms)	DataLoss Chance(P_{ov}, unitless)	Residual Status(R_s, unitless)	Protocols Selecting Node
1	20	1.0	5120	500	1.0	0.35	Proposed, Buffer-Aware
2	25	1.25	3584	350	1.0	0.33	None
3	22.5	1.125	2560	250	1.0	0.37	Distance Vector, Energy-Aware

Computed metrics (w1 = w2 = w3 = 1/3, Rmax = 0.8, Rmin = 0.2) in Table 4. Qb(t) equals Bt for unstable queues (μ ≤ λ(t)), otherwise computed via queueing theory.

A. Node Metrics Analysis

Node 1: Moderate congestion ($W_b(t)$ = 500 ms), R_s = 0.35 > R_{min}, full buffer ($Q_b(t)$ = 5120 bytes), P_{ov} = 1.0 due to ρ = 1.0. **Node 2**: High congestion ($W_b(t)$ = 350 ms), R_s = 0.33 > R_{min}, full buffer ($Q_b(t)$ = 3584 bytes), P_{ov} = 1.0 due to ρ > 1. **Node 3**: Moderate congestion ($W_b(t)$ = 250 ms), R_s = 0.37 > R_{min}, full buffer ($Q_b(t)$ = 2560 bytes), P_{ov} = 1.0 due to ρ > 1.

B. Routing Comparison

Distance Vector: Selects Node 3 arbitrarily (ignores buffer/traffic constraints). **Energy-Aware**: Selects Node 3 (highest Eres/Emax = 0.35), overlooks buffer/traffic. **Buffer-Aware**: Selects Node 1 (lowest traffic load, Tr = 20 p/s), despite all nodes having full buffers (1 − Qs/Bt = 0). **Proposed**: Selects Node 1 (Rs = 0.35, highest viable Rs > Rmin), balances energy, buffer, and traffic, excludes Nodes 2 and 3 (Rs < Rmax = 0.8). The proposed protocol integrates energy, buffer,

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and traffic, proactively excluding unreliable nodes via thresholds, enhancing reliability over single-metric protocols.

Further analysis assumes the M/M/1/K queueing model to compute throughput and packet loss for three nodes under the proposed and existing distance vector, Energy-Aware, and Buffer-Aware protocols. The Proposed protocol selects Node 1 to minimize packet loss, while others select Node 3, increasing drops and degrading performance. The results are shown in Table 5.

Table 5: Throughput And Packet Loss Probability For Intermediate Nodes (Node 1, Node 2, Node 3) In The MANET Simulation, Comparing The Proposed Rs-Based Protocol With AODV, Energy-Aware, And Buffer-Aware Protocols, Based On The M/M/1/K Queueing Model. The Table Shows: Chance Of Data Loss (P_B, In Percent, %), Data Delivery Speed (Throughput, In Bits Per Second, Bits/S), And Which Routing Protocols Select Each Node.

Node	P_B (%)	Throughput (bits/s)	Selected by
1	9.09	74,472.73	Proposed, Buffer-Aware
2	24.03	77,791.35	---
3	21.93	71,951.99	Distance Vector, Energy-Aware

The Proposed protocol selects Node 1 and outperforms others by minimizing packet loss through balanced resource allocation (Rs = 0.35). Distance Vector and Energy-Aware protocols select Node 3 (PB = 21.93%), suffer higher losses due to unstable queues (ρ = 1.125), negatively impacting network performance. Buffer-Aware matches the proposed approach but is less robust. These results confirm the superiority of the proposed protocol for reliable MANET communication.

Furthermore, we compare the performance of MANETs under the proposed routing protocol with that of existing ones. We conducted simulations in NS-2 using the parameters outlined in Table 6. The simulation environment comprises 200 heterogeneous nodes within a 1000 m × 1000 m area, utilizing the IEEE 802.11 MAC protocol. Traffic follows a Constant Bit Rate (CBR) pattern with 512-byte packets and a 200 ms time-to-live (TTL), per ITU G.114 recommendations. The M/M/1/K queue model governs buffer dynamics, with a buffer capacity (B_t) of 512 KB, a base arrival rate (λ_0) of 10 packets/s (varied to 20–30 packets/s for high-traffic scenarios), and a service rate (μ) of 20 packets/s. Node energy capacities (E_{res}) range from 5 J to 7 J, with a maximum energy (E_{max}) of 20 J. The proposed protocol, which leverages stochastic queue analysis (Algorithm 1) and knapsack-based dynamic programming (Algorithm 2), is compared against the AODV, Energy-Aware, and Buffer-Aware protocols. Performance results are shown in Figures 2-5.

Table 6: Simulation Parameters For The MANET Performance Evaluation Using NS-2, Including Node Count, Area, Traffic Pattern, Packet Size, Buffer Capacity, And Energy Constraints.

Parameter	Value
Simulator	NS-2
Simulation Area	1000 m × 1000 m
Number of Nodes	200 (heterogeneous)
MAC Protocol	IEEE 802.11
Traffic Type	Constant Bit Rate (CBR)
Packet Size	512 bytes
Time-to-Live (TTL)	200 ms (per ITU G.114)
Queue Model	M/M/1/K
Buffer Capacity (Bt)	512 KB
Arrival Rate (λ_0)	10 packets/s (base), varied (20–30)
Service Rate (μ)	20 packets/s
Energy Capacity (Eres)	5 J – 7 J (per node, heterogeneous)
Maximum Energy (Emax)	20 J
Simulation Algorithms	Stochastic Queue Analysis, Knapsack-based Dynamic Programming
Protocols Compared	AODV, Energy-Aware, Buffer-Aware, Proposed Rs-based Protocol

Figure 2 compares throughput across protocols as the number of nodes increases. The proposed Rs-based protocol achieves higher throughput, starting at 75 Kbps at 100 nodes and gradually declining to 71 Kbps at 300 nodes, outperforming AODV, Energy-Aware, and Buffer-Aware.

Figure 3 compares the packet loss probability across protocols as node count increases. The proposed protocol exhibits lower packet loss compared to AODV and Energy-Aware. Buffer-Aware starts low but increases due to limited energy and traffic considerations. The proposed protocol's stochastic queue analysis predicts congestion, and knapsack-based dynamic programming optimizes packet processing, reducing P_B by excluding unreliable nodes.

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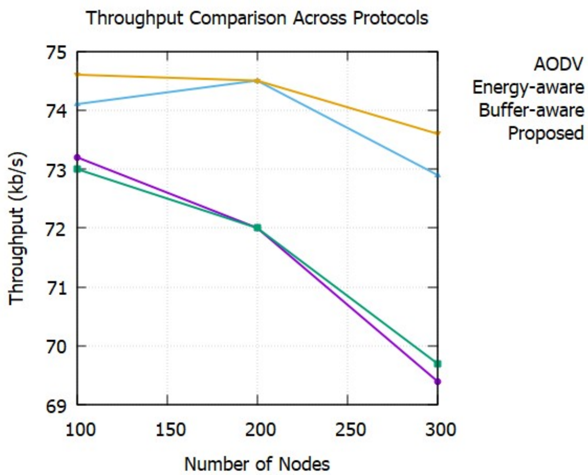

Figure 2: Throughput Comparison Of The Proposed Rs-Based Routing Protocol Against AODV, Energy-Aware, And Buffer-Aware Protocols Across Increasing Node Counts (100–300 Nodes) In A MANET Simulation, Demonstrating Superior Performance Of The Rs-Based Protocol.

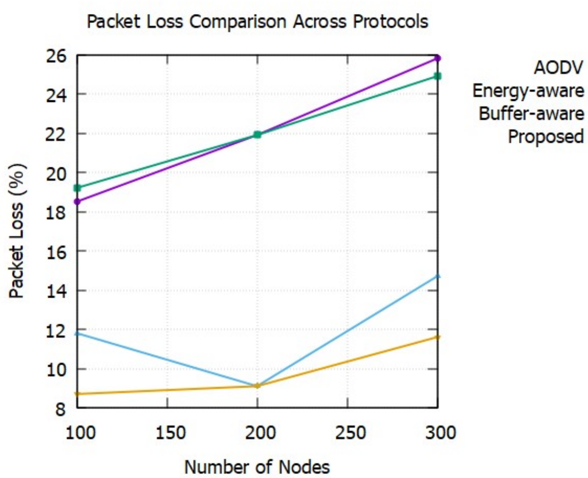

Figure 3: Packet Loss Probability Comparison Across The Proposed Rs-Based Routing Protocol, AODV, Energy-Aware, And Buffer-Aware Protocols With Increasing Node Counts (100–300 Nodes) In A MANET Simulation, Highlighting The Rs-Based Protocol's Lower Packet Loss.

A. Mitigation of Unintentional Packet Drops

The proposed protocol mitigates unintentional packet drops, which is explained as follows.

Proactive Node Exclusion: Nodes with $R_s < R_{min}$ = 0.2 are excluded from routing, preventing selection of nodes at risk of energy depletion, buffer overflow, or traffic overload. For example, Node 2 (R_s = 0.33, ρ = 1.25) is avoided due to its high packet loss probability (P_B = 24.03%).

Stochastic Queue Analysis: Algorithm 1 predicts buffer overflow by computing queue length ($Q_b(t)$), waiting time ($W_b(t)$), and overflow probability (Pov). This enables proactive avoidance of congested nodes, such as Node 3 (Wb(t) = 250ms > TTL =200ms, Pov = 1.0)

Knapsack-Based Optimization: Algorithm 2 optimizes packet processing within energy(E_{res}) and buffer (B_t)constraints, maximizing throughput while minimizing drops. For Node 1, this ensures efficient processing of up to 10 packets (512 bytes each) within B_t = 5120bytes.

Balanced Resource Consideration: The Rsmetric integrates residual energy (Eres/Emax), buffer availability (1 − Q_s/B_t), and traffic load ($1 - \frac{T_r}{T_{max}}$)with equal weights (w1 = w2 = w3 = 1/3), selecting Node 1 (Rs = 0.35) for its balanced resources and lower traffic load (Tr = 20p/s). These mechanisms collectively reduce packet loss (e.g., P_B = 9.09% for Node 1 vs. 21.93% for Node 3), enhancing packet delivery fraction, throughput, and network lifetime for critical applications.

B. Results Discussion

Simulation results show that the proposed Rs-based routing protocol offers better performance in MANET than conventional distance-vector-based, energy-aware, and buffer-aware routing protocols. Node 1, as chosen by the implemented protocol, experienced the least packet loss (9.09%) and stable throughput (74,472 bps), while Node 3, as chosen by the distance vector and energy-aware protocols, recorded higher losses (21.93%) due to unstable queues.

The best-effort packet forwarding in Buffer-Aware was like the proposed approach but not optimized, as it did not consider both energy and traffic load. It combined residual energy, buffer availability, and steering considerations into a single metric to achieve fair resource allocation and actively avoid nodes unlikely to relay data in subsequent transmissions (e.g., Node 2, which has high congestion and a 24.03% loss rate).

These results also demonstrate that the proposed technique reduces the number of unwanted packet drops, increases the packet delivery ratio, and prolongs the network lifetime. The integrated measure overcomes the deficiencies of single-factor measures; therefore, it is highly suitable for mission-critical applications, including disaster relief and healthcare monitoring.

The proposed routing protocol for MANETs introduces a novel "residual status" metric integrating residual energy, buffer capacity, and traffic load, using stochastic queue analysis for proactive congestion prediction and knapsack-based dynamic programming for resource optimization, outperforming traditional AODV, energy-aware, and buffer-aware protocols by minimizing unintentional packet drops and enhancing packet delivery, throughput, and network lifetime for critical applications.

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6. CONCLUSION

This work addresses unintentional packet drops in MANETs due to resource constraints. It designs a simplified routing metric ("residual status of node" (Rs)) by integrating residual energy, buffer capacity, and traffic load. The protocol mitigates unintentional packet drops by predicting buffer overflow using stochastic queue analysis and optimizing delay tolerance through a knapsack-based dynamic programming approach for energy-buffer optimization. The proposed protocol enhances the existing reactive AODV routing protocol's routing metric, hop count, with Rs, ensuring resource-aware routing prioritizes nodes with sufficient energy and buffer space and low traffic. The novelty of our work is to cope with the various forms of resource constraints as a single entity, unlike existing single-metric protocols. The protocol guarantees reliable message delivery for important MANET applications (e.g., disaster recovery, healthcare monitoring) by timely discarding unreliable nodes (Rs < Rmin). Future work will consider testing the protocol over multi-hop (mobility) scenarios, adding security features, and optimizing the weighting factors of Rs in order to improve performance.

Ethical Compliance:

This research received no funding. The authors declare no conflict of interest, and no ethical approval is required

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