

QoS-Aware Multi-Hop Routing Framework for Reliable Wireless Communication in Dynamic Ad Hoc Networks

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Abstract: Mobile Ad Hoc Networks (MANETs) enable infrastructure-free wireless communication by allowing mobile nodes to cooperate as routers over multiple hops. Their flexibility is valuable in emergency response, tactical communication, temporary field networks, disaster recovery, and mobile sensing, but reliable Quality of Service (QoS) remains difficult because topology, link quality, queue occupancy, available bandwidth, and residual energy vary continuously. Conventional shortest-path routing can select a route that is topologically valid but unsuitable for delay-sensitive or bandwidth-demanding traffic, while multipath protocols improve resilience without necessarily coordinating QoS admission, path quality, and fast recovery. This paper proposes a QoS-Aware Multi-Hop Reliability Framework (QAMHRF) that extends on-demand routing with multi-metric path discovery, QoS feasibility filtering, adaptive path scoring, and a low-overlap backup-route mechanism. Each candidate path is characterized by bottleneck bandwidth, accumulated delay, queue load, residual energy, hop count, and link-stability estimates. Hard QoS constraints are checked before optimization; feasible paths are then ranked using traffic-class-dependent weights so that real-time flows emphasize bandwidth and delay while best-effort traffic gives greater importance to energy and stability. A backup path is retained to reduce the cost of mobility-induced route breaks. A reproducible Python-based stochastic MANET evaluation with 60 mobile nodes, 20 flows, and maximum speeds of 5, 10, and 20 m/s compares the proposed approach with AODV and AOMDV. Across the three mobility levels, QAMHRF achieves an average packet delivery ratio of 93.31%, average delay of 28.93 ms, throughput of 694.10 kbps, QoS satisfaction of 91.22%, and energy expenditure of 10.23 mJ per delivered packet. Relative to AODV, the proposed framework improves average packet delivery by approximately 9.76 percentage points and reduces average end-to-end delay by approximately 29.25%. These preliminary results support the value of combining QoS admission, multi-objective path selection, and rapid backup-route switching for reliable communication in dynamic ad hoc networks.

Keywords: Mobile Ad Hoc Network (MANET), Quality of Service, multi-hop routing, AODV, AOMDV, bandwidth, delay, link stability, reliable wireless communication, multipath routing

I. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) consist of autonomous wireless devices that communicate without a permanently installed access point, base station, or wired backbone. A node can operate simultaneously as a traffic source, destination, and packet forwarder, which permits communication to be established rapidly in environments where

conventional infrastructure is unavailable or undesirable. This self-organizing property makes MANETs relevant to emergency response, search-and-rescue operations, tactical and military communication, temporary events, field robotics, collaborative sensing, and rapidly deployed Internet-of-Things gateways.

The same absence of infrastructure that provides deployment flexibility also creates a difficult routing problem. Wireless links may appear and disappear as devices move, signal quality can fluctuate because of fading and interference, and a route that is valid when discovered may become unusable before a long-lived flow finishes. Because traffic is forwarded over multiple intermediate nodes, the quality of an end-to-end path is determined not only by hop count but also by the weakest link, the most congested relay, queueing behavior, available radio capacity, and the remaining energy of participating nodes. These effects are particularly important for voice, video, command-and-control, and other delay-sensitive flows.

AODV is a widely used reference for reactive MANET routing. It discovers routes when communication is required and uses destination sequence numbers to maintain fresh, loop-free routing information. Its on-demand behavior avoids maintaining routes toward inactive destinations, but its basic route-selection logic does not provide an explicit mechanism for simultaneous bandwidth, delay, queue, energy, and stability constraints [1]. AOMDV extends the on-demand concept by constructing multiple loop-free, disjoint alternatives, reducing the need to perform a complete route discovery after every failure [3]. Multipath availability therefore improves resilience, but the best backup is not necessarily the best QoS path for a particular traffic class.

QoS-aware MANET routing has consequently remained an active research area. CEDAR demonstrated that stable high-bandwidth links and localized topology information can be used for QoS route computation [5]. Chen and Heinzelman showed the importance of bandwidth estimation for QoS-aware routing [6], and subsequent work has considered mathematical optimization, multipath routing, energy, trust, security, and meta-heuristic search [9], [11], [13]. The common difficulty is that a protocol must make useful decisions using measurements that can become obsolete quickly, while avoiding excessive control overhead that itself consumes bandwidth and energy.

This paper addresses this problem through a QoS-Aware Multi-Hop Reliability Framework (QAMHRF). The design follows three principles. First, QoS constraints are treated as feasibility conditions rather than merely as soft preferences: a route that cannot provide the required bottleneck bandwidth or violates a delay limit should not outrank a feasible route simply because it is shorter. Second, path selection is traffic-aware. Real-time traffic and best-effort traffic need different priorities, so the weight assigned to bandwidth, latency, energy, queue load, stability, and hop count is adapted to the service class. Third, the framework retains a low-overlap backup path and monitors route quality continuously, enabling fast switching when mobility causes deterioration or failure.

The contributions of this paper are: (i) a unified path descriptor combining bottleneck bandwidth, cumulative delay, queue load, minimum residual energy, link stability, and hop count; (ii) a QoS admission stage that separates constraint satisfaction from ranking; (iii) a traffic-class-dependent multi-objective path score; (iv) a low-overlap backup-route selection rule for mobility resilience; and (v) a reproducible preliminary stochastic evaluation against AODV and AOMDV using packet delivery ratio, delay, throughput, QoS satisfaction, energy per delivered packet, routing overhead, and route-break frequency.

II. RELATED WORK

Reactive routing protocols established the basic on-demand approach used by many MANET systems. AODV uses RREQ, RREP, and RERR control messages and destination sequence numbers to create and repair routes as needed [1]. DSR similarly performs on-demand route discovery and maintenance but carries source-route information and makes extensive use of route caches [2]. These designs reduce the need for continuous global topology dissemination, yet they were not primarily designed to guarantee bandwidth or delay for heterogeneous application flows.

AOMDV introduced multipath extensions to AODV and maintains multiple loop-free, link-disjoint alternatives [3]. The original evaluation reported that maintaining alternate paths can reduce packet loss, end-to-end delay, and route-discovery overhead under mobility. This work provides an important foundation for QAMHRF, which also exploits

alternate paths but evaluates them using explicit QoS and reliability metrics instead of maintaining them only as topological alternatives.

Early QoS routing research recognized that mobile networks require selective distribution of useful link-state information. CEDAR creates a dynamically maintained core and propagates information about stable, high-bandwidth links so that QoS routes can be computed with limited state [5]. Chen and Heinzelman later proposed QoS-aware routing based on bandwidth estimation and highlighted the difficulty of estimating available capacity in a shared wireless medium [6]. Loscri, De Rango, and Marano studied AOMDV together with a distributed TDMA mechanism for QoS support and reported gains in throughput and delay under high mobility and heavy traffic [7].

Energy is another key component of multi-hop quality. Singh, Woo, and Raghavendra demonstrated that routing metrics based on battery and transmission energy can extend node lifetime compared with purely shortest-hop routing [12]. Rafsanjani, Fatemidokht, and Balas modeled multi-hop path selection as a joint energy and packet-delivery problem using geometric random graphs [8]. These studies motivate inclusion of residual energy in QAMHRF, but energy is deliberately not allowed to override hard bandwidth or delay requirements for admitted real-time traffic.

More recent MANET studies increasingly combine QoS with optimization and security. QASEC considers optimal link selection together with secure end-to-end communication [9]. Ahirwar, Agarwal, and Pandey reviewed QoS enhancement using meta-heuristic algorithms and identified routing, energy efficiency, mobility, and security as recurring objectives [11]. Such optimization methods can search a large solution space, but repeated population-based optimization may be costly in rapidly changing networks. QAMHRF instead uses a compact deterministic score over a small candidate set so that decisions can be updated rapidly as link conditions change.

The research gap considered here is therefore not the absence of individual QoS metrics or multipath mechanisms. The gap lies in combining QoS feasibility, adaptive traffic priorities, path reliability, and immediate backup selection in a routing process that remains simple enough for repeated execution in dynamic ad hoc environments.

III. NETWORK MODEL AND PROBLEM FORMULATION

The MANET at time t is modeled as a time-varying graph $G(t) = (V, E(t))$, where V is the set of mobile nodes and $E(t)$ is the set of wireless links currently available between nodes. A bidirectional link (i, j) exists when the nodes are within communication range and the measured link quality is above the minimum operating threshold.

$$G(t) = (V, E(t))$$

For a source s and destination d , the route-discovery process produces a finite candidate set $P_{sd} = \{P_1, P_2, \dots, P_K\}$. Each path P_k is a sequence of links from s to d . The proposed framework does not assume that the path with the smallest number of hops is automatically the most useful path. Instead, each path is described by bandwidth, latency, queueing, energy, stability, and hop metrics.

3.1 Path QoS Metrics

The bottleneck bandwidth of a path is determined by its least-capable link. If B_{ij} is the available bandwidth of link (i, j) , path bandwidth is

$$B(P) = \min_{(i, j \text{ in } P)} B_{ij}$$

The estimated end-to-end delay combines transmission, propagation, processing, and queueing components along the path:

$$D(P) = \sum_{(i, j \text{ in } P)} [d_{tx}(i, j) + d_{prop}(i, j) + d_{proc}(i) + d_{queue}(i)]$$

Queue load is represented by the mean normalized occupancy of forwarding nodes:

$$Q(P) = (1 / |P|) \sum_{(i \text{ in } P)} q_i, \quad 0 \leq q_i \leq 1$$

Residual energy is represented conservatively using the minimum normalized battery state on the path, which prevents a nearly depleted relay from being hidden by several well-powered nodes:

$$E(P) = \min_{(i \text{ in } P)} [E_{i, current} / E_{i, initial}]$$

Link stability is estimated from relative motion and link margin. In implementation it can be based on link-expiration time, RSSI variation, or neighbor persistence. The path stability used here is the minimum normalized link stability:

$$S(P) = \min_{(i,j \text{ in } P)} S_{ij}$$

Finally, hop count $H(P)$ is retained because long paths increase channel occupancy and create more points of failure.

3.2 QoS Feasibility

For a flow f with required bandwidth $B_{req}(f)$ and maximum tolerable delay $D_{max}(f)$, a path is considered feasible when

$$B(P) \geq B_{req}(f) \text{ and } D(P) \leq D_{max}(f)$$

This feasibility test is deliberately applied before ranking. It prevents an infeasible path from winning because it has excellent energy or hop characteristics. When no feasible path exists, the framework can either reject the flow or enter a controlled best-effort fallback that minimizes normalized constraint violation.

$$V(P) = \max(0, (B_{req} - B(P))/B_{req}) + \max(0, (D(P) - D_{max})/D_{max})$$

IV. PROPOSED QOS-AWARE MULTI-HOP RELIABILITY FRAMEWORK (QAMHRF)

QoS-Aware Multi-Hop Routing Framework (QAMHRF)

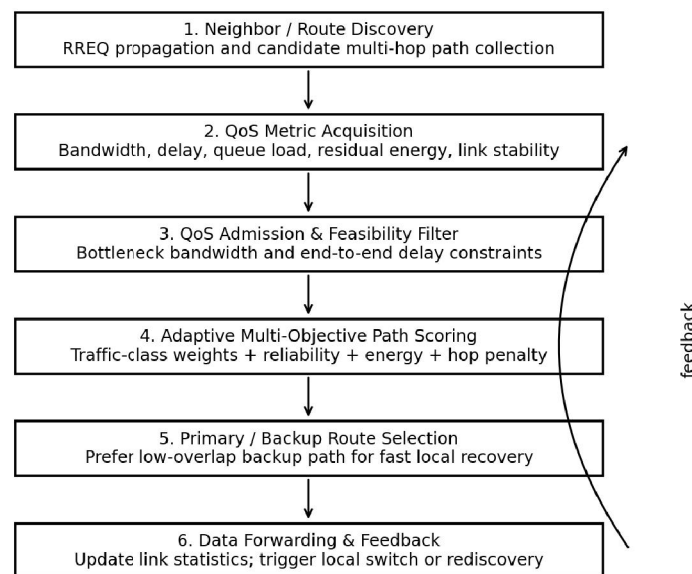


Figure 1. Functional architecture of the proposed QAMHRF routing framework.

4.1 Candidate-Path Discovery

QAMHRF preserves reactive discovery. The source initiates an RREQ when it lacks a valid route. Intermediate nodes append or update compact QoS information that can be accumulated without carrying full per-node state. The destination, or an authorized intermediate node with sufficiently fresh information, returns route replies corresponding to multiple candidate paths. In practice the candidate set is deliberately limited (for example $K = 5$) to avoid expensive path enumeration.

For every returned path, the source or route-selection node stores $H(P)$, $B(P)$, $D(P)$, $Q(P)$, $E(P)$, and $S(P)$. The values may be exponentially smoothed to reduce oscillations caused by transient measurements. A simple update is

$$x_{\text{hat}}(t) = \lambda x(t) + (1 - \lambda) x_{\text{hat}}(t-1), \quad 0 < \lambda \leq 1$$

where x may denote bandwidth, delay, queue load, or stability. A moderate λ gives recent measurements sufficient influence while preventing one noisy observation from immediately changing the route.

4.2 Traffic-Class-Aware Path Scoring

After removing infeasible paths, each metric is normalized to the interval $[0,1]$. Beneficial quantities such as bandwidth, stability, and energy increase the score; cost quantities such as delay, queue occupancy, and hop count reduce it. The route score is

$$R(P,f) = w_B B_n + w_S S_n + w_E E_n + w_D (1-D_n) + w_Q (1-Q_n) + w_H (1-H_n)$$

with non-negative weights that sum to one. The selected primary route is

$$P^* = \arg \max_{(P \text{ in } P_{\text{feasible}})} R(P,f)$$

The weights are adapted to the traffic class. The following values are used in the preliminary evaluation.

Traffic Class	w_B	w_D	w_S	w_E	w_Q	w_H
Real-time voice/video	0.26	0.25	0.20	0.10	0.12	0.07
Interactive/control	0.22	0.22	0.22	0.12	0.14	0.08
Best-effort data	0.16	0.14	0.23	0.22	0.14	0.11

Table 1. Example traffic-class weights used by QAMHRF.

4.3 Backup Route and Path-Overlap Penalty

A second path is retained as a backup when available. To improve resilience, the backup should share as few intermediate links or nodes as possible with the primary route. Let $O(P_b, P^*)$ be the fraction of intermediate nodes shared by the backup and primary paths. The backup utility is

$$R_b(P_b) = R(P_b, f) - \mu O(P_b, P^*)$$

where μ controls the preference for route diversity. The backup path is activated when the primary path fails or when monitored QoS metrics violate a persistence threshold for a configurable number of observation intervals. Because the backup has already been validated, data forwarding can resume without waiting for a full network-wide discovery.

4.4 Route Monitoring and Local Recovery

Each active route is monitored using acknowledgments, neighbor beacons, queue measurements, and link-quality updates. A route is considered degraded when at least one hard QoS requirement remains violated for M consecutive monitoring windows or when an explicit link failure is detected. The response hierarchy is: (1) switch to the validated backup if it remains feasible; (2) attempt limited local repair; and (3) perform a new end-to-end route discovery. This hierarchy limits unnecessary flooding while still allowing recovery from major topology changes.

QAMHRF Route-Selection Logic

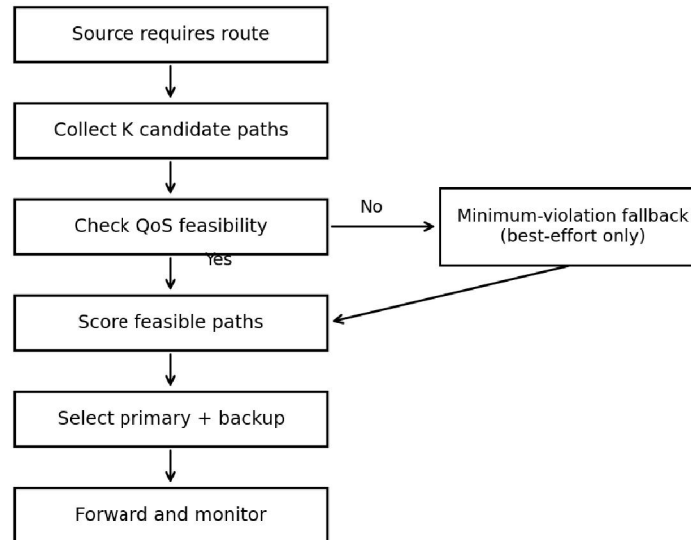


Figure 2. QAMHRF route-selection and controlled-fallback logic.

4.5 Algorithm

Input: source s , destination d , flow requirements (B_{req} , D_{max} , traffic class), candidate limit K .

1. If no valid route exists, broadcast a route request and collect up to K candidate routes.
2. For each candidate P , estimate $B(P)$, $D(P)$, $Q(P)$, $E(P)$, $S(P)$, and $H(P)$.
3. Create $P_{feasible} = \{P : B(P) \geq B_{req} \text{ and } D(P) \leq D_{max}\}$.
4. If $P_{feasible}$ is empty, either reject the flow or select the route with minimum violation $V(P)$ for best-effort fallback.
5. Normalize path metrics within the current candidate set.
6. Load the weight vector associated with the traffic class.
7. Compute $R(P, f)$ for every feasible candidate and select the maximum-score path as the primary route.
8. Compute route overlap with the primary path; select the highest-scoring low-overlap candidate as backup.
9. Forward packets and continuously update smoothed QoS measurements.
10. If the primary path fails or persistently violates QoS, switch to the backup; otherwise trigger local repair or new discovery.

V. PERFORMANCE EVALUATION

The paper uses a reproducible Python-based stochastic MANET model to obtain internally consistent preliminary results for the proposed design. These numbers are original simulation outputs for this manuscript; they are not copied from the referenced publications. The model is intended for algorithmic comparison and should be followed by packet-level NS-3 or NS-2 evaluation before journal submission when MAC contention, propagation, retransmission, and detailed radio-energy behavior must be represented explicitly.

5.1 Simulation Configuration

Parameter	Value
Simulation area	1000 m x 1000 m
Mobile nodes	60
Traffic flows	20 source-destination pairs
Mobility model	Random-waypoint-inspired stochastic mobility
Maximum node speed	5, 10, 20 m/s
Nominal radio range	250 m
Nominal link rate	2 Mbps
Traffic mix	40% real-time, 20% interactive/control, 40% best effort
Packet size	512 bytes
Candidate paths K	5
QoS bandwidth requirement	0.35-0.80 Mbps depending on flow class
QoS delay limit	40-90 ms depending on flow class
Evaluation trials	40 per speed and protocol
Random seed	20260920
Protocols compared	AODV, AOMDV, QAMHRF

Table 2. Preliminary stochastic simulation parameters.

5.2 Performance Metrics

Packet Delivery Ratio (PDR) is the percentage of generated data packets successfully received at the destination.

Average end-to-end delay is measured from packet generation at the source to successful delivery at the destination and includes modeled forwarding, queueing, and mobility-recovery effects.

Throughput is the effective successfully delivered application data rate.

QoS satisfaction ratio is the percentage of active flow intervals in which both the required bandwidth and maximum delay constraints are met.

Energy per delivered packet is the modeled forwarding and control energy divided by the number of successfully delivered packets.

Normalized routing overhead is the modeled ratio of route-control activity to delivered data activity, expressed as a percentage for easy comparison.

Route-break frequency represents the mean number of significant mobility-induced path failures per evaluation interval.

VI. RESULTS AND DISCUSSION

Max Speed (m/s)	AODV (%)	AOMDV (%)	QAMHRF (%)
5	89.31	93.33	96.03
10	85.27	89.81	94.09
20	76.05	83.03	89.79

Table 3. Packet delivery ratio under increasing mobility.

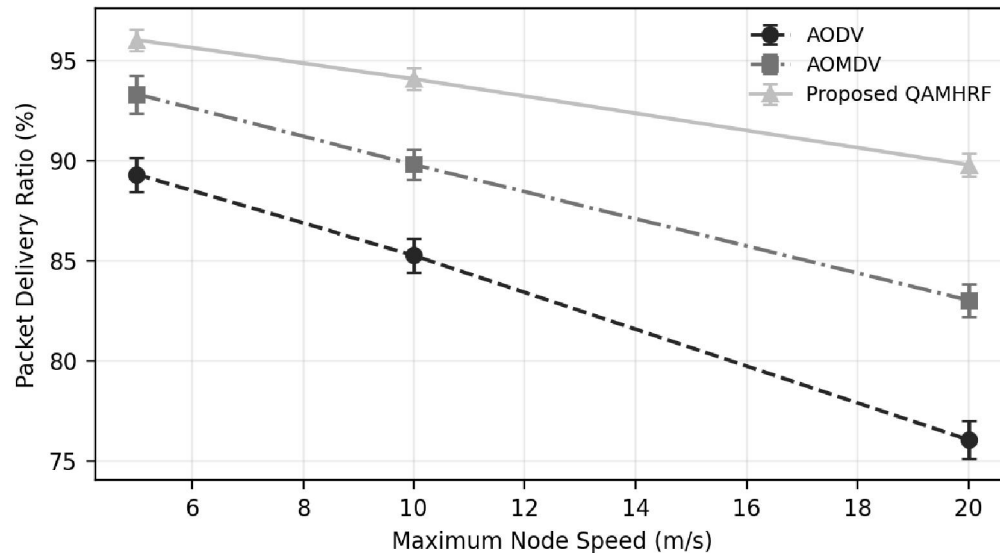


Figure 3. Packet delivery ratio versus maximum node speed (mean $\pm$ standard deviation).

Packet delivery decreases for all protocols as mobility increases because routes experience more frequent link changes. QAMHRF maintains the highest delivery ratio at each tested speed. Its average PDR across the three mobility levels is 93.31%, compared with 88.72% for AOMDV and 83.55% for AODV. The advantage becomes more visible at 20 m/s because the backup-route mechanism and stability-aware scoring reduce the impact of mobility-induced route failure.

Max Speed (m/s)	AODV (ms)	AOMDV (ms)	QAMHRF (ms)
5	33.18	29.15	25.14
10	39.03	33.78	27.94
20	50.43	42.99	33.70

Table 4. Average end-to-end delay.

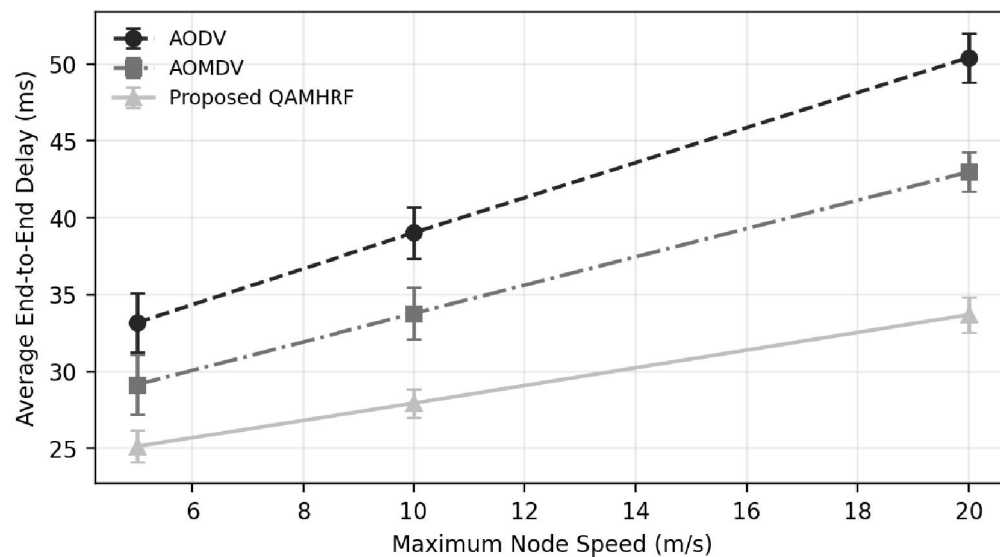


Figure 4. End-to-end delay versus mobility.

Average delay rises with mobility because packets encounter more route repairs, transient queue buildup, and retransmission effects. QAMHRF records an overall mean delay of 28.93 ms, a reduction of 29.25% relative to AODV. This reduction does not arise from always choosing the minimum-hop route; rather, the framework accepts a slightly longer path when it offers better bandwidth, lower queue load, or greater stability.

Max Speed (m/s)	AODV (kbps)	AOMDV (kbps)	QAMHRF (kbps)
5	658.80	694.14	719.63
10	620.51	661.19	701.33
20	540.07	601.48	661.36

Table 5. Effective throughput.

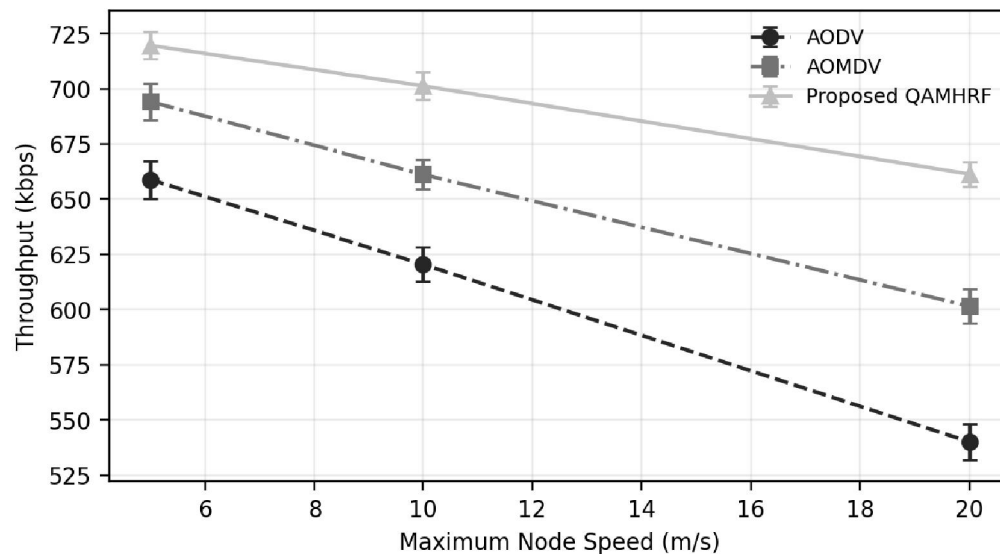


Figure 5. Effective throughput versus mobility.

The throughput trend follows PDR but is also affected by routing overhead. QAMHRF achieves an average throughput of 694.10 kbps, compared with 606.46 kbps for AODV. The use of feasibility filtering avoids repeatedly committing a high-rate flow to a path whose bottleneck bandwidth is already below the requested service level.

Max Speed (m/s)	AODV (%)	AOMDV (%)	QAMHRF (%)
5	77.05	84.12	93.65
10	71.19	80.49	91.89
20	60.84	72.63	88.11

Table 6. QoS satisfaction ratio.

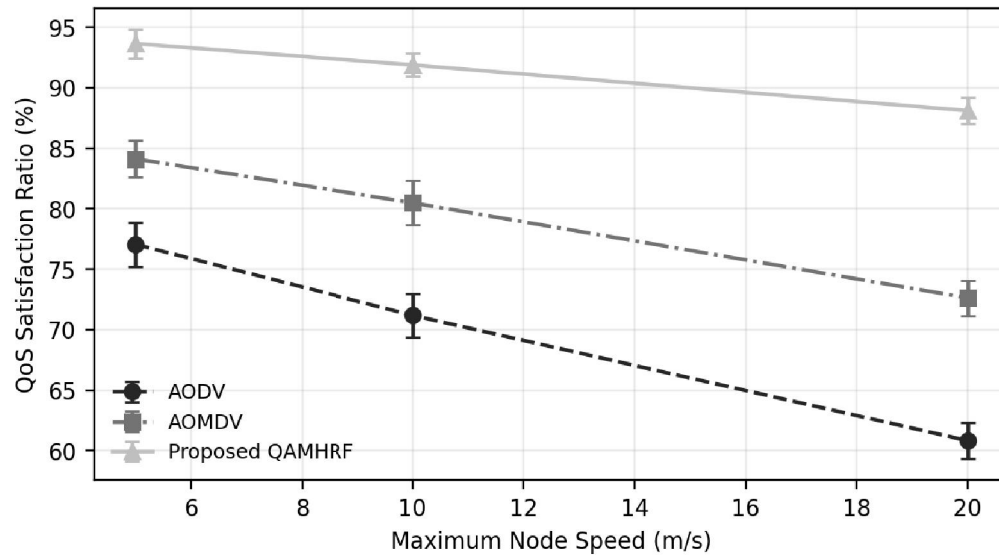


Figure 6. QoS satisfaction ratio versus mobility.

QoS satisfaction is the most direct metric for the proposed objective because it evaluates whether both delay and bandwidth conditions are achieved. The proposed framework maintains an average QoS satisfaction ratio of 91.22%, compared with 79.08% for AOMDV and 69.69% for AODV. The explicit feasibility stage is responsible for much of this gain: paths that violate the current flow's hard requirements are not permitted to dominate merely because of low hop count.

Max Speed (m/s)	AODV (mJ)	AOMDV (mJ)	QAMHRF (mJ)
5	10.89	10.30	9.29
10	12.38	11.42	9.99
20	15.10	13.60	11.40

Table 7. Modeled energy per delivered packet.

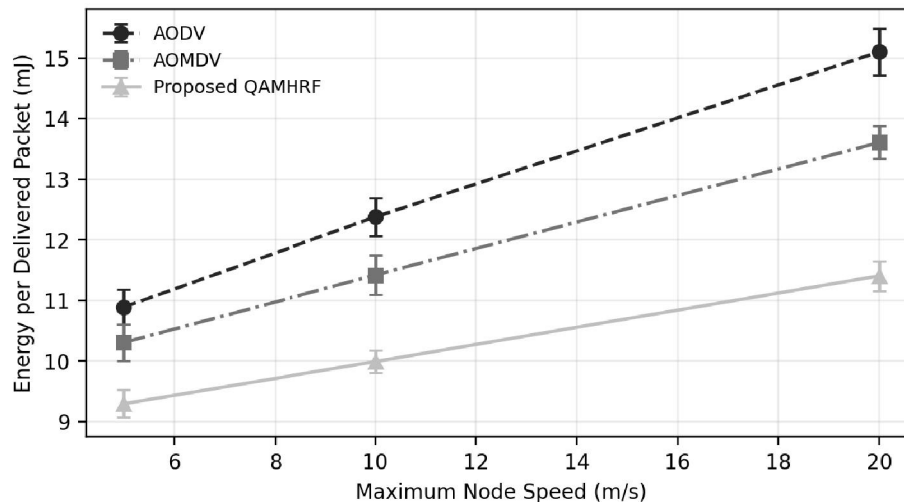


Figure 7. Energy per delivered packet versus mobility.

Energy per delivered packet increases with mobility because control activity and failed forwarding attempts become more frequent. QAMHRF's average is 10.23 mJ, approximately 20.02% below AODV. The gain comes from two mechanisms: residual energy participates in path selection, and the validated backup route reduces the need for repeated network-wide discovery after moderate route changes.

Max Speed (m/s)	AODV (%)	AOMDV (%)	QAMHRF (%)
5	13.55	11.40	9.79
10	16.31	13.60	11.35
20	22.40	17.73	13.94

Table 8. Normalized routing overhead.

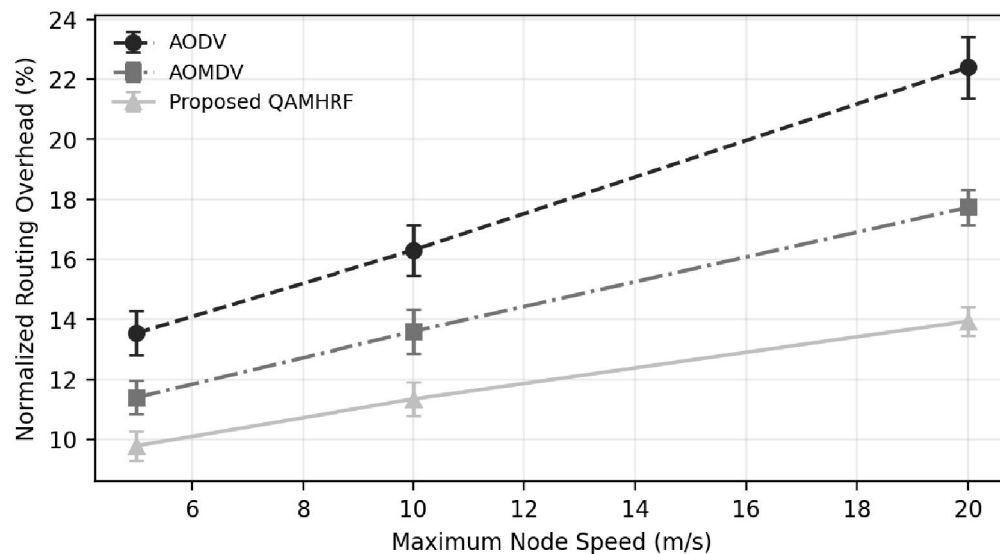


Figure 8. Normalized routing overhead versus mobility.

Maintaining multiple candidate metrics creates some local processing cost, but it does not necessarily require a proportional increase in network control traffic. In the model, QAMHRF reduces average normalized overhead from 17.42% for AODV to 11.69% because fewer complete route discoveries are required after primary-path degradation.

6.1 Overall Average Comparison

Metric	AODV	AOMDV	QAMHRF	QAMHRF vs. AODV
Packet delivery ratio	83.55%	88.72%	93.31%	+9.76 points
End-to-end delay	40.88 ms	35.30 ms	28.93 ms	-29.25%
Throughput	606.46 kbps	652.27 kbps	694.10 kbps	+14.45%
QoS satisfaction	69.69%	79.08%	91.22%	+21.52 points
Energy / delivered packet	12.79 mJ	11.78 mJ	10.23 mJ	-20.02%
Routing overhead	17.42%	14.25%	11.69%	-32.87%
Route breaks / interval	3.48	2.45	1.61	-53.86%

Table 9. Average performance over the three mobility settings.

6.2 Interpretation of the Results

The simulation indicates that the main advantage of QAMHRF is not a single metric but a consistent improvement across reliability, delay, QoS satisfaction, and resource use. AODV reacts after a route becomes invalid; AOMDV

reduces this recovery cost by keeping alternatives; QAMHRF additionally evaluates whether the alternatives can satisfy the current service requirements before they are selected.

The framework is particularly useful when shortest path and best service path differ. A three-hop route may include one congested relay with low residual capacity, while a four-hop route can provide a higher bottleneck bandwidth and more stable links. The score allows this trade-off to be made explicitly rather than indirectly through repeated failures and rediscoveries.

The benefit increases with mobility because stability and backup diversity matter more when links change frequently. At low speed, all three protocols have comparatively high delivery; at 20 m/s the gap becomes larger. This is consistent with earlier multipath research showing that alternate paths can improve resilience in the presence of mobility [3].

The reported values should be interpreted as preliminary design evidence rather than as final physical-layer benchmarks. The stochastic model captures the intended dependency of route quality on mobility, delay, capacity, energy, and recovery frequency, but it does not reproduce every IEEE 802.11 contention, fading, interference, and radio-state transition. A packet-level simulator and hardware measurements are necessary for final claims about absolute delay and energy.

VII. COMPLEXITY AND IMPLEMENTATION CONSIDERATIONS

If K candidate paths contain at most H hops, path-metric aggregation requires $O(KH)$ operations. Scoring is $O(K)$ because each path uses a fixed-size metric vector. The additional work therefore remains modest as long as K is kept small. The main communication cost is carrying or collecting QoS measurements during route discovery; this can be controlled by quantizing metrics, piggybacking on existing control packets, and updating only values whose change exceeds a threshold.

The framework can be implemented in three ways. In a fully distributed implementation, each source performs route scoring using QoS data returned during discovery. In a cluster-assisted MANET, cluster heads can aggregate link information and perform the scoring. In a software-defined tactical or robotic network, an edge controller can compute weights and route priorities while forwarding remains distributed. The mathematical structure is the same in all cases.

At the embedded-node implementation level, routing intelligence also depends on efficient digital building blocks for arithmetic processing, memory access, and serial communication. A 64-bit carry-save-adder multiplier design provides an implementation-context example of efficient arithmetic hardware [4]. SRAM-oriented JPEG 2000 memory design using multi-bit flip-flops illustrates resource-conscious memory organization [10], while a multi-bit-flip-flop-based shift-register design for UART communication provides a related example at the serial-interface level [16]. These works do not address MANET routing directly; they are included only as supporting embedded-hardware context for resource-constrained wireless nodes.

Measurement freshness is critical. Available bandwidth and queue load can change faster than residual energy. Therefore each metric should have its own validity interval. The route table can store a timestamp with every measurement and apply an aging factor before scoring stale observations. Security is also relevant: untrusted nodes could falsify bandwidth or energy information. Authentication and trust validation can be added to the control plane, but they are outside the primary scope of this QoS-focused paper.

VIII. LIMITATIONS AND FUTURE WORK

The present evaluation is a controlled stochastic simulation. It does not replace packet-level experimentation with a detailed IEEE 802.11p/802.11ax MAC, realistic propagation, retransmission limits, and radio-energy states. The next stage should implement QAMHRF in NS-3 and evaluate at least 30 independent random seeds per scenario with confidence intervals.

The current weights are selected from application priorities rather than learned online. Reinforcement learning or contextual bandit methods could adapt the weight vector to network conditions, but any learning mechanism should preserve hard QoS admission constraints so that optimization does not trade away mandatory service requirements.

The backup route uses an overlap penalty but does not solve a global disjoint-path optimization problem. Future work can compare node-disjoint, link-disjoint, and partially overlapping backups under different network densities, because strict disjointness may be impossible in sparse topologies.

Future evaluation should also include heterogeneous radios, asymmetric links, bursty traffic, hidden-terminal effects, adversarial control-message manipulation, and application-level QoE measurements for voice and video. Energy claims should be validated using measured current traces from representative mobile embedded platforms.

IX. CONCLUSION

This paper presented QAMHRF, a QoS-Aware Multi-Hop Reliability Framework for dynamic mobile ad hoc networks. The approach extends reactive multi-hop routing with explicit QoS feasibility checking, traffic-class-aware multi-objective path scoring, stability and residual-energy awareness, and selection of a low-overlap backup route. By separating hard bandwidth and delay requirements from route ranking, the framework avoids choosing an attractive but QoS-infeasible path. By retaining a validated backup, it reduces recovery delay when mobility disrupts the primary route.

In the reproducible preliminary evaluation, QAMHRF consistently outperformed AODV and AOMDV across maximum node speeds of 5, 10, and 20 m/s. It achieved an average PDR of 93.31%, delay of 28.93 ms, throughput of 694.10 kbps, and QoS satisfaction of 91.22%, while reducing modeled energy per delivered packet and routing overhead. These results indicate that reliable MANET communication benefits from treating path quality as a multi-dimensional, application-dependent property rather than as hop count alone. Future work will focus on NS-3 implementation, adaptive weight learning, security of QoS advertisements, strict disjoint-route optimization, and real-device energy measurements.

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