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ORIGINAL RESEARCH ARTICLE

A QoS-Aware Utility-Based Forwarding Strategy for Opportunistic Routing in Vehicular Ad Hoc Networks (VANETs)

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ABSTRACT
Opportunistic routing improves robustness in Vehicular Ad Hoc Networks (VANETs) by delaying relay selection until transmission time, but baseline schemes may not explicitly optimize Quality-of-Service (QoS) requirements such as delay, jitter, and bandwidth. This paper proposes A-BOR (Adaptive BOR), a QoS-aware enhancement of Bitmap-Based Opportunistic Routing (BOR) that ranks candidate forwarding options using a lightweight utility function and a feedback mechanism to refresh QoS indicators under dynamic conditions. A routing-layer VANET simulation with 100 mobile nodes under Manhattan-grid mobility is used for evaluation with Time-to-Live (TTL) = 60 s, 500 injected packets over a 200 s injection window, and a 600 s simulation duration. Results over 50 independent runs (mean ± 95% confidence interval) show that A-BOR improves packet delivery ratio (0.254 ± 0.023 vs 0.089 ± 0.009) and throughput (2598.5 ± 231.8 bps vs 906.4 ± 95.9 bps) compared with BOR, while reducing mean end-to-end delay (39.37 ± 1.25 s vs 41.96 ± 1.68 s) and jitter (5.04 ± 0.62 s vs 12.81 ± 1.90 s). These findings indicate that QoS-aware utility-based relay selection with feedback can improve reliability and delivery stability in dynamic VANET environments.

INTRODUCTION
Vehicular Ad Hoc Networks (VANETs) represent a specialized class of Mobile Ad Hoc Networks (MANETs) where vehicles serve as mobile nodes that communicate wirelessly without requiring a fixed infrastructure. VANETs have emerged as a critical technology for intelligent transportation systems, enabling vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication to enhance road safety, traffic management, and passenger services (Dulange & Info, 2025). The fundamental distinction of VANETs lies in their unique operational environment, characterized by high-speed mobility patterns, dense or sparse network topologies depending on traffic densities, and rapid topology changes that present significant challenges for routing protocol design.

The routing challenges specific to VANETs stem from several interconnected factors (Aminu & Nura, 2025; Isiyaku et al., 2024; Muhammad & Umar, 2023; Ogbe & Abubakar, 2025; Olugbenga et al., 2024; Umar et al., 2025; Yahuza et al., 2024). Vehicular ad hoc networks have the characteristics of high mobility, frequently changing topology and uneven distribution, which make it a challenge to design an efficient and robust routing protocol with low latency and high packet delivery rate (Rui et al., 2023).

The dynamic nature of VANETs presents several critical challenges for communication. Vehicles move at high speeds, causing frequent link disconnections and topology changes that make maintaining stable communication paths difficult (Khoza et al., 2018). The uneven distribution of vehicles means network density varies significantly across different road segments and times. Additionally, urban environments with buildings and obstacles obstruct radio signals, creating transmission barriers that traditional routing protocols struggle to overcome (Rashid et al., 2024).

The dynamic nature of vehicular environments demands routing protocols that can rapidly adapt to changing network conditions while maintaining quality of service (QoS) guarantees. VANETs face significant challenges due to dynamic topology, high mobility, and varying traffic densities, which hinder reliable, energy-efficient, and QoS-aware routing (Dulange & Info, 2025). This necessitates innovative routing approaches that consider both the physical mobility constraints and the QoS requirements of emerging vehicular applications, ranging from safety-critical message dissemination to infotainment services with varying latency and reliability demands.

Quality of Service in VANETs encompasses multiple metrics including packet delivery ratio (PDR), end-to-end

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delay (E2ED), and throughput, with each application imposing distinct requirements. Video streaming in VANETs, for instance, poses significant challenges due to strict Quality of Service requirements, such as high throughput, reliable packet delivery, low transmission delay, and stable performance, particularly in emergency scenarios (Benzerogue et al., 2025). The challenge of maintaining QoS in highly mobile environments has driven research toward adaptive protocols that dynamically adjust their behavior based on current network conditions and application requirements.

ExOR (Extremely Opportunistic Routing) represents a foundational approach in this domain, with numerous variants addressing specific network challenges. Bhorkar et al. (2012) explores opportunistic routing with congestion diversity, proposing D-ORCD (Distributed Opportunistic Routing with Congestion Diversity), which balances shortest path routing with backpressure techniques to ensure bounded expected delay in multi-hop networks.

The Vehicles in Network Simulator (Veins) has become the most widely used framework for VANET simulation research. Veins couples OMNeT++ (a discrete event simulator) with SUMO (Simulation of Urban Mobility) for realistic traffic modeling (Altmemi et al., 2025). Network Simulator 3 (NS-3) coupled with SUMO is another popular approach for VANET simulation (Bintoro et al., 2024). Google Colab provides a cloud-based Python environment ideal for simulating VANETs without requiring local installation of heavy simulation tools (Aljabry & Al-Suhail, 2021).

One of the prediction-based routing strategies for efficient data transfer is the opportunistic network model. Because opportunistic networks are mobile and dynamic, determining the routing path is a crucial challenge. A key component of efficient communication in the microscopic opportunistic routing strategy is route prediction. Additionally, choosing decisions is crucial to the calculation of routes (Ali et al., 2022). The Quality of Service (QoS) needs will determine how the network resources are distributed dynamically. The main worry, though, is that distribution networks might become clogged shortly after network resources are allocated (Waqar et al., 2023).

Utility-Based Opportunistic Routing (UBOR) improves routing decision-making by using the current state of the network along with utility-based metrics to calculate the forwarding node. This approach demonstrated superior performance against established protocols like AODV and OLSR across various mobility models, showing increased throughput, decreased latency, and improved packet delivery rates (Shreya et al., 2025).

One of the most critical applications of feedback and adaptation in VANETs is congestion control. These mechanisms dynamically adjust transmission parameters based on real-time network conditions (Jain, 2024). Fuzzy logic-based techniques for congestion control use real-time data and expert knowledge to dynamically change transmission rates in response to changing network conditions, achieving throughput speeds of 20.1 Mbps with packet loss reduced to 4.7% and latency of 160 milliseconds.

Opportunistic routing (OR) represents a fundamental shift from traditional routing paradigms by exploiting the broadcast nature of wireless communications. Rather than selecting a single predetermined path, OR allows multiple relay nodes to opportunistically forward packets (Khawatreh et al., 2019). By allowing packets to adapt to current link conditions opportunistic routing improves delivery ratios and reduces delays compared to traditional routing which is based on pre-defined paths. A unique path was identified using a single bitmap. It is necessary to convert the node-generating packet to bitmap format. This bitmap is used to access the appropriate path directly without encountering extra paths once the node producing packet reaches the parent node, saving time (Nahideh & Reza, 2021).

Bitmap-Based Opportunistic Routing (BOR) is an appropriate baseline for this study because it is a lightweight OR strategy designed around efficient candidate selection and routing representation, making it attractive for resource-constrained vehicular nodes and dynamic topologies. However, BOR primarily emphasizes forwarding feasibility and opportunistic relay availability and does not explicitly optimize key QoS indicators such as latency, jitter, and available bandwidth, nor does it incorporate feedback to adjust decisions as network conditions evolve. This creates the precise gap targeted in this work: BOR can deliver packets opportunistically, but it lacks a mechanism to rank forwarding options according to QoS requirements and to adapt those rankings in real time when congestion or link quality changes.

This study addresses that gap by proposing A-BOR (Adaptive BOR), which augments BOR with a utility-based relay ranking and a lightweight feedback mechanism. At each forwarding opportunity, A-BOR evaluates a limited set of candidates forwarding alternatives and selects the option with the highest utility computed from delay, jitter, and available bandwidth indicators, while feedback refreshes these indicators so that decisions reflect current network conditions rather than static assumptions. The novelty of A-BOR is its BOR-compatible, low-complexity integration of QoS utility scoring with feedback adaptation, aimed specifically at VANET conditions where relay suitability can change rapidly between contacts.

QoS evaluation in this paper uses four metrics: packet delivery ratio (PDR), throughput, mean end to end delay, and jitter, because they capture delivery reliability, efficiency, responsiveness, and timing stability required by VANET applications. The utility weights (α, β and γ) sum to one and reflect the relative importance of delay and jitter stability and bandwidth availability. The weights are kept fixed in this study to isolate the effect of the proposed decision mechanism and feedback adaptation.

We hypothesize that integrating QoS-aware utility scoring with feedback-based updates will improve delivery reliability and throughput while reducing delay and jitter compared with BOR under dynamic VANET conditions. The objectives of this research are to design A-BOR for QoS-aware candidate selection in VANET opportunistic routing, to implement a reproducible routing-layer VANET simulation with defined mobility, contact, buffering, and TTL constraints, and to compare A-BOR against BOR using PDR, throughput, mean end-to-end delay, and jitter with statistical confidence over multiple independent runs.

MATERIALS AND METHODS

This section describes the simulation environment and VANET scenario used to evaluate the proposed A-BOR protocol. It details the mobility, contact, traffic, buffering, and TTL settings, as well as the utility-based forwarding and feedback mechanisms. The baseline BOR protocol and the evaluation metrics used for comparison are also specified.

2.1 Simulation Environment

A routing-layer, algorithmic VANET simulation was implemented in Python to evaluate the proposed QoS-aware forwarding strategy. The simulator models mobility-driven contacts, store–carry–forward forwarding, finite buffering, and TTL-based packet expiration. Detailed MAC/PHY effects are abstracted to isolate the impact of the forwarding decision logic and to enable controlled multi-run experiments with statistical reporting.

2.2 Network Topology, Mobility, and Communication Model

A VANET scenario with 100 mobile nodes was simulated in a 1200 m × 1200 m urban area using a Manhattan-grid mobility model. Vehicles move along orthogonal road segments with speeds uniformly sampled in [8, 18] m/s, and probabilistically turn at intersections (turn probability 0.25), reflecting urban driving behavior. Communication is opportunistic: two vehicles are considered in contact if their Euclidean distance is within R = 200 m. During contact opportunities, link capacity is represented using a distance-dependent rate proxy that decreases linearly from 6 Mbps (near distance 0) to 1 Mbps (at the range boundary).

Traffic consists of 500 packets injected during a 200 s injection window, while the total simulation duration is 600 s to allow store–carry–forward delivery after injection. Each packet has TTL = 60 s from its creation time; packets exceeding TTL are dropped. Each node maintains a finite drop-tail buffer of 200 packets, and can forward at most one packet per second (service rate 1 packet/step). For each run, three source to destination flows are randomly selected to generate packet transmissions. The main simulation parameters used for the VANET evaluation, including mobility, communication range, traffic generation, TTL, buffer size, utility weights, and number of runs, are summarized in Table 1.

Table 1: Simulation parameters used in the VANET evaluation

Parameter	Value
Number of nodes	100
Mobility model (speed range)	Manhattan grid (8–18 m/s)
Simulation area	1200 m × 1200 m
Communication range (R)	200 m
Simulation time	600 s
Injection window / packets	200 s / 500 packets
Time-to-live (TTL)	60 s
Buffer capacity	200 packets (drop-tail)
Utility weights (α, β, γ)	0.3, 0.3, 0.4
Number of runs	50 (independent seeds)

2.3 Utility Function Implementation (A-BOR)

The proposed protocol, termed A-BOR (Adaptive BOR), augments the baseline BOR by selecting the next-hop forwarder using a composite QoS utility function. At each forwarding opportunity, the current node forms a set of eligible candidate relays and evaluates up to K = 10 candidates using:

$$U_{\text{path}} = \alpha \cdot \frac{1}{T_{\text{total}}} + \beta \cdot \frac{1}{J_{\text{total}}} + \gamma \cdot B_{\text{available}}$$

where T_{total} denotes the estimated end-to-end delay associated with forwarding through the candidate, J_{total} denotes the corresponding cumulative jitter estimate, and $B_{\text{available}}$ denotes the estimated available bandwidth. The weighting factors α, β, and γ control the importance of each QoS component and satisfy $\alpha+\beta+\gamma=1$. In this study, the weights are set to $\alpha=0.3$, $\beta=0.3$, and $\gamma=0.4$. The candidate relay that maximizes U_{path} is selected as the forwarder for the next hop, enabling QoS-aware adaptation under dynamic VANET conditions.

The step-by-step decision process of A-BOR is summarized in Figure 1, and the corresponding pseudocode is provided in Algorithm 1.

2.4 Feedback Mechanism

A lightweight feedback mechanism updates the QoS indicators used in the utility computation. Each node periodically exchanges a compact summary of its current forwarding condition (e.g., queue occupancy and recent delivery-timing indicators). These feedback updates refresh the delay/jitter-related estimates and the effective bandwidth indicator so that relay selection reflects current network conditions rather than static assumptions.

Algorithm 1: A-BOR Utility-Based Candidate Path Selection

Input: $P = \{p_1, p_2, \ldots, p_n\}$: set of candidate paths, $n \leq K$
Input: α, β, γ: utility weights for delay, jitter, and bandwidth, $\alpha + \beta + \gamma = 1$
Output: p^*: selected path with the highest utility score
$U_{\max} \leftarrow -\infty$
$p^* \leftarrow \emptyset$
foreach $p_i \in P$ **do**
  $T_{\text{total}}(p_i) \leftarrow$ total estimated end-to-end delay along p_i
  $J_{\text{total}}(p_i) \leftarrow$ total estimated jitter along p_i
  $B_{\text{available}}(p_i) \leftarrow$ minimum (bottleneck) available bandwidth along p_i
  $U_{\text{path}}(p_i) \leftarrow \alpha \cdot \frac{1}{T_{\text{total}}(p_i)} + \beta \cdot \frac{1}{J_{\text{total}}(p_i)} + \gamma \cdot B_{\text{available}}(p_i)$
  if $U_{path}(p_i) > U_{\max}$ **then**
    $U_{\max} \leftarrow U_{\text{path}}(p_i)$
    $p^* \leftarrow p_i$
Forward packet along the selected path p^*

Algorithm 1: A-BOR Utility-Based Candidate Selection

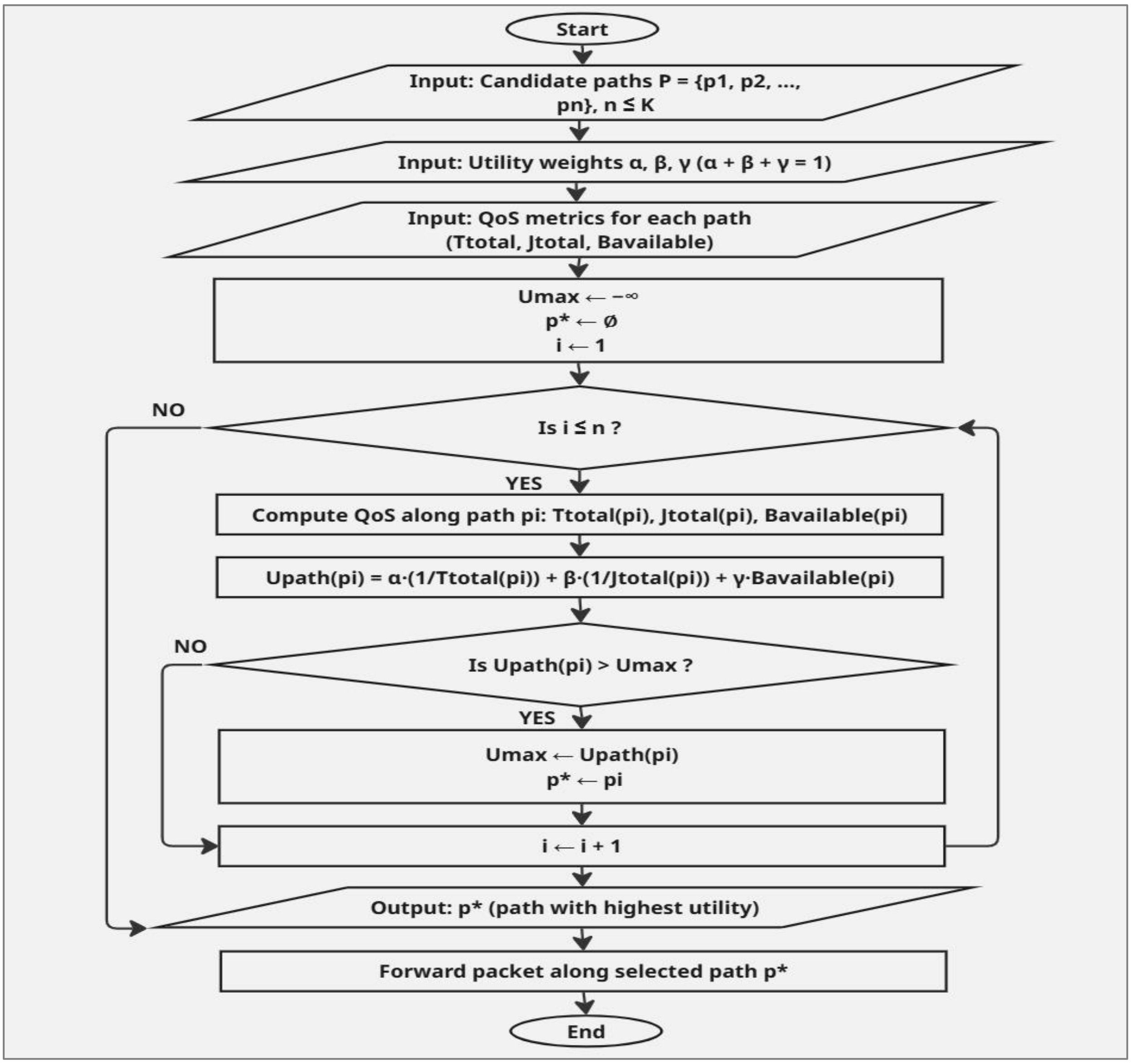

Figure 1: Flowchart of the A-BOR utility-based candidate path selection process

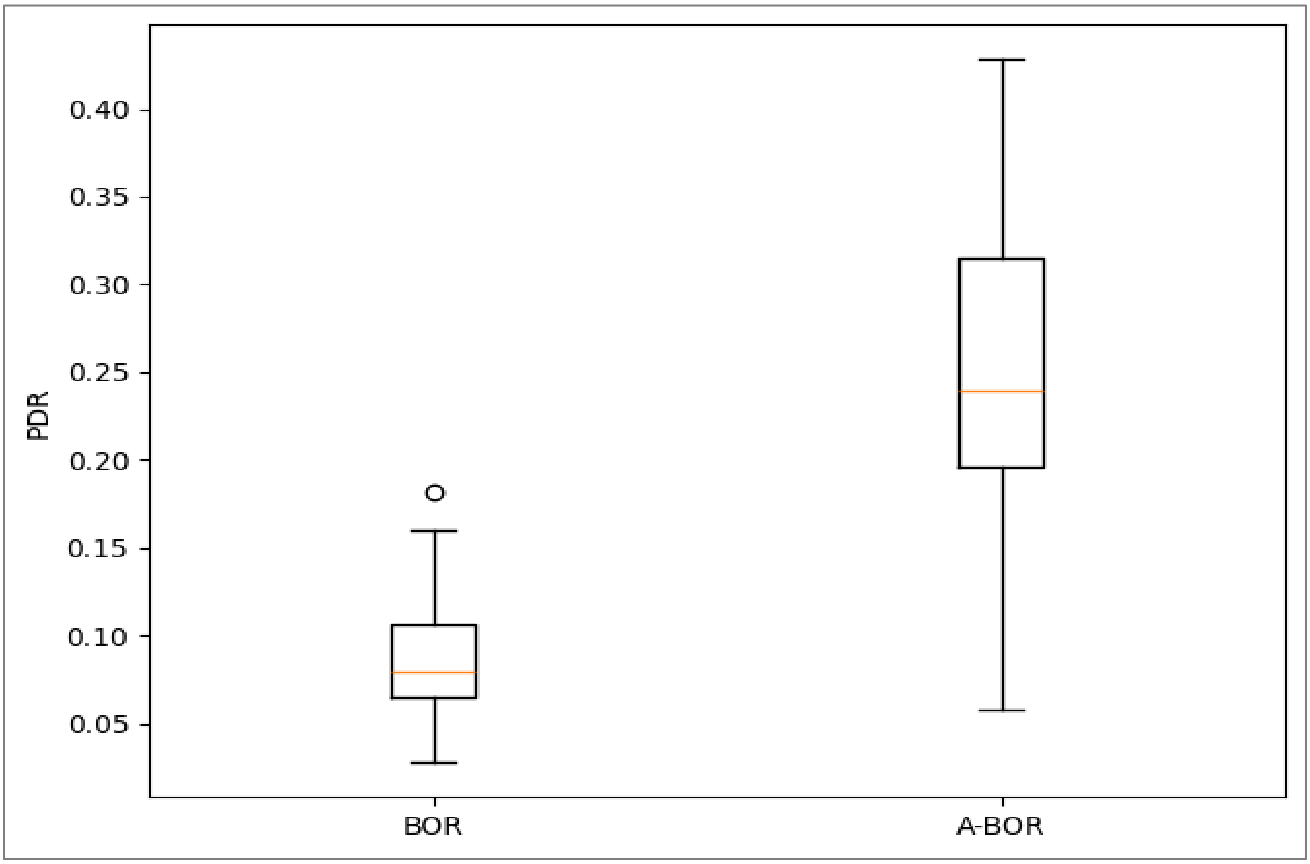

Figure 2a: Boxplot of packet delivery ratio (PDR) for BOR and A-BOR over 50 independent runs

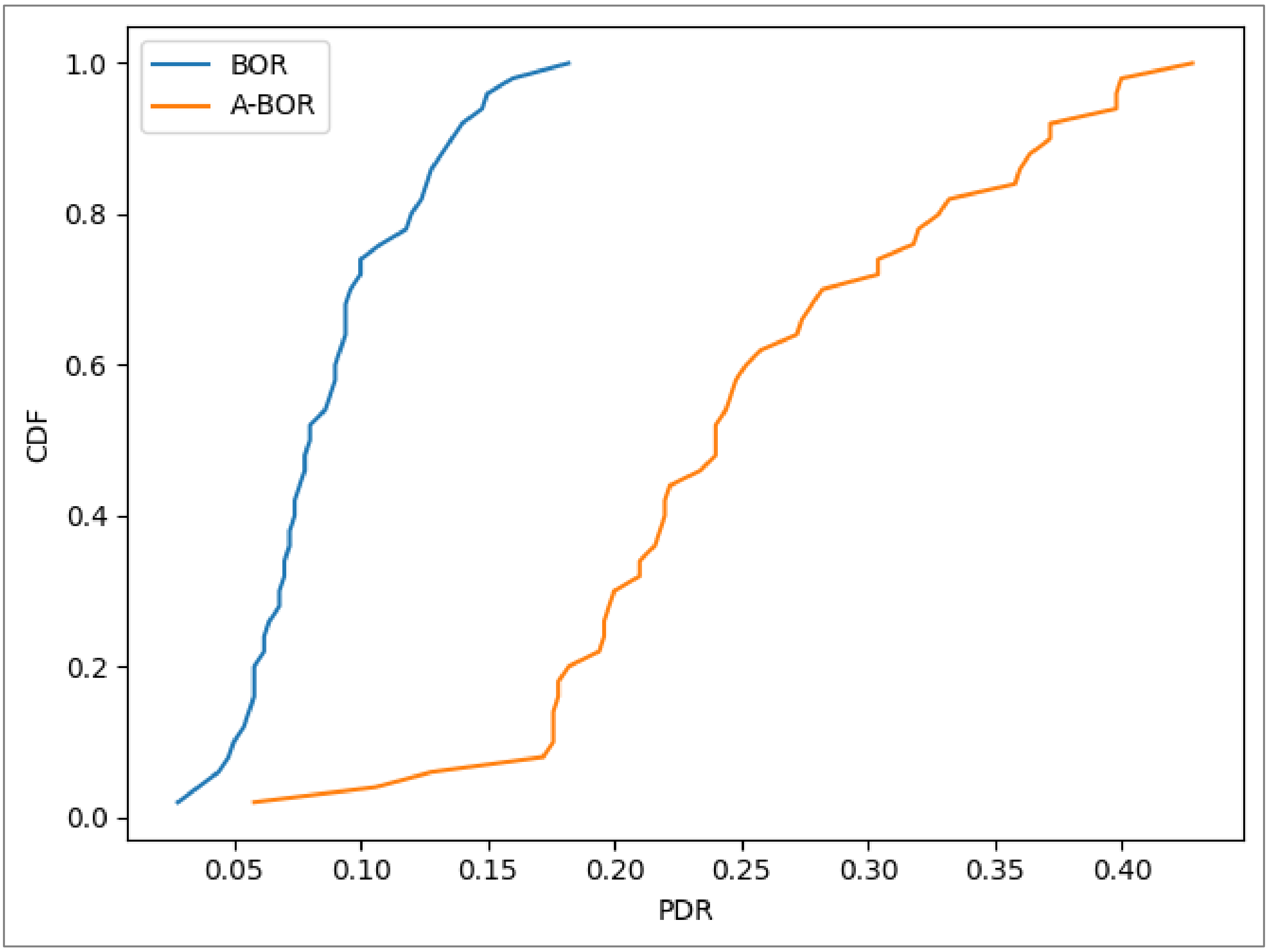

Figure 2b: Empirical CDF of packet delivery ratio (PDR) across 50 independent runs for BOR and A-BOR.

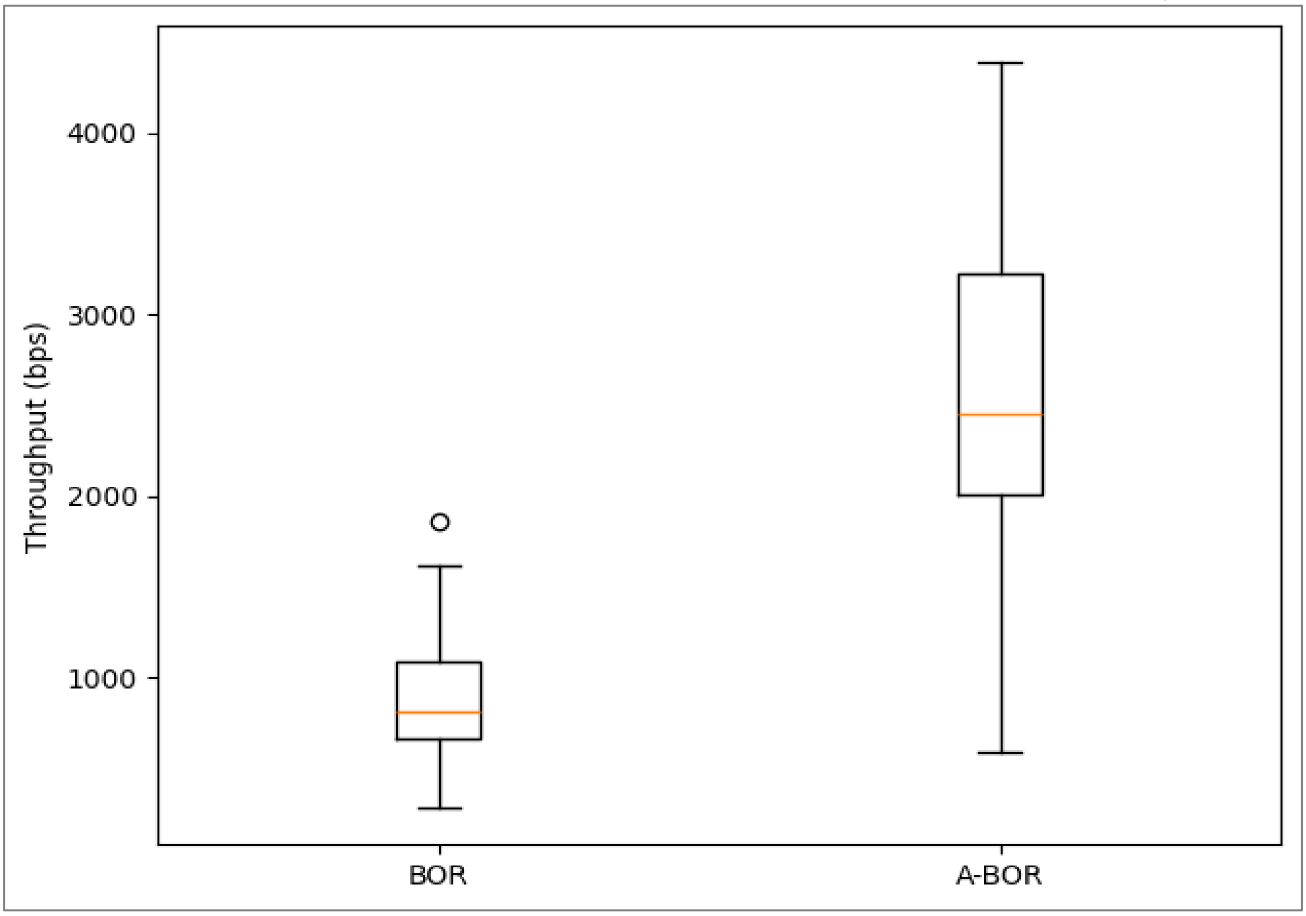

Figure 3: Boxplot of throughput (bps) for BOR and A-BOR over 50 independent runs; throughput is averaged over the 200 s injection window

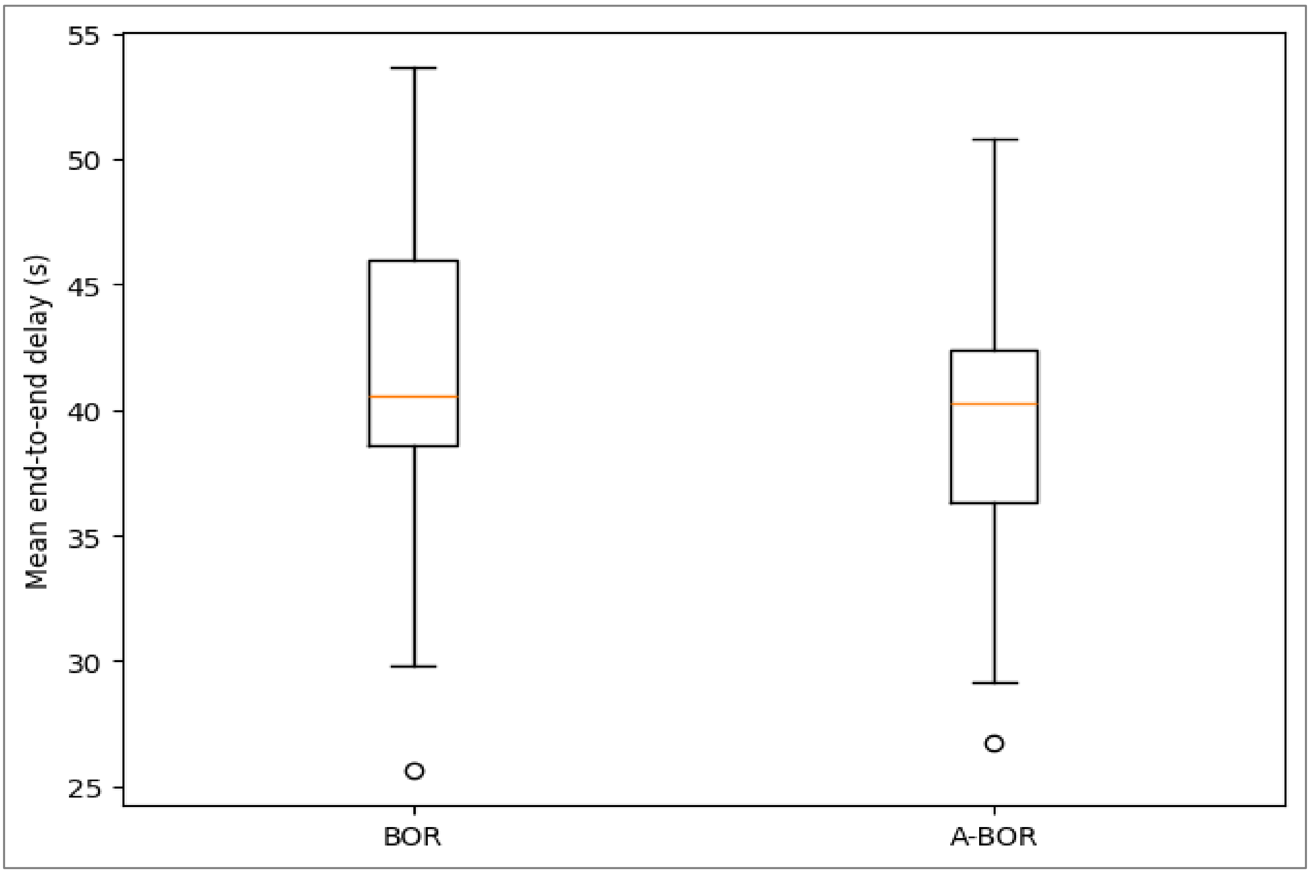

Figure 4a: Boxplot of mean end-to-end delay (s) for BOR and A-BOR over 50 independent runs

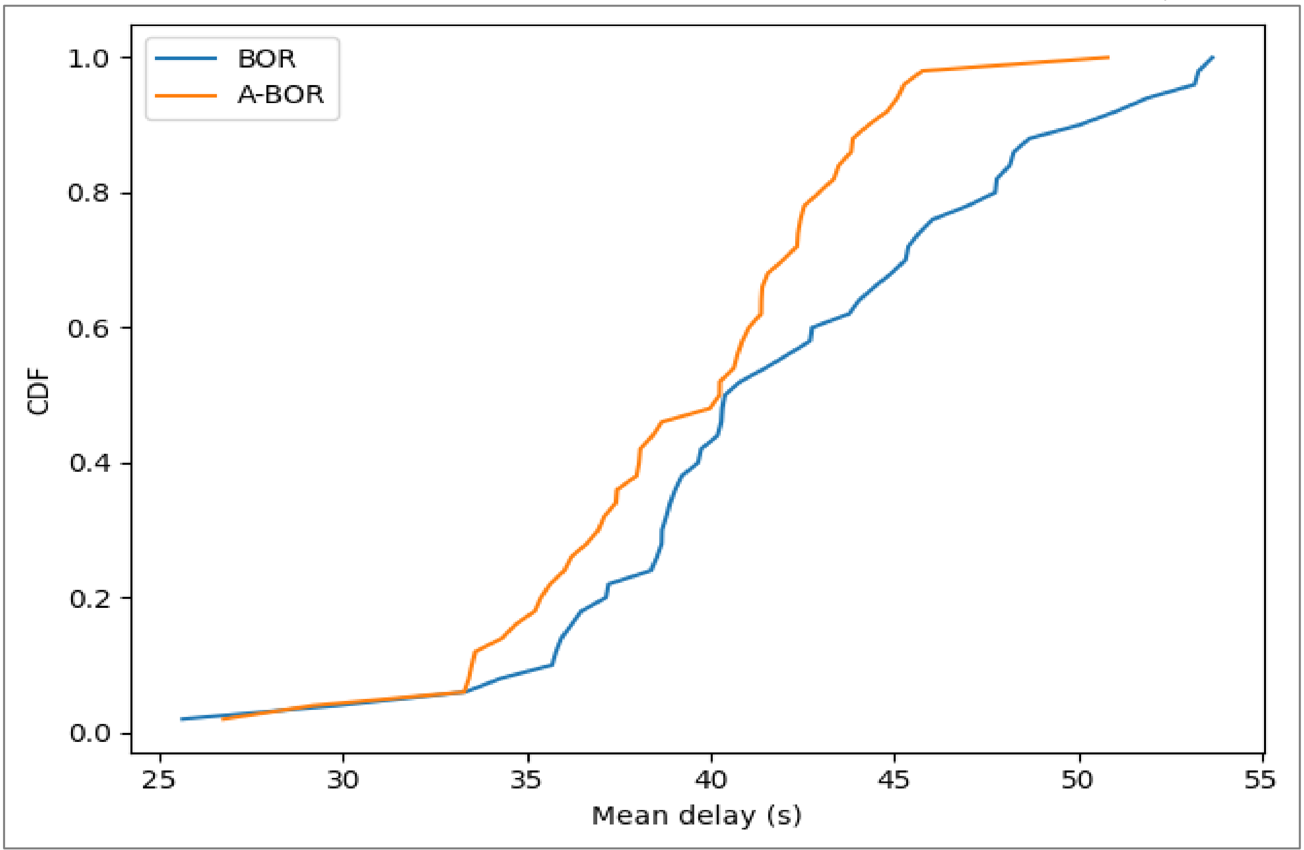

Figure 4b: Empirical CDF of mean end-to-end delay (s) across 50 independent runs for BOR and A-BOR

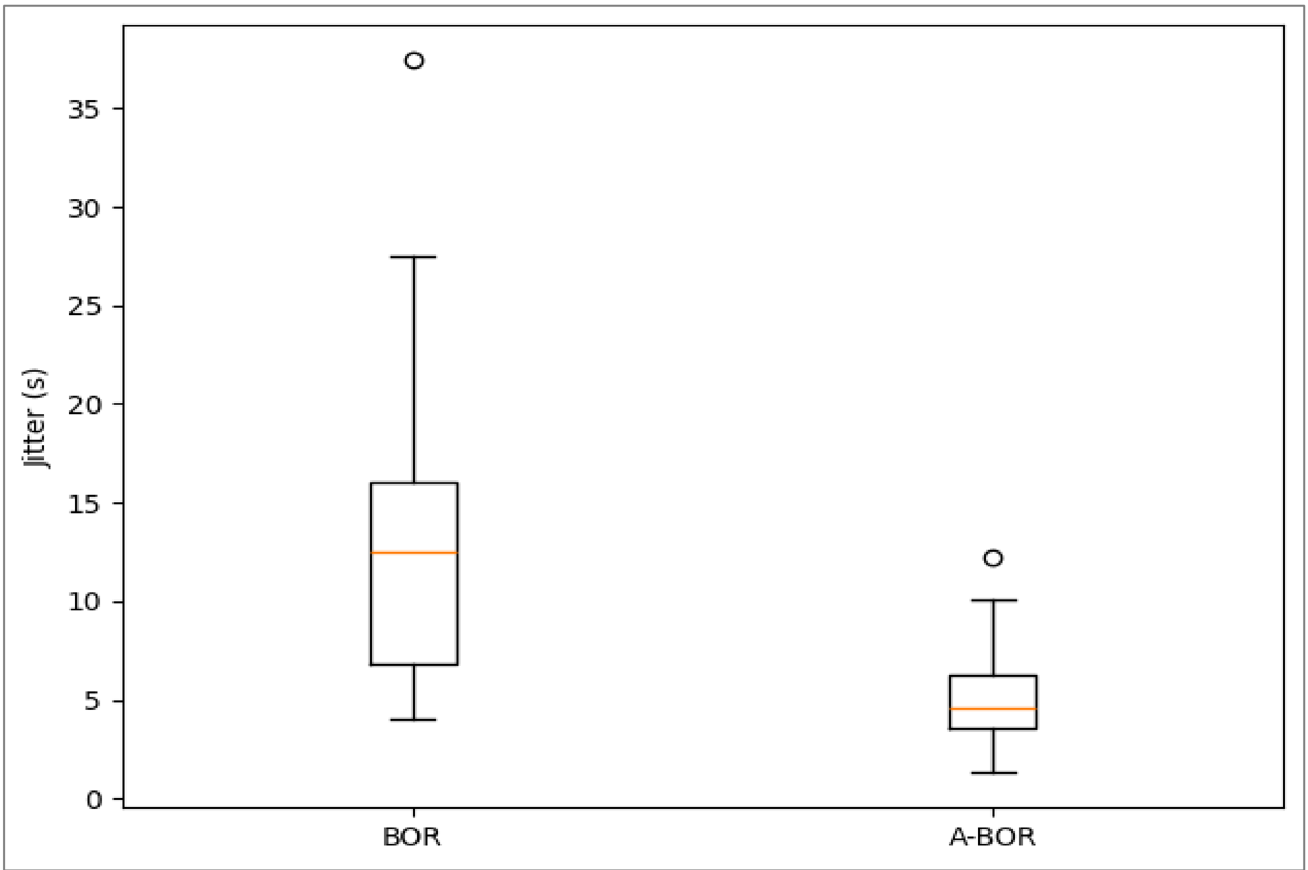

Figure 5: Boxplot of jitter (s) for BOR and A-BOR over 50 independent runs

This feedback implements a four-layer framework: the Input Layer gathers Quality-of-Service (QoS) measures (latency, jitter, and available bandwidth), the processing layer computes U_{path}, the decision layer selects the next hop (or forwarding alternative) with maximum utility, and the output layer evaluates performance and continuously informs subsequent decisions.

Table 2: Summary table (mean ± 95% CI) for PDR, throughput, mean delay, jitter

Protocol	PDR	Throughput (bps)	Mean delay (s)	Jitter (s)
A-BOR	0.254 ± 0.023	2598.5 ± 231.8	39.37 ± 1.25	5.04 ± 0.62
BOR	0.089 ± 0.009	906.4 ± 95.9	41.96 ± 1.68	12.81 ± 1.90

2.5 Protocols for Comparison

The proposed A-BOR is compared against the baseline Bitmap-Based Opportunistic Routing (BOR) under identical simulation conditions (mobility, communication range, traffic load, TTL, buffering, and run count). This direct comparison isolates the impact of the proposed utility-based forwarding and feedback adaptation.

2.6 Evaluation Metrics and Statistical Reporting

Four metrics are used to evaluate performance: Packet Delivery Ratio (PDR), mean end-to-end delay, jitter, and throughput. PDR measures delivery reliability as the fraction of generated packets successfully delivered. Mean end-to-end delay is the average delivery time from source to destination. Jitter quantifies variability in delivery timing based on inter-arrival variation at the destination. Throughput is computed as delivered payload bits per second, averaged over the 200 s injection window (goodput during active packet generation).

Each protocol is executed over 50 independent runs with different random seeds, and results are reported as mean ± 95% confidence interval to capture dispersion and ensure reproducibility.

RESULTS

This section reports the performance of the proposed A-BOR (Adaptive BOR) compared with the baseline Bitmap-Based Opportunistic Routing (BOR) under identical routing-layer VANET simulation conditions. Performance is evaluated using four QoS metrics: Packet Delivery Ratio (PDR), mean end-to-end delay, jitter, and throughput. All results are reported over 50 independent runs as mean ± 95% confidence interval (CI). Throughput is computed over the 200 s injection window (goodput during active packet generation). The confidence intervals show consistent separation between A-BOR and BOR across all four metrics, indicating robust performance differences across independent runs.

3.1 Packet Delivery Ratio (PDR)

A-BOR achieves a substantially higher packet delivery ratio than BOR under the same mobility, contact, buffering, and TTL constraints. As shown in Figure 2a, A-BOR attains PDR = 0.254 ± 0.023, while BOR achieves 0.089 ± 0.009 (mean ± 95% CI over 50 runs). This improvement indicates that the utility-based selection in A-BOR more effectively chooses forwarding opportunities that sustain delivery reliability in highly dynamic VANET conditions. The empirical distribution presented in Figure 2b further confirms that A-BOR consistently achieves higher PDR values than BOR across the independent simulation runs.

3.2 Throughput

Throughput is measured as the delivered payload rate averaged over the 200 s injection window. As presented in Figure 3, A-BOR achieves 2598.5 ± 231.8 bps, compared with 906.4 ± 95.9 bps for BOR. The throughput gain is consistent with the higher delivery ratio achieved by A-BOR and reflects improved efficiency in opportunistic forwarding decisions during active traffic generation.

3.3 Mean End-to-End Delay

A-BOR reduces mean end-to-end delay relative to BOR. As shown in Figure 4a, A-BOR yields 39.37 ± 1.25 s, while BOR yields 41.96 ± 1.68 s across the 50 independent runs. The lower delay suggests that A-BOR's QoS-aware forwarding tends to avoid slower or less favorable forwarding opportunities, improving responsiveness despite intermittent connectivity. The empirical CDF in Figure 4b further illustrates the delay distribution of both protocols and supports the observed reduction in mean delay for A-BOR.

3.4 Jitter

A-BOR significantly improves delivery stability by reducing jitter. As shown in Figure 5, the measured jitter is 5.04 ± 0.62 s for A-BOR compared with 12.81 ± 1.90 s for BOR. Lower jitter indicates more consistent packet delivery timing, which is important for time-sensitive vehicular applications.

3.5 Summary of Quantitative Results

Table 2 summarizes the four evaluated metrics using mean ± 95% CI over 50 runs. Overall, A-BOR improves reliability (higher PDR), efficiency (higher throughput), and stability (lower jitter), while also reducing mean delay relative to BOR.

DISCUSSION

A-BOR (Adaptive BOR) demonstrates that incorporating QoS-aware utility scoring and feedback into opportunistic routing can improve VANET operation under dynamic connectivity. Compared with BOR, which forwards opportunistically without explicit QoS optimization, A-BOR ranks candidate forwarding alternatives using delay, jitter, and available bandwidth indicators and refreshes these indicators through lightweight feedback, enabling more informed relay selection under rapidly changing congestion and contact opportunities. The observed performance improvements are consistent with this design: utility-based ranking discourages QoS-unfavorable relays, and feedback reduces the impact of stale network-condition estimates between forwarding opportunities.

This study provides routing-layer, algorithmic evidence under a defined mobility and contact model. In addition, performance depends on the selected utility weights and feedback frequency; ablation and sensitivity studies are therefore important next steps to quantify component contributions and to tune trade-offs among throughput, delay, and jitter.

CONCLUSION AND FUTURE WORK

This paper proposed A-BOR, a QoS-aware enhancement of Bitmap-Based Opportunistic Routing (BOR) for VANETs. A-BOR combines a weighted utility function (delay, jitter, and available bandwidth) with lightweight feedback to adapt forwarding decisions to changing network conditions. In a routing-layer VANET simulation with 100 nodes, TTL = 60 s, and 500 packets injected over 200 s, evaluated across 50 independent runs (mean ± 95% CI), A-BOR outperformed BOR in PDR, throughput, mean delay, and jitter, indicating improved reliability, efficiency, and timing stability.

Future work will quantify component contributions through ablation and sensitivity studies (utility-only vs utility plus feedback, and variation of α, β and γ), evaluate additional operating regimes (node density, range, speed, and traffic load), and validate the protocol in packet-level simulators (NS-3 or OMNeT++/Veins) and/or real mobility traces to assess MAC/PHY effects and channel contention.

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REFERENCES

Ali, M., et al. (2022). Predictive hybrid routing with multi objective optimization model for opportunistic routing for VANET. In *2022 5th International Conference on Engineering Technology and its Applications (IICETA)*. IEEE. [Crossref]

Aljabry, I. A., & Al-Suhail, G. A. (2021). A survey on network simulators for vehicular ad-hoc networks (VANETS). *International Journal of Computer Applications*. [Crossref]

Altmemi, S. A., et al. (2025). A software-centric evaluation of the VEINS framework in vehicular ad-hoc networks. *Journal of Robotics and Control (JRC)*. [Crossref]

Aminu, A. A., & Nura, A. (2025). Improved Fast Mobile IPv6 Scheme with Optimized Distributed Signaling Utilizing Media Independent Handover and Efficient Link Layer Triggers. *UMYU Scientifica*, *4*(2), 396–404. [Crossref]

Benzerogue, A., et al. (2025). Comparative evaluation of swarm intelligence-based multipath routing protocols for video streaming in vehicular ad-hoc networks. *Algerian Journal of Signals and Systems*. [Crossref]

Bhorkar, A. A., et al. (2012). Opportunistic routing with congestion diversity in wireless ad hoc networks. *IEEE/ACM Transactions on Networking*. [Crossref]

Bintoro, K. B., et al. (2024). Performance analysis of AODV and DSDV routing protocols for UDP communication in VANET. *SinkrOn*. [Crossref]

Dulange, P. S., & Info, P. S. (2025). A novel technique of Odịgbo metaheuristic algorithm based optimized energy efficient and reliable routing protocol for VANETs to augment QoS conditions. *Journal of Machine and Computing*. [Crossref]

Isiyaku, H., Aliyu, M. S., & Muaazu, A. A. (2024). Early Address Detection: A Soft Vertical Handover Approach in Proxy Mobile IPv6. *UMYU Scientifica*, *3*(4), 36–45. [Crossref]

Jain, P. (2024). Innovative fuzzy logic methods for congestion control in vehicular ad-hoc networks. *Advances in Nonlinear Variational Inequalities*. [Crossref]

Khawatreh, S. A., et al. (2019). A survey on opportunistic routing. *International Journal of Advanced Computer Science and Applications*. [Crossref]

Khoza, T. P., et al. (2018). Comparative study on routing protocols for vehicular ad-hoc networks (VANETs). In *2018 International Conference on Advances in Big Data, Computing and Data Communication Systems (icABCD)*. IEEE. [Crossref]

Muhammad, M. Y., & Umar, D. M. (2023). Resource Limitations for Wireless Sensor Networks to Establish a Comprehensive Security System in the 5G Network. *UMYU Scientifica*, *2*(2), 44–52. [Crossref]

Nahideh, D., & Reza, S. (2021). Opportunistic routing in wireless networks using bitmap-based weighted tree. *Computer Networks*. [Crossref]

Ogbe, S. M., & Abubakar, A. A. (2025). An Efficient Neural Architecture Search Algorithm for AutoEncoder Optimization - A Systematic Literature Review. *UMYU Scientifica*, *4*(3), 9–18. [Crossref]

Olugbenga, O. E. M., Kolajo, T., & Babatunde, J. A. (2024). Development and Evaluation of a Hybrid Machine Learning-Based Intrusion Detection System Using NSL-KDD Dataset. *UMYU Scientifica*, *3*(3), 277–283. [Crossref]

Rashid, S. A., et al. (2024). Link stability based multipath routing and effective mobility prediction in cognitive radio enabled vehicular ad hoc network. *Bulletin of Electrical Engineering and Informatics*. [Crossref]

Rui, S., et al. (2023). An intersection-based QoS routing for vehicular ad hoc networks with reinforcement learning. *IEEE Transactions on Intelligent Transportation Systems*. [Crossref]

Shreya, V. K., et al. (2025). Utility-based opportunistic routing for wireless ad hoc networks: Performance evaluation in Ns-3. In *2025 6th International Conference on Data Intelligence and Cognitive Informatics (ICDICI)*. IEEE. [Crossref]

Umar, A., Umar, A. Z., Ibrahim, Y. G., & Lawal, M. B.

(2025). Ensemble of Synthetic and Balancing Techniques for Credit Card Fraud Detection. *UMYU Scientifica*, *4*(4), 137–153. [Crossref]

Waqar, M., et al. (2023). Content-aware network traffic prediction framework for quality of service-aware dynamic network resource management. *IEEE Access*. [Crossref]

Yahuza, K., Aliyu, U. M., Salisu, B. D., Atalabi, E. T., Mukhtar, G. L., & Bashir, A. (2024). Recent Advancements in Detection and Quantification of Malaria Using Artificial Intelligence. *UMYU Journal of Microbiology Research*, *9*(2), 1–21. [Crossref]