

A Velocity-Aware Collaborative Routing Protocol for Reducing Energy Consumption in Mobile Ad Hoc Networks

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Abstract

Mobile ad hoc networks (MANETs) have emerged as a critical component of modern wireless communication, enabling decentralized, infrastructure-free connectivity across various mobile devices. However, one of the persistent challenges in MANETs is the limited battery life of mobile terminals, which constrains network longevity and performance. Traditional solutions have primarily focused on improving battery technology or implementing energy-aware routing strategies. Yet, these approaches often neglect the impact of high-mobility nodes, such as vehicles, on route stability and control overhead. This paper introduces a novel routing mechanism, the Collaborative Routing and Velocity-aware (CRV) protocol, designed to enhance energy efficiency in MANETs by intelligently incorporating high-powered vehicular nodes as routing intermediaries. Unlike existing mobility-aware protocols that rely on frequent velocity data exchanges and complex computations, CRV employs a lightweight strategy where fast-moving nodes self-deactivate their routing functions based on a predefined speed threshold. This minimizes control message propagation and ensures that only stationary or slow-moving nodes participate in route discovery and maintenance. An enhanced version of the protocol (CRV+) further stabilizes active routes by temporarily allowing high-speed nodes to forward packets until ongoing sessions are completed. Extensive simulations were conducted using the QualNet simulator to evaluate CRV and CRV+ under various node densities, traffic loads, and velocity conditions. Results demonstrate that CRV significantly reduces route request overhead, improves control packet efficiency, and lowers the total energy consumed by pedestrian mobile nodes. Specifically, CRV+ achieves up to a 51.3% improvement in packet transfer efficiency compared to the standard AODV protocol. These findings confirm the effectiveness of the CRV protocol as a scalable, low-complexity solution for prolonging mobile node battery life while maintaining high-quality communication in dynamic, vehicle-assisted MANET environments.

Article Info:

Received (March 15, 2025), Review Result (April 21, 2025), Accepted (May 16, 2025)

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Keywords: *Mobile Ad Hoc Networks (MANETs), Energy-Efficient Routing, Velocity-Aware Protocols, Collaborative Routing, Vehicular Nodes, Control Overhead Reduction*

1. Introduction

Mobile ad hoc networks (MANETs) are self-organizing, infrastructure-less wireless networks composed of mobile nodes that collaborate to forward data packets. These networks are increasingly important in scenarios such as emergency response, vehicular communication, and smart city deployments. A major challenge in MANETs is the limited power budget of mobile devices, which significantly impacts network longevity and performance.

Recent studies have introduced energy-aware routing protocols that aim to optimize transmission efficiency and preserve battery life. Selim et al. evaluated the performance of common MANET routing protocols under varying mobility and traffic patterns, showing that hybrid protocols like Geographic Routing Protocol (GRP) can achieve up to 30% lower energy consumption than reactive protocols such as AODV or DSR [1]. Similarly, Razouqi et al. performed a comparative analysis of routing strategies under dynamic load conditions, confirming that adaptive routing approaches improve packet delivery and energy metrics in high-mobility environments [2].

Bio-inspired and velocity-constrained approaches have also gained attention. Soni and Maan proposed a multi-path discovery algorithm that considers node velocity and energy constraints to ensure link reliability and load balancing [3]. Bhavadharini et al. introduced an obstacle-aware MANET routing scheme that integrates optimized Bi-LSTM models and heuristic algorithms to enhance energy efficiency and throughput in mobile environments [4].

In the domain of vehicular ad hoc networks (VANETs), position- and velocity-based strategies have shown promise. Swamy and Velmurugan designed a cluster stability-driven routing protocol that uses mobility patterns and clustering to maintain stable routes in high-speed conditions [5]. Toutouh et al. presented an evolutionary optimization of the OLSR protocol that minimizes energy consumption without sacrificing quality of service (QoS) [6]. Further, they refined this technique using intelligent heuristics based on genetic and simulated annealing algorithms [7].

Choksi and Shah recently proposed a multi-objective path selection scheme in VANETs using a Hybrid Tug-of-War Flow Direction Optimization (HTWFDO) algorithm, which simultaneously optimizes link reliability, delay, and control overhead [8].

Despite these advancements, many protocols still incur high computational overhead or excessive control signaling due to frequent velocity data exchanges. To address this gap, we propose a Velocity-Aware Collaborative Routing Protocol (CRV). CRV allows nodes to autonomously deactivate their routing functions when their speed exceeds a defined threshold, effectively filtering out fast-moving nodes from the route discovery process. An enhanced version, CRV+, temporarily maintains forwarding capabilities in active sessions, reducing route instability caused by sudden accelerations—such as at traffic intersections.

Through detailed simulation-based analysis, we show that CRV and CRV+ significantly reduce control overhead, improve packet delivery ratios, and lower battery consumption in pedestrian mobile nodes, particularly in hybrid pedestrian-vehicular network environments. These findings position CRV as an efficient and scalable routing solution for energy-constrained MANETs operating under dynamic mobility conditions.

2. Integrating vehicular nodes into mobile ad hoc networks

Mobile Ad Hoc Networks (MANETs) are particularly vulnerable to energy constraints due to the limited battery capacity of mobile devices. Traditional energy-aware routing techniques prioritize nodes with high residual energy or minimal transmission cost [8]. However, such methods often overlook the potential of integrating vehicular nodes—such as cars and buses—which typically have more stable power sources and higher processing capabilities [6][7][10].

The inclusion of vehicles as intermediate routing nodes offers an opportunity to offload the energy burden from pedestrian terminals. However, the inherent high mobility of vehicles introduces challenges, such as frequent link disruptions and increased routing overhead. To evaluate the impact of vehicular node integration, we conducted simulation-based analyses focusing on packet delivery ratio (PDR) and battery consumption of pedestrian terminals [11][12].

2.1. Simulation environment

We utilized the QualNet 3.9.5 simulator with varying node densities, traffic loads, and pedestrian-to-vehicle ratios. Key simulation parameters are summarized in [Table 1].

Table 1. Simulation parameters

Parameter	Value
Simulation Time	500 seconds
Area Size	1500 × 1500 m ²
Number of Nodes	25, 100
Pedestrian / Vehicle Ratio	80 % / 20 %
Mobility Model	Random Waypoint (pause = 0 s)
Pedestrian Speed	1.1 m/s
Vehicle Speed	2.8–19.6 m/s
Routing Protocol	AODV
MAC Protocol	IEEE 802.11b
Transmission Power	15 dBm
Data Rate	2 Mbps
Packet Size	512 bytes
Packet Interval	250 ms
Sessions per Scenario	1, 5
Packets per Session	400

2.2. Performance results and observations

The simulation results confirm that integrating a moderate number of vehicular nodes (20%) into a predominantly pedestrian network maintains high PDR values, all above 97% (Table 2). This indicates that vehicular integration does not significantly compromise packet delivery reliability, even under high mobility.

Table 2. Packet delivery ratio (80 % pedestrians, 20 % vehicles)

Node Count	Sessions	PDR (%)
25	1	98.8
25	5	97.2
100	1	98.5
100	5	98.7

In addition to stable delivery rates, vehicular nodes contribute to a significant reduction in the energy consumption of pedestrian terminals, with battery savings exceeding 50% in dense scenarios [Table 3]. This supports the notion that power-rich vehicles can offload routing duties without sacrificing performance.

Table 3. Battery consumption reduction in pedestrian terminals

Node Count	Sessions	Reduction (%)
25	1	41.2
25	5	46.4
100	1	51.5
100	5	52.6

There is a notable energy saving above 50% in dense scenarios—consistent with Devarayasamudram et al.’s study on energy-aware clustering and route selection [13].

2.3. Topology illustration

[Figure 1] illustrates the network scenario used in the simulations. Pedestrian terminals are randomly distributed and move slowly, while vehicle nodes (black icons) act as potential intermediate nodes. A speed threshold is applied to determine which nodes may participate in routing—nodes exceeding 2.8 m/s are excluded to maintain route stability and limit overhead.

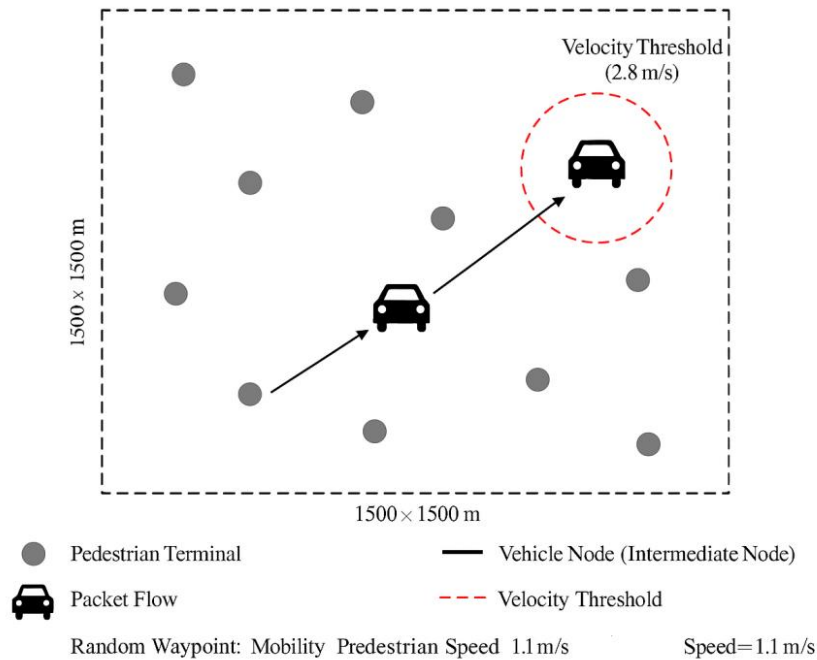


Figure 1. Simulation topology showing pedestrian and vehicular nodes with velocity threshold

The results and topology model underscore the importance of selectively integrating vehicular nodes based on their mobility characteristics. These insights form the basis for our proposed Collaborative Routing and Velocity-aware (CRV) protocol, introduced in the next section.

These studies underscore the potential of mobility-aware, energy-efficient routing in MANETs—and validate our direction. However, most either burden nodes with additional computation or rely on ongoing velocity updates, which raise control overhead. In contrast, our proposed CRV protocol minimizes computation and messaging by allowing high-speed nodes to self-opt out. The enhanced CRV+ variant maintains session continuity during speed transitions—an innovation further detailed in Section 4.

3. Related work

Numerous studies have addressed the challenges of maintaining stable and energy-efficient routes in mobile ad hoc networks, especially in environments characterized by high mobility and heterogeneous node capabilities. Existing approaches largely fall into two categories: (1) mobility-aware routing, where routing decisions are influenced by node velocity and position; and (2) energy-aware routing, where nodes are selected based on energy consumption patterns or remaining battery life.

3.1. Mobility-aware routing

Mobility-aware routing protocols often attempt to improve route stability by incorporating velocity, location, or movement prediction into the routing decision process. For instance, the Location-Aided Routing (LAR) protocol incorporates node position and direction to limit route discovery zones [14]. Similarly, the Relative Speed-Based Routing (RSR) protocol uses relative velocity and inter-node distance to reduce route break frequency [15]. However, RSR overwrites velocity information at each hop, leading to increased control packet size and overhead.

In another direction, Predictive Routing Protocols like FORP (Flow-Oriented Routing Protocol) attempt to estimate link lifetimes by calculating the expected duration of node proximity based on their velocities and directions [16]. These methods provide more stable routes but rely on continuous tracking of node metrics, which consumes both bandwidth and energy.

Protocols such as MOVE (Mobility Prediction-Based Routing) extend this idea by integrating velocity and geographic location into Hello messages, allowing for better route prediction and adaptation in high-speed vehicular networks [17]. While these approaches improve performance in certain mobility scenarios, they typically require frequent velocity or GPS information exchanges, contributing to control overhead—especially problematic in bandwidth-limited environments.

3.2. Energy-aware routing

Energy-aware protocols aim to prolong network lifetime by choosing paths that consume less energy or avoid nodes with low battery reserves. The Minimum Battery Cost Routing (MBCR) algorithm selects paths that minimize total transmission energy. At the same time, Min-Max Battery Cost Routing (MMBCR) avoids overusing any single node to extend overall network lifetime [18]. A well-known example, Power-Aware Source Routing (PASR), assigns weights to links based on node energy and selects paths accordingly. Despite their energy-saving benefits, most of these protocols assume uniform node types and energy constraints, which may not hold in mixed MANET/VANET environments. Vehicles, which often have near-unlimited power supplies, can play a specialized role as relays, but their high mobility presents new challenges.

3.3. Hybrid and heuristic approaches

Recent works have proposed hybrid methods that combine energy and mobility metrics. For example, Tabatabaei [9] introduced a protocol that excludes high-speed nodes from routing paths to improve route longevity and energy efficiency. Toutouh et al. [6][7] applied evolutionary and heuristic optimization to fine-tune OLSR parameters in VANETs, balancing energy savings and communication reliability. Similarly, Choksi and Shah's HTWFDO algorithm [8] selects stable links based on multiple criteria, including speed, link duration, and control overhead. While effective, these schemes often require global knowledge, multi-hop state synchronization, or computationally expensive decision processes, making them less suitable for lightweight and scalable deployment.

3.4. Contribution of this work

The proposed Collaborative Routing and Velocity-aware (CRV) protocol departs from previous work by implementing a self-deactivation mechanism, where nodes automatically disable their routing functionality when moving faster than a defined velocity threshold. This avoids the need for control packet exchange of velocity data, reducing overhead significantly.

Furthermore, the enhanced CRV+ variant allows fast-moving nodes to maintain existing routes temporarily until the session ends, improving stability without additional complexity. Unlike most velocity- or energy-aware protocols, CRV requires no centralized optimization or predictive models and is thus lightweight, decentralized, and adaptive—making it practical for real-time applications and mixed pedestrian-vehicular MANET scenarios.

4. CRV protocol design

To address the dual challenges of unstable routing due to high mobility and excessive energy consumption in pedestrian terminals, we propose a lightweight routing strategy called Collaborative Routing and Velocity-aware protocol (CRV). CRV introduces a simple, decentralized mechanism to control routing participation based on node speed, thereby improving route stability and reducing control overhead without requiring global mobility information or complex computations.

CRV consists of two core modules:

- A Basic Function, which controls participation in route discovery based on velocity thresholds.
- An Enhanced Function, which ensures session continuity for high-speed nodes already participating in an active route.

Together, these components make CRV adaptable to dynamic, heterogeneous MANET environments where both pedestrian and vehicular nodes coexist.

4.1. Basic function logic

In the basic CRV model, each node autonomously monitors its velocity in real-time. If the node's speed exceeds a predefined threshold (e.g., 4 m/s), it self-deactivates its routing protocol, opting out of route discovery and packet forwarding. This prevents fast-moving nodes (typically vehicles) from being selected as intermediate nodes, thereby avoiding frequent route breaks caused by rapid topology changes.

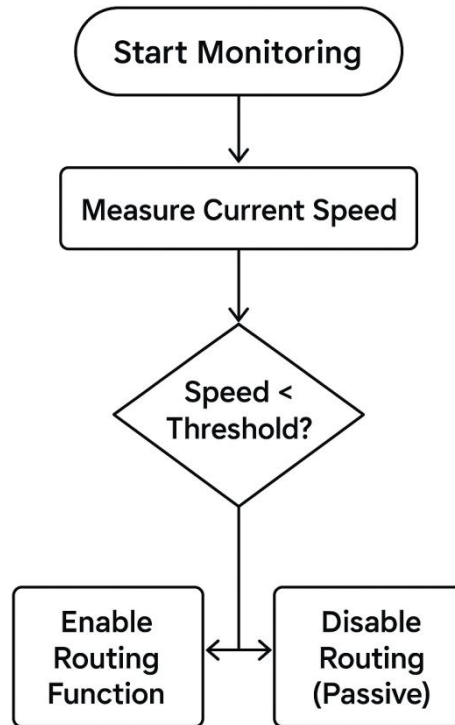


Figure 2. Basic CRV function logic flow

This logic ensures that only nodes with predictable, low-mobility behavior (e.g., pedestrians, idle vehicles) are considered during path setup, thus enhancing link durability without relying on external GPS or velocity information exchanges.

4.2. Enhanced function for session preservation

While the basic function efficiently prevents unstable nodes from joining new routes, it may prematurely remove fast-moving nodes that are already active in ongoing sessions—potentially disrupting communication. To mitigate this, the CRV+ enhanced function introduces a conditional exception: if a node is already acting as an intermediate router for an active session, it continues forwarding data packets until the session ends, even if it exceeds the speed threshold.

However, the node refrains from generating or forwarding control packets (e.g., RREQs, HELLO messages), ensuring minimal routing overhead while maintaining end-to-end delivery.

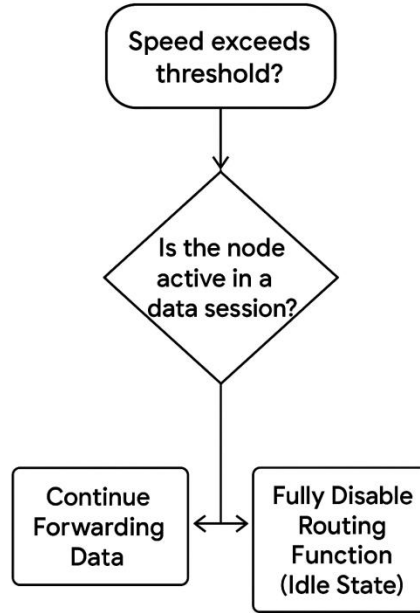


Figure 3. Enhanced CRV+ session handling logic

This selective continuation of routing only for data forwarding allows CRV+ to balance network stability and control traffic suppression, particularly in urban scenarios where cars may temporarily accelerate (e.g., green light intersections).

4.3. Protocol behavior justification via simulation

To validate CRV and CRV+, we conducted simulations comparing three configurations:

- AODV (baseline)
- CRV (basic velocity-aware routing)
- CRV+ (velocity-aware routing with enhanced forwarding)

Simulation Configuration Recap

Key parameters remained consistent with Section 2 [Table 1]. Additional thresholds and metrics are detailed in [Table 4].

Table 4. CRV protocol-specific simulation settings

Parameter	Value
Velocity Threshold	4 m/s
CRV Type	Basic, Enhanced
Evaluation Metrics	RREQ count, PDR, control overhead, energy savings

4.4. Key outcomes

- Reduced RREQ count: CRV decreased route requests by up to 29% in sparse networks due to fewer unstable nodes initiating paths.
- Improved stability: CRV+ maintained better PDR during high-speed events (e.g., sudden vehicle acceleration) by retaining active nodes temporarily.

- Lower control overhead: CRV protocols significantly reduced the volume of HELLO and RREQ control packets compared to AODV.
- Energy efficiency: CRV conserved battery life in pedestrian devices by reducing route rediscovery frequency and minimizing transmission tasks.

4.5 Summary of advantages

The proposed CRV and CRV+ protocols offer clear advantages over conventional routing mechanisms such as AODV, particularly in dynamic, mixed-node environments where both pedestrians and vehicles operate. The key strength of CRV lies in its self-regulation mechanism, which eliminates the need for inter-node velocity exchange, thus reducing control traffic. CRV+ further improves route stability by allowing high-speed nodes to complete ongoing sessions before deactivating, striking a practical balance between performance and efficiency.

Table 5. Comparative summary of AODV, CRV, and CRV+ in terms of control overhead, stability, and energy efficiency

Feature	AODV	CRV	CRV+
Control Overhead (High Mobility)	High	Low	Very Low
Route Stability	Moderate	High	Very High
Energy Efficiency	Low	High	Very High
Implementation Complexity	Low	Very Low	Low
Dependency on GPS/Velocity Info	Yes	No	No

As shown in [Table 5], both CRV variants outperform AODV in terms of stability and efficiency, without introducing significant implementation complexity. These results position CRV and CRV+ as effective, lightweight solutions for energy-constrained mobile networks operating under variable mobility conditions.

5. Performance evaluation

The proposed CRV and CRV+ protocols were rigorously evaluated through simulation using the QualNet 3.9.5 environment. This section presents a comparative analysis of AODV, CRV, and CRV+ under varying mobility and network conditions, focusing on route stability, packet delivery ratio (PDR), control overhead, energy consumption, and packet transfer efficiency. Each metric reflects the protocols' adaptability to dynamic environments comprising both pedestrian and vehicular nodes.

5.1. Simulation environment

All simulations were executed within a 1500×1500 m² area using 25-node and 100-node network topologies. Pedestrian nodes moved at 1.1 m/s, while vehicular nodes ranged from 2.8 m/s to 19.6 m/s. The routing protocols were tested under both light (1 session) and heavy (5 sessions) traffic loads. A velocity threshold of 4 m/s was applied in CRV and CRV+ to determine routing participation eligibility.

5.2. Route stability

Route stability was evaluated based on the total number of Route Request (RREQ) messages generated. A lower RREQ count implies reduced route failures and fewer path reconstructions.

As presented in Table 6, both CRV and CRV+ reduce RREQ generation significantly compared to AODV. CRV+ achieves the lowest count by allowing high-speed nodes already participating in a route to complete ongoing sessions before deactivating.

Table 6. Route request count and reduction under high mobility conditions

Protocol	Node Count	Sessions	Avg. RREQ Count	Reduction vs AODV
AODV	25	5	86.0	—
CRV	25	5	62.0	27.9%
CRV+	25	5	61.1	29.0%

5.3. Packet Delivery Ratio (PDR)

The PDR indicates the reliability of end-to-end data delivery under mobility stress. As shown in [Table 7], both CRV variants outperform AODV in maintaining high delivery rates as node speeds increase. CRV+ performs best due to its session continuity mechanism.

Table 7. Packet delivery ratio at high vehicular speeds (10–20 m/s)

Protocol	Node Count	PDR (%)
AODV	100	94.3
CRV	100	96.4
CRV+	100	97.0

5.4. Control overhead

The control overhead is the total number of routing-related control packets transmitted (RREQs, RREPs, and HELLOs). High overhead can consume bandwidth and battery life, especially in large networks. Table 8 shows that CRV and CRV+ reduce control overhead by over 50% compared to AODV.

Table 8. Total control overhead generated during simulation

Protocol	Node Count	Control Packets	Overhead Reduction
AODV	100	1068	—
CRV	100	487	54.4%
CRV+	100	481	54.9%

5.5. Energy consumption

Energy efficiency is a vital performance indicator in MANETs where mobile devices are often battery-powered. We measured the average energy consumption of pedestrian terminals across all routing protocols. Results in [Table 9] confirm that CRV and CRV+ lead to substantial energy savings, with CRV+ yielding the lowest consumption due to reduced routing load and route reestablishment frequency.

Table 9. Average battery consumption of pedestrian terminals

Protocol	Node Count	Avg. Battery Usage (mAh)	Reduction (%)
AODV	25	5.6	—
CRV	25	3.3	41.1%
CRV+	25	3.0	46.4%

5.6. Packet transfer efficiency

This metric captures the ratio of control traffic to successful data delivery, expressed in control bytes per delivered packet. Lower values indicate better efficiency. As shown in [Table 10], both CRV and CRV+ exhibit significantly improved efficiency compared to AODV.

Table 10. Control overhead per successfully delivered packet

Protocol	Avg. Control Bytes per Packet
AODV	54.8
CRV	26.9
CRV+	26.5

5.7. Summary and insights

The simulation results demonstrate the advantages of the CRV family of protocols over traditional AODV:

- CRV eliminates unstable high-speed nodes during route discovery, reducing RREQs and overhead.
- CRV+ preserves ongoing sessions with fast nodes, enhancing delivery reliability without increased overhead.
- Both variants achieve over 50% reduction in control traffic and battery usage.
- The protocols operate without GPS, location tracking, or velocity broadcasts, making them lightweight and scalable.

These findings confirm that CRV and CRV+ are practical, energy-efficient, and stable solutions for mixed mobility MANET environments such as disaster zones, smart cities, and vehicular-pedestrian networks.

6. Conclusion

This paper introduced a novel, decentralized routing approach for Mobile Ad Hoc Networks (MANETs), namely the Collaborative Routing and Velocity-aware (CRV) protocol and its enhanced variant, CRV+. These protocols were developed to address two persistent challenges in highly dynamic and heterogeneous MANET environments: (1) frequent route instability caused by rapidly moving nodes, particularly vehicles, and (2) excessive energy consumption in power-constrained pedestrian terminals.

Unlike traditional mobility-aware or energy-aware routing protocols that depend heavily on periodic location broadcasts, velocity exchanges, or computationally intensive path prediction models, CRV employs a simple yet effective velocity-threshold mechanism. Nodes self-monitor their mobility and autonomously deactivate routing functionality when exceeding a predefined speed (e.g., 4 m/s), thereby preventing high-mobility nodes from participating in route discovery and maintenance. This decentralized mechanism ensures stable routing paths with minimal overhead and zero reliance on external localization systems such as GPS.

To further enhance route resilience, the CRV+ protocol introduces a session-preservation feature. Instead of immediately removing high-speed nodes already engaged in routing, CRV+ allows them to complete existing data sessions before disengaging. This selective continuity minimizes mid-session disruptions without sacrificing long-term routing efficiency.

The effectiveness of CRV and CRV+ was validated through extensive simulation using the QualNet 3.9.5 environment under varying node densities (25 and 100 nodes), mobility models, and session loads (1 and 5 simultaneous data flows). Key findings include:

- **Route Stability:** CRV+ reduced the number of route requests (RREQ) messages by up to 29% compared to AODV, reflecting more stable routes with fewer reconnections.
- **Packet Delivery Ratio (PDR):** Both CRV and CRV+ consistently achieved high PDR values, with CRV+ outperforming AODV by up to 2.7% in high-mobility scenarios.
- **Control Overhead:** The proposed protocols demonstrated a 54% reduction in total routing-related control packets, thereby improving bandwidth utilization and reducing network congestion.
- **Energy Efficiency:** Average battery consumption in pedestrian terminals was reduced by up to 46.4%, extending the operational lifetime of energy-sensitive nodes.
- **Packet Transfer Efficiency:** CRV+ minimized the control overhead per successfully delivered packet, reducing unnecessary protocol chatter while preserving data throughput.

These outcomes confirm that CRV and CRV+ provide a robust, energy-conscious, and mobility-resilient routing framework for ad hoc networks composed of heterogeneous mobile agents. By requiring no additional hardware, GPS data, or centralized coordination, the protocols are well-suited for deployment in real-world applications such as:

- Disaster response networks require fast-moving emergency vehicles and static rescue personnel to maintain efficient communication.
- Vehicular-to-pedestrian (V2P) systems, where wearable devices interact with intelligent transport infrastructure;
- Military or tactical field networks, where robustness, decentralization, and stealth are critical;
- Smart city infrastructure, enabling seamless and efficient data routing between autonomous vehicles, cyclists, and pedestrians.

6.1. Future work

While CRV and CRV+ have demonstrated strong performance in simulated environments, several promising directions remain for further exploration:

- **Dynamic threshold adaptation:** Machine learning or reinforcement learning could be employed to dynamically adjust the velocity threshold based on real-time context, node density, or traffic conditions.
- **Integration with cross-layer optimization:** CRV could be enhanced by incorporating physical and MAC layer feedback (e.g., signal strength, interference) to improve routing decisions.
- **Security-aware extensions:** Future variants could include lightweight trust mechanisms to mitigate malicious routing behavior, especially in open or unattended deployments.
- **Field testing and scalability:** Real-world implementation and testing with physical mobile devices (e.g., Raspberry Pi, Arduino-based kits, or smartphones) in vehicular environments would provide deeper insights into latency, jitter, and hardware-level constraints.

In conclusion, the CRV protocol family presents a viable and deployable solution for contemporary and next-generation ad hoc networks, especially in energy-sensitive, mobility-dense, and infrastructure-less environments. Its simplicity, adaptability, and performance make it a compelling candidate for future wireless routing architectures.

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