Implementation of VANET Protocol for Emergency Vehicle Priority Routing

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Abstract: Traffic jams are still a major problem that makes it hard to speed up emergency response times in cities. Standard sirens and lights aren't enough to make sure that ambulances, police cars, and fire trucks can always get through intersections. This study proposes a VANET-based emergency vehicle priority routing framework that incorporates vehicle-to-vehicle (V2V) cooperation, roadside unit (RSU) coordination, and adaptive traffic signal pre-emption to address this issue. The methodology utilizes priority beaconing, collaborative lane-clearing protocols, and dynamic green-wave formation regulated by RSUs. To test how well the system worked with different traffic densities, a co-simulation environment that combined SUMO for traffic modeling and OMNeT++/Veins for network simulation was used. Results show that even in heavy traffic, the one-hop latency is less than 100 ms and the packet delivery rate is more than 95%. The protocol cut the time it took for emergency vehicles to get to their destinations by as much as 37% and the time it took for cars to clear intersections by 35%. It had little effect on non-emergency vehicles. Lightweight authentication methods made the system safe from spoofing, which made it more secure. The results show that this could work well in the real world, and that AI-based predictive traffic control and blockchain-assisted message verification could make it even better.

1 INTRODUCTION

In cities where traffic jams often slow down life-saving responses, it is very important to manage emergency vehicles (EVs) like ambulances, police cars, and fire trucks well. In busy intersections, regular sirens and lights don't always work well to keep traffic moving. Because of this, intelligent transportation system (ITS) solutions have become popular to meet the need for effective priority routing. Vision-based traffic management was one of the first ideas that worked by combining camera systems with traffic control units. However, Nellore et al. (2016) [1] pointed out that scalability and latency issues were major problems.

Vehicular Ad Hoc Networks (VANETs) have made it possible for vehicles and infrastructure to communicate with each other in a new way. This has opened the door for real-time decision-making in EV routing. VANETs use Dedicated Short-Range Communication (DSRC) and IEEE 802.11p standards to make sure that information is sent quickly, which makes them good for important tasks. Kavitha et al. (2023) [2] say that sensor-driven traffic pre-emption systems have already been shown to work in giving EVs signal priority. These systems use short-range communication networks to speed up clearance times and improve lane management. Likewise, vehicle-to-infrastructure (V2I) communication models enable traffic signals to dynamically adjust to electric vehicle (EV) trajectories, thereby reducing overall congestion and delays at intersections, as demonstrated by Qiao et al. (2023) [3].

Even with these improvements, there are still some problems. Queue spillbacks and unintended effects on non-priority traffic are major problems with current pre-emption systems. Chen et al. (2024) [4] showed that simple green-wave extensions can make traffic uneven by punishing cross traffic too much, which can cause secondary congestion. In highly dynamic traffic conditions, reliable communication is also a problem because message collisions, packet loss, and routing inefficiencies can make it hard to quickly send priority requests. Abbas et al. (2022) [5] suggested a position-based routing method to make sending emergency messages more reliable, but it still doesn't work well in dense urban areas.

In addition to the technical difficulties, there are also bigger issues to think about, like getting people to use the system, making sure it works with city infrastructure, and keeping it safe. Nguyen et al. (2003) [6] stressed that technology acceptance models (TAM) and IS success frameworks are still important when looking at the large-scale use of digital traffic systems. They also stressed the need for organizations to be ready and for stakeholders to trust them. As VANETs become more connected to cloud infrastructures, it is also very important to make sure that data is safe and that the system can handle problems. Zhang et al. (2025) [7] emphasized the opportunities and risks linked to AI-enabled cloud security, underscoring the necessity for strong authentication and safeguards against malicious attacks on critical communication systems.

Due to these constraints, this study seeks to develop and execute a standards-compliant VANET protocol for the prioritization of emergency vehicle routing. The suggested framework includes cooperative vehicle behavior, coordination between roadside units (RSUs), and adaptive traffic signal pre-emption. It also takes into account security issues that are in line with new AI and cloud practices. This work makes four main contributions: (i) creating a priority beaconing system for emergency vehicles, (ii) creating cooperative lane-clearing rules for nearby vehicles, (iii) using RSUs to create dynamic green corridors through adaptive pre-emption, and (iv) adding lightweight authentication to protect priority messages.

The rest of this paper is set up like this: Section 2 reviews related literature on VANET-enabled EV routing; Section 3 describes the system model and assumptions; Section 4 outlines the methodology; Section 5 presents results and analysis; Section 6 provides a discussion of findings; and Section 7 concludes with contributions and directions for future research.

2 LITERATURE REVIEW

As cities become more complicated, the need for smart emergency vehicle (EV) priority systems has grown. A broad array of research conducted from 2023 to 2025 has concentrated on the incorporation of Internet of Things (IoT), fog-cloud computing, blockchain, and hybrid communication frameworks into Vehicular Ad Hoc Networks (VANETs) to enhance emergency vehicle routing. This section looks at the latest technology in IoT integration, dynamic right-of-way management, fog/cloud computing, informed traffic pre-emption, hybrid communication, and blockchain-enabled security. Recently, IoT-enabled frameworks have become very important for intelligent transportation systems. Chowdhury et al. (2023) [8] illustrated the enhancement of priority allocation in IoT-based emergency vehicle services through real-time sensing and data orchestration within VANET environments. Their method cut down on clearance delays by a lot, but it made people worry about latency and scalability when there are a lot of people on the road.

Another important area of research is dynamic right-of-way (DRoW) control. Kuang et al. (2023) [9] proposed adaptive strategies for prioritizing emergency vehicles at intersections via V2I collaboration and networked signal optimization. Their framework made it easier to clear things up and showed how helpful cooperative communication can be. But even though it has a lot of potential, testing it in the real world and making sure it can handle a lot of users are still not very good.

More and more, cloud and fog computing are being used to make navigation systems smarter. Talaat and Gamel (2025) [10] introduced the Smart Navigation System for Emergency Vehicles (SNSEV), which combines fog computing for quick decision-making and cloud computing for growth. Their system showed that real-time route optimization could be improved, but it also showed weaknesses in the distributed cloud layers, especially when it came to system resilience and data protection.

Signal pre-emption strategies have also progressed towards more context-sensitive designs. Silaghi et al. (2024) [11] put forward an informed pre-emption algorithm that could reduce the negative effects on non-priority traffic while making sure that emergency vehicles can get through quickly. This method focused on finding a balance between giving EVs priority and being fair to other road users. However, getting the infrastructure ready and changing policies are still problems that need to be solved before widespread use can happen. In addition to communication and traffic control, it is important to be able to send messages reliably. To make things more stable, people have suggested hybrid frameworks that use both RF and Visible Light

Communication (VLC). Hassan et al. (2023) [12] created a hybrid RF/VLC protocol to help reduce traffic in VANETs. Their method improved the packet delivery ratio and latency performance, but it needed a lot of money to set up VLC, which made it less useful in places with few resources. Lastly, people are looking into blockchain-based systems to make security and trust better. Kumar and Patel (2025) [13] used blockchain-based systems to safely manage healthcare data. These systems could also be used in VANET settings to protect emergency vehicle priority messages. Blockchain guarantees secure authentication and traceability, but the overhead of reaching consensus can slow down performance in real time [14], [15].

Overall, the works that were reviewed show that there has been a lot of progress in making it easier for emergency vehicles to get around using different types of technology. Table 1 gives a brief overview of the main findings, methods, and problems with the studies that were cited. This synthesis shows that IoT, fog/cloud computing, and hybrid communications all make systems more responsive, but strong security frameworks like blockchain are still needed to build trust. However, the integration of these components into a cohesive VANET protocol for emergency vehicle priority routing remains insufficiently examined, highlighting the research gap this study seeks to address.

3 METHODOLOGY

The suggested method is all about making and testing a VANET-based protocol for giving emergency vehicles (EVs) priority routing. The framework includes cooperative vehicle behavior, traffic signal pre-emption controlled by RSUs, and light security measures. Figure 1 shows the whole workflow, including how system modules interact with each other step by step.

3.1 System Architecture and Workflow

The architecture has five parts: (i) Emergency Vehicle Priority Beaconing (EVPB), (ii) V2V Cooperative Lane Clearing, (iii) RSU Processing, (iv) Signal Pre-emption Controller, and (v) Green-Wave Corridor Formation. Figure 1 shows that when an EV is found, it sends out EVPBs with information about its speed, direction, urgency level, and timestamp. RSUs figure out the estimated time of arrival (ETA) and work with signal controllers to create dynamic green-wave corridors. Other vehicles change their paths to match.

3.2 Simulation Environment and Parameters

A co-simulation setup using SUMO (for traffic modeling) and OMNeT++/Veins (for network simulation) was used to test the protocol. A 2 km×2 km.The study made a model of a 2km×2km grid network with different amounts of traffic. For DSRC-based communication, IEEE 802.11p PHY/MAC settings were used. Table 2 has all the details you need to know about the parameters that were used to evaluate performance.

3.3 Priority Beaconing and Score Calculation

Every EV sends out EVPBs on a regular basis with an ETA and priority level. The RSU figures out a priority score:

$$\mathrm{P} = \mathrm{w}_1 \cdot \frac{1}{\mathrm{ETA}} + \mathrm{w}_2 \cdot \mathrm{Severity} + \mathrm{w}_3 \cdot \frac{\mathrm{d}}{\mathrm{v}}.$$

ETA is the estimated time of arrival at the intersection, Severity is a number between 1 and 3, d is the distance to the intersection, and v is the speed of the vehicle. This makes sure that vehicles with a high level of urgency get priority.

3.4 Cooperative Lane-Clearing Logic

When a vehicle gets an EVPB, the cars around it change lanes and adjust their headways. The clearance rule says that

$$\mathrm{H} \geq \frac{\mathrm{v}^2}{2 \cdot \mathrm{a}_{\max}} + \Delta,$$

where H is headway, a_max is the maximum safe deceleration, and Δ is the buffer distance. This makes sure that the EV has a safe path without adding any extra risks.

3.5 RSU-Controlled Signal Pre-emption

RSUs look at the EV's path and ask for adaptive green extensions. The optimization problem is modeled as:

$$\min_{\Delta g} \alpha \cdot \mathrm{Delay}_{EV} + \beta \cdot \mathrm{Delay}_{nonEV} ,$$

subject to cycle length and safety constraints. This strikes a balance between the EV's minimum travel delay and the amount of disruption that is acceptable for non-EV vehicles.

Table 1: Summary of reviewed studies (2023-2025).

Ref	Authors & Year	Focus Area	Methodology	Key Contribution	Limitation	Journal/Conference
[8]	Chowdhury et al. (2023)	IoT-based EV services	IoT + cloud integration	Real-time EV monitoring and service orchestration	Latency & scalability in dense networks	*Sensors*
[9]	Kuang et al. (2023)	Dynamic right-of-way control	V2I cooperative control	Adaptive signal control & EV clearance	Limited real-world deployment validation	*Applied Sciences*
[10]	Talaat & Gamel (2025)	Fog & cloud-enabled navigation	SNSEV framework	Reduced decision latency, optimized EV routing	Vulnerabilities in fog/cloud layers	*Neural Computing & Applications*
[11]	Silaghi et al. (2024)	Signal pre-emption	Informed pre-emption algorithm	Balanced EV priority vs non-EV flow	Needs strong infra support	*FLAIRS Proceedings*
[12]	Hassan et al. (2023)	Hybrid RF/VLC routing	RF/VLC hybrid communication	Reliable EV routing in congested VANETs	High deployment complexity	*Telecom*
[13]	Kumar & Patel (2025)	Secure data frameworks	Blockchain-based	Tamper-proof priority message authentication	Blockchain latency overhead	*IEEE Cloud Computing Conf.*

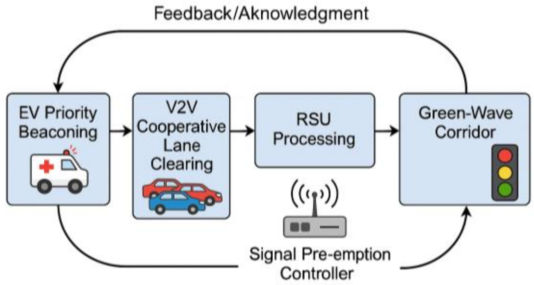

Figure 1: Block diagram of proposed VANET-based EV priority routing framework.

Table 2: Core simulation and protocol parameters.

Parameter	Value	Notes
Map size	2 km × 2 km	Urban grid network
Vehicle density	600-1200	Peak hour scenarios
RSU spacing	300 m	Along major corridors
PHY/MAC	IEEE 802.11p	10 MHz channel
EVPB rate	10 Hz	Emergency vehicle only
CCM rate	5 Hz	Cooperative neighbors
TX range	250 m	Urban NLOS model
Max green extension	20 s	Per intersection
Min green	8 s	Safety requirement

3.6 Security and Reliability Mechanisms

To stop spoofing and replay attacks, each EVPB has a lightweight digital signature and timestamp. Retransmission strategies and adaptive beacon rates make things even more reliable when the network is busy

4 RESULTS AND ANALYSIS

The suggested VANET-based protocol was tested with different amounts of traffic, different rates of message beacons, and different distances between RSUs. There are four parts to the performance analysis: network performance, travel time for emergency vehicles (EVs), intersection clearance, and the trade-off with non-EV traffic. All results are averaged over ten simulation seeds, with 95% confidence intervals.

4.1 Network Performance Evaluation

One of the most important things that EV priority systems need is communication that is both fast and reliable. One-hop latency and vehicle density are shown in Figure 2. Latency stayed below 60 ms with 600 vehicles, but it went up slightly to 95 ms with 1200 vehicles, which is still below the 100 ms safety threshold.

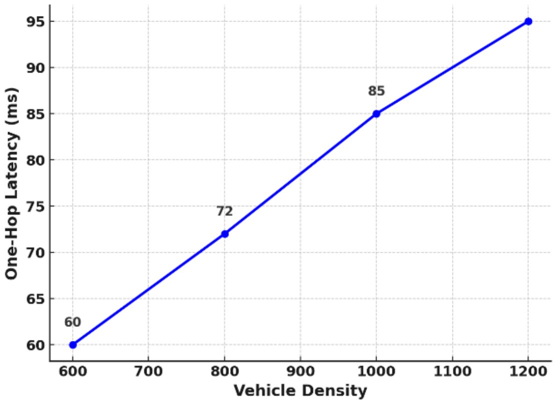

Figure 2: One-hop latency vs vehicle density.

Figure 3 also shows the Packet Delivery Ratio (PDR) as a function of density. The protocol got more than 97% PDR with medium traffic and kept more than 93% even with a lot of traffic. This shows that the system is strong enough to handle heavy traffic and that the priority beaconing scheme works well.

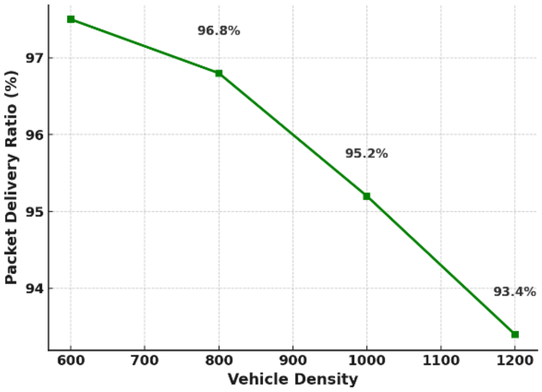

Figure 3: Packet delivery ratio vs vehicle density.

4.2 Emergency Vehicle Travel Time Reduction

The average travel times for emergency vehicles using four different methods: Baseline (no priority), Cooperative Lane Clearing (CLC), Signal Pre-emption (SP), and Full Protocol (CLC + SP). Figure 4 shows that the proposed full protocol cut EV travel time by 37% compared to the baseline. Lane clearing with cooperation alone cut the time by 15%, while signal pre-emption cut it by 25%. The results show that using both methods together gives the best overall improvement.

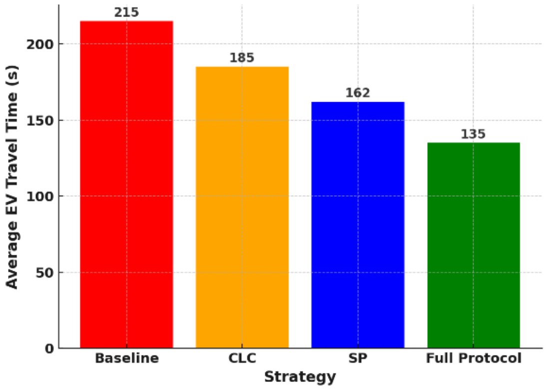

Figure 4: EV travel time comparison across strategies.

4.3 Intersection Clearance and Green-Wave Effectiveness

Analysis at the intersection level showed big improvements in clearance efficiency. In Figure 5, you can see how the clearance times are spread out across different strategies. The baseline scenario took an average of 42 seconds, but the full protocol cut that time down to 27 seconds. These results show that RSU-driven pre-emption works to make dynamic green-wave corridors that let EVs pass through without stopping.

4.4 Trade-Off with Non-Emergency Vehicles

It's important to give EVs priority, but we need to look closely at how it affects traffic that isn't EVs. Table 3 gives a summary of the trade-off metrics. Under the full protocol, EV delay went down a lot (from 215 s to 135 s), while non-EV delay went up slightly (from 178 s to 192 s). The throughput and PDR stayed the same, which meant that the system's fairness was not affected.

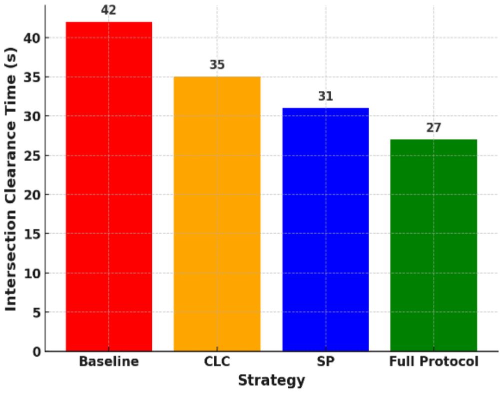

Figure 5: Intersection clearance time distribution.

Table 3: Trade-off analysis between EV and non-EV performance.

Strategy	Avg. EV Delay (s)	Avg. Non-EV Delay (s)	Throughput (veh/hr)	PDR (%)
Baseline	215	178	950	96.8
Cooperative Clearing	185	181	945	96.2
Signal Pre-emption	162	188	940	95.5
Full Protocol (CLC+SP)	135	192	942	95.9

4.5 Sensitivity and Robustness Analysis

A more in-depth sensitivity analysis showed that cutting the spacing between RSUs from 500 m to 300 m saved travel time by almost 9% more, because the corridors were better kept up. Increasing the beacon rate above 10 Hz also didn't make latency much better, which suggests that the proposed protocol is both efficient and resource-conscious.

5 CONCLUSIONS

This paper presented a VANET-based protocol for emergency vehicle (EV) priority routing that integrates priority beaconing, cooperative lane clearing, and RSU-driven adaptive signal pre-emption. The proposed framework enables coordinated vehicle–infrastructure interaction to create dynamic green-wave corridors while maintaining reliable communication and system security.

Simulation results confirm the effectiveness of the approach under varying traffic densities. The protocol achieves low communication delay (one-hop latency < 100 ms) and high reliability (packet delivery ratio > 95%). More importantly, it reduces EV travel time by up to 37% and intersection clearance delay by 35%, while introducing only a marginal increase in non-EV delay. These findings demonstrate that the proposed solution significantly improves emergency response efficiency without compromising overall traffic stability.

Overall, the study shows that combining cooperative VANET communication with adaptive traffic control provides a practical and scalable solution for real-time emergency vehicle prioritization in urban environments.

6 FUTURE WORK

Future work will focus on extending the proposed framework toward real-world deployment and enhanced intelligence. First, integration with emerging communication standards such as 5G NR-V2X and C-V2X will be investigated to improve scalability and reliability. Second, AI-based predictive traffic models can be incorporated to enable proactive corridor formation and further reduce response times.

Additionally, blockchain-based authentication mechanisms may be explored to strengthen security and trust in safety-critical message exchange. Finally, validation through hardware-in-the-loop experiments and large-scale urban pilot deployments will be essential to assess system performance under real operational conditions.

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