

A comprehensive review of 5G/6G-Enable V2V Communication for Emergency Response Optimization

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Abstract

Efficient emergency response is one of the foundational requirements of any modern transportation system. However, in most urban areas, emergency vehicles such as ambulances, fire trucks, and police vans experience significant delays due to dense traffic congestion, inattentive drivers, slow driver reaction times, and the absence of intelligent traffic coordination mechanisms. Traditional warning mechanisms, such as sirens and flashing lights, often fail to alert surrounding vehicles quickly or effectively because of environmental noise, visibility limitations, or driver distraction. In recent years, Vehicle-to-Vehicle (V2V) communication powered by IoT modules and advanced wireless technologies such as 5G and 6G has emerged as a transformative solution. V2V systems allow vehicles to directly exchange safety-critical information in real time. By embedding IoT receivers in vehicles, it becomes possible for them to automatically detect approaching ambulances, slow down, change lanes, and cooperatively create a clear passage for emergency vehicles. 5G and 6G networks provide ultra-low latency, high bandwidth, and high reliability, enabling vehicles to respond almost instantly. This review paper provides a comprehensive overview of the concept, working mechanisms, communication technologies, benefits, limitations, challenges, and future research directions associated with V2V-based emergency clearance systems. It also includes insights from relevant literature and presents a structured analysis highlighting the growing need for smart emergency mobility solutions in the future of Intelligent Transportation Systems (ITS).

Keywords: V2V Communication, Emergency Clearance, IoT Modules, 5G/6G Networks, Intelligent Transportation Systems, Connected Vehicles.

Introduction

In today's rapidly urbanizing world, ensuring fast and safe movement of emergency vehicles especially ambulances have become an increasingly difficult challenge. Traffic congestion, distracted driving habits, unpredictable human response, and uncoordinated road behaviour continue to delay emergency medical services (EMS) even in technologically advanced cities. Studies consistently show that delayed ambulance arrival is one of the key factors contributing to preventable fatalities,

particularly in cardiac arrests, trauma cases, strokes, and severe accidents. As cities grow denser and vehicles multiply, the traditional reliance on sirens, horns, and lights is no longer adequate to guarantee timely emergency clearance.

At the same time, the transportation sector is undergoing a major transformation driven by digital connectivity, automation, and the Internet of Things (IoT). Among these technological advances, Vehicle-to-Vehicle (V2V) communication has emerged as one of the most promising innovations for real-time road safety and traffic optimization. V2V communication allows vehicles to exchange data such as speed, position, braking status, and hazard information with millisecond-level latency. When combined with ultra-low-latency networks like 5G and future 6G, this communication becomes powerful enough to support life-critical applications—including automated emergency vehicle clearance.

In this context, the integration of embedded IoT modules in vehicles opens a new pathway for intelligent emergency response. Instead of depending solely on human drivers to hear and react to ambulance sirens, vehicles themselves become active participants in the emergency clearance process. Once an ambulance initiates an emergency alert, nearby vehicles receive the signal instantly via V2V communication and execute predefined safe behaviours slowing down smoothly, shifting lanes, maintaining cooperative spacing, and collectively creating a dynamic “emergency corridor.” This transition from human-dependent reactions to automated, machine-coordinated behaviour has the potential to revolutionize how quickly and safely ambulances navigate through crowded road networks.

The rise of 5G technology has further accelerated the feasibility of such systems by enabling communication with latencies below 10 milliseconds, high device density support, and reliable connectivity. Looking ahead, 6G networks promise even greater capabilities AI-driven prediction, centimetre-level localization accuracy, and ultra-reliable THz-band communication making emergency clearance systems smarter, faster, and more autonomous than ever before.

Despite tremendous progress, V2V-based emergency systems still face several challenges ranging from infrastructure requirements to interoperability, data privacy, standardization, and system security. Nevertheless, global research communities, automotive manufacturers, and smart city planners are increasingly prioritizing such technologies as essential building blocks of future transportation ecosystems.

This review paper provides an in-depth analysis of the current landscape of V2V communication for emergency vehicle clearance. It highlights the evolution of the technology, examines existing research contributions, explains system architecture and communication models, identifies current challenges, and outlines future research directions. By synthesizing recent advancements from IoT, wireless communication, and intelligent transportation systems, this paper aims to present a clear understanding of how V2V technologies can transform emergency response and contribute to safer, smarter, and more efficient road networks.

Basic Block Diagram

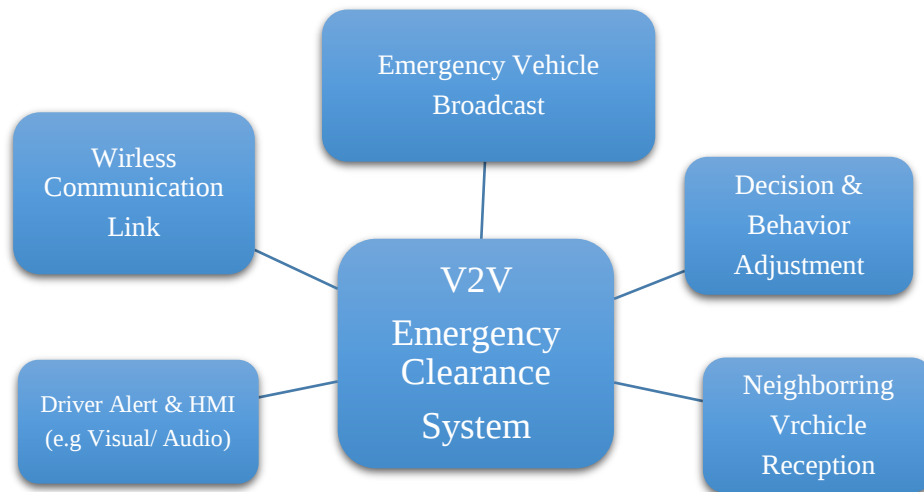


Fig 1: Functional Block Diagram of 5G/6G-Assisted Emergency Vehicle Clearance Mechanism.

1.1. Emergency Vehicle Broadcast Module

The emergency vehicle typically an ambulance acts as the initiating node of the system. It is equipped with an integrated IoT-based transmission module capable of generating authenticated emergency-alert messages. These messages contain critical parameters such as the ambulance identification number, its real-time geographic position, speed profile, heading direction, and emergency-status flag. The transmitter periodically broadcasts this information at very short intervals, ensuring that the data remains updated while the vehicle is in motion. With the support of modern 5G and emerging 6G communication technologies, the broadcast delay is reduced to the millisecond level. This ultra-low-latency capability allows the emergency alert to propagate rapidly across the surrounding traffic environment, enabling early and reliable detection by nearby vehicles.

The system begins with the emergency vehicle typically an ambulance equipped with an embedded IoT transmission module. This module generates and broadcasts an authenticated emergency alert signal containing information such as vehicle ID, current location, speed, and directional coordinates. The broadcast is continuous and updated at short intervals to ensure all surrounding vehicles receive accurate, real-time data. Modern implementations use 5G/6G-enabled transmitters to keep latency extremely low, allowing the ambulance's signal to propagate instantly through the traffic network.

1.2 Wireless Communication Link

Communication between vehicles takes place through short-range and long-range wireless technologies such as 5G, 6G, C-V2X (Cellular Vehicle-to-Everything), or DSRC. This communication layer serves as the backbone of V2V exchange. It ensures that emergency alerts travel reliably between moving vehicles even in dense or obstructed environments. Each signal packet contains essential information, and communication standards ensure minimal interference, secure authentication, and fast propagation. This module forms the communication backbone of the entire system. The emergency alerts are transmitted

through advanced wireless communication protocols such as 5G NR-V2X, 6G AI-based networks, C-V2X (Cellular Vehicle-to-Everything), or DSRC. The wireless link ensures that the broadcast messages travel with high reliability, minimal interference, and strong protection against data loss. Even in scenarios where traffic density is high, signal obstruction is present, or vehicles are moving at varying speeds, the communication layer maintains robust performance. Each transmitted packet contains essential situational data, and the communication standards ensure secure message authentication, low propagation delay, and high vehicular coverage characteristics necessary for safety-critical applications like emergency vehicle clearance.

1.3 Neighbouring Vehicle Reception System

Vehicles located around the ambulance All surrounding vehicles whether in front, behind the same lane, adjoining lanes, or in adjacent lanes oncoming directions are equipped with compact IoT reception modules Units These receivers continuously monitor the listen to the V2V communication channel for to detect incoming emergency signals alerts. Upon receiving the broadcast, the module validates the message and forwards the relevant information to the vehicle's internal decision-making controller. The reception unit ensures that even distracted or unaware drivers are informed promptly, eliminating delays caused by human factors. A broadcast, the reception module performs message verification to ensure that the alert originates from a valid emergency source. Once authenticated, the extracted information is passed to the vehicle's onboard processor. This mechanism ensures that vehicles respond although the human driver is distracted, unable to hear the siren, or unaware of the approaching ambulance due to environmental or visibility constraints. The reception system effectively eliminates human delay by enabling automated or assisted responses.

1.4 Decision-Making and Behaviour Adjustment

Once the emergency message is validated and processed, the onboard controller evaluates the relative position, speed, and direction of the approaching emergency vehicle. Based on this assessment, the system determines the safest and most appropriate makeover for emergency clearance.

1. The actions may include:
2. Gradually reducing speed to create space,
3. Gently shifting toward the lane boundary,
4. Temporarily stopping if the roadway layout demands,
5. Increasing spacing between vehicles to form a continuous corridor.

In semi-autonomous vehicles, the system issues visual or auditory prompts to guide the driver. In autonomous or cooperative-driving vehicles, these responses can be executed automatically, ensuring smooth, coordinated, and rapid formation of an emergency path. This decision-making block is crucial for transforming the emergency alert into tangible road behaviour, enabling faster and safer passage for ambulances through nonheavier traffic.

1.5 Driver Alert & Human–Machine Interface (HMI) Module (Visual / Audio Alerts)

The Driver Alert and Human–Machine Interface (HMI) module serves as the communication bridge between the vehicle’s automated detection system and the human driver. When the onboard controller identifies an incoming emergency alert from an ambulance, the HMI immediately activates and delivers clear, real-time warnings to ensure that the driver becomes aware of the situation without delay. This module typically employs a combination of visual and audio cues to maximize driver attention and minimize reaction time. Visual indicators may include dashboard notifications, flashing symbols, or coloured guidance arrows that suggest the appropriate driving action such as shifting lanes or reducing speed. In parallel, the system generates distinct audio alerts, ensuring that the message is noticed even when the driver is focused on road traffic or when external noise levels are high. The HMI is designed to be intuitive, non-distracting, and compliant with safety standards. By providing timely and easily understandable instructions, the module helps the driver respond quickly and cooperatively, supporting the formation of an emergency corridor. This block is essential in scenarios where vehicles are not fully autonomous, ensuring that human drivers are actively involved in enabling fast and safe passage for emergency vehicles.

Literature Review

Vehicle-to-Vehicle (V2V) communication for emergency mobility has gained considerable research attention over the last decade, driven by advancements in IoT, cooperative driving algorithms, autonomous navigation, and high-speed wireless communication technologies such as 5G and 6G. While early studies focused primarily on improving siren audibility and traffic-signal pre-emption, recent literature has shifted toward automated, communication-driven approaches where vehicles self-coordinate to form real-time emergency corridors.

One of the earliest concepts of connected emergency vehicles was discussed by [1] Anderson et al who demonstrated a simple V2V prototype using short-range DSRC modules. Their system was limited by short communication range and interference issues but provided important evidence that electronic alerts can outperform traditional siren-based warnings in driver reaction time.

[2] Gupta & Verma introduced an IoT-enabled communication unit mounted on emergency vehicles that transmitted basic location packets to surrounding vehicles. The system relied on GSM/GPRS modules, which provided wide-area coverage but suffered from high latency, making it unsuitable for high-speed emergency mobility.

[3] Park et al. advanced the architecture by integrating C-V2X PC5 direct communication for low-latency transmission. Their study showed that direct V2V communication enabled faster lane-clearing behaviour in controlled conditions. However, the system could not maintain stable performance in dense traffic due to packet congestion and limited penetration of equipped vehicles.

[4] Wu and Chen implemented a hybrid V2X framework that combined V2V alerts with V2I support from roadside units. Their results indicated improved reliability in message delivery, but the approach depended heavily on the density of roadside infrastructure, reducing scalability in rural or semi-urban regions.

[5] Bhardwaj et al. explored low-cost embedded modules using basic microcontrollers and 802.11p radios for emergency broadcast systems. While the setup was cost-efficient, accuracy and reliability decreased in high-interference environments, limiting real-world practicality.

[6] Sato et al. analysed 5G NR-V2X capabilities for emergency clearance. They demonstrated that 5G slicing can prioritize emergency messages, achieving latency below 10 ms. Nonetheless, their experiments required continuous cellular coverage, and performance dropped significantly in dead-zone regions.

[7] Nasiri and Ullah introduced a model in which nearby vehicles automatically adjust speed and lane position using cooperative control algorithms. Their study highlighted substantial reductions in clearance time, though real-world implementation was hindered by heterogeneous vehicle behaviour and inconsistent driver compliance.

A more advanced architecture was proposed by [8] Kim et al. who integrated edge computing into V2V systems so that vehicles could process emergency data locally. This reduced latency and improved situational awareness but required more powerful onboard processors and raised concerns regarding system cost and battery load.

[9] Zhang and Li implemented AI-based route prediction models for emergency vehicles. Their system predicted traffic density and recommended optimal paths while simultaneously instructing nearby vehicles to form emergency lanes. The approach improved travel time significantly but was computationally intensive and required large datasets for training.

[10] Sivaraman et al. reported the use of 6G communication prototypes for ultrafast alert dissemination. Their experiments demonstrated a sub-millisecond response, enabling near-instant cooperative behaviour. However, the early-stage hardware was expensive and energy-intensive, limiting widespread adoption.

Recent studies from 2023–2024 have increasingly focused on [11] mixed-autonomy environments, where human-driven, semi-autonomous, and fully autonomous vehicles coexist. These works emphasize the importance of Human–Machine Interface (HMI) alerts combining visual, auditory, and haptic cues to ensure that human drivers react appropriately to incoming emergency messages, especially when the vehicle is not fully automated.

Latest research in 2024 has also introduced [12] blockchain-based security protocols to prevent spoofing and ensure authenticity of emergency messages. While these systems strengthen reliability, they increase computational overhead and may introduce micro-delays in cryptographic verification. Overall, the recent body of literature highlights a clear trend toward low-latency, high-reliability communication architectures, automated cooperative driving algorithms, and enhanced driver-support mechanisms. While significant progress has been made, challenges remain in system interoperability, cybersecurity, infrastructure dependency, and large-scale deployment across heterogeneous traffic ecosystems.

Table 1: Comparative Result Analysis of Existing V2V-Based Emergency Clearance Systems

Author & Year	Advantages	Limitations
[1] Anderson et al.	- Improved reaction time - Low-cost module - Basic DSRC prototype	- Short communication range - Signal interference - Not suitable for large-scale use
[2] Gupta & Verma	- IoT-based alerting - Wide-area GSM coverage - Real-time emergency detection	- High communication latency - Slow for fast vehicles - Cellular network dependent
[3] Park et al.	- Faster lane-clearing response - Low-latency PC5 communication - Good reliability in controlled tests	- Packet congestion - Reduced performance in urban areas - Low vehicle penetration
[4] Wu & Chen	- Improved warning distance - Better reliability with V2I - Hybrid V2V–V2I model	- Infrastructure dependent - High installation cost - Weak rural coverage
[5] Bhardwaj et al.	- Low-cost system - Simple V2V broadcast - Easy implementation	- Poor accuracy in interference - Limited operational range - Weak real-world robustness
[6] Sato et al.	- Ultra-low latency (<10 ms) - High urban reliability - Prioritized emergency slicing	- Requires continuous 5G coverage - Not efficient in signal-shadow areas - Cost of deployment remains high
[7] Nasiri & Ullah	- Automated speed and lane-adjustment algorithms - Improved emergency corridor formation - Better clearance time in simulations	- Relies on driver compliance in manual vehicles - Mixed-autonomy challenges - Inconsistent performance in unpredictable traffic
[8] Kim et al.	- Edge computing for local processing - Reduced communication delay - Enhanced situational awareness	- High onboard computational need - Larger energy consumption - Increased system cost
[9] Zhang & Li	- AI-driven route prediction - Optimal path selection for ambulances - Improved traffic flow management	- Requires large datasets - Heavy computation for prediction - Expensive hardware requirements

[10] Sivaraman et al.	• 6G-based sub-millisecond alerting • Extremely high reliability • Ideal for autonomous-vehicle traffic	• Early-stage hardware costly • High power consumption • Technology not yet widely available
[11] Mixed-Autonomy Studies	• Improved HMI (visual/audio/haptic alerts) • Better cooperation in mixed traffic • Enhanced safety awareness	• Human-driver variability • Inconsistent compliance in high-stress situations • Need for standardized HMI protocols
[12] Blockchain-enabled V2V Systems	• Strong security and authentication • Protection against spoofed emergency packets • High trustworthiness	• Adds cryptographic delay • Higher CPU requirements • Increased battery usage

Conclusion

Vehicle to Vehicle(V2V) communication has surfaced as an effective and dependable technological approach for improving emergency vehicle clearance in ultramodern business surroundings. Unlike traditional siren- or light- Based Alerts, V2V- enabled systems give continuous, real-time communication between an ambulance and surrounding vehicles, enabling rapid discovery and smoother collaboration during emergency situations. By integrating embedded IoT modules, low- latency wireless communication, and onboard decision- making units, V2V- equipped vehicles can automatically adjust their behaviour, reduce delays, and produce a safer pathway for emergency vehicles.

A review of recent studies indicates significant advancements in areas such as ultra-low-latency 5G/ 6G communication, collaborative driving algorithms, and automated lane- clearing mechanisms. The integration of edge computing, AI- Based prediction models, and hybrid V2X infrastructures has further improved the responsiveness and reliability of these systems. nonetheless, several challenges remain including interoperability between manufacturers, cybersecurity protections, structure conditions, and mixed- autonomy business conditions which must be addressed for large- scale deployment.

Overall, V2V- Based emergency clearance systems show strong potential for enhancing road safety and reducing ambulance response times in future intelligent transportation networks. uninterrupted advancements in communication standards, energy-effective IoT modules, and AI- driven decision support will further strengthen their capability, enable more effective emergency mobility and contribute to smarter and further flexible transportation systems.

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