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IoT Based V2X Traffic Management System for Emergency Vehicles

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A B S T R A C T

The rapid movement of emergency vehicles, such as ambulances, fire engines, and police vehicles, is essential for saving lives and ensuring public safety. However, traffic congestion, fixed-time traffic signals, and delays at road intersections significantly affect their response time. To address these challenges, this paper proposes an IoT-Based Vehicle-to-Everything (V2X) Traffic Management System for Emergency Vehicles that enables intelligent communication between emergency vehicles, roadside units, traffic signals, and nearby vehicles. The proposed system uses a GPS module to obtain the real-time location and speed of the emergency vehicle, while a microcontroller processes and transmits the emergency status through wireless communication technologies such as LoRa. The roadside unit receives and validates the transmitted information to identify the approaching emergency vehicle and its route.

Based on the received information, the proposed system automatically controls traffic signals by providing green signal priority along the emergency vehicle's route, thereby creating a dynamic green corridor and reducing unnecessary waiting time at intersections. In addition, nearby vehicles can receive alerts to facilitate lane clearance and improve road safety. Once the emergency vehicle passes the junction, the traffic signal is restored to its normal operating sequence. The system aims to provide a low-cost, energy-efficient, and reliable solution for intelligent emergency traffic management without depending entirely on internet connectivity. Its performance can be evaluated based on emergency vehicle travel time, wireless communication latency, packet delivery ratio, and traffic signal recovery time. The proposed approach has the potential to improve emergency response efficiency, reduce traffic-related delays, and contribute to the development of smart transportation infrastructure.

Keywords: Internet of Things (IoT), Vehicle-to-Everything (V2X), LoRa Communication, Emergency Vehicle, Intelligent Traffic Management, Green Corridor, GPS, Traffic Signal Pre-emption.

I. Introduction

Traffic congestion has become a major challenge in modern transportation systems, particularly in urban areas where the number of vehicles is continuously increasing. One of the most critical consequences of traffic congestion is the delay faced by emergency vehicles such as ambulances, fire engines, and police vehicles. In emergency situations, every second is valuable, and delays caused by congested roads and traffic signals can lead to serious consequences, including loss of human lives and property damage. Conventional traffic management systems mainly operate using fixed-time signal control or basic vehicle detection techniques, which are unable to identify and respond dynamically to approaching emergency vehicles. Therefore, an intelligent and automated traffic management system is required to provide priority access to emergency vehicles and improve overall road efficiency.

The Internet of Things (IoT) and Vehicle-to-Everything (V2X) communication technologies provide an effective approach to addressing these challenges. IoT enables communication between connected devices, sensors, and traffic infrastructure, while V2X supports information exchange between vehicles and roadside units. In the proposed system, a GPS module is used to obtain the real-time location and speed of an emergency vehicle, and a microcontroller processes the information before transmitting it through wireless communication technology such as LoRa. The roadside unit receives the emergency vehicle information and determines its approach towards the traffic junction. Based on the received data, the traffic signal controller automatically provides a green signal to the approaching emergency vehicle, creating a dynamic green corridor. Furthermore, nearby vehicles can receive warning messages to clear the road and allow the emergency vehicle to pass safely.

This paper proposes an IoT-based V2X Traffic Management System for Emergency Vehicles to reduce traffic delays and improve emergency response efficiency. The system integrates GPS positioning, wireless communication, microcontroller-based processing, and intelligent traffic signal control into a unified framework. It also includes automatic restoration of the normal traffic signal sequence after the emergency vehicle passes the junction, helping minimize disruption to regular traffic flow. The proposed approach aims to provide a low-cost, energy-efficient, and reliable solution for emergency vehicle prioritization, with LoRa communication enabling wireless data exchange without complete dependence on internet connectivity. The performance of the system can be assessed using parameters such as communication latency, packet delivery ratio, emergency vehicle travel time, and

traffic signal recovery time. This approach has the potential to support smart city transportation infrastructure and improve road safety and emergency service efficiency.

II. Problem Statements

The increasing number of vehicles on roads has resulted in severe traffic congestion, creating significant difficulties for emergency vehicles such as ambulances, fire engines, and police vehicles. Conventional traffic signal systems generally operate using fixed-time intervals and are unable to detect or identify approaching emergency vehicles. As a result, emergency vehicles often experience delays at traffic intersections, even when immediate access is required. Existing systems mainly depend on sirens, manual traffic control, or limited vehicle detection techniques, which may not provide sufficient warning to nearby vehicles or ensure smooth traffic movement. These limitations increase emergency response time and may lead to serious consequences, including loss of lives and property damage.

To overcome these challenges, there is a need for an intelligent IoT-based traffic management system that enables real-time communication between emergency vehicles and traffic infrastructure. The proposed system aims to use GPS positioning, microcontrollers, and LoRa-based wireless communication to detect approaching emergency vehicles and automatically control traffic signals according to their location and route. It also provides alerts to nearby vehicles to facilitate road clearance and ensure safe passage. The system must create a dynamic green corridor for emergency vehicles and automatically restore normal traffic signal operation after they pass through the junction. Therefore, the main problem is to develop a low-cost, reliable, and efficient emergency vehicle traffic management system that reduces intersection delays, minimizes dependence on internet connectivity, and improves emergency response efficiency.

III. Proposed System

A. The System Design and Development

The proposed IoT-Based V2X Traffic Management System for Emergency Vehicles is designed to provide a smart and automated solution for managing traffic during emergency situations. The system consists of an emergency vehicle unit, roadside unit, traffic signal controller, and wireless communication module. The emergency vehicle unit is equipped with a GPS module and a microcontroller to collect real-time location and speed information. When an emergency vehicle is activated, its identification, geographical position, speed, and emergency status are transmitted wirelessly to the roadside unit using LoRa communication technology. This enables communication between the emergency vehicle and traffic infrastructure without complete dependence on internet connectivity.

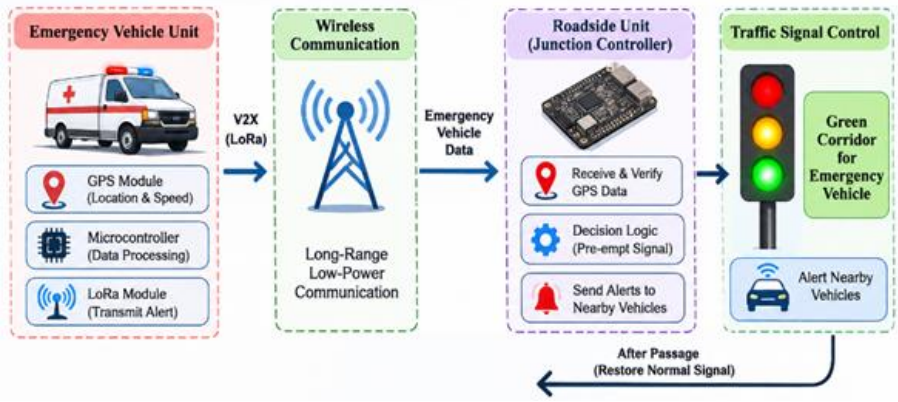


Figure 1: System design

The roadside unit acts as the central processing unit at the traffic junction. It receives the information transmitted by the emergency vehicle and verifies the emergency status and vehicle location. Based on the received GPS coordinates and distance from the junction, the controller determines whether traffic signal pre-emption is required. If an emergency vehicle approaches the junction, the system automatically changes the corresponding traffic signal to green, allowing the vehicle to pass without unnecessary waiting. At the same time, warning messages can be provided to nearby vehicles to facilitate lane clearance and reduce the possibility of accidents. The microcontroller controls the traffic signal model using suitable driver circuits and switching components.

The development of the system involves integrating hardware and software components, including an ESP32 or Arduino-based microcontroller, GPS module, LoRa wireless communication module, and LED-based traffic signal model. Embedded C programming using the Arduino IDE is used to implement communication, GPS data processing, and traffic signal control logic. The system also incorporates automatic signal restoration after the emergency vehicle crosses the junction, ensuring that normal traffic operation resumes. A multi-junction corridor can be developed to demonstrate the movement of an emergency vehicle through successive traffic signals. The overall system is intended to reduce emergency vehicle waiting time, improve traffic coordination, and provide an efficient and low-cost solution for intelligent emergency traffic management.

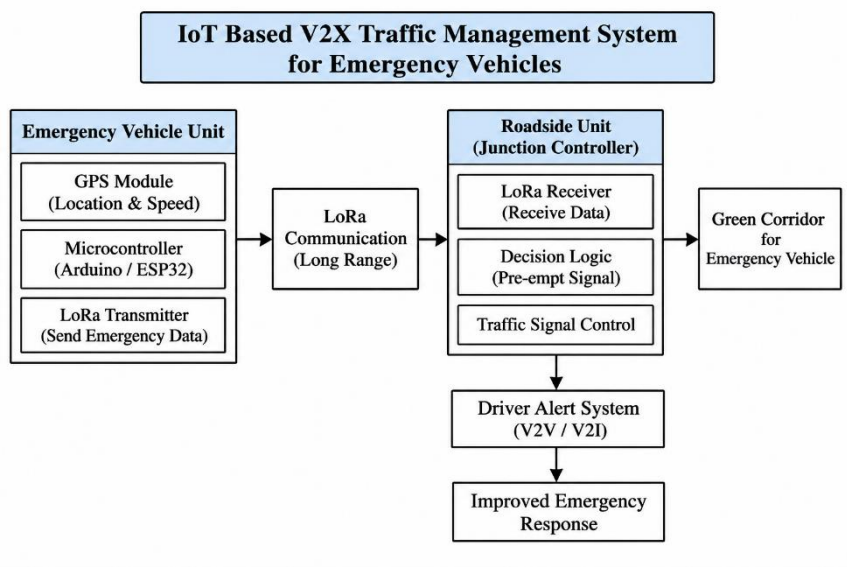


Figure 2: Block diagram of the proposed system

The proposed wireless charging system uses an ESP32 microcontroller as the central monitoring and control unit to manage and monitor the charging process. The system operates based on electromagnetic induction, where the transmitter coil generates an alternating magnetic field using power supplied through a high-frequency inverter. This magnetic field induces an alternating voltage in the receiver coil without requiring a physical connection. The received AC voltage is converted into DC using a rectifier and regulated to provide a suitable supply for the EV battery charging section. The ESP32 monitors important electrical parameters, such as voltage and current, and supports coil alignment monitoring and charging control. It can interface with suitable voltage and current sensors to obtain real-time operating information.

The ESP32 also provides wireless connectivity through its built-in Wi-Fi functionality, enabling remote monitoring through a web-based dashboard and Telegram notifications. The measured parameters and charging status can be displayed on an OLED screen or accessed through a mobile device or computer. Based on the monitored conditions, the controller can support charging management and protection functions against abnormal operating conditions such as overvoltage, overcurrent, and coil misalignment. The proposed integration of wireless power transfer and ESP32-based monitoring improves system automation, monitoring convenience, and operational reliability. Thus, the system provides a foundation for developing an intelligent and cost-effective wireless charging solution for electric vehicles.

The block diagram represents the overall architecture of the proposed IoT-Based V2X Traffic Management System for Emergency Vehicles. The system consists of an Emergency Vehicle Unit, LoRa Communication Module, Roadside Unit (Junction Controller), Traffic Signal Control, and Driver Alert System. The emergency vehicle unit contains a GPS module, microcontroller (Arduino/ESP32), and LoRa transmitter. The GPS module collects the real-time location and speed of the emergency vehicle. The microcontroller processes the collected information and prepares the emergency data for wireless transmission through the LoRa transmitter.

B. Circuit diagram

The proposed wireless charging system uses ready-made wireless power transfer transmitter and receiver modules to transfer electrical energy without requiring a direct cable connection. The transmitter module is connected to a suitable DC power supply and generates an alternating magnetic field through its coil. When the receiver coil is positioned within the effective magnetic field, electrical energy is induced and transferred through electromagnetic coupling. The received electrical output is processed through the appropriate rectification and voltage regulation stages before being supplied to the EV battery charging circuit. The use of ready-made wireless charging modules simplifies hardware development and reduces the complexity of designing individual power electronic circuits.

An ESP32 microcontroller is integrated into the system for monitoring and controlling the charging operation. A voltage sensor and ACS712 current sensor are interfaced with the ESP32 to measure the electrical parameters of the charging system. The measured voltage, current, and charging status can be displayed on an I2C OLED display, while the built-in Wi-Fi functionality enables remote monitoring through a web dashboard or Telegram notifications. A relay module can be used for charging control, and a buzzer provides an audible indication of abnormal operating conditions. The integration of wireless power transfer modules with ESP32-based monitoring provides a convenient and automated approach to EV wireless charging, with scope for improved monitoring, protection, and system reliability.

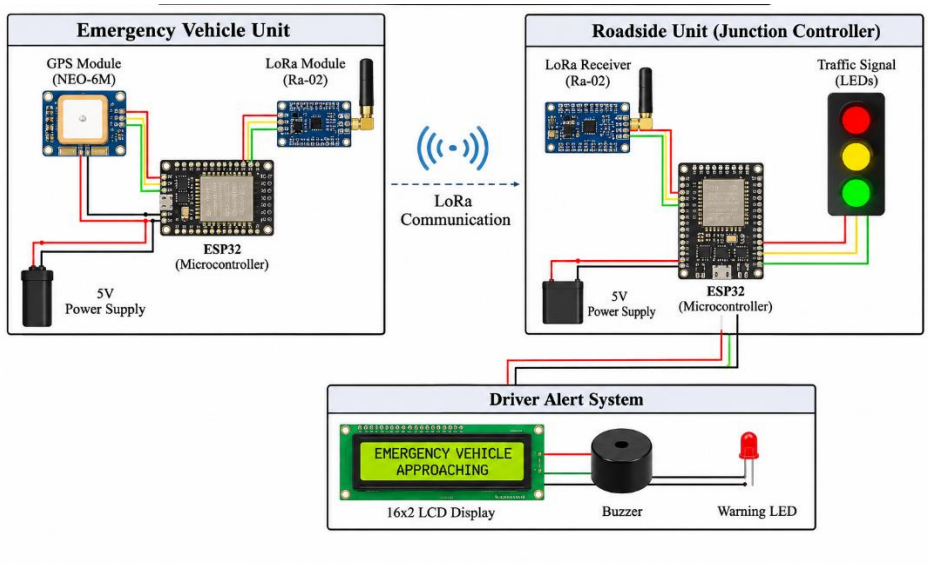


Figure 3: detailed circuit and hardware interconnection diagram of the proposed System.

4. Result analysis

The proposed IoT-Based V2X Traffic Management System for Emergency Vehicles provides an intelligent approach to reducing traffic delays during emergency situations. The system uses GPS technology to track the real-time location and speed of emergency vehicles and LoRa communication to transmit the information to roadside units. Based on the received data, the microcontroller identifies the approaching emergency vehicle and automatically controls the traffic signals to provide green signal priority. This helps create a clear path for emergency vehicles and reduces unnecessary waiting time at road intersections.

The system also improves traffic safety by providing alerts to nearby vehicles, allowing drivers to clear the road and make way for emergency vehicles. The automatic restoration of traffic signals after the emergency vehicle passes ensures smooth operation of normal traffic flow. The integration of ESP32 or Arduino, GPS, LoRa modules, and traffic signal controllers provides a low-cost and energy-efficient solution. The system can also be extended to multiple junctions to establish a continuous green corridor for emergency vehicles. Its performance can be assessed through response time, communication latency, packet delivery ratio, and signal recovery time.



Figure 3(a) : Prototype model

The proposed system demonstrates the potential of IoT and V2X communication in improving emergency traffic management. It can reduce emergency vehicle delays, improve coordination between vehicles and traffic infrastructure, and enhance road safety. The system offers a reliable and scalable approach for future smart city transportation applications. Further improvements can include real-time route optimization, vehicle identification, advanced obstacle detection, and integration with centralized traffic monitoring systems to achieve more efficient emergency vehicle management

If an emergency vehicle approaches the junction, the system automatically changes the corresponding traffic signal to green, allowing the vehicle to pass without unnecessary waiting. At the same time, warning messages can be provided to nearby vehicles to facilitate lane clearance and reduce the possibility of accidents. The microcontroller controls the traffic signal model using suitable driver circuits and switching components.

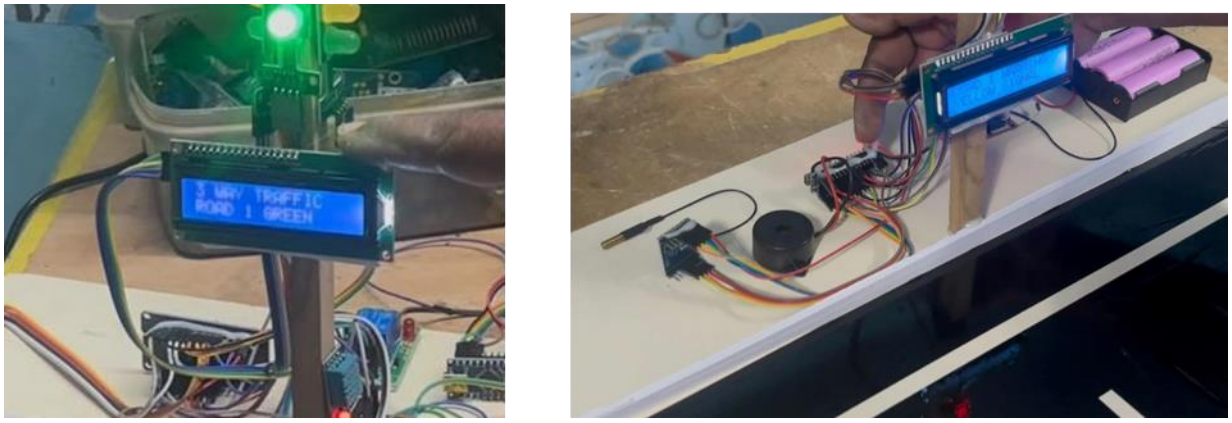


Figure 3(b) : warning messages Displayed on 16x2 LCD

The overall system provides an effective foundation for developing an intelligent emergency traffic management solution. By combining GPS tracking, wireless communication, and automated traffic signal control, it helps improve communication between emergency vehicles and road infrastructure. Although factors such as communication range, GPS accuracy, and network interference may influence system performance, these limitations can be addressed through proper hardware selection and system optimization. Therefore, the proposed approach has significant potential to support faster emergency response, reduce traffic congestion, and improve public safety in future smart transportation systems.

5. Conclusion and Future scope

The proposed IoT-Based V2X Traffic Management System for Emergency Vehicles provides an intelligent and efficient solution for reducing traffic delays during emergency situations. By integrating GPS, ESP32/Arduino, LoRa communication, and automated traffic signal control, the system enables real-time communication between emergency vehicles and roadside units. The automatic green signal priority helps emergency vehicles cross road intersections with minimum waiting time, while driver alert notifications improve road safety and traffic coordination. The proposed system is cost-effective, energy-efficient, and suitable for future smart city applications. Overall, it has the potential to improve emergency response time, reduce traffic congestion, and support the development of intelligent transportation infrastructure. the proposed system can be enhanced by integrating artificial intelligence and machine learning techniques for intelligent route selection and traffic prediction. GPS-based tracking accuracy and wireless communication reliability can also be improved to support emergency vehicle movement across multiple junctions. The system can further be connected to cloud platforms and mobile applications for real-time monitoring, emergency notifications, and traffic data analysis. Advanced features such as automatic vehicle identification, obstacle detection, ambulance priority management, and centralized traffic control can also be implemented. These improvements can make the system more reliable, scalable, and effective for large-scale smart city traffic management.

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