# A Lora-Based AD Hoc Traffic Signal Network for Safe and Efficient Temporary Road Control

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## ABSTRACT

Temporary traffic management during road construction and maintenance activities presents significant challenges in ensuring traffic efficiency and road user safety, particularly in areas where conventional wired traffic signal systems are impractical or costly to deploy. This study presents the design, development, and performance evaluation of a wireless ad hoc traffic light system utilizing Long Range (LoRa) communication technology for temporary road control applications. The proposed system integrates microcontroller-based traffic signal units with LoRa transceiver modules to establish wireless communication and coordinate traffic signal operations without requiring permanent infrastructure. A functional prototype was developed and experimentally evaluated to assess wireless communication reliability, signal synchronization, and overall system functionality. The experimental findings demonstrate that the proposed system successfully establishes wireless communication between traffic light units and enables coordinated traffic signal operations. Furthermore, the wireless architecture simplifies system deployment, reduces dependence on wired infrastructure, and provides flexibility for temporary road management applications. The proposed LoRa-based ad hoc traffic light system demonstrates its potential as a practical, cost-effective, and adaptable alternative to conventional temporary traffic control methods, contributing to improved traffic management and enhanced road safety in construction and maintenance zones.

**Keywords**: LoRa Communication, Ad Hoc Network, Wireless Traffic Control, Temporary Road Management

## INTRODUCTION

The increasing frequency of road construction, maintenance, and utility infrastructure activities has intensified the demand for reliable and efficient temporary traffic control systems. Conventional traffic management in roadwork zones predominantly relies on manual flaggers who regulate vehicular movement using hand signals or portable signboards. However, such approaches expose personnel to occupational hazards and depend heavily on human vigilance, communication, and decision-making. These limitations highlight the need for alternative traffic management solutions that can improve operational safety while maintaining effective traffic flow[1-4].

Manual traffic control presents several challenges, including prolonged exposure to moving vehicles, adverse weather conditions, limited visibility during nighttime operations, and physical fatigue. These factors may contribute to communication failures, delayed responses, and human errors, potentially increasing the risk of traffic-related incidents involving road users and construction personnel. Furthermore, maintaining effective coordination between traffic controllers stationed at opposite ends of a temporary single-lane road section remains challenging, particularly in the absence of a reliable communication infrastructure. Recent advancements in embedded systems and wireless communication technologies have facilitated the development of automated traffic management solutions aimed at addressing these operational limitations [4-7].

To address these challenges, this study proposes the design and development of a LoRa-based ad hoc traffic light system for temporary road management applications. The proposed system integrates microcontroller-based traffic signal units with Long Range (LoRa) wireless communication technology to enable coordinated traffic signal operations without requiring permanent wired infrastructure. Through wireless communication between

traffic light units, the system is designed to support synchronized traffic control at opposite ends of a temporary single-lane road section, thereby reducing the need for direct human intervention in traffic regulation.

The proposed approach aims to enhance operational safety by minimizing workers' exposure to moving traffic while improving the consistency and coordination of temporary traffic signal operations. Additionally, the adoption of LoRa communication technology offers a potentially cost-effective and flexible solution for temporary deployment in road construction and maintenance environments. Therefore, this research contributes to the development and experimental evaluation of a wireless traffic management approach intended to improve the reliability, practicality, and safety of temporary road control systems.

Recent advancements in Intelligent Transportation Systems (ITS) have introduced various technologies to improve traffic management efficiency and road safety. Conventional temporary traffic control systems commonly rely on manual flaggers or fixed-time portable traffic signals, which may result in communication difficulties, traffic congestion, and increased safety risks [3-5], [8]. Wireless communication technologies, particularly Long Range (LoRa), have emerged as promising solutions due to their low power consumption, extended communication range, and cost-effective implementation [6,7]. Furthermore, LoRa peer-to-peer (P2P) communication enables direct data transmission between devices without requiring centralized network infrastructure, making it suitable for temporary traffic control applications [10].

Several studies have investigated LoRa-based intelligent traffic management systems for wireless signal synchronization and traffic flow optimization. Previous research demonstrated the feasibility of coordinating multiple traffic signals using Arduino microcontrollers and LoRa communication modules [9]. Additionally, sensor-based traffic scheduling and predictive algorithms have been explored to improve traffic efficiency and reduce congestion [10, 11]. Decentralized LoRa communication networks have also demonstrated the potential to synchronize traffic signals without permanent infrastructure [9-11]. However, existing approaches may face limitations related to communication reliability, system complexity, and adaptability to temporary road conditions [8,9].

Despite these developments, further investigation is required into portable, decentralized traffic control systems specifically designed for temporary single-lane road operations. Most existing intelligent traffic management systems focus on permanent intersections or rely on centralized communication infrastructure. To address this gap, the present study proposes a LoRa-based ad hoc traffic light system integrating an Arduino Mega microcontroller, LoRa P2P communication, and ultrasonic sensors for vehicle detection and adaptive signal coordination. The proposed system aims to provide reliable wireless communication, synchronized traffic signal operations, and flexible deployment for temporary road construction and maintenance applications.

In addition, the proposed research aligns with several United Nations Sustainable Development Goals (SDGs) [9]. The utilization of energy-efficient electronic components and potential integration of renewable energy technologies contribute to SDG 7 (Affordable and Clean Energy). The application of embedded systems and LoRa-based wireless communication to temporary traffic management supports SDG 9 (Industry, Innovation, and Infrastructure) by promoting technological innovation and infrastructure adaptability. Furthermore, the development of a coordinated traffic control approach contributes to SDG 11 (Sustainable Cities and Communities) by supporting safer and more efficient transportation environments. Overall, this research demonstrates the potential application of wireless communication and embedded technologies in addressing practical traffic management challenges while supporting sustainable infrastructure development.

# METHODOLOGY

The selection of appropriate hardware and software components is essential for developing a reliable, energy-efficient, and cost-effective LoRa-based temporary traffic control system. LoRa communication technology was selected due to its long-range wireless transmission capabilities, low power consumption, and suitability for infrastructure-independent applications. The proposed system incorporates a microcontroller, LoRa transceiver modules, traffic signal units, and power supply components to establish wireless communication and coordinate traffic signal operations at both ends of a temporary road construction zone.

The hardware components were evaluated based on communication reliability, transmission range, energy efficiency, and implementation cost. System performance was assessed through communication range testing, packet transmission success rate, and transmission latency to determine the reliability and responsiveness of wireless traffic signal synchronization. Meanwhile, the Arduino Integrated Development Environment (IDE) was utilized for system programming, debugging, and monitoring due to its hardware compatibility, accessibility, and flexibility in embedded system development.

From a sustainability perspective, the proposed wireless architecture reduces dependence on physical cabling and associated installation materials, potentially minimizing resource consumption and deployment complexity. Furthermore, the low-power characteristics of LoRa communication and the utilization of affordable, readily available electronic components support energy-efficient operation and cost-effective implementation. Overall, the systematic selection and evaluation of hardware and software tools contribute to the development of a practical, reliable, and sustainable traffic management solution for temporary road construction applications.

This study adopts an experimental research approach involving prototype development and performance evaluation under various operating conditions. The methodology comprises hardware integration, software implementation, system deployment, and experimental assessment of wireless communication performance. The collected experimental data are statistically analysed to evaluate the reliability of LoRa communication, traffic signal synchronization, and overall system performance. The research design and methodological framework are illustrated in Figure 3.1.

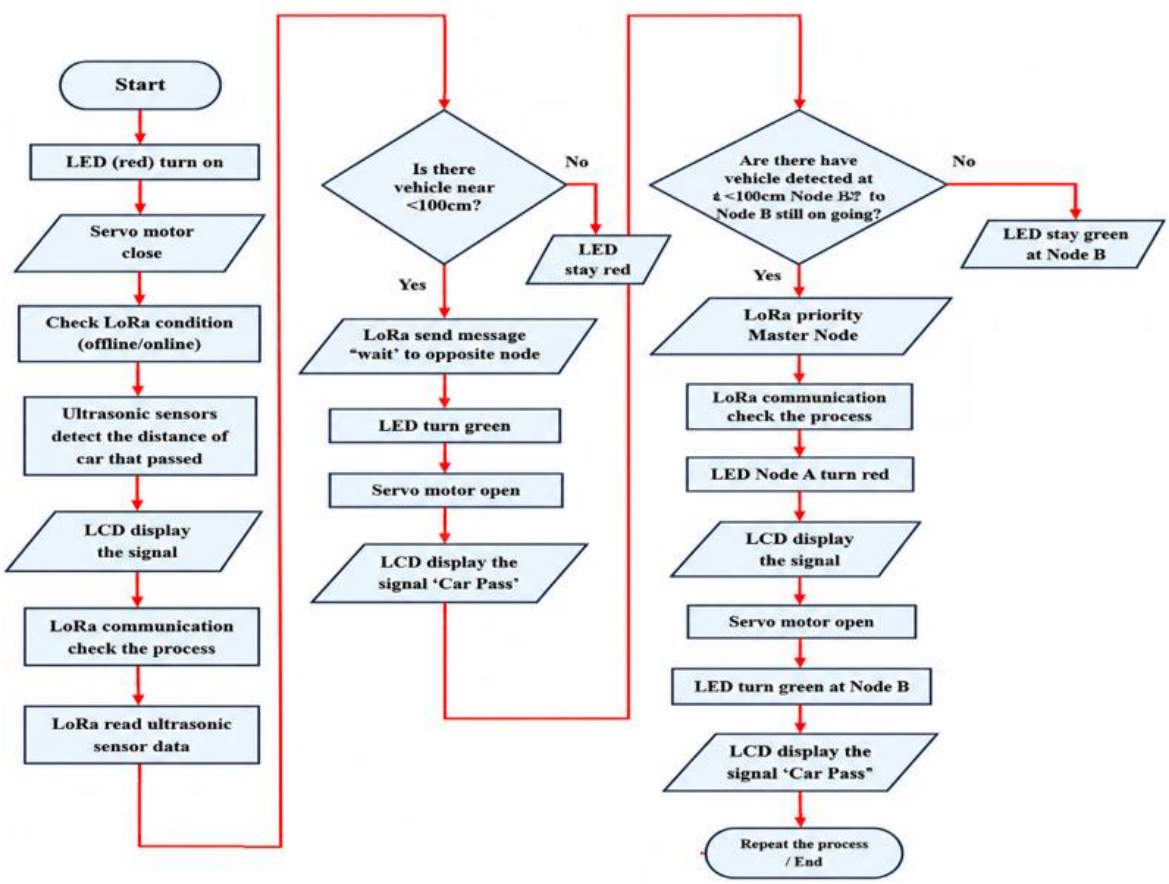



Figure 3.1 Research process flow

This study presents the design and development of a LoRa-based ad hoc traffic light system for temporary road construction applications. The proposed system utilizes LoRa wireless communication technology to establish reliable and synchronized traffic signal operations between two nodes positioned at opposite ends of a temporary single-lane road section. The experimental setup consists of two identical traffic signal units, designated as Node A (Master) and Node B (Slave), which communicate directly through a peer-to-peer (P2P) wireless network without requiring an intermediate gateway. Both nodes exchange control and timing information to coordinate traffic signal operations and regulate vehicle movement. The system performance is evaluated based on key

parameters, including communication range, packet delivery rate, transmission latency, and overall operational reliability. Figure 3.2 illustrates the research design and experimental framework adopted in this study.

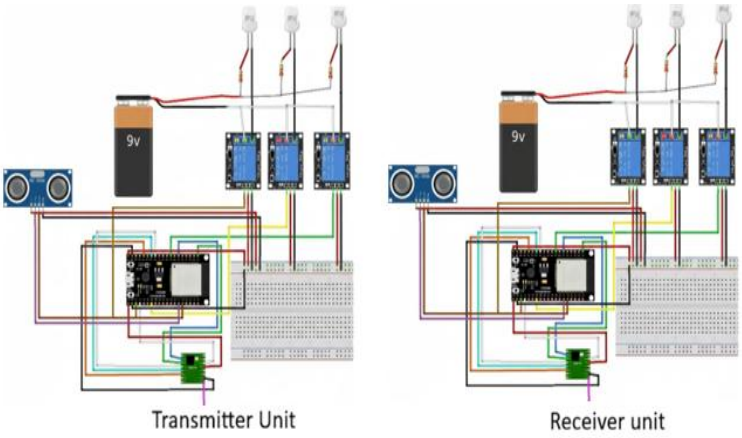



Figure 3.2 Schematic design for Master (Transmitter) and Slave (Receiver) unit

## REULTS AND DISCUSSION

This section presents the experimental results and performance analysis of the proposed LoRa-based ad hoc traffic light system for temporary road management applications. The system performance is evaluated based on key communication parameters, including transmission range, packet delivery rate (PDR), received signal strength indicator (RSSI), communication latency, and operational reliability. Experimental tests were conducted at varying communication distances to assess wireless transmission performance and determine the maximum reliable communication range. Additionally, functional testing was performed to evaluate traffic signal synchronization and coordination between the two traffic light nodes. The experimental findings are analyzed to determine the feasibility and effectiveness of the proposed system for temporary single-lane road control applications. The discussion further highlights the system's performance, operational limitations, and potential improvements for future development.

This experiment evaluates the effect of increasing communication distance on wireless signal strength and transmission performance. The experimental setup involved positioning the master node (Node A) and slave node (Node B) at varying separation distances, beginning at 100 m and progressively increasing to the maximum operational range permitted by the test environment as shown in Table 3.1.

The first scenario evaluates the system's response when a vehicle is detected near Node A at a scaled distance of 0.5 cm, representing approximately 500 m, while no vehicle is detected at Node B. Upon vehicle detection, Node A transmits a control request to the master controller through LoRa communication. The controller subsequently prioritizes Node A by extending its green signal duration to a maximum of 45 s while maintaining Node B in the red phase. This coordinated operation enables vehicles at Node A to proceed while preventing conflicting traffic movements from Node B, demonstrating the system's adaptive traffic signal control capability.

The second scenario examines the system's response when a vehicle is detected at a scaled distance of 3.0 cm, representing approximately 3 km, beyond the predefined activation threshold of 1.5 cm. Under this condition, Node A transmits a low-priority status message without initiating an immediate signal change. Consequently, the controller maintains the traffic signals in their predefined standby state until the vehicle enters the active detection zone. This approach minimizes unnecessary signal switching and supports more efficient traffic management during low-demand conditions.

The third scenario investigates simultaneous vehicle detection at both nodes at a scaled distance of 0.5 cm. When both nodes transmit traffic requests, the controller applies a priority-based scheduling mechanism to determine the signal sequence. The first successfully received request is assigned priority, allowing Node A to operate with a green signal duration of 20s, while Node B remains in the waiting state. Once Node A complet-

es its traffic clearance phase, the controller transmits a LoRa command to switch Node A to red before activating the green signal at Node B. This sequential coordination demonstrates the proposed system's capability to manage competing traffic demands while minimizing conflicting vehicle movements in temporary single-lane road operations.

Table 3.1: Car Distance from two nodes: A and B

| Traffic Scenario | Reported Car distance (m) | Node A status | Node B status | Control interpretation |
|---|---|---|---|---|
| Vehicle detected near Node A | 500 | Green | Red | Node A receives priority |
| No vehicle detected | 0 | Red | Red | Both signal remains red |
| Simultaneous vehicle detection at both nodes | 500 | Green First | Waiting | Node A receives initial priority, Node B waits |

The analysis aims to determine the relationship between transmission distance and signal degradation, thereby assessing the communication performance of the proposed LoRa-based traffic light system and presented in Table 3.2.

Table 3.2: Traffic Signal Coordination and priority Control Matrix

| Distance (LoS) | Test distance (m) | RSSI (dBm) | Packet delivery Rate (%) |
|---|---|---|---|
| Short distance | 100 | -68 | 100 |
| Medium distance | 500 | -84 | 98.4 |
| Maximum range | 1000 | -97 | 95.6 |

The results presented in the Figure 4.1 demonstrate the potential of the proposed LoRa-based ad hoc traffic light system as an alternative to conventional manual traffic control. In Scenario 1, the system improves traffic management efficiency by prioritizing the approach with detected vehicles, potentially reducing unnecessary waiting time by up to 45s when traffic demand is uneven between the two nodes. In Scenario 2, the system maintains its standby operation when vehicles are detected beyond the predefined activation threshold. This mechanism prevents unnecessary traffic signal switching, reduces redundant operational cycles, and supports more efficient traffic control during low-demand conditions. In Scenario 3, the proposed system utilizes LoRa-based communication and priority scheduling to coordinate simultaneous vehicle detection at both nodes. The packet queuing mechanism enables sequential traffic signal activation, reducing the possibility of conflicting vehicle movements. Overall, these findings indicate that the proposed system offers a promising approach to improving traffic signal coordination, operational efficiency, and safety in temporary single-lane road management applications. The final prototype of functional LoRa ad hoc network traffic control is shown in Figure 4.2.

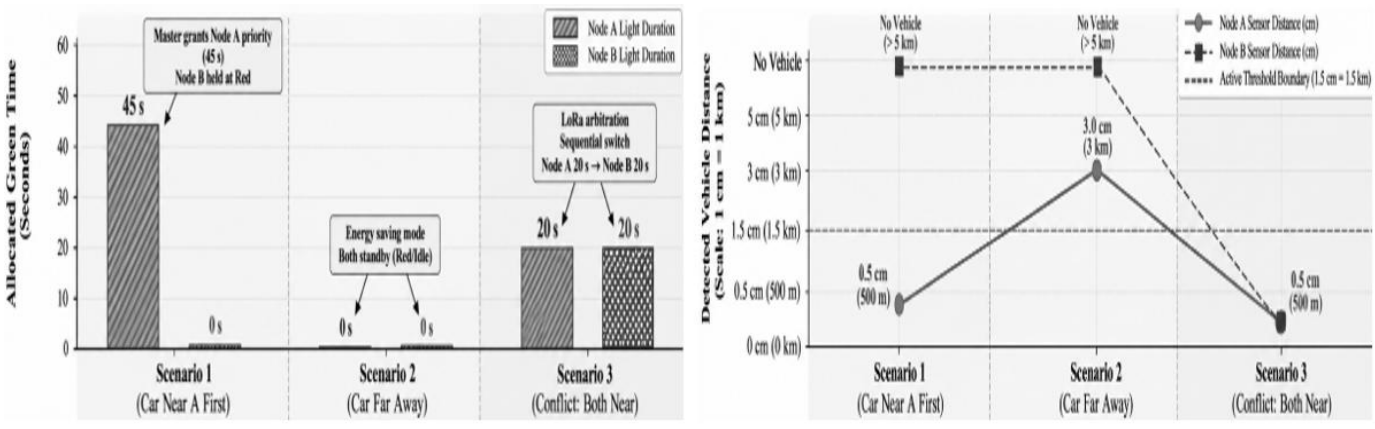



Figure 4.1 Implemented LoRa adhoc network on simulated field test



Figure 4.2 Functional Ad Hoc Network Traffic Control

## CONCLUSIONS

This study successfully developed and evaluated an intelligent LoRa-based ad hoc traffic light system for temporary road management applications. The proposed system integrates a decentralized master and slave architecture, proximity sensors, and a priority-based control algorithm to enable adaptive traffic signal coordination based on vehicle detection. By utilizing LoRa communication, the system reduces dependence on conventional wired infrastructure and cellular networks while minimizing the need for manual traffic control. The experimental results demonstrate the system's capability to coordinate traffic signal operations, allocate green light durations according to traffic demand, and reduce unnecessary waiting periods under simulated traffic conditions. These features highlight its potential to improve operational efficiency and reduce road workers' exposure to traffic-related hazards in temporary construction zones.

The experimental evaluation further demonstrated reliable wireless communication between the traffic signal nodes using the LoRa (SX1278) module. Communication testing conducted over distances of up to 500m recorded received signal strength indicator (RSSI) values ranging from −68dBm at shorter distances to −97 dBm at the maximum tested range, with a reported link margin of 20dB above the receiver sensitivity. Furthermore, scaled prototype testing, based on a simulation ratio of 1cm representing 1km, demonstrated the system's ability to respond to varying traffic conditions through adaptive signal timing and priority-based coordination. Overall, the findings indicate that the proposed LoRa-based traffic control system offers a promising, cost-effective, and infrastructure-independent alternative for temporary single lane road management. Future research should focus on full-scale field validation, communication reliability under varying environmental conditions, and further optimization of traffic signal control algorithms to enhance practical deployment and operational performance.

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