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Smart Traffic Signal Preemption System for Ambulance Clearance Using IOT

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***Abstract*— This system addresses life-threatening delays caused by traditional, inflexible traffic management at urban intersections. The architecture utilizes an IoT-based framework where sound sensors distinguish ambulance sirens from ambient noise to dynamically activate a green corridor. Specifically, a sound sensor placed 120 meters from an intersection identifies the approaching vehicle's sound level, while a second sensor near the traffic pole confirms clearance, allowing the system to revert to normal operation. To ensure reliable long-range communication, the system integrates LoRa (Long Range) technology for signal transmission and reception between the ESP32 controlled components. Experimental results indicate this automated approach is significantly more efficient than GPS or image processing, reducing 50km transit times to approximately**
20 minutes. By combining LoRa connectivity with acoustic sensing, the system provides a cost-effective solution to prioritize emergency vehicles and save human lives.

Keywords* — *sound sensors, IoT (Internet of Things), Arduino UNO, traffic light, Ambulance, LoRa (Long Range), traffic signal preemption, siren detection, green corridor, emergency vehicle clearance.

I. INTRODUCTION

Rapid urbanization and the surge in global population growth have led to a significant increase in vehicle density, resulting in severe urban traffic congestion. Conventional traffic management systems typically rely on fixed-time signal sequences and durations, which are inherently inflexible and fail to adapt to the real-time requirements of Emergency Medical Services (EMS). These delays at signalized intersections are a critical factor in emergency response times, where even a few minutes' delay can drastically reduce a patient's chances of survival. Statistics indicate that in some regions, hundreds of fatalities occur annually due to late ambulance arrivals caused by traffic gridlock. Consequently, there is an urgent need for intelligent transportation systems (ITS) that can autonomously prioritize emergency vehicles.

The proposed "smart traffic signal preemption system for ambulance clearance using iot" addresses these challenges by integrating a multi-layered sensor network and advanced communication protocols. A central innovation of this architecture is the implementation of LoRa (Long Range) technology for robust signal transmission and reception. Specifically, the system utilizes LoRa modules Such as the RFM69HCW, which operate at 900 MHz and provide a reliable communication range of up to 2 km in line-of-sight conditions. This facilitates seamless Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communication, allowing an approaching ambulance to broadcast a "hello" message or beacon status to the traffic infrastructure well before it reaches the intersection.

To ensure high precision in localization, the system employs Received Signal Strength Indicator (RSSI) measurement and Two-Way Time of Arrival (TwToA) techniques to identify the ambulance's specific lane and approach direction. Because RSSI can fluctuate due to multipath fading in urban environments, a Kalman filter is applied to stabilize these measurements, ensuring the correct Roadside Unit (RSU) is triggered. Once the ambulance is detected within a predefined radius—typically between 100 and 300 meters—the system activates a green corridor by overriding the current traffic cycle.

The system's reliability is further enhanced by a dual-detection framework that combines AI-powered visual sensing with acoustic backup. An AI module utilizing YOLOv8 processes live video feeds from cameras at the intersection to identify ambulances with high confidence. As a fail-safe, LM393 sound sensors or frequency measuring controllers are positioned at intervals (e.g., 120 meters) to detect the specific 120dB siren frequencies of an approaching emergency vehicle. These detection events are managed by microcontrollers like the ESP32 or Arduino Mega, which can also leverage Peer-to-Peer (P2P) networks via the ESP-NOW protocol for internet-less operation.

Data processing is handled through cloud-based servers or edge computing nodes, allowing for real-time traffic analysis and predictive route optimization using machine learning algorithms like Random Forest Regressors. This enables the system to calculate the optimal time required to clear all traffic at a specific junction before the ambulance arrives. Furthermore, digital display boards can be activated to warn other motorists and pedestrians to clear the path, enhancing safety for all road users.

Experimental results and simulations conducted via platforms like SUMO (Simulation of Urban Mobility) demonstrate that



This integrated IoT and LoRa-based approach is highly effective. Implementation of these systems has shown a 42% to 50% reduction in intersection delay. In practical scenarios, these frameworks have successfully reduced transit times for 50 km distances to approximately 20 minutes, vastly outperforming traditional GPS-only or manual methods. By automating the establishment of green corridors and reverting to normal operations once the vehicle has cleared the zone, the system provides a scalable and cost-effective solution for modern smart cities to save human lives

II. RELATED WORK

Proposes a distributed IoT framework that uses real-time GPS data to detect ambulances within a 100-meter radius of an intersection. The system, tested via SUMO simulation, employs roadside units and edge controllers to override signals, achieving a 42% reduction in ambulance delay. Its O(1) computational complexity ensures suitability for real-time edge processing in smart city environments [1].presents an adaptive traffic control model that identifies emergency vehicles through integrated visual and acoustic sensing without requiring vehicle-side sensors. It utilizes Arduino-based controllers to measure siren frequencies, specifically "yelp" and "wail," to trigger prioritized green lights at a consistent average distance of 300 meters. Simulations validate that the system significantly reduces travel time across various traffic densities [2].focuses on a hardware-centric solution utilizing Radio Frequency (RF) transmitter and receiver pairs operating at 433MHz to preempt traffic signals. The system is built around the Arduino ATmega 2560 microcontroller to grant signal priority, aiming to address the 20% of patient deaths attributed to traffic delays. It is designed to be an automated traffic freeway system that enables communication between hospitals and ambulances [3].introduces the "Future Sight" system, which combines machine learning and IoT to perform predictive analysis of traffic signals through an Android app that factors in patient criticality. Using a Random Forest Regressor and NodeMCU microcontrollers, the system successfully reduced travel times by 8 to 10 minutes in optimized test runs. It aims to ensure an obstacle-free path from source to destination by turning signals green in advance [4].implements a Vehicle-to-Everything (V2X) communication system using On-Board Units (OBUs) and Roadside Units (RSUs) to expedite ambulance transit at intersections. It employs RSSI and Two-Way Time of Arrival (TwToA) techniques to precisely identify the ambulance's lane and has demonstrated a 40% reduction in average wait times. The system also utilizes V2V communication to broadcast alert messages to surrounding vehicles [5].combines visual sensing with specialized network protocols to calculate ambulance distance using Euclidean measurements from real-time video feeds. It introduces the PE-MAC protocol to prioritize emergency data transmission in a VANET environment, resulting in a 42% reduction in end-to-end delay compared to standard protocols. Simulations in NS-2 prove it also improves throughput and significantly reduces energy consumption [6].presents the Smart Traffic Management Alert System (STMAS), which uses GPS tracking via NEO-7M modules and ESP32 microcontrollers to establish a "Green Corridor". The system uniquely integrates LED display boards that warn surrounding drivers with messages like “Ambulance Approaching – Give Way” before switching signals. This synchronized operation is designed to reduce response times while improving road safety and public Awareness[7].mirrors the methodology of 2.pdf, presenting an automated signal pre-emption system that utilizes IoT and machine learning to assist ambulances. It focuses on minimizing human intervention by using software APIs for data collection and controlling signals based on predictive models. The research demonstrates that travel time can be significantly reduced by accurately predicting signal clearance requirements beforehand[8].Explores an acoustic methodology utilizing sound sensors placed 120 meters from traffic poles to detect siren levels of 120dB. An Arduino UNO controller processes the captured sound via IoT to provide lane-specific clearance, reverting to normal operation once the ambulance crosses the traffic pole. Comparative analysis shows that this sensor-based system is a more efficient way to reduce delays than standard GPS methods [9].details a hybrid prioritization system that combines real-time AI visual sensing using YOLOv8 with an acoustic LM393 sound sensor fail-safe. Controlled by an ESP32 microcontroller, the system provides high-confidence detection and automatic green signal triggers to reduce response times in metropolitan areas. It also integrates with a Flask-based IoT dashboard, allowing authorities to verify and monitor signal status in real time [10].

III. PROPOSED METHODOLOGY

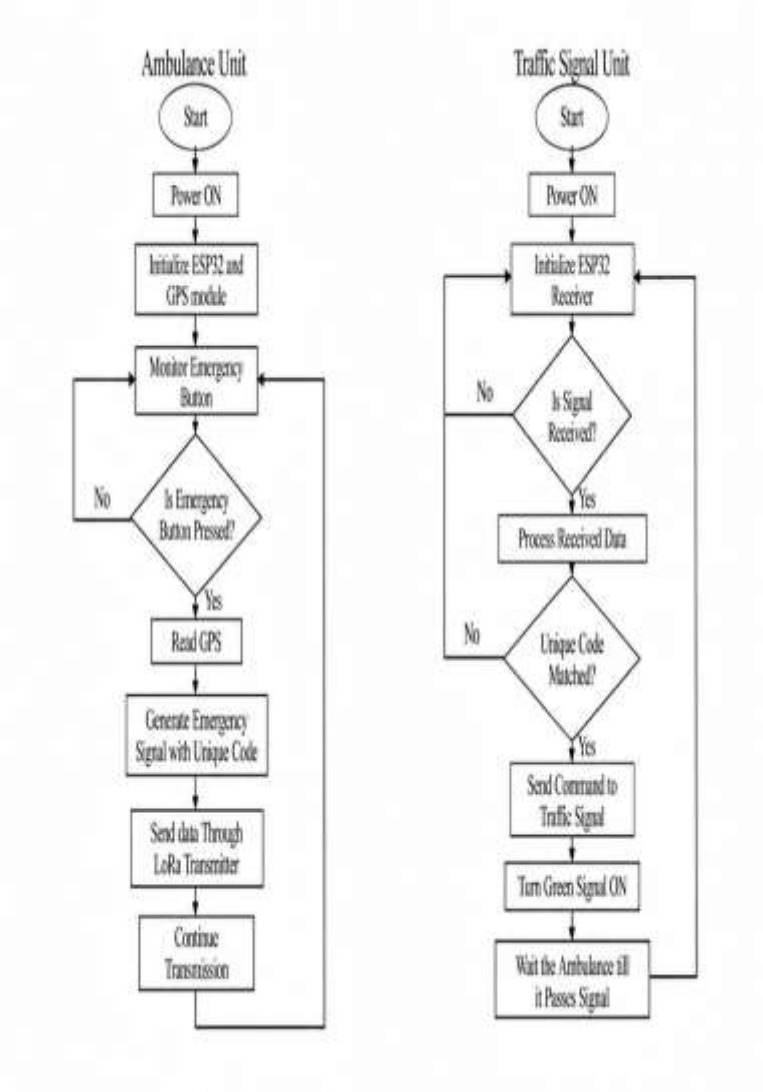


Fig 1: Flowchart of Smart Traffic Signal Preemption System for Ambulance Clearance Using IoT



1. Ambulance Side Flowchart

The operational architecture of the Ambulance Unit begins at the initial start node designated as Start, which represents the system's baseline state prior to hardware operation. Upon supplying electrical power to the module via Power ON, the control logic immediately transitions to the hardware setup phase labelled Initialize ESP32 and GPS module. In this state, the system configures the internal micro-controller peripherals and establishes connection with the Global Positioning System module to ensure sensor readiness. Once initialization completes, the control flow moves into the active polling phase, designated as Monitor Emergency Button, where the system continuously monitors the digital input status of the emergency trigger switch.

The workflow then encounters its primary conditional branch at the decision diamond Is Emergency Button Pressed?. This decision gateway evaluates whether an emergency condition has been initiated by the operator. If the condition evaluates to No, indicating that no emergency input is detected, the control flow executes a feedback loop directing the system straight back to Monitor Emergency Button. This negative branch creates a continuous polling loop, keeping the unit in a standby monitoring state until an emergency input occurs.

Conversely, when the decision evaluates to Yes, confirming that the emergency button has been pressed, the execution path breaks out of the polling loop and advances to Read GPS. In this process block, the ESP32 queries the initialized GPS module to acquire real-time geographical location coordinates. Immediately following spatial data acquisition, the system moves to Generate Emergency Signal with Unique Code. Within this functional block, the system packages the acquired GPS location data alongside a specific vehicle identifier code into a standardized emergency data transmission payload.

Following data payload construction, the control flow advances to send data Through LoRa Transmitter. In this step, the ESP32 interfaces with the Long Range radio module to broadcast the payload across the wireless communication channel. Once the transmission is executed, the process flow does not terminate; instead, it follows a continuous return loop that leads directly back to Monitor Emergency Button. This structural feedback loop ensures that the Ambulance Unit repeatedly checks the emergency button state, reads updated GPS location coordinates, generates refreshed payloads, and retransmits the signal continuously throughout the duration of the emergency trip.

2. Traffic Signal Side Flowchart

The operational architecture of the Traffic Signal Unit functions as the corresponding receiving control system, initiating at its own designated Start node. Following the activation of the signal station via Power ON, the system immediately executes the initialization task labelled Initialize ESP32 Receiver. During this phase, the traffic control unit configures the ESP32 micro-controller along with its connected LoRa receiver hardware, setting up the wireless parameters necessary to listen for incoming signals broadcast by approaching vehicles.

Upon completing initialization, the system transitions into its primary detection stage at the decision diamond Is Signal Received?. This stage acts as a continuous gateway monitoring the wireless communication channel. If the evaluation result is No, indicating that no wireless transmission has been detected, the system executes a recurrent loop returning directly back to Initialize ESP32 Receiver. This maintains the traffic station in a persistent listening state while preserving the normal traffic signal operations at the intersection.

When an incoming transmission is successfully captured by the receiver hardware, the evaluation yields a Yes, causing the control flow to advance to Process Received Data. In this process block, the ESP32 unpacks the incoming LoRa radio packet to extract the embedded transmission parameters, specifically isolating the location data and the broadcast vehicle code. The flow then immediately moves to a critical verification block represented by the decision diamond Unique Code Matched?.

At Unique Code Matched?, the unit compares the extracted vehicle code against an authorized database of registered emergency vehicle identifiers. If the decision evaluates to No, indicating an invalid, unrecognized, or non-matching code, the system discards the payload and executes a return branch back to Initialize ESP32 Receiver, preventing unauthorized signal state modifications. If the code verification evaluates to Yes, confirming a legitimate emergency vehicle transmission, the control flow advances to Send Command to Traffic Signal.

In the Send Command to Traffic Signal block, the ESP32 issues an override instruction to the traffic light controller hardware. This leads directly to Turn Green Signal ON, which forces the traffic light for the approaching ambulance lane to illuminate green, establishing immediate lane clearance. To maintain safety during traversal, the workflow enters the state Wait the Ambulance till it Passes Signal. In this phase, the green signal state is held active to allow the emergency vehicle to clear the intersection. Once the ambulance successfully passes the signal, the workflow completes its operational cycle by executing a structural loop back to Initialize ESP32 Receiver, returning the system to baseline monitoring to await subsequent emergency signals.

3. Overall Flowchart Analysis

The overall flowchart analysis demonstrates a dual-module IoT control system divided into the Ambulance Unit (Transmitter side) and the Traffic Signal Unit (Receiver side), both controlled by ESP32 microcontrollers. The workflow relies on conditional decision gateways to govern system operations. On the ambulance side, the decision node Is Emergency Button Pressed? controls whether the hardware remains in a standby state (Monitor Emergency Button) or executes spatial data capture (Read GPS), payload construction (Generate Emergency Signal with Unique Code), and wireless broadcasting (Send data Through LoRa Transmitter). On the traffic signal side, a two-tier validation mechanism (Is Signal Received? and Unique Code Matched?) filters wireless data and authenticates vehicle credentials before initiating hardware overrides (Send Command to Traffic Signal), switching lights (Turn Green Signal ON), and maintaining lane clearance (Wait the Ambulance till it Passes Signal). Both units operate through continuous closed-loop feedback cycles, ensuring real-time readiness without terminal end states.

IV. CONCLUSION

The Smart traffic signal preemption system for ambulance clearance using IOT provides an automated traffic override framework using an Ambulance Unit and a Traffic Signal Unit. The Ambulance Unit starts at Start with Power ON and proceeds to Initialize ESP32 and GPS module. It continuously monitors inputs via Monitor Emergency Button. When Is Emergency Button Pressed? evaluates to Yes, the system executes Read GPS, Generate Emergency Signal with Unique Code, and Send



data Through LoRa Transmitter**.** The logic then loops back to Monitor Emergency Button to maintain real-time broadcasting.

The Traffic Signal Unit begins at Start with Power ON and Initialize ESP32 Receiver. It checks Is Signal Received?**.** Upon signal detection, it moves to Process Received Data and evaluates Unique Code Matched?**.** If verified, the system executes Send Command to Traffic Signal, triggers Turn Green Signal ON, and holds the light state during Wait the Ambulance till it Passes Signal**.** Unmatched codes or completed traversals automatically loop back to Initialize ESP32 Receiver**.**In summary, integrating GPS tracking, LoRa transmission, ESP32 microcontrollers, and Unique Code security creates an effective, closed-loop IoT system for automated emergency vehicle clearance.

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