Traffic Signals Pre-Alerting System for Ambulance

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Abstract

It is heartbreaking to learn about the infrastructure of insufficient roads as a result of neglect for traffic rules. In these incidents, an ambulance is sent to a nearby hospital in the hope of saving the victim's life, but on the route, it faces a crowd at traffic signals. This is a problem that affects a large part of the nation. No matter how loud the siren, there will always be a crowd at traffic signals, which puts the patient at risk inside the ambulance. The traffic police's inability to effectively clear the path for the ambulance using its siren presents a serious obstacle in this dangerous scenario, as it limits their ability to intervene and change traffic signals when an ambulance approaches. The failure to determine the direction of the ambulance presents an opportunity to suggest a fix by supporting the amendment of the generic system of traffic light concepts through the use of a Peer-to-Peer Network Model. A wireless IoT concept called Peer Network is used to connect devices without the need for an internet connection. An internet-less paradigm has been proposed to execute a wireless perception of traffic signals. Using the Peer-to-Peer Protocol, all traffic signals and ambulances are connected without internet access to provide alert messages, such as transforming traffic lights into an emergency mode based on the direction from which the ambulance is approaching. Peer-to-Peer eliminates obstacles between communication devices, and the reliability of this system is greater than that of the Internet. The prototype of this model was successfully implemented using a traffic light and four NodeMCUs, with a master NodeMCU that controls all four NodeMCUs to change the traffic lights.

Keywords: Traffic signal, Ambulance, Peer network, Master-Slave

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1. Introduction

The disability of an ambulance to warn other cars and traffic police to make way is an inability to reach a considerable distance, given that the alerts can only be active when the ambulance is detected and its direction and speed are measurable. Heavy traffic is one of the main causes of one of the ten deaths occurring during ambulance rides to the hospital. The siren of the ambulance is a valuable feature, but it only works to alert traffic during emergencies; it does not help with traffic signals where gridlock occurs. The ambulance siren serves as a means of warning other drivers of the emergency vehicle. Since severity of emergencies varies, the siren is calibrated in terms of both volume and intensity depending on conditions. It is clear that on-road drivers are able to hear the approaching ambulance only when it is close to them. Most of the time, this results from drivers competing immorally, leading to crashes at the intersections.

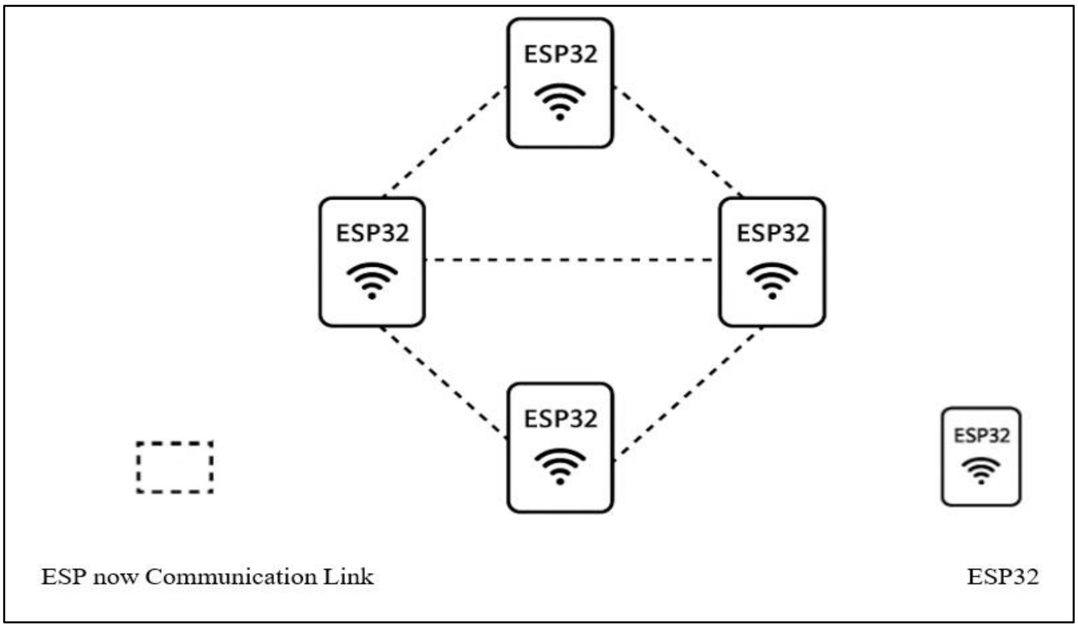

Figure 1. Peer-to-Peer Network

Figure 1 illustrates the peer-to-peer network; the paper proposes a peer-to-peer network as an additional or alternative method. In this network, vehicles and traffic junctions that are unable to hear the ambulance's siren can see the traffic light changing to emergency lights, alerting them to the impending arrival of an ambulance and requiring them to make room for it. The benefit in this case is that the ambulance arrives at the intersection before a specified number of kilometre’s, allowing the other cars in the intersection to prepare to yield to it. Furthermore, because peer-to-peer connections link to specific peers, they have a lower chance of failing than internet-connected systems. The noteworthy aspect of this situation is that, in contrast to siren sounds, which are only audible to nearby vehicles, the network allows those who are far from the ambulance to become aware of an emergency by means of altered traffic signals. An embedded device called NodeMCU, which has a better peer network, is used to implement the peer-to-peer network The "esp-now" protocol, a peer-to-peer network protocol common to all generic ESP modules, is utilized with the Nodemcu. All of the Nodemcu devices can be networked together and utilized for data sharing without requiring an internet connection thanks to the esp-now protocol.

2. Related Work

Optimal emergency care relies on good communication in ambulance pre-alerts. Sampson et al. [1] carried out a qualitative study of UK emergency services to find out what makes "good" pre-alert communication. They found it crucial to have clarity, relevance, and an organized format in pre-alert messages for better situational awareness among ED staff. Nevertheless, Boyd et al. [2] pointed out a critical inconsistency among UK ambulance services in pre-alert guidelines. In their review, they found that although the majority of services do have frameworks, the absence of standardization in criteria and terminology can complicate inter-agency collaboration and prompt response. Long et al. [3] also investigated the internal processes of EDs in reacting to pre-alerts. Their findings indicated differences in the interpretation and response to pre-alerts by different hospitals, with some following deliberate triage protocols while others used informal judgment, resulting in inconsistent outcomes in patient prioritization. Concurrent with the above, Gunn [4] investigated the correlation between hospital pre-alert processes and on-scene intervals for acute stroke patients. His retro-prospective study indicated that efficient and targeted pre-alert procedures have the potential to greatly decrease response times, ultimately affecting stroke outcomes. The application of technology in emergency response and traffic systems is becoming ever more pertinent. Vennila et al. [5] suggested an IoT-based system for traffic monitoring to help with real-time route optimization and congestion relief. Although not specifically related to ambulance traffic, such systems are significant in enhancing emergency vehicle travel using intelligent signaling and routing.

Prehospital innovation is also changing beyond logistics. Eder and Rashid [6] proposed telemedicine in trauma care, allowing for remote clinical input in prehospital stages. Their contribution highlights the increasing convergence of digital health and emergency response, especially in rural or resource-constrained environments. Similarly, Ramsay et al. [7] assessed the effect of video triage for patients with suspected strokes. The mixed-methods analysis identified that the combination of live video consultations with clinical evaluation improved early decision-making, decreased unwarranted transfers, and enhanced access to specialists. In trauma settings, Holton et al. [8] performed a prospective study to determine the timing of the evacuation of head injury patients prior to and following the establishment of a major trauma center. Their results demonstrated that system-wide reorganization can significantly reduce time to surgery, directly enhancing outcomes. Finally, from a broader vehicle management perspective, Kanakala et al. [9] reviewed IoT and transfer learning applications for predictive vehicle maintenance. While their focus was on general vehicles, the methodologies have potential in ambulance fleet management, contributing to operational readiness and reduced mechanical failure rates during critical missions.

3. Proposed Work

A peer network-based traffic control system for ambulances is proposed, which consists of microcontrollers to monitor the traffic junction for incoming emergency vehicles, such as ambulances, destined for hospitals or accident zones without encountering congestion problems on the road.

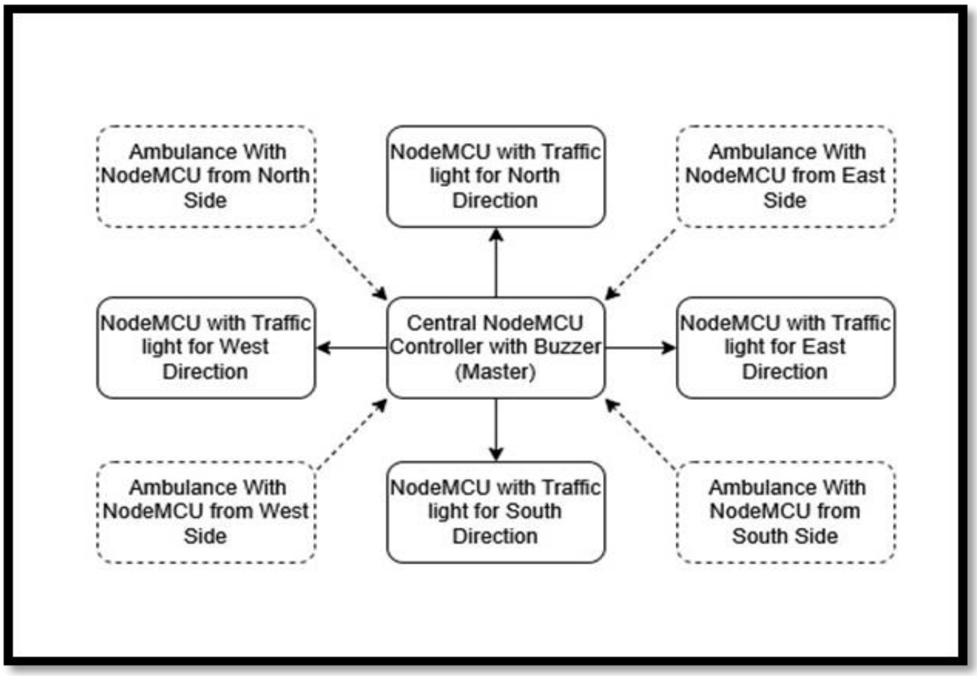

Figure 2. Block Diagram of Proposed Design Principle

The peer-to-peer network facilitates communication between microcontrollers or wireless devices to transmit and acknowledge data without relying on internet connectivity. Initially, the traffic junction has traffic lights for four-way roads: north, south, east, and west. Generally, traffic lights operate on a timer basis, where the lights change color based on a delay timer synchronized with all the other traffic lights. This timer-based approach aims to keep the traffic lights in sync so that vehicles can move fairly and smoothly. However, the problem arises when an emergency vehicle approaches the junction; this timer-based approach is ineffective in controlling congestion, preventing the ambulance from receiving priority in crossing the junction to reach its destination.

To overcome this emergency problem, a peer network-based traffic light approach is implemented where all the traffic lights are synchronized not by a timer but by a peer-to-peer network, in which every device communicates its status to every other device to ensure they stay on the same page. A simple representation of the working process of the proposed method is shown in Figure 2.

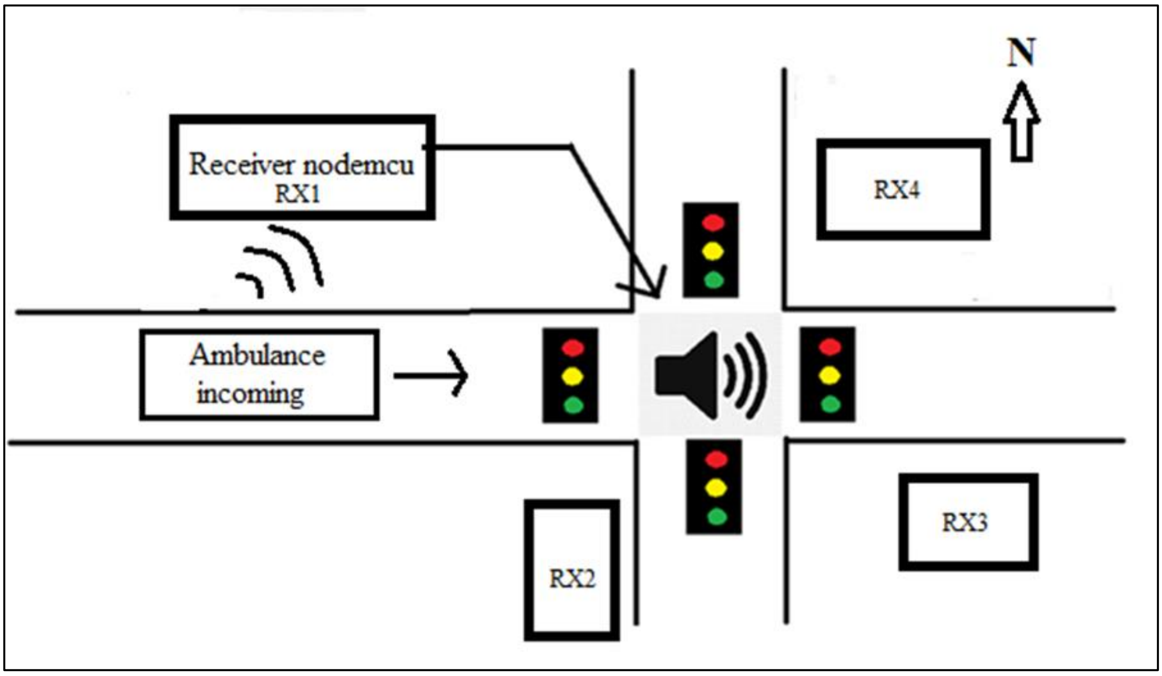

Figure 3. Idea Diagram of the Proposed Method

This peer network controls all the traffic lights and changes their colors based on the general concept of traffic lights. These four traffic lights (north, south, east, west) are not individually connected to one another, as that would create synchronization and timing errors when a decision needs to be made. Every node would start to behave independently, disrupting the algorithm and failing to avoid congestion. To ensure they all work in sync, a central controller is introduced, to which all four traffic lights are connected. The central controller acts as the master, while the other four traffic lights act as slaves. They receive what the master sends but do not send any data or messages back to the master. The central controller and traffic lights use a microcontroller called NodeMCU, which is better suited for a peer network infrastructure. This peer network is only available over a few meters; to extend this peer network infrastructure, additional nodes are added to increase the range in terms of distance. The transmission range of the peer network has been extended from meters to kilometers based on the power of the microcontroller.

Another microcontroller is placed on an ambulance or any emergency vehicle, which gets activated when the vehicle is in an emergency. In the case of an ambulance, when it starts its siren to indicate the emergency to nearby drivers on the road, the microcontroller gets activated and begins to transmit its status of emergency to nearby nodes in the peer network, as shown in Figure 3. When an ambulance is in an emergency and has its microcontroller activated, it starts sending its beacon status, indicating the stressful situation and its approach to the traffic junction. The microcontroller used for extending its peer network range receives the beacon signal. The reception of the beacon signal by the receiver controller indicates that the ambulance is nearing the traffic junction, and if there is any congestion or group of vehicles in its lane, they need to be cleared out immediately. The process of the receiver controller on the ambulance connecting to the peer network is represented in Figure 4. When the beacon is received from the ambulance approaching the junction, it is passed to the central NodeMCU, which controls the traffic lights to provide a path for the emergency vehicle. As soon as the status is transmitted to the central NodeMCU, it stops the normal operation of the traffic light and starts to operate to allow the emergency vehicle to pass, as shown in Figure 5. The central NodeMCU can determine the direction of the incoming ambulance by the corresponding receiver NodeMCU direction that sent the beacon signal. With that information, the central NodeMCU changes the ambulance's incoming lane to green to allow vehicles on the road to pass quickly and provide a way for the ambulance, while changing the traffic signal to red for the opposite lanes to prevent them from intruding into the junction until the ambulance passes through.

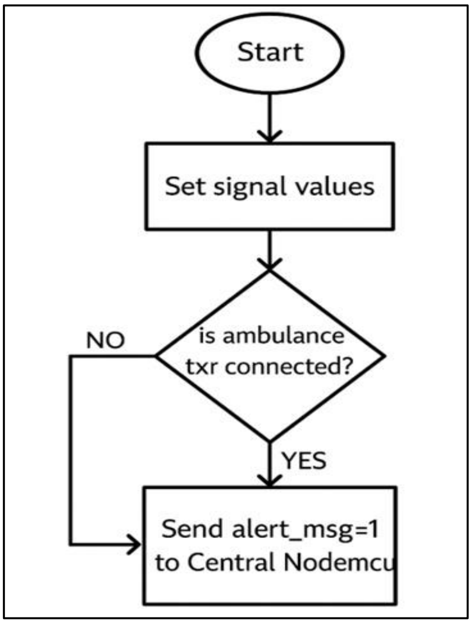

Figure 4. Receiver Controller's Process Flowchart

Once the ambulance passes the traffic junction, the status of the past traffic lights (when they were functioning on a general concept) is saved and resumed from that exact combination of traffic lights to continue the synchronization of all four traffic lights. Additionally, a speaker is fitted to announce the ambulance's arrival message on all sides to alert speeding drivers. In this way, vehicles not only in the lane where the ambulance is arriving but also on all four sides can be informed about the incoming ambulance and make informed decisions at the intersection.

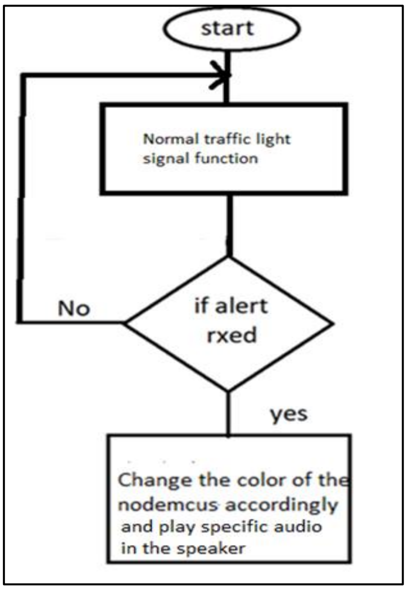

Figure 5. Central Receiver's Process Flowchart

The best part about this framework is that the ambulance's arrival is known pre-emptively even before it reaches the traffic junction, thanks to the extended peer-to-peer network, allowing standby vehicles to be moved out of the way before the ambulance arrives at the junction, which could save time for the ambulance to pass through the traffic junction.

3.1 Peer Node Model and ESP-NOW Protocol

In the peer-to-peer network model, the devices are connected to one another without the help of internet or Wi-Fi services. In the peer network model, the nodes or devices are connected using their unique IDs so that the messages sent are not misdirected. Once the devices are paired with each other, the connection is safe, and a peer connection is established with no handshake privileges. The peer network representation is shown in Figure 6. The devices can run out of power and restart, and still, they can automatically connect with the nearby devices without prior handshake mechanisms.

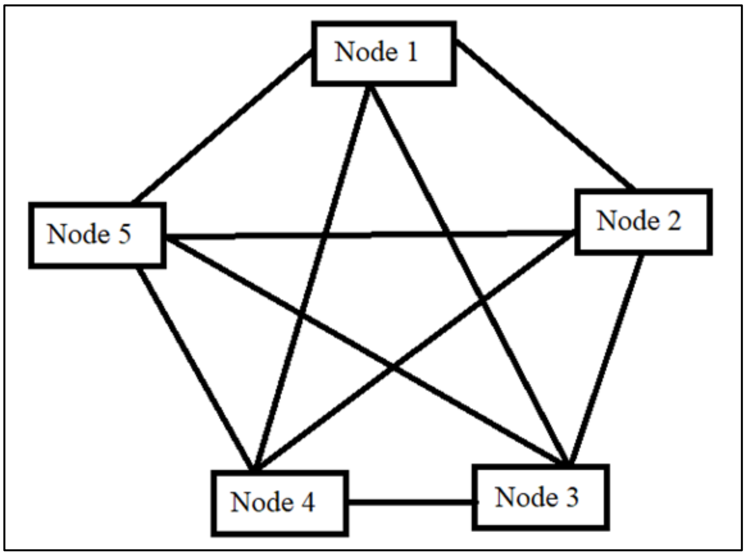

Figure 6. Central Receiver's Process Flowchart

And one such peer network protocol used widely for embedded devices is the ESP-NOW protocol, which should be briefly explained in the Introduction section to highlight its significance. The proposed work uses the ESP-NOW protocol to communicate with other devices in the peer network. The Arduino IDE supports the ESP-NOW protocol, which should be briefly explained in the Introduction section to highlight its significance. The ESP-NOW protocol, developed by Espressif, works like the 2.4GHz wireless transmission deployed in wireless devices. A vendor-specific action frame containing the application data is transferred from one Wi-Fi device to another without requiring a connection. Data action frames are secured by the usage of CTR in conjunction with the CBC-MAC Protocol (CCMP). The ESP-NOW protocol uses short packet transmission for data transmission and has fast, connectionless communication technology. ESP-NOW communication can help in master and slave transmission by keeping one device as master and the others as slaves, allowing for communication and data transmission through a peer-to-peer network (a detailed architecture diagram should be added to illustrate this) model.

3.2 Master-Slave Method

The master-slave characteristic is where a device acts as a master and sends data messages to other devices that act as slaves. The master initiates messages, and slaves initiate messages upon the master's request. Only one master is available in a network. Unless the master asks for any information from the slaves, they do not initiate or send messages; they just receive messages and act as per command. The master can address all slaves individually using their specific MAC addresses or all slaves simultaneously using the broadcasting method. The master-slave communication can exchange information using two communication modes: unicast and broadcast. In the case of the proposed work, the master-slave connection is established at the traffic junction. As the traffic lights are situated closely, the implementation of the master-slave in a peer network model is easy. The central controller acts as the master, and the other four traffic signals act as slaves, as shown in Figure 7.

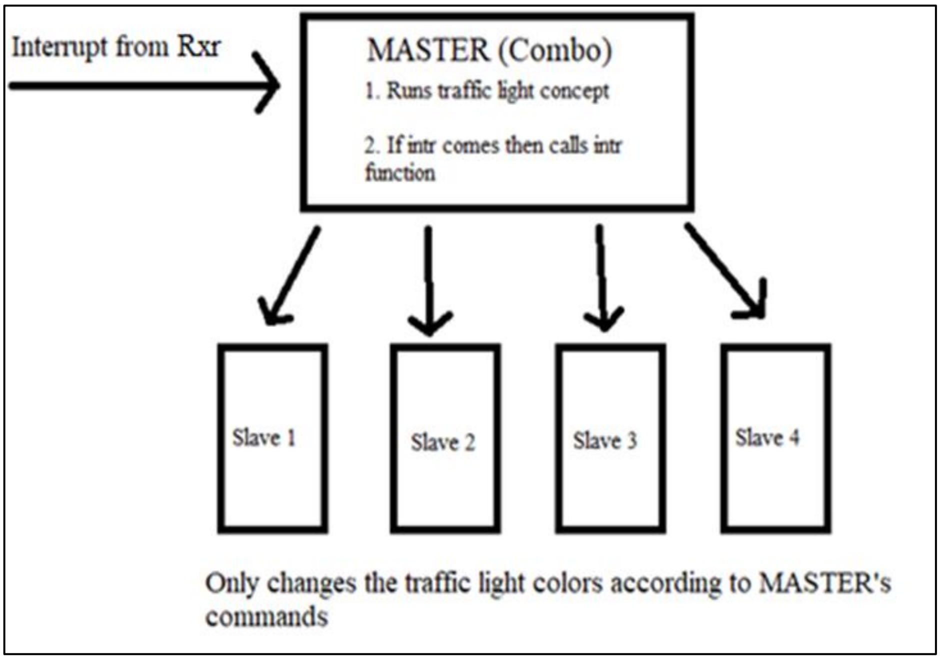

Figure 7. Master-Slave Implementation

The central controller shares all the information in the master-slave communication using the P2P (Peer-to-Peer) method. Initially, it shares the traffic light information, specifically which traffic color should be glowing on the four sides of the traffic signals, to all the slaves according to the general traffic light concept. When an alert interrupt is given by the receiver controller to the central controller, it sends the specific traffic light color messages to all four slave traffic signals to update their respective colors. In this system, the slaves do not send any messages; only the master controller sends messages, and the slaves change their traffic lights accordingly.

4. Results and Discussion

The microcontrollers are uploaded with the ESP-NOW protocol, which should be briefly explained in the Introduction section to highlight its significance and to illustrate the implemented peer-to-peer network (a detailed architecture diagram should be added). This network contains four controllers representing the North, South, East, and West traffic lights, along with one central controller to coordinate all four traffic lights. The central controller is initially designed to broadcast the traffic light status to all four controllers to keep them in sync. The model of the network is presented in Figure 8.

Figure 8. Peer Network

There is another microcontroller in Figure 7 connected to the OLED display to check for errors and debug accordingly, and to visualize the traffic light's status. Now, with this peer network structure, the interrupts were not able to be passed as they created delays, disturbances, and looping errors in the code, which led to the malfunction of the network. The interrupts were sent as in the controller, which needed to stay green while in an emergency; the emergency interrupt would be transmitted using the central controller. However, after that, the controller that changed to green would take over to sync all three controllers and change them to red. This method created malfunctions and disruptions in the traffic light concept. To avoid this, another method was implemented where the interrupt was sent by the central controller, as before, but this time it didn't allow any other controller to take control. It stored the general traffic light concept based on a delay-timer approach and started running the traffic junction with that general concept. Then, as interrupts came in, it broadcasted the information of which traffic lights should glow to all controllers based on the direction, making decisions on which traffic lights should glow green and which should glow red. By this, unnecessary transmissions were avoided, and the peer network worked better. The adopted model of the peer network with interrupts is shown in Figure 9.

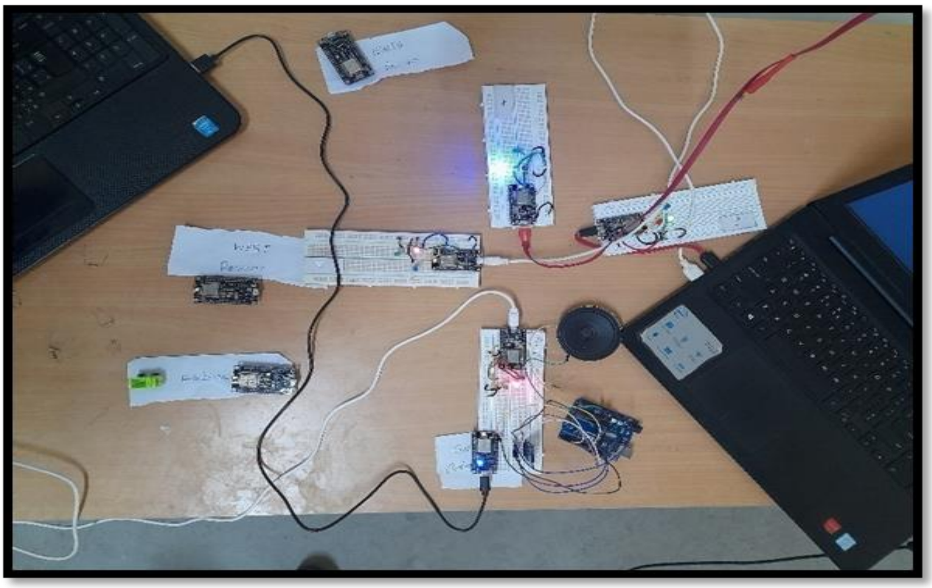

Figure 9. Interrupt on Peer Network

After this, an ambulance transmitter was coded and implemented into the peer network. This transmitter was essential, using a broadcasting method to transmit its message. The transmitter was coded in the Arduino IDE in a way that it connects to the peer network through a receiver controller that is used to extend the range of the peer-to-peer network. The ambulance transmitter gets activated during an emergency situation and starts transmitting its beacon signals to nearby devices. As the traffic junction peer network is provided over a wide range, the ambulance connects to the peer network upon its arrival near the traffic junction. Once connected, the receiver controller recognizes that the ambulance is part of the peer-to-peer network due to its emergency status. To broadcast this message to all the nodes, it sends the information to the central controller. From Figure 9, it can be inferred that as the ambulance connects to the peer network, the receiver controller recognizes the emergency as the ambulance approaches the junction.

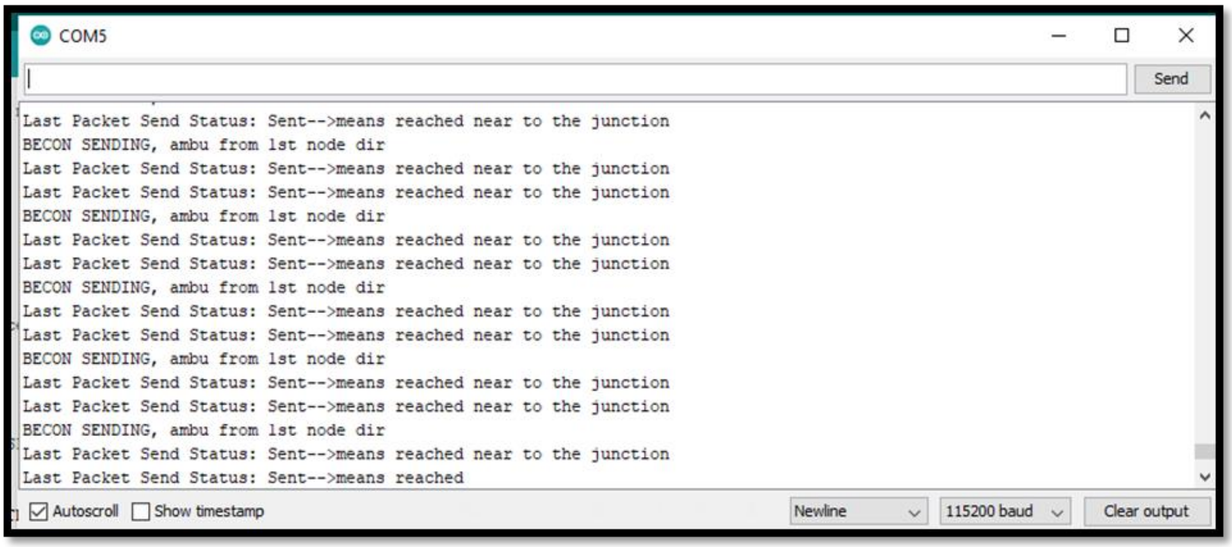

Figure 10. Receiver Controller Detects the Emergency

Once the ambulance was recognized as an emergency by the central controller, the central controller stopped the operation of the general traffic lights, changed the traffic lights' color by adjusting their LED status, and activated the speaker to announce the direction of the ambulance's arrival to drivers who were speeding in order to slow down their vehicles. The central controller received the direction of the ambulance's arrival from the receiver controller that sent the alert message, and with that directional information, the colors were changed. Here, the representation of the direction was given as West as 1, South as 2, East as 3, and North as 4.

Table 1. Changing of Traffic Colours on Emergency

Sl.No	Ambulance Arrival	Red Colour Indication	Green Colour Indication
From West	1,2,4	3	From West

From South	1,2,3	4	From South
From East	2,3,4	1	From East
From North	1,3,4	2	From North

1-West, 2- South, 3- East, 4- North

As shown in Table 1, it can be recognized that in the event of an emergency from any side of the traffic junction, the traffic signals can be changed accordingly. The important thing about emergency vehicles is that they don't need to wait for traffic signals to change to green, and they can make free turns, unlike conventional vehicles, which only have a left free turn. Taking this advantage, we don't need to specify or know in which direction the ambulance is going to pass; simply making the opposite traffic light green is primarily for conventional vehicles to move past the traffic junction. This way, by the time the ambulance arrives, it can have a clear path, and changing all the other traffic signals to red is for conventional vehicles to stop at the junction, allowing other vehicles from the emergency lane to pass through. By this method of changing colors, the ambulance can move freely and take any turn without worrying about incoming conventional vehicles.

Table 2. Comparative Study of Reference Papers and Proposed Method

References	Method used	Shortcomings	Overcame by
[1]	IPv6 Internet communication protocol with geographic addressing	Uses internet and dedicates separate lane for ambulance emergency	Using peer network and clearing existing lane before-hand
[2]	GPS based, uses Location Information method for edge server	Uses internet	Peer network for finding ambulance direction
[3]	App based approach	Causes all traffic signals to be in sync which is controlled by ambulance drivers.	Not introducing internet approach rather using peer approach

		It highly leads to congestion.	
[7]	Already available Traffic Management System in traffic control rooms.	Ambulance needs to be verified before crossing junction which leads to waiting time and congestion	Lane is cleared before-hand and only ambulance can be connected to peer network which reduces verification stage
Proposed Method	Peer-to-peer network and master-slave method	Larger distance between ambulance nodeMCU and Central controller	Usage of additional nodeMCU

Table II shows that the proposed method is better at making the lane congestion-free and detecting the location of the ambulance. In all the referenced papers, either a GPS-based approach or a Location Information (LOI)-based approach is implemented to detect the presence of the ambulance. However, in the proposed method, the controllers are active only in emergencies and can be easily detected by the peer network. Since they use internet-based communication protocols, the peer network employs a peer protocol to transmit data messages and does not require any internet connection to connect with other devices in the network. The peer network and master-slave method assist in detecting, connecting, and acting when an ambulance with an emergency arrives.

5. Conclusion

The proposed method, which incorporates a peer-to-peer network and a Master-Slave system, successfully detects the presence of ambulances. The ambulance presence is not detected when it is not in an emergency; rather, it is detected when the controller is activated due to an emergency. The peer network transmits the alert message to the central controllers, and the Master-Slave method implemented in the central controller allows four traffic lights to receive the alert message and change their signals accordingly. This enables drivers in the ambulance's incoming emergency lane to clear out before the ambulance reaches the traffic junction. Once the ambulance passes the traffic junction, vehicles in the other lanes are alerted by the traffic lights and speaker announcements, allowing the ambulance to pass through without disturbances from other vehicles. The novelty of this project lies in its distinction from other methods involving image processing in CCTV cameras at traffic signals, which are often inefficient at identifying vehicle types using basic networks. Knowing the arrival of an ambulance when it is near a traffic signal is crucial for facilitating emergency measures to control traffic signal lights. This peer network detection of ambulances is more reliable than antenna or image processing-based systems, which consume significant power and rely on internet communication protocols. The project has the potential to significantly contribute to saving human lives, where even minutes' matter, and can enhance traffic systems with an emergency alert-based system that could also be implemented for various other emergency or VIP vehicles.

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