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Smart Traffic Light Prototype Implementation using LoRa Technology

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ABSTRACT

Smart traffic light systems have the potential to significantly improve traffic flow and safety in both urban and suburban areas. Most smart traffic lights were deployed in a city with adequate infrastructure. However, building a smart traffic light in suburban areas can be challenging due to the limited availability of communication infrastructure. This paper aims to build and implement a smart traffic light system in a suburban area by incorporating LoRa (Long Range) technology for communication. LoRa is a low-power wireless technology that allows long-distance communication between devices and has low data rates and power consumption. It was created especially for Internet of Things (IoT) devices that run on batteries. The peer-to-peer method was used, which utilized three LoRa nodes for enabling the communication between traffic lights. Usability testing was conducted to determine the impact of the smart traffic light system on traffic flow and safety. The result of the testing shows that the system is necessary to improve traffic management in suburban areas, and the respondents were positive about its potential benefits. Received Signal Strength (RSS) was measured in two different environments: paddy field and residential areas in Kampung Alor Ara, Arau, Perlis. Results show a slight difference in RSS indicator versus distance for the placement of traffic lights in three-junction lanes. The optimum distance between any two traffic lights is *100m in the paddy field area*. *While for residential areas, the optimum distance is only 50m. The successful implementation of this prototype demonstrates the potential of LoRa technology in enhancing traffic management in suburban areas. Further research such as implementing artificial intelligence (AI) and utilizing advanced LoRa devices and antennas is needed to explore the scalability and long-term sustainability of the system.*

Keywords: *LoRa, traffic light, Arduino, LoRa Shield*

1 INTRODUCTION

The Internet of Things (IoT) has been identified as a potential solution for smart cities' traffic problems. IoT uses sensors, data analytics, and connected devices to collect and analyze traffic data in real-time. Traffic management systems that utilize the IoT have the capability to enhance the flow of traffic. This outcome can notably influence the quality of air and the well-being of the public [1].

With the use of this technology, traffic management may be enhanced, and drivers can receive real-time traffic information, which helps ease congestion and enhance traffic flow. The concept of the IoT encompasses linking diverse compact computing systems with minimal energy usage. In addition, connectivity can be established through wired or wireless means. Integrating both of these connectivity approaches enables the supervision, control, and administration of distinct locations comprising the infrastructure [2]. In smart cities, a few IoT technologies including Long Range (LoRa), ZigBee, and Wi-Fi, are being used to alleviate traffic challenges. These technologies enable the capturing and analyzing real-time data for traffic management [4]. IoT holds the capability to transform sectors like healthcare, agriculture, transportation, and manufacturing by furnishing instantaneous information and automated management of tangible systems, leading to a potential revolution in these industries [3].

LoRa is a low-power wireless technology created for IoT applications. LoRa allows for long-distance communication between devices and has low data rates and power consumption, making it perfect for IoT devices [5,6]. With LoRa, both user convenience and energy conservation as integral aspects of its implementation [7]. The technology is perfect for usage in urban contexts because it is simple to deploy, integrate with existing infrastructure, and overcome barriers like walls and buildings. The technology is also affordable because it uses unlicensed frequencies, allowing unrestricted use and eliminating the need for licenses. LoRa is recognized as a wireless modulation technique within the realm of the physical layer and distinguishes itself from conventional wireless systems predominantly adopting frequency shift keying (FSK) for achieving energy efficiency [8]. This technology showcases an innovative approach in addressing these issues by achieving low power.

Smaller regions, like suburban and college campuses, and urban areas, also experience traffic concerns. Narrow roads, poor infrastructure, or a lack of traffic control systems may all contribute to traffic problems in these locations. LoRa, as an extended-range communication technology, finds application in supporting the production of renewable energy. Moreover, LoRa serves the purpose of enabling extensive communication ranges for sensors grounded in the IoT. Implementing IoT technologies like LoRa can aid in resolving these problems by supplying real-time traffic data and enhancing overall traffic flow. Small-scale locations can benefit from reduced congestion, enhanced safety, and increased efficiency with the use of intelligent traffic management technologies [9]. Traffic signal systems are established within suburban regions to alleviate traffic congestion and avert collisions. However, the reference value of these signals remains uniform across all roadways. The intricate traffic conditions on both sides of the road lead to inefficient resource utilization and wastage [10]. The idea of smart cities evolved through the utilization of IoT that utilizes LoRa infrastructure, facilitating the effective and comprehensive deployment of various systems. This aims to enhance the efficiency and productivity of urban management functions holistically [11].

This paper is divided into four sections. The next section presents literature that describes few related works. The development and implementation section explains the overall methodology used in building and implementing the LoRa network that consists of LoRa clients and servers. Results and analysis are presented and discussed in the next section. Finally, the paper is concluded, and the recommended work is summarized in thein the last section.

2 RELATED WORKS

In this section, a few related works, and their different methods for implementing LoRa and smart traffic lights. Research by Yang Kai [12], where an intelligent traffic control system was built with two-way communication based on LED visible light communication. The system solves the problem of one-way communication between the control center and the vehicle by applying OFDM, MIMO and CDMA technologies. The functions are to broaden the communication channel, improve the anti-interference ability and reduce the power consumption of the system. There is also a congestion level-based dynamic traffic management system using IoT.

Next, is the development of a congestion level-based dynamic traffic management system using IoT [13]. The objective of the research is to regulate the traffic light duration based on the real-time congestion level of the traffic measured at the road crossings by using ultrasonic sensors. This system was developed in three phases. In the first phase, the logic used to regulate traffic lights and simulations are done in Proteus. In the next phase the real-time development of IoT in terms of unidirectional and bidirectional is done using the Node-Red software. Finally, real-time implementation of the prototype is developed. The results show an improvement in traffic management where real-time traffic situations are stored in terms of the congestion level of a particular area.

Another research by Bingo et al. [14], LoRa-based Smart Streetlighting System for Smart Cities. The objective of the research is to design and build traffic lights based on streetlights and adjust them according to the brightness of the traffic. This system utilized Artificial intelligence to remotely control the brightness. The finding of the research paper is that it provides alarm management, consumption reporting, scheduling on/off times and adjusting the brightness of light fixtures.

Finally, a Smart traffic light for congestion monitoring using LoRaWAN [15]. The objective is to estimate the range of signals in urban areas. The method uses multiple sensors and connects them with LoRaWAN. The finding is that it provides a full system to monitor current traffic lights in urban cities for a better system, including the sensor, database and accessible monitoring system. This paper presents a prototype of a traffic light implemented in a suburban area in Arau, Perlis.

3 DEVELOPMENT AND IMPLEMENTATION

The methodology consists of system design and system development.

3.1 System Design

The method employed to establish a connection between two devices in this scenario is known as peer-to-peer connection. The testbed consists of three LoRa nodes, acting as both client and server to transmit and receive data. At a given time, one of these servers will act as the initiator of the connection while the other will function as the receiver. To visualize the scenario in a real-world scenario, a diagram has been provided in Figure 1. This diagram is intended to be used on streets, providing a visual representation of how the peer-to-peer connection between the three servers will be functioning.

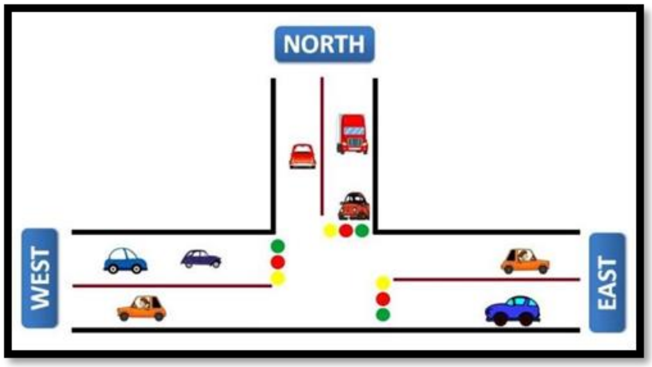

Figure 1: Three-junctions traffic light virtualization

However, if there is no motion (movement of vehicles) detected, there will be no data sent from client to server or from server to client. The traffic light will be in its default state, which is red. Conversely, if there is motion detected, the process of sending data either from server to client or client to server enables one of the traffic lights to change to green and the other two traffic lights will turn red.

3.2 System Development

The process of creating a single node for this research involves pairing the LoRa Shield and Arduino Uno together. Once the pairing is completed, the other two sets of LoRa nodes are assembled. In total, this testbed consists of three Lora nodes that are programmed as a client and a server node server, for each of the nodes to transmit and receive at the given time. Each traffic light utilized LEDs and a Mini PIR motion sensor. These components will work together to ensure that the traffic lights are triggered when there is movement detected and synchronized effectively to allow efficient and reliable traffic control. Figure 2 shows the physical diagram of the testbed consisting of three traffic light prototypes.

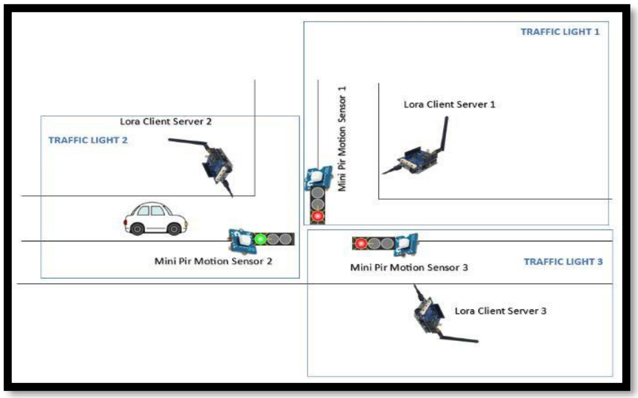

Figure 2: Physical diagram of three LoRa nodes

The testbed using the real LoRa node is demonstrated in Figure 3. Arduino IDE is used to create sketches and upload code to Arduino devices. Calling RadioHead-Master and selecting the rf95 client allows to obtain the entire client component coding from the installed Arduino library.

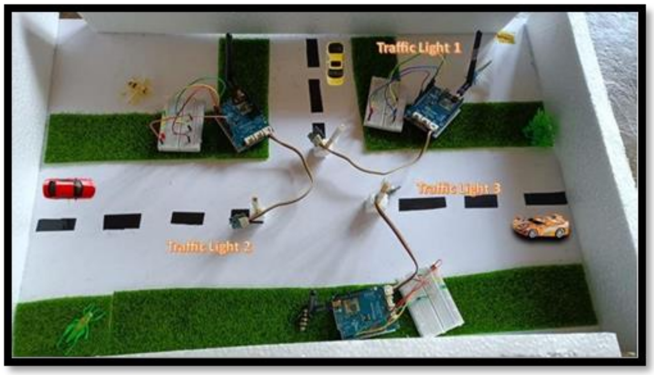

Figure 3: Real component used in the testbed

3.2.1 LoRa Client Setup

The Mini PIR motion sensor and traffic light coding were added to the rf95 client coding. When a motion is detected at the sensor, the data will be sent to the other shields indicating that the traffic light has detected a vehicle. Thus, the traffic light will turn green. While other traffic lights will remain red. After the Mini PIR motion sensor and traffic light codes have been added to the rf95 client coding, the code must contain a second definition to describe the motion sensor coding that defines the motion sensor and the pinning number indicating the sensor has been attached.

3.2.2 LoRa Server Setup

The client component and server component both used the same traffic light hardware setup. As well as the LoRa Client, the LoRa Server also sends data to other LoRa shields that also act as listeners when a motion is detected at any traffic light. Thus, the client's current coding was updated with the traffic light's code. The code was altered to make it possible for the client and server to connect. At the server-side setup, in order for the LoRas to communicate with each other, a function WaitForAnswer() was created to wait for the reply from any node throughout the LoRas. It returns a value of 0 or 1 because the data type used was int 0 indicates that there is no reply while 1 indicates there is a reply. When there is a request, there must be a reply. Thus, there is another request created by SendRequest(). The purpose of this function is to send a request to the server to initiate or tell the server that there is a motion detected at the requested node.

4 RESULTS AND DISCUSSION

Received Signal Strength Indicator (RSSI) has been captured for different distances between all three traffic lights from 50m to 250m in both areas: paddy field and residential area in Kampung Alor Ara in Arau, Perlis. Table 1 shows the RSSI level at the paddy field where Traffic Light 1 is stationary.

Table 1: RSSI results for at the Paddy Field

Distance (m) (from Traffic Light 1)	RSSI (-dBm) (to Traffic Light 2)	RSSI (-dBm) (to Traffic Light 3)
50	-73	-69
100	-79	-85
150	-87	-88
200	-94	-90
250	-101	-96

Upon analyzing, it becomes evident that Traffic Light 3 has a more stable RSSI signal compared to Traffic Light 2. In contrast, the RSSI signal received from Traffic Light 2 is observed to be constantly decreasing over time. This comparison of RSSI data can be instrumental in evaluating the performance and reliability of the two traffic lights tested in the paddy field area in Kampung Alor Ara, Arau Perlis.

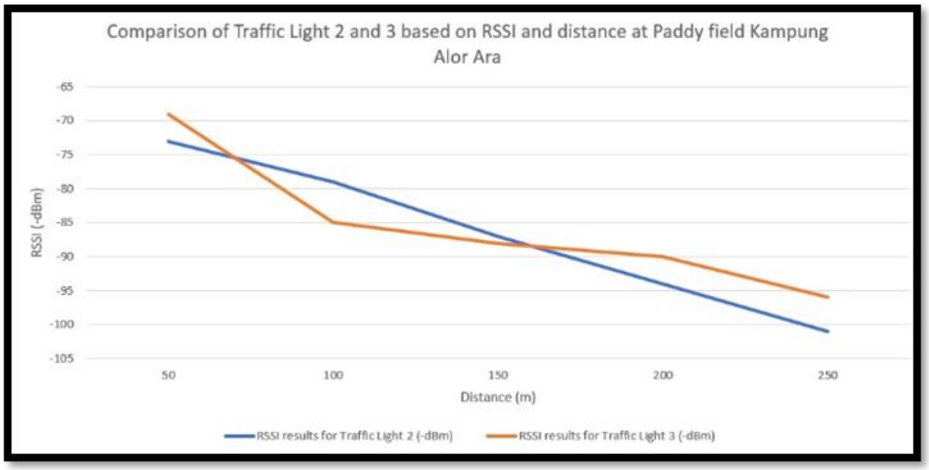

Figure 4: RSSI comparison in Paddy Field for Traffic Light 2 and 3

Another experiment was tested in a residential area in Kampung Alor Ara, Arau Perlis, the client nodes were moved to the test locations while traffic light 1 stayed stationary at Kampung Alor Ara. RSSI data was captured by using the serial monitor of the Arduino IDE. Table 2 shows RSSI results for Traffic Light 2 and 3 in the residential areas.

Table 2: RSSI results for the Residential Area

Distance (m) (from Traffic Light 1)	**RSSI (-dBm)** (to Traffic Light 2)	**RSSI (-dBm)** (to Traffic Light 3)
50	-75	-67
100	-90	-79
150	-100	-84
200	-101	-90
250	-101	-101

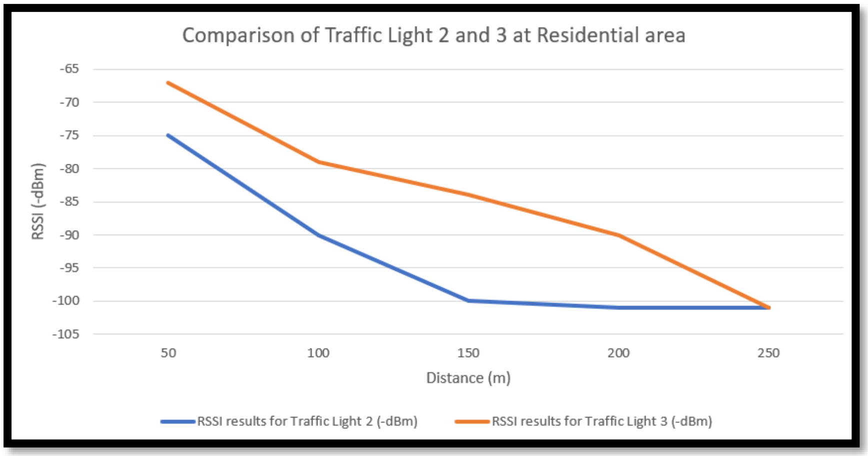

Figure 5: RSSI comparison in Residential Area for Traffic Light 2 and 3

This information can be crucial for understanding the signal strength and coverage of traffic light 2 in the residential area, as well as for identifying potential areas for signal improvement or optimization. By analyzing the data from the graph, researchers or engineers can make decisions about the placement of traffic lights or the use of signal boosters to improve signal strength and coverage. Additionally, the graph can be used to compare the signal strength of different traffic lights in the residential area and identify patterns or trends in signal degradation over time. Overall, the generation and display of the graph for traffic light 2 in the residential area provides valuable insights into the performance and optimization of wireless signal transmission in the area.

The construction and presentation of the graph for traffic light 3 in the residential area can provide useful information about the performance of the wireless signal and the coverage area of the traffic light. By observing the drop in signal strength as the distance between the traffic light and the receiving device increases, researchers or engineers can identify potential signal interference or obstructions and make informed decisions about optimizing signal transmission in the residential area. Moreover, the graph can be used to compare the signal strength of traffic light 3 with other traffic lights in the region and identify patterns or trends in signal degradation over time. a visual representation of the data that can be easily interpreted and used for further analysis and optimization.

By analyzing the RSSI data collected earlier, a comparison was made between the signal strength of traffic lights 2 and 3. From the observation, it can be concluded that Traffic Light 3 has a more reliable connection than Traffic Light 2, as indicated by the consistently falling values in the graph. This information can be critical for improving signal transmission and coverage in the suburban area, as well as in rural areas as it highlights potential areas for improvement and signal optimization. Moreover, the comparison can provide insights into the performance of wireless signal transmission across different types of traffic lights and help researchers or engineers make decisions regarding the placement or use of signal boosters to improve signal strength and reliability.

5 CONCLUSION AND RECOMMENDATIONS

This paper presents a method to improve traffic management in suburban areas using Lora Shields in controlling narrow road traffic. A Mini PIR motion sensor is used to detect vehicles approaching from a direction, and the traffic signal decisions are executed at the client and server nodes. The method uses peer-to-peer communication, with a distance ranging from 50 meters to 250 meters. However, the results are slightly affected due to the limited distance and interference around the testbed. This leads to a longer waiting time for the server to receive sensor data and reduced RSSI as distance increases. As a conclusion, the optimum distance in building a traffic light in three-junction using LoRa Technology is 50 to 100m to obtain a good signal from other traffic lights. Further research can be continued by implementing artificial intelligence (AI) and utilizing advanced LoRa devices and antennas needed to explore the scalability and long-term sustainability of the system.

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