

# Prototype Design and Development of an IoT-Enabled Monitoring and Control System for Public Street Lighting

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## ABSTRACT

This research discusses the Internet of Things (IoT)-based Public Street Lighting (PJU) system to improve energy efficiency and remote monitoring. The background problem is the need to improve operational efficiency and energy savings in the PJU system. This final project aims to design and test an IoT-based PJU system that transmits real-time data between nodes and gateways using LoRa technology and the MQTT protocol. The research process involves hardware and software design, as well as system testing under various conditions. The tests measured the data transmission time and analyzed the delay using LED indicators on the gateway and dashboard devices. The test results showed significant variations in data transmission time compared to the programmed time. The programmed transmission time was 10 seconds for node 1 and 20 seconds for node 2, but the test results showed an average time of about 15 seconds for node 1 and 21.89 to 36.02 seconds for node 2. This variation is due to factors such as network communication delay, processor load, and LoRa system efficiency.

## INTRODUCTION

Street lighting is a critical component of urban infrastructure, ensuring safety, visibility, and promoting economic activity during nighttime hours (Kabir et al., 2023). Traditional street lighting systems, however, consume a significant portion of a city's energy budget, accounting for a substantial percentage of the yearly power output on a global scale (Kabir et al., 2023). Inefficient control methods, lack of real-time monitoring, and outdated technologies contribute to energy wastage and increased operational costs (Adriansyah et al., 2020).

Existing public street lighting systems often rely on conventional control methods, such as simple on/off switches or time-based controls (Adriansyah et al., 2020). These approaches lack the adaptability to respond to real-time conditions, such as changes in ambient light levels or traffic density (Adriansyah et al., 2020). Furthermore, these systems typically lack integrated monitoring capabilities, making it difficult to identify and address maintenance issues promptly (Adriansyah et al., 2020).

The rise of the Internet of Things presents an opportunity to revolutionize street lighting management (García-Castellano et al., 2019). IoT-based smart city systems can facilitate traffic monitoring and control, energy consumption management, and smart lighting solutions (Agadakos et al., 2020). An IoT-based approach enables the development of intelligent street lighting systems that can adapt to changing conditions, optimize energy consumption, and streamline maintenance operations (Kabir et al., 2023). Design of smoke detector for smart room based on arduino uno (Ilham et al., 2021). These systems leverage a network of connected sensors, microcontrollers, and communication technologies to monitor and control individual streetlights or groups of lights (Adriansyah et al., 2020).

By integrating sensors such as light-dependent resistors and power consumption meters, an IoT system can monitor ambient light levels, streetlight performance, and energy usage in real-time (Adriansyah et al., 2020). This data can be transmitted wirelessly to a central management platform, where it can be analyzed to optimize lighting schedules, detect faulty lamps, and identify potential energy savings (Adriansyah et al., 2020). Remote control capabilities enable operators to adjust lighting levels, dim lights during off-peak hours, or turn them on/off based on specific needs (Adriansyah et al., 2020). Prototype of IoT-Based Fruit Alcohol Level Measurement Tool (Nursila et al., 2021). Monitoring dan Stimulasi Detak Jantung dengan Murottal Al-Qur'an Berbasis Internet of Things (IOT) (Ilham, 2020).

The implementation of IoT-based street lighting systems can lead to significant benefits, including reduced energy consumption, lower maintenance costs, improved public safety, and enhanced operational efficiency (Agadakos et al., 2020).



## LITERATURE REVIEW

Smart street lighting systems are gaining traction as urbanization increases and cities seek sustainable solutions (Agramelal et al., 2023). These systems leverage the Internet of Things to enhance energy efficiency, reduce maintenance costs, and improve public safety (Agramelal et al., 2023); (Kabir et al., 2023).

- **Transition to LED Lighting:** A fundamental aspect of smart street lighting involves the transition from conventional lighting to Light-Emitting Diodes (Khemakhem & Krichen, 2024). LEDs offer significant advantages in terms of energy efficiency, lifespan, and controllability compared to traditional lighting technologies (Khemakhem & Krichen, 2024).
- **IoT-Enabled Control and Monitoring:** The integration of wireless networked sensors and controllers enables dynamic brightness control in operational zones, leading to substantial energy savings (Adriansyah et al., 2020). These systems use sensors to monitor ambient light, weather conditions, and lamp performance, allowing for real-time adjustments and remote diagnostics (Adriansyah et al., 2020); (Omar et al., 2022).
- **Smart City Applications:** Smart streetlights can serve as a platform for various smart city applications (Mahoor et al., 2020). Beyond lighting, they can host communication networks, environmental monitors, and even electric vehicle charging stations (Agramelal et al., 2023).
- **Internet of Things:** IoT is a network of interconnected devices that can collect and exchange data (Adriansyah et al., 2020). In the context of street lighting, IoT enables remote monitoring and control of individual lights or groups of lights, optimizing energy consumption and maintenance (Adriansyah et al., 2020).
- **Control Theory:** Control theory provides the framework for designing systems that can regulate and optimize processes (Adriansyah et al., 2020). Smart street lighting systems utilize control algorithms to adjust lighting levels based on real-time conditions, such as traffic density or ambient light (Adriansyah et al., 2020).
- **Sensor Networks:** Wireless sensor networks play a crucial role in smart street lighting by providing real-time data on environmental conditions and system performance (Kabir et al., 2023). These networks consist of sensor nodes that collect data and transmit it wirelessly to a central management platform (Kabir et al., 2023).
- **IoT-Based Smart Solar Photovoltaic Remote Monitoring System:** Systems like the one described in (Tellawar & Chamat, 2019) can provide a model for the remote monitoring aspects of your street lighting system.
- **Smart Public Street Lighting System for Smart Cities:** This survey (Khemakhem & Krichen, 2024) offers a comprehensive overview of smart public street lighting infrastructure tailored for IoT applications. It highlights the transition to LEDs and the incorporation of wireless networked sensors for dynamic brightness control, which are key components of your research.
- **Cloud-Based Automatic Street Lighting Control System:** This paper (Younis & Salim, 2021) suggests an automatic smart street light and traffic light system using an infrared sensor to automate the function of street lights and monitor traffic density, which could be relevant if your system incorporates traffic monitoring.
- **Public Street Lighting Control and Monitoring System Using the Internet of Things:** This paper (Adriansyah et al., 2020) focuses on designing an integrated control and monitoring system based on IoT to solve the problems of ineffective power consumption and lack of integrated systems for monitoring and maintenance.

## METHOD

### System Design

The design of the Public Street Lighting System (PJU) based on LoRa technology and the Internet of Things (IoT) aims to create a more efficient, energy-saving, and smart lighting solution. This system consists of hardware and software working synchronously. The hardware includes nodes installed on streetlights to collect environmental data through light and motion sensors. The collected data is then sent to a gateway, which connects the nodes to the control center and transmits the data to a server.

### System Block Diagram

In the block diagram of this system, a detailed explanation of the block diagram for the PJU system will be provided, which is divided into two main parts: the block diagram of the node system as the data sender and the block diagram of the gateway system as the data receiver. These two diagrams will illustrate the workflow, key components, and interactions between the node and gateway within the PJU system, as well as how data is transmitted, received, and processed to ensure the system functions effectively and efficiently.

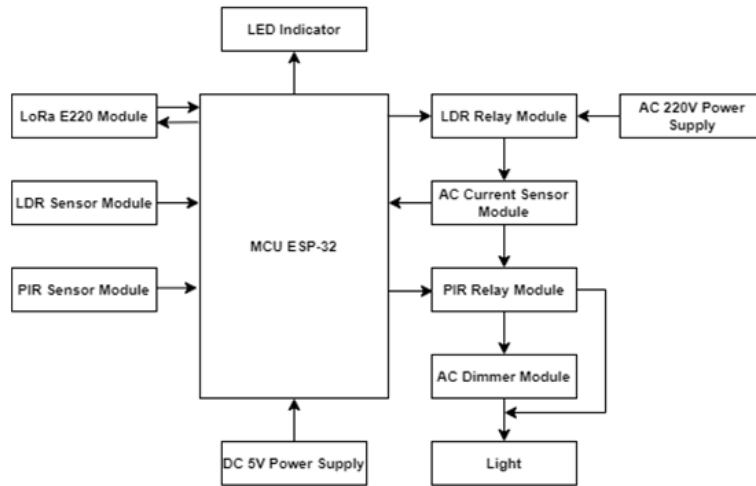


Figure 1. Block Diagram Node

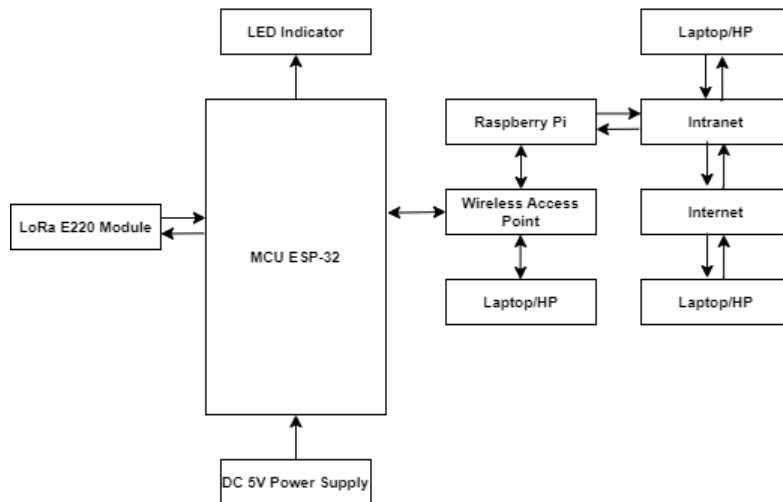


Figure 2. Block Diagram Gateway

### System Flowchart

In this section there is a flowchart of the node and gateway, which describes in detail the workflow between the two components. This section discusses the flowchart of the node system, which describes the workflow from data collection by the sensor to sending it to the gateway via LoRa. The process begins with initialization, then the data is processed and prepared to be sent if the power supply is available. On data reception (Rx LoRa), if there is data, the system processes and saves the lamp control status, then resets the sending time. On data sending (Tx LoRa), data is sent if the sending time interval is reached, and if not, the process ends without sending.

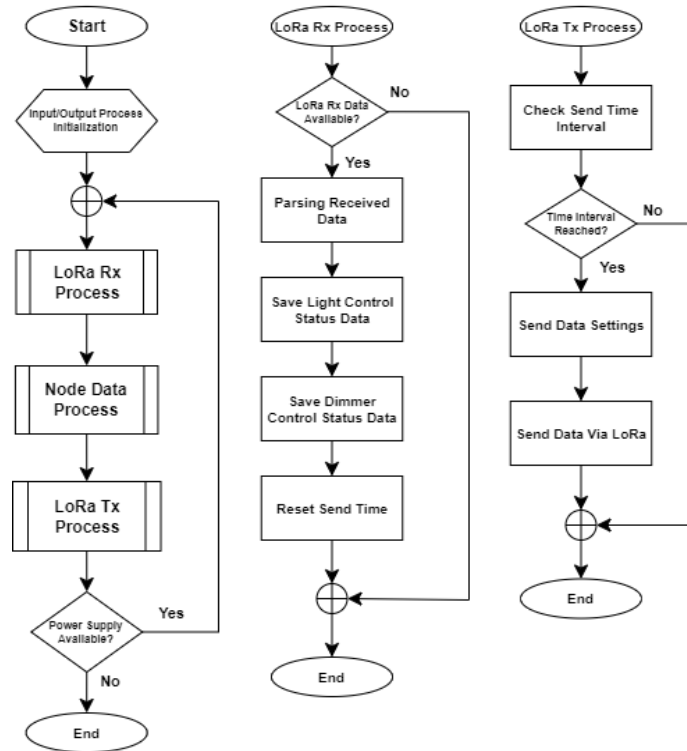


Figure 3. Flowchart Node

The gateway system flowchart outlines the communication and data management process in operating the PJU, utilizing MQTT and LoRa protocols. The workflow begins with initialization to ensure the readiness of hardware and software, followed by the system subscribing to relevant MQTT topics, enabling the reception of control commands and data from nodes or other gateways.

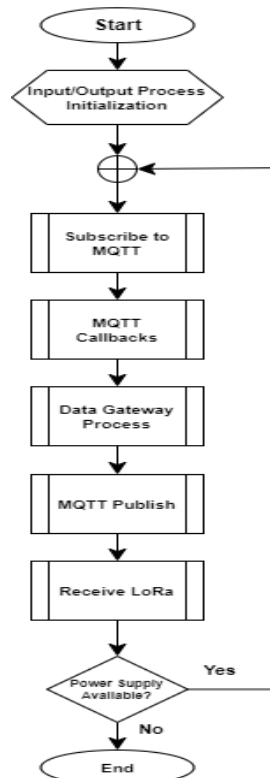


Figure 4. Flowchart Gateway

### Flow Node-RED Design

This system uses Node-RED to manage and control street lights (PJU) by connecting hardware, APIs, and online services, and communicates via the MQTT protocol with a server on a Raspberry Pi. The system consists of several key components, including a PJU monitor debug that monitors data from the PJU nodes, and a node acting as an MQTT client connected to the broker on the Raspberry Pi. Other components process MQTT messages and convert JSON data for use by Node-RED. Control nodes manage the status and brightness of the lights, while notification and indicator nodes display real-time status updates.

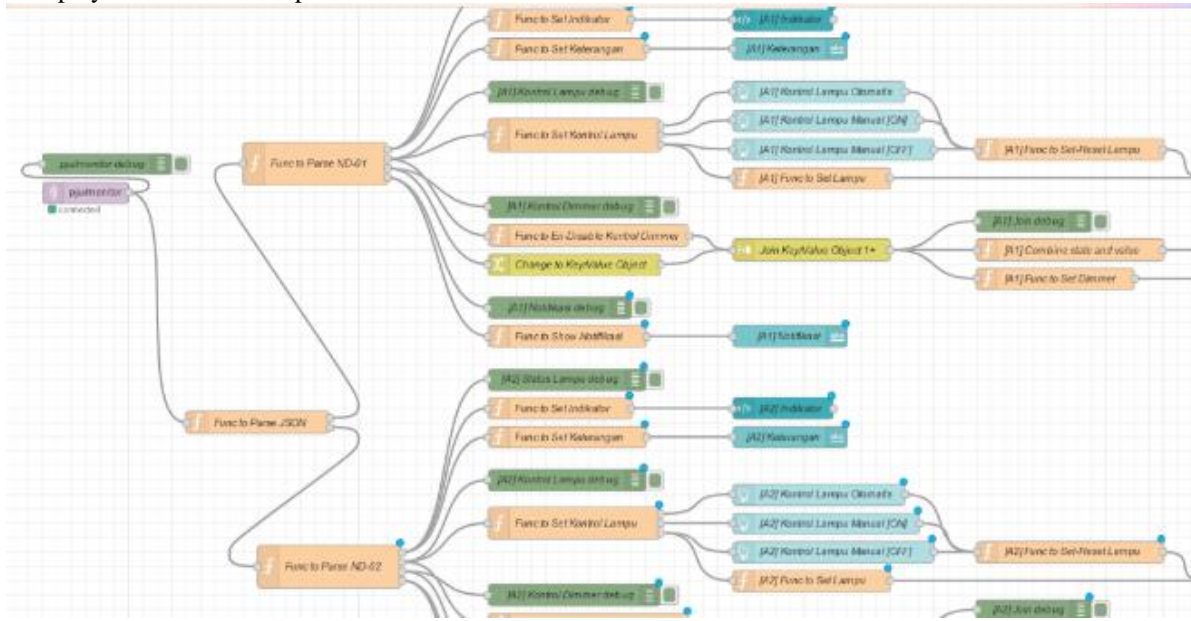


Figure 5. Flow Design Node-RED

### Dashboard Design

This dashboard is designed to manage and monitor various connected nodes, primarily related to light control and notifications. Each node has similar controls, including indicators, descriptions, automatic and manual light controls, as well as dimmer controls to adjust brightness.

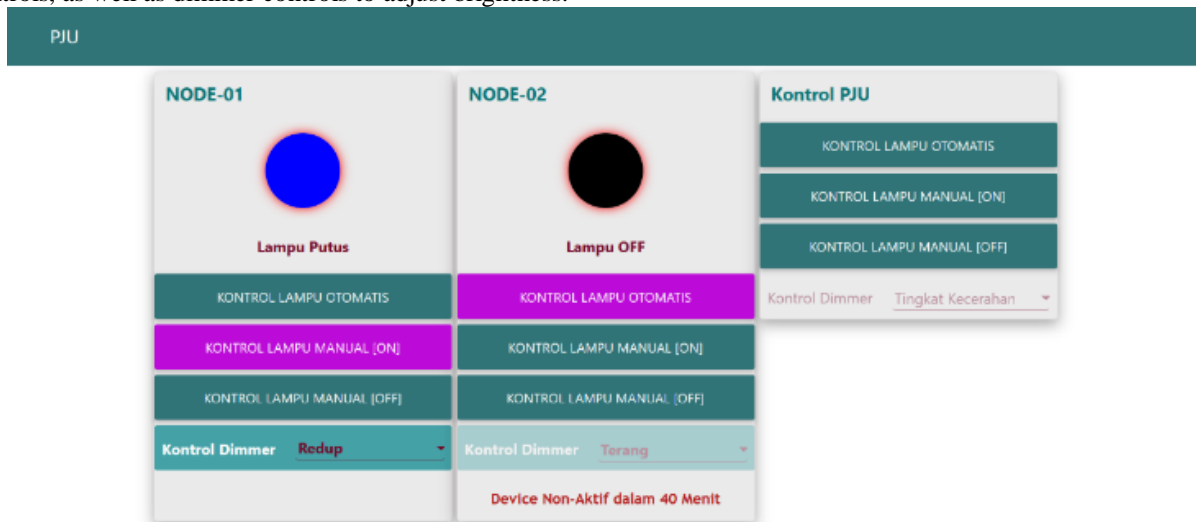


Figure 6. Design Dashboard

## RESULT AND DISCUSSION

### Testing Network Connection to Raspberry using LAN

The connection testing to the Raspberry Pi through the LAN network with IP 10.30.29.11 aims to evaluate the stability and speed of the local connection. The ping results indicate that the payload size of each ICMP packet is 32 bytes, and the packet still has 64 hops remaining (TTL=64), suggesting that it has not passed through many routers.

This testing is crucial to ensure the Raspberry Pi functions well as the system's control center, with results covering data transmission speed, packet loss, and overall connection quality, which are essential for the system's daily operations.

```

C:\Windows\system32\cmd.exe
Microsoft Windows [Version 10.0.22621.3296]
(c) Microsoft Corporation. All rights reserved.

C:\Users\pcace>ping 10.30.29.11

Pinging 10.30.29.11 with 32 bytes of data:
Reply from 10.30.29.11: bytes=32 time<1ms TTL=64
Reply from 10.30.29.11: bytes=32 time<1ms TTL=64
Reply from 10.30.29.11: bytes=32 time<1ms TTL=64
Reply from 10.30.29.11: bytes=32 time<1ms TTL=64

Ping statistics for 10.30.29.11:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 0ms, Maximum = 0ms, Average = 0ms

C:\Users\pcace>

```

Figure 7. Testing Network Connection to Raspberry using LAN

### Testing Data Delivery on Dashboard Through LAN Network

The testing was conducted to measure the data transmission time displayed on the dashboard via the LAN network. It involved observing changes in values on the dashboard, including the status of node devices such as light status, light control, and dimmer control. The tests were performed three times on node 1 and node 2.

#### 1. Node 1

The testing of data transmission time from node 1 to the dashboard over the LAN network in the PJU system yielded significant results. This test aimed to measure the efficiency of the time taken for data to be displayed on the dashboard, which is crucial for monitoring and controlling the system. The results indicated that the time required for the transition of PJU node conditions ranged from 20 to 40 seconds, even though the program was set to send data every 10 seconds using LoRa.

An additional 2 seconds was needed for data transmission to the dashboard via the gateway and Raspberry Pi using the MQTT protocol. This protocol facilitates machine-to-machine (M2M) and Internet of Things (IoT) communication through a publish-subscribe mechanism. The test results showed that the recorded transmission time varied between 20.93 seconds and 42.75 seconds, indicating delays in data transmission, which could be attributed to factors such as network speed, network capacity, and the efficiency of the LoRa system. This variation in time signifies that the data transmission did not align with the programmed schedule.

Table 1. Node 1 Data Delivery Time On The Dashboard

Node 1 Data Delivery Time on Dashboard	
<b>25.19 s</b>	24.61 s
<b>27.01 s</b>	41.38 s
<b>20.93 s</b>	42.75 s

#### 2. Node 2

The following is the documentation of data transmission times recorded when data was sent to the dashboard over the LAN network from node 2. According to Table 2, although the programmed transmission time was set at 20 seconds, the recorded transmission times varied between 21.89 seconds and 36.02 seconds. While some delays were closer to the programmed time, significant variations indicate that there were delays in data transmission.

Table 2. Data Delivery Time For Node 2 On The Dashboard

Node 2 Data Delivery Time on Dashboard	
<b>31.86 s</b>	21.89 s
<b>36.02 s</b>	22.05 s
<b>33.31 s</b>	21.57 s

## CONCLUSION

The connection testing to the Raspberry Pi through the LAN network for the Public Street Lighting (PJU) system with IP 10.30.29.11 shows significant results in evaluating the stability and speed of the local connection. The ping test results indicate that the ICMP packets have a payload size of 32 bytes with a TTL of 64, suggesting that the connection does not pass through many routers, which is important for the system's performance. The data transmission time from node 1 to the dashboard ranges from 20 to 40 seconds, even though the program is set to send data every 10 seconds.

An additional 2 seconds for data transmission through the gateway and Raspberry Pi using the MQTT protocol indicates delays. The variation in recorded transmission times, ranging from 20.93 to 42.75 seconds, reflects issues with alignment to the programmed schedule.

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