IoT-Based Forest Fire Monitoring System in Bengkalis Using Cosmic LoRa Ray

Jefri Lianda[1], Adam Adam[2], Muhamad Nasir[3], Dea Fitriana[4], Mhd. Riyan Kurniawan[5] and Muhammad As'Ad Hayyan Zahuri[6]

[12345] Electrical Engineering Department, Bengkalis State Polytechnic, Bathin Alam, Indonesia
jefri@polbeng.ac.id

Abstract. Forest and land fires occur annually in Bengkalis Regency, especially during the dry season. According to the Riau Governor, as of October 2023, fires have affected 398.29 hectares in Bengkalis. Based on the Riau Provincial Coordination Meeting (rakor) for forest and land fire management (kartahutla), the provincial government needs support from the central government to monitor hot spots, weather forecasts, and groundwater levels. This study aims to detect fires quickly and enable timely intervention by installing GPS (Global Positioning System) to send the fire location data. The system, which uses Cosmic LoRa Ray technology, is deployed at multiple peatland points, interconnected via LoRa to the main data center, and sends data to the Bengkalis BPBD using Internet of Things (IoT) technology for prompt response. Data on air temperature, humidity, and smoke density are collected and transmitted from the sender (client) to the receiver (server) node. The server is a single unit with a solar panel, charging system, Li-Ion battery, temperature and smoke sensors, a 20x4 character LCD, and a Cosmic LoRa Ray-based microcontroller. The data transmission time at the transmitter node ranges from 2.86 to 3.25 seconds, whereas at the server node, it ranges from 1.92 to 2.13 seconds. This indicates that the server node has a faster data transmission time compared to the transmitter node. The server's power consumption data is 1046.48 milliwatts, while the client's power consumption can reach up to 1795.71 milliwatts. This indicates that the client uses significantly more power than the server.

Keywords: Bengkalis, LoRa, Node.

1 Introduction

Forest and land fires (karhutla) occurred in parts of Riau, encompassing all districts in the province in 2023. According to Riau Governor Syamsuar, from January to October 8, 2023, there were 2,169 hotspots in Riau Province, burning an area of 2,029.15 hectares. Bengkalis Regency was the hardest hit, with 398.29 hectares of land affected by fires. Forest and land fires damage ecosystems and destroy flora and fauna that grow and live in the forest. The smoke produced also leads to air pollution, which can cause respiratory illnesses such as Upper Respiratory Tract Infections (URTI), asthma, and

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Chronic Obstructive Pulmonary Disease (COPD). Additionally, smoke can impair visibility, especially for aviation transportation. Therefore, an early detection system for forest and land fires is needed to prevent widespread fires by providing information to the Regional Disaster Management Agency (BPBD) and firefighting units (DAMKAR), enabling prompt firefighting efforts. Figure 1 shows BPBD personnel from Bengkalis Regency extinguishing a peatland fire in Teluk Lecah Village, Rupat District, Bengkalis Regency on May 9, 2023.

Fig. 1. Peatland fires in Bengkalis.

Local governments urgently need an application that can detect fire hotspots quickly and accurately. The development of wireless technology is highly significant at present. The LoRa Cosmic application has been used to transmit data in forest fire systems in Riau Province [1]. The application of wireless technology with interconnected node models can be implemented both indoors and outdoors, even in open areas, and can detect environmental conditions [2]. Various wireless communication devices are used, with different range capabilities. For short to medium ranges (up to 3.2 km), Xbee Pro modules with IEEE 802.15.4 network standards can be used [3], while for medium to long ranges, LoRa modules with a maximum distance of 15 km and a frequency of 1 GHz can be employed [4-5]. LoRa technology has been used for geoinformatics monitoring and human movement detection [6-9].

Experimental tests of LoRa have shown a range of up to 22 km under clear Line of Sight (LOS) conditions [10]. Additionally, the use of LoRa is believed to improve energy efficiency, thus extending battery life [11]. Figure 2 illustrates that LoRa communication technology is more reliable in terms of energy efficiency compared to VHF radio communication technology with similar transmission range capabilities.

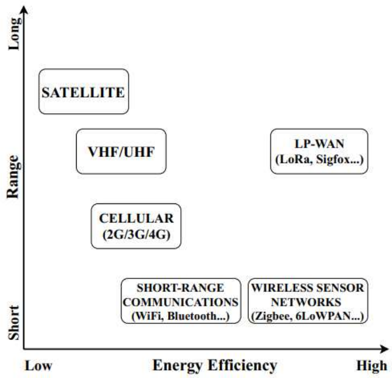

Fig. 2. Comparison of transmission range and energy efficiency [12].

Based on the issues outlined, the researchers are developing an affordable early forest and land fire detection device that can be installed in each sub-district of Bengkalis Regency, at a lower cost and in real-time (IoT). Each detection device will be capable of receiving and sending data to nearby devices, the central database, and the relevant personnel.

2 Method

Table 1 outlines the components utilized in this study. The components include the LoRa Raspberry Pi, smoke sensor, fire sensor, and temperature sensor. Each of these elements plays a critical role in the overall system setup. The LoRa Raspberry Pi is central to the wireless communication network, facilitating data transfer between various sensors and the server. The smoke sensor is designed to detect the presence of smoke, which is essential for identifying potential fire outbreaks. The fire sensor monitors for signs of fire, providing real-time alerts to ensure timely response. Lastly, the temperature sensor measures ambient temperature, which is crucial for understanding environmental conditions and assessing fire risk. Together, these components form a comprehensive monitoring system that collects, processes, and transmits data to enable effective management and response strategies. The integration of these sensors with the LoRa Raspberry Pi ensures that data from the field is reliably communicated to the central server for analysis and action. This setup is integral to achieving accurate monitoring and prompt responses to potential fire hazards.

Table 1. Data component

No	Components
1	Solar panel
2	Battery Lippo
3	Buck Converter
4	LoRa Raspberry Pi

5	LCD
6	Smoke sensor
7	Fire sensor
8	Temperature sensor
9	Humidity sensor

Figure 3 illustrates the structural design for data transmission and reception from a sensor node for a single device to be installed in peatland areas. The sensor node consists of a fire sensor, smoke sensor, temperature sensor, air quality sensor, wind speed sensor, and water level sensor. Data from the sensor node will be read if there are changes in conditions, and subsequently processed and transmitted by the LoRa Raspberry Pi.

Fig. 3. Design of the data transmission and reception structure from the sensor node.

The primary function of the Cosmic LoRa Ray system is to handle sensor data processing, manage the wireless network, and facilitate the transmission of data from clients to the server. On the server side, the measured values from the sensors are often presented on a character LCD screen. This is because the server maintains a comprehensive record of sensor data, including hourly, daily, weekly, monthly, and yearly reports. Utilizing the LoRa Cosmic Ray wireless network, the forest fire monitoring system is structured into two main components: the data collection and receiving unit for atmospheric conditions (transmitter) and the receiver node sensors. The transmitter node sensor is composed of several distinct blocks, which are further detailed in Figure 4. Each block within the transmitter node plays a crucial role in ensuring accurate data collection and transmission. The effective operation of these components ensures that data is reliably sent to the server, where it is analyzed and stored for ongoing monitoring and reporting purposes. The organization and functionality of these blocks are integral to maintaining the efficiency and effectiveness of the forest fire monitoring system.

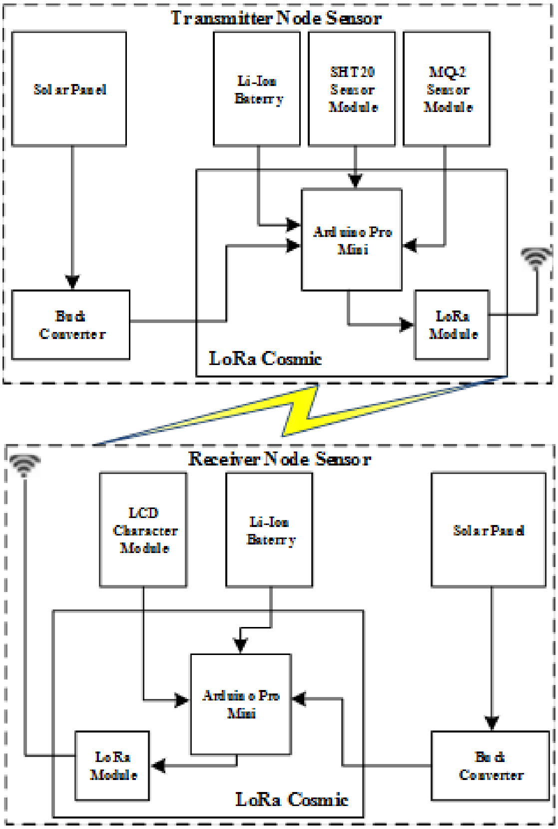

Fig. 4. Block diagram illustrates data flow in a node sensor transmission system.

Figure 5 shows the proposed system design, which consists of several integrated units. The database station unit is used to store data from devices installed in forest and peatland areas. Data from each device will be read by the LoRa gateway via a LoRa connection. If a device unit experiences a data change, the nearest units will receive the information and forward it to the LoRa Gateway. The received data will then be forwarded to the web server via a web service (Restful API). The data sent to the web server will be stored in a PostgreSQL database to ensure real-time data availability and easy access for end users. On the end user side, a web application serves as the user interface for accessing the forest and land fire monitoring application.

The application development process includes creating the system database, developing the backend web service (Restful API), and building the frontend web application on the web server. The application update process involves adding features for http post requests of fire detection data from LoRa module devices to the backend application, and updating both the frontend web application and the database server.

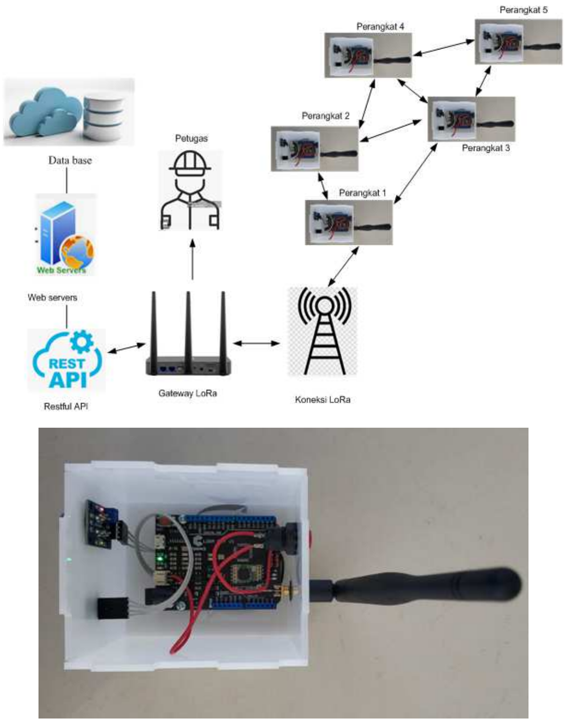

Fig. 5. The overall system design

The specifications for the designed forest and land fire detection device include several module components:

1. Communication Module:
2. LoRa Module: Operates in the frequency range of 920 MHz – 923 MHz. This frequency selection complies with the Indonesian Ministry of Communication and Information (Kominfo) Regulation No. 1 of 2019 on radio frequency spectrum usage

and PERDIRJEN SDPPI No. 3 of 2019: LPWASpecification, which permits LoRaWAN devices to operate within this frequency range.

3. Location Module
   GPS Module: Matek System SAM M8Q GPS Ublox, known for its high accuracy with tracking and navigation sensitivity of 165 dBm.
4. Sensor Modules
   Temperature Sensor: Measures ambient temperature.
5. Fire Sensor: Detects the presence of fire.
6. Smoke Sensor: Identifies smoke to signal a potential fire.
7. Water Level Sensor: Measures water levels in peatland.
8. Solar Panel:
   Provides power to the device, especially since it is installed far from the PLN (national electricity grid) sources.
9. Microcontroller Module
   Raspberry Pi: Serves as the main controller for all modules within the fire detection device.
10. Power Supply Module:
    LiPo Battery: 5200 mAh, serves as the primary power source for the device.
11. Casing:
    The outer shell or enclosure that protects and houses the components of the forest and land fire detection device.

3 Result And Discussion

The data collected by the temperature sensor has been calibrated using a Digital Temperature Meter to ensure accuracy and reliability. This calibration process aligns the sensor's readings with a known standard, providing precise temperature measurements. Similarly, the data from the humidity sensor has been calibrated using an air humidity measurement device. This step is crucial for verifying that the humidity sensor accurately reflects the environmental moisture levels. Additionally, the instruments used for measuring current and voltage have been calibrated with a digital multimeter. The multimeter's precise readings serve as a benchmark, ensuring that the sensor outputs for current and voltage are accurate. By performing these calibration procedures, the system guarantees that all sensor readings are consistent and dependable. This meticulous calibration process is essential for maintaining the integrity of the data collected and for supporting accurate monitoring and analysis in the system.

The testing of sensor nodes involves several stages before data is transmitted to the server. Initially, the node reads temperature and humidity data using the SHT20 sensor and measures smoke concentration in the air with a dedicated smoke sensor. These sensors provide raw data that is then processed by the microcontroller. During this process, the data is calibrated to ensure it adheres to international units, which helps maintain accuracy and consistency. Once the calibration is complete, the adjusted data is transmitted to the receiving node (server). This comprehensive testing ensures that the data sent to the server is both accurate and reliable, facilitating effective monitoring and analysis of environmental conditions. By following these steps, the system can provide timely and precise information, which is crucial for managing and responding to fire and environmental conditions. Figure 6 shows the device testing.

Fig. 6. Device Testing

The results of the transmitter sensor node testing are detailed in Table 2. This table presents the data collected during various tests, including sensor readings for temperature, humidity, smoke concentration, and other parameters. The results demonstrate the accuracy and performance of the sensor nodes, highlighting their effectiveness in detecting and transmitting environmental data. These findings are essential for validating the reliability and functionality of the fire detection system.

Table 2. Transmitter Sensor Node (Client)

No.	Time (WIB)	Temperature Data (°C)	Humidity Data (%RH)	Smoke Data (PPM)	Transmissi on Duration
1	07.30	33,52	58,38	0	3,15
2	09.30	31,82	63,24	0	3,25
3	11.30	33,74	58,62	0	2,98
4	13.30	35,86	55,16	0	3,05
5	14.30	35,18	54,86	0	2,86
6	15.40	34,39	55,24	0	3,15
7	16.30	33,62	58,23	253	2,89
8	17.40	32,71	60,15	194	3,08

Temperature data is inversely related to humidity data. As the temperature increases, the humidity decreases. For instance, at a temperature of 33.52°C, the humidity is 58.38% RH, whereas at a temperature of 35.86°C, the humidity drops to 55.16% RH. This inverse relationship highlights the impact of temperature changes on relative humidity levels. Additionally, the data transmission time ranges from 2.86 to 3.25 seconds. This interval ensures that sensor data is effectively sent from the transmitter node to the server, allowing for timely monitoring and analysis of environmental conditions. The consistency in transmission time further supports the reliability of the sensor node in providing accurate and prompt data for effective fire detection and environmental monitoring.

Table 3. Receiving Node Sensor (Server)

No.	Time (WIB)	Temperature Data (°C)	Humidity Data (%RH)	Smoke Data (PPM)	Transmissi on Duration
1	07.30	33,52	58,38	0	2,03
2	09.30	31,82	63,24	0	2,13
3	11.30	33,74	58,62	0	1,99
4	13.30	35,86	55,16	0	2,12
5	14.30	35,18	54,86	0	1,92
6	15.40	34,39	55,24	0	2,03
7	16.30	33,62	58,23	253	2,13
8	17.40	32,71	60,15	194	1,98

The Receiving Node Sensor (Server) is responsible for receiving data transmitted from the sending node. Each data packet comprises information from temperature sensors, humidity sensors, and smoke sensors. Upon receiving a data packet, the server performs data parsing to separate and organize this information appropriately. This parsed data is then displayed on a monitoring screen for real-time observation.

After the data is successfully displayed, the Receiving Node Sensor sends a confirmation message back to the sending node. This message serves as an acknowledgment that the data has been received and processed by the server. This feedback mechanism is crucial for ensuring accurate communication and data integrity between nodes. It helps verify that the transmitted data has been correctly received and displayed, and it provides a way to troubleshoot any potential issues in the data transmission process. Overall, this system enables efficient monitoring and reliable data management across the network.

Based on Table 3, the fastest and slowest durations for each data reception before providing feedback to the client are 1.92 seconds and 2.13 seconds, respectively. This indicates the time taken by the server to process and acknowledge the data received from the client. The variation in duration reflects the efficiency of the server's data handling and communication process. Ensuring that these times are minimized is crucial for maintaining real-time responsiveness and reliability in the system. This performance measurement helps in evaluating the effectiveness of the server in managing and processing data efficiently, which is vital for optimizing overall system performance and user satisfaction.

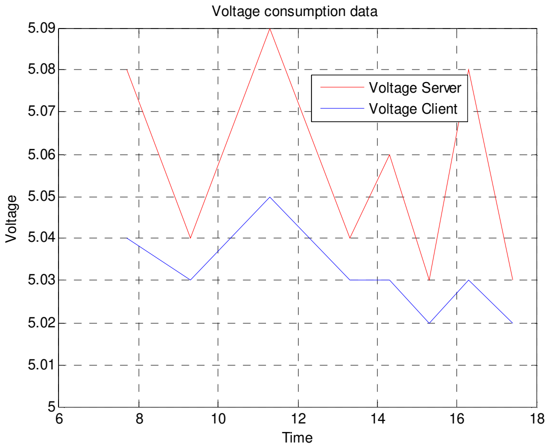

Fig. 7. Voltage consumption data for the device.

Figure 7 depicts the voltage consumption graphs for both the server and client systems. The graph clearly shows that the voltage readings on the server are consistently higher compared to those on the client. The server's maximum recorded voltage is 5.09 volts, whereas the client's highest voltage is 5.03 volts. This difference in voltage levels indicates a variation in power consumption between the two systems. The higher voltage observed on the server may suggest that it requires more power to operate or has higher power demands compared to the client.

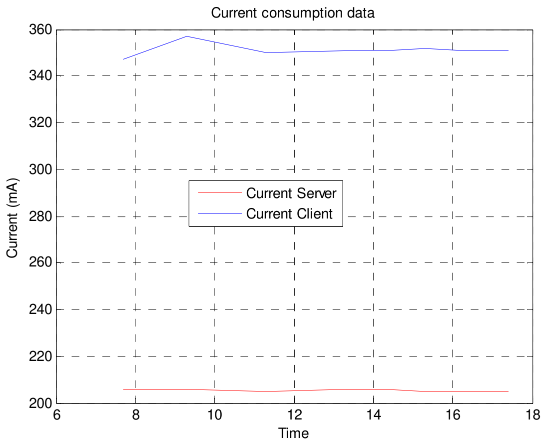

Fig. 8. Current consumption data for the device.

Figure 8 displays the current consumption graphs for both the server and client. The graph reveals that the current readings on the server are lower compared to those on the client. Specifically, the maximum current consumption on the server is 206 milli amperes, while the client's current consumption can reach up to352 milli amperes. This significant difference indicates that the client system consumes more current than the server. The higher current consumption on the client may be attributed to its greater power requirements or higher operational demands. Analyzing these current consumption patterns is essential for understanding the power efficiency of each system and for making decisions regarding power management, resource allocation, and system optimization.

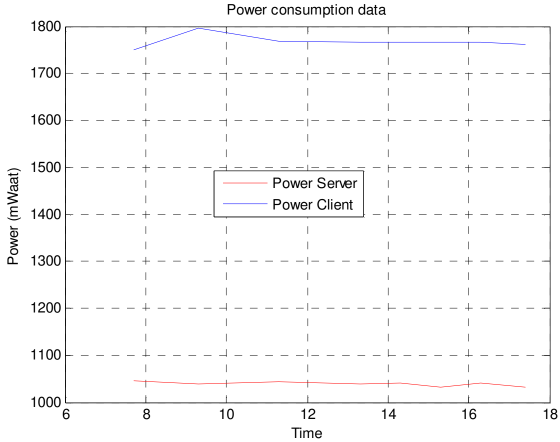

Fig. 9. Power consumption data for the device.

Figure 9 illustrates the power consumption graphs for both the server and client systems. The graph reveals that the power consumption readings on the server are lower compared to those on the client. Specifically, the maximum power consumption on the server is 1046.48 milliwatts, while the client's power consumption can reach up to 1795.71 milliwatts. This significant difference indicates that the client system uses more power than the server. The higher power consumption on the client could be attributed to greater operational demands or more intensive processes. Analyzing these power consumption patterns is essential for evaluating the efficiency of each system, optimizing resource allocation, and making informed decisions about power management and system performance.

4 Conclusion

This study utilizes Cosmic LoRa technology, deployed across various peatland sites and interconnected via LoRa to a central data hub, with data transmitted to personnel using Internet of Things (IoT) technology. Air temperature, humidity, and smoke density data are collected and sent from the transmitter node (client) to the receiver node (server). The data transmission time at the transmitter node ranges from 2.86 to 3.25 seconds, while at the server node, it ranges from 1.92 to 2.13 seconds, indicating that the server node has faster data transmission. The server's power consumption is 1046.48 milliwatts, whereas the client's power consumption can reach up to 1795.71 milliwatts, showing that the client uses significantly more power than the server.

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