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# Internet Network Monitoring in Oil Palm Irrigation Using MQTT Based on QoS Parameters

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***ABSTRACT***

*Oil palm plantations require continuous and reliable monitoring to ensure efficient irrigation, yet many farmers still depend on manual watering methods that are time-consuming and inconsistent. To address this issue, this study develops an IoT-based irrigation system monitoring using the MQTT communication protocol to support real-time data delivery and automated control. The system integrates ESP32 microcontrollers, soil moisture and environmental sensors, HiveMQ Cloud as the MQTT broker, and Telegram Bot notifications. The research was conducted on a 27 m × 70 m oil palm plantation consisting of 24 trees. System testing was performed over seven days with two irrigation sessions daily, during which sensor data transmission and notification timestamps were recorded. QoS parameters such as throughput, packet loss, delay, and jitter were analyzed using Wireshark. The results show that sensor data and irrigation notifications were consistently delivered within 3–5 seconds, demonstrating stable real-time communication. QoS evaluation indicates 0% packet loss, an average delay 180 ms, and an average jitter 0.17 ms, with an overall QoS index of 3.02, classified as "Satisfied." These findings confirm that MQTT provides reliable communication performance in plantation environments and effectively supports automated irrigation monitoring for improving agricultural efficiency.*

*Keywords : MQTT, IoT, Quality of Service (QoS), ESP32, Oil Palm Irrigation, Wireshark, Telegram*

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## 1. INTRODUCTION

Oil palm (Elaeis guineensis Jacq.) remains one of Indonesia's leading export commodities, covering more than 14.9 million hectares with production exceeding 45 million tons in 2022 (Syah, 2023). Its optimal growth depends on adequate rainfall, high humidity, and favorable soil conditions. However, many smallholder farmers still rely on manual irrigation practices, which are labor-intensive, inefficient, and often fail to ensure consistent water distribution (Nugroho, 2019). In a 5-hectare plantation in Rumbai, Pekanbaru, for instance, daily watering can take up to 6–8 hours, resulting in frequent delays and uneven irrigation that may affect plant growth and productivity. These limitations indicate the need for automated systems capable of supporting continuous monitoring and timely water management.

### *A. Oil Palm*

Oil palm (Elaeis guineensis Jacq.) thrives in environments with high humidity, stable temperatures, and sufficient rainfall. As a major agricultural commodity, maintaining suitable field conditions is essential to support optimal growth and maximize production (Derry et al., 2018).

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*B. IoT-Based Irrigation Systems in Agriculture*

The application of Internet of Things (IoT) technology in agriculture has expanded significantly, particularly in irrigation management systems that require continuous environmental monitoring and automated control (Islamy & Wisudawati, 2023). Advances in Internet of Things (IoT) technology enable improved irrigation management through real-time data collection and automated control (Sasono, 2017). Previous studies have shown that IoT-based irrigation systems can improve water-use efficiency, reduce labor dependency, and enhance crop productivity by enabling real-time sensing and remote system management. (Jupita et al., 2021) (Sari et al., 2024).

*C. Soil Moisture Sensor*

A soil moisture sensor is used to detect the amount of water present in the soil, helping identify whether the soil is in a dry or wet condition. This type of sensor is crucial in automated irrigation systems because it supplies real-time information for regulating water distribution (Jupita et al., 2021).

*D. Temperature and Humidity Sensor (DHT22)*

The DHT22 sensor captures environmental temperature and humidity using a thermistor and a capacitive humidity sensor. This sensor provides accurate microclimate data required for monitoring field conditions (Agus et al., 2020).

*E. ESP32 Microcontroller*

The ESP32 is a system-on-chip microcontroller equipped with Wi-Fi and Bluetooth, designed for IoT applications that require stable wireless communication and efficient data processing capabilities (Al-Azam et al., 2019). The use of ESP32 microcontrollers combined with soil moisture sensors and DHT22 temperature–humidity sensors supports continuous environmental monitoring in agricultural fields (Agustina & Amrulloh, 2023).

*F. Telegram Bot*

Telegram is a cloud-based messaging platform that supports bot development for automated interactions. Its open API enables integration with IoT systems, allowing devices to send alerts or receive commands in real time (Prasetyo et al., 2024).

*G. MQTT Protocol for Agricultural IoT Communication*

Message Queuing Telemetry Transport (MQTT) is a lightweight publish–subscribe messaging protocol designed for IoT applications operating over low-bandwidth and unstable networks. Due to its minimal communication overhead and efficient message delivery, MQTT has been widely adopted in agricultural IoT systems (Suryatini et al., 2021).

Several studies have successfully integrated MQTT with agricultural monitoring systems and reported satisfactory communication performance. For instance, Kristiyanti et al. (2022) applied MQTT in mushroom cultivation monitoring (Kristiyanti et al., 2022), while Islamy and Wisudawati (2023) implemented MQTT combined with Telegram Bot notifications for smart garden systems. However, these studies often evaluate MQTT performance using limited QoS parameters or short observation periods, leaving a gap in comprehensive performance assessment under long-term field deployment (Islamy & Wisudawati, 2023).

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*H. Quality of Service (QoS)*

QoS parameters are widely applied to assess the reliability and performance of network communication systems. In IoT-based applications, QoS evaluation typically includes data throughput, packet loss rate, transmission delay, and jitter (Hasbi & Saputra, 2021). These parameters are essential for determining whether a communication protocol can support real-time monitoring and control functions effectively.

Previous studies indicate that low delay and minimal packet loss are more critical than high throughput in sensor-based IoT applications, as transmitted data packets are generally small and periodic (Sari et al., 2024). Nevertheless, comprehensive QoS evaluations incorporating all four parameters simultaneously remain limited in agricultural IoT research, particularly in outdoor plantation environments .

Table 1. Standard QoS Index Category

| Index | Percentage | Category |
|---|---|---|
| 3.8–4 | 95%–100% | Very Satisfied |
| 3–3.79 | 75%–94.75% | Satisfied |
| 2–2.99 | 50%–74.75% | Unsatisfied |
| 1–1.99 | 25%–49.75% | Bad |

The formulas used to compute the QoS parameters are presented as follows (Kusbandono et al., 2024):

$$Throughput = \frac{Packet\ received\ (bytes)}{Time\ transmitted\ (s)} \ldots (1)$$

$$Packet\ Loss = \frac{(Packet\ Transmitted - Packet\ Received)}{Packet\ Transmitted} \times 100\% \ldots (2)$$

$$Delay = \frac{Total\ Delay}{Total\ Number\ of\ Packets} \ldots (3)$$

$$Jitter = \frac{total\ Delay\ variation}{total\ packets\ received} \ldots (4)$$

Each parameter has a standard quality index and category, as presented below (Bari et al., 2022):

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Table 2. Throughput Index Category

| Throughput (Kbps) | Index | Category |
|---|---|---|
| >2100 | 4 | Very Good |
| 1200 - 2100 | 3 | Good |
| 70-1200 | 2 | Average |
| 0 - 338 | 1 | Bad |

Table 3. Packet Loss Index Category

| Packet Loss (%) | Index | Category |
|---|---|---|
| 0 - 2 | 4 | Very Good |
| Mar-13 | 3 | Good |
| 14 - 25 | 2 | Average |
| >25 | 1 | Bad |

Table 4. Delay Index Category

| Delay (ms) | Index | Category |
|---|---|---|
| ≤150 | 4 | Very Good |
| >150 - 300 | 3 | Good |
| >300 - 450 | 2 | Average |
| >450 | 1 | Bad |

Table 5. Jitter Index Category

| Jitter (ms) | Index | Category |
|---|---|---|
| 0 | 4 | Very Good |
| Jan-75 | 3 | Good |
| 76 - 125 | 2 | Average |
| 126 - 225 | 1 | Bad |

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### *I. Related Work and Research Gap*

Table 6 summarizes selected previous studies related to IoT-based agricultural systems utilizing MQTT and QoS analysis.

Table 6. Summary of Related Research

| Author | Year | Application | Protocol | QoS Parameters | Limitations |
|---|---|---|---|---|---|
| Kristiyanti et al. | 2022 | Mushroom cultivation monitoring | MQTT | Throughput, Delay | No throughput and jitter analysis<br>Short testing duration |
| Islamy & Wisudawati | 2023 | Smart garden system | MQTT | Functional testing only | No QoS evaluation |
| Prasetyo et al. | 2024 | Automatic irrigation system | MQTT | Functional testing only | No QoS evaluation |
| Sasono | 2017 | Sensor network monitoring | Wi-Fi | Throughput, packet loss, delay, jitter | Not agriculture-focused |
| This study | 2025 | Oil palm irrigation monitoring | MQTT | Throughput, packet loss, delay, jitter | Seven-day field deployment |

Based on Table 6, most existing studies focus on short-term evaluation or specific crop applications and do not analyze the long-term QoS behavior of MQTT-based irrigation systems under real plantation network conditions, particularly in oil palm cultivation environments. Furthermore, none of the reviewed studies explicitly examined whether low throughput degrades system reliability in agricultural IoT applications. Therefore, this study positions itself as an extension of existing research by providing a comprehensive QoS analysis and critical discussion tailored to oil palm plantation environments.

## 2. METHOD

The overall methodological workflow is shown in Figure 1.

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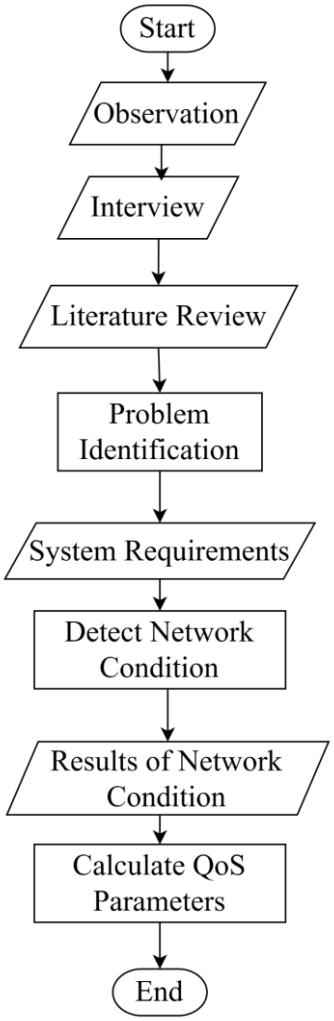



Figure 1. Method

The study began with field observations and interviews with plantation personnel to identify irrigation problems, operational constraints, and user requirements. A literature review was conducted to support system design and to establish references related to IoT-based irrigation, MQTT communication, and QoS evaluation.

Based on the identified challenges, particularly manual irrigation limitations and unstable communication, system requirements were defined, including sensor selection, ESP32 microcontroller utilization, relay-based actuator control, wireless communication, and user interface design. An MQTT-based system architecture was then developed to support real-time data transmission, remote monitoring, and automated irrigation control.

The system was implemented by configuring sensor nodes to publish environmental data and a controller node to subscribe and trigger irrigation actions. HiveMQ Cloud served as the MQTT broker, while a Telegram Bot enabled real-time notifications and remote interaction.

Performance testing was conducted over seven consecutive days with two daily irrigation sessions. QoS parameters throughput level, packet loss ratio, delay, and jitter were analyzed using Wireshark to assess communication reliability, while actuator responses were monitored to verify accurate and timely

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irrigation control. The final analysis evaluated network stability and system responsiveness, demonstrating the effectiveness of MQTT in supporting reliable and efficient IoT-based irrigation management for oil palm plantations.

## 3. RESULT AND DISCUSSION

The system was successfully deployed in an oil palm plantation test area, where real-time environmental data including soil moisture, air temperature, and soil pH were continuously collected and monitored. Field experiments were performed to evaluate hardware functionality, data transmission reliability, and system responsiveness under real environmental conditions.

### *A. Time Results Using MQTT*

System testing was conducted over a seven-day period, with two irrigation sessions performed daily at 08:35–09:35 and 16:00–17:00. Data collection was carried out by comparing sensor readings taken at the start of irrigation with those recorded immediately after irrigation was completed. Measurements included soil moisture, air temperature, and device status.

Table 7. Time Result

| Day | Line | Notification | Time Sent | Time Received | Time Sent | Time Received |
|---|---|---|---|---|---|---|
| 1 | 1 | System on | 8:35:07 | 8:35:10 | 16:00:07 | 16:00:13 |
| | | System off | 8:50:04 | 8:50:09 | 16:10:04 | 16:10:09 |
| | 2 | System on | 8:50:09 | 8:50:14 | 16:10:09 | 16:10:15 |
| | | System off | 9:05:05 | 9:05:12 | 16:20:05 | 16:20:11 |
| | 3 | System on | 9:05:12 | 9:05:19 | 16:20:11 | 16:20:18 |
| | | System off | 9:20:03 | 9:20:09 | 16:30:03 | 16:30:09 |
| 2 | 1 | System on | 8:35:09 | 8:35:12 | 16:00:06 | 16:00:11 |
| | | System off | 8:50:06 | 8:50:13 | 16:10:05 | 16:10:10 |
| | 2 | System on | 8:50:13 | 8:50:17 | 16:10:09 | 16:10:15 |
| | | System off | 9:05:07 | 9:05:14 | 16:20:07 | 16:20:13 |
| | 3 | System on | 9:05:14 | 9:05:20 | 16:20:08 | 16:20:15 |
| | | System off | 9:15:04 | 9:15:10 | 16:25:06 | 16:25:12 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | System on | 8:35:10 | 8:35:14 | 16:00:08 | 16:00:14 |
| | 1 | | | | | |
| | | System off | 8:45:07 | 8:45:12 | 16:10:06 | 16:10:12 |
| | | System on | 8:45:12 | 8:45:16 | 16:10:10 | 16:10:16 |
| 3 | 2 | | | | | |
| | | System off | 8:55:08 | 8:55:13 | 16:15:08 | 16:15:14 |
| | | System on | 8:55:13 | 8:55:18 | 16:15:07 | 16:15:13 |
| | 3 | | | | | |
| | | System off | 9:00:05 | 9:00:10 | 16:20:05 | 16:20:11 |
| | | System on | 8:35:10 | 8:35:14 | 16:00:06 | 16:00:12 |
| | 1 | | | | | |
| | | System off | 8:45:05 | 8:45:11 | 16:10:05 | 16:10:11 |
| | | System on | 8:45:11 | 8:45:16 | 16:10:09 | 16:10:16 |
| 4 | 2 | | | | | |
| | | System off | 8:50:07 | 8:50:13 | 16:15:07 | 16:15:13 |
| | | System on | 8:50:13 | 8:50:19 | 16:15:06 | 16:15:13 |
| | 3 | | | | | |
| | | System off | 8:55:04 | 8:55:09 | 16:20:04 | 16:20:10 |
| | | System on | 8:35:09 | 8:35:11 | 16:00:08 | 16:00:14 |
| | 1 | | | | | |
| | | System off | 8:45:06 | 8:45:12 | 16:10:07 | 16:10:13 |
| | | System on | 8:45:12 | 8:45:17 | 16:10:11 | 16:10:17 |
| 5 | 2 | | | | | |
| | | System off | 8:55:08 | 8:55:14 | 16:20:09 | 16:20:15 |
| | | System on | 8:55:14 | 8:55:19 | 16:20:08 | 16:20:15 |
| | 3 | | | | | |
| | | System off | 9:00:05 | 9:00:11 | 16:25:06 | 16:25:12 |
| | | System on | 8:35:11 | 8:35:15 | 16:00:09 | 16:00:15 |
| 6 | 1 | | | | | |
| | | System off | 8:45:08 | 8:45:14 | 16:15:08 | 16:15:14 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| | | System on | 8:45:14 | 8:45:20 | 16:15:12 | 16:15:18 |
| | 2 | | | | | |
| | | System off | 8:55:09 | 8:55:15 | 16:25:10 | 16:25:16 |
| | | System on | 8:55:15 | 8:55:21 | 16:25:09 | 16:25:15 |
| | 3 | | | | | |
| | | System off | 9:05:06 | 9:05:12 | 16:35:07 | 16:35:13 |
| | | System on | 8:35:11 | 8:35:15 | 16:00:10 | 16:00:16 |
| | 1 | | | | | |
| | | System off | 8:45:09 | 8:45:13 | 16:05:09 | 16:05:15 |
| | | System on | 8:45:13 | 8:45:17 | 16:05:13 | 16:05:19 |
| 7 | 2 | | | | | |
| | | System off | 8:55:10 | 8:55:14 | 16:10:11 | 16:10:17 |
| | | System on | 8:55:08 | 8:55:12 | 16:10:10 | 16:10:17 |
| | 3 | | | | | |
| | | System off | 9:00:07 | 9:00:11 | 16:15:08 | 16:15:14 |

Table 7 presents the notification timestamps recorded during seven days of system operation. For each irrigation line, two types of messages were logged: notifications sent at the start of irrigation and notifications sent after irrigation was completed. The table includes both the time the message was transmitted by the system and the time it was successfully received on the user's Telegram application.

The results show that the system consistently delivered start-irrigation notifications within approximately 3–5 seconds, indicating stable real-time communication between the ESP32 controller, MQTT broker, and Telegram Bot API. Similarly, post-irrigation notifications were received with only a short delay after the message was sent, demonstrating reliable end-to-end delivery during mission-critical events such as irrigation completion.

*B. Quality of Service (QoS)*

QoS measurements were conducted to assess data transmission performance between the ESP32 device, MQTT broker, and subscriber. Four indicators were analyzed over a one-week period (26 June–2 July 2025):

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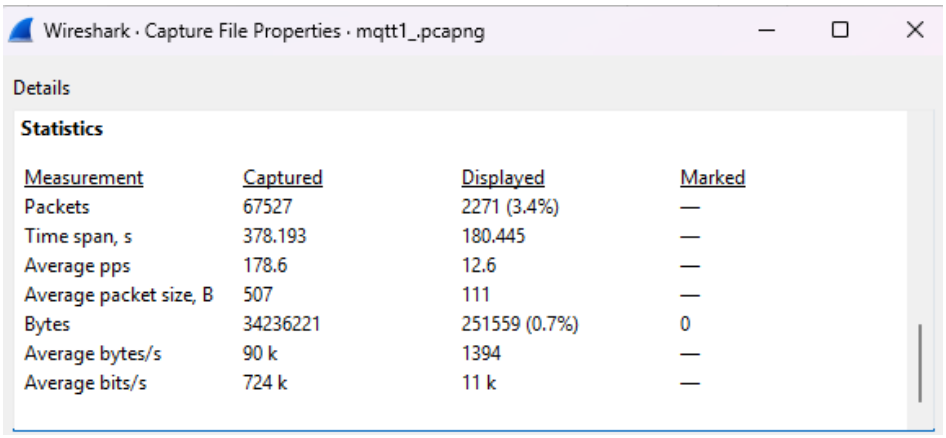



Figure 2. Wireshark Analysis

1) Throughput

An example throughput calculation shows 251559 bytes received over 180.445 seconds. Using Equation (1):

$$Throughput = \frac{Packet\ received\ (bytes)}{Time\ transmitted\ (s)} = \frac{251559\ bytes}{180{,}445\ s} = 1394{,}1034664\ byte/s \times 8 = 11152{,}82\ bit/s$$

Based on Table 2, this value is classified as *Bad* with an index of 1. Results from all sessions are summarized in Table 8.

Table 8. Summary of Throughput Results

| hari | session | Throughput (kbps) | Index | Category |
|---|---|---|---|---|
| 1 | Morning | 11,15 | 1 | Bad |
| | Afternoon | 7.11 | 1 | Bad |
| | Morning | 4,7 | 1 | Bad |
| 2 | Afternoon | 2,51 | 1 | Bad |
| | Morning | 5,32 | 1 | Bad |
| 3 | Afternoon | 5.44 | 1 | Bad |
| 4 | Morning | 4,11 | 1 | Bad |
| | Afternoon | 5.27 | 1 | Bad |
| 5 | Morning | 5,17 | 1 | Bad |
| | Afternoon | 5.54 | 1 | Bad |
| 6 | Morning | 5,02 | 1 | Bad |
| | Afternoon | 5.42 | 1 | Bad |

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| | | | | |
|---|---|---|---|---|
| 7 | Morning | 5,43 | 1 | Bad |
| | Afternoon | 5,47 | 1 | Bad |
| **Average** | | **5.618.571.429** | **1** | **Bad** |

Although the measured throughput values were classified as “Bad” according to standard QoS categories, this result must be interpreted within the context of IoT-based irrigation systems. MQTT communication in this study transmitted small-sized sensor data packets at low transmission intervals, which inherently results in low throughput values.

Compared to multimedia or high-bandwidth applications, irrigation monitoring systems do not require high throughput. Similar findings were reported by Sasono et al. (2017), where stable system operation was achieved despite limited bandwidth availability. Therefore, low throughput in this study does not indicate poor system performance, but rather reflects the efficiency of MQTT in minimizing network usage while maintaining reliable message delivery.

2) Packet Loss

Based on Equation (2), when all 2271 transmitted packets were successfully received, the packet loss rate was 0%, which is classified as *Very Good* with a QoS index value of 4. Similar results were observed across all test sessions, as summarized in Table 9.

Table 9. Summary of Packet Loss Results

| Day | session | packet loss % | Index | Category |
|---|---|---|---|---|
| 1 | Morning | 0 | 4 | Very Good |
| | Afternoon | 0 | 4 | Verv Good |
| 2 | Morning | 0 | 4 | Very Good |
| | Afternoon | 0 | 4 | Verv Good |
| 3 | Morning | 0 | 4 | Very Good |
| | Afternoon | 0 | 4 | Verv Good |
| 4 | Morning | 0 | 4 | Very Good |
| | Afternoon | 0 | 4 | Verv Good |
| 5 | Morning | 0 | 4 | Very Good |
| | Afternoon | 0 | 4 | Verv Good |
| 6 | Morning | 0 | 4 | Very Good |
| | Afternoon | 0 | 4 | Verv Good |
| 7 | Morning | 0 | 4 | Very Good |
| | Afternoon | 0 | 4 | Verv Good |
| **Average** | | **0** | **4** | **Very Good** |

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3) Delay

Delay represents the time taken by a data packet to be transmitted from the source to the destination. Based on Equation (3), a measured delay of 158.75 ms is categorized as *Good* with a QoS index value of 3. The delay measurements obtained from all testing sessions are presented in Table 10.

Table 10. Summary of Delay Results

| hari | sesi | Delay (ms) | Index | Category |
|---|---|---|---|---|
| 1 | Morning | 158,75 | 3 | Good |
| | Afternoon | 143,83 | 4 | Very Good |
| 2 | Morning | 189,39 | 3 | Good |
| | Afternoon | 231,03 | 3 | Good |
| 3 | Morning | 245,00 | 3 | Good |
| | Afternoon | 201,55 | 3 | Good |
| 4 | Morning | 185,96 | 3 | Good |
| | Afternoon | 187,05 | 3 | Good |
| 5 | Morning | 163,98 | 3 | Good |
| | Afternoon | 159,11 | 3 | Good |
| 6 | Morning | 168,82 | 3 | Good |
| | Afternoon | 169,40 | 3 | Good |
| 7 | Morning | 156,36 | 3 | Good |
| | Afternoon | 160,43 | 3 | Good |
| **Average** | | **180.0471429** | **3.071428571** | **Good** |

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4) Jitter

Jitter describes the variation in packet delay over time. Based on Equation (4), a measured jitter value of 0.37 ms is classified as *Very Good* with a QoS index of 4. The complete jitter results from all testing sessions are summarized in Table 11..

Table 11. Summary of Jitter Results

| hari | sesi | Jitter (ms) | Index | Category |
|---|---|---|---|---|
| 1 | Morning | 0,37 | 4 | Very Good |
| | Afternoon | 0.0009 | 4 | Verv Good |
| 2 | Morning | 0,2 | 4 | Very Good |
| | Afternoon | 0.12 | 4 | Verv Good |
| 3 | Morning | 0,49 | 4 | Very Good |
| | Afternoon | 0.04 | 4 | Verv Good |
| 4 | Morning | 0,29 | 4 | Very Good |
| | Afternoon | 0.09 | 4 | Verv Good |
| 5 | Morning | 0,12 | 4 | Very Good |
| | Afternoon | 0.07 | 4 | Verv Good |
| 6 | Morning | 0,12 | 4 | Very Good |
| | Afternoon | 0.11 | 4 | Verv Good |
| 7 | Morning | 0,1 | 4 | Very Good |
| | Afternoon | 0.11 | 4 | Verv Good |
| **Average** | | **0.1715384615** | **4** | **Very Good** |

5) Overall QoS Index Qualification

Table 12. Overall QoS Index

| Parameter | | | | Overall QoS Index | Category |
|---|---|---|---|---|---|
| Throughput | Packet Loss | Delay | Jitter | | |
| 1.00 | 4.00 | 3.07 | 4.00 | 3.02 | Satisfied |

Table 12 presents the QoS index calculated from average values of all parameters. All sessions fall consistently within the “Satisfied” category, ranging from 75%–94.75%. The overall mean QoS index is 3.02, indicating that system communication performance meets acceptable standards for reliable operation. Compared to previous MQTT-based irrigation studies that primarily evaluated latency or system functionality, this study provides a more comprehensive QoS analysis over an extended testing period.

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*C. Telegram Application Interface*




Figure 3. Telegram Interface

The system integrates with the Telegram Bot API to send real-time alerts regarding irrigation and fertilization status. Notifications such as “Soil Moisture: Dry” or “Soil Condition Normal” were successfully delivered, enabling remote monitoring via smartphone without requiring physical access to the device.

## 4. CONCLUSION

This study successfully evaluated an IoT-based irrigation monitoring system for oil palm plantations using the MQTT communication protocol under real field conditions. The integration of ESP32 microcontrollers, environmental sensors, an MQTT broker, and Telegram Bot notifications enabled reliable real-time monitoring and automated irrigation control in a plantation environment with limited network infrastructure.

Experimental results obtained from a seven-day continuous testing period demonstrate that MQTT provides stable end-to-end communication for irrigation operations. Irrigation start and completion notifications were consistently delivered within 3–5 seconds during both morning and afternoon sessions, confirming the suitability of MQTT for time-sensitive agricultural monitoring applications.

Quality of Service (QoS) analysis further validates the robustness of the proposed system. Packet loss remained at 0% throughout all testing sessions, while average delay (180.05 ms) and jitter (0.17 ms) were classified as Good and Very Good, respectively. Although measured throughput values were

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relatively low, this condition does not indicate poor system performance. Instead, it reflects the lightweight nature of MQTT communication, which transmits small sensor payloads efficiently and minimizes bandwidth usage. For irrigation monitoring systems, where data volume is low and reliability is more critical than high data rates, low throughput is therefore acceptable and even advantageous in rural plantation environments.

Overall, the system achieved an average QoS index of 3.02, categorized as Satisfied, indicating that MQTT-based communication is technically adequate for supporting reliable and efficient irrigation monitoring in oil palm plantations. This research contributes empirical evidence that MQTT can maintain stable performance despite limited bandwidth availability and provides practical guidance for the deployment of bandwidth-efficient IoT systems in agricultural and rural settings.

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