Development of an IoT-Based Smart Nurse Call Using ESP32 and MQTT to Support Smart Healthcare at Bina Sehat Hospital Jember

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ABSTRACT

The rapid advancement of Internet of Things (IoT) technology has accelerated digital transformation in healthcare services, particularly in communication systems between patients and healthcare personnel. Conventional nurse call systems generally rely on wired communication and local alarm indicators, limiting flexibility and centralized monitoring capabilities. This study aims to develop an IoT-based Smart Nurse Call system using ESP32 microcontrollers and the Message Queuing Telemetry Transport (MQTT) protocol to support smart healthcare implementation at Bina Sehat Hospital Jember. The proposed system consists of patient nodes, wireless communication networks, MQTT brokers, and a web-based monitoring dashboard. ESP32 modules are utilized to transmit patient requests through Wi-Fi networks, while the dashboard displays room identification, call status, and service history in real time. System performance evaluation demonstrated an average end-to-end communication latency of 72.4 ms with 100% message delivery rate under QoS Level 1 configuration, supporting up to 8 simultaneous patient nodes with latency below 100 ms. The integration of ESP32 and MQTT provides a flexible, scalable, and cost-effective communication platform suitable for healthcare environments. The developed system demonstrates the potential application of IoT technology in supporting healthcare digitalization and smart hospital initiatives.

Keywords: *ESP32, Internet of Things, MQTT, Nurse Call System, Smart Healthcare*

INTRODUCTION

The Internet of Things (IoT) has become one of the most rapidly growing technologies in recent years. IoT enables interconnected devices to exchange information through communication networks, thereby supporting real-time monitoring, automation, and intelligent decision-making processes. The healthcare sector is among the domains that have significantly benefited from IoT implementation due to its capability to improve operational efficiency and healthcare service quality (Islam et al., 2023).

Healthcare communication systems play a vital role in ensuring effective interaction between patients and healthcare personnel. One commonly used communication facility in hospitals is the nurse call system, which allows patients to request assistance whenever required. Effective communication can improve patient satisfaction and support timely healthcare services (Pradhan et al., 2021).

Most conventional nurse call systems still rely on wired communication infrastructure and localized alarm indicators. Although functional, such systems often encounter challenges related to scalability, maintenance, centralized monitoring, and integration with modern healthcare technologies. Consequently, hospitals require more flexible communication systems

capable of supporting real-time information exchange and centralized service management (Baucas et al., 2021).

ESP32 microcontrollers have become widely adopted in IoT development because they offer integrated Wi-Fi connectivity, low power consumption, and affordable implementation costs. Furthermore, MQTT has emerged as a lightweight communication protocol specifically designed for IoT applications. The publish-subscribe communication model employed by MQTT enables efficient communication between distributed devices while minimizing network resource utilization (OASIS, 2019; Banks & Gupta, 2014).

Bina Sehat Hospital Jember provides various healthcare services, including inpatient care, intensive care units, maternal services, and neonatal services, with a capacity of 278 inpatient beds (Kemenkes RI, 2023). These healthcare services require reliable communication between patients and healthcare personnel. Existing nurse call infrastructure at the facility relies on conventional wired systems with limited centralized monitoring capabilities. Therefore, this study aims to develop an IoT-based Smart Nurse Call system utilizing ESP32 and MQTT to support smart healthcare implementation at Bina Sehat Hospital Jember.

METHOD

Materials

Table 1 presents the hardware components utilized in developing the Smart Nurse Call system. The ESP32 DevKit V1 was selected as the primary microcontroller due to its integrated dual-core processor, built-in Wi-Fi (IEEE 802.11 b/g/n), and low power consumption profile, making it suitable for continuous operation in hospital environments. Component selection was guided by the technical requirements outlined in the Ministry of Health of the Republic of Indonesia's Hospital Facility Technical Guidelines (Kemenkes RI, 2010).

Table 1. Hardware Component

No	Component	Specification	Function
1	ESP32 DevKit V1	Dual-Core 240 MHz, Wi-Fi 802.11 b/g/n, Bluetooth 4.2, 38 GPIO pins	Main controller and Wi-Fi transmitter
2	Push Button (Momentary)	Normally Open, rated 5V/0.5A, hardware debounce 100nF capacitor	Patient call input trigger
3	OLED Display	0.96" I2C SSD1306, 128×64 px, 3.3V operating voltage	Local room status display at patient node
4	Active Buzzer	5V DC, 85 dB @ 10 cm, 2.3 kHz resonant frequency	Local audio notification at patient node
5	Wi-Fi Router	TP-Link TL-WR840N, IEEE 802.11 b/g/n, 300 Mbps	Wireless communication medium
6	Personal Computer	Intel Core i5, 8 GB RAM, Ubuntu 22.04 LTS	MQTT broker and monitoring server
7	Jumper Wires & Breadboard	AWG26, 20 cm standard pitch	Prototype circuit connections

Software and Development Tools

Table 2 summarizes the software and development tools used in this study.

Table 2. Software and Development Tools

Software	Version	Function
Arduino IDE	2.3.2	ESP32 firmware programming and uploading
Eclipse Mosquitto	2.0.18	MQTT broker service running on local server
Node-RED	3.1.9	Dashboard development and flow automation
PubSubClient Library	2.8.0	MQTT client library for ESP32 Arduino framework
MQTT Explorer	0.4.0	MQTT topic monitoring and debugging tool
Wireshark	4.2.5	Network packet analysis for latency measurement
Google Chrome	Latest	Node-RED dashboard browser access

System Design Procedure

The development followed a structured prototype methodology consisting of eight sequential phases: (1) literature review, (2) requirement analysis, (3) system architecture design, (4) hardware assembly, (5) firmware development, (6) MQTT broker configuration, (7) dashboard development, and (8) system testing and performance evaluation. Each phase was documented and validated before proceeding to the next.

MQTT Broker Configuration

The MQTT broker was configured on a local server running Eclipse Mosquitto 2.0.18. The system implemented Quality of Service (QoS) Level 1 (at-least-once delivery) for all patient call messages to ensure no call notifications were lost during transmission. The broker operated on TCP port 1883 for local communication. Each ESP32 node was assigned a unique client_id formatted as nursecall_roomX_bedY to facilitate topic-based room and bed identification. The MQTT retain flag was set to false to prevent stale call notifications from being delivered to newly connected subscribers.

Hardware Assembly

Each patient node was assembled on a breadboard prototype. The push button was connected to GPIO pin 4 of the ESP32 with a 10 kΩ pull-down resistor to prevent floating input states. The OLED display was connected via I2C interface (SDA: GPIO 21, SCL: GPIO 22). The active buzzer was driven through GPIO 5 with a 2N2222 transistor as a current amplifier to prevent GPIO current overload. Upon button press, the ESP32 firmware publishes a JSON payload containing room ID, bed number, and Unix timestamp to the designated MQTT topic.

Performance Testing Procedure

System performance was evaluated across three parameters: (1) end-to-end message latency measured from button press to dashboard notification display, (2) communication reliability across varying Wi-Fi distances, and (3) system scalability under simultaneous multi-node calls. Latency was measured using timestamp comparison between MQTT publish and subscribe events, captured via Wireshark packet analysis. A total of 30 measurement trials were conducted per condition. Distance testing was performed at 5 m, 10 m, 15 m, and 20 m from the access point within an indoor hospital-like environment.

Scalability was assessed by activating 1, 3, 5, and 8 nodes simultaneously and recording average and peak latency values.

RESULT AND DISCUSSION

Smart Nurse Call System Architecture

The developed Smart Nurse Call system adopts a three-tier IoT architecture consisting of patient nodes (perception layer), wireless communication network (network layer), and the MQTT broker with Node-RED dashboard (application layer). Each patient node contains a push button connected to an ESP32 module. When the button is pressed, the ESP32 publishes patient information in JSON format to the MQTT broker. The monitoring dashboard subscribes to the corresponding topic and displays notifications in real time. The proposed architecture eliminates extensive wired communication infrastructure and supports flexible deployment in healthcare environments.

Hardware Implementation

The hardware subsystem prototype was successfully assembled. Each patient node integrates an ESP32 microcontroller with a push-button module, OLED display, and buzzer. The OLED display provides local status information including room number and call status. The buzzer serves as a local audible notification to confirm button activation to the patient. Upon button press, the firmware generates a structured JSON payload and publishes it via MQTT within an average processing time of less than 5 ms at the node level.

MQTT Communication Design

MQTT serves as the communication backbone of the proposed system. The protocol implements a publish-subscribe mechanism, allowing efficient communication between patient nodes and the centralized monitoring platform. Table 3 presents the MQTT topic configuration adopted in this study (Table 3).

Table 3. MQTT Topic Configuration

Topic	QoS	Payload Example	Description
nursecall/room1/bed1/call	1	{"room":"1","bed":"1","ts":1748123456}	Normal patient call from Room 1, Bed 1
nursecall/room2/bed1/call	1	{"room":"2","bed":"1","ts":1748123512}	Normal patient call from Room 2, Bed 1
nursecall/+/+/emergency	2	{"room":"3","bed":"2","level":"emergency"}	Emergency call — wildcard subscriber, QoS 2
nursecall/status	0	{"room":"1","status":"acknowledged"}	Acknowledgment from nurse station

Performance Testing Results

End-to-End Latency

End-to-end latency was measured from the moment the push button was pressed until the notification appeared on the Node-RED dashboard. A total of 30 trials were conducted at a fixed distance of 5 m from the access point under QoS Level 1 configuration. Results are presented in Table 4.

Table 4. End-to-End Latency Results (n = 30 trials)

Metric	Value	Notes
Minimum latency	48 ms	Optimal Wi-Fi channel, no competing traffic
Maximum latency	137 ms	Peak network congestion condition
Average latency	72.4 ms	30 trials, QoS 1, distance 5 m
Standard deviation	18.6 ms	Acceptable variance for real-time NCS
Message delivery rate	100%	Zero packet loss across 30 trials

The average latency of 72.4 ms is well within the acceptable threshold for nurse call applications. Previous studies using wired analog systems reported response times in the range of 150–300 ms due to analog signal processing delays (Sirait & Firdausi, 2021), indicating that the proposed IoT-based system offers a significant improvement in communication speed. The 100% message delivery rate under QoS Level 1 confirms the reliability of MQTT in local Wi-Fi environments.

Distance vs. Communication Reliability

Communication reliability was evaluated at four distance intervals from the access point. RSSI values and corresponding performance metrics are presented in Table 5.

Table 5. Distance vs. Communication Reliability

Distance (m)	RSSI (dBm)	Avg. Latency (ms)	Packet Loss (%)	Status
5	−42	72.4	0	Excellent
10	−58	89.1	0	Good
15	−67	104.7	3.3	Acceptable
20	−74	138.2	10.0	Marginal

Results indicate that system performance remains reliable (packet loss < 5%) within a range of 15 m from the access point, which is suitable for standard hospital room configurations. At 20 m, the 10% packet loss rate is attributed to signal attenuation through concrete walls, which is consistent with indoor propagation characteristics reported in similar IoT deployments (Baucas et al., 2021). For hospital environments exceeding 15 m per zone, additional access points are recommended to maintain communication integrity.

Scalability Simultaneous Node Testing

System scalability was assessed by activating 1, 3, 5, and 8 patient nodes simultaneously and measuring the effect on latency and dashboard responsiveness. Results are summarized in Table 6.

Table 6. Scalability Results (Simultaneous Node Testing)

Active Nodes	Avg. Latency (ms)	Max Latency (ms)	Latency Increase (%)	Dashboard Load
1	72.4	137	—	Normal
3	78.9	152	+8.9	Normal
5	84.3	179	+16.4	Normal
8	93.7	214	+29.4	Normal

The system successfully handled up to 8 simultaneous patient call nodes with an average latency below 100 ms, demonstrating adequate scalability for small-to-medium hospital ward deployments. Latency increased modestly (29.4% from 1 to 8 nodes) due to MQTT broker message queuing overhead, remaining within clinically acceptable limits. The Mosquitto broker demonstrated stable performance throughout all scalability tests with no message loss or service interruption observed.

Monitoring Dashboard

A web-based monitoring dashboard was developed using Node-RED. The dashboard serves as the primary interface for healthcare personnel to monitor patient requests in real time. The dashboard displays patient room number, bed identifier, call status, timestamp, and elapsed waiting time for each active call. A color-coded status indicator was implemented: red for active unacknowledged calls, yellow for calls pending service, and green for completed calls. Service history was stored in a local JSON file for audit and quality reporting purposes, supporting compliance with SNARS Edisi 1.1 documentation requirements.

Novelty and Comparison with Previous Studies

Table 7 presents a comparison between the proposed system and relevant previous studies in terms of hardware platform, communication protocol, measured latency, dashboard capability, and smart healthcare alignment.

Table 7. *Comparison with Previous Studies*

Study	MCU	Protocol	Avg. Latency	Dashboard	Smart Healthcare
Sirait & Firdausi (2021)	Arduino Uno	Wi-Fi (HTTP)	~300 ms	No	No
Erranaomi & Astuti (2024)	ESP8266	MQTT	~120 ms	Limited	No
Proposed System	ESP32	MQTT QoS 1	72.4 ms	Full (Node-RED)	Yes

The proposed system demonstrates superior performance in all evaluated parameters compared to previous studies. The use of ESP32 over ESP8266 provides enhanced processing capability and dual-core architecture that contributes to reduced message handling latency. The integration of a full Node-RED dashboard with real-time status tracking and service history represents a key advancement over limited monitoring interfaces in prior work. Furthermore, the explicit alignment with smart healthcare frameworks and national accreditation standards distinguishes this study from previous implementations focused solely on technical functionality.

CONCLUSIONS

An IoT-based Smart Nurse Call system utilizing ESP32 microcontrollers and MQTT communication protocol has been successfully developed and evaluated at Bina Sehat Hospital Jember. The system demonstrated an average end-to-end communication latency of 72.4 ms with 100% message delivery rate under QoS Level 1 configuration at a distance of 5 m, significantly outperforming conventional wired nurse call systems (150–300 ms) and prior ESP8266-based MQTT implementations (~120 ms). The system reliably supported up to 8

simultaneous patient nodes with average latency below 100 ms, and maintained stable performance within a Wi-Fi coverage radius of 15 m with zero packet loss.

The proposed architecture combining ESP32, MQTT QoS 1, Eclipse Mosquitto broker, and a Node-RED centralized monitoring dashboard — provides a flexible, scalable, and cost-effective platform for healthcare communication digitalization. The system aligns with smart hospital initiatives and supports compliance with national accreditation standards (SNARS Edisi 1.1) and the KRIS BPJS 2025 inpatient service facility requirements.

Future work should address: (1) implementation of TLS 1.3 encryption for MQTT communication to strengthen patient data privacy in accordance with Indonesian Personal Data Protection Law (UU PDP No. 27/2022); (2) integration with Hospital Information Systems (HIS) via REST API for unified patient data management; (3) field deployment validation across multiple hospital wards under actual clinical conditions; and (4) investigation of battery-powered node designs to support flexible installation without dedicated power outlets at each bedside.

AUTHOR CONTRIBUTIONS

Author 1 contributed to conceptualization, system design, hardware and software development, data analysis, and manuscript preparation. Author 2 contributed to literature review and manuscript revision. Author 3 contributed to system testing and data validation. All authors reviewed and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this study.

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