JURNAL INFOTEL
VOL. 16, NO. 4, NOVEMBER 2024, PP. 695–712. DOI:10.20895/INFOTEL.V16I3.1259

RESEARCH ARTICLE

Revolutionizing Classroom Attendance: A Wireless Smart System Using ESP-NOW Protocol

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Received: October 18, 2024; Revised: December 02, 2024; Accepted: December 03, 2024.

Abstract: In an era where technological advancements drive improvements across various sectors, enhancing efficiency in educational management systems is crucial. This paper presents a novel wireless attendance system that leverages the Espressif wireless network over Wi-Fi (ESP-NOW) protocol, which offers advantages over traditional wireless fidelity (Wi-Fi) by enabling low-power, low-latency, and direct device-to-device communication without the need for an intermediary network. The system employs ESP32 modules configured as both slave and master devices. Slave devices, positioned on the lecturer's desk, interact with students' smartphones when the lecturer initiates the class, while master devices, strategically placed at multiple locations within the classroom, compile and consolidate attendance data for each room. The system incorporates Received Signal Strength Indicator (RSSI) based restrictions via the ESP-NOW protocol to prevent overlapping attendance between rooms and ensure that students can only record their presence if they are physically within the designated classroom. Attendance data is automatically logged and made accessible in real-time through a dedicated mobile application for lecturers. Empirical testing shows exceptional accuracy in attendance recording, with no packet loss observed during trials, an average verification time of less than 1 second, and a data transmission rate consistently ranging from 700 to 800 Bytes/seconds. This paper highlights the system's potential for reliable and efficient attendance tracking and identifies future improvements, including expanded coverage and data security features.

Keywords: ESP-NOW Protocol, ESP32 Modules, Real-Time Data Logging, RSSI-Based Restrictions, Wireless Attendance System

1 Introduction

In contemporary educational settings, the effective and precise management of attendance is vital for ensuring administrative organization and boosting academic productivity. Traditional attendance systems often rely on manual processes or outdated technology, leading to inefficiencies and inaccuracies [1]. These conventional methods can be time-consuming and prone to errors, impacting both educators and students [2]. As institutions of higher education place greater emphasis on student engagement and retention, the demand for robust and reliable attendance tracking systems has become increasingly important. Automatic attendance systems play a crucial role in modern educational environments by not only saving time and reducing administrative burdens but also by offering valuable data insights that help streamline administrative processes and improve overall operational efficiency [3].

Several automatic attendance tracking technologies have been proposed, each with its own advantages and limitations. Biometric systems, such as fingerprint and facial recognition [4–6], offer high accuracy and security but face drawbacks like privacy concerns, high implementation costs, and potential inaccuracies due to environmental conditions or user errors. Radio Frequency Identification (RFID) and Near Field Communication (NFC) based solutions [7, 8] facilitate easy automation by allowing devices to read tags or cards from a distance, but they are limited by issues such as tag loss or damage, restricted read range, privacy concerns, and additional costs associated with tags and system maintenance. Mobile app-based [2,9,10] check-ins provide flexibility but depend on smartphone availability and connectivity, making them susceptible to signal strength variations, app security concerns, battery life issues, and user compliance challenges. Additionally, mobile apps cannot effectively verify if students are physically present at the specified location, potentially compromising the accuracy of attendance records. Quick Response (QR) code systems offer a cost-effective solution by allowing users to scan codes to record attendance [11], but they face limitations such as the need for a clear line of sight and the potential for code tampering. Moreover, QR codes can be easily shared or photographed, which undermines the credibility of attendance records and does not guarantee that the student is present at the location. Internet of Things (IoT) based attendance systems, which utilize interconnected devices for real-time data collection [12–14], offer seamless integration and efficient monitoring. Despite their benefits, these systems may encounter challenges related to network reliability, data security, and higher infrastructure costs. Additionally, IoT systems also require significant setup and maintenance, making them more suitable for back-end integration after a primary wireless-based system is in place. Wireless-based technologies [15], such as Bluetooth [16–18] and Wi-Fi [19], present a compelling option for attendance tracking, as they provide broad compatibility, ease of integration, and a relatively straightforward implementation process compared to other systems. Given these benefits, wireless-based technologies are particularly well-suited for efficient and scalable attendance management solutions, with IoT systems serving as a valuable back-end enhancement for more comprehensive monitoring and data analysis.

To overcome the limitations of existing attendance tracking technologies, this paper proposes a novel wireless system that utilizes the ESP-NOW protocol. This protocol offers substantial advantages over traditional Wi-Fi and other automatic methods by enabling direct, low-power, and low-latency communication between devices. ESP-NOW effectively reduces common issues such as high costs and connectivity problems by bypassing intermediary networks. Compared to Wi-Fi, which often incurs higher costs and increased power consumption due to its extensive infrastructure requirements, ESP-NOW provides a more cost-effective and energy-efficient solution. Additionally, while Bluetooth offers low-power communication, ESP-NOW surpasses it in terms of latency and range, providing faster and more reliable direct peer-to-peer communication without the need for pairing and connection establishment processes [20]. ESP-NOW has been successfully applied in various domains, such as smart home automation, environmental monitoring, and industrial IoT, where its efficiency in enabling quick and secure device-to-device communication is crucial. Applications include one-to-many audio transmission for collaborative environments [21], energy-efficient synchronized communication [22], and secure home automation systems using mesh networks [23]. Moreover, ESP-NOW has been employed in coal mine monitoring for real-time data acquisition [24] and decentralized voice communication systems [25]. An indoor performance evaluation has demonstrated its effectiveness in varying conditions [26]. Research has shown that ESP-NOW can improve the performance of Wi-Fi-based communication systems with multiple sensors through enhanced collaboration and protocol integration [27]. These attributes make ESP-NOW particularly suitable for enhancing attendance tracking systems, providing reliable and efficient solutions. Recognizing the strengths of ESP-NOW, Bluetooth, and Wi-Fi, this paper proposes a system that integrates all three technologies to optimize performance.

The system utilizes ESP32 modules configured as both slave and master units, integrating Bluetooth Low Energy (BLE), ESP-NOW, and Wi-Fi technologies to leverage the strengths of each. BLE, a subset of Bluetooth technology, is employed for initial interactions between slave devices on the lecturer's desk and students' smartphones, offering low power consumption and efficient communication suitable for frequent, short-range exchanges. In contrast, classic Bluetooth, while also low power, is typically used for continuous, longer-range communication, which can be less efficient for the purposes of this system. ESP-NOW is used for direct, low-latency communication between master devices distributed throughout the classroom, providing quick and reliable data aggregation. Wi-Fi facilitates broader network connectivity and data management, enhancing overall system integration. By combining these three technologies, the system maximizes the advantages of each such as the low power usage of BLE, the rapid communication of ESP-NOW, and the extensive connectivity of Wi-Fi while addressing common issues such as connectivity problems and high costs. RSSI-based restrictions are incorporated to prevent overlapping attendance records between different rooms, ensuring accurate presence verification. The contributions of this paper include the innovative integration of ESP-NOW, BLE, and Wi-Fi technologies to create a highly efficient attendance tracking system, the use of RSSI-based restrictions for advanced location verification, and the demonstration of a scalable approach suitable for real-world applications, thus enabling more accurate, cost-effective, and energy-efficient attendance solutions.

This paper is organized as follows: The Introduction outlines the study's objectives and reviews relevant work, emphasizing the benefits of the ESP-NOW protocol over existing technologies. In section 2 presents the Research Method, focusing on the supporting components of the system, including the ESP-NOW protocol, BLE, and Wi-Fi technologies, and detailing the construction of the proposed system. This includes the design and implementation aspects, such as the configuration of ESP32 modules as slave and master units, the communication protocols used, and the system architecture. In section 3 covers the Results, analyzing the system's performance regarding time efficiency, data transmission speed, reception accuracy, and RSSI-based restrictions. In section 4 provides the Discussion, exploring the implications of the results and how they address the limitations of existing attendance tracking systems. The paper concludes with a summary of key findings and proposes future research directions in section 5. This structure ensures a coherent presentation of the system's development and its impact on attendance tracking.

2 Research Method

In this section, we provide an overview of the supporting technologies utilized in this paper, focusing on their functionalities and roles in the proposed smart wireless attendance system. The system architecture is designed to efficiently track attendance by integrating ESP-NOW, BLE, and Wi-Fi technologies. ESP32 modules, configured as both master and slave units, establish initial low-power connections between students' and teachers' smartphones via BLE. This setup enables seamless communication for attendance verification. ESP-NOW facilitates fast, direct peer-to-peer communication among master devices distributed throughout the classroom, ensuring rapid data aggregation. The collected data is then transferred through the campus's existing Wi-Fi infrastructure to the university's central server, enhancing data management and connectivity. This integrated approach leverages the strengths of each technology, addressing challenges related to connectivity and data integrity to provide a reliable attendance tracking solution.

2.1 ESP-NOW

ESP-NOW is a lightweight, proprietary wireless communication protocol developed by Espressif Systems for use with their ESP32 and ESP8266 microcontrollers. The protocol integrates several functionalities of the OSI model layers into a streamlined communication mechanism that primarily relies on the IEEE 802.11-1999 standard. Unlike traditional Wi-Fi, which also builds upon IEEE 802.11, ESP-NOW operates without the need to establish a formal connection between devices. Instead, it facilitates peer-to-peer communication in an ad hoc manner, allowing for quick data exchange with minimal setup [21, 22]. ESP-NOW uses direct sequence spread spectrum (DSSS) modulation at the physical layer, similar to the original IEEE 802.11 version, ensuring robust communication. The default data rate is 1 Mbit per second, with a long-range version available at 250 or 500 Kbits per second for extended reach. This proprietary modulation allows all devices to communicate effectively within the same configuration. ESP-NOW supports one-to-many and many-to-many communication modes at the MAC layer, utilizing CSMA/CA to avoid collisions, as shown in Figure 1. It offers unicast and broadcast transmission options, with the ability to send payloads up to 250 bytes using IEEE vendor-specific action frames. Each ESP-NOW packet includes an identifier based on the device's MAC address, which ensures that data is directed to the correct recipient or broadcast to multiple devices. Security is enhanced with optional application-layer encryption via AES-128, using Primary Master Keys (PMK) and Local Master Keys (LMK) for data protection [23–25].

Operating in the 2.4 GHz band, ESP-NOW minimizes interference risk due to its low power and range, provided it avoids simultaneous use with other 2.4 GHz devices. The protocol is optimized for short-range communication, making it suitable for scenarios where devices are in close proximity and high data throughput is not necessary [4, 27].

Given its low latency, energy efficiency, and direct device-to-device communication capabilities, ESP-NOW is particularly well-suited for attendance tracking systems. It meets the critical requirements of speed and accuracy in data recording, ensuring reliable and efficient attendance management.

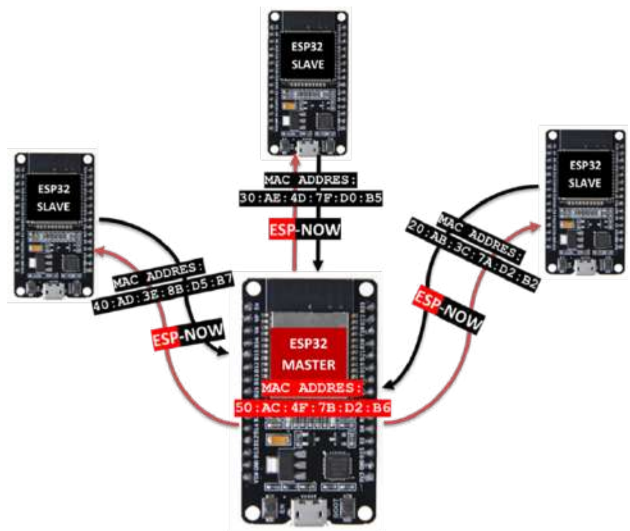


Figure 1: ESP-Now link communication system.

2.2 Bluetooth Low Energy (BLE)

Bluetooth Low Energy (BLE) is a wireless communication protocol designed for low-power, short-range applications. Introduced as part of the Bluetooth 4.0 standard, BLE is optimized for devices that require minimal energy consumption, enabling them to run for extended periods on small batteries. This makes BLE particularly suitable for Internet of Things (IoT) applications, including wearable devices, health monitors, and smart home products. BLE operates in the 2.4 GHz ISM band, utilizing Gaussian frequency-shift keying (GFSK) modulation to achieve data rates of up to 2 Mbps. Its architecture is designed to support infrequent short bursts of data transmission, which is ideal for scenarios where continuous data exchange is unnecessary [20].

While both BLE and ESP-NOW serve as low-power communication protocols, they have distinct differences that cater to specific use cases. BLE operates through a traditional connection-oriented architecture, where devices must establish a connection before data exchange, which can introduce latency and requires more overhead for connection management. In contrast, ESP-NOW offers a connectionless communication model that allows for immediate data transmission without the need for pairing or connection setup, resulting in lower latency and faster data transfer. Additionally, while BLE supports higher data rates and a broader range of interoperability with various devices, ESP-NOW provides more efficient peer-to-peer communication with lower power consumption and enhanced range in certain configurations [20].

Due to its characteristics, BLE is particularly well-suited to support the connectivity of end devices, such as students' and teachers' smartphones, to ESP32 modules configured as slaves in attendance tracking systems as shown in Figure 2. BLE's low power consumption and efficient communication make it ideal for facilitating the initial interactions between smartphones and the ESP32 network, enabling seamless integration and reliable data exchange in the system. Once connected, ESP32 devices can communicate with each other via the ESP-NOW protocol, which allows for rapid, direct communication between devices. This configuration enhances the speed and efficiency of the system, ensuring timely and accurate attendance tracking. By leveraging the strengths of both BLE and ESP-NOW, the system achieves a robust and efficient solution for modern attendance management.

Figure 2: BLE connectivity of smart classroom attendance system.

2.3 Wireless Fidelity (Wi-Fi)

Wi-Fi, or Wireless Fidelity, is a widely used wireless communication technology that enables devices to connect to the internet and communicate with each other over a local area network (LAN). Based on the IEEE 802.11 standards, Wi-Fi operates in the 2.4 GHz and 5 GHz frequency bands, offering high data rates that can reach up to several gigabits per second, depending on the specific standard version (e.g., Wi-Fi 5, Wi-Fi 6). Wi-Fi's ability to support multiple devices simultaneously and provide extensive coverage makes it ideal for various applications, from home networking and business environments to public hotspots. Its infrastructure mode, which involves a central access point managing connections between devices, facilitates organized and efficient network communication [27].

Wi-Fi differs significantly from ESP-NOW and BLE in terms of architecture, range, and power consumption. While Wi-Fi provides high-speed internet connectivity and can handle large volumes of data, it typically requires more power than BLE and ESP-NOW due to its extensive infrastructure and higher data rates. This makes Wi-Fi less suitable for battery-powered devices or applications requiring minimal energy consumption. BLE, on

Figure 3: Wi-Fi connectivity of smart classroom attendance system.

the other hand, excels in low-power, short-range applications, making it ideal for IoT devices and wearable technology, but it offers lower data rates compared to Wi-Fi. ESP-NOW combines some advantages of both technologies by enabling direct, low-latency peer-to-peer communication with minimal power consumption, although it is not designed for internet connectivity like Wi-Fi [20].

In an attendance tracking system as illustrated in Figure 3, the combination of these technologies leverages their strengths: BLE facilitates efficient communication between students' and teachers' smartphones and ESP32 devices, ESP-NOW ensures rapid and reliable data transmission between ESP32 modules, and Wi-Fi provides the infrastructure to collect data from master ESP32 devices located at strategic points in the classroom. This setup allows the attendance data to be efficiently transferred to the existing Wi-Fi network infrastructure within the campus, ultimately consolidating the attendance records on the university's server for accurate and timely tracking. This integrated approach ensures that the system is both efficient and effective, addressing the varying demands of modern connectivity solutions.

2.4 Network Topology

This paper details the implementation of a smart wireless attendance system using BLE, ESP-NOW, and Wi-Fi technologies. The use of ESP-NOW is particularly emphasized due to its capability to support simultaneous communication between multiple ESP32 devices, enabling quick and efficient data transmission across the system. This feature allows for multiple devices to send data concurrently from each classroom, ensuring rapid attendance data collection. The system as illustrated in Figure 4 is designed to operate across three classrooms at the Faculty of Engineering, University of Surabaya. Within each classroom, three ESP32 devices serve as slave units and are strategically positioned near the blackboard to facilitate seamless communication with students' and lecturers' smartphones via BLE. Additionally, a single ESP32 device is placed outside the second classroom, acting as a master unit to extend its range across all three classrooms using the ESP-NOW protocol.

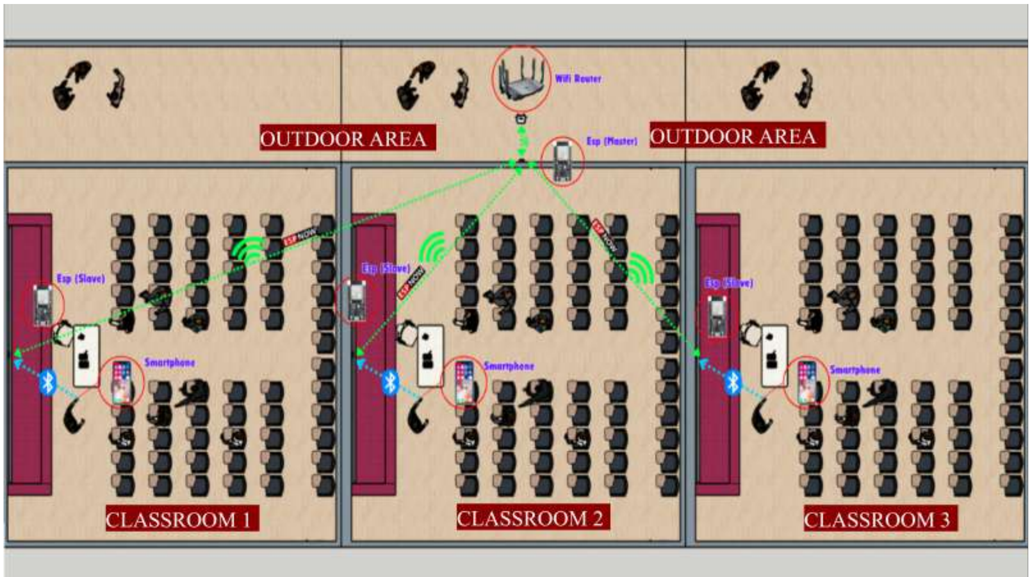


Figure 4: Network topology of smart classroom attendance system.

The attendance recording process begins when the lecturer opens the class via their smartphone, sending a signal to the ESP32 slave device using BLE. Once the class is open, students can register their attendance by connecting their smartphones to the ESP32 slave device via BLE. Each ESP32 slave collects attendance data from its respective classroom and transmits this information to the ESP32 master device using the ESP-NOW protocol. The ESP32 master device, positioned to cover all three classrooms, consolidates the attendance data received from the slave units. It then sends the aggregated data to the university's central database server through the existing Wi-Fi network. This ensures that attendance records are efficiently managed and stored in the university's system. To support data management and connectivity, the system integrates with the existing Wi-Fi network at the University of Surabaya. A router located just outside the classrooms connects to the university's infrastructure, enabling the seamless transfer of attendance data from the ESP32 master device to the university's central server. This network model ensures that the system leverages the strengths of each communication technology, providing an effective and reliable solution for tracking attendance across multiple classrooms.

2.5 Proposed Smart Wireless Attendance System

The proposed smart wireless attendance system integrates advanced communication technologies, including BLE, ESP-NOW, and Wi-Fi, to facilitate efficient and accurate attendance tracking in educational environments. The system's architecture is designed to optimize data transmission speed, minimize energy consumption, and ensure reliable verification of student presence within classrooms. As illustrated in Figure 5, the communication process begins with the lecturer using a smartphone to establish a BLE connection with the ESP32 slave device located within the classroom.

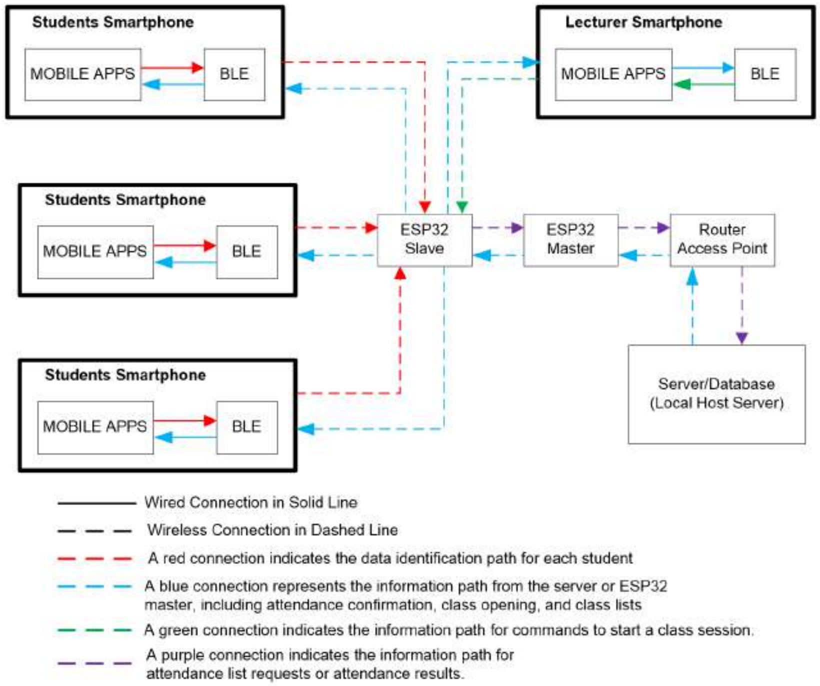


Figure 5: Block diagram of proposed smart wireless attendance system.

This initial interaction confirms the lecturer's presence and initiates the class session. Upon successful connection, the smartphone transmits a data frame in a format optimized for BLE communication, as shown in Figure 6. This frame contains essential information such as a command code indicating whether the class is being opened ("o") or closed ("c"), the lecturer or student ID, and a truncated MAC address. The MAC address is reduced to the last 6 bytes, which are unique to each device, to prevent fraudulent attendance attempts, such as students trying to register attendance on behalf of others. The decision to truncate the MAC address to 6 bytes is due to the BLE protocol's limitation, which allows a maximum of 23 bytes per transmission. Typically, the last 6 bytes of a MAC address are unique identifiers for each device, while the first 6 bytes represent the manufacturer's code. This truncated approach ensures that no two devices with the same 6-bytes sequence can register attendance simultaneously, thereby enhancing security. Additionally, the frame includes a timestamp, which serves as a justification for when the class was opened or when students are allowed to register their attendance.

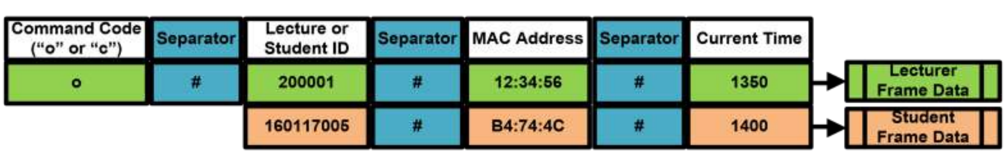


Figure 6: Frame data format of smartphone data transmission to the ESP32 slave via BLE.

This BLE-optimized data frame is then forwarded to the central university server via the ESP32 master device located outside the classroom, utilizing the ESP-NOW protocol, which supports low-latency and direct peer-to-peer communication without the need for intermediary networks. For the ESP-NOW link, the data frame is reformatted to align with ESP-NOW's protocol, ensuring efficient data transmission. Additionally, during the communication process, a data frame is sent via ESP-NOW from each ESP32 slave device within the classrooms to the ESP32 master device outside the classroom. ESP-NOW supports a maximum data payload of 250 bytes per transmission; therefore, to minimize delays caused by the volume of data being transmitted to the ESP32 master, the communication link between the ESP32 slave and master devices is limited to a maximum of 64 bytes data per frame. The maximum frame size of 64 bytes is optimized for efficient data handling and transmission, ensuring swift and accurate record-keeping. The data frame format sent from the ESP32 slave to the master device is largely like the format used in the smartphone and ESP32 data transmission, as shown in Figure 7. However, it incorporates additional fields for classroom id and course code, and the command code status has been updated: a command code of "0" represents the lecturer's action of opening or closing the class, while a command code of "1" indicates that a student is marking their attendance.

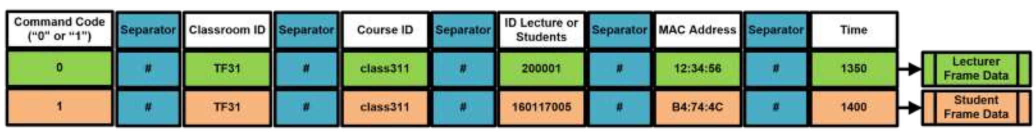


Figure 7: Frame data format of ESP32 slave data transmission to the ESP32 master via ESP-NOW.

Subsequent to the class initiation, students register their attendance through their smartphones, which communicate with ESP32 slave devices strategically positioned within each classroom via BLE. Each student's smartphone sends a structured data packet to the nearest slave device, including the class code, classroom number, course code, student ID, MAC address, and timestamp. The BLE protocol is employed to ensure energy-efficient communication while providing sufficient range for classroom settings. The inherently bidirectional nature of communication across all protocols enables robust data exchange and feedback loops for system verification, thereby facilitating reliable and real-time attendance management. The maximum frame size of 64 bytes is optimized for efficient data handling and transmission, ensuring swift and accurate record-keeping.

Figure 8: Frame data format of ESP32 master data transmission to the ESP32 slave via ESP-NOW.

Communication within this system is bidirectional to minimize fraud or unauthorized attendance outside the designated class schedule. Consequently, at the start of the class, before students can register their attendance, the ESP32 master must first receive a response from the server in the form of an 'accept' or 'deny' signal to either open or not open the class. This is achieved by sending a data frame, as depicted in Figure 8, which closely resembles the frame format from ESP32 slave to ESP32 master. However, it includes additional fields such as start time and end time, which indicate the start and end times of the class. This validation process ensures that attendance can only be registered within the specified class times, thereby preventing any attempts at out-of-schedule attendance. Any discrepancies or attempts to register attendance outside the authorized time frame are promptly flagged by the system, maintaining the accuracy and reliability of attendance records. Meanwhile, the communication link from the ESP32 master to the server via Wi-Fi acts as a forwarding mechanism, transmitting the messages received by the ESP32 master. Consequently, the format of the data is adapted to align with the content of the messages initially received by the ESP32 master.

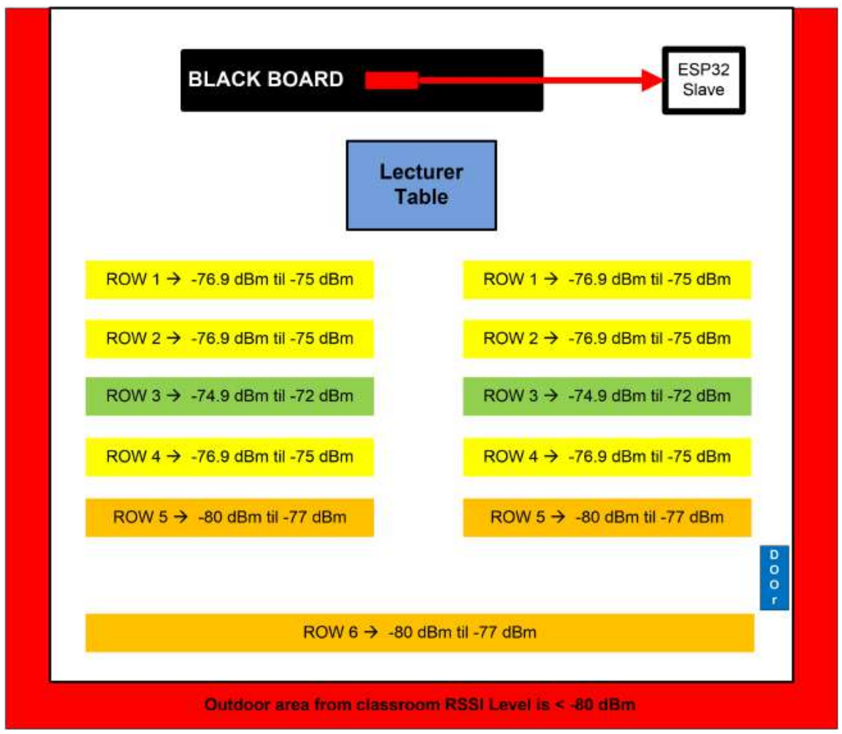


Figure 9: An example of the RSSI distribution measurement results in classroom 3.

A key feature of the system is the implementation of RSSI-based restrictions to verify the physical presence of students and lecturers within the classroom. During the initial BLE pairing process between the smartphones and ESP32 slave devices, the RSSI measurement is displayed to indicate the signal strength. If the RSSI is below -80 dBm at this stage, the system prevents the attendance process from proceeding, ensuring that only individuals within the designated area can register their presence. The RSSI measurement between the smartphones and ESP32 slave devices is utilized to establish a minimum acceptable threshold of -80 dBm, corresponding to the maximum range at the back of the classroom. This threshold serves as a validation mechanism, ensuring that only individuals within the designated area are recorded as present. When both the slave device and smartphone are inside the room, the RSSI is typically above -80 dBm. If the smartphone is outside the room, the RSSI falls below -80 dBm, preventing attendance registration due to signal attenuation caused by walls and other obstructions. This is further illustrated in Figure 9, which shows RSSI levels within the classroom. This contrasts with the minor impact of obstacles such as chairs and students on signal transmission within the same room, thereby maintaining the integrity of the attendance records. To manage attendance times and detect latecomers, the lecturer can utilize the smartphone app to stop the attendance process. This action sends a command to the ESP32 slave devices containing a data frame like the class start frame, but with the class status updated to "closed." This command is transmitted to the server via ESP-NOW by the ESP32 master device. Upon receiving this command, the ESP32 slave devices prevent any further attendance registrations, ensuring that students attempting to register after the designated time are not permitted.

Once attendance data is successfully collected by the ESP32 slave devices, it is transmitted to the ESP32 master device outside the classrooms using the ESP-NOW protocol. The system's architecture supports high data throughput, necessitating the use of ESP-NOW to handle the substantial volume of data and ensure rapid processing and transmission to the university's central server. The existing Wi-Fi infrastructure is utilized to relay the consolidated attendance records from the ESP32 master device to the server, enabling real-time data analysis and reporting. This comprehensive approach ensures that the system meets the demands of modern educational environments by providing a reliable, efficient, and scalable solution for attendance tracking.

3 Results

In this section, we present the performance evaluation of the proposed system, focusing on RSSI-based restriction, which is used to limit student attendance registration to within a designated area. The results include analysis of transmission time, delay, bit rate, and packet loss to assess the system's efficiency and reliability. These metrics indicate that the system can accurately enforce attendance restrictions and maintain robust communication, validating the effectiveness of the ESP-NOW protocol for real-time attendance tracking.

3.1 RSSI-Based Restriction Performance

The initial measurements were conducted to evaluate the communication link quality between students' smartphones and the ESP32 devices in each classroom. These measurements were performed using a Xiaomi RedMi Note 5A Prime, equipped with the student wireless attendance application. The application has a feature to display the RSSI level when connected to the ESP32 slave device. This measurement was also carried out to determine the RSSI threshold that enables the system to detect whether a student is registering attendance from inside or outside the classroom. The division of zones in each classroom, based on the average RSSI levels recorded, is illustrated in Figure 9. The RSSI distribution in each classroom was based on the average measurements recorded in Table 1, obtained using the measurement scenario outlined in Figure 4.

The measurements were taken from 10 locations: 6 inside the classroom (one from each of the 6 rows of student seats) and 4 outside the classroom at specific angles relative to the

Table 1: RSSI based restriction measurement data

RSSI Measurement Scenario	Classroom 1 (dBm)	Classroom 2 (dBm)	Classroom 3 (dBm)
Row 1 (distances measurement in 3.1 - 6.5 meters)	-71.9	-72.8	-75.9
Row 2 (distances measurement in 3.3 - 7 meters)	-76.6	-75.3	-76.5
Row 3 (distances measurement in 4.9 - 8 meters)	-74.7	-74.4	-74.4
Row 4 (distances measurement in 5.6 - 8.4 meters)	-76.2	-76.2	-76.4
Row 5 (distances measurement in 6.5 - 9.4 meters)	-77.7	-75,5	-77.4
Row 6 (distances measurement in 8.5 - 10.3 meters)	-76.8	-74.4	-78.3
Outside the classroom (elevation angle in ±900)	-83	-83.8	-85.2
Outside the classroom (elevation angle in ±450)	-82.5	-81.1	-83.2
Outside the classroom (elevation angle in ±300)	-84.4	-80.8	-83.9
Outside the classroom (elevation angle in ±00)	-88.5	-80.9	-87

ESP32 slave. For indoor measurements, each row was sampled 10 times, with measurement points randomly selected from 10 different seats in each row. This analysis shows the range of distances from the nearest to the farthest seat relative to the ESP32 slave. For instance, in the first row, the nearest seat was 3.1 meters away, while the farthest seat used for testing was 6.5 meters away. The other 8 seats tested were located between these distances. This random selection of seats aimed to simulate the varied positioning of students within each row. The average RSSI distribution inside the classroom is typically above -80 dBm. Although RSSI levels occasionally fluctuate below -80 dBm, these drops are minimal, making -80 dBm a reliable threshold for confirming a student's presence inside the classroom. In contrast, measurements taken from outside the classroom often show RSSI levels below -80 dBm. This threshold is crucial for the RSSI-Based Restriction in the Smart Wireless Attendance System, as it helps accurately determine whether students are within the designated classroom area.

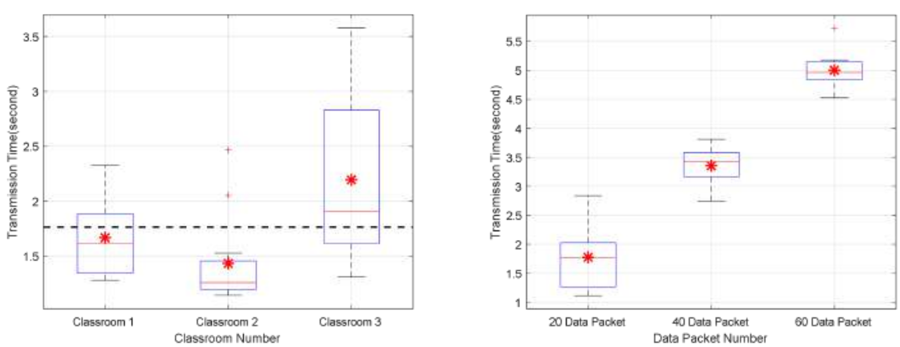
3.2 Data Transmission Time Performance

The performance of data transmission time in the Smart Wireless Attendance System plays a crucial role in ensuring accurate and timely attendance records. To analyze this performance, a boxplot method was employed, providing a visual representation of transmission time distributions and enabling easier identification of variations across different classrooms. The transmission time measurements were conducted under Line of Sight (LOS) conditions, with random positioning at 12 different locations within each classroom. Each measurement phase involved 12 transmissions, with each transmission consisting of 20 packets of data. With each packet sized at 64 bytes, the cumulative data size for one transmission amounted to 1,280 bytes.

The results from Figure 10a indicated that the system maintained low latency in data transmission, with an average transmission time of 1.7 seconds across classrooms. While Classroom 3 exhibited the highest recorded transmission time of 3.7 seconds, the variations between classrooms remained within a manageable range of approximately 2 seconds. Based on the obtained results, the measurement positions within the classrooms had minimal influence on transmission times, provided the RSSI remained above -80 dBm. This consistency is reflected in the transmission time outliers, which remained close to the average, generally below 3 seconds. When the number of packets per transmission was varied using 20, 40, and 60 packets as shown at Figure 10b, transmission times remained relatively stable, ranging between 1.5 and 2 seconds.

Specifically, transmissions involving 60 packets, totaling 3,840 bytes, required between 4.5 and 5.8 seconds to complete. From these results at Figure 11, the data rate, expressed in bytes per second (Bps), was calculated by dividing the transmitted data size by the corresponding transmission time. The data rate based on Figure 11a across classrooms averaged between 714 and 885 Bps, with only minor differences between classrooms. While some outliers reached as high as 1,018 Bps or dropped to 572 Bps, these variations did not negatively impact the overall performance. Even with varying data loads as shown at Figure 11b, the system consistently achieved a stable data rate, averaging around 780 Bps across transmissions with 20, 40, and 60 packets.

Furthermore, the testing process confirmed that all transmitted packets were received intact without any packet loss, ensuring the reliability of data delivery. This finding proves that the system can maintain accurate and timely attendance records by ensuring efficient and reliable data transmission. The combination of stable transmission times, reliable data rates, and zero packet loss proves the system's robustness, enabling smooth real-time communication and enhancing the user experience, even under varied data loads and classroom conditions.

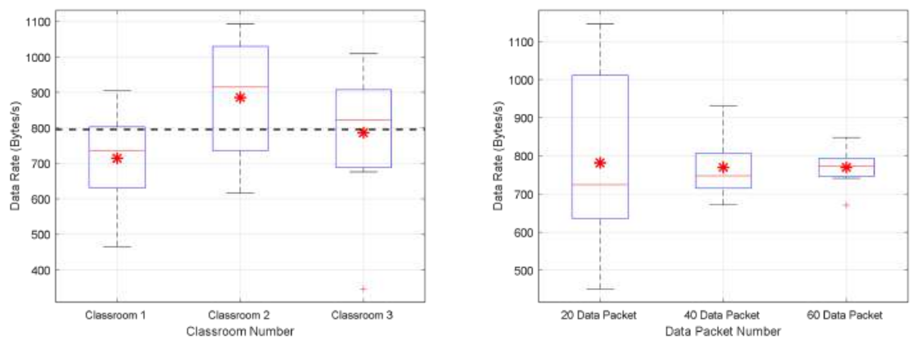


(a) (b)

Figure 10: (a) Comparison of transmission time based on classroom location; (b) Comparison of transmission time based on data packet variation.

4 Discussion

The results of this study highlight the effectiveness of the Smart Wireless Attendance System in maintaining accurate and timely attendance tracking, with minimal transmission delays and consistent performance across various classroom conditions. As shown in Table 2, the system achieves an average data rate between 714 and 885 Bps across classrooms, with transmission times ranging from 1.49 to 1.85 seconds. These results confirm the system's ability to maintain stable communication regardless of environmental differences between



(a) (b)

Figure 11: (a) Comparison of data rate performance based on classroom location; (b) Comparison of data rate performance based on data packet variation.

classrooms. Furthermore, the packet delivery was consistently successful without any data loss, validating the reliability of the communication process.

Table 2: Average parameter performance of transmission time, and data rate

Parameter Performance	**Classroom 1**	**Classroom 2**	**Classroom 3**
Transmission Time (s)	1.85	1.49	1.75
Data Rate (Bps)	714.39	885.84	785.95
Parameter Performance	**20 Data Packet**	**40 Data Packet**	**60 Data Packet**
Transmission Time (s)	1.77	3.35	5.00
Data Rate (Bps)	782.18	770.43	769.49

Compared to other attendance technologies, such as image-based systems, which can be influenced by environmental factors like lighting conditions or camera resolution, the proposed system demonstrates superior reliability under Line of Sight (LOS) conditions. The use of ESP-NOW also ensures lower latency compared to Wi-Fi-based solutions, which are more vulnerable to network congestion and interference. Additionally, the system integrates multiple communication protocols to enhance performance, providing rapid data transmission and flexibility in coverage—advantages that are not typically achieved by RFID or BLE-only solutions.

A unique feature of this system is the RSSI-based restriction mechanism, which ensures that students are physically present within the classroom during attendance registration. If a device records an RSSI value weaker than -80 dBm, attendance is denied, indicating that the student is outside the designated area. This threshold also helps prevent overlap between adjacent classrooms, ensuring accurate attendance tracking without cross-room interference. As demonstrated in Table 2, variations in packet size (20, 40, and 60 packets) yielded consistent data rates between 769 and 782 Bps, with transmission times scaling predictably from 1.77 to 5.00 seconds. Even at the largest packet load, the system maintained reliable performance with transmission times between 4.5 to 5.8 seconds, underscoring its scalability for real-world applications. This combination of low latency, reliable packet delivery, and precise attendance verification provides a significant advantage over other systems by minimizing operational disruptions and enhancing the overall user experience for both students and lecturers.

Future work will focus on enhancing data security by incorporating encryption schemes to safeguard transmitted data and protect user privacy. Additionally, the integration of LoRaWAN technology will expand the system's coverage across multiple buildings and outdoor areas on campus, enabling seamless, large-scale attendance tracking while maintaining low power consumption for long-term deployment.

5 Conclusion

This paper presents a Smart Wireless Attendance System leveraging ESP-NOW communication to deliver low-latency, reliable performance for accurate attendance tracking. The system maintains consistent transmission times across classrooms, with average times ranging between 1.5 to 1.85 seconds for smaller data loads and reaching up to 5.8 seconds when handling 60-packet transmissions. Data rates remained stable, averaging between 714 to 885 bytes per second, with no packet loss detected during testing. The RSSI-based restriction mechanism ensures that students are physically present within the classroom by enforcing a threshold of -80 dBm, preventing attendance registration from outside the designated area and minimizing cross-room interference. These results confirm the system's effectiveness in maintaining real-time attendance tracking while enhancing accuracy and reliability. Future development will focus on integrating encryption for data security and expanding system coverage using LoRaWAN technology to support multi-building and outdoor tracking scenarios.

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