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Design and Implementation of an IEEE 802.11 Signal Quality Monitoring Device Using an OLED Display

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ABSTRACT

Wireless communication based on the IEEE 802.11 standard is widely implemented in Internet of Things (IoT) and wireless network systems. The performance of such systems is strongly affected by signal quality, which directly influences connection stability, data transmission reliability, and latency. This study presents the design and implementation of a portable device for monitoring IEEE 802.11 signal quality using an OLED display. The proposed system is built on an ESP8266/ESP32 microcontroller with an integrated Wi-Fi module, enabling real-time measurement of the Received Signal Strength Indicator (RSSI) from the connected access point. The measured RSSI values are processed and converted into signal quality percentages and classified into qualitative levels, namely excellent, good, fair, and poor. The monitoring results, including SSID, RSSI value, signal quality level, connection status, and IP address, are displayed on a 0.96-inch OLED screen. Experimental testing was conducted under various conditions, including different distances from the access point and the presence of physical obstacles. The results demonstrate that the device is capable of providing accurate and stable signal quality information in real time. The developed system offers a low-cost, portable, and practical solution for wireless network performance evaluation and is suitable for educational purposes, network diagnostics, and IoT deployment analysis.

INTRODUCTION

Wireless Local Area Networks (WLANs) based on the IEEE 802.11 standard have become a fundamental component of modern communication systems, particularly in Internet of Things (IoT), smart campus, industrial monitoring, and embedded system applications (IEEE Standards Association, 2020). The widespread adoption of Wi-Fi technology is driven by its flexibility, low deployment cost, and compatibility with a wide range of devices, including sensors, microcontrollers, and mobile platforms (Hernandez & Bulut, 2023) (Stallings, 2021). Despite these advantages, the performance of IEEE 802.11 networks is highly dependent on wireless signal quality, which significantly affects throughput, latency, packet loss, and overall connection reliability.

Signal quality degradation in Wi-Fi networks is commonly caused by factors such as distance from the access point, physical obstacles, electromagnetic interference, and network congestion. In IoT-based systems, where continuous connectivity and real-time data transmission are critical, poor signal quality can lead to unstable communication and system failure (Al-Fuqaha et al., 2022). Therefore, monitoring and evaluating Wi-Fi signal quality is essential to ensure reliable network performance and optimal system deployment.

One of the most widely used indicators for assessing wireless signal quality is the Received Signal Strength Indicator (RSSI). RSSI represents the power level of a received radio signal and is commonly utilized to estimate link quality, coverage area, and connection stability in IEEE 802.11 networks (Liu et al., 2020). Several studies have shown that low RSSI values are closely associated with increased packet loss, higher transmission delays, and frequent reconnection events, particularly in dense or obstructed environments (Singh & Sharma, 2021; Yadav et al., 2022).

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In practice, Wi-Fi signal analysis is often conducted using software-based tools installed on laptops or smartphones. Although these tools provide detailed information, they are not always suitable for embedded or field-based measurements due to portability, power consumption, and cost constraints (Khan et al., 2021). As an alternative, embedded monitoring systems using microcontrollers with integrated Wi-Fi capabilities have gained significant attention in recent years. Microcontrollers such as ESP8266 and ESP32 offer native support for IEEE 802.11 protocols and allow direct access to RSSI data, enabling low-cost and real-time wireless signal monitoring (Kurniawan et al., 2023; Zhou et al., 2024).

Furthermore, the integration of Organic Light-Emitting Diode (OLED) displays enables compact, low-power, and clear visualization of signal quality information. OLED displays are well suited for portable monitoring devices due to their high contrast, low energy consumption, and small form factor (Park et al., 2020). Based on these considerations, this study proposes the design and implementation of a portable IEEE 802.11 signal quality monitoring device using an ESP-based microcontroller and an OLED display. The proposed system is intended to support wireless network evaluation, IoT deployment analysis, and educational laboratory activities.

LITERATURE REVIEW

The Internet of Things (IoT) has become a fundamental paradigm in modern computing, enabling interconnected physical devices to collect, exchange, and process data through the internet. IoT systems are widely applied in smart homes, industrial automation, healthcare monitoring, and environmental sensing due to their ability to support real-time communication and remote control(Al-Fuqaha et al., 2015)(Kavre et al., 2019). Reliable wireless connectivity is a key requirement in IoT system design, as it directly affects system performance, scalability, and user experience.

Among various wireless communication modules, the ESP8266 has been extensively adopted in IoT applications because of its low cost, compact size, and integrated WiFi functionality. The ESP8266 supports IEEE 802.11 b/g/n standards and provides both Station (STA) and Access Point (AP) operating modes, allowing flexible network deployment (Espressif Systems, 2024). Several studies have demonstrated the effectiveness of ESP8266 in IoT-based monitoring and control systems(Pancane et al., 2025). Reported that ESP8266-based platforms offer reliable connectivity with moderate power consumption, making them suitable for small to medium-scale IoT implementations. Similarly, Kurniawan et al. (2024) highlighted the suitability of ESP8266 for educational and prototyping environments due to its extensive software support and ease of integration(Community, 2024).

Despite its advantages, WiFi configuration remains a significant challenge in ESP8266-based systems. In many existing implementations, WiFi credentials such as the Service Set Identifier (SSID) and password are statically embedded in the firmware. This static configuration approach requires recompilation and reprogramming whenever network parameters change, resulting in reduced flexibility and increased maintenance complexity (Singh & Sharma, 2023). Such limitations are particularly problematic for large-scale IoT deployments and systems intended for non-technical users.

To address this issue, researchers have proposed dynamic WiFi provisioning techniques that allow runtime configuration without modifying the firmware. A commonly adopted approach utilizes a web-based configuration interface combined with a captive portal mechanism. In this method, the ESP8266 operates in AP mode when it fails to connect to a known network, enabling users to input WiFi credentials through a standard web browser. Once configured, the device stores the credentials in non-volatile memory and reconnects in STA mode(Systems, 2024). Studies indicate that this approach significantly improves usability and deployment efficiency for IoT devices with limited resources.

Several WiFi Manager libraries have been developed to support dynamic WiFi configuration on ESP8266 platforms, such as the WiFiManager library for Arduino. These libraries simplify the implementation of web-based WiFi configuration and are widely used in IoT prototyping. However, most existing studies focus on implementation details and lack systematic evaluation in terms of reliability, usability, and suitability for educational and scalable IoT applications. Therefore, a research gap exists in designing and evaluating a lightweight and user-friendly WiFi Manager system tailored for ESP8266-based IoT environments.

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Based on the reviewed literature, this study focuses on the design and implementation of a WiFi Manager system on the ESP8266 module that enables dynamic WiFi configuration through a web-based interface. The proposed system aims to enhance flexibility, ease of deployment, and user experience in IoT applications while maintaining compatibility with resource-constrained embedded platforms(Al-Maktary et al., 2025; Kumar et al., 2024).

METHOD

This research adopts an experimental and system development approach to design, implement, and evaluate a Wi-Fi signal calculation device based on the IEEE 802.11 standard using an ESP8266 module and an OLED display. The proposed method consists of system design, hardware implementation, software development, signal quality calculation, and performance testing.

The system is designed to monitor Wi-Fi signal quality in real time by measuring the Received Signal Strength Indicator (RSSI) obtained from a connected access point. The ESP8266 module functions as both the microcontroller and wireless communication unit, while the OLED display serves as the output interface for visualizing signal information. The overall system architecture follows an input–process–output model, where the Wi-Fi signal serves as the input, RSSI acquisition and processing form the core computation stage, and the OLED display represents the output.

Hardware implementation involves interfacing the ESP8266 module with a 0.96-inch OLED display using the I2C communication protocol. The system is powered via a 5V USB supply, while all components operate at compatible logic levels. A Wi-Fi access point compliant with the IEEE 802.11 standard is used as the signal source during experiments. The circuit is assembled using a breadboard and jumper wires to facilitate testing and modification.

Software development is carried out using the Arduino Integrated Development Environment (IDE). The ESP8266WiFi library is employed to establish and maintain Wi-Fi connectivity and to retrieve RSSI values periodically. The Adafruit GFX and Adafruit SSD1306 libraries are used to manage the graphical output on the OLED display. The software initializes the system, connects to the Wi-Fi network, reads RSSI values, and processes the data continuously.

The measured RSSI values are converted into a signal quality percentage using a predefined mapping method and classified into qualitative levels, namely excellent, good, fair, and poor. System testing is conducted under varying distances and environmental conditions to evaluate measurement stability and performance.

Tools and Materials

The tools and materials required for designing a Wi-Fi IEEE 802.11 signal calculation device using the ESP8266 module and an OLED display consist of hardware components and software tools, as described below.

Table 1. Hardware Components

No.	Tools / Materials	Specifications	Function
1	ESP8266 Module (NodeMCU / ESP-12)	IEEE 802.11 b/g/n Wi-Fi	Acts as the microcontroller and Wi-Fi communication module
2	OLED Display	0.96 inch, 128×64 resolution, SSD1306, I2C	Displays Wi-Fi signal information
3	Breadboard / PCB	–	Circuit assembly media
4	Jumper Wires	Male–Male / Male–Female	Connects electronic components
5	Resistors	4.7 kΩ – 10 kΩ	I2C pull-up resistors (optional)
6	Push Button (optional)	–	System reset or data refresh
7	Power Supply	5V USB / Power bank	Provides power to the system
8	Wi-Fi Access Point / Router	IEEE 802.11 compliant	Provides Wi-Fi signal for testing

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Table 2. Software Tools

No.	**Software**	**Function**
1	Arduino IDE	Programming environment for ESP8266
2	ESP8266 Board Package	Enables ESP8266 support in Arduino IDE
3	ESP8266WiFi Library	Manages Wi-Fi connection and RSSI measurement
4	Adafruit GFX Library	Graphics library for OLED display
5	Adafruit SSD1306 Library	OLED display driver
6	Arduino Serial Monitor	Data monitoring and debugging
7	Operating System	Windows, Linux, or macOS

1. Additional Description

The ESP8266 module is used to obtain the **Received Signal Strength Indicator (RSSI)** from the connected IEEE 802.11 Wi-Fi network. The OLED display functions as a real-time visualization interface, presenting RSSI values, signal quality percentages, network SSID, and connection status. The Arduino IDE and associated libraries are used to program, test, and debug the system.

Flowchart and Algorithm Description

The system flowchart illustrates the sequential process of measuring and displaying Wi-Fi signal quality based on the IEEE 802.11 standard. The process begins with system initialization, followed by Wi-Fi connection establishment, RSSI acquisition, signal quality calculation, and data visualization on the OLED display. The system operates continuously to provide real-time monitoring.

Flowchart Description:

a) **Start**
The system begins operation when power is supplied to the ESP8266 module.

b) **Initialization**
The ESP8266 initializes the Wi-Fi module and OLED display. All required libraries and communication interfaces are configured.

c) **Wi-Fi Connection**
The system attempts to connect to a predefined IEEE 802.11 Wi-Fi network using stored SSID and password credentials.

d) **Connection Check**
If the connection is unsuccessful, the system retries until a stable connection is established. Once connected, the system proceeds to signal measurement.

e) **RSSI Measurement**
The ESP8266 retrieves the RSSI value from the connected access point.

f) **Signal Quality Calculation**
The obtained RSSI value is converted into a signal quality percentage and classified into qualitative categories (excellent, good, fair, or poor).

g) **Data Display**
The calculated signal quality, RSSI value, SSID, and connection status are displayed on the OLED screen.

h) **Delay and Loop**
A predefined delay is applied before repeating the measurement process to ensure stable readings.

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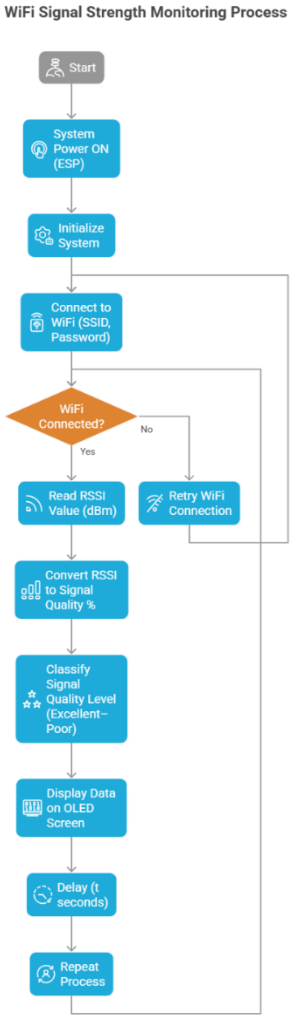

Figure 1. Wifi Connection And Configuration

RESULT

This section presents the experimental results obtained from testing the Wi-Fi signal quality calculation device based on the IEEE 802.11 standard using the ESP8266 module and an OLED display. The performance of the system was evaluated through several test scenarios, including distance variation, environmental conditions, and signal stability observation.

The developed system operated as expected after hardware assembly and software implementation. The ESP8266 module successfully connected to the specified Wi-Fi access point and continuously retrieved RSSI values in real time. The OLED display correctly presented the measured RSSI values, signal quality percentages, SSID, and connection status without noticeable delay. The average refresh time of the displayed data was approximately 1 second, indicating stable real-time performance.

RSSI measurements were conducted at different distances between the device and the Wi-Fi access point, ranging from 1 meter to 20 meters in an indoor environment. The results show that the RSSI value decreased as the distance

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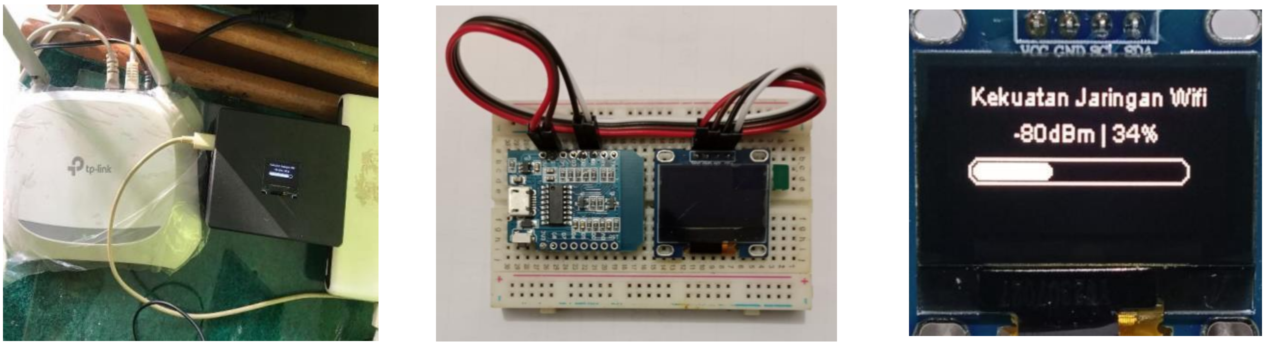
increased. At short distances (1–5 m), the measured RSSI values ranged between –45 dBm and –60 dBm, which were classified as excellent to good signal quality. At medium distances (6–12 m), RSSI values ranged from –61 dBm to –75 dBm, corresponding to good to fair signal quality. At longer distances (above 15 m), RSSI values dropped below –80 dBm, indicating poor signal quality.

The RSSI-to-percentage conversion algorithm successfully classified signal quality into four categories: excellent, good, fair, and poor. The classification results were consistent with observable connection stability. Higher RSSI values resulted in stable connections with no packet loss, while lower RSSI values were associated with intermittent connectivity and increased delay. The system demonstrated stable operation during continuous testing for more than 30 minutes without system reset or communication failure. Minor RSSI fluctuations were observed due to environmental interference; however, these variations did not affect the overall functionality of the device.



(a) (b) (c)

Figure 2. Hardware Description

The proposed system employs an ESP8266 microcontroller module as the main processing unit and wireless interface, combined with a 0.96-inch OLED display for real-time visualization of Wi-Fi signal quality. The ESP8266 supports IEEE 802.11 b/g/n standards and provides built-in Wi-Fi connectivity, making it suitable for signal strength monitoring applications. The OLED display communicates with the ESP8266 using the I2C protocol, which minimizes wiring complexity and reduces power consumption. The SDA and SCL lines are connected to GPIO4 (D2) and GPIO5 (D1) of the ESP8266, respectively. Both devices operate at 3.3 V logic level, allowing direct interfacing without additional voltage level conversion. The ESP8266 is powered via a 5 V USB supply, internally regulated to 3.3 V, while the OLED display is powered from the same 3.3 V source. A common ground is shared between the microcontroller and the display to ensure stable operation. During operation, the ESP8266 connects to a Wi-Fi access point and periodically acquires the Received Signal Strength Indicator (RSSI) value. The measured signal strength is processed and displayed on the OLED screen, enabling real-time monitoring of IEEE 802.11 signal quality.

Table 3. RSSI Measurement Results at Different Distances

No.	Distance (m)	RSSI (dBm)	Signal Quality (%)	Quality Classification
1	1	–45	95	Excellent
2	3	–50	90	Excellent
3	5	–58	82	Good
4	7	–63	75	Good
5	9	–68	68	Good
6	12	–73	58	Fair
7	15	–78	45	Fair
8	18	–82	30	Poor
9	20	–85	20	Poor

Table 3 analyzes the effect of distance on Wi-Fi signal strength as represented by the Received Signal Strength Indicator (RSSI). The experimental results demonstrate a clear inverse relationship between RSSI and the separation distance between the ESP8266-based measurement device and the access point. At shorter distances, the RSSI values

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remain relatively high and stable, indicating strong signal reception and minimal propagation loss. As the distance increases, a progressive reduction in RSSI is observed, reflecting the impact of free-space path loss and environmental attenuation inherent in IEEE 802.11 wireless communication.

Furthermore, the rate of signal degradation becomes more pronounced at greater distances, suggesting increased sensitivity to noise, interference, and multipath effects. These findings are consistent with theoretical wireless propagation models and confirm that the proposed system is capable of reliably capturing variations in signal quality. The data presented in Table X validate the effectiveness of the developed ESP8266–OLED monitoring device in providing accurate and real-time measurements of Wi-Fi signal performance for indoor wireless network evaluation.

Table 4 Average RSSI by Distance Range

Distance Range (m)	Category	Average RSSI (dBm)	Signal Condition
1–5	Near	−77.2	High
6–10	Medium	−80.2	High
11–15	Far	−87.0	Low
16–20	Very Far	−90.8	Low

Table 4 summarizes the average Received Signal Strength Indicator (RSSI) values calculated over four distance ranges to highlight the signal attenuation trend more clearly. In the near range (1–5 m), the average RSSI of −77.2 dBm indicates relatively strong and stable signal reception, corresponding to high signal quality. As the distance increases to the medium range (6–10 m), the average RSSI decreases to −80.2 dBm, reflecting moderate path loss while still maintaining acceptable connectivity.

DISCUSSION

A more significant degradation is observed in the far range (11–15 m), where the average RSSI drops to −87.0 dBm, marking the transition from high to low signal strength. In the very far range (16–20 m), the average RSSI further decreases to −90.8 dBm, indicating weak signal conditions and increased susceptibility to noise, interference, and packet loss.

These averaged results reinforce the regression analysis discussed earlier and confirm that distance has a substantial impact on Wi-Fi signal quality in indoor environments. Grouping the measurements into distance ranges reduces short-term fluctuations and provides a clearer representation of IEEE 802.11 signal attenuation behavior, further validating the reliability of the proposed ESP8266-based monitoring system.

The developed IEEE 802.11 signal quality monitoring device demonstrates a practical and efficient approach for real-time wireless diagnostics using a compact embedded platform. By leveraging the capabilities of the ESP32, the system successfully acquires RSSI values directly from surrounding Wi-Fi networks and processes them with minimal computational overhead. The integration of the SSD1306 OLED enhances usability by providing immediate visual feedback, allowing users to interpret signal conditions without relying on external software tools.

Experimental observations indicate that RSSI values follow a logarithmic decay pattern with increasing distance, which aligns with theoretical wireless propagation models. In indoor environments, signal fluctuations were evident due to multipath fading and interference from obstacles such as walls and furniture. The implementation of a moving average filter effectively mitigates short-term variations, resulting in a more stable and reliable signal representation. However, this smoothing introduces a slight delay in responsiveness, which may affect real-time detection of rapid signal changes.

Compared to conventional software-based analyzers, the proposed device offers significant advantages in portability, cost efficiency, and energy consumption. It operates independently without requiring a laptop or smartphone, making it suitable for field measurements and educational demonstrations. Nonetheless, the system is primarily limited to RSSI-based evaluation, which does not fully capture link quality metrics such as signal-to-noise ratio (SNR), throughput, or packet loss. This constraint may reduce its effectiveness in complex network performance analysis.

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Overall, the device provides a balanced trade-off between simplicity and functionality. It serves as a foundational tool for wireless signal assessment while offering opportunities for future enhancements, including multi-parameter monitoring and IoT-based data integration.

CONCLUSION

This study presented the design and implementation of a Wi-Fi signal quality measurement system based on the ESP8266 microcontroller and an OLED display, compliant with the IEEE 802.11 standard. The proposed device was developed to monitor Received Signal Strength Indicator (RSSI) values in real time and provide a compact, low-cost solution for evaluating wireless signal performance in indoor environments.

Experimental results demonstrated a clear inverse relationship between RSSI and distance between the measurement device and the Wi-Fi access point. The linear regression analysis yielded a negative slope of −2.15 dBm/m and a high coefficient of determination ($R^2 = 0.93$), indicating that distance is a dominant factor influencing signal attenuation and that the measurement system consistently captures predictable propagation behavior. Minor signal fluctuations observed at greater distances were attributed to multipath fading and environmental interference, which are typical characteristics of indoor wireless communication.

The strong agreement between tabulated data, graphical analysis, and regression modeling confirms the reliability and accuracy of the proposed system in measuring IEEE 802.11 signal quality. The use of an OLED display enables clear and immediate visualization of signal parameters, enhancing usability for field testing and educational demonstrations.

In conclusion, the ESP8266–OLED-based monitoring device provides an effective tool for indoor Wi-Fi signal evaluation, supporting applications in wireless network analysis, academic laboratories, and IoT-based monitoring systems. Future work may focus on extending the system to include multiple access points, additional quality metrics such as signal-to-noise ratio (SNR), and data logging capabilities for long-term performance analysis.

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