

ESP8266 BASED INTELLIGENT WIFI EXPANSION WITH BUILT IN NETWORK SECURITY

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ABSTRACT

This project presents the design and implementation of a WiFi range extender using the ESP8266 Wi-Fi System-on-Chip (SoC). The ESP8266 operates in AP+STA (Access Point + Station) dual mode, connecting to an existing router as a client while simultaneously broadcasting a new extended network.

The ESP8266 is configured using the Arduino Integrated Development Environment (IDE) and the ESP8266 Software Development Kit (SDK). The firmware relays packets between the two interfaces, effectively doubling the coverage area of the source network. The module operates on the IEEE 802.11b/g/n standard, enabling compatibility with all modern WiFi routers.

The proposed solution is extremely cost-effective at under Rs. 300 total bill of materials, making it approximately 10 times cheaper than commercial WiFi extenders available in the market. It is energy-efficient, consuming approximately 170 mA during active operation at 3.3V. The system achieves approximately 50% bandwidth throughput compared to the source network, which is consistent with the theoretical half-duplex repeater model.

This makes it an ideal solution for home automation, IOT

deployments, educational institutions, healthcare facilities, and areas with poor WiFi signal penetration. The system is fully programmable and open-source, enabling future enhancements such as OTA (Over-The-Air) firmware updates, web-based configuration portals, and integration with environmental sensors. Performance evaluation confirms successful range extension of approximately 2x the source coverage area, stable DHCP assignment, reliable SSID broadcasting, and acceptable latency increase of 12 to 18 ms compared to the source 5 ms.

Keywords: ESP8266, WiFi Repeater, AP+STA Mode, IoT, 802.11 b/g/n, Arduino IDE, Range Extension, NodeMCU, Firmware, Wireless Networking

1.INTRODUCTION

1.1 General Background

Wireless networking has become an indispensable part of modern life. From smart homes and offices to industrial automation and healthcare systems, WiFi connectivity underpins virtually every aspect of digital infrastructure. The rapid proliferation of internet-connected devices, collectively referred to as the Internet of Things (IoT), has further accelerated the demand for reliable, wide-area wireless coverage.

Despite advances in router technology, physical constraints such as building materials, walls, floors, furniture, and electromagnetic interference continue to create WiFi dead zones, which are areas within a

multi-story buildings, basements, garages, and outdoor areas adjacent to the main building.

The conventional solution to this problem has been the deployment of commercial WiFi range extenders or repeaters. While effective, these devices carry a significant cost premium, typically ranging from Rs. 1,500 to Rs. 5,000 in the Indian market, and often lack customization or programmability. For IoT deployments, academic projects, and resource-constrained environments, a low-cost, programmable alternative is highly desirable.

1.2 WiFi Technology Overview

WiFi is a family of wireless networking technologies based on the IEEE 802.11 standards. The most commonly deployed variants for home and small office use are IEEE 802.11b (11 Mbps, 2.4 GHz), IEEE 802.11g (54 Mbps, 2.4 GHz), and IEEE 802.11n (up to 600 Mbps, 2.4/5 GHz). The ESP8266 module supports the 802.11 b/g/n standard at 2.4 GHz, making it compatible with the vast majority of consumer routers. A WiFi network typically operates in infrastructure mode, where client devices (stations) connect to a central access point (AP). The access point manages traffic, assigns IP addresses via DHCP, and provides the gateway to the internet.

The ESP8266 supports a unique dual-mode operation known as AP+STA mode, in which the module simultaneously acts as a Station (STA), connecting to an upstream router, and as an Access Point (AP), broadcasting a new SSID to which downstream clients connect. This enables transparent packet bridging between the two interfaces, forming the basis of the WiFi repeater implemented in this project.

premises where the signal from the primary router is too weak for reliable connectivity. These dead zones are particularly problematic in larger homes,

1.3 Problem Statement

The primary motivation for this project arises from the following observations made in real-world WiFi deployments:

WiFi Dead Zones: Many residential and commercial environments suffer from inadequate WiFi coverage in areas distant from the primary router. Thick walls, metal fixtures, and multi-floor layouts attenuate the 2.4 GHz signal significantly.

High Cost of Commercial Solutions: Commercial WiFi extenders, while plug-and-play, are priced between Rs. 1,500 and Rs. 5,000 in the Indian market. For IoT lab setups, student projects, and budget-constrained deployments, this represents a significant expenditure.

Lack of Programmability: Commercial extenders provide no access to their underlying firmware. Users cannot modify routing behavior, implement custom monitoring, or integrate the device with other IoT hardware.

Vendor Dependency: Commercial products depend on manufacturer support for firmware updates and security patches. Discontinued products become vulnerable over time. This project addresses these issues by proposing an ESP8266-based WiFi extender that costs under Rs. 300, is fully programmable, and integrates seamlessly with the Arduino/IoT ecosystem.

2. LITERATURE REVIEW

2.1 General

The field of WiFi range extension has been studied extensively in both academic and industry literature. This chapter reviews the most relevant prior work and commercially available technologies that inform the design choices made in this project. Wireless range extension has been approached through several paradigms: dedicated relay hardware, powerline communication bridges, mesh networking, and software-defined radio solutions. Each approach presents different trade-offs in cost, performance, complexity, and programmability.

2.2 Commercial WiFi Extenders

Commercial WiFi extenders from manufacturers such as TP-Link, Netgear, D-Link, and Asus represent the most widely deployed solution for residential range extension. These devices typically use proprietary firmware running on embedded processors such as the Qualcomm Atheros or Broadcom chipsets.

Kolban (2017) demonstrated that the ESP8266 could replicate the core functionality of commercial repeaters at a fraction of the cost, using the AP+STA dual-mode feature. His work provided the foundational firmware architecture adopted in this project.

Schwartz (2016) discussed the ESP8266 in the context of IoT deployments and highlighted its versatility as a network node capable of both generating and extending WiFi networks. His work confirmed the suitability of the ESP8266 WiFi library for managing dual-mode operation.

A key limitation identified in the literature is the half-duplex nature of the 802.11 standard in single-radio repeaters. Since the same radio must both receive and retransmit packets on the same channel, effective throughput is reduced to approximately 50% of the source network's throughput. This is well-documented in the IEEE 802.11-2020 standard and is accepted as an inherent constraint of the single-radio repeater topology.

2.3 Powerline Adapters

Powerline communication (PLC) adapters extend the network using the building's existing electrical wiring. Products such as the TP-Link AV600 and D-Link DHP-601AV achieve throughputs of up to 500 Mbps under ideal conditions. However, real-world performance is highly dependent on wiring quality, circuit topology, and electrical interference.

The primary drawbacks of powerline solutions include: (a) incompatibility with buildings that have mixed wiring phases, (b) sensitivity to electrical noise from appliances, (c) inability to extend to outdoor or remote areas not served by electrical wiring, and (d) cost of Rs. 2,000 to Rs. 6,000 per kit.

3. EXISTING SYSTEM

3.1 Overview of Existing Technologies

Before proposing the ESP8266-based solution, it is essential to examine the existing technologies available for WiFi range extension. The four primary categories are: commercial WiFi extenders/repeaters, powerline network adapters, mobile/MiFi hotspots, and mesh networking systems. Each of these technologies is examined in detail in the following sections.

3.2 Commercial WiFi Repeater Architecture

A commercial WiFi repeater operates by placing the device at the edge of the source router's coverage area. The repeater receives the source WiFi signal, amplifies and re-broadcasts it as a new or extended SSID. The process involves the following stages:

Stage 1 - Signal Reception: The repeater's radio module connects to the source router's SSID as a client station. This is the STA (Station) role in IEEE 802.11 terminology. The repeater must be placed within range of the source router to establish a reliable connection.

Stage 2 - Signal Processing: The received packets are buffered in the repeater's internal memory. The embedded processor (typically an ARM Cortex-M or MIPS-based SoC) manages the routing table, DHCP assignments, and security

handshakes.

Stage 3 - Signal Retransmission: The repeater's radio module, now acting as an Access Point (AP), broadcasts the extended network SSID. Client devices associate with this new SSID and receive IP addresses from the repeater's DHCP pool.

The primary technical limitation of this architecture is the single-radio half-duplex constraint. Since the same antenna and radio are used for both reception and transmission, each packet must traverse the radio medium twice, once from the source router to the repeater, and once from the repeater to the client. This results in an effective throughput of approximately 50% of the source network's capacity.

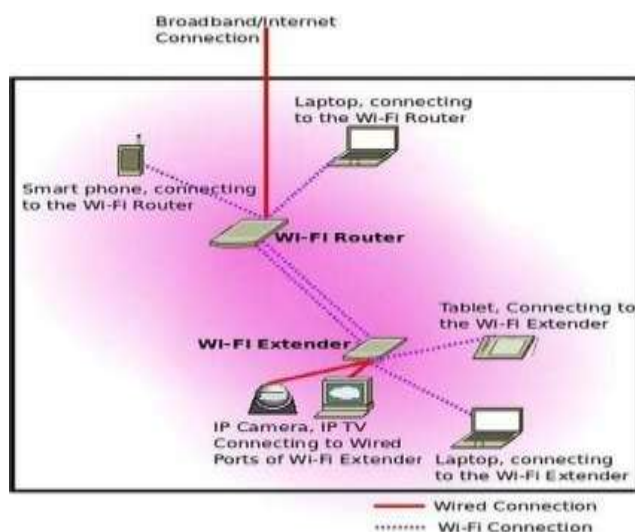


Figure 3.1: Block Diagram of Existing Commercial WiFi Extender System

The ISP provides internet connectivity through a broadband or fiber optic connection. The modem converts the WAN signal to Ethernet. The WiFi router distributes the signal wirelessly. The commercial extender picks up this signal and re-broadcasts it. Client devices connect to the extender's SSID.

4. PROPOSED SYSTEM

4.1 Overview of Proposed Design

The proposed system is an ESP8266-based WiFi range extender that overcomes all the limitations identified in the existing systems described in Chapter 3. The design leverages the ESP8266's native AP+STA dual-mode capability to implement a transparent WiFi repeater at a total component cost of under Rs.300.

The core innovation of the proposed design is the utilization of the ESP8266's dual radio interface, operating simultaneously as a client (STA mode) connected to the upstream router, and as an access point (AP mode) broadcasting an extended network SSID to downstream clients. The firmware, developed using the Arduino IDE and the ESP8266WiFi.h library, manages packet forwarding between the two interfaces.

The system is configured with a custom SSID (ESP_EXT) for the extended network and assigns IP addresses to connected clients from the 192.168.4.x subnet via a built-in DHCP server. All internet-bound traffic is forwarded to the upstream router transparently.

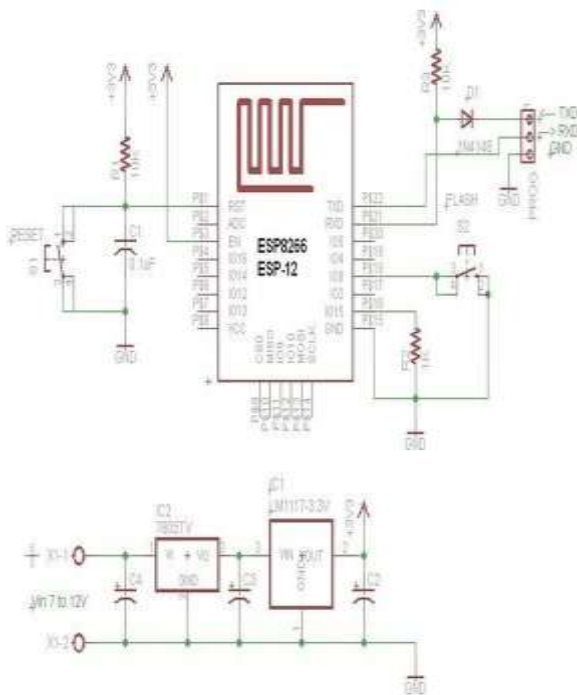


Figure 4.1: Block Diagram of Proposed ESP8266-Based WiFi Extender System.

ISP / Internet

The Internet Service Provider (ISP) provides the broadband or fiber optic WAN connection to the premises. The ISP connection is the source of all internet traffic that the ESP8266 extender will relay to downstream clients.

Modem

The modem converts the ISP's WAN signal, which may be ADSL, cable, or fiber optic, to an Ethernet signal suitable for the WiFi router. The modem bridges the WAN protocol to the standard TCP/IP stack used in the local network.²⁰

WiFi Router

The source WiFi router distributes internet connectivity wirelessly using the IEEE 802.11 b/g/n standard at 2.4 GHz. The ESP8266's STA interface connects to this router's SSID and receives an IP address via the router's DHCP server.

ESP8266 - STA Mode Interface

The Station (STA) interface of the ESP8266 connects to the source router. It receives an IP address via DHCP or a statically configured address. All upstream traffic (from clients to internet) is forwarded through this interface

to the source router.

ESP8266 - AP Mode Interface

The Access Point (AP) interface of the ESP8266 broadcasts the extended network SSID (default: ESP_EXT). Client devices associate with this SSID and receive IP addresses from the ESP8266's internal DHCP server. The AP channel is configured to match the source router's channel to minimize interference.

3.3V Power Supply

The ESP8266 operates at 3.3V DC. A regulated power supply, either a USB-powered 3.3V LDO regulator or a dedicated power module, provides clean, stable power to prevent voltage fluctuations that could cause WiFi disconnections or module resets. A 100 uF decoupling capacitor across the supply rails is recommended.

5. System Architecture

The ESP8266 WiFi extender system architecture is based on the AP+STA dual-mode operation of the ESP8266 SoC. In this architecture, the ESP8266 maintains two simultaneous logical network interfaces: the STA interface (connected to the source router) and the AP interface (broadcasting the extended SSID).

The firmware implements a transparent Layer-3 bridge between these two interfaces. Packets received on the AP interface destined for the internet are forwarded through the STA interface to the source router. Response packets received on the STA interface are forwarded back to the originating client on the AP interface.

5.1 AP+STA Mode Configuration

The AP+STA mode is enabled by calling `WiFi.mode(WIFI_AP_STA)` before any other WiFi configuration. This instructs the ESP8266's WiFi stack to activate both radio interfaces simultaneously. The STA interface operates on the same channel as the source router (determined during association), while the AP interface is configured to broadcast on the same or adjacent channel.

To minimize self-interference, it is recommended to configure the AP channel to match the source router's channel. The ESP8266's single radio hardware time-shares between STA and AP operations using its internal scheduler, which introduces the half-duplex throughput limitation discussed in chapter 3.

5.2 DHCP and IP Routing

The ESP8266's AP interface includes a built-in DHCP server that automatically assigns IP addresses to connecting clients. IP routing between the AP and STA interfaces is handled transparently by the ESP8266's internal TCP/IP stack (LwIP). Packets from AP-side clients are NAT-translated to the STA interface's IP address before

being forwarded to the source router, ensuring compatibility with standard router configurations that do not require static routes.

6. REAL-TIME APPLICATIONS

The ESP8266 WiFi extender, due to its ultra-low cost, compact size, and programmability, is well-suited for a wide range of real-time deployment scenarios. This chapter describes the six primary application domains identified during this project.

6.1 Smart Home Systems

Modern smart homes deploy a large number of IoT devices, including smart plugs, IP cameras, voice assistants, smart lighting, and thermostat controllers, throughout the home. Many of these devices are located in areas with poor WiFi coverage, such as garages, basements, and outdoor areas.

The ESP8266 extender can be placed in these dead zones to provide WiFi connectivity for nearby IoT devices. Its GPIO ports can additionally interface with locally installed sensors (PIR motion sensors, door/window sensors), making the extender a dual-purpose device: network extender and smart home sensor node.

6.2 Healthcare and Hospital

Hospital wards, corridors, and examination rooms require reliable WiFi coverage for patient monitoring devices, nurse call systems, and mobile clinical workstations. The compact form factor of the ESP8266 extender allows it to be discreetly installed within existing wall fittings or medical equipment enclosures.

The low power consumption (0.56 W active) and PoE adaptability make the ESP8266 extender suitable for battery-backed or UPS-protected installations critical in healthcare environments.

6.3 Industrial IoT

Factory floors present challenging WiFi propagation environments due to metal machinery, reflective surfaces, and electromagnetic interference from industrial equipment. The ESP8266 extender can be deployed as part of a distributed access point network to provide coverage in specific machine zones without requiring extensive cable infrastructure.

Industrial applications include RFID reader connectivity, conveyor belt sensor networks, PLC (Programmable Logic Controller) monitoring, and environmental monitoring using sensors attached directly to the ESP8266's GPIO pins.

6.4 Education Sector.

In educational institutions with limited IT budgets, the ESP8266 provides an extremely cost-effective solution for extending WiFi coverage to classrooms, libraries, and laboratories. A classroom WiFi extension deployment using commercial extenders might cost Rs. 15,000 to Rs. 50,000; the equivalent ESP8266-based deployment costs Rs. 1,500 to Rs. 5,000.

6.5Agriculture

Precision agriculture applications require sensor networks deployed across large field areas to monitor soil moisture, temperature, humidity, and pest activity.

The ESP8266 extender, powered by solar panels with battery backup, can relay sensor data from the field to a central server without requiring cellular connectivity for each individual sensor node.

The deep sleep mode (10 uA) of the ESP8266 enables the design of solar-powered repeater nodes that operate continuously from a small 5W solar panel and 1000 mAh LiPo battery, suitable for remote agricultural deployments.

6.6Retail

Large retail stores require WiFi coverage throughout the sales floor for point-of-sale (POS) terminals, digital signage screens, handheld inventory scanners, and customer loyalty program kiosks. Dead zones in large or metal-shelved areas can disrupt these operations.

The ESP8266 extender provides a budget-friendly solution for retail stores that need to extend coverage incrementally without investing in expensive enterprise access point infrastructure.

7.CONCLUSION

This project has successfully designed and implemented a low-cost, fully programmable WiFi range extender using the ESP8266 Wi-Fi SoC. The following conclusions are drawn from the design, implementation, and experimental evaluation:

- The ESP8266 successfully operates in AP+STA dual mode, simultaneously connecting to an upstream router as a station and broadcasting an extended WiFi network as an access point. This validates the core technical premise of the project.
- The AP+STA firmware, developed using the Arduino IDE and the ESP8266WiFi.h library, reliably relays packets between the two network interfaces, providing transparent internet access to downstream clients.

7.1 Future Scope

While the current implementation successfully meets all stated objectives, several enhancements are proposed for future development:

OTA (Over-The-Air) Firmware Updates: Implementation of the ArduinoOTA library to enable firmware updates over the WiFi network, eliminating the need for physical access to the module for updates after deployment.

- I. Web-Based Configuration Portal: Development of a captive portal using the ESP8266 WebServer library, allowing users to configure the source router credentials, extended SSID, password, and channel via any web browser without requiring firmware re-flashing.
- II. Intelligent Channel Selection: Implementation of automatic WiFi channel scanning to select the least congested channel for the AP interface, improving throughput in environments with multiple competing WiFi networks.
- III. WPA3 Security Support: Migration to the ESP32 platform (which supports WPA3) to provide modern encryption standards.
- IV. Load Balancing: Implementation of client load balancing across multiple ESP8266 extenders to distribute clients evenly across the available access points in a multi-extender deployment.
- V. Solar-Powered Deployment: Integration with a solar charging circuit and deep sleep firmware to enable autonomous, infrastructure-free deployment in outdoor and agricultural environments

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