ESP32-S3 Wi-Fi Extender

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Abstract

The ESP32-S3 Wi-Fi Extender is a high-performance, firmware-based network expansion solution designed to eliminate wireless dead zones. It leverages the ESP32-S3 microcontroller's native dual-core architecture to perform Network Address Port Translation (NAPT), transparently extending Wi-Fi range. The system features a hosted, professional Glassmorphism web dashboard for real-time monitoring of signal metrics, device tracking, and system uptime, stored entirely within the device's flash memory.

1. System Overview

The system operates as a Layer 3 bridge, utilizing two network interfaces within the ESP32-S3:

- **Station Interface (STA):** Acts as a client, connecting to the source router (e.g., Home Router) to receive internet bandwidth.
- **SoftAP Interface (AP):** Acts as a hotspot, broadcasting a new SSID (Service Set Identifier) for client devices to connect to.

Packet forwarding is handled by the lightweight IP (lwIP) stack, ensuring low latency and efficient NAT routing without the need for external routing hardware.

2. Key Features

- **High-Speed NAPT Routing:** Native packet forwarding optimized for the ESP32 architecture.
- **Glassmorphism Dashboard:** Modern, semi-transparent UI design stored in `PROGMEM` to optimize RAM usage and prevent heap fragmentation.
- **Real-Time Metrics:**
  - **RSSI:** Live signal strength monitoring (dBm).
  - **Uptime:** Exact connection duration timer.
  - **Status Indicator:** Visual Green/Red dot for instant connectivity checks.
- **Device Tracking:** Advanced tracking identifying connected devices via MAC address, assigned IP, and individual session duration.
- **Dual Speed Test Integration:**

  - **Ookla:** External link for comprehensive speed analysis.
  - **OpenSpeedTest:** Embedded iframe for quick, in-dashboard throughput checks.
- **Captive Portal:** DNS hijacking to automatically redirect new users to the configuration dashboard (`192.168.4.1`).

3. Hardware Requirements

3.1. Core Components

- **Microcontroller:** ESP32-S3 Dev Module (Dual-core XTENSA LX7, 240MHz).
- **Power Supply:** 5V / 2A USB-C Power Adapter (Critical; prevents brownouts during RF transmission bursts).
- **Antenna:** External IPEX/U.FL antenna (Recommended for +3dB gain over PCB antennas).

4. Software Environment

- **IDE:** Arduino IDE (v1.8.19 or v2.x).
- **Board Manager:** Espressif ESP32 Systems (v2.0.14 or newer).
- **Required Libraries:**
  - `ESPAsyncWebServer` & `AsyncTCP`: Asynchronous HTTP handling.
  - `ArduinoJson` (v6.x): Efficient JSON parsing/serialization.
  - `esp_wifi.h`: Low-level ESP-IDF Wi-Fi primitives.

5. Configuration and Installation

5.1. Network Setup

The following configuration block within `ESP32_Extender_Pro.ino` must be updated before flashing:

```
// --- Network Settings ---
#define STA_SSID        "Your_Home_Router"     // Input Network (Source)
#define STA_PASS        "Router_Password"      // Input Password

#define AP_SSID         "ESP32-Extender-Pro"   // Output Network Name
#define AP_PASS         "securepassword123"    // Output Password
```

5.2. Flashing Procedure

1. Select Board: **ESP32S3 Dev Module**.
2. Set **USB CDC On Boot** to **Enabled**.
3. Set **Partition Scheme** to **Default 4MB with SPIFFS**.
4. Connect ESP32 via USB and click **Upload**.

6. Usage Guide

6.1. Operation

1. **Power On:** Connect the ESP32 to a stable USB power source.
2. **Connect:** Join the `ESP32-Extender-Pro` Wi-Fi network.
3. **Dashboard:** The captive portal opens automatically. Alternatively, visit `http://192.168.4.1`.
4. **Verify:** Ensure the "System Vitality" indicator shows **Online** (Green).

6.2. Dashboard Interface

The dashboard serves as the central control hub. It provides visual feedback on network health and allows users to monitor client devices.

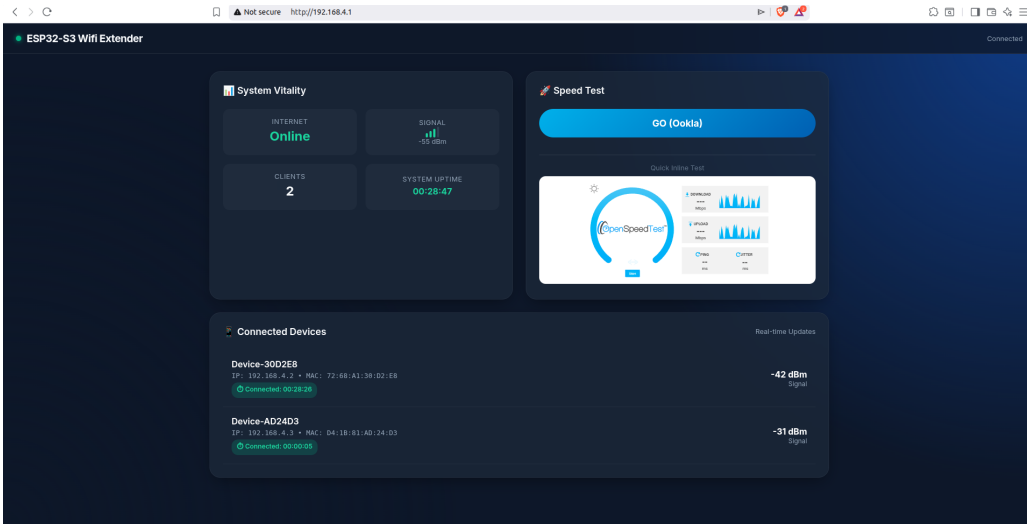

Figure 1: Real-Time Glassmorphism Web Dashboard

7. Limitations and Drawbacks

- **Throughput Reduction:** Due to the single-radio architecture (Half-Duplex), the ESP32 must switch between receiving and transmitting. An input of 50 Mbps typically yields 10–15 Mbps output.
- **Hardware Limits:** The ESP32 is a microcontroller, not a dedicated router CPU. Heavy traffic (e.g., 4K streaming on multiple devices) may cause latency.
- **Frequency:** Supports 2.4GHz Wi-Fi only (No 5GHz support).
- **Client Capacity:** Stable operation is limited to approximately 10–12 simultaneous clients.

8. Future Scope

- **OTA Updates:** Implementation of Over-The-Air firmware updates.
- **Mesh Networking:** Integration with ESP-MESH for multi-node coverage.
- **Battery Support:** Adding LiPo battery management for portable operation.

9. Conclusion

The ESP32-S3 Pro Wi-Fi Extender provides a cost-effective, customizable solution for extending network coverage. By combining robust firmware engineering with a professional user interface, it offers a superior user experience for home automation and dead-zone elimination.