ESP32 IIoT Configuration Panel

Complete Line-by-Line Code Documentation
WiFi + GSM + Double Reset Detection System

Project: IIOT-device-config-panel-GSM-Mailing
Documentation v1.0

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Abstract

This document provides exhaustive line-by-line documentation for the ESP32 IIoT Configuration Panel firmware. The system implements a dual-dashboard architecture with WiFi and GSM connectivity, featuring Double Reset Detection (DRD) for mode switching, persistent configuration storage, environmental sensor monitoring, and GSM communication capabilities (SMS, voice calls, email over GPRS).

Contents

1 System Architecture Overview

1.1 Core Design Philosophy

The firmware implements a modular, event-driven architecture with the following key characteristics:

- **Dual-Mode Operation**: Physical double-reset detection switches between Main (WiFi+GSM management) and Email configuration dashboards
- **Persistent Configuration**: SPIFFS-based JSON storage for WiFi, GSM, user, and email settings
- **Async WiFi Scanning**: Non-blocking network discovery with cached results
- **GSM Abstraction**: Hardware modem control via AT commands with caching layer
- **Embedded Dashboards**: Pre-compiled HTML/CSS/JS served from program memory
- **RESTful API**: JSON-based endpoints for all configuration and telemetry operations

1.2 Hardware Requirements

- ESP32 DevKit (or compatible)
- GSM Modem on Serial2 (RX=GPIO16, TX=GPIO17)
- SIM card with active data plan
- USB connection for programming and debugging

1.3 Software Dependencies

`Arduino.h`	Core ESP32 framework
`WiFi.h`	WiFi stack (AP and Station modes)
`WebServer.h`	HTTP server implementation
`DNSServer.h`	Captive portal DNS redirection
`SPIFFS.h`	Flash filesystem for configuration storage
`ArduinoJson.h`	JSON serialization/deserialization
`Preferences.h`	NVS storage for DRD state

2 File Structure and Organization

File	Purpose
`platformio.ini`	Build configuration, dependencies, upload settings
`src/main.cpp`	Core firmware (1766 lines): initialization, web server, API routes
`src/dashboard_html.h`	Main dashboard: WiFi, GSM, Device tabs (embedded binary)
`src/config_html.h`	Email configuration dashboard (embedded binary)
`src/GSM_Test.h/.cpp`	GSM modem abstraction: signal, network, SMS, calls
`src/SMTP.h/.cpp`	Email sending over GSM GPRS connection
`src/DRD_Manager.h`	Double Reset Detection utility (NVS-based)
`architecture.html`	Visual system architecture diagram

File	Purpose
README.md	Quick start guide and feature overview

3 main.cpp: Complete Line-by-Line Analysis

3.1 File Header and Metadata (Lines 1–24)

```
1  /**
2   * ESP32 Configuration Panel with Double Reset Detection
3   *
4   * Features:
5   * - Single reset: Main dashboard (WiFi + GSM management)
6   * - Double reset: Email configuration dashboard
7   * - Automatic dashboard switching via DRD
8   *
9   * Double Reset: Press reset button twice within 3 seconds
10  *
11  * @version 2.3.0
12  * @date 2025-01-30
13  */
```

Lines 1–13: File banner Documentation header explaining the dual-dashboard system and user interaction pattern. Critical for understanding the DRD mechanism.

Line 11: Version identifier Semantic versioning: `v2.3.0` indicates major version 2, minor 3, patch 0. Used in `/api/system/info` endpoint.

Line 12: Last updated timestamp ISO 8601 date format for tracking firmware build date. Exposed via API for client version checking.

3.2 System Includes (Lines 15–26)

```
1  #include <Arduino.h>
2  #include <WiFi.h>
3  #include <WebServer.h>
4  #include <DNSServer.h>
5  #include <SPIFFS.h>
6  #include <ArduinoJson.h>
7  #include "GSM_Test.h"
8  #include "SMTP.h"
9  #include "DRD_Manager.h"
10 #include "dashboard_html.h"
11 #include "config_html.h"
```

Line 15: `Arduino.h` ESP32 core framework. Provides `Serial`, `millis()`, `delay()`, `random()`, GPIO functions.

Line 16: `WiFi.h` Dual-mode WiFi stack. Enables simultaneous AP (for configuration portal) and STA (for internet connectivity).

Line 17: `WebServer.h` Synchronous HTTP/1.1 server. Handles REST API requests on port 80. Not async but sufficient for low-concurrency embedded use.

Line 18: `DNSServer.h` Captive portal DNS server. Redirects all DNS queries to ESP32's IP, forcing devices to open configuration page.

Line 19: `SPIFFS.h` SPI Flash File System. Provides `fopen()`-like API for persistent configuration storage in flash memory.

Line 20: `ArduinoJson.h` JSON library (v6.x). Used for all configuration serialization and API responses. Efficient memory management with `DynamicJsonDocument`.

Lines 21–22: GSM modules `GSM_Test.h` abstracts modem hardware with methods for signal strength, network detection, SMS, calls. `SMTP.h` implements email over GPRS.

Line 23: `DRD_Manager.h` Double Reset Detection. Uses ESP32's NVS (non-volatile storage) to persist reset timestamps across reboots.

Lines 24–25: Dashboard headers Pre-compiled HTML/CSS/JS stored as C arrays in program memory. `dashboard_html.h` contains main interface; `config_html.h` holds email configuration UI.

3.3 Global Configuration Constants (Lines 30–38)

```
#define DNS_PORT 53
#define DRD_TIMEOUT 3000  // 3 seconds for double reset detection

#define DEVICE_MODEL "ESP32 DevKit"
#define FIRMWARE_VERSION "v2.3.0"
#define LAST_UPDATED "2025-01-30"
```

Line 30: DNS_PORT Standard DNS port (53). Captive portal DNS server listens here to intercept all DNS requests.

Line 31: DRD_TIMEOUT 3000ms window for double reset detection. User must press reset twice within this interval to trigger email configuration mode.

Lines 36–38: System metadata Device identification strings exposed via `/api/system/info`. Used by dashboards for display and version checking.

3.4 Dashboard Mode Enumeration (Lines 48–52)

```
enum DashboardMode {
  MODE_MAIN,      // Main dashboard (WiFi + GSM)
  MODE_EMAIL      // Email configuration dashboard
};

DashboardMode currentMode = MODE_MAIN;
```

Lines 48–51: Mode enumeration Two operating modes determined at boot by DRD. `MODE_MAIN` serves `dashboard_html.h`; `MODE_EMAIL` serves `config_html.h`.

Line 53: Default mode Initialized to `MODE_MAIN`. Overridden in `setup()` if double reset detected.

3.5 Core System Instances (Lines 58–65)

```
DNSServer dnsServer;              // DNS server for captive portal
WebServer server(80);             // HTTP web server on port 80
DRD_Manager drd(DRD_TIMEOUT);     // Double reset detector

GSM_Test gsmModem(Serial2, 16, 17, 115200);  // GSM modem on Serial2
SMTP smtp(Serial2, 16, 17, 115200);          // SMTP client for GSM email
```

Line 58: DNSServer instance Handles DNS queries for captive portal. Redirects all hostnames to ESP32's AP IP (192.168.4.1).

Line 59: WebServer instance HTTP server listening on port 80. Serves dashboards and REST API. Synchronous, single-threaded.

Line 60: DRD_Manager instance Constructed with 3-second timeout. Checks NVS on boot to detect double reset pattern.

Line 63: GSM_Test instance Hardware abstraction for modem on `Serial2`. RX=GPIO16, TX=GPIO17, 115200 baud. Supports AT commands, signal queries, SMS, calls.

Line 64: SMTP instance Email client using same serial interface. Implements AUTH LOGIN, MAIL FROM, RCPT TO, DATA sequence over GSM GPRS.

3.6 Configuration File Paths (Lines 71–77)

```
static const char* WIFI_FILE = "/wifi.json";
static const char* GSM_FILE = "/gsm.json";
static const char* USER_FILE = "/user.json";
static const char* EMAIL_FILE = "/email.json";
static const char* DEFAULT_AP_SSID = "Config panel";
static const char* DEFAULT_AP_PASS = "12345678";
```

Lines 71–74: SPIFFS file paths JSON configuration files stored in root directory. Each module (WiFi, GSM, User, Email) has dedicated storage.

Lines 75–76: AP defaults Fallback credentials when configuration is missing or invalid. `DEFAULT_AP_PASS` meets WPA2 8-character minimum.

3.7 WiFi Scan Cache (Lines 81–83)

```
String lastScanJson;
bool lastScanAvailable = false;
```

Line 81: Scan result storage Cached JSON string from last WiFi scan. Avoids re-serialization on multiple `/api/wifi/scan/results` requests.

Line 82: Cache validity flag `true` after successful scan processing. Prevents serving stale/uninitialized data.

3.8 WiFi Scan Processing Function (Lines 87–126)

```
void processWiFiScanResults() {
  int n = WiFi.scanComplete();
  if (n == WIFI_SCAN_FAILED) {
    Serial.println(" WiFi scan failed");
    lastScanAvailable = false;
    return;
  }

  if (n == 0) {
    Serial.println(" No networks found");
    lastScanJson = "[]";
    lastScanAvailable = true;
    return;
  }

  Serial.printf(" Found %d networks\n", n);

  DynamicJsonDocument doc(2048);
  JsonArray networks = doc.to<JsonArray>();

  for (int i = 0; i < n; i++) {
    JsonObject network = networks.createNestedObject();
    network["ssid"] = WiFi.SSID(i);
    network["rssi"] = WiFi.RSSI(i);
    network["encryption"] = (WiFi.encryptionType(i) == WIFI_AUTH_OPEN)
                            ? "Open" : "Secure";
    network["auth"] = (WiFi.encryptionType(i) == WIFI_AUTH_OPEN) ? 0 : 1;

    int rssi = WiFi.RSSI(i);
    if (rssi >= -60) network["strength"] = "strong";
    else if (rssi >= -75) network["strength"] = "medium";
    else network["strength"] = "weak";
  }

  serializeJson(doc, lastScanJson);
  lastScanAvailable = true;
  WiFi.scanDelete();
}
```

Lines 88–94: Scan failure handling Checks `WiFi.scanComplete()` return value. `WIFI_SCAN_FAILED` indicates error; clears cache flag.

Lines 96–101: Empty scan result If no networks found, returns valid empty JSON array `[]`. Sets cache flag to prevent error state.

Lines 106–107: JSON document allocation Allocates 2KB document for network array. Sufficient for 15 networks with metadata.

Lines 109–122: Network iteration Builds JSON object per network with:

- `ssid`: Network name
- `rssi`: Signal strength in dBm
- `encryption`: "Open" or "Secure" (simplified)
- `auth`: Binary flag (0=open, 1=secured)
- `strength`: Human-readable quality (strong/medium/weak)

Lines 117–120: Signal strength classification RSSI thresholds:

- ≥ -60 dBm: "strong" (excellent connection)
- -75 to -60 dBm: "medium" (good connection)
- < -75 dBm: "weak" (marginal connection)

Lines 124–126: Cache update and cleanup Serializes JSON to `lastScanJson`, sets validity flag, calls `WiFi.scanDelete()` to free memory.

3.9 WifiConfig Structure (Lines 136–176)

```
struct WifiConfig {
  String staSsid;  // Station mode SSID (client mode)
  String staPass;  // Station mode password
  String apSsid;   // Access Point SSID
  String apPass;   // Access Point password

  bool load() {
    if (!SPIFFS.exists(WIFI_FILE)) return false;
    File f = SPIFFS.open(WIFI_FILE, "r");
    if (!f) return false;
    DynamicJsonDocument doc(1024);
    if (deserializeJson(doc, f)) { f.close(); return false; }
    f.close();
    staSsid = doc["staSsid"] | "";
    staPass = doc["staPass"] | "";
    apSsid = doc["apSsid"] | DEFAULT_AP_SSID;
    apPass = doc["apPass"] | DEFAULT_AP_PASS;
    return true;
  }

  bool save() const {
    DynamicJsonDocument doc(1024);
    doc["staSsid"] = staSsid;
    doc["staPass"] = staPass;
    doc["apSsid"] = apSsid.length() ? apSsid : DEFAULT_AP_SSID;
    doc["apPass"] = apPass.length() ? apPass : DEFAULT_AP_PASS;
    File f = SPIFFS.open(WIFI_FILE, "w");
    if (!f) return false;
    serializeJson(doc, f);
    f.close();
    return true;
  }
} wifiCfg;
```

Lines 137–141: Member variables Stores both Station (client) and AP (hotspot) credentials. Allows ESP32 to simultaneously provide configuration portal and connect to internet.

Lines 143–157: `load()` method Loads from `/wifi.json`:

1. Check file existence (line 144)
2. Open for reading (line 145)
3. Deserialize JSON (line 148)
4. Extract fields with defaults using `|` operator (lines 150–153)
5. Return success/failure

Lines 159–173: `save()` method Persists to `/wifi.json`:

1. Populate JSON document (lines 161–164)
2. Apply defaults for empty fields (lines 163–164)
3. Open file for writing (line 165)
4. Serialize and close (lines 167–169)

Line 175: Global instance `wifiCfg` instantiated globally for access from API handlers.

3.10 GsmConfig Structure (Lines 182–222)

```
struct GsmConfig {
  String carrierName;  // Network carrier name
  String apn;          // Access Point Name for data
  String apnUser;      // APN username (if required)
  String apnPass;      // APN password (if required)

  bool load() {
    if (!SPIFFS.exists(GSM_FILE)) return false;
    File f = SPIFFS.open(GSM_FILE, "r");
    if (!f) return false;
    DynamicJsonDocument doc(1024);
    if (deserializeJson(doc, f)) { f.close(); return false; }
    f.close();
    carrierName = doc["carrierName"] | "";
    apn = doc["apn"] | "";
    apnUser = doc["apnUser"] | "";
    apnPass = doc["apnPass"] | "";
    return true;
  }

  bool save() const {
    DynamicJsonDocument doc(1024);
    doc["carrierName"] = carrierName;
    doc["apn"] = apn;
    doc["apnUser"] = apnUser;
    doc["apnPass"] = apnPass;
    File f = SPIFFS.open(GSM_FILE, "w");
    if (!f) return false;
    serializeJson(doc, f);
    f.close();
    return true;
  }
} gsmCfg;
```

Lines 183–187: GSM parameters

- `carrierName`: User-friendly label (e.g., "Dialog", "Mobitel")
- `apn`: Network APN for GPRS (e.g., "internet", "data.mobile")
- `apnUser`/`apnPass`: Credentials if carrier requires authentication

Lines 189–217: Load/save implementation Identical pattern to `WifiConfig`. Stores to `/gsm.json`.

3.11 UserConfig and EmailConfig Structures (Lines 228–322)

(Similar structure to above; omitting detailed breakdown for brevity. See full code for implementation.)

UserConfig (lines 228–265) Stores user profile: name, email, phone. Persisted to `/user.json`.

EmailConfig (lines 271–322) SMTP settings with validation:

- `smtpHost`: SMTP server hostname (default: `smtp.gmail.com`)
- `smtpPort`: Port number (default: 465 for SSL)
- `emailAccount`: Email address for authentication
- `emailPassword`: App-specific password
- `senderName`: Display name in email headers
- `isValid()`: Returns `true` if all required fields populated

3.12 SensorData Structure (Lines 331–377)

```
struct SensorData {
  float temperature = 22.5;     // Temperature in Celsius
  float humidity = 65.0;         // Humidity percentage
  float light = 850.0;           // Light level in lux
  unsigned long lastUpdate = 0;
  const unsigned long UPDATE_INTERVAL = 3000;

  void update() {
    if (millis() - lastUpdate > UPDATE_INTERVAL) {
      temperature += (random(-20, 21) / 100.0);
      temperature = constrain(temperature, 18.0, 32.0);

      humidity += (random(-30, 31) / 100.0);
      humidity = constrain(humidity, 30.0, 90.0);

      light += (random(-200, 201) / 10.0);
      light = constrain(light, 0.0, 2000.0);

      lastUpdate = millis();
    }
  }

  String toJson() {
    DynamicJsonDocument doc(256);
    doc["temperature"] = round(temperature * 10) / 10.0;
    doc["humidity"] = round(humidity * 10) / 10.0;
    doc["light"] = round(light);
    doc["timestamp"] = millis();
    String out;
    serializeJson(doc, out);
    return out;
  }
} sensorData;
```

Lines 332–335: Sensor state Simulated environmental readings:

- Temperature: 18–32°C range
- Humidity: 30–90% range
- Light: 0–2000 lux range

Lines 339–358: `update()` method Applies realistic drift every 3 seconds:

- Temperature: ±0.2°C per update
- Humidity: ±0.3% per update
- Light: ±20 lux per update

Uses `constrain()` to enforce physical limits.

Lines 363–373: `toJson()` method Serializes current readings with timestamp. Rounds temperature/humidity to 1 decimal place, light to integer.

3.13 Sensor Test Sampling Helper (Lines 387–417)

```
String buildSensorTestSamplesJson(size_t sampleCount) {
  float t = sensorData.temperature;
  float h = sensorData.humidity;
  float l = sensorData.light;

  DynamicJsonDocument doc(1024);
  JsonArray arr = doc.to<JsonArray>();

  for (size_t i = 0; i < sampleCount; i++) {
    t += (random(-20, 21) / 100.0f);
    t = constrain(t, 18.0f, 32.0f);

    h += (random(-30, 31) / 100.0f);
    h = constrain(h, 30.0f, 90.0f);

    l += (random(-200, 201) / 10.0f);
    l = constrain(l, 0.0f, 2000.0f);

    JsonObject sample = arr.createNestedObject();
    sample["temperature"] = round(t * 10) / 10.0;
    sample["humidity"] = round(h * 10) / 10.0;
    sample["light"] = round(l);
    sample["index"] = (int)i;
  }

  String out;
  serializeJson(doc, out);
  return out;
}
```

Lines 388–391: Local state copies Creates temporary variables initialized from live `sensorData`. Prevents mutation of global state during sampling.

Lines 393–395: JSON array preparation Allocates 1KB document (sufficient for 10 samples with metadata). Creates root array.

Lines 397–414: Sample generation loop Generates `sampleCount` (typically 10) readings with simulated drift:

1. Apply random delta to each parameter (lines 398–405)
2. Create JSON object with rounded values (lines 407–411)
3. Add sample index for client-side ordering (line 412)

Lines 416–418: Serialization Converts JSON document to string and returns. Used by `/api/sensors/test` endpoint.

3.14 GSMCache Structure (Lines 424–442)

```
struct GSMCache {
  int signalStrength = 0;
  int signalQuality = 99;
  String grade = "Unknown";
  String carrierName = "Unknown";
  String networkMode = "Unknown";
  bool isRegistered = false;
  unsigned long lastUpdate = 0;
  const unsigned long UPDATE_INTERVAL = 300000;  // 5 minutes

  bool needsUpdate(bool forceRefresh = false) {
    return forceRefresh || (millis() - lastUpdate) > UPDATE_INTERVAL;
  }

  void updateSignal(bool forceRefresh = false) {
    if (needsUpdate(forceRefresh)) {
      signalStrength = gsmModem.getSignalStrength();
      if (signalStrength != 0) {
        signalQuality = (signalStrength + 113) / 2;
        if (signalQuality < 0) signalQuality = 0;
        if (signalQuality > 31) signalQuality = 31;

        if (signalQuality >= 20) grade = "Excellent";
        else if (signalQuality >= 15) grade = "Good";
        else if (signalQuality >= 10) grade = "Fair";
        else grade = "Poor";
      }
      lastUpdate = millis();
    }
  }

  void updateNetwork(bool forceRefresh = false) {
    if (needsUpdate(forceRefresh)) {
      GSM_Test::NetworkInfo networkInfo = gsmModem.detectCarrierNetwork();
      carrierName = networkInfo.carrierName;
      networkMode = networkInfo.networkMode;
      isRegistered = networkInfo.isRegistered;
      lastUpdate = millis();
    }
  }
} gsmCache;
```

Lines 425–432: Cache state Stores GSM telemetry with 5-minute TTL:

- `signalStrength`: RSSI in dBm
- `signalQuality`: CSQ value (0–31 scale)
- `grade`: Human-readable quality
- `carrierName`: Network operator name
- `networkMode`: Technology (GSM/EDGE/UMTS/LTE)
- `isRegistered`: Network registration status

Lines 434–436: `needsUpdate()` helper Returns `true` if cache expired or force refresh requested. Prevents excessive modem queries.

Lines 438–453: `updateSignal()` method Queries modem for signal strength and converts dBm to CSQ scale:

$$CSQ = \frac{RSSI + 113}{2}, \quad clampedto[0, 31] \tag{1}$$

Classifies quality: Excellent (≥ 20), Good (≥ 15), Fair (≥ 10), Poor (< 10).

Lines 455–463: `updateNetwork()` method Fetches carrier information via modem's network detection routine. Updates cache with operator name, technology, and registration status.

3.15 Utility Functions (Lines 453–508)

```
String ipToStr(const IPAddress &ip) {
  char buf[24];
  snprintf(buf, sizeof(buf), "%u.%u.%u.%u", ip[0], ip[1], ip[2], ip[3]);
  return String(buf);
}

void addCORS() {
  server.sendHeader("Access-Control-Allow-Origin", "*");
  server.sendHeader("Access-Control-Allow-Headers", "Content-Type");
  server.sendHeader("Access-Control-Allow-Methods", "GET,POST,OPTIONS");
  server.sendHeader("Cache-Control", "no-store");
}

void sendJson(int code, const String& body) {
  addCORS();
  server.send(code, "application/json", body);
}

void sendText(int code, const String& body, const String& ctype = "text/plain") {
  addCORS();
  server.send(code, ctype, body);
}
```

Lines 453–457: `ipToStr()` function Converts ESP32's `IPAddress` object to dotted-decimal string notation. Uses `snprintf` for safe formatting. Returns heap-allocated `String` for API responses.

Lines 459–464: `addCORS()` function Adds Cross-Origin Resource Sharing headers to HTTP responses:

- `Access-Control-Allow-Origin: *`: Permits requests from any domain
- `Access-Control-Allow-Headers: Content-Type`: Allows JSON payloads
- `Access-Control-Allow-Methods`: Permits GET, POST, OPTIONS
- `Cache-Control: no-store`: Prevents browser caching of dynamic data

Lines 466–469: `sendJson()` helper Wraps `WebServer::send()` with automatic CORS headers and `application/json` content type. Used by all REST API endpoints.

Lines 471–474: `sendText()` helper Similar to `sendJson()` but with configurable content type (defaults to `text/plain`). Used for error messages and captive portal redirects.

3.16 WiFi Management Functions (Lines 476–508)

```
void startAP(const String& ssid, const String& pass) {
  WiFi.mode(WIFI_AP_STA);
  WiFi.softAPConfig(IPAddress(192, 168, 4, 1),
                    IPAddress(192, 168, 4, 1),
                    IPAddress(255, 255, 255, 0));

  String validPass = pass;
  if (validPass.length() < 8) {
    validPass = DEFAULT_AP_PASS;
  }

  bool ap_ok = WiFi.softAP(ssid.c_str(), validPass.c_str());
  if (!ap_ok) {
    Serial.println(" Failed to start AP, using defaults");
    WiFi.softAP(DEFAULT_AP_SSID, DEFAULT_AP_PASS);
  }
  delay(500);
  dnsServer.start(DNS_PORT, "*", WiFi.softAPIP());
}

void connectSTA(const String& ssid, const String& pass) {
  if (!ssid.length()) return;
  WiFi.begin(ssid.c_str(), pass.c_str());
}

const char* rssiToStrength(int rssi) {
  if (rssi >= -60) return "strong";
  if (rssi >= -75) return "medium";
  return "weak";
}
```

Lines 476–494: `startAP()` function Initializes Access Point mode:

1. Sets dual mode (AP + STA) on line 477
2. Configures static IP 192.168.4.1/24 (lines 478–480)
3. Validates password length (≥ 8 chars for WPA2, lines 482–485)
4. Attempts AP creation with provided credentials (line 487)
5. Falls back to defaults on failure (lines 488–491)
6. Starts DNS server for captive portal (line 493)

Lines 496–499: `connectSTA()` function Non-blocking WiFi connection initiation. Returns immediately; connection status checked via `WiFi.status()` in API handlers.

Lines 501–505: `rssiToStrength()` function Converts RSSI (Received Signal Strength Indicator) to qualitative labels using standard thresholds.

3.17 Email Sending Function (Lines 510–538)

```
bool sendEmailGSM(const String& toEmail, const String& subject,
                  const String& content) {
  Serial.println(" Sending email via GSM...");

  if (!emailCfg.isValid()) {
    Serial.println(" Email configuration incomplete");
    return false;
```

```
  }

  smtp.begin();
  smtp.setAPN(gsmCfg.apn.length() ? gsmCfg.apn.c_str() : "internet");
  smtp.setAuth(emailCfg.emailAccount.c_str(),
               emailCfg.emailPassword.c_str());
  smtp.setRecipient(toEmail.c_str());
  smtp.setFromName(emailCfg.senderName.c_str());
  smtp.setSubject(subject);
  smtp.setBody(content);

  return smtp.sendEmail();
}
```

Lines 510–538: GSM email implementation Sends email via GPRS:

1. Validates email configuration (lines 514–517)
2. Initializes SMTP client (line 519)
3. Configures APN with fallback to "internet" (line 520)
4. Sets authentication credentials (lines 521–522)
5. Populates email headers and body (lines 523–526)
6. Executes SMTP transaction (line 528)

Returns `true` on success, `false` on configuration error or transmission failure.

3.18 System Status Builder (Lines 581–621)

```
String buildStatusJson() {
  DynamicJsonDocument doc(1024);
  doc["mode"] = "AP+STA";
  doc["dashboardMode"] = (currentMode == MODE_MAIN) ? "main" : "email";

  JsonObject ap = doc.createNestedObject("ap");
  ap["ssid"] = WiFi.softAPSSID();
  ap["ip"] = ipToStr(WiFi.softAPIP());
  ap["mac"] = WiFi.softAPmacAddress();
  ap["connectedDevices"] = WiFi.softAPgetStationNum();

  JsonObject sta = doc.createNestedObject("sta");
  bool staConnected = (WiFi.status() == WL_CONNECTED);
  sta["ssid"] = staConnected ? WiFi.SSID() : "";
  sta["connected"] = staConnected;
  sta["ip"] = staConnected ? ipToStr(WiFi.localIP()) : "0.0.0.0";
  sta["rssi"] = staConnected ? WiFi.RSSI() : 0;
  sta["hostname"] = WiFi.getHostname() ? WiFi.getHostname() : "";

  if (staConnected) {
    String statusMsg = "Connected to " + WiFi.SSID();
    sta["status"] = statusMsg;
    sta["statusClass"] = "status-connected";
  } else {
    sta["status"] = "Not connected";
    sta["statusClass"] = "status-disconnected";
  }

  JsonObject email = doc.createNestedObject("email");
  email["configured"] = emailCfg.isValid();
  email["account"] = emailCfg.emailAccount;
```

```

  String out;
  serializeJson(doc, out);
  return out;
}
```

Lines 581–621: Complete system status Builds comprehensive JSON response for `/api/status`:

Access Point section (lines 585–589):

- Current AP SSID (may differ from configured if defaults used)
- AP IP address (typically 192.168.4.1)
- MAC address
- Number of connected client devices

Station section (lines 591–606):

- Connection status and SSID
- Assigned IP address (0.0.0.0 if disconnected)
- Signal strength (RSSI)
- mDNS hostname
- Human-readable status message
- CSS class for UI styling (`status-connected`/`status-disconnected`)

Email section (lines 608–610):

- Configuration validity flag
- Email account (for display; password excluded)

3.19 HTTP Route Handlers - Common (Lines 623–683)

```
void handleRoot() {
  addCORS();
  if (currentMode == MODE_MAIN) {
    server.send_P(200, "text/html", dashboard_html, dashboard_html_len);
  } else {
    server.send_P(200, "text/html", config_html, config_html_len);
  }
}

void handleOptions() {
  addCORS();
  server.send(204);
}

void handleNotFound() {
  String host = server.hostHeader();

  if (host.startsWith("connectivitycheck.") ||
      host.startsWith("captive.apple.com") ||
      host.startsWith("msftconnecttest.") ||
      host.startsWith("detectportal.")) {
    addCORS();
    server.sendHeader("Location", "http://" + WiFi.softAPIP().toString() + "/");
    server.send(302, "text/plain", "");
  } else {
    handleRoot();
  }
}
```

Lines 623–631: `handleRoot()` function Serves appropriate dashboard based on `currentMode`:

- Uses `server.send_P()` to transmit from PROGMEM (flash storage)
- Avoids copying large HTML to RAM
- Dashboard selected by DRD at boot

Lines 633–636: `handleOptions()` function Handles CORS preflight requests (HTTP OPTIONS method). Returns 204 No Content with CORS headers.

Lines 638–652: `handleNotFound()` function Captive portal magic:

- Detects OS-specific connectivity check URLs (lines 641–644)
- Redirects to dashboard (302 Found) for captive portal detection
- Serves dashboard for unknown paths (default behavior)

Supports:

- Android: `connectivitycheck.*`
- iOS/macOS: `captive.apple.com`
- Windows: `msftconnecttest.*`
- Generic: `detectportal.*`

3.20 Mode Switching Handlers (Lines 685–722)

```
void handleSwitchMode() {
  DynamicJsonDocument doc(256);
  doc["currentMode"] = (currentMode == MODE_MAIN) ? "main" : "email";
  doc["message"] = "To switch modes, perform a double reset";
  String out;
  serializeJson(doc, out);
  sendJson(200, out);
}

void handleModeSwitchRequest() {
  if (!server.hasArg("plain")) {
    sendText(400, "Invalid JSON");
    return;
  }

  DynamicJsonDocument doc(256);
  if (deserializeJson(doc, server.arg("plain"))) {
    sendText(400, "Invalid JSON");
    return;
  }

  String mode = doc["mode"] | "";
  if (mode != "main" && mode != "email") {
    sendText(400, "Invalid mode. Use 'main' or 'email'");
    return;
  }

  DynamicJsonDocument resp(256);
  resp["success"] = false;
  resp["message"] = "Mode switching requires device reset. Double-reset to switch.";
  resp["currentMode"] = (currentMode == MODE_MAIN) ? "main" : "email";
  String out;
```

```
  serializeJson(resp, out);
  sendJson(200, out);
}
```

Lines 685–693: `handleSwitchMode()` (GET /api/mode) Informational endpoint returning current mode and switching instructions. No actual mode change performed.

Lines 695–719: `handleModeSwitchRequest()` (POST /api/mode/switch) Validates mode switch request but refuses runtime switching:

1. Validates JSON body (lines 696–700)
2. Parses requested mode (lines 702–706)
3. Validates mode value (lines 708–711)
4. Returns error explaining physical reset required (lines 713–719)

Design rationale: Runtime mode switching would require complex state management. Physical reset ensures clean transition.

3.21 Main Dashboard Routes Setup (Lines 724–1265)

```
void setupMainDashboardRoutes() {
  Serial.println(" Setting up MAIN dashboard routes");

  // Status endpoint
  server.on("/api/status", HTTP_GET, []() {
    sendJson(200, buildStatusJson());
  });

  // Sensor endpoints
  server.on("/api/sensors", HTTP_GET, []() {
    sendJson(200, sensorData.toJson());
  });

  server.on("/api/sensors/test", HTTP_GET, []() {
    sendJson(200, buildSensorTestSamplesJson(10));
  });

  // System info endpoint
  server.on("/api/system/info", HTTP_GET, []() {
    DynamicJsonDocument doc(512);
    doc["deviceModel"] = DEVICE_MODEL;
    doc["firmwareVersion"] = FIRMWARE_VERSION;
    doc["lastUpdated"] = LAST_UPDATED;
    doc["uptime"] = millis();
    doc["freeHeap"] = ESP.getFreeHeap();
    doc["chipModel"] = ESP.getChipModel();
    doc["chipRevision"] = ESP.getChipRevision();
    doc["cpuFreqMHz"] = ESP.getCpuFreqMHz();
    String out;
    serializeJson(doc, out);
    sendJson(200, out);
  });

  // ... (GSM, WiFi, configuration endpoints follow)
}
```

Lines 724–730: Status endpoint (GET /api/status) Returns complete system status via `buildStatusJson()`. Updated on every request (no caching).

Lines 732–739: Sensor endpoints

- **GET /api/sensors**: Returns current sensor snapshot without mutation
- **GET /api/sensors/test**: Generates 10 immediate test samples for UI validation

Lines 741–757: System info endpoint (GET /api/system/info) Returns device metadata and runtime statistics:

- `deviceModel`: Hardware identifier
- `firmwareVersion`: Software version
- `lastUpdated`: Build date
- `uptime`: Milliseconds since boot
- `freeHeap`: Available RAM in bytes
- `chipModel`: ESP32 variant (e.g., "ESP32-D0WDQ6")
- `chipRevision`: Silicon revision
- `cpuFreqMHz`: Clock speed (typically 240 MHz)

Lines 759–821: GSM signal endpoint (GET /api/gsm/signal)

```
server.on("/api/gsm/signal", HTTP_GET, []() {
  bool forceRefresh = server.hasArg("force") && server.arg("force") == "true";
  gsmCache.updateSignal(forceRefresh);

  DynamicJsonDocument doc(256);
  doc["ok"] = (gsmCache.signalStrength != -999);
  doc["dbm"] = gsmCache.signalStrength;
  doc["csq"] = gsmCache.signalQuality;
  doc["grade"] = gsmCache.grade;
  String out;
  serializeJson(doc, out);
  sendJson(200, out);
});
```

Supports optional `?force=true` query parameter to bypass 5-minute cache. Returns signal strength in dBm, CSQ value, and quality grade.

Lines 823–855: GSM network endpoint (GET /api/gsm/network) Similar caching strategy. Returns carrier name, network mode (GSM/LTE/etc), and registration status.

Lines 857–902: GSM call endpoints **POST /api/gsm/call**: Initiates voice call

```
server.on("/api/gsm/call", HTTP_POST, []() {
  if (!server.hasArg("plain")) {
    sendText(400, "Invalid JSON");
    return;
  }

  DynamicJsonDocument doc(256);
  if (deserializeJson(doc, server.arg("plain"))) {
    sendText(400, "Invalid JSON");
    return;
  }

  String phoneNumber = doc["phoneNumber"] | "";
```

```
  if (!phoneNumber.length()) {
    // Error response
    return;
  }

  bool success = gsmModem.makeCall(phoneNumber);

  if (success) {
    delay(10000);  // 10-second call duration
    gsmModem.hangupCall();
  }

  // JSON response with success status
});
```

Automatically hangs up after 10 seconds to prevent indefinite connections.
POST /api/gsm/call/hangup: Immediately terminates active call.

Lines 904–968: GSM SMS endpoint (POST /api/gsm/sms) Sends SMS message. Validates phone number and message content before transmission.

Lines 970–1014: WiFi scan endpoints **GET /api/wifi/scan**: Starts asynchronous scan

```
server.on("/api/wifi/scan", HTTP_GET, []() {
  Serial.println(" Starting WiFi network scan...");
  int n = WiFi.scanNetworks(true);  // true = async

  if (n == WIFI_SCAN_FAILED) {
    sendJson(500, "{\"error\":\"Scan failed to start\"}");
    return;
  }

  DynamicJsonDocument doc(256);
  doc["status"] = "scanning";
  doc["message"] = "Scan started, use /api/wifi/scan/results";
  String out;
  serializeJson(doc, out);
  sendJson(200, out);
});
```

Returns immediately with "scanning" status. Results retrieved via separate endpoint.
GET /api/wifi/scan/results: Returns cached scan results from `lastScanJson`.

Lines 1016–1133: WiFi connect/disconnect endpoints **POST /api/wifi/connect**:

1. Validates SSID parameter
2. Disconnects from current network if connected
3. Initiates connection with 20-second timeout
4. Saves credentials to SPIFFS on success
5. Returns connection status and IP address

POST /api/wifi/disconnect:

1. Disconnects from network
2. Clears saved credentials from SPIFFS
3. Returns success confirmation

Lines 1135–1177: User configuration endpoints **GET /api/load/user**: Returns user profile (name, email, phone)

POST /api/save/user: Persists user profile to `/user.json`

Lines 1179–1217: GSM configuration endpoints **GET /api/load/gsm**: Returns GSM settings (carrier, APN, credentials)

POST /api/save/gsm: Persists GSM configuration to `/gsm.json`

3.22 Email Dashboard Routes Setup (Lines 1228–1467)

```
void setupEmailDashboardRoutes() {
  Serial.println(" Setting up EMAIL dashboard routes");

  // Sensor endpoints (identical to main mode)
  server.on("/api/sensors", HTTP_GET, []() {
    sendJson(200, sensorData.toJson());
  });

  server.on("/api/sensors/test", HTTP_GET, []() {
    sendJson(200, buildSensorTestSamplesJson(10));
  });

  // System info (identical to main mode)
  server.on("/api/system/info", HTTP_GET, []() { /* ... */ });

  // AP configuration endpoints
  server.on("/api/load/ap", HTTP_GET, []() { /* ... */ });
  server.on("/api/save/ap", HTTP_POST, []() { /* ... */ });

  // Email configuration endpoints
  server.on("/api/load/email", HTTP_GET, []() { /* ... */ });
  server.on("/api/save/email", HTTP_POST, []() { /* ... */ });

  // Email sending endpoints
  server.on("/api/email/gsm/send", HTTP_POST, []() { /* ... */ });
  server.on("/api/email/send", HTTP_POST, []() { /* ... */ });
}
```

Lines 1228–1265: Sensor and system info Identical implementations to main dashboard. Allows email configuration UI to include device monitoring.

Lines 1267–1329: AP configuration endpoints **GET /api/load/ap**: Returns current AP SSID, password, IP, and connected device count

POST /api/save/ap:

1. Validates SSID (non-empty, $\leq$ 32 chars)
2. Validates password ($\geq$ 8 chars or empty)
3. Saves to SPIFFS
4. Returns message: "Restart required to apply changes"

Lines 1331–1395: Email configuration endpoints **GET /api/load/email**: Returns SMTP settings (excludes password for security)

POST /api/save/email:

1. Updates SMTP host, port, account, sender name
2. Only updates password if provided in request

3. Allows partial updates without requiring password re-entry
4. Persists to `/email.json`

Lines 1397–1467: Email sending endpoints **POST /api/email/gsm/send**: Dedicated GSM email endpoint
POST /api/email/send?via=gsm: Alternative endpoint with method parameter
Both validate recipient, subject, content and call `sendEmailGSM()`.

3.23 Setup Function (Lines 1477–1693)

```
void setup() {
  Serial.begin(115200);
  delay(200);

  // Double Reset Detection
  Serial.println("");
  Serial.println("  ESP32 Configuration Panel with DRD   ");
  Serial.println("");

  bool doubleResetDetected = drd.detectDoubleReset();

  if (doubleResetDetected) {
    currentMode = MODE_EMAIL;
    Serial.println(" DOUBLE RESET DETECTED!");
    Serial.println(" Loading EMAIL Configuration Dashboard");
  } else {
    currentMode = MODE_MAIN;
    Serial.println(" Single reset detected");
    Serial.println(" Loading MAIN Dashboard");
  }

  // SPIFFS initialization
  if (!SPIFFS.begin(true)) {
    Serial.println(" SPIFFS mount failed");
  } else {
    Serial.println(" SPIFFS mounted successfully");
  }

  // Load configurations
  wifiCfg.load();
  gsmCfg.load();
  userCfg.load();
  emailCfg.load();

  // Start WiFi AP
  String apSsid = (currentMode == MODE_MAIN && wifiCfg.apSsid.length())
                  ? wifiCfg.apSsid : DEFAULT_AP_SSID;
  String apPass = (currentMode == MODE_MAIN && wifiCfg.apPass.length())
                  ? wifiCfg.apPass : DEFAULT_AP_PASS;
  startAP(apSsid, apPass);

  // Connect to WiFi STA if configured
  if (wifiCfg.staSsid.length()) {
    connectSTA(wifiCfg.staSsid, wifiCfg.staPass);
  }

  // Initialize GSM (main mode only)
  if (currentMode == MODE_MAIN) {
    Serial.println("\n Initializing GSM modem...");
    gsmModem.begin();
    delay(2000);
  }
```

```

  // Setup web server routes
  server.on("/", HTTP_GET, handleRoot);
  server.on("/index.html", HTTP_GET, handleRoot);
  server.on("/config", HTTP_GET, handleRoot);

  // Captive portal endpoints
  server.on("/generate_204", HTTP_GET, []() { /* Android */ });
  server.on("/ncsi.txt", HTTP_GET, []() { /* Windows */ });
  server.on("/hotspot-detect.html", HTTP_GET, handleRoot); /* iOS */

  // Mode management
  server.on("/api/mode", HTTP_GET, handleSwitchMode);
  server.on("/api/mode/switch", HTTP_POST, handleModeSwitchRequest);
  server.on("/api/restart", HTTP_GET, []() {
    sendText(200, "Restarting ESP32...");
    delay(200);
    ESP.restart();
  });

  // Common status endpoint
  server.on("/api/status", HTTP_GET, []() {
    sendJson(200, buildStatusJson());
  });

  // Setup mode-specific routes
  if (currentMode == MODE_MAIN) {
    setupMainDashboardRoutes();
  } else {
    setupEmailDashboardRoutes();
  }

  // CORS OPTIONS handlers for all endpoints
  server.on("/api/status", HTTP_OPTIONS, handleOptions);
  // ... (additional OPTIONS handlers)

  // Error handlers
  server.onNotFound(handleNotFound);

  // Start server
  server.begin();
  Serial.println(" HTTP server started");

  Serial.println("\n");
  Serial.println("         SYSTEM READY                   ");
  Serial.println("");
  Serial.printf(" Portal URL: http://%s\n", ipToStr(WiFi.softAPIP()).c_str());
  Serial.printf(" Dashboard Mode: %s\n",
                (currentMode == MODE_MAIN) ? "MAIN" : "EMAIL");
}
```

Lines 1477–1500: Initialization and DRD

1. Initialize serial console at 115200 baud (line 1478)
2. Print banner (lines 1482–1485)
3. Detect double reset via DRD_Manager (line 1487)
4. Set `currentMode` based on detection result (lines 1489–1497)

Lines 1502–1509: SPIFFS mounting Attempts to mount filesystem with `formatOnFail=true`. Formats flash partition if corrupted.

Lines 1511–1515: Configuration loading Loads all configuration files from SPIFFS. Missing files return gracefully with empty/default values.

Lines 1517–1530: WiFi AP startup

1. Selects SSID/password based on mode and configuration
2. Email mode always uses default AP for consistency
3. Main mode uses configured AP if available
4. Starts DNS server for captive portal

Lines 1532–1535: WiFi STA connection Initiates connection to saved network if configured. Non-blocking; status checked later.

Lines 1537–1542: GSM initialization Only initialized in main mode:

1. Calls `gsmModem.begin()` to initialize serial and modem
2. 2-second delay allows modem to boot and stabilize
3. Email mode skips GSM init to save boot time

Lines 1544–1580: Route registration

1. Common routes: root, status, mode switching (lines 1545–1561)
2. Captive portal endpoints for multiple OS (lines 1563–1569)
3. Mode-specific routes via helper functions (lines 1573–1577)
4. CORS preflight handlers for all API endpoints (lines 1579–1619)

Lines 1621–1625: Server startup

1. Register 404 handler for unknown paths (line 1621)
2. Start HTTP server (line 1623)
3. Print confirmation message (line 1624)

Lines 1627–1641: Startup complete message Prints formatted box with portal URL, dashboard mode, and usage instructions.

3.24 Loop Function (Lines 1703–1766)

```
void loop() {
  // Network handling
  dnsServer.processNextRequest();  // Handle DNS requests for captive portal
  server.handleClient();            // Handle HTTP requests

  // WiFi scan processing
  if (WiFi.scanComplete() >= 0) {
    processWiFiScanResults();
  }

  // Double reset detection
  drd.loop();  // Auto-clear DRD flag after timeout

```

```
  // Periodic status logging
  static unsigned long lastStatusPrint = 0;
  const unsigned long STATUS_INTERVAL = 30000;  // 30 seconds

  if (millis() - lastStatusPrint > STATUS_INTERVAL) {
    lastStatusPrint = millis();

    Serial.printf("\n Status Update [%s mode]\n",
                  (currentMode == MODE_MAIN) ? "MAIN" : "EMAIL");

    // Access Point status
    Serial.printf("  AP IP: %s\n", ipToStr(WiFi.softAPIP()).c_str());
    Serial.printf("  Connected devices: %d\n", WiFi.softAPgetStationNum());

    // Station mode status
    if (WiFi.status() == WL_CONNECTED) {
      Serial.printf("  STA IP: %s\n", ipToStr(WiFi.localIP()).c_str());
      Serial.printf("  RSSI: %d dBm (%s)\n", WiFi.RSSI(),
                    rssiToStrength(WiFi.RSSI()));
    } else {
      Serial.println("  STA: Not connected");
    }

    // Email configuration status (only in EMAIL mode)
    if (currentMode == MODE_EMAIL) {
      Serial.printf("  Email: %s\n",
                    emailCfg.isValid() ? "Configured " : "Not configured ");
    }

    // GSM status (only in MAIN mode)
    if (currentMode == MODE_MAIN) {
      if (gsmCache.signalStrength != 0) {
        Serial.printf("  GSM Signal: %d dBm (%s)\n",
                      gsmCache.signalStrength,
                      gsmCache.grade.c_str());
        Serial.printf("  GSM Carrier: %s\n", gsmCache.carrierName.c_str());
      } else {
        Serial.println("  GSM: Not initialized");
      }
    }

    Serial.println("");
  }
}
```

Lines 1704–1705: DNS and HTTP processing Core network event loop. Must be called frequently to maintain responsiveness:

- **dnsServer.processNextRequest()**: Handles captive portal DNS queries. Redirects all DNS lookups to ESP32's IP (192.168.4.1), forcing client devices to open configuration portal.
- **server.handleClient()**: Processes incoming HTTP requests. Synchronous; blocks until request completed. Typical request duration: 5–50ms depending on endpoint.

Lines 1707–1710: Asynchronous WiFi scan completion Monitors scan state machine:

- `WiFi.scanComplete()` returns:
  - `WIFI_SCAN_RUNNING` (-1): Scan in progress
  - `WIFI_SCAN_FAILED` (-2): Scan error
  - $n \geq 0$: Number of networks found

- When scan completes, `processWiFiScanResults()` builds JSON cache
- Non-blocking design prevents UI freezes during 3–5 second scan duration

Lines 1712–1713: DRD timeout management `drd.loop()` must be called regularly to:

- Clear double-reset flag after `DRD_TIMEOUT` (3 seconds) expires
- Prevent false positives from rapid power cycling
- Update NVS state for next boot cycle

Lines 1715–1764: Periodic status reporting Every 30 seconds, prints comprehensive system state:

Access Point metrics (lines 1723–1724):

- AP IP address (static 192.168.4.1)
- Number of connected client devices (0–4 typical range)

Station mode metrics (lines 1726–1733):

- Connection status via `WiFi.status() == WL_CONNECTED`
- Assigned IP from DHCP server
- Signal strength in dBm and qualitative grade
- Useful for diagnosing connectivity issues

Mode-specific status (lines 1735–1752):

- **Email mode**: Configuration validity check
- **Main mode**: GSM signal strength and carrier name
- Conditional logging reduces serial clutter

Design considerations The loop executes at high frequency (typically 100–1000 Hz) to maintain network responsiveness. No `delay()` calls present; all timing via `millis()` comparison. This non-blocking approach ensures:

- Immediate HTTP request handling
- Responsive captive portal redirection
- Smooth sensor data updates (if real sensors integrated)
- Consistent DRD timeout enforcement

4 Configuration File Formats

4.1 WiFi Configuration (/wifi.json)

```json
{
  "staSsid": "MyHomeNetwork",
  "staPass": "password123",
  "apSsid": "ESP32-Config",
  "apPass": "12345678"
}
```

Field specifications:

Field	Type	Description
staSsid	String	Station mode SSID. Client network to connect to. Empty string = disabled.
staPass	String	Station mode password. WPA/WPA2 pre-shared key.
apSsid	String	Access Point SSID. Hotspot name for configuration portal. Max 32 characters.
apPass	String	Access Point password. WPA2 minimum 8 characters. Empty = open network (not recommended).

4.2 GSM Configuration (/gsm.json)

```json
{
  "carrierName": "Dialog",
  "apn": "internet",
  "apnUser": "",
  "apnPass": ""
}
```

Field specifications:

Field	Type	Description
carrierName	String	Display name for network operator. User-defined label.
apn	String	Access Point Name for GPRS/LTE data. Carrier-specific (e.g., "internet", "web.gprs.mtnnigeria.net").
apnUser	String	APN username. Optional; most carriers don't require.
apnPass	String	APN password. Optional; empty for most consumer SIM plans.

4.3 User Profile (/user.json)

```json
{
  "name": "John Doe",
  "email": "john@example.com",
  "phone": "+94712345678"
}
```

Field specifications:

Field	Type	Description
name	String	Full name for display in dashboard.
email	String	Contact email address. Not used for authentication.
phone	String	Phone number in E.164 format (+countrycode...).

4.4 Email Configuration (/email.json)

```json
{
  "smtpHost": "smtp.gmail.com",
  "smtpPort": 465,
  "emailAccount": "myesp32@gmail.com",
  "emailPassword": "app_specific_password_here",
  "senderName": "ESP32 Device"
}
```

Field specifications:

Field	Type	Description
`smtpHost`	String	SMTP server hostname. Default: `smtp.gmail.com`.
`smtpPort`	Integer	SMTP port. 465 (SSL), 587 (TLS), or 25 (plaintext, deprecated).
`emailAccount`	String	Email address for SMTP authentication.
`emailPassword`	String	App password (Gmail) or account password. **Warning**: Stored in plaintext.
`senderName`	String	Display name in "From" header.

Security notes:

- Passwords stored unencrypted in SPIFFS. Flash encryption recommended for production.
- For Gmail: Use App Passwords (2FA required). Regular passwords rejected.
- `GET /api/load/email` excludes password field to prevent leakage.
- `POST /api/save/email` allows password-optional updates.

5 API Reference

5.1 Common Endpoints (Both Modes)

5.1.1 GET / (Root)

Description: Serves appropriate dashboard HTML based on current mode.
Response: HTML document (dashboard_html.h or config_html.h)
Headers:

- `Content-Type: text/html`
- `Access-Control-Allow-Origin: *`

5.1.2 GET /api/status

Description: Returns complete system status including WiFi, mode, and email configuration.
Response: JSON object

```
{
  "mode": "AP+STA",
  "dashboardMode": "main",
  "ap": {
    "ssid": "ESP32-Config",
    "ip": "192.168.4.1",
    "mac": "AA:BB:CC:DD:EE:FF",
    "connectedDevices": 2
  },
  "sta": {
    "ssid": "MyNetwork",
    "connected": true,
    "ip": "192.168.1.100",
    "rssi": -45,
    "hostname": "esp32",
    "status": "Connected to MyNetwork",
    "statusClass": "status-connected"
  },
  "email": {
```

```
    "configured": true,
    "account": "myesp32@gmail.com"
  }
}
```

5.1.3 GET /api/system/info

Description: Returns device metadata and runtime statistics.
Response: JSON object

```
{
  "deviceModel": "ESP32 DevKit",
  "firmwareVersion": "v2.3.0",
  "lastUpdated": "2025-01-30",
  "uptime": 123456,
  "freeHeap": 245632,
  "chipModel": "ESP32-D0WDQ6",
  "chipRevision": 1,
  "cpuFreqMHz": 240
}
```

5.1.4 GET /api/sensors

Description: Returns current sensor readings (simulated data).
Response: JSON object

```
{
  "temperature": 23.5,
  "humidity": 67.2,
  "light": 1024,
  "timestamp": 123456
}
```

5.1.5 GET /api/sensors/test

Description: Generates 10 rapid sensor samples for testing (does not affect live sensor state).
Response: JSON array

```
[
  {
    "temperature": 23.5,
    "humidity": 67.2,
    "light": 1024,
    "index": 0
  },
  {
    "temperature": 23.7,
    "humidity": 67.0,
    "light": 1045,
    "index": 1
  }
  // ... 8 more samples
]
```

5.1.6 GET /api/mode

Description: Returns current dashboard mode and switching instructions.
Response: JSON object

```
{
  "currentMode": "main",
  "message": "To switch modes, perform a double reset (reset twice within 3 seconds)"
}
```

5.1.7 POST /api/mode/switch

Description: Informs user that mode switching requires physical reset (does not perform switch).
Request body:

```json
{
  "mode": "email"
}
```

Response: JSON object

```json
{
  "success": false,
  "message": "Mode switching requires device reset. Double-reset to switch.",
  "currentMode": "main"
}
```

5.1.8 GET /api/restart

Description: Restarts ESP32 device immediately.
Response: Plain text "Restarting ESP32..." (200ms delay then reboot)

5.2 Main Dashboard Endpoints (MODE_MAIN Only)

5.2.1 GET /api/gsm/signal?force=true

Description: Returns GSM signal strength and quality. Optional `force=true` bypasses 5-minute cache.
Response: JSON object

```json
{
  "ok": true,
  "dbm": -73,
  "csq": 20,
  "grade": "Good"
}
```

Grade thresholds:

- Excellent: CSQ $\geq$ 20
- Good: CSQ $\geq$ 15
- Fair: CSQ $\geq$ 10
- Poor: CSQ $<$ 10

5.2.2 GET /api/gsm/network?force=true

Description: Returns GSM network information. Optional `force=true` bypasses cache.
Response: JSON object

```json
{
  "carrierName": "Dialog Axiata",
  "networkMode": "LTE",
  "isRegistered": true
}
```

5.2.3 POST /api/gsm/call

Description: Initiates voice call with 10-second duration and automatic hangup.

Request body:

```json
{
  "phoneNumber": "+94712345678"
}
```

Response: JSON object

```json
{
  "success": true,
  "message": "Call completed (10 seconds)"
}
```

5.2.4 POST /api/gsm/call/hangup

Description: Immediately terminates active call.

Response: JSON object

```json
{
  "success": true,
  "message": "Call ended successfully"
}
```

5.2.5 POST /api/gsm/sms

Description: Sends SMS message via GSM modem.

Request body:

```json
{
  "phoneNumber": "+94712345678",
  "message": "Hello from ESP32!"
}
```

Response: JSON object

```json
{
  "success": true,
  "message": "SMS sent successfully"
}
```

5.2.6 GET /api/wifi/scan

Description: Starts asynchronous WiFi network scan (non-blocking).

Response: JSON object

```json
{
  "status": "scanning",
  "message": "Scan started, use /api/wifi/scan/results to get results"
}
```

5.2.7 GET /api/wifi/scan/results

Description: Returns cached WiFi scan results.

Response: JSON array

```json
[
  {
    "ssid": "MyNetwork",
    "rssi": -45,
    "encryption": "Secure",
```

```json
    "auth": 1,
    "strength": "strong"
  },
  {
    "ssid": "NeighborWiFi",
    "rssi": -78,
    "encryption": "Secure",
    "auth": 1,
    "strength": "weak"
  }
]
```


5.2.8 POST /api/wifi/connect

Description: Connects to WiFi network with 20-second timeout. Saves credentials on success.
Request body:


```json
{
  "ssid": "MyNetwork",
  "password": "password123"
}
```


Success response:


```json
{
  "success": true,
  "ssid": "MyNetwork",
  "ip": "192.168.1.100",
  "rssi": -45,
  "message": "Connected successfully"
}
```


Failure response:


```json
{
  "success": false,
  "error": "Connection failed - check password or signal strength"
}
```


5.2.9 POST /api/wifi/disconnect

Description: Disconnects from WiFi network and clears saved credentials.
Response: JSON object


```json
{
  "success": true,
  "message": "Disconnected from MyNetwork"
}
```


5.2.10 GET /api/load/user

Description: Loads user profile configuration.
Response: JSON object


```json
{
  "name": "John Doe",
  "email": "john@example.com",
  "phone": "+94712345678"
}
```

5.2.11 POST /api/save/user

Description: Saves user profile to SPIFFS.
Request body:


```json
{
  "name": "Jane Smith",
  "email": "jane@example.com",
  "phone": "+94723456789"
}
```


Response: JSON object


```json
{
  "success": true
}
```


5.2.12 GET /api/load/gsm

Description: Loads GSM configuration.
Response: JSON object


```json
{
  "carrierName": "Dialog",
  "apn": "internet",
  "apnUser": "",
  "apnPass": ""
}
```


5.2.13 POST /api/save/gsm

Description: Saves GSM configuration to SPIFFS.
Request body:


```json
{
  "carrierName": "Mobitel",
  "apn": "mobitel",
  "apnUser": "",
  "apnPass": ""
}
```


Response: Plain text "OK" (200) or "SAVE_FAILED" (500)

5.3 Email Dashboard Endpoints (MODE_EMAIL Only)

5.3.1 GET /api/load/ap

Description: Loads Access Point configuration and status.
Response: JSON object


```json
{
  "apSsid": "ESP32-Config",
  "apPass": "12345678",
  "currentApSsid": "ESP32-Config",
  "currentApIp": "192.168.4.1",
  "connectedDevices": 2
}
```

5.3.2 POST /api/save/ap

Description: Saves Access Point configuration (requires restart to apply).
Request body:

```
{
  "apSsid": "MyESP32Portal",
  "apPass": "newpass123"
}
```

Validation rules:

- SSID: Non-empty, $\leq$ 32 characters
- Password: $\geq$ 8 characters or empty (open network)

Response: JSON object

```
{
  "success": true,
  "message": "AP configuration saved. Restart required to apply changes."
}
```

5.3.3 GET /api/load/email

Description: Loads email configuration (excludes password for security).
Response: JSON object

```
{
  "smtpHost": "smtp.gmail.com",
  "smtpPort": 465,
  "emailAccount": "myesp32@gmail.com",
  "senderName": "ESP32 Device"
}
```

5.3.4 POST /api/save/email

Description: Saves email configuration. Password optional (preserves existing if omitted).
Request body:

```
{
  "smtpHost": "smtp.gmail.com",
  "smtpPort": 465,
  "emailAccount": "newemail@gmail.com",
  "emailPassword": "app_password_here",
  "senderName": "My ESP32"
}
```

Response: JSON object

```
{
  "success": true
}
```

5.3.5 POST /api/email/gsm/send

Description: Sends email via GSM GPRS connection.
Request body:

```
{
  "to": "recipient@example.com",
  "subject": "Alert from ESP32",
  "content": "Temperature threshold exceeded: 32.5°C"
}
```

Success response:

```json
{
  "success": true,
  "message": "GSM email sent successfully"
}
```

Failure response:

```json
{
  "success": false,
  "error": "Failed to send GSM email"
}
```

5.3.6 POST /api/email/send?via=gsm

Description: Alternative email endpoint with method parameter (GSM only supported).
Request body: Same as `/api/email/gsm/send`
Response: Same as `/api/email/gsm/send`

6 Captive Portal Implementation

6.1 DNS Redirection Mechanism

The captive portal forces connected devices to open the configuration dashboard by intercepting all DNS queries and redirecting them to the ESP32's IP address.

Implementation details:

1. DNSServer listens on port 53 (standard DNS port)
2. Wildcard domain "*" configured to match all queries
3. All lookups return 192.168.4.1 (ESP32 AP IP)
4. Client devices detect captive portal and display popup

6.2 OS-Specific Detection URLs

Different operating systems use specific URLs to detect captive portals:

OS	Detection URL	Expected Response
Android	`connectivitycheck.gstatic.com/generate_204`	HTTP 204 No Content
iOS/macOS	`captive.apple.com/hotspot-detect.html`	HTML with "Success"
Windows	`msftconnecttest.com/ncsi.txt`	Text "Microsoft NCSI"
Generic	`detectportal.firefox.com/success.txt`	Text "success"

6.3 Redirect Logic

```cpp
void handleNotFound() {
  String host = server.hostHeader();

  if (host.startsWith("connectivitycheck.") ||
      host.startsWith("captive.apple.com") ||
      host.startsWith("msftconnecttest.") ||
      host.startsWith("detectportal.")) {
    // Redirect to dashboard
    server.sendHeader("Location", "http://192.168.4.1/");
    server.send(302, "text/plain", "");
```

```
  } else {
    // Serve dashboard for unknown paths
    handleRoot();
  }
}
```

Behavior:

- Detection URLs: HTTP 302 redirect to dashboard
- Unknown paths: Directly serve dashboard HTML
- Ensures captive portal popup on all platforms

7 Security Considerations

7.1 Current Implementation

Vulnerabilities present in v2.3.0:

1. **No authentication**: Web interface open to anyone connected to AP
2. **Plaintext passwords**: Email and WiFi credentials stored unencrypted in SPIFFS
3. **No HTTPS**: HTTP-only communication (credentials sent in clear)
4. **Open CORS**: `Access-Control-Allow-Origin: *` permits requests from any domain
5. **No rate limiting**: API endpoints vulnerable to brute force
6. **No input sanitization**: Potential for command injection in SMS/call phone numbers

7.2 Recommended Mitigations

Production deployment checklist:

1. **Enable flash encryption**: Protect SPIFFS data at rest
2. **Implement HTTPS**: Use self-signed certificates for TLS
3. **Add authentication**: HTTP Basic Auth or session tokens
4. **Restrict CORS**: Whitelist specific origins or disable
5. **Input validation**: Sanitize phone numbers, email addresses, SSID strings
6. **Rate limiting**: Throttle API requests per IP address
7. **Change default credentials**: Require AP password change on first boot
8. **Firmware signing**: Prevent unauthorized code uploads

Attack Vector	Severity	Mitigation

7.3 Attack Surface Analysis

Attack Vector	Severity	Mitigation
WiFi credential theft	Critical	Flash encryption, HTTPS
Email password exposure	Critical	Flash encryption, HTTPS, app passwords
Unauthorized configuration	High	Authentication, session management
SMS/call spam	Medium	Rate limiting, input validation
DNS spoofing	Low	Inherent to captive portal design
XSS in dashboard	Medium	Content-Security-Policy headers
CSRF attacks	Medium	CSRF tokens, SameSite cookies

8 Memory and Performance Analysis

8.1 Flash Memory Usage

Component	Size	Notes
Program code	450 KB	Compiled firmware (.bin)
dashboard_html.h	250 KB	Main dashboard (gzipped in some builds)
config_html.h	180 KB	Email configuration dashboard
SPIFFS partition	1.5 MB	Configuration files, future data logging
OTA partition	1.5 MB	For over-the-air firmware updates
Total flash required	**4 MB**	Standard ESP32 has 4–16 MB

8.2 RAM Usage

Component	Heap	Notes
WiFi stack	35 KB	ESP-IDF WiFi driver
HTTP server	15 KB	WebServer instance + buffers
DNS server	2 KB	Minimal overhead
JSON documents	8 KB	Peak during large responses
String buffers	5 KB	Scan results, status JSON
GSM serial buffers	2 KB	AT command I/O
Typical free heap	**240 KB**	Out of 320 KB total DRAM

Memory optimization strategies:

- `server.send_P()`: Streams HTML from flash (PROGMEM) without RAM copy
- JSON document sizing: Exact allocations prevent heap fragmentation
- `WiFi.scanDelete()`: Frees scan result memory immediately
- Static cache strings: Reuse `lastScanJson` buffer
- Const string literals: Stored in flash, not duplicated in RAM

8.3 Performance Benchmarks

Operation	Duration	Notes
Boot to HTTP ready	2–3 seconds	Includes WiFi AP start, SPIFFS mount
WiFi scan	3–5 seconds	Async, doesn't block HTTP
GSM signal query	500–1500 ms	Hardware AT command latency
SPIFFS config load	10–30 ms	Per file, cached in RAM
JSON serialization (2KB)	5–15 ms	Status endpoint response
HTTP request handling	5–50 ms	Varies by endpoint complexity
Email via GSM	10–30 seconds	GPRS connection + SMTP handshake
SMS send	2–5 seconds	Modem processing time
Voice call initiation	3–8 seconds	Network routing delay

8.4 Network Throughput

HTTP server capacity:

- **Concurrent connections**: 4–5 max (synchronous server limitation)
- **Request rate**: 20 requests/second sustained
- **Dashboard load time**: 1–3 seconds (depends on client bandwidth)
- **API response time**: 10–100 ms average (excluding GSM queries)

WiFi performance:

- **AP mode range**: 30–100 meters (depends on environment)
- **STA mode throughput**: 5–10 Mbps typical
- **Dual-mode penalty**: 10% throughput reduction vs single mode

9 Troubleshooting Guide

9.1 Common Issues and Solutions

9.1.1 Issue: Cannot access configuration portal

Symptoms:

- No WiFi network visible
- "Config panel" SSID not appearing
- Captive portal not opening automatically

Diagnosis steps:

1. Check serial console for AP startup messages
2. Verify AP SSID/password in `/wifi.json`
3. Confirm ESP32 not stuck in boot loop (check for panic messages)
4. Test manual connection to 192.168.4.1 instead of relying on captive portal

Solutions:

- Erase flash and reprogram: `esptool.py erase_flash`
- Check power supply (USB must provide 500+ mA)
- Verify GPIO pins not shorted (especially GPIO16/17 for GSM)
- Delete `/wifi.json` to restore default AP credentials

9.1.2 Issue: Double reset detection not working

Symptoms:

- Always boots to main dashboard despite double-reset
- DRD timeout too short/long
- Mode stuck in one configuration

Diagnosis:

1. Check serial output for "DOUBLE RESET DETECTED!" message
2. Verify NVS partition not corrupted
3. Confirm reset button timing (must be < 3 seconds between presses)

Solutions:

- Increase `DRD_TIMEOUT` to 5000 ms (5 seconds)
- Erase NVS partition: `esptool.py erase_region 0x9000 0x5000`
- Use hardware reset button, not power cycling
- Ensure `drd.loop()` called in main loop

9.1.3 Issue: GSM modem not responding

Symptoms:

- Signal strength always 0 or -999
- SMS/call operations timeout
- "GSM: Not initialized" in status logs

Diagnosis:

1. Check Serial2 wiring (RX=GPIO16, TX=GPIO17)
2. Verify modem power supply (some modules require 2A @ 5V)
3. Test AT commands manually via serial monitor
4. Confirm SIM card inserted and PIN disabled

Solutions:

- Swap RX/TX connections (common wiring mistake)
- Add external power supply for modem (don't rely on ESP32 regulator)
- Increase serial timeout in `GSM_Test.cpp`
- Check APN configuration matches carrier requirements
- Verify antenna connected properly

9.1.4 Issue: WiFi connection fails

Symptoms:

- `/api/wifi/connect` returns "Connection failed"
- Station mode shows "Not connected" despite correct credentials
- Connection timeout after 20 seconds

Diagnosis:

1. Check router SSID visibility (hidden networks require special handling)
2. Verify password correctness (case-sensitive)
3. Confirm router not using unsupported security (WEP, WPA3-only)
4. Check MAC address filtering on router

Solutions:

- Use 2.4 GHz network (ESP32 doesn't support 5 GHz)
- Temporarily disable router security for testing
- Increase connection timeout in `handleWiFiConnect()`
- Check signal strength (RSSI must be > -80 dBm)
- Clear saved WiFi config: delete `/wifi.json` and restart

9.1.5 Issue: Email sending via GSM fails

Symptoms:

- "Failed to send GSM email" error
- SMTP authentication rejection
- Timeout during email transmission

Diagnosis:

1. Verify email configuration via `/api/load/email`
2. Check GPRS data connection (APN must be correct)
3. Confirm Gmail app password, not regular password
4. Test SMTP server accessibility from mobile network

Solutions:

- For Gmail: Generate app password at https://myaccount.google.com/apppasswords
- Enable "Less secure app access" for non-Gmail servers
- Verify APN settings match carrier documentation
- Check firewall rules on SMTP server (allow port 465)
- Increase SMTP timeout in `SMTP.cpp`
- Test with alternative SMTP server (e.g., Mailgun, SendGrid)

9.1.6 Issue: SPIFFS mount failure

Symptoms:

- "SPIFFS mount failed" on boot
- Configuration not persisting across reboots
- Crash during config save operations

Diagnosis:

1. Check partition table in `platformio.ini`
2. Verify SPIFFS partition size and offset
3. Look for flash corruption errors in serial output

Solutions:

- Format SPIFFS: `SPIFFS.format()` in setup (one-time)
- Upload SPIFFS image with data: `pio run -t uploadfs`
- Increase partition size in `partitions.csv`
- Check for flash memory hardware failure (rare)

9.2 Serial Debug Commands

Enable verbose WiFi debugging:

```
// Add to setup()
Serial.setDebugOutput(true);
WiFi.setOutputPower(20);  // Max TX power for debugging
```

Manual SPIFFS inspection:

```
// Temporary debug code in setup()
File root = SPIFFS.open("/");
File file = root.openNextFile();
while (file) {
  Serial.printf("File: %s, Size: %d\n", file.name(), file.size());
  file = root.openNextFile();
}
```

GSM modem raw AT commands:

```
// Send directly via Serial2
Serial2.println("AT");          // Test connectivity
Serial2.println("AT+CSQ");      // Check signal quality
Serial2.println("AT+COPS?");    // Query operator
Serial2.println("AT+CREG?");    // Registration status
```

10 Extension and Customization

10.1 Adding New Sensors

Example: Integrate DHT22 temperature/humidity sensor **Step 1: Include library**

```
#include <DHT.h>
#define DHT_PIN 4
#define DHT_TYPE DHT22
DHT dht(DHT_PIN, DHT_TYPE);
```

Step 2: Initialize in setup()

```
dht.begin();
Serial.println(" DHT22 sensor initialized");
```

Step 3: Replace simulated data in SensorData::update()

```
void update() {
  if (millis() - lastUpdate > UPDATE_INTERVAL) {
    temperature = dht.readTemperature();  // Real data
    humidity = dht.readHumidity();        // Real data

    if (isnan(temperature) || isnan(humidity)) {
      Serial.println(" DHT read failed");
      return;
    }

    lastUpdate = millis();
  }
}
```

10.2 Implementing User Authentication

Basic HTTP authentication example: **Step 1: Add credentials to configuration**

```
struct AuthConfig {
  String username = "admin";
  String password = "esp32";
  // Load/save methods similar to other configs
} authCfg;
```

Step 2: Create authentication middleware

```
bool checkAuth() {
  if (!server.authenticate(authCfg.username.c_str(),
                           authCfg.password.c_str())) {
    server.requestAuthentication();
    return false;
  }
  return true;
}
```

Step 3: Protect endpoints

```
server.on("/api/wifi/connect", HTTP_POST, []() {
  if (!checkAuth()) return;
  // Original handler code...
});
```

10.3 Adding HTTPS Support

Requires ESP32 HTTPS server library: Step 1: Generate self-signed certificate

```
openssl req -x509 -newkey rsa:2048 -keyout key.pem \
  -out cert.pem -days 365 -nodes
```

Step 2: Convert to C header

```
xxd -i cert.pem > cert.h
xxd -i key.pem > key.h
```

Step 3: Replace WebServer with HTTPSServer

```
#include <HTTPSServer.hpp>
#include <SSLCert.hpp>
#include "cert.h"
#include "key.h"

SSLCert cert = SSLCert(cert_pem, cert_pem_len,
                       key_pem, key_pem_len);
HTTPSServer server = HTTPSServer(&cert);
```

10.4 Data Logging to SD Card

Log sensor data and events to SD card: Step 1: Add SD library

```
#include <SD.h>
#define SD_CS 5  // Chip select pin
```

Step 2: Initialize in setup()

```
if (!SD.begin(SD_CS)) {
  Serial.println(" SD card mount failed");
} else {
  Serial.println(" SD card ready");
}
```

Step 3: Create logging function

```
void logSensorData() {
  File logFile = SD.open("/sensors.csv", FILE_APPEND);
  if (logFile) {
    String logEntry = String(millis()) + "," +
                      String(sensorData.temperature) + "," +
                      String(sensorData.humidity) + "," +
                      String(sensorData.light) + "\n";
    logFile.print(logEntry);
    logFile.close();
  }
}
```

Step 4: Call periodically in loop()

```
static unsigned long lastLog = 0;
if (millis() - lastLog > 60000) {  // Log every minute
  logSensorData();
  lastLog = millis();
}
```

10.5 MQTT Integration

Publish sensor data to MQTT broker: Step 1: Add PubSubClient library

```
#include <PubSubClient.h>
WiFiClient espClient;
PubSubClient mqtt(espClient);
```

Step 2: Configure broker

```
mqtt.setServer("broker.hivemq.com", 1883);
// Or use local broker: mqtt.setServer("192.168.1.10", 1883);
```

Step 3: Connect and publish

```
void publishSensorData() {
  if (!mqtt.connected()) {
    mqtt.connect("ESP32Client");
  }

  if (mqtt.connected()) {
    String payload = sensorData.toJson();
    mqtt.publish("esp32/sensors", payload.c_str());
  }
}
```

Step 4: Add MQTT endpoint

```
server.on("/api/mqtt/publish", HTTP_POST, []() {
  publishSensorData();
  sendJson(200, "{\"success\":true}");
});
```

10.6 OTA (Over-The-Air) Updates

Enable firmware updates via WiFi: Step 1: Include OTA library

```
#include <ArduinoOTA.h>
```

Step 2: Configure in setup()

```
ArduinoOTA.setHostname("esp32-config-panel");
ArduinoOTA.setPassword("admin");  // OTA password

ArduinoOTA.onStart([]() {
  Serial.println(" OTA update started");
});

ArduinoOTA.onEnd([]() {
  Serial.println("\n OTA update complete");
});

ArduinoOTA.onProgress([](unsigned int progress, unsigned int total) {
  Serial.printf("Progress: %u%%\r", (progress / (total / 100)));
});

ArduinoOTA.onError([](ota_error_t error) {
  Serial.printf(" OTA Error[%u]: ", error);
});

ArduinoOTA.begin();
```

Step 3: Handle in loop()

```
void loop() {
  ArduinoOTA.handle();
  // Rest of loop code...
}
```

Step 4: Upload via network

```
# PlatformIO
pio run -t upload --upload-port esp32-config-panel.local

# Arduino IDE
# Tools > Port > Network Ports > esp32-config-panel
```

11 Conclusion

This document has provided comprehensive line-by-line documentation for the ESP32 IIoT Configuration Panel firmware (v2.3.0). The system implements a sophisticated dual-dashboard architecture with the following key achievements:

11.1 Future Development Roadmap

Potential enhancements for future versions:

- **v2.4.0**: User authentication, HTTPS support
- **v2.5.0**: MQTT integration, webhooks for alerts
- **v3.0.0**: Multi-device management, cloud dashboard
- **v3.1.0**: Custom automation rules, scheduling
- **v3.2.0**: OTA configuration.

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