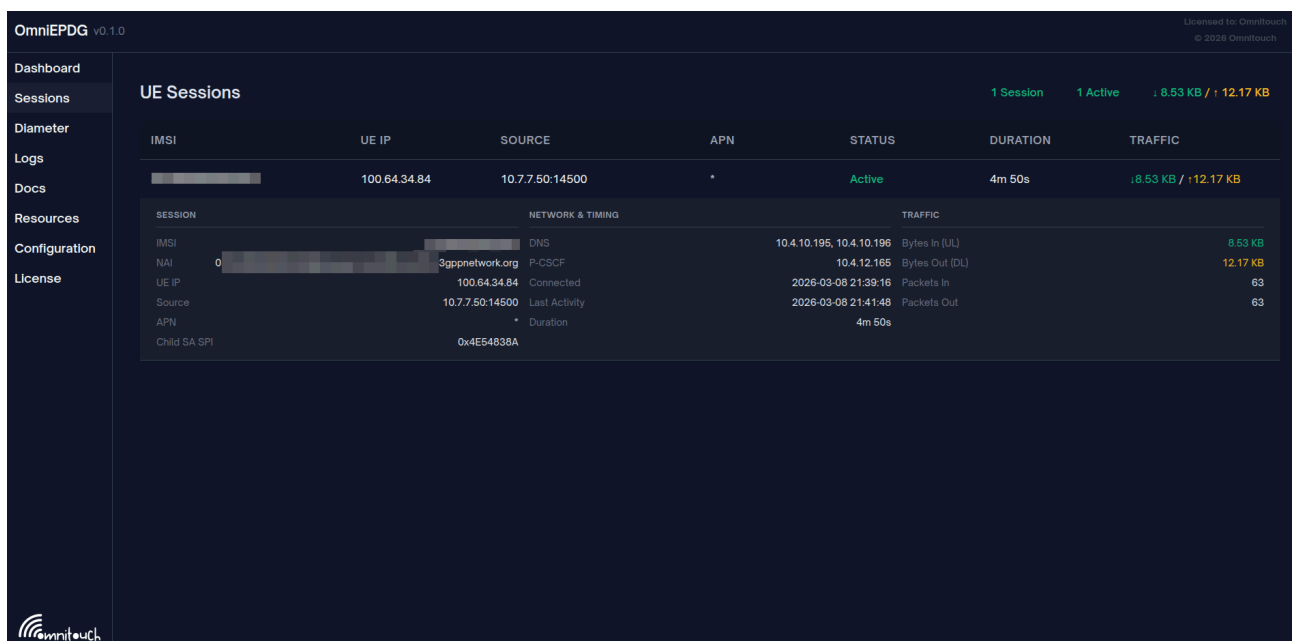


# OmniEPDG Operations Guide

OmniEPDG is an evolved Packet Data Gateway (ePDG) that enables Voice over WiFi (VoWiFi) calling. It authenticates mobile subscribers over untrusted WiFi networks using EAP-AKA, and connects them to the mobile core network through Diameter signaling to the HSS and GTP tunnels to a Packet Gateway (PGW).



The screenshot displays the OmniEPDG v0.1.0 control panel. The main section is titled "UE Sessions" and shows a summary of 1 session, 1 active, with 8.53 KB of traffic. Below this is a table of active sessions with columns for IMSI, UE IP, SOURCE, APN, STATUS, DURATION, and TRAFFIC. A detailed view of the session is shown below, including session details, network timing, and traffic statistics.

| IMSI       | UE IP        | SOURCE          | APN | STATUS | DURATION | TRAFFIC            |
|------------|--------------|-----------------|-----|--------|----------|--------------------|
| [REDACTED] | 100.64.34.84 | 10.7.7.50:14500 | *   | Active | 4m 50s   | 8.53 KB / 12.17 KB |

| SESSION      |                 | NETWORK & TIMING |                          | TRAFFIC               |                         |
|--------------|-----------------|------------------|--------------------------|-----------------------|-------------------------|
| IMSI         | [REDACTED]      | DNS              | 10.4.10.195, 10.4.10.196 | Bytes In (UL) 8.53 KB |                         |
| NAI          | 0 [REDACTED]    | 3gppnetwork.org  | P-CSCF                   | 10.4.12.165           | Bytes Out (DL) 12.17 KB |
| UE IP        | 100.64.34.84    | Connected        |                          |                       | Packets In 63           |
| Source       | 10.7.7.50:14500 | Last Activity    |                          |                       | Packets Out 63          |
| APN          | *               | Duration         |                          |                       |                         |
| Child SA SPI | 0x4E54838A      |                  |                          |                       |                         |

*The OmniEPDG control panel showing an active subscriber session with real-time traffic statistics.*

OmniEPDG supports two operational modes:

- **GTP Mode** (default) - Full 3GPP-compliant tunneling through a PGW via GTPv2-C and GTP-U
- **Simple VPN Mode** - Local breakout with a built-in IP pool and Linux TUN interface, no PGW required

# Documentation

## Configuration & Operations

- **Architecture & Call Flows** - System architecture, protocol interfaces, UE state machines, and message sequence diagrams for both modes
- **Configuration Reference** - Complete parameter documentation for Diameter, GTPv2-C, GTP-U, Simple VPN, and logging
- **Control Panel** - Web-based monitoring UI for sessions, Diameter peers, and logs

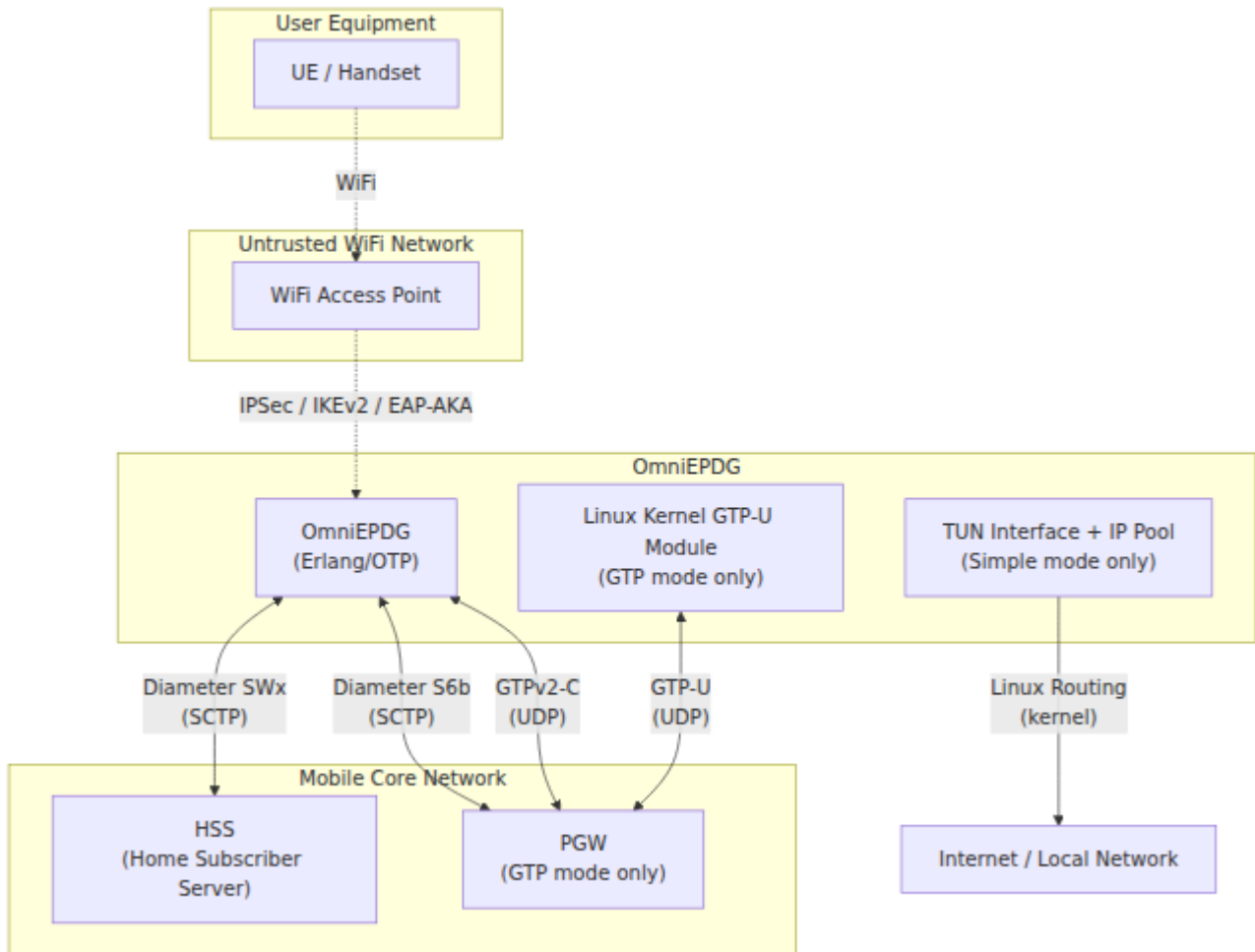
## Security

- **Security Guide** - Authentication rate limiting and GeoIP country blocking

## Monitoring & Troubleshooting

- **Metrics Reference** - Prometheus metrics for monitoring authentication, sessions, Diameter signaling, and system health
- **Troubleshooting** - Common issues, diagnostic procedures, and resolution steps

# Operational Modes



## GTP Mode

The default mode. OmniEPDG tunnels all subscriber traffic through a PGW using GTPv2-C for session control and GTP-U (via Linux kernel module) for the user plane. This is fully 3GPP compliant and suitable for carrier deployments with existing EPC infrastructure.

**Traffic path:** UE → IPsec → OmniEPDG → GTPv2-C Create Session → GTP-U tunnel → PGW → Internet

**Required infrastructure:** HSS, PGW

## Simple VPN Mode

OmniEPDG allocates IP addresses from a local pool and routes subscriber traffic directly through a Linux TUN interface (`tun_epdg`) using standard kernel routing. No PGW or GTP infrastructure is needed. Authentication still happens via Diameter SWx to the HSS.

**Traffic path:** UE → IPsec → OmniEPDG → Local IP allocation → TUN interface → Linux routing → Internet

**Required infrastructure:** HSS only (PGW not needed)

**Optional optimization:** The `skip_sar` flag bypasses HSS Server-Assignment-Request/Answer, reducing connection setup time. This means the HSS will not track which ePDG serves the subscriber and HSS-initiated procedures (deregistration, profile push) will not function. Suitable for private deployments without roaming requirements.

# Mode Comparison

| Capability             | GTP Mode            | Simple VPN Mode                                     |
|------------------------|---------------------|---|
| 3GPP compliant         | Yes                 | No (with <code>skip_sar</code> ), Partial (without) |
| PGW required           | Yes                 | No  |
| HSS required           | Yes                 | Yes (authentication only)                           |
| IP allocation          | From PGW            | Local pool (CIDR)                                   |
| User plane             | GTP-U kernel module | Linux TUN + routing                                 |
| HSS profile push       | Yes (PPR/PPA)       | No  |
| HSS deregistration     | Yes (RTR/RTA)       | No (with <code>skip_sar</code> )                    |
| PGW-initiated teardown | Yes                 | N/A   |
| Roaming support        | Yes                 | No  |
| IPv6 / Dual-stack      | Yes                 | IPv4 only   |

# Protocol Interfaces

| Interface | Protocol        | Transport | Mode     | Peer | Purpose                                      | Ref             |
|-----------|-----------------|-----------|----------|------|--|-----------------|
| SWu       | IKEv2 / IPsec   | UDP       | Both     | UE   | Secure tunnel and EAP-AKA authentication     | 3GPP 33.4       |
| SWx       | Diameter        | SCTP      | Both     | HSS  | Authentication vectors and server assignment | 3GPP 29.270 Sec |
| S6b       | Diameter        | SCTP      | GTP only | PGW  | Session authorization and policy             | 3GPP 29.270 Sec |
| S2b       | GTPv2-C / GTP-U | UDP       | GTP only | PGW  | Control and user plane tunnel                | 3GPP 29.270     |

## Features

### Core Functionality

- **EAP-AKA Authentication** - Full 3GPP EAP-AKA subscriber authentication via HSS
- **IPsec Tunnel Management** - IKEv2-based secure tunnel between UE and ePDG
- **Dual Operational Modes** - GTP tunneling to PGW or local breakout with Simple VPN
- **Per-UE State Machines** - Independent Erlang FSM per subscriber for session lifecycle management

- **Dual-Stack Support** - IPv4, IPv6, and IPv4v6 PDP address types (GTP mode)

## GTP Mode Features

- **GTP Tunnel Establishment** - GTPv2-C session creation and GTP-U user plane via Linux kernel module
- **PGW-Initiated Teardown** - PGW sends Delete Bearer Request, ePDG cascades teardown to UE
- **Network-Initiated Teardown** - HSS triggers deregistration via SWx RTR, ePDG tears down all sessions
- **Re-Authentication** - HSS-triggered profile push and re-authorization per [3GPP TS 29.273 Section 7.1.2.5.1](#)

## Simple VPN Mode Features

- **Local IP Pool** - CIDR-based IPv4 address allocation with per-IMSI tracking
- **TUN Interface Routing** - Standard Linux TUN device (`tun_epdg`) with per-UE host routes
- **DNS Configuration** - Configurable DNS servers provided to UEs via PCO
- **Optional SAR Skip** - Bypass HSS registration for faster connection setup

## Security Features

- **Authentication Rate Limiting** - Per-IP and per-IMSI brute-force protection with configurable thresholds
- **GeoIP Country Blocking** - Whitelist or blacklist based country access control using MaxMind GeoLite2
- **Dead Peer Detection** - Active liveness monitoring with configurable probes
- **ESP Anti-Replay Protection** - RFC 4303 compliant 64-bit sliding window

## HSS Integration (SWx Diameter)

- **Multimedia-Auth-Request/Answer (MAR/MAA)** - Retrieve EAP-AKA authentication vectors (both modes)

- **Server-Assignment-Request/Answer (SAR/SAA)** - Download subscriber profile and APN configuration (skippable in Simple mode)
- **Push-Profile-Request/Answer (PPR/PPA)** - Receive updated subscriber profiles from HSS (GTP mode)
- **Registration-Termination-Request/Answer (RTR/RTA)** - HSS-initiated subscriber deregistration (GTP mode)

## **PGW Integration (GTP Mode Only)**

### **S6b Diameter:**

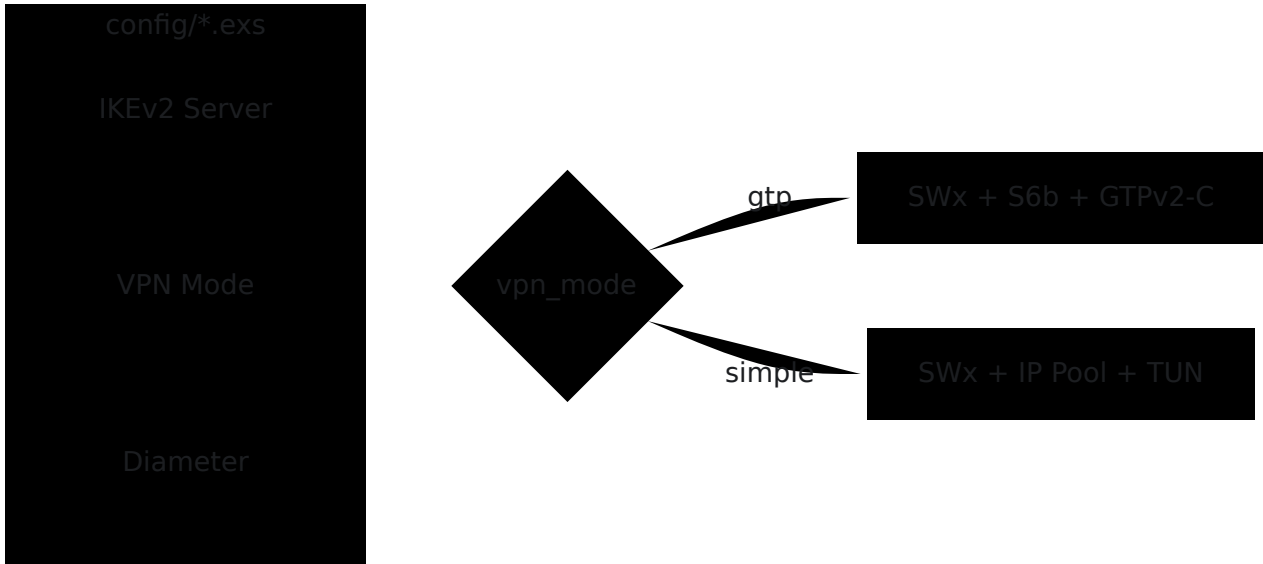
- **AA-Request/Answer (AAR/AAA)** - Authorize PGW sessions
- **Session-Termination-Request/Answer (STR/STA)** - Terminate PGW sessions
- **Re-Auth-Request/Answer (RAR/RAA)** - Re-authorize active sessions
- **Abort-Session-Request/Answer (ASR/ASA)** - Forcefully terminate sessions

### **S2b GTPv2-C:**

- **Create Session Request/Response** - Establish GTP tunnels with TEID allocation
- **Delete Session Request/Response** - Tear down GTP tunnels
- **Delete Bearer Request/Response** - PGW-initiated bearer management

# Quick Start

## Configuration Structure



Configuration is done in `config/runtime.exs` or via environment variables. The `vpn_mode` parameter selects between GTP and Simple VPN modes. See the [Configuration Reference](#) for complete parameter documentation.

## Typical Network Addressing (GTP Mode)

| Component               | IP Address | Port | Notes                 |
|-------------------------|------------|------|-----------------------|
| OmniEPDG (GTP-U)        | 10.74.0.11 | -    | GTP-U tunnel endpoint |
| OmniEPDG (Diameter S6b) | 10.74.0.12 | 3868 | S6b Diameter listener |
| HSS                     | 10.74.0.21 | 3868 | SWx Diameter peer     |
| PGW                     | 10.74.0.23 | 2123 | GTPv2-C and S6b peer  |

## Typical Network Addressing (Simple VPN Mode)

| Component              | IP Address      | Notes   |
|------------------------|-----------------|---|
| OmniEPDG (TUN gateway) | 10.44.0.1       | Gateway IP on the <code>tun_epdg</code> interface |
| UE IP pool             | 10.45.0.0/16    | Configurable CIDR pool for subscriber IPs         |
| HSS                    | 10.74.0.21:3868 | SWx Diameter peer (authentication only)           |

# 3GPP Specifications

| Specification             | Title   | Relevance  |
|---------------------------|---|--|
| <a href="#">TS 29.273</a> | EPS AAA interfaces (SWx, S6b, SWm)              | Primary specification for ePDG Diameter interfaces |
| <a href="#">TS 29.274</a> | GTPv2-C and GTP-U                               | S2b tunnel control and user plane (GTP mode)       |
| <a href="#">TS 33.402</a> | Security for non-3GPP accesses                  | EAP-AKA authentication for untrusted WiFi          |
| <a href="#">TS 23.402</a> | Architecture enhancements for non-3GPP accesses | Overall ePDG architecture and procedures           |
| <a href="#">TS 23.003</a> | Numbering, addressing and identification        | NAI format, IMSI structure                         |
| <a href="#">TS 29.229</a> | Cx/Dx Diameter (common definitions)             | Server-Assignment-Type values used by SWx          |
| <a href="#">RFC 6733</a>  | Diameter Base Protocol                          | Diameter transport, peer management, watchdog      |
| <a href="#">RFC 4187</a>  | EAP-AKA   | Authentication method used over IKEv2              |

## Documentation By Role

### Network Operators:

1. Start with the [Architecture & Call Flows](#) to understand the system and both operational modes
2. Review the [Configuration Reference](#) for deployment parameters

3. Review the [Security Guide](#) to configure rate limiting and GeoIP blocking
4. Set up monitoring using the [Metrics Reference](#) for Prometheus integration
5. Keep the [Troubleshooting](#) guide available for operations

### **System Integrators:**

1. Review the [Architecture & Call Flows](#) for interface details and state machines
2. Use the [Configuration Reference](#) for peer connectivity setup
3. Configure alerting using the [Metrics Reference](#)
4. Reference the 3GPP specifications table above for protocol compliance

# OmniEPDG Operations Guide

OmniEPDG is a 3GPP-compliant ePDG (evolved Packet Data Gateway) that enables WiFi calling by bridging untrusted WiFi access to the mobile core network. It supports two operational modes: **GTP mode** for PGW tunneling and **Simple VPN mode** for local IP breakout.

## Quick Links

### Configuration & Deployment

- **Network Requirements** - Firewall ports and DNS entries required for deployment
- **Configuration Reference** - Complete parameter documentation for IKEv2, Diameter, VPN modes, and all runtime settings
- **Architecture Overview** - System architecture, call flows, state machines, and protocol references

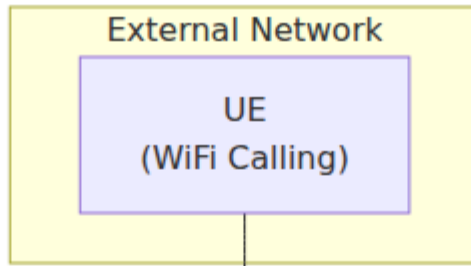
### Operations & Monitoring

- **Control Panel** - Web-based monitoring interface for sessions, Diameter peers, and logs
- **Metrics Reference** - Prometheus metrics, example queries, and alerting rules
- **Troubleshooting** - Common issues, diagnostic procedures, and resolution steps

### Security

- **Authentication Security** - Rate limiting and GeoIP country blocking

# Architecture Overview



IKEv2

OmniCore  
5GC

OmniCall

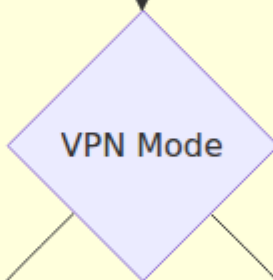
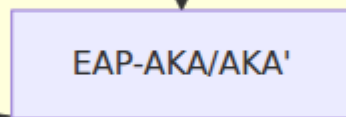
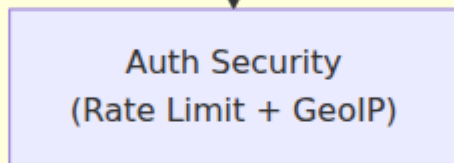
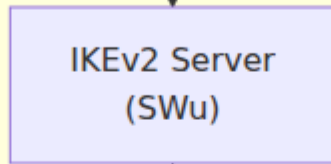
OmniRAN

OmniCharge

Platform

Engl

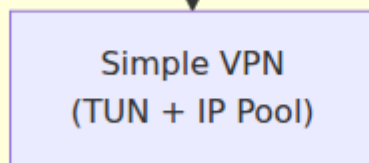
OmniEPDG



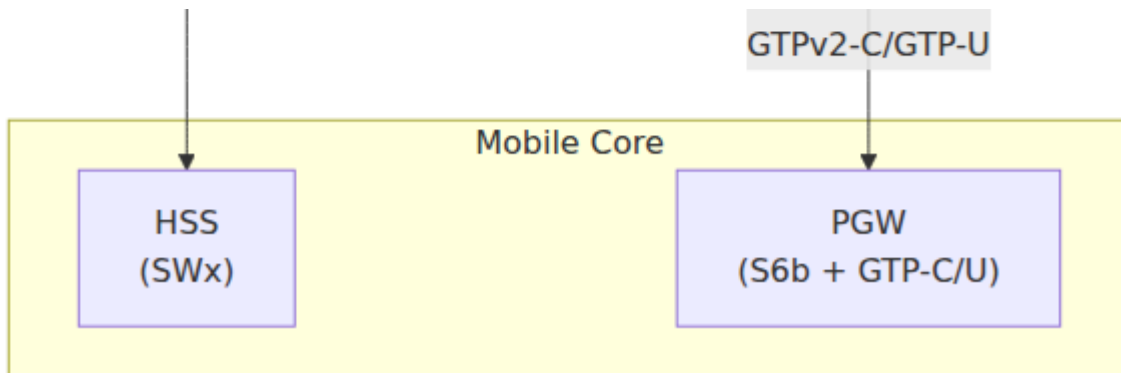
Diameter SWx

Simple Mode

GTP Mode



Diameter S6b



## Operational Modes

OmniEPDG supports two operational modes selected via the `vpn_mode` configuration parameter.

### GTP Mode

Full 3GPP tunneling through a PGW. Subscriber traffic is encapsulated in GTP-U and routed through the mobile core.

#### Use when:

- Integration with existing mobile core infrastructure
- Policy and charging through PCRF/PCEF
- Roaming and inter-operator handoff required

#### Components:

- Diameter S6b for PGW session authorization
- GTPv2-C for session management (Create/Delete/Modify Session)
- Linux kernel GTP-U module for user plane

### Simple VPN Mode

Local IP breakout via TUN interface. Subscriber traffic is routed directly through the OmniEPDG host without PGW involvement.

#### Use when:

- Standalone deployment without PGW

- Testing and development
- Local breakout scenarios

### Components:

- Local IP pool management (IPv4/IPv6)
- TUN interface (`omniepdg0`) with per-subscriber host routes
- Optional NAT/masquerade for internet access

## Authentication Security

OmniEPDG includes built-in security features to protect against brute-force attacks and restrict access by geographic location. See the [Authentication Security](#) guide for details.

### Rate Limiting

Protects against brute-force attacks by tracking failed authentication attempts:

- **Per-IP limiting** - Blocks IPs after 10 failures in 1 minute (5 minute block)
- **Per-IMSI limiting** - Blocks IMSIs after 5 failures in 1 minute (10 minute block)
- Sliding window algorithm with automatic expiration
- Successful authentication clears failure history

### GeoIP Country Blocking

Optional geographic access control using MaxMind GeoLite2 database:

- **Whitelist mode** - Only allow connections from specified countries
- **Blacklist mode** - Block connections from specified countries
- Configurable handling of unknown/private IPs
- Fail-open or fail-closed behavior when database unavailable

# Key Configuration

## Minimal Configuration (Simple VPN Mode)

```
config :omniepdg,  
  vpn_mode: :simple,  
  simple_vpn: [  
    pool_ipv4: "10.45.0.0/16",  
    dns_servers_ipv4: ["8.8.8.8", "8.8.4.4"]  
  ]  
  
config :diameter_ex,  
  diameter: %{  
    host: "epdg",  
    realm: "epc.mnc001.mcc001.3gppnetwork.org",  
    peers: [  
      %{host: "hss", ip: "10.74.0.21", port: 3868, transport:  
:tcp}  
    ]  
  }  
}
```

## Enable Authentication Security

```
config :omniepdg,  
  # Rate limiting (enabled by default with these values)  
  auth_rate_limit_per_ip: 10,  
  auth_rate_limit_ip_block_ms: 300_000,  
  auth_rate_limit_per_imsi: 5,  
  auth_rate_limit_imsi_block_ms: 600_000,  
  
  # GeoIP blocking (disabled by default)  
  geoip_enabled: true,  
  geoip_mode: :whitelist,  
  geoip_countries: ["AU", "NZ"]
```

See the [Configuration Reference](#) for complete parameter documentation.

# Monitoring

## Control Panel

Access the web control panel at `http://<host>:4000/dashboard` for:

- Real-time session monitoring
- Diameter peer status
- Live log streaming
- System configuration

See the [Control Panel](#) guide for details.

## Prometheus Metrics

Scrape metrics from `http://<host>:9568/metrics` for:

- Authentication success/failure rates
- Session lifecycle events
- Diameter signaling latency
- Security events (rate limiting, GeoIP blocks)
- IP pool utilization
- ESP data plane statistics

See the [Metrics Reference](#) for queries and alerting rules.

# Troubleshooting

Common issues and resolution steps:

| Issue                         | Quick Check                        | Guide Section                           |
|-------------------------------|------------------------------------|---|
| Authentication failures       | Check SWx MAR/MAA in logs          | <a href="#">Authentication Failures</a> |
| Diameter connection issues    | Check peer status in control panel | <a href="#">Diameter Connectivity</a>   |
| GTP tunnel failures           | Check GTPv2-C cause codes          | <a href="#">GTP Tunnel Failures</a>     |
| Simple VPN issues             | Check TUN interface and routes     | <a href="#">Simple VPN Failures</a>     |
| Rate limiting false positives | Adjust thresholds                  | <a href="#">Rate Limiting Issues</a>    |
| GeoIP blocking issues         | Check database and country codes   | <a href="#">GeoIP Issues</a>            |

See the [Troubleshooting](#) guide for detailed diagnostic procedures.

# Documentation Index

| Document                             | Description  |
|--------------------------------------|--|
| <a href="#">Architecture</a>         | System design, state machines, call flows, protocol references |
| <a href="#">Configuration</a>        | Complete configuration reference with examples                 |
| <a href="#">Control Panel</a>        | Web interface guide with screenshots                           |
| <a href="#">Metrics</a>              | Prometheus metrics, queries, and alerting                      |
| <a href="#">Network Requirements</a> | Firewall ports and DNS entries for deployment                  |
| <a href="#">Security</a>             | Rate limiting and GeoIP country blocking                       |
| <a href="#">Troubleshooting</a>      | Common issues and diagnostic procedures                        |

# OmniEPDG Architecture & Call Flows

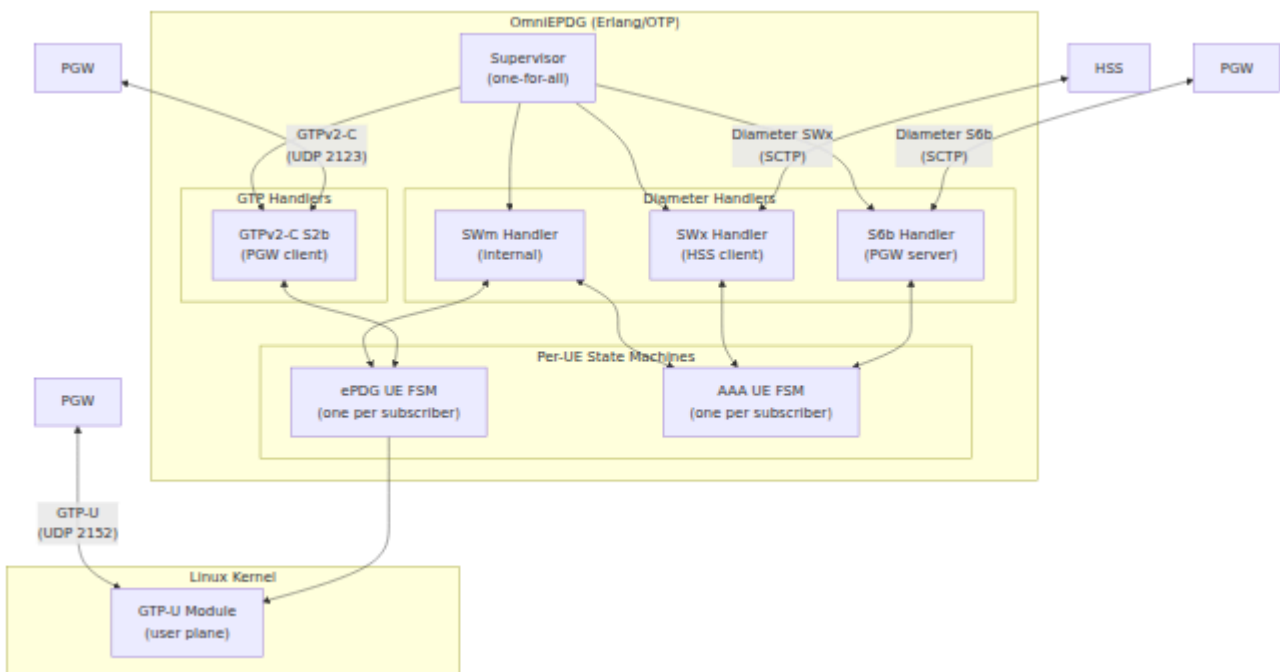
This document describes the internal architecture of OmniEPDG, its protocol interfaces, UE state machines, and detailed message sequence diagrams for key procedures. OmniEPDG supports two operational modes: **GTP mode** (full 3GPP tunneling via PGW) and **Simple VPN mode** (local breakout with TUN interface). See the [Operations Guide](#) for a high-level comparison.

## System Architecture

OmniEPDG is built on Erlang/OTP and implements the 3GPP ePDG (evolved Packet Data Gateway) network function. It bridges untrusted WiFi access to the mobile core network, allowing UEs to make and receive VoWiFi calls.

## GTP Mode Architecture

In GTP mode, subscriber traffic is tunneled through a PGW using GTPv2-C for session control and the Linux kernel GTP-U module for the user plane.



# Simple VPN Mode Architecture

In Simple VPN mode, subscriber traffic is routed locally through a Linux TUN interface. No PGW or GTP infrastructure is required. The Diameter S6b, GTPv2-C, and GTP-U components are replaced by the Simple VPN subsystem.



## Supervisor Tree

OmniEPDG uses a **one-for-all** supervisor strategy, meaning if any child process crashes, all children are restarted. The supervisor conditionally starts different child processes depending on the operational mode.

**Processes started in both modes:**

| Process           | Role                    | Description  |
|-------------------|-------------------------|--|
| aaa_diameter_swx  | Diameter SWx Client     | Connects to the HSS for authentication and subscriber profile operations |
| aaa_diameter_swm  | Diameter SWm (Internal) | Routes Diameter EAP and session messages between the ePDG and AAA FSMs   |
| epdg_diameter_swm | SWm ePDG Handler        | Handles the ePDG side of internal SWm Diameter signaling                 |

**GTP mode additional processes:**

| Process          | Role                 | Description  |
|------------------|----------------------|--|
| aaa_diameter_s6b | Diameter S6b Server  | Accepts connections from the PGW for session authorization |
| epdg_gtpc_s2b    | GTPv2-C Client       | Sends Create/Delete Session requests to the PGW over S2b   |
| gtp_u_kmod       | GTP-U Kernel Handler | Manages GTP-U PDP contexts in the Linux kernel module      |

**Simple VPN mode additional processes:**

| Process                            | Role                     | Description   |
|------------------------------------|--------------------------|---|
| <code>simple_vpn_supervisor</code> | VPN Subsystem Supervisor | Supervises the IP pool and route manager processes                                      |
| <code>simple_vpn_pool</code>       | IP Pool Manager          | Allocates and releases IPv4 addresses from the configured CIDR pool using ETS           |
| <code>simple_vpn_route</code>      | Route Manager            | Creates the <code>omniepdg0</code> TUN interface and manages per-subscriber host routes |

## Per-UE State Machines

For each active subscriber (identified by IMSI), OmniEPDG creates two state machine instances:

- **ePDG UE FSM** (`epdg_ue_fsm`) - Manages the subscriber's session lifecycle from the ePDG perspective: authentication, GTP tunnel creation, and teardown coordination
- **AAA UE FSM** (`aaa_ue_fsm`) - Manages the AAA-side signaling: Diameter SWx exchanges with the HSS and S6b exchanges with the PGW

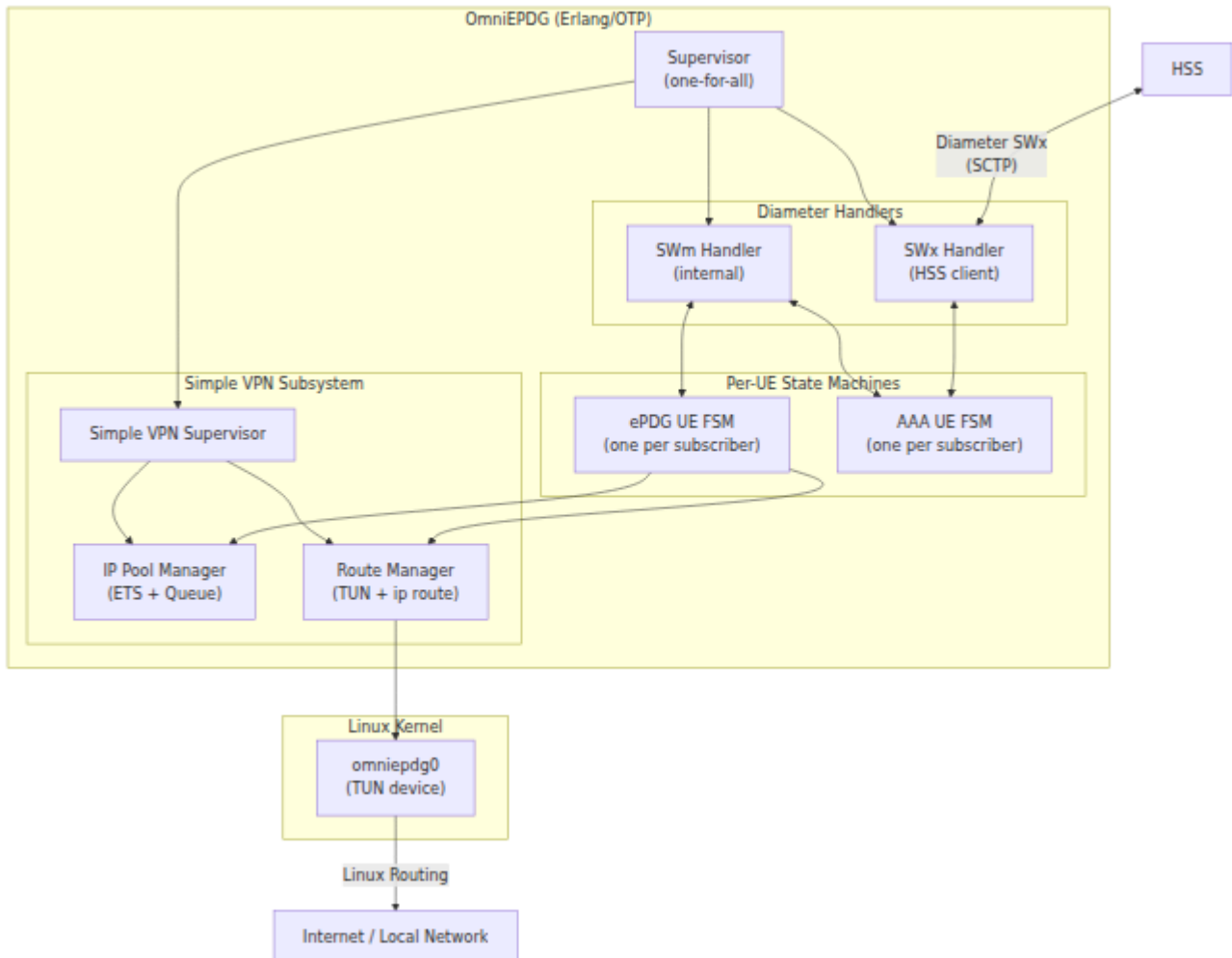
Both FSMs are implemented as Erlang `gen_statem` processes with state function callback mode.

## ePDG UE FSM States

The ePDG UE FSM tracks a subscriber's session from initial authentication request through active tunnel state to teardown. The FSM behavior diverges at the `authenticated` state based on the operational mode.

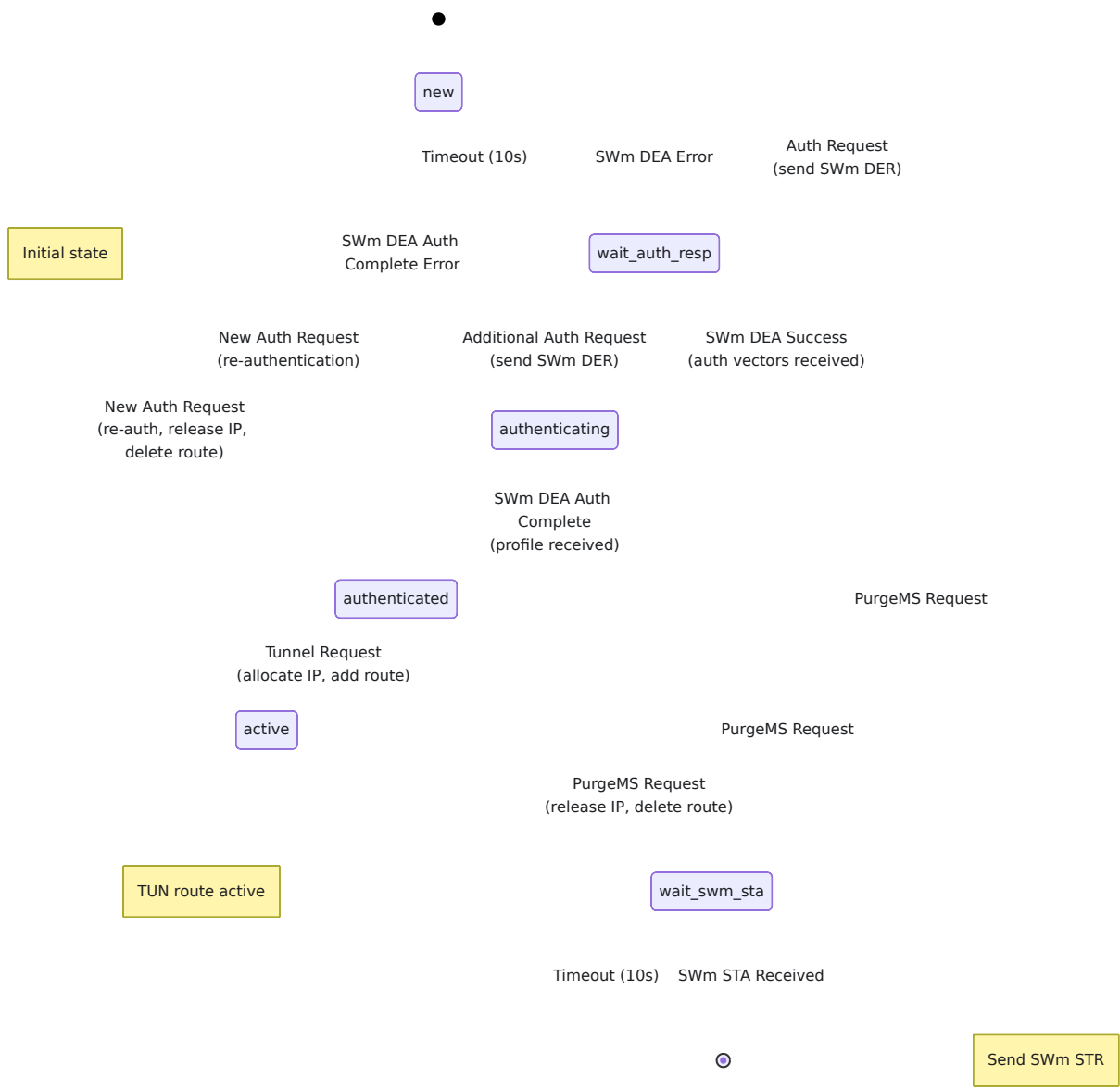
# GTP Mode FSM

In GTP mode, tunnel establishment goes through GTPv2-C Create Session to the PGW, and teardown involves GTPv2-C Delete Session, PGW-initiated Delete Bearer, and HSS-initiated deregistration flows.



# Simple VPN Mode FSM

In Simple VPN mode, the FSM takes a shortcut at the `authenticated` state. Instead of sending a GTPv2-C Create Session Request, the FSM allocates an IP address from the local pool, creates a host route on the TUN interface, and transitions directly to `active`. The GTP-specific teardown states (`wait_create_session_resp`, `wait_delete_session_resp`, `dereg_pgw_wait_cancel`, `dereg_net_wait_s2b_delete`) are not used.



## ePDG UE FSM State Reference

| State                    | Mode | Description   | Waiting For                        |
|--------------------------|------|---|------------------------------------|
| new                      | Both | Initial state. No active session.                                   | Auth request from UE               |
| wait_auth_resp           | Both | Authentication request sent via SWm DER.                            | SWm DEA with auth vectors or error |
| authenticating           | Both | Auth vectors received, EAP exchange in progress.                    | Location update / auth completion  |
| authenticated            | Both | Authentication complete, subscriber profile downloaded.             | Tunnel request from UE             |
| wait_create_session_resp | GTP  | GTPv2-C Create Session Request sent to PGW.                         | Create Session Response from PGW   |
| active                   | Both | Tunnel/route operational. Subscriber traffic is flowing.            | Teardown trigger                   |
| wait_delete_session_resp | GTP  | GTPv2-C Delete Session Request sent to PGW (UE-initiated teardown). | Delete Session Response from PGW   |

| State                     | Mode | Description   | Waiting For             |
|---------------------------|------|---|-------------------------|
| wait_swm_sta              | Both | SWm Session Termination Request sent.                             | SWm STA from AAA        |
| dereg_pgw_wait_cancel     | GTP  | PGW-initiated deregistration. Cancel Location sent to UE.         | Cancel Location Result  |
| dereg_net_wait_cancel     | GTP  | Network/HSS-initiated deregistration. Cancel Location sent to UE. | Cancel Location Result  |
| dereg_net_wait_s2b_delete | GTP  | Network-initiated deregistration. S2b Delete Session sent to PGW. | Delete Session Response |

## AAA UE FSM States

The AAA UE FSM manages the Diameter signaling toward the HSS (SWx) and PGW (S6b) on behalf of each subscriber.



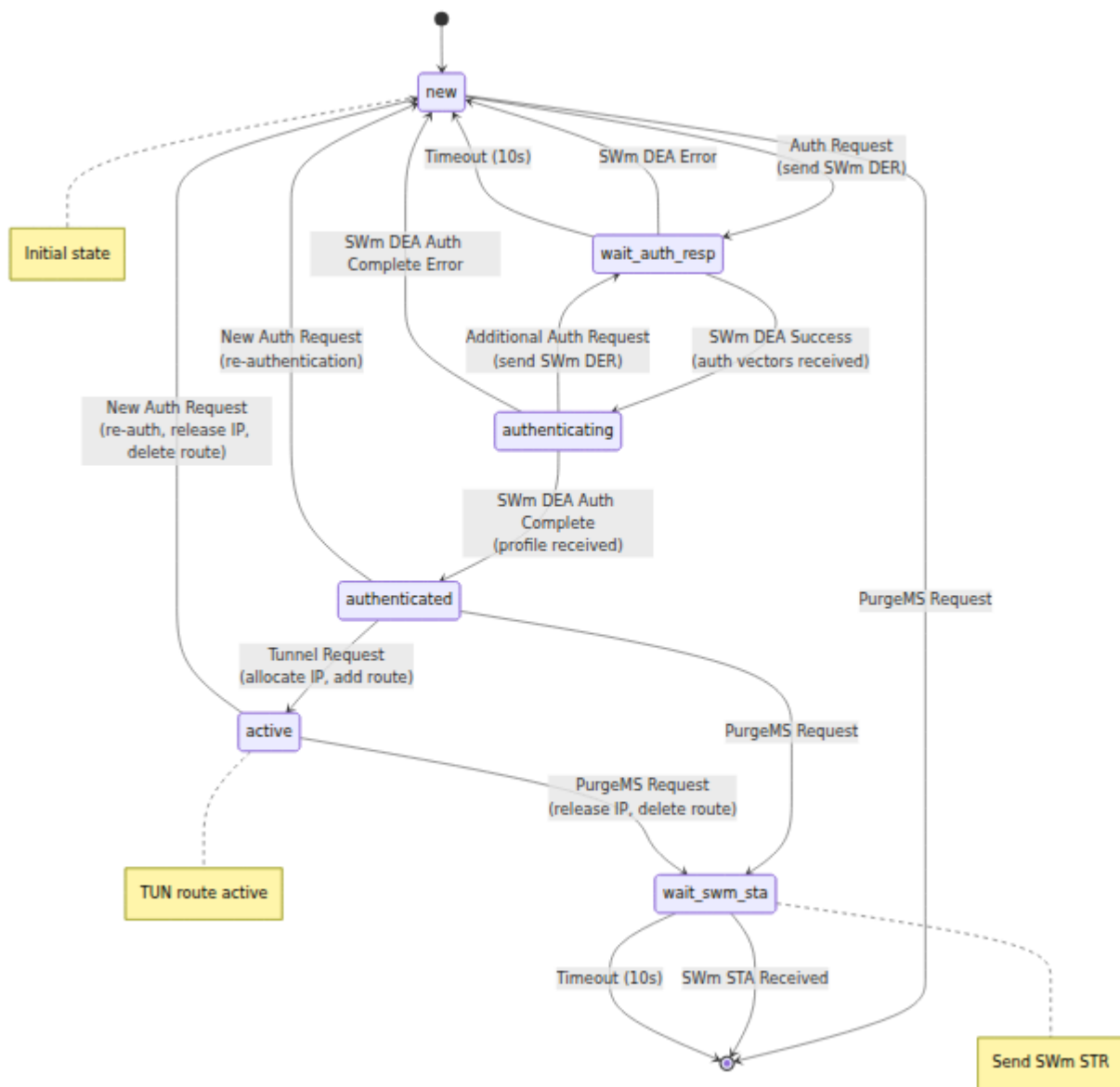
# AAA UE FSM State Reference

| State                               | Description  | Waiting For           |
|-------------------------------------|--|-----------------------|
| <code>new</code>                    | Initial state. No active AAA session.                                | Diameter auth request |
| <code>wait_swx_maa</code>           | SWx MAR sent to HSS for EAP-AKA vectors.                             | SWx MAA from HSS      |
| <code>wait_swx_saa</code>           | SWx SAR sent to HSS for server assignment.                           | SWx SAA from HSS      |
| <code>authenticated</code>          | Both ePDG and PGW sessions may be active. Tracks dual session state. | Session events        |
| <code>auth_wait_swx_saa</code>      | SWx SAR sent for PGW update or user deregistration.                  | SWx SAA from HSS      |
| <code>dereg_net_wait_s6b_asa</code> | HSS-initiated deregistration. S6b ASR sent to PGW.                   | S6b ASA from PGW      |
| <code>dereg_net_wait_swm_asa</code> | S6b teardown complete. SWm ASR sent to ePDG.                         | SWm ASA from ePDG     |

## Call Flows

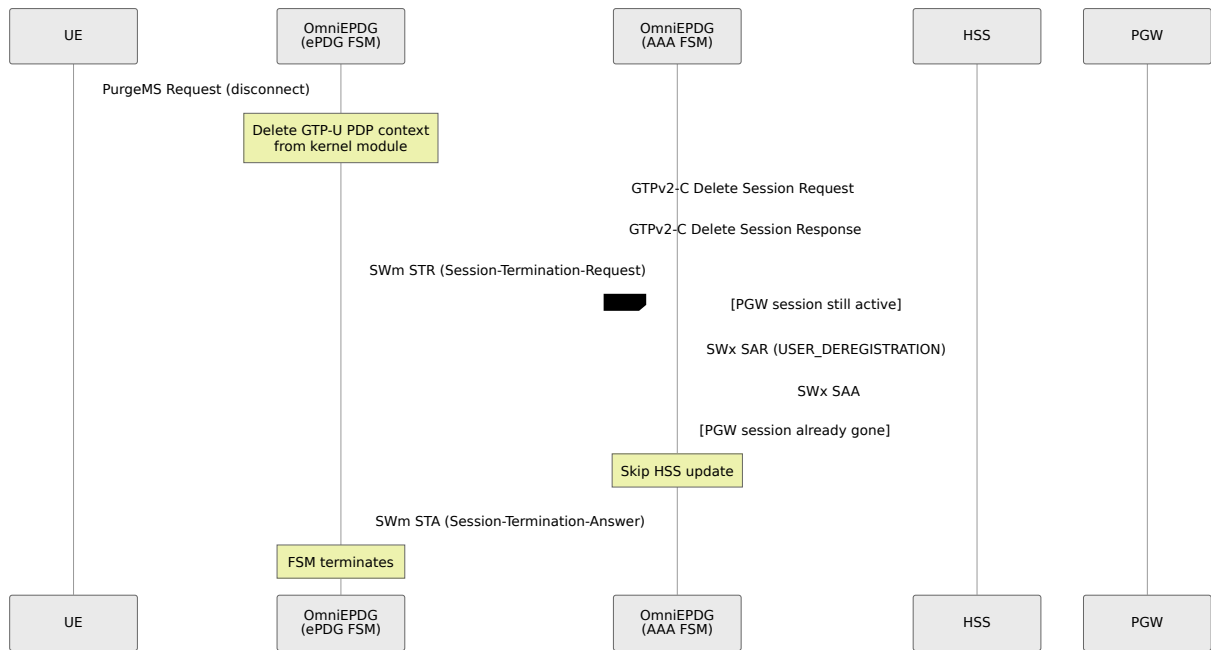
### GTP Mode: Successful Session Establishment

This sequence shows a complete successful session from EAP-AKA authentication through to an active GTP tunnel.



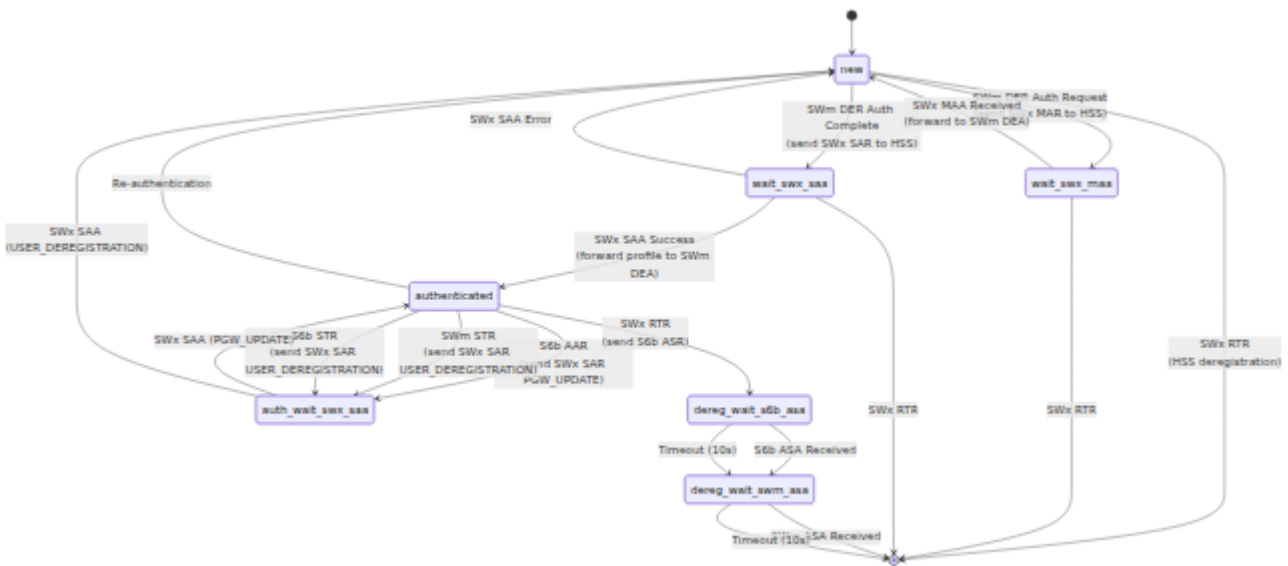
## GTP Mode: UE-Initiated Session Teardown

When the UE disconnects (e.g., switches from WiFi to cellular or user hangs up).



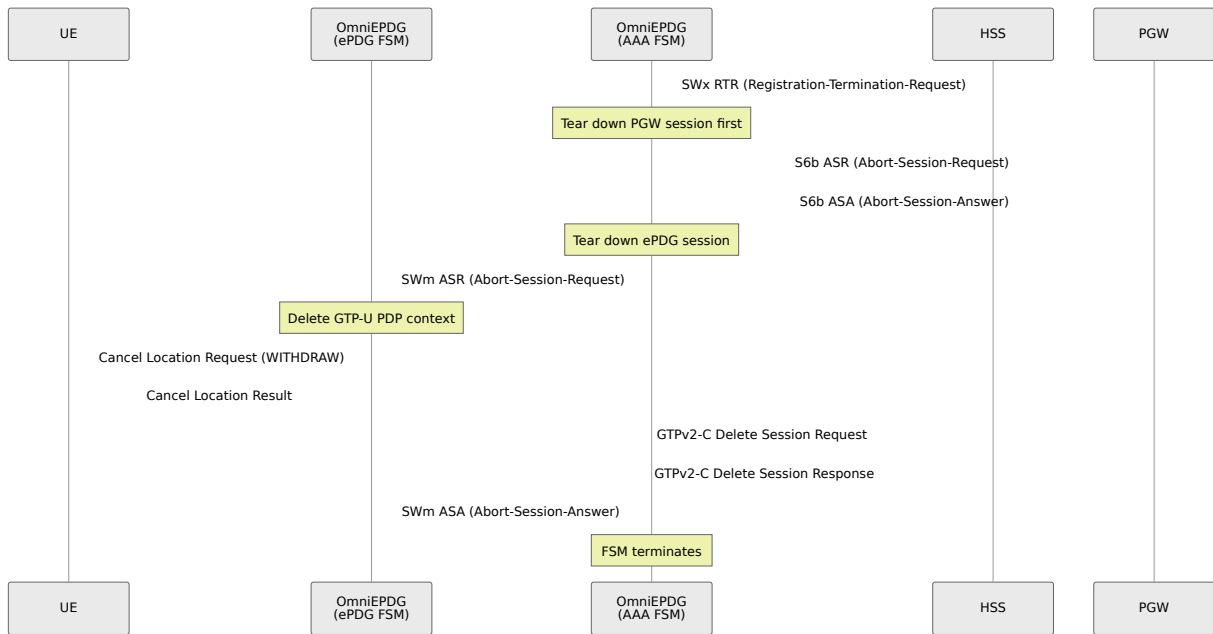
## GTP Mode: PGW-Initiated Session Teardown

When the PGW terminates the session (e.g., policy violation, timeout, or administrative action).



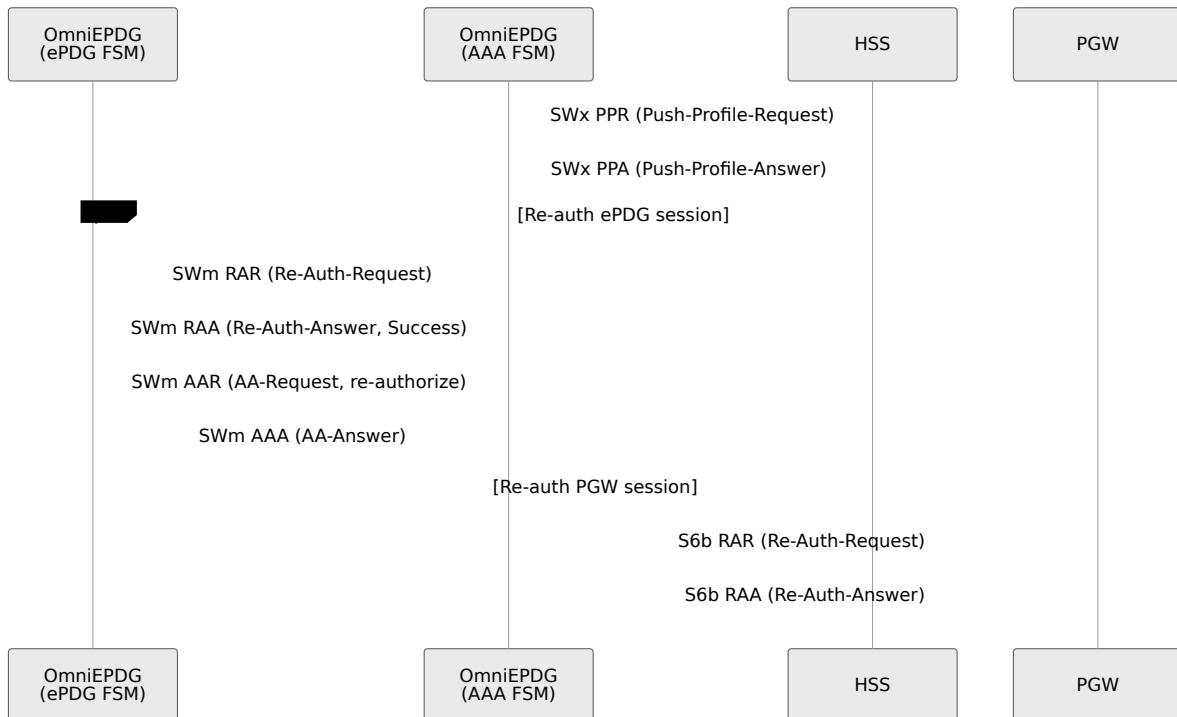
## GTP Mode: Network (HSS) Initiated Deregistration

When the HSS revokes a subscriber's registration (e.g., subscription change, fraud detection, or administrative action).



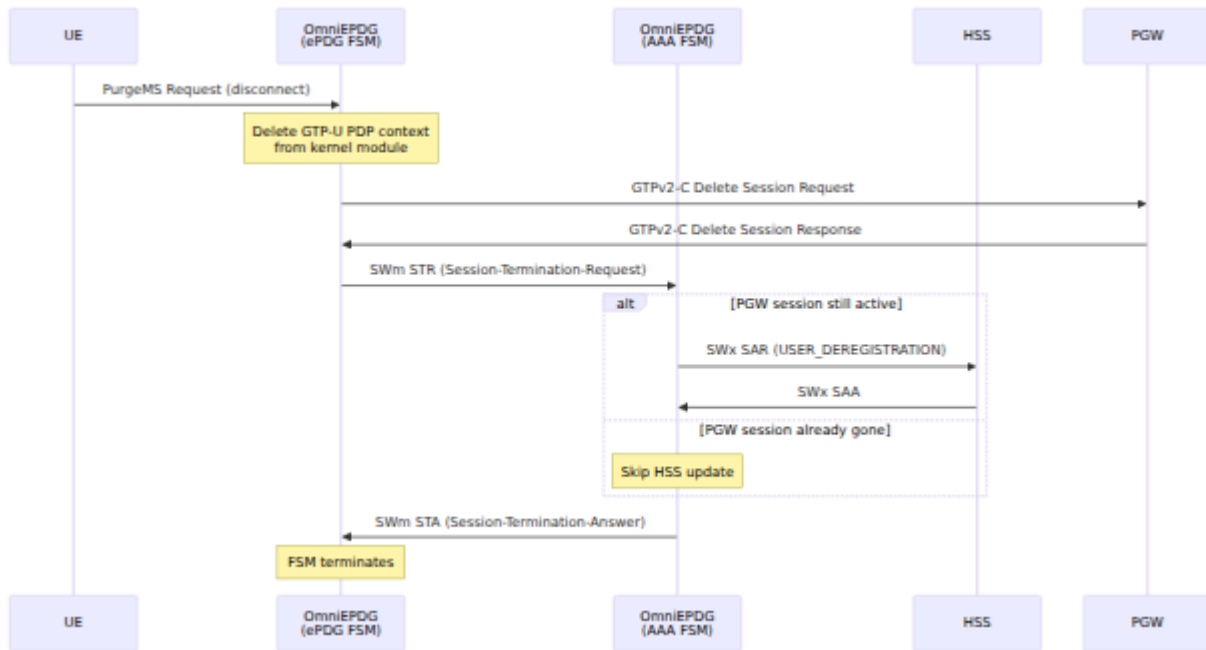
## GTP Mode: HSS Profile Push and Re-Authentication

When the HSS pushes an updated subscriber profile, OmniEPDG triggers re-authentication on both the ePDG (SWm) and PGW (S6b) sessions per [3GPP TS 29.273 Section 8.1.2.3.3](#).



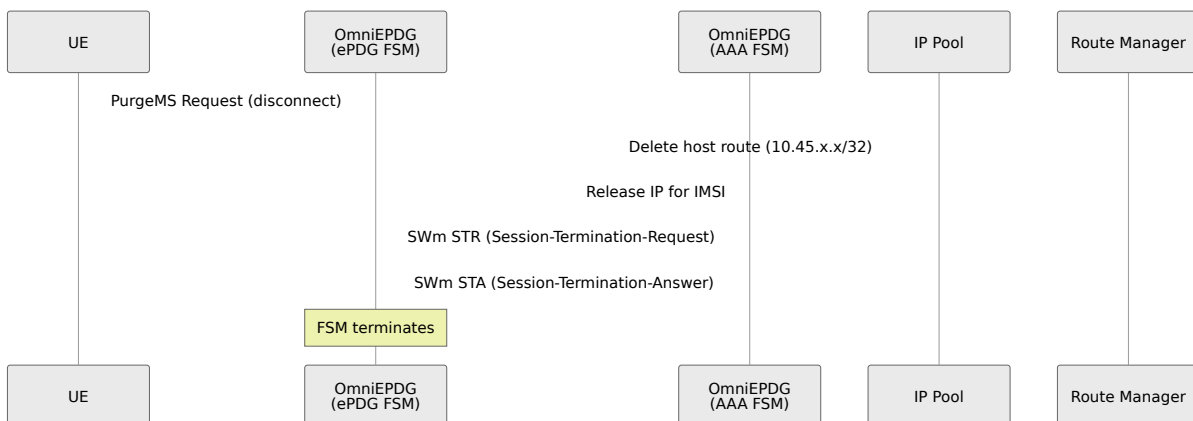
# Simple VPN Mode: Successful Session Establishment

In Simple VPN mode, the session establishment is shorter. After EAP-AKA authentication, the ePDG FSM allocates an IP from the local pool and sets up a host route on the TUN interface, bypassing all PGW interaction. If `skip_sar` is enabled, the SAR/SAA exchange with the HSS is also skipped.



# Simple VPN Mode: UE-Initiated Session Teardown

When the UE disconnects in Simple VPN mode, the FSM releases the allocated IP address and removes the host route.



# Diameter Application IDs

| Application ID | Interface | Vendor ID       | Description   | Reference         |
|----------------|-----------|-----------------|---|-------------------|
| 16777265       | SWx       | 10415<br>(3GPP) | ePDG ↔ HSS authentication and subscriber management | 3GPP TS<br>29.273 |
| 16777272       | S6b       | 10415<br>(3GPP) | AAA ↔ PGW session authorization                     | 3GPP TS<br>29.273 |

## Diameter Result Codes

OmniEPDG maps Diameter result codes to internal cause values for cross-protocol error propagation.

### Standard Result Codes

| Result Code | Name                     | Meaning                          |
|-------------|--------------------------|----------------------------------|
| 2001        | DIAMETER_SUCCESS         | Operation completed successfully |
| 2002        | DIAMETER_LIMITED_SUCCESS | Operation partially successful   |

## 3GPP Experimental Result Codes

| Result Code | Name                                     | Meaning                                    |
|-------------|--|--|
| 4181        | DIAMETER_AUTHENTICATION_DATA_UNAVAILABLE | HSS temporarily cannot provide auth data   |
| 5001        | DIAMETER_ERROR_USER_UNKNOWN              | Subscriber IMSI not found in HSS           |
| 5002        | DIAMETER_UNKNOWN_SESSION_ID              | Session not found (used for stale STR/AAR) |
| 5003        | DIAMETER_AUTHORIZATION_REJECTED          | Subscriber not authorized for service      |
| 5004        | DIAMETER_ERROR_ROAMING_NOT_ALLOWED       | Roaming restrictions apply                 |
| 5005        | DIAMETER_MISSING_AVP                     | Required AVP missing from message          |
| 5012        | DIAMETER_UNABLE_TO_COMPLY                | Generic processing                         |

| Result Code | Name                                    | Meaning                         |
|-------------|---|---------------------------------|
|             |   | failure                         |
| 5420        | DIAMETER_ERROR_UNKNOWN_EPS_SUBSCRIPTION | No EPS subscription found       |
| 5421        | DIAMETER_ERROR_RAT_NOT_ALLOWED          | Access technology not permitted |
| 5422        | DIAMETER_ERROR_EQUIPMENT_UNKNOWN        | Device IMEI not recognized      |

## GTPv2-C Cause Codes (GTP Mode Only)

OmniEPDG handles the following GTPv2-C cause codes in Create/Delete Session responses from the PGW. Codes 1-15 are informational, 16-63 indicate success, and 64+ indicate errors. See [3GPP TS 29.274 Section 8.4](#).

## Success Causes

| Code | Name                                 | Description   |
|------|--------------------------------------|---|
| 16   | Request Accepted                     | Operation completed successfully                          |
| 17   | Request Accepted Partially           | Partial success   |
| 18   | New PDN Type (Network Preference)    | PDN type changed due to network preference                |
| 19   | New PDN Type (Single Address Bearer) | PDN type changed due to single address bearer restriction |

## Error Causes (Selected)

| Code | Name                           | Description                         |
|------|--------------------------------|-------------------------------------|
| 64   | Context Not Found              | Session context not found on PGW    |
| 73   | No Resources Available         | PGW resource exhaustion             |
| 78   | Missing or Unknown APN         | Requested APN not configured on PGW |
| 82   | Denied in RAT                  | Access technology not permitted     |
| 84   | All Dynamic Addresses Occupied | IP address pool exhausted on PGW    |
| 92   | User Authentication Failed     | Authentication failure at PGW       |
| 93   | APN Access Denied              | Subscriber not authorized for APN   |
| 96   | IMSI/IMEI Not Known            | Subscriber identity not recognized  |
| 109  | Invalid Peer                   | Peer validation failed              |
| 113  | APN Congestion                 | APN overloaded                      |
| 120  | GTP-C Entity Congestion        | PGW control plane overloaded        |

## NAI Format

OmniEPDG identifies subscribers using the Network Access Identifier (NAI) format defined in [3GPP TS 23.003 Section 19](#):

```
<prefix><IMSI>@nai.epc.mnc<MNC>.mcc<MCC>.3gppnetwork.org
```

# Identity Prefix and Authentication Type

The NAI prefix determines the EAP authentication method per 3GPP TS 23.003:

| Prefix | Authentication Type | Description  |
|--------|---------------------|--|
| 0      | EAP-AKA             | Standard AKA authentication (most common for WiFi calling) |
| 6      | EAP-AKA'            | Enhanced AKA authentication with network binding           |

OmniEPDG automatically selects the authentication method based on the UE's identity prefix. Most UEs use prefix 0 (EAP-AKA) for WiFi calling.

OmniEPDG extracts the IMSI from the NAI by parsing everything between the prefix and the @ symbol. The IMSI is then used as the primary key for all per-subscriber state machines and signaling operations.

## Cryptographic Algorithms

OmniEPDG implements cryptographic algorithms per [3GPP TS 33.402](#) and [RFC 7296](#) (IKEv2).

## IKEv2 Encryption Algorithms

| Algorithm  | ID | Key Size           | Status                   | Reference                |
|------------|----|--------------------|--------------------------|--------------------------|
| AES-CBC    | 12 | 128, 192, 256 bits | Supported (default: 256) | <a href="#">RFC 3602</a> |
| AES-GCM-16 | 20 | 128, 192, 256 bits | Supported                | <a href="#">RFC 5282</a> |
| AES-GCM-12 | 19 | 128, 192, 256 bits | Supported                | <a href="#">RFC 5282</a> |
| AES-GCM-8  | 18 | 128, 192, 256 bits | Supported                | <a href="#">RFC 5282</a> |
| 3DES       | 3  | 192 bits           | Supported (legacy)       | <a href="#">RFC 2451</a> |

## IKEv2 Integrity Algorithms

| Algorithm         | ID | Key Size | ICV Size | Status              | Reference                |
|-------------------|----|----------|----------|---------------------|--------------------------|
| HMAC-SHA2-256-128 | 12 | 256 bits | 128 bits | Supported (default) | <a href="#">RFC 4868</a> |
| HMAC-SHA2-384-192 | 13 | 384 bits | 192 bits | Supported           | <a href="#">RFC 4868</a> |
| HMAC-SHA2-512-256 | 14 | 512 bits | 256 bits | Supported           | <a href="#">RFC 4868</a> |
| AES-XCBC-96       | 5  | 128 bits | 96 bits  | Supported           | <a href="#">RFC 3566</a> |
| HMAC-SHA1-96      | 2  | 160 bits | 96 bits  | Supported (legacy)  | <a href="#">RFC 2404</a> |
| HMAC-MD5-96       | 1  | 128 bits | 96 bits  | Supported (legacy)  | <a href="#">RFC 2403</a> |

AES-XCBC-96 (`AUTH_AES_XCBC_96`) is required by some handsets — notably certain Samsung VoWiFi clients — which offer it as their only integrity transform. It is implemented per RFC 3566 with the variable-key handling and SKEYSEED nonce truncation defined in [RFC 4434](#) and [RFC 7296 Section 2.14](#).

## IKEv2 PRF Algorithms

| Algorithm         | ID | Output Size | Status              | Reference                |
|-------------------|----|-------------|---------------------|--------------------------|
| PRF-HMAC-SHA2-256 | 5  | 256 bits    | Supported (default) | <a href="#">RFC 4868</a> |
| PRF-HMAC-SHA2-384 | 6  | 384 bits    | Supported           | <a href="#">RFC 4868</a> |
| PRF-HMAC-SHA2-512 | 7  | 512 bits    | Supported           | <a href="#">RFC 4868</a> |
| PRF-AES128-XCBC   | 4  | 128 bits    | Supported           | <a href="#">RFC 4434</a> |
| PRF-HMAC-SHA1     | 2  | 160 bits    | Supported (legacy)  | <a href="#">RFC 2104</a> |
| PRF-HMAC-MD5      | 1  | 128 bits    | Supported (legacy)  | <a href="#">RFC 2104</a> |

When `PRF-AES128-XCBC` is negotiated, SKEYSEED is derived from only the first 64 bits of each of  $N_i$  and  $N_r$  (per RFC 7296 Section 2.14), while the full nonces feed the prf+ key expansion.

## IKEv2 Diffie-Hellman Groups

| Group      | ID | Size      | Status              | Reference                |
|------------|----|-----------|---------------------|--------------------------|
| MODP-2048  | 14 | 2048 bits | Supported (default) | <a href="#">RFC 3526</a> |
| MODP-1024  | 2  | 1024 bits | Supported (legacy)  | <a href="#">RFC 2409</a> |
| MODP-1536  | 5  | 1536 bits | Supported           | <a href="#">RFC 3526</a> |
| MODP-3072  | 15 | 3072 bits | Supported           | <a href="#">RFC 3526</a> |
| MODP-4096  | 16 | 4096 bits | Supported           | <a href="#">RFC 3526</a> |
| ECP-256    | 19 | 256 bits  | Supported           | <a href="#">RFC 5903</a> |
| ECP-384    | 20 | 384 bits  | Supported           | <a href="#">RFC 5903</a> |
| ECP-521    | 21 | 521 bits  | Supported           | <a href="#">RFC 5903</a> |
| Curve25519 | 31 | 256 bits  | Supported           | <a href="#">RFC 8031</a> |
| Curve448   | 32 | 448 bits  | Supported           | <a href="#">RFC 8031</a> |

## ESP (Child SA) Algorithms

The ESP tunnel algorithms are negotiated from the SA proposal the UE offers in IKE\_AUTH (and in CREATE\_CHILD\_SA on rekey). OmniEPDG selects a transform the UE actually offered and derives the Child SA keys with the matching key and ICV sizes — it does not force a fixed suite.

| Type       | Algorithms   | Notes   |
|------------|--|---|
| Encryption | AES-CBC-128 / 192 / 256  | Cipher follows the negotiated key length                  |
| Integrity  | HMAC-SHA2-256-128, HMAC-SHA2-384-192, HMAC-SHA2-512-256, AES-XCBC-96, HMAC-SHA1-96 | AES-XCBC-96 ICV is 12 bytes (vs 16 for HMAC-SHA2-256-128) |

**Fallback (only when the UE's proposal cannot be parsed):**

- Encryption: AES-CBC-256 (32-byte key, 16-byte IV)
- Integrity: HMAC-SHA2-256-128 (32-byte key, 16-byte ICV)

## EAP-AKA Cryptographic Functions

| Function           | Algorithm              | Reference                              |
|--------------------|------------------------|--|
| MK derivation      | SHA-1                  | <a href="#">RFC 4187</a> Section 7     |
| PRF+ key expansion | FIPS 186-2 PRF (SHA-1) | <a href="#">RFC 4187</a> Appendix D    |
| AT_MAC             | HMAC-SHA1-128          | <a href="#">RFC 4187</a> Section 10.15 |
| Milenage (f1-f5)   | AES-128                | <a href="#">3GPP TS 35.206</a>         |

## EAP-AKA' Cryptographic Functions

| Function           | Algorithm       | Reference                            |
|--------------------|-----------------|--------------------------------------|
| CK'/IK' derivation | HMAC-SHA-256    | <a href="#">RFC 5448</a> Section 3.3 |
| MK derivation      | SHA-256         | <a href="#">RFC 5448</a> Section 3.4 |
| AT_MAC             | HMAC-SHA256-128 | <a href="#">RFC 5448</a> Section 3.1 |

# 3GPP Compliance

OmniEPDG implements all mandatory cryptographic algorithms specified in [3GPP TS 33.402](#) Section 8:

| Requirement                  | Algorithm            | Status                |
|------------------------------|----------------------|-----------------------|
| IKEv2 Encryption (mandatory) | AES-CBC-128          | ✓ Supported           |
| IKEv2 Integrity (mandatory)  | HMAC-SHA2-256-128    | ✓ Supported (default) |
| IKEv2 PRF (mandatory)        | PRF-HMAC-SHA-256     | ✓ Supported (default) |
| IKEv2 DH (mandatory)         | Group 14 (MODP-2048) | ✓ Supported (default) |
| ESP Encryption (mandatory)   | AES-CBC-128/256      | ✓ Supported           |
| ESP Integrity (mandatory)    | HMAC-SHA2-256-128    | ✓ Supported (default) |
| EAP-AKA                      | RFC 4187             | ✓ Implemented         |
| EAP-AKA'                     | RFC 5448             | ✓ Implemented         |

Beyond the mandatory set, OmniEPDG also supports the AES-XCBC integrity and PRF transforms (RFC 3566 / RFC 4434) for interoperability with handsets that offer them exclusively — for example certain Samsung VoWiFi clients, which propose AES-CBC-256 / AUTH\_AES\_XCBC\_96 / PRF\_AES128\_XCBC / MODP-2048 and will not fall back to HMAC-SHA2.

# PDP Address Types (GTP Mode Only)

OmniEPDG supports the following PDP address types as defined in [3GPP TS 29.274 Section 8.14](#). In Simple VPN mode, only IPv4 addresses are allocated from the local pool.

| Type   | Description       | GTPv2-C PAA Format                                |
|--------|-------------------|---|
| IPv4   | IPv4-only bearer  | 4-byte IPv4 address                               |
| IPv6   | IPv6-only bearer  | 1-byte prefix length + 16-byte IPv6 address       |
| IPv4v6 | Dual-stack bearer | 1-byte prefix length + 16-byte IPv6 + 4-byte IPv4 |

# OmniEPDG Configuration Reference

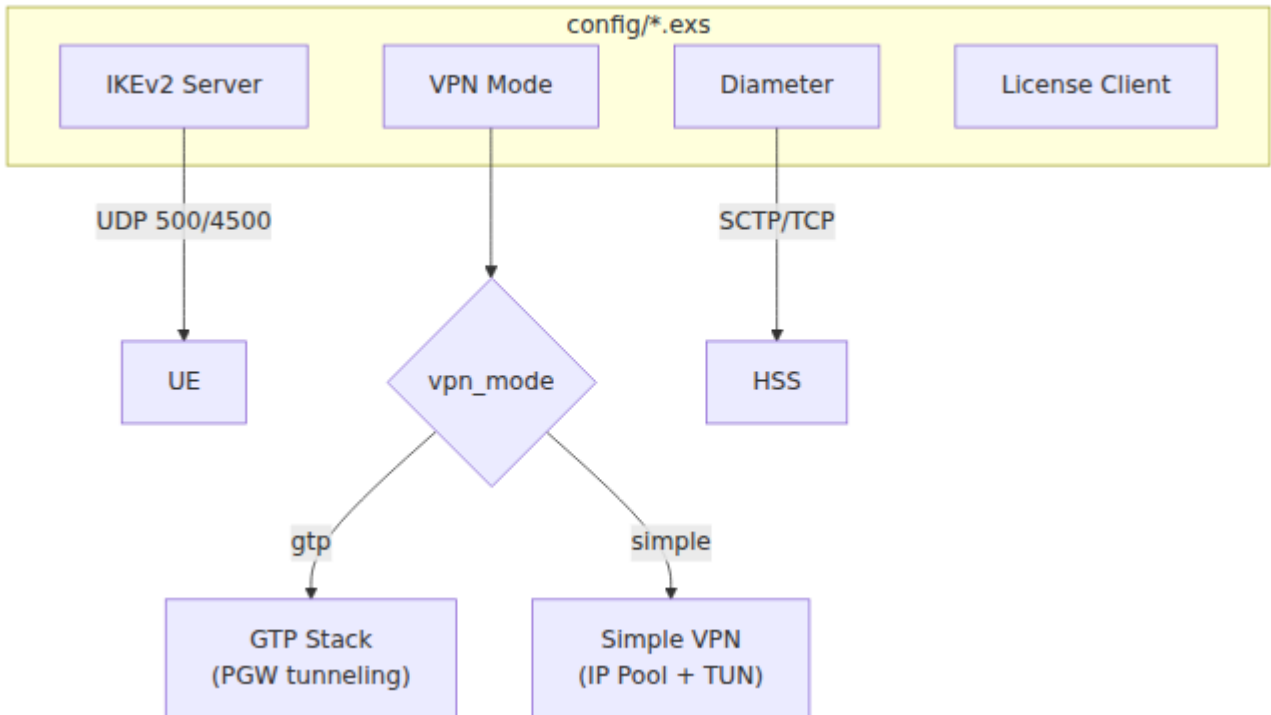
OmniEPDG is configured via `config/runtime.exs` and environment variables. All customer-facing configuration is performed at runtime - compile-time defaults are built into the release and not exposed.

For containerized deployments, use environment variables as documented in the [Environment Variables Reference](#) section.

## Table of Contents

- [IKEv2 Server Parameters](#)
- [Authentication Security Parameters](#)
- [VPN Mode Selection](#)
- [Simple VPN Parameters](#)
- [Diameter Parameters](#)
- [License Client Configuration](#)
- [Control Panel Configuration](#)
- [Prometheus Metrics Configuration](#)
- [Environment Variables Reference](#)
- [Timeout Reference](#)

# Configuration Structure



## Configuration File

All configuration is done in `config/runtime.exs`. This file is read when OmniEPDG starts and supports environment variable substitution for containerized deployments.

# Configuration Example

```
# config/runtime.exs
config :omniepdg,
  # IKEv2 server settings
  listen_ip: {0, 0, 0, 0},
  port_500: 500,
  port_4500: 4500,

  # VPN mode: :simple (local breakout) or :gtp (PGW via GTP-C)
  vpn_mode: :simple,

  # Simple VPN mode settings
  simple_vpn: [
    pool_ipv4: "10.45.0.0/16",
    pool_ipv6: "2001:db8::/32",
    dns_servers_ipv4: ["8.8.8.8", "8.8.4.4"],
    dns_servers_ipv6: ["2001:4860:4860::8888",
"2001:4860:4860::8844"]
  ]

# Control panel configuration
config :control_panel,
  parent_application: :omniepdg,
  parent_application_readable_name: "OmniEPDG",
  use_additional_pages: [
    {OmniEpdg.Web.DashboardLive, "/", "Dashboard"},
    {OmniEpdg.Web.SessionsLive, "/sessions", "Sessions"},
    {OmniEpdg.Web.DiameterLive, "/diameter", "Diameter"}
  ]

# Diameter configuration (runtime.exs)
config :diameter_ex,
  diameter: %{
    service_name: :omniepdg,
    listen_ip: "0.0.0.0",
    listen_port: 3868,
    host: "epdg",
    realm: "epc.mnc001.mcc001.3gppnetwork.org",
    product_name: "OmniEPDG",
    vendor_id: 10415,
    applications: [
      %{application_name: :swx, application_id: 16_777_265,
```

```
vendor_id: 10415},
  %{application_name: :s6b, application_id: 16_777_272,
vendor_id: 10415}
],
peers: [
  %{host: "hss", ip: "127.0.0.1", port: 3868, transport: :tcp}
]
}

# License client configuration (runtime.exs)
config :license_client,
  server_url: "https://license.example.com/api",
  product: "omniepdg"
```

## IKEv2 Server Parameters

The IKEv2 server handles the SWu interface between UEs and OmniEPDG. It terminates IPsec tunnels and performs EAP-AKA authentication.

| Parameter              | Type    | Required | Default                         |
|------------------------|---------|----------|---------------------------------|
| <code>listen_ip</code> | Tuple   | No       | <code>{0, 0, 0, 0}</code>       |
| <code>port_500</code>  | Integer | No       | <code>500</code>                |
| <code>port_4500</code> | Integer | No       | <code>4500</code>               |
| <code>cert_file</code> | String  | Yes      | <code>/etc/omniepdg/cert</code> |
| <code>key_file</code>  | String  | Yes      | <code>/etc/omniepdg/key</code>  |

| Parameter                                  | Type    | Required | Default             |
|--|---------|----------|---------------------|
| <code>session_inactivity_timeout_ms</code> | Integer | No       | <code>300000</code> |

## Authentication Security Parameters

OmniEPDG includes built-in protection against brute-force attacks and geographic access control. See the [Security Guide](#) for detailed documentation.

### Rate Limiting Parameters

```
config :omniepdg,
  # Per-IP rate limiting
  auth_rate_limit_per_ip: 10,
  auth_rate_limit_ip_window_ms: 60_000,
  auth_rate_limit_ip_block_ms: 300_000,

  # Per-IMSI rate limiting
  auth_rate_limit_per_imsi: 5,
  auth_rate_limit_imsi_window_ms: 60_000,
  auth_rate_limit_imsi_block_ms: 600_000
```

| Parameter                      | Type    | Required | Default | Description   |
|--------------------------------|---------|----------|---------|---|
| auth_rate_limit_per_ip         | Integer | No       | 10      | Maximum failed attempts per IP before blocking            |
| auth_rate_limit_ip_window_ms   | Integer | No       | 60000   | Sliding window count of failed attempts (milliseconds)    |
| auth_rate_limit_ip_block_ms    | Integer | No       | 300000  | Block duration for IPs exceeding the threshold (minutes)  |
| auth_rate_limit_per_imsi       | Integer | No       | 5       | Maximum failed attempts per IMSI before blocking          |
| auth_rate_limit_imsi_window_ms | Integer | No       | 60000   | Sliding window count of failed attempts (milliseconds)    |
| auth_rate_limit_imsi_block_ms  | Integer | No       | 600000  | Block duration for IMSI exceeding the threshold (minutes) |

## GeoIP Parameters

```
config :omniepdg,  
  geoip_enabled: false,  
  geoip_database_path: "/etc/omniepdg/GeoLite2-Country.mmdb",  
  geoip_mode: :whitelist,  
  geoip_countries: ["AU", "NZ"],  
  geoip_allow_unknown: false,  
  geoip_fail_open: true
```

| Parameter                        | Type    | Required | Default  |
|----------------------------------|---------|----------|--|
| <code>geoup_enabled</code>       | Boolean | No       | <code>false</code>                                 |
| <code>geoup_database_path</code> | String  | No       | <code>"/etc/omniepdg/GeoLite2-Country.mmdb"</code> |
| <code>geoup_mode</code>          | Atom    | No       | <code>:whitelist</code>                            |
| <code>geoup_countries</code>     | List    | No       | <code>[]</code>                                    |
| <code>geoup_allow_unknown</code> | Boolean | No       | mode-dependent                                     |

| Parameter                    | Type    | Required | Default           |
|------------------------------|---------|----------|-------------------|
|                              |         |          |                   |
| <code>geoup_fail_open</code> | Boolean | No       | <code>true</code> |

## VPN Mode Selection

| Parameter             | Type | Required | Default              | Env Var                    | Description   |
|-----------------------|------|----------|----------------------|----------------------------|---|
| <code>vpn_mode</code> | Atom | No       | <code>:simple</code> | <code>EPDG_VPN_MODE</code> | Operational mode:<br><code>:simple</code> for local IP breakout via TUN interface,<br><code>:gtp</code> for tunneling through a PGW via GTPv2-C/GTP-U. See the <a href="#">Operations Guide</a> for a detailed comparison |

## Simple VPN Parameters

The `simple_vpn` configuration block controls IP allocation and DNS for Simple VPN mode. OmniEPDG supports both IPv4 and IPv6 address pools.

```
config :omniepdg,  
  simple_vpn: [  
    pool_ipv4: "10.45.0.0/16",  
    pool_ipv6: "2001:db8::/32",  
    dns_servers_ipv4: ["8.8.8.8", "8.8.4.4"],  
    dns_servers_ipv6: ["2001:4860:4860::8888",  
"2001:4860:4860::8844"],  
    p_cscf_ipv4: ["10.4.12.165"],  
    p_cscf_ipv6: [],  
    mtu: 1400,  
    nat_enabled: true  
  ]
```

| Parameter                     | Type   | Required | Default   |                     |
|-------------------------------|--------|----------|---|---------------------|
| <code>pool_ipv4</code>        | String | Yes      | <code>"10.45.0.0/16"</code>                                   | IF p n IF p         |
| <code>pool_ipv6</code>        | String | No       | <code>"2001:db8::/32"</code>                                  | IF p n d s          |
| <code>dns_servers_ipv4</code> | List   | No       | <code>["8.8.8.8", "8.8.4.4"]</code>                           | IF s p U (f C O     |
| <code>dns_servers_ipv6</code> | List   | No       | <code>["2001:4860:4860::8888", "2001:4860:4860::8844"]</code> | IF s p U            |
| <code>p_cscf_ipv4</code>      | List   | No       | <code>[]</code>   | IF (l a V P U IN re |

| Parameter                | Type    | Required | Default           |                      |
|--------------------------|---------|----------|-------------------|----------------------|
| <code>p_cscf_ipv6</code> | List    | No       | <code>[]</code>   | IF (I a V            |
| <code>mtu</code>         | Integer | No       | <code>1400</code> | M th ir L re fr      |
| <code>nat_enabled</code> | Boolean | No       | <code>true</code> | E S tr tr m r a o tr |

## Diameter Parameters

The Diameter configuration controls the SWx (HSS) and S6b (PGW) interfaces. When `diameter_enabled` is `true`, OmniEPDG starts the Diameter stack and connects to configured peers.

```
config :diameter_ex,  
  diameter: %{  
    service_name: :omniepdg,  
    listen_ip: "0.0.0.0",  
    listen_port: 3868,  
    host: "epdg",  
    realm: "epc.mnc001.mcc001.3gppnetwork.org",  
    product_name: "OmniEPDG",  
    vendor_id: 10415,  
    applications: [  
      %{application_name: :swx, application_id: 16_777_265,  
vendor_id: 10415},  
      %{application_name: :s6b, application_id: 16_777_272,  
vendor_id: 10415}  
    ],  
    peers: [  
      %{host: "hss", ip: "10.74.0.21", port: 3868, transport:  
:tcp}  
    ]  
  }  
}
```

## Service Parameters

| Parameter                 | Type    | Required | Default   |
|---------------------------|---------|----------|---|
| <code>service_name</code> | Atom    | No       | <code>:omniepdg</code>                          |
| <code>listen_ip</code>    | String  | No       | <code>"0.0.0.0"</code>                          |
| <code>listen_port</code>  | Integer | No       | <code>3868</code>                               |
| <code>host</code>         | String  | Yes      | <code>"epdg"</code>                             |
| <code>realm</code>        | String  | Yes      | <code>"epc.mnc001.mcc001.3gppnetwork.or"</code> |

| Parameter                 | Type    | Required | Default                 |
|---------------------------|---------|----------|-------------------------|
|                           |         |          |                         |
| <code>product_name</code> | String  | No       | <code>"OmniEPDG"</code> |
| <code>vendor_id</code>    | Integer | No       | <code>10415</code>      |

### Peer Parameters

Each entry in the `peers` list defines a Diameter peer connection (typically to the HSS).

| Parameter              | Type    | Required | Default           | Env Var               | Description  |
|------------------------|---------|----------|-------------------|-----------------------|--|
| <code>host</code>      | String  | Yes      | -                 | <code>HSS_HOST</code> | Peer's Diameter identity (Origin-Host). Must match the peer's configured identity. |
| <code>ip</code>        | String  | Yes      | -                 | <code>HSS_IP</code>   | Peer's IP address for TCP/SCTP connection.   |
| <code>port</code>      | Integer | No       | <code>3868</code> | <code>HSS_PORT</code> | Peer's Diameter port.  |
| <code>transport</code> | Atom    | No       | <code>:tcp</code> | -                     | Transport protocol:<br><code>:tcp</code> or<br><code>:sctp</code> .                |

## Application IDs

| Application | ID       | Vendor ID | Interface  | Reference                      |
|-------------|----------|-----------|------------|--------------------------------|
| SWx         | 16777265 | 10415     | ePDG ↔ HSS | <a href="#">3GPP TS 29.273</a> |
| S6b         | 16777272 | 10415     | AAA ↔ PGW  | <a href="#">3GPP TS 29.273</a> |

## License Client Configuration

The license client validates OmniEPDG against a license server.

```

config :license_client,
  server_url: "https://license.example.com/api",
  product: "omniepdg"

```

| Parameter               | Type   | Required | Default                 | Env Var                         | Description                          |
|-------------------------|--------|----------|-------------------------|---------------------------------|--------------------------------------|
| <code>server_url</code> | String | Yes      | -                       | <code>LICENSE_SERVER_URL</code> | URL of the license server.           |
| <code>product</code>    | String | No       | <code>"omniepdg"</code> | -                               | Product ID for license verification. |

## Control Panel Configuration

The web control panel provides monitoring and management capabilities.

```

config :control_panel,
  port: 4000

```

| Parameter         | Type    | Required | Default           | Env Var                         | Description                                |
|-------------------|---------|----------|-------------------|---------------------------------|--|
| <code>port</code> | Integer | No       | <code>4000</code> | <code>CONTROL_PANEL_PORT</code> | HTTP port for the control panel interface. |

## Prometheus Metrics Configuration

OmniEPDG exposes Prometheus metrics via HTTP for monitoring and alerting.

```

config :omniepdg,
  prometheus: %{
    port: 9568
  }

```

| Parameter | Type    | Required | Default | Env Var         | Description  |
|-----------|---------|----------|---------|-----------------|--|
| port      | Integer | No       | 9568    | PROMETHEUS_PORT | HTTP port for Prometheus metrics endpoint (/metrics) |

## Exposed Metrics

### Counter Metrics (Event-driven):

- `epdg_ikev2_session_initiated_count` - IKE\_SA\_INIT exchanges started
- `epdg_ikev2_session_established_count` - IKE SAs successfully established
- `epdg_ikev2_session_failed_count` - IKE SA establishment failures (by reason)
- `epdg_eap_identity_count` - EAP Identity requests
- `epdg_eap_aka_challenge_count` - EAP-AKA Challenges sent
- `epdg_eap_aka_success_count` - EAP-AKA authentications succeeded
- `epdg_eap_aka_failure_count` - EAP-AKA authentications failed (by reason)
- `epdg_eap_aka_sync_failure_count` - EAP-AKA SQN sync failures
- `epdg_diameter_swx_mar_count` - Multimedia-Auth-Requests (by result)
- `epdg_diameter_swx_sar_count` - Server-Assignment-Requests (by result)
- `epdg_diameter_s6b_aar_count` - AA-Requests handled (by result)
- `epdg_diameter_s6b_str_count` - Session-Termination-Requests
- `epdg_session_created_count` - Sessions created (by vpn\_mode)
- `epdg_session_terminated_count` - Sessions terminated (by reason)
- `epdg_esp_packets_in_count` - ESP packets decrypted

- `epdg_esp_packets_out_count` - ESP packets encrypted
- `epdg_ip_allocated_count` - IP addresses allocated (by type)
- `epdg_ip_released_count` - IP addresses released (by type)

### **Gauge Metrics (Polled every 5s):**

- `epdg_sessions_active_count` - Total active sessions
- `epdg_sessions_by_state_count` - Sessions by FSM state
- `epdg_ip_pool_allocated_count` - IPs currently allocated
- `epdg_ip_pool_available_count` - IPs available in pool
- `epdg_ip_pool_utilization_ratio` - Pool utilization (0.0-1.0)
- `epdg_diameter_swx_pending_count` - Pending SWx requests
- `epdg_diameter_s6b_active_sessions_count` - Active S6b sessions

### **Histogram Metrics (Latency tracking):**

- `epdg_auth_duration_ms` - Full auth flow duration
- `epdg_diameter_swx_mar_latency_ms` - MAR response time
- `epdg_diameter_swx_sar_latency_ms` - SAR response time
- `epdg_session_duration_seconds` - Session lifetime

### **VM Metrics:**

- `vm_memory_total` - Total VM memory
- `vm_memory_processes` - Process memory
- `vm_memory_binary` - Binary memory
- `vm_memory_ets` - ETS table memory
- `vm_system_info_process_count` - Running processes
- `vm_system_info_port_count` - Open ports
- `vm_statistics_run_queue` - Scheduler run queue

### **Prometheus Scrape Configuration**

```
scrape_configs:
  - job_name: 'omniepdg'
    static_configs:
      - targets: ['localhost:9568']
```

---

## Timeout Reference

All internal FSM timeouts are hardcoded. These govern how long state machines wait for responses before considering them failed.

| Timeout    | Value     | Mode | Context     | Description   |
|------------|-----------|------|-------------|---|
| GTP answer | 10,000 ms | GTP  | ePDG UE FSM | Maximum wait for GTPv2-C Create/Delete Session Response from PGW.   |
| SWm answer | 10,000 ms | Both | ePDG UE FSM | Maximum wait for internal Diameter SWm response (DER/DEA, STR/STA). |
| S6b answer | 10,000 ms | GTP  | AAA UE FSM  | Maximum wait for Diameter S6b response (ASR/ASA).                   |

---

## Environment Variables Reference

Environment variables are read in `config/runtime.exs` and override compile-time defaults.

# IKEv2 Server

| Variable             | Default                        | Description  |
|----------------------|--------------------------------|--|
| EPDG_LISTEN_IP       | "0.0.0.0"                      | IKEv2 server bind address (dotted decimal format, e.g., "10.0.0.1"). |
| EPDG_PORT_500        | "500"                          | IKE protocol port.   |
| EPDG_PORT_4500       | "4500"                         | IKE NAT-Traversal port.  |
| EPDG_CERT_FILE       | "/etc/omniepdg/certs/epdg.crt" | Path to IKEv2 server certificate (PEM).                              |
| EPDG_KEY_FILE        | "/etc/omniepdg/certs/epdg.key" | Path to IKEv2 server private key (PEM).                              |
| EPDG_SESSION_TIMEOUT | "300000"                       | Session inactivity timeout in milliseconds.                          |

## VPN Mode

| Variable      | Default  | Description                  |
|---------------|----------|------------------------------|
| EPDG_VPN_MODE | "simple" | VPN mode: "simple" or "gtp". |

## Diameter

| Variable        | Default                             | Description                           |
|-----------------|-------------------------------------|---------------------------------------|
| DIA_LISTEN_IP   | "0.0.0.0"                           | Diameter listener bind address.       |
| DIA_LISTEN_PORT | "3868"                              | Diameter listener port.               |
| DIA_HOST        | "epdg"                              | Diameter Origin-Host (without realm). |
| DIA_REALM       | "epc.mnc001.mcc001.3gppnetwork.org" | Diameter Origin-Realm.                |

## HSS Peer

| Variable              | Default                  | Description                          |
|-----------------------|--------------------------|--------------------------------------|
| <code>HSS_HOST</code> | <code>"hss"</code>       | HSS Diameter identity (Origin-Host). |
| <code>HSS_IP</code>   | <code>"127.0.0.1"</code> | HSS IP address.                      |
| <code>HSS_PORT</code> | <code>"3868"</code>      | HSS Diameter port.                   |

## License, Control Panel, and Metrics

| Variable                        | Default             | Description   |
|---------------------------------|---------------------|---|
| <code>LICENSE_SERVER_URL</code> | -                   | License server API URL (required).                              |
| <code>CONTROL_PANEL_PORT</code> | <code>"4000"</code> | Control panel HTTP port.  |
| <code>PROMETHEUS_PORT</code>    | <code>"9568"</code> | Prometheus metrics HTTP port ( <code>/metrics</code> endpoint). |

## Example: Docker Compose

```
services:
  omniepdg:
    image: omniepdg:latest
    environment:
      # IKEv2
      EPDG_LISTEN_IP: "0.0.0.0"
      EPDG_CERT_FILE: "/certs/epdg.crt"
      EPDG_KEY_FILE: "/certs/epdg.key"

      # VPN mode
      EPDG_VPN_MODE: "simple"

      # Diameter
      DIA_HOST: "epdg"
      DIA_REALM: "epc.mnc001.mcc001.3gppnetwork.org"
      HSS_HOST: "hss"
      HSS_IP: "10.74.0.21"
      HSS_PORT: "3868"

      # License
      LICENSE_SERVER_URL: "https://license.example.com/api"

      # Control panel
      CONTROL_PANEL_PORT: "4000"

      # Prometheus metrics
      PROMETHEUS_PORT: "9568"
    ports:
      - "500:500/udp"
      - "4500:4500/udp"
      - "4000:4000"
      - "9568:9568"
    volumes:
      - ./certs:/certs:ro
    cap_add:
      - NET_ADMIN
```

# OmniEPDG Control Panel

OmniEPDG includes a web-based control panel for real-time monitoring of sessions, Diameter peers, and system logs. The control panel provides live-updating views without page refreshes.

## Table of Contents

- [Accessing the Control Panel](#)
- [Dashboard](#)
- [Sessions View](#)
- [Diameter Peers View](#)
- [Logs View](#)
- [Docs View](#)
- [Resources View](#)
- [Configuration View](#)

## Accessing the Control Panel

The control panel is served on the configured HTTP port (default 4000):

```
http://<host>:4000/dashboard
```

## Navigation

The control panel provides a sidebar with links to all views:

| Path                           | View           | Description                         |
|--------------------------------|----------------|-------------------------------------|
| <a href="#">/dashboard</a>     | Dashboard      | System overview and quick links     |
| <a href="#">/sessions</a>      | Sessions       | Active UE session list              |
| <a href="#">/diameter</a>      | Diameter Peers | Diameter peer connection status     |
| <a href="#">/logs</a>          | Logs           | Real-time log streaming             |
| <a href="#">/docs</a>          | Docs           | Integrated documentation browser    |
| <a href="#">/resources</a>     | Resources      | BEAM VM and application information |
| <a href="#">/configuration</a> | Configuration  | System configuration viewer         |

## Dashboard

The Dashboard provides a high-level overview of OmniEPDG status with key metrics and quick navigation.

# Statistics Cards

The dashboard displays four primary statistics:

| Statistic                 | Description                                      |
|---------------------------|--|
| <b>Active Sessions</b>    | Current number of established UE sessions        |
| <b>Data Received (UL)</b> | Total bytes received from UEs (uplink direction) |
| <b>Data Sent (DL)</b>     | Total bytes sent to UEs (downlink direction)     |
| <b>Diameter Peers</b>     | Connected peers / total configured peers         |

Data values automatically scale to appropriate units (B, KB, MB, GB).

## Quick Links

Direct navigation to detailed views:

- **View Sessions** - Navigate to the Sessions view for detailed UE information
- **Diameter Peers** - Navigate to the Diameter Peers view for connectivity status
- **System Logs** - Navigate to the Logs view for real-time log streaming
- **Configuration** - Navigate to the Configuration view for system settings

## System Information

Displays current operational configuration:

| Field                  | Description   |
|------------------------|---|
| <b>VPN Mode</b>        | Current mode: <span>GTP</span> or <span>SIMPLE</span> |
| <b>IKEv2 Ports</b>     | Standard ports: 500 (IKE), 4500 (NAT-T)               |
| <b>Diameter Status</b> | Whether Diameter signaling is enabled                 |
| <b>IP Pool (IPv4)</b>  | Configured IP pool CIDR (Simple VPN mode only)        |

## Auto-Refresh

The dashboard automatically refreshes every second to display current statistics.

## Sessions View

The Sessions view displays all active UE sessions with detailed information for each subscriber.

The screenshot shows the OmniEPDG v0.1.0 dashboard. The 'Sessions' view is active, displaying a summary of 1 Session, 1 Active, and 8.53 KB / 12.17 KB of traffic. The table below shows the following session details:

| IMSI       | UE IP        | SOURCE          | APN | STATUS | DURATION | TRAFFIC            |
|------------|--------------|-----------------|-----|--------|----------|--------------------|
| [Redacted] | 100.64.34.84 | 10.7.7.50:14500 | *   | Active | 4m 50s   | 8.53 KB / 12.17 KB |

The detailed view below the table includes:

- SESSION:** IMSI, NAI, UE IP, Source, APN, Child SA SPI
- NETWORK & TIMING:** DNS, P-CSCF, Connected, Last Activity, Duration
- TRAFFIC:** Bytes In (UL), Bytes Out (DL), Packets In, Packets Out

The Sessions view shows active UE connections with real-time traffic statistics and session duration.

## Session List

Each session row displays:

| Column          | Description   |
|-----------------|---|
| <b>IMSI</b>     | Subscriber's International Mobile Subscriber Identity |
| <b>UE IP</b>    | Assigned IPv4/IPv6 address                            |
| <b>SOURCE</b>   | UE's external IP and port (NAT address)               |
| <b>APN</b>      | Access Point Name for the connection                  |
| <b>STATUS</b>   | Current session state (Active/Inactive)               |
| <b>DURATION</b> | Time since session establishment                      |
| <b>TRAFFIC</b>  | Bytes received / sent (UL/DL)                         |

## Status Indicators

Sessions display status with color-coded badges:

| Status            | Color  | Description                               |
|-------------------|--------|---|
| <b>Active</b>     | Green  | Session fully established and operational |
| <b>Connecting</b> | Yellow | Session establishment in progress         |
| <b>Inactive</b>   | Red    | Session terminated or failed              |

## Session Details

Click any session row to expand detailed information:

*Expanded session view showing IMSI, NAI, network configuration, and traffic statistics.*

### **Session Section**

| <b>Field</b>        | <b>Description</b>                       |
|---------------------|--|
| <b>IMSI</b>         | Full IMSI value                          |
| <b>NAI</b>          | Network Access Identifier (3GPP format)  |
| <b>UE IP</b>        | Assigned IPv4/IPv6 address               |
| <b>Source</b>       | UE's external IP and port (NAT address)  |
| <b>APN</b>          | Access Point Name for the PDN connection |
| <b>Child SA SPI</b> | IPSec Child SA Security Parameter Index  |

### **Network & Timing Section**

| Field                | Description                              |
|----------------------|--|
| <b>DNS</b>           | DNS servers provided to the UE           |
| <b>P-CSCF</b>        | Proxy-CSCF servers for IMS signaling     |
| <b>Connected</b>     | Timestamp when session was established   |
| <b>Last Activity</b> | Timestamp of most recent packet activity |
| <b>Duration</b>      | Time since session establishment         |

### Traffic Section

| Field                 | Description                           |
|-----------------------|---------------------------------------|
| <b>Bytes In (UL)</b>  | Total bytes received from UE (uplink) |
| <b>Bytes Out (DL)</b> | Total bytes sent to UE (downlink)     |
| <b>Packets In</b>     | Total packets received from UE        |
| <b>Packets Out</b>    | Total packets sent to UE              |

## Empty State

When no sessions are active, the view displays:

- "No active sessions" message
- Indicates whether UE connections should be attempted

## Auto-Refresh

The session list automatically refreshes every second.

# Diameter Peers View

The Diameter Peers view displays the status of all configured Diameter peers (HSS for SWx, PGW for S6b).

## Peer List

Each peer row displays:

| Column     | Description   |
|------------|---|
| Peer       | Diameter Identity (Origin-Host)                             |
| Realm      | Diameter Realm (Origin-Realm)                               |
| IP Address | Transport address in format <code>protocol://ip:port</code> |
| Status     | Connection status   |

## Status Indicators

| Status       | Color | Description                          |
|--------------|-------|--------------------------------------|
| Connected    | Green | Diameter peer connection established |
| Disconnected | Red   | Peer not connected                   |
| Unknown      | Gray  | Status cannot be determined          |

## Peer Count Summary

The header displays aggregate counts:

- **X Connected** - Number of peers with active connections
- **Y Disconnected** - Number of peers without connections

## Peer Details

Click any peer row to expand detailed information:

| Field                          | Description   |
|--------------------------------|---|
| <b>Connection Initiation</b>   | Who initiates: <code>local</code> (we connect to peer) or <code>remote</code> (peer connects to us) |
| <b>Transport</b>               | Protocol: <code>tcp</code> or <code>sctp</code>   |
| <b>Product Name</b>            | Peer's advertised product name from CER/CEA   |
| <b>Advertised Applications</b> | Diameter Application IDs supported by the peer  |

## Empty State

When no peers are configured, the view displays:

- "No Diameter Peers configured" if Diameter is enabled
- "Diameter is disabled" with configuration hint if disabled

## Auto-Refresh

The peer list automatically refreshes every second.

## Logs View

The Logs view provides real-time streaming of system logs with filtering and search capabilities.

## Log Display

Logs appear in a scrolling container with newest entries at the bottom. Each log entry displays:

| Element          | Description                      |
|------------------|----------------------------------|
| <b>Timestamp</b> | When the log entry was generated |
| <b>Level</b>     | Severity level with color coding |
| <b>Message</b>   | Log message content              |

## Log Levels

Logs are color-coded by severity:

| Level          | Color  | Description                     |
|----------------|--------|---------------------------------|
| <b>debug</b>   | Gray   | Detailed diagnostic information |
| <b>info</b>    | Blue   | General informational messages  |
| <b>warning</b> | Yellow | Warning conditions              |
| <b>error</b>   | Red    | Error conditions                |

## Level Filtering

Filter logs by minimum severity level using the dropdown:

| Filter            | Shows                       |
|-------------------|-----------------------------|
| <b>All Levels</b> | debug, info, warning, error |
| <b>Info+</b>      | info, warning, error        |
| <b>Warning+</b>   | warning, error              |
| <b>Error Only</b> | error                       |

## Search

The search box filters logs in real-time:

- Enter any text to filter log messages
- Matching is case-insensitive
- Clears when the search box is emptied

## Controls

| Control             | Description                                  |
|---------------------|--|
| <b>Pause/Resume</b> | Toggle log streaming on/off                  |
| <b>Clear</b>        | Remove all displayed logs                    |
| <b>Auto-scroll</b>  | Toggle automatic scrolling to newest entries |

## Log Buffer

- Maximum 1000 log entries are retained
- Oldest entries are removed when the limit is reached
- Clearing logs removes all entries from the display

## Empty State

When no logs match the current filters:

- "No logs to display" message
- Verify filter settings if logs are expected

## Auto-Refresh

New logs appear automatically as they are generated (when not paused).

# Docs View

The Docs view provides an integrated documentation browser, allowing operators to access all OmniEPDG documentation directly from the control panel.

## Document Selection

Select from available documentation files using the button bar:

| Document                  | Description                                      |
|---------------------------|--|
| <b>OPERATIONS.md</b>      | Operations guide with quick start and procedures |
| <b>README.md</b>          | Project overview and setup instructions          |
| <b>architecture.md</b>    | System architecture and call flows               |
| <b>configuration.md</b>   | Complete configuration reference                 |
| <b>control-panel.md</b>   | This control panel guide                         |
| <b>metrics.md</b>         | Prometheus metrics reference                     |
| <b>troubleshooting.md</b> | Common issues and resolution steps               |

## Markdown Rendering

Documentation is rendered with full Markdown support including:

- Headers and text formatting
- Code blocks with syntax highlighting
- Tables
- Links (internal and external)
- Lists and blockquotes

## Resources View

The Resources view displays BEAM VM statistics and running OTP applications.

## System Metrics

| Metric                | Description                               |
|-----------------------|---|
| <b>Memory Usage</b>   | Total memory used by the BEAM VM          |
| <b>BEAM Processes</b> | Number of Erlang/Elixir processes running |
| <b>Uptime</b>         | Time since the application started        |

## Running Applications

Lists all loaded OTP applications grouped by category:

| Category      | Description                             |
|---------------|---|
| <b>Main</b>   | The OmniEPDG application                |
| <b>System</b> | Core Erlang/OTP and Elixir applications |

Click an application to view its details including version, description, and dependencies.

# Configuration View

The Configuration view displays runtime configuration and loaded applications.

## Environment Information

| Field                 | Description                                      |
|-----------------------|--|
| <b>Environment</b>    | Current Mix environment (Development/Production) |
| <b>Elixir Version</b> | Running Elixir version                           |

## Application List

Displays all loaded OTP applications with their versions. Select an application to view:

- Application description
- Version information
- Dependencies
- Configuration parameters

# Control Panel Configuration

## HTTP Port

Configure the control panel port in `config/runtime.exs`:

```
config :omniepdg, OmniEpdg.Web.Endpoint,  
  http: [port: 4000]
```

| Parameter         | Type    | Default | Description                     |
|-------------------|---------|---------|---------------------------------|
| <code>port</code> | Integer | 4000    | HTTP port for the control panel |

## Disabling the Control Panel

The control panel can be disabled by not starting the web endpoint in production if not needed. Contact your system integrator for deployment-specific configuration.

# OmniEPDG Metrics Reference

OmniEPDG exposes Prometheus metrics for monitoring authentication flows, session lifecycle, Diameter signaling, and system health. Metrics are served via HTTP for Prometheus scraping.

## Table of Contents

- [Metrics Endpoint](#)
- [Configuration](#)
- [Metric Categories](#)
  - [IKEv2 Session Metrics](#)
  - [EAP Authentication Metrics](#)
  - [Authentication Security Metrics](#)
  - [Diameter SWx Metrics](#)
  - [Diameter S6b Metrics](#)
  - [Session Lifecycle Metrics](#)
  - [ESP Data Plane Metrics](#)
  - [IP Pool Metrics](#)
  - [VM Metrics](#)
- [Prometheus Integration](#)
- [Example Queries](#)
- [Alerting Rules](#)

## Metrics Endpoint

OmniEPDG exposes metrics at:

```
http://<host>:9568/metrics
```

The endpoint returns metrics in Prometheus exposition format, compatible with Prometheus, Grafana, and other monitoring tools.

## Configuration

Configure the metrics endpoint in `config/runtime.exs`:

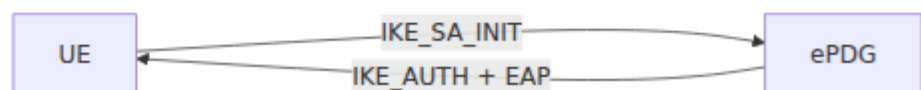
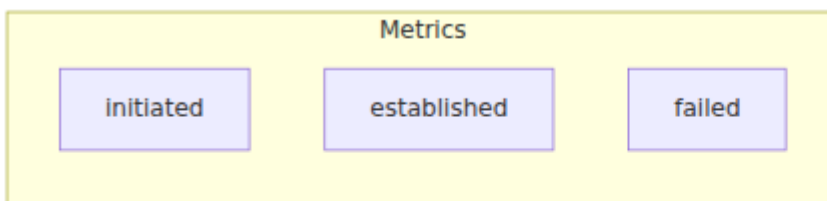
```
config :omniepdg,  
  prometheus: %{  
    port: 9568  
  }
```

| Parameter         | Type    | Default           | Env Var                      | Description                                      |
|-------------------|---------|-------------------|------------------------------|--|
| <code>port</code> | Integer | <code>9568</code> | <code>PROMETHEUS_PORT</code> | HTTP port for the <code>/metrics</code> endpoint |

## Metric Categories

### IKEv2 Session Metrics

Metrics tracking IKEv2 tunnel establishment on the SWu interface.



**Metric:** `epdg_ikev2_session_initiated_count` **Type:** Counter **Description:** Total IKE\_SA\_INIT exchanges started. Increments when a UE initiates tunnel establishment.

---

**Metric:** `epdg_ikev2_session_established_count` **Type:** Counter **Description:** Total IKE SAs successfully established. Increments after successful EAP-AKA authentication and Child SA creation.

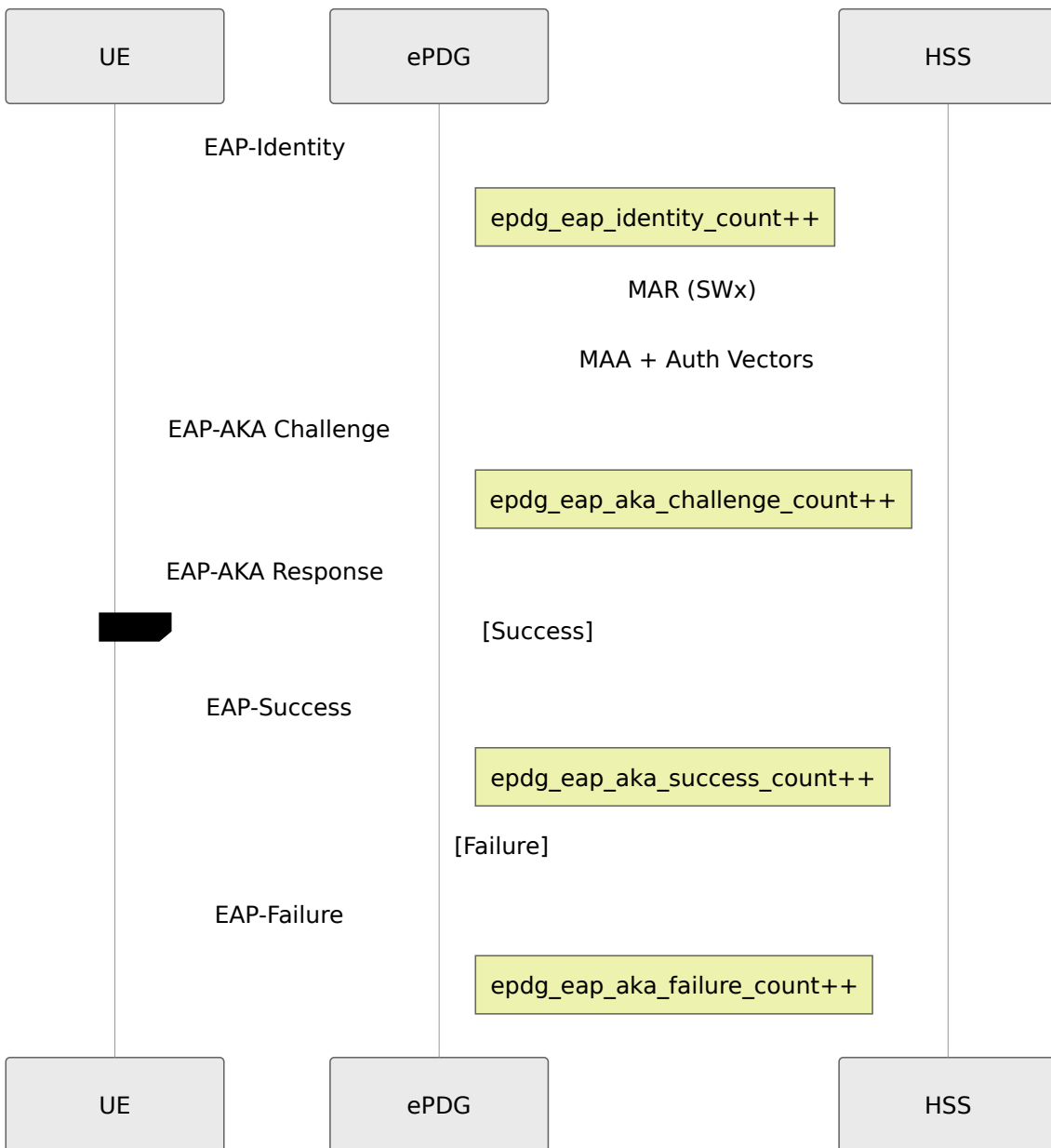
---

**Metric:** `epdg_ikev2_session_failed_count` **Type:** Counter **Description:** Total IKE SA establishment failures **Labels:**

- `reason` - Failure reason (e.g., `auth_failed`, `timeout`, `invalid_proposal`)

## EAP Authentication Metrics

Metrics tracking EAP-AKA authentication flows per [RFC 4187](#). OmniEPDG also supports EAP-AKA' per [RFC 5448](#), with the authentication type automatically selected based on the UE's NAI identity prefix.



**Metric:** `epdg_eap_identity_count` **Type:** Counter **Description:** Total EAP-Identity requests received from UEs

---

**Metric:** `epdg_eap_aka_challenge_count` **Type:** Counter **Description:** Total EAP-AKA challenges sent to UEs

---

**Metric:** `epdg_eap_aka_success_count` **Type:** Counter **Description:** Total successful EAP-AKA authentications

---

**Metric:** `epdg_eap_aka_failure_count` **Type:** Counter **Description:** Total failed EAP-AKA authentications **Labels:**

- `reason` - Failure reason (e.g., `res_mismatch`, `invalid_identity`, `authentication_rejected`)
- 

**Metric:** `epdg_eap_aka_sync_failure_count` **Type:** Counter **Description:** Total EAP-AKA sequence number (SQN) synchronization failures. Indicates USIM/HSS sequence number mismatch requiring resynchronization.

## Authentication Security Metrics

Metrics for the authentication security layer. See the [Security Guide](#) for configuration details.

**Metric:** `epdg_auth_verification_failed_count` **Type:** Counter **Description:** Total AUTH payload verification failures. Indicates potential man-in-the-middle attacks or implementation bugs.

---

**Metric:** `epdg_auth_rate_limited_count` **Type:** Counter **Description:** Total authentication attempts blocked by rate limiting **Labels:**

- `type` - Blocking reason: `ip` (per-IP threshold exceeded) or `imsi` (per-IMSI threshold exceeded)

### Example queries:

```
# Rate limited attempts per minute
rate(epdg_auth_rate_limited_count[1m])

# Rate limited by type
sum by (type) (rate(epdg_auth_rate_limited_count[5m]))
```

---

**Metric:** `epdg_auth_geoip_blocked_count` **Type:** Counter **Description:** Total authentication attempts blocked by GeoIP country filtering **Labels:**

- `country` - ISO 3166-1 alpha-2 country code (e.g., `CN`, `RU`), or `UNKNOWN` for IPs that could not be geolocated

### Example queries:

```
# GeoIP blocks per minute
rate(epdg_auth_geoip_blocked_count[1m])

# Top blocked countries
topk(10, sum by (country) (epdg_auth_geoip_blocked_count))
```

---

**Metric:** `epdg_esp_replay_detected_count` **Type:** Counter **Description:** Total ESP packets rejected due to replay detection (per RFC 4303). Indicates potential replay attacks or network issues causing packet reordering.

## Diameter SWx Metrics

Metrics for the SWx interface between ePDG and HSS per [3GPP TS 29.273](#).

**Metric:** `epdg_diameter_swx_mar_count` **Type:** Counter **Description:** Total Multimedia-Auth-Requests sent to HSS for authentication vector retrieval

**Labels:**

- `result` - Request outcome: `success` or `failure`

---

**Metric:** `epdg_diameter_swx_sar_count` **Type:** Counter **Description:** Total Server-Assignment-Requests sent to HSS for registration/deregistration **Labels:**

- `result` - Request outcome: `success` or `failure`

---

**Metric:** `epdg_diameter_swx_mar_latency_ms` **Type:** Histogram **Description:** MAR response time in milliseconds **Buckets:** 50, 100, 250, 500, 1000, 2500 ms

---

**Metric:** `epdg_diameter_swx_sar_latency_ms` **Type:** Histogram **Description:** SAR response time in milliseconds **Buckets:** 50, 100, 250, 500, 1000, 2500 ms

---

**Metric:** `epdg_diameter_swx_pending_count` **Type:** Gauge **Description:** Current number of pending SWx requests awaiting response. High values indicate HSS congestion or connectivity issues.

## Diameter S6b Metrics

Metrics for the S6b interface between AAA server and PGW per [3GPP TS 29.273](#). Only applicable in GTP mode.

**Metric:** `epdg_diameter_s6b_aar_count` **Type:** Counter **Description:** Total AA-Requests handled for session authorization **Labels:**

- `result` - Request outcome: `success` or `failure`
- 

**Metric:** `epdg_diameter_s6b_str_count` **Type:** Counter **Description:** Total Session-Termination-Requests processed

---

**Metric:** `epdg_diameter_s6b_active_sessions_count` **Type:** Gauge **Description:** Current number of active S6b sessions

## Session Lifecycle Metrics

Metrics tracking PDN session creation and termination.

**Metric:** `epdg_session_created_count` **Type:** Counter **Description:** Total sessions created **Labels:**

- `vpn_mode` - VPN mode: `simple` or `gtp`
- 

**Metric:** `epdg_session_terminated_count` **Type:** Counter **Description:** Total sessions terminated **Labels:**

- `reason` - Termination reason: `user_request`, `timeout`, `error`, `admin`
- 

**Metric:** `epdg_sessions_active_count` **Type:** Gauge **Description:** Current number of active sessions. Polled every 5 seconds.

---

**Metric:** `epdg_sessions_by_state_count` **Type:** Gauge **Description:** Sessions grouped by FSM state **Labels:**

- `state` - Session state (e.g., `init`, `eap_identity`, `eap_aka_challenge`, `authenticated`, `established`)
- 

**Metric:** `epdg_auth_duration_ms` **Type:** Histogram **Description:** Full authentication flow duration from IKE\_SA\_INIT to session established **Buckets:** 100, 250, 500, 1000, 2500, 5000, 10000 ms

---

**Metric:** `epdg_session_duration_seconds` **Type:** Histogram **Description:** Session lifetime from establishment to termination **Buckets:** 60, 300, 900, 1800, 3600, 7200, 14400 seconds (1 min to 4 hours)

---

## ESP Data Plane Metrics

Metrics for ESP packet processing per [RFC 4303](#).

**Metric:** `epdg_esp_packets_in_count` **Type:** Counter **Description:** Total ESP packets successfully decrypted (UE → network direction)

---

**Metric:** `epdg_esp_packets_out_count` **Type:** Counter **Description:** Total ESP packets encrypted (network → UE direction)

---

**Metric:** `epdg_esp_bytes_in_total` **Type:** Gauge **Description:** Total bytes decrypted from ESP packets

---

**Metric:** `epdg_esp_bytes_out_total` **Type:** Gauge **Description:** Total bytes encrypted into ESP packets

## IP Pool Metrics

Metrics for IP address pool management in Simple VPN mode.

**Metric:** `epdg_ip_allocated_count` **Type:** Counter **Description:** Total IP addresses allocated **Labels:**

- `type` - Address type: `ipv4` or `ipv6`
- 

**Metric:** `epdg_ip_released_count` **Type:** Counter **Description:** Total IP addresses released **Labels:**

- `type` - Address type: `ipv4` or `ipv6`
- 

**Metric:** `epdg_ip_pool_allocated_count` **Type:** Gauge **Description:** Current number of allocated IP addresses

---

**Metric:** `epdg_ip_pool_available_count` **Type:** Gauge **Description:** Current number of available IP addresses in the pool

---

**Metric:** `epdg_ip_pool_utilization_ratio` **Type:** Gauge **Description:** IP pool utilization as a ratio from 0.0 to 1.0. Values approaching 1.0 indicate pool exhaustion risk.

## VM Metrics

Erlang/BEAM virtual machine metrics for system health monitoring.

**Metric:** `vm_memory_total` **Type:** Gauge **Unit:** Bytes **Description:** Total memory allocated by the VM

---

**Metric:** `vm_memory_processes` **Type:** Gauge **Unit:** Bytes **Description:** Memory used by Erlang processes

---

**Metric:** `vm_memory_binary` **Type:** Gauge **Unit:** Bytes **Description:** Memory used for binaries (including packet buffers)

---

**Metric:** `vm_memory_ets` **Type:** Gauge **Unit:** Bytes **Description:** Memory used by ETS tables (session state, registries)

---

**Metric:** `vm_system_info_process_count` **Type:** Gauge **Description:** Number of running Erlang processes

---

**Metric:** `vm_system_info_port_count` **Type:** Gauge **Description:** Number of open ports (sockets, file handles)

---

**Metric:** `vm_statistics_run_queue` **Type:** Gauge **Description:** Total length of scheduler run queues. High values indicate CPU saturation.

# Prometheus Integration

## Scrape Configuration

Add OmniEPDG to your Prometheus `prometheus.yml`:

```
scrape_configs:
  - job_name: 'omniepdg'
    scrape_interval: 15s
    static_configs:
      - targets: ['epdg-host:9568']
        labels:
          instance: 'epdg-01'
          environment: 'production'
```

# Service Discovery

For Kubernetes deployments, use service discovery:

```
scrape_configs:
  - job_name: 'omniepdg'
    kubernetes_sd_configs:
      - role: pod
    relabel_configs:
      - source_labels: [__meta_kubernetes_pod_label_app]
        action: keep
        regex: omniepdg
      - source_labels:
          [__meta_kubernetes_pod_annotation_prometheus_io_port]
        action: replace
        target_label: __address__
        regex: (.+)
        replacement: ${1}:9568
```

## Example Queries

### Authentication Success Rate

```
# Success rate over 5 minutes
sum(rate(epdg_eap_aka_success_count[5m]))
/
(sum(rate(epdg_eap_aka_success_count[5m])) +
sum(rate(epdg_eap_aka_failure_count[5m])))
```

### Session Establishment Rate

```
# Sessions established per second
rate(epdg_ikev2_session_established_count[5m])
```

## Authentication Latency (p95)

```
histogram_quantile(0.95,  
sum(rate(epdg_auth_duration_ms_bucket[5m])) by (le))
```

## HSS Latency (p99)

```
histogram_quantile(0.99,  
sum(rate(epdg_diameter_swx_mar_latency_ms_bucket[5m])) by (le))
```

## Active Sessions

```
epdg_sessions_active_count
```

## IP Pool Utilization

```
epdg_ip_pool_utilization_ratio * 100
```

## ESP Throughput

```
# Bytes per second (inbound)  
rate(epdg_esp_bytes_in_total[5m])  
  
# Packets per second (both directions)  
rate(epdg_esp_packets_in_count[5m]) +  
rate(epdg_esp_packets_out_count[5m])
```

## Failure Breakdown by Reason

```
# EAP failures by reason
sum by (reason) (rate(epdg_eap_aka_failure_count[5m]))

# Session terminations by reason
sum by (reason) (rate(epdg_session_terminated_count[5m]))
```

## Alerting Rules

Example Prometheus alerting rules for OmniEPDG:

```
groups:
- name: omniepdg
  rules:
    # High authentication failure rate
    - alert: OmniEPDGHighAuthFailureRate
      expr: |
        sum(rate(epdg_eap_aka_failure_count[5m]))
        /
        (sum(rate(epdg_eap_aka_success_count[5m])) +
        sum(rate(epdg_eap_aka_failure_count[5m])))
        > 0.1
      for: 5m
      labels:
        severity: warning
      annotations:
        summary: "High EAP-AKA authentication failure rate"
        description: "Authentication failure rate is {{ $value |
humanizePercentage }} over the last 5 minutes"

    # IP pool near exhaustion
    - alert: OmniEPDGIPPoolLow
      expr: epdg_ip_pool_utilization_ratio > 0.9
      for: 5m
      labels:
        severity: warning
      annotations:
        summary: "IP pool utilization above 90%"
        description: "IP pool is {{ $value | humanizePercentage
}} utilized"

    # IP pool exhausted
    - alert: OmniEPDGIPPoolExhausted
      expr: epdg_ip_pool_available_count == 0
      for: 1m
      labels:
        severity: critical
      annotations:
        summary: "IP pool exhausted"
        description: "No IP addresses available for new
sessions"

    # HSS latency high
    - alert: OmniEPDGHSSLatencyHigh
```

```
    expr: |
      histogram_quantile(0.95,
sum(rate(epdg_diameter_swx_mar_latency_ms_bucket[5m])) by (le))
      > 1000
    for: 5m
    labels:
      severity: warning
    annotations:
      summary: "High HSS (SWx) latency"
      description: "95th percentile MAR latency is {{ $value
}}ms"
```

```
# Pending SWx requests backlog
```

```
- alert: OmniEPDGSWxBacklog
  expr: epdg_diameter_swx_pending_count > 100
  for: 2m
  labels:
    severity: warning
  annotations:
    summary: "SWx request backlog building"
    description: "{{ $value }} pending SWx requests"
```

```
# VM memory high
```

```
- alert: OmniEPDGMemoryHigh
  expr: vm_memory_total > 2147483648
  for: 10m
  labels:
    severity: warning
  annotations:
    summary: "OmniEPDG memory usage high"
    description: "VM memory usage is {{ $value |
humanize1024 }}"
```

```
# Scheduler overload
```

```
- alert: OmniEPDGSchedulerOverload
  expr: vm_statistics_run_queue > 10
  for: 5m
  labels:
    severity: warning
  annotations:
    summary: "Erlang scheduler run queue high"
    description: "Run queue length is {{ $value }},
indicating CPU saturation"
```

```
# No sessions (potential service issue)
- alert: OmniEPDGNoSessions
  expr: epdg_sessions_active_count == 0 and
epdg_ikev2_session_initiated_count > 0
  for: 10m
  labels:
    severity: warning
  annotations:
    summary: "No active sessions despite connection
attempts"
    description: "Sessions are being initiated but none are
active"

# High rate limiting activity (potential attack)
- alert: OmniEPDGHighRateLimiting
  expr: rate(epdg_auth_rate_limited_count[5m]) > 10
  for: 5m
  labels:
    severity: warning
  annotations:
    summary: "High rate of blocked authentication attempts"
    description: "{{ $value | printf \"%.1f\" }} auth
attempts blocked per second"

# GeoIP blocking spike (potential attack from specific
region)
- alert: OmniEPDGGeoIPBlockingSpike
  expr: |
    rate(epdg_auth_geoip_blocked_count[5m]) > 5
  for: 5m
  labels:
    severity: warning
  annotations:
    summary: "Elevated GeoIP blocking activity"
    description: "{{ $value | printf \"%.1f\" }} connections
blocked per second by GeoIP"

# ESP replay attacks detected
- alert: OmniEPDGReplayAttack
  expr: rate(epdg_esp_replay_detected_count[5m]) > 0
  for: 2m
  labels:
    severity: warning
  annotations:
```

```
summary: "ESP replay attacks detected"
description: "{{ $value | printf \"%.1f\" }} replay
attempts per second"

# AUTH verification failures (potential MITM)
- alert: OmniEPDGAUTHVerificationFailures
  expr: rate(epdg_auth_verification_failed_count[5m]) > 0
  for: 2m
  labels:
    severity: critical
  annotations:
    summary: "AUTH payload verification failures detected"
    description: "Potential man-in-the-middle attack or
implementation bug"
```

# Network Requirements

This document covers the firewall ports and DNS entries required to deploy OmniEPDG for WiFi calling.

## Firewall Ports

### Internet-Facing Ports (UE ↔ ePDG)

These ports must be open to the internet for mobile devices to establish WiFi calling connections.

| Port | Protocol | Direction | Purpose  |
|------|----------|-----------|--|
| 500  | UDP      | Inbound   | IKEv2 initial exchange (IKE_SA_INIT, IKE_AUTH)   |
| 4500 | UDP      | Inbound   | IKEv2 NAT-Traversal and ESP-in-UDP encapsulation |

**Port 500/UDP** handles the initial IKEv2 negotiation. If NAT is detected between the UE and ePDG (which is almost always the case for WiFi calling), the connection automatically migrates to port 4500.

**Port 4500/UDP** carries both IKEv2 signaling and ESP-encrypted user data when NAT-T is active. This is the primary data path for all WiFi calling traffic.

### Internal Network Ports (ePDG ↔ Core)

These ports are used for communication between OmniEPDG and the mobile core network. They should be accessible from the ePDG but not exposed to the internet.

| Port | Protocol | Direction     | Purpose                              | Peer      |
|------|----------|---------------|--------------------------------------|-----------|
| 3868 | TCP      | Bidirectional | Diameter SWx (authentication)        | HSS / DRA |
| 3868 | TCP      | Bidirectional | Diameter S6b (session authorization) | PGW / AAA |
| 2123 | UDP      | Bidirectional | GTPv2-C control plane (S2b)          | PGW       |
| 2152 | UDP      | Bidirectional | GTP-U user plane (S2b-U)             | PGW       |

## Management Ports

These ports are for operational monitoring and should be restricted to management networks.

| Port | Protocol | Purpose   |
|------|----------|---|
| 4000 | TCP      | Control panel web interface (HTTP)              |
| 443  | TCP      | Control panel web interface (HTTPS, production) |
| 9568 | TCP      | Prometheus metrics endpoint                     |

## DNS Requirements

### ePDG Discovery DNS Record

Mobile devices discover the ePDG using a standardized DNS naming convention defined in 3GPP TS 23.003. The FQDN format is:

```
epdg.epc.mnc<MNC>.mcc<MCC>.pub.3gppnetwork.org
```

Where:

- `<MCC>` is the 3-digit Mobile Country Code (e.g., `505` for Australia)
- `<MNC>` is the 2 or 3-digit Mobile Network Code, zero-padded to 3 digits (e.g., `001`)

The DNS record should be an **A record** (or AAAA for IPv6) pointing to the public IP address of OmniEPDG.

```
epdg.epc.mnc999.mcc999.pub.3gppnetwork.org. IN A 203.0.113.10
```

## Certificate Common Name

The ePDG's TLS certificate must have a Subject Alternative Name (SAN) matching the ePDG FQDN that devices will connect to. This is validated by the UE during IKEv2 authentication.

### Certificate requirements:

- SAN must include the ePDG discovery FQDN (e.g., `epdg.epc.mnc001.mcc001.pub.3gppnetwork.org`)
- Certificate must be signed by a trusted CA (devices validate the chain)
- RSA 2048-bit or ECDSA P-256 minimum

## Diameter Realm DNS

For proper Diameter routing, the realm should resolve via DNS NAPTR/SRV records per RFC 6408. The realm format is:

```
epc.mnc<MNC>.mcc<MCC>.3gppnetwork.org
```

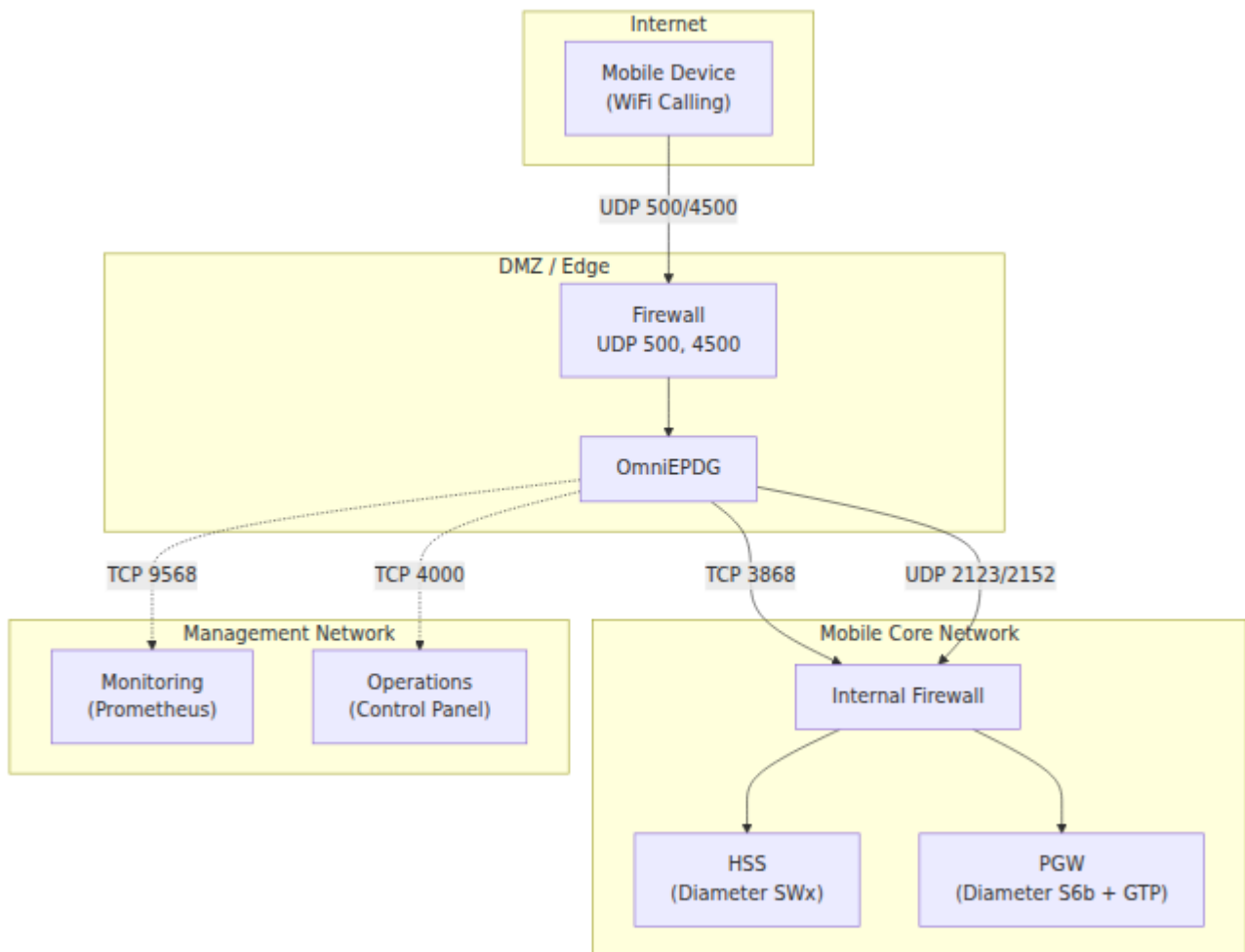
### Example:

```
epc.mnc001.mcc001.3gppnetwork.org
```

This realm is used in:

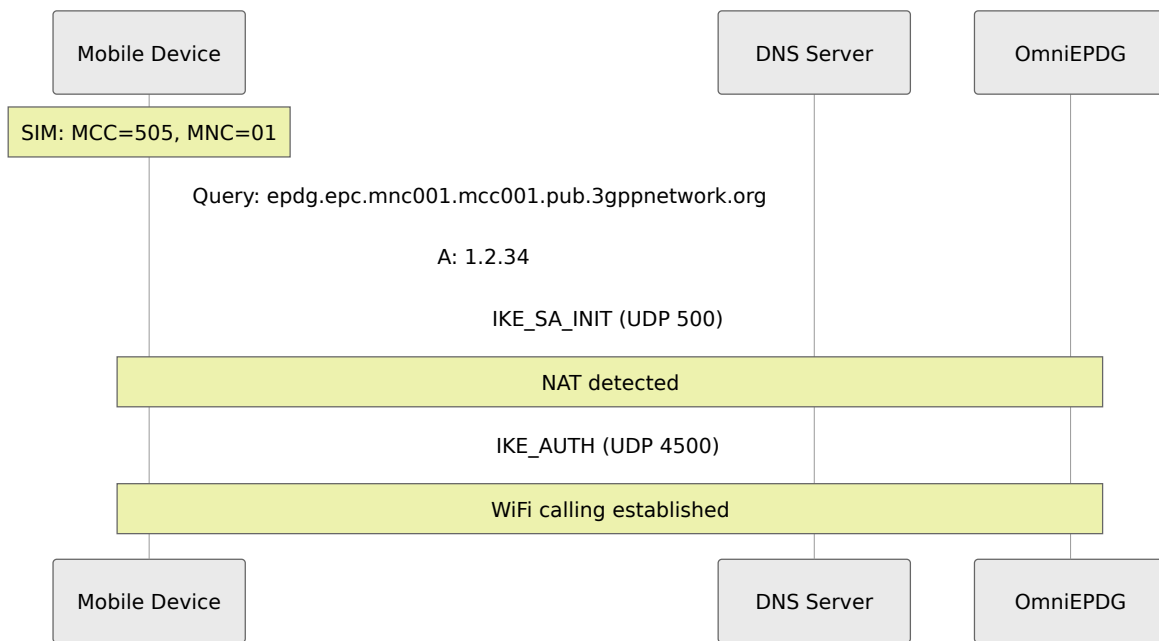
- NAI (Network Access Identifier) sent by the UE during authentication
- Diameter Origin-Realm and Destination-Realm AVPs
- Diameter routing decisions

## Network Topology



## DNS Lookup Flow

When a mobile device initiates WiFi calling, the following DNS resolution occurs:



# Checklist

## Internet-Facing Requirements

- UDP 500 open inbound to OmniEPDG
- UDP 4500 open inbound to OmniEPDG
- DNS A record: `epdg.epc.mnc<MNC>.mcc<MCC>.pub.3gppnetwork.org` → ePDG public IP
- TLS certificate with matching SAN installed

## Core Network Requirements

- TCP 3868 open between OmniEPDG and HSS/DRA
- TCP 3868 open between OmniEPDG and PGW/AAA (GTP mode only)
- UDP 2123 open between OmniEPDG and PGW (GTP mode only)
- UDP 2152 open between OmniEPDG and PGW (GTP mode only)

## Management Requirements

- TCP 4000/443 accessible from operations network
- TCP 9568 accessible from monitoring infrastructure

# References

- [3GPP TS 23.003](#) - Numbering, addressing and identification (ePDG FQDN format)
- [3GPP TS 23.402](#) - Architecture enhancements for non-3GPP accesses
- [RFC 7296](#) - IKEv2 Protocol
- [RFC 3948](#) - UDP Encapsulation of IPsec ESP Packets (NAT-T)
- [RFC 6733](#) - Diameter Base Protocol

# OmniEPDG

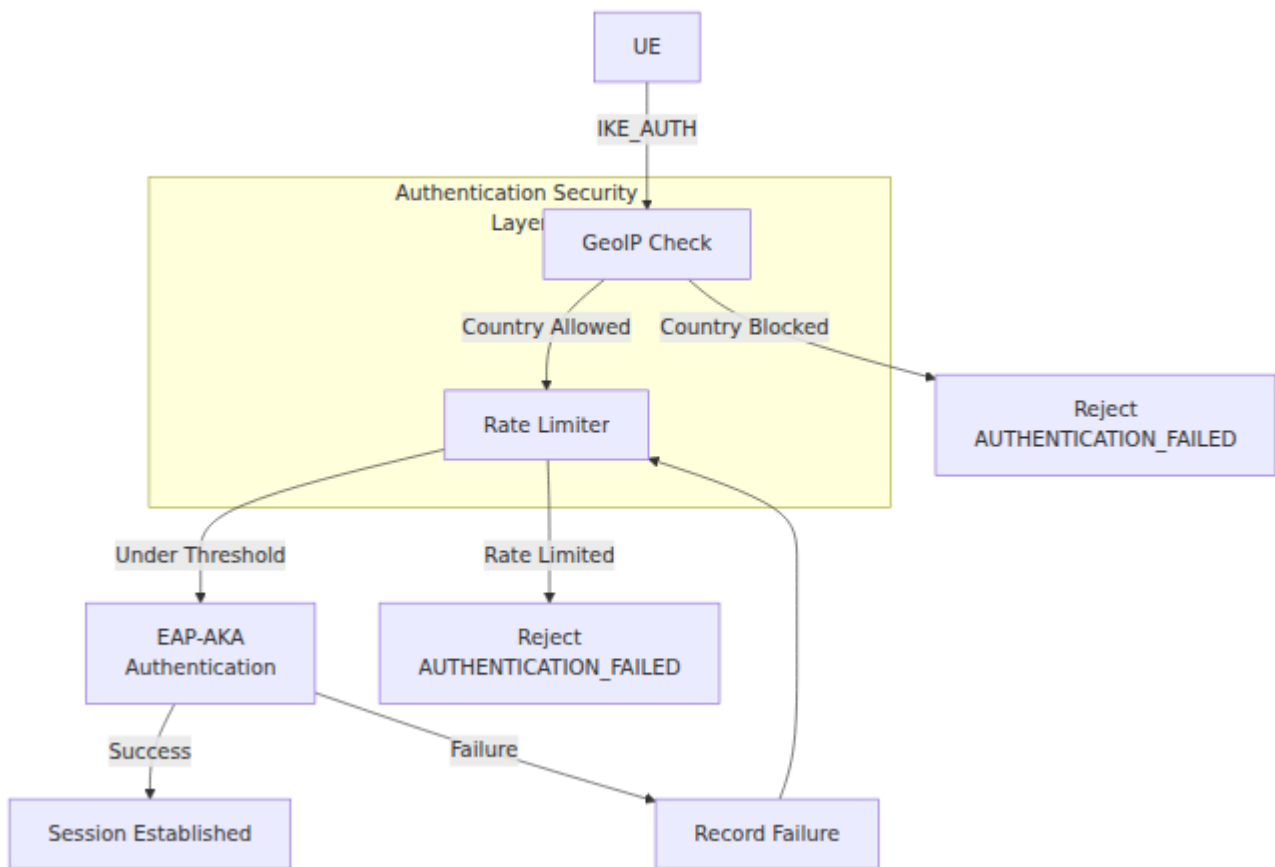
# Authentication Security

OmniEPDG implements multiple layers of authentication security to protect against brute-force attacks, credential stuffing, and unauthorized access from restricted regions.

## Table of Contents

- [Overview](#)
- [Authentication Rate Limiting](#)
- [GeoIP Country Blocking](#)
- [Security Flow](#)
- [Metrics](#)
- [Troubleshooting](#)

# Overview



OmniEPDG performs security checks at the start of the IKE\_AUTH exchange, before expensive cryptographic operations:

1. **GeoIP Check** (optional) - Verifies the source IP is from an allowed country
2. **Rate Limit Check** - Ensures the IP/IMSI hasn't exceeded failure thresholds
3. **EAP-AKA Authentication** - Standard 3GPP authentication proceeds if checks pass

## Authentication Rate Limiting

Rate limiting protects against brute-force attacks by tracking failed authentication attempts per source IP and per IMSI. When thresholds are exceeded, further attempts are temporarily blocked.

# How It Works



The rate limiter uses a **sliding window algorithm**:

- Each failed attempt is recorded with a timestamp
- Attempts older than the configured window are automatically expired
- When failures in the window exceed the threshold, the source is blocked
- Blocks expire after the configured cooldown period

## Dual Tracking

Two independent limits are enforced simultaneously:

| Tracking Type   | Purpose   | Default Threshold    | Default Block |
|-----------------|---|----------------------|---------------|
| <b>Per-IP</b>   | Catches port scanners and distributed attacks from single sources | 10 failures / minute | 5 minutes     |
| <b>Per-IMSI</b> | Catches targeted attacks on specific subscribers                  | 5 failures / minute  | 10 minutes    |

Both checks must pass for an authentication attempt to proceed. If either threshold is exceeded, the attempt is rejected.

# Configuration

```
config :omniepdg,  
  # Per-IP rate limiting  
  auth_rate_limit_per_ip: 10,           # Max failures before  
blocking  
  auth_rate_limit_ip_window_ms: 60_000, # Window size (1 minute)  
  auth_rate_limit_ip_block_ms: 300_000, # Block duration (5  
minutes)  
  
  # Per-IMSI rate limiting  
  auth_rate_limit_per_imsi: 5,         # Max failures before  
blocking  
  auth_rate_limit_imsi_window_ms: 60_000, # Window size (1  
minute)  
  auth_rate_limit_imsi_block_ms: 600_000 # Block duration (10  
minutes)
```

## Per-IP Parameters

| Parameter                                 | Type    | Required | Default | Description  |
|---|---------|----------|---------|--|
| <code>auth_rate_limit_per_ip</code>       | Integer | No       | 10      | Maximum failed authentication attempts allowed for a single IP address within the window period before blocking. |
| <code>auth_rate_limit_ip_window_ms</code> | Integer | No       | 60000   | Sliding window in milliseconds for counting IP failures. Failures exceeding this count will not be counted.      |
| <code>auth_rate_limit_ip_block_ms</code>  | Integer | No       | 300000  | Duration in milliseconds to block an IP address after exceeding the threshold. Default is 5 minutes.             |

## Per-IMSI Parameters

| Parameter                                   | Type    | Required | Default | Description   |
|---|---------|----------|---------|---|
| <code>auth_rate_limit_per_imsi</code>       | Integer | No       | 5       | Maximum failed authentication attempts allowed within a sliding window period. Lower values protect against IP block attacks.             |
| <code>auth_rate_limit_imsi_window_ms</code> | Integer | No       | 60000   | Sliding window in milliseconds for counting IMSI failures.  |
| <code>auth_rate_limit_imsi_block_ms</code>  | Integer | No       | 600000  | Duration in milliseconds to block an IMSI address after exceeding the threshold. Default is 10 minutes (longer than IP block protection). |

| Parameter | Type | Required | Default | Description         |
|-----------|------|----------|---------|---------------------|
|           |      |          |         | specific subscriber |

## Behavior on Success

When authentication succeeds, the rate limiter clears all failure history for that IP/IMSI pair. This allows legitimate users who experienced transient failures (e.g., network issues) to recover without being permanently penalized.

## Example Configurations

### High-Security Environment

Strict limits for environments with low tolerance for failed attempts:

```
config :omniepdg,
  auth_rate_limit_per_ip: 5,
  auth_rate_limit_ip_window_ms: 120_000,    # 2 minute window
  auth_rate_limit_ip_block_ms: 900_000,     # 15 minute block

  auth_rate_limit_per_imsi: 3,
  auth_rate_limit_imsi_window_ms: 120_000,
  auth_rate_limit_imsi_block_ms: 1_800_000 # 30 minute block
```

**How it works:** Only 5 failures per IP or 3 failures per IMSI are allowed within a 2-minute window. Blocks last 15-30 minutes respectively.

**Use case:** Enterprise deployments, high-value subscriber bases, or networks under active attack.

### Relaxed Environment

More permissive limits for development or testing:

```

config :omniepdg,
  auth_rate_limit_per_ip: 50,
  auth_rate_limit_ip_window_ms: 60_000,
  auth_rate_limit_ip_block_ms: 60_000,      # 1 minute block

  auth_rate_limit_per_imsi: 20,
  auth_rate_limit_imsi_window_ms: 60_000,
  auth_rate_limit_imsi_block_ms: 120_000   # 2 minute block

```

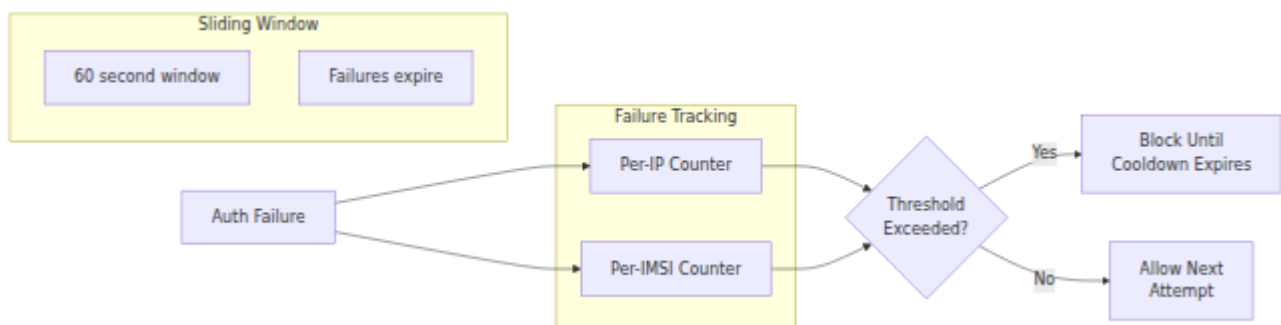
**How it works:** Higher thresholds and shorter blocks allow more testing flexibility.

**Use case:** Development environments, integration testing.

## GeoIP Country Blocking

GeoIP blocking restricts WiFi calling access based on the geographic location of the connecting IP address. This is useful for operators who need to limit service to specific countries for regulatory or business reasons.

### Overview



### IP geolocation database

OmniEPDG uses the **DB-IP IP-to-City Lite** database (CC BY 4.0 — see [priv/geoup/ATTRIBUTION.md](#)). It is **not** committed to git (~125 MB); instead it's **downloaded at build time** — `mix release` runs the `geoip.fetch` task as a release step, so every package ships a current database. (Dev/test fetch it on demand via the `mix test` alias.) Because of this:

- **Every session is annotated out of the box** with country, city and approximate coordinates — shown in the web UI ("Location" column) and the `/api/sessions` response: `country_code`, `country_name`, `continent_code`, `geo_city`, `geo_latitude`, `geo_longitude`.
- `geoip_enabled` **only** controls whether connections are *blocked* by country. Annotation happens regardless of this flag.

**Using your own database (optional).** Set `geoip_database_path` to a MaxMind GeoLite2 (<https://www.maxmind.com/en/geolite2/signup>) or another DB-IP/MaxMind MMDB. If the configured file is missing, the bundled (downloaded) database is used. Note: MaxMind GeoLite2's EULA does **not** permit redistributing it inside a product, which is why DB-IP Lite (CC BY 4.0) is used instead.

To refresh the database manually (DB-IP publishes monthly):

```
mix geoip.fetch
```

# Configuration

```
config :omniepdg,  
  # Block connections by country (geolocation annotation is always  
  on)  
  geoip_enabled: true,  
  
  # Optional: override the bundled DB with your own MMDB (Country  
  or City)  
  # geoip_database_path: "/etc/omniepdg/GeoLite2-Country.mmdb",  
  
  # Access control mode  
  geoip_mode: :whitelist,  
  
  # Country list (ISO 3166-1 alpha-2 codes)  
  geoip_countries: ["AU", "NZ"],  
  
  # Handle unknown IPs  
  geoip_allow_unknown: false,  
  
  # Behavior when database unavailable  
  geoip_fail_open: true
```

# Parameters

| Parameter                        | Type    | Required | Default                                     | Description  |
|----------------------------------|---------|----------|---|--|
| <code>geoup_enabled</code>       | Boolean | No       | <code>false</code>                          | Enable or disable GeolP-based access control (blocking). When <code>false</code> , all IPs are allowed — but sessions are still geo-annotated. |
| <code>geoup_database_path</code> | String  | No       | <code>bundled dbip-country-lite.mmdb</code> | Path to an MMDB-format database (Country or City). Falls back to the bundled DB-IP database if unset or missing.                               |
| <code>geoup_mode</code>          | Atom    | No       | <code>:whitelist</code>                     | Access control mode: <code>:whitelist</code> (only allow listed countries) or <code>:blacklist</code> (block listed                            |

| Parameter                        | Type    | Required | Default           | Description   |
|----------------------------------|---------|----------|-------------------|---|
|                                  |         |          |                   | countries, allow others).   |
| <code>geoiP_countries</code>     | List    | No       | <code>[]</code>   | List of ISO 3166-1 alpha-2 country codes. Interpretation depends on <code>geoiP_mode</code> .   |
| <code>geoiP_allow_unknown</code> | Boolean | No       | See below         | Allow connections from IPs that cannot be geolocated (private IPs, unknown ranges). Default is <code>false</code> for whitelist mode, <code>true</code> for blacklist mode. |
| <code>geoiP_fail_open</code>     | Boolean | No       | <code>true</code> | Behavior when the GeoiP database fails to load. When <code>true</code> , allow all connections (fail open).   |

| Parameter | Type | Required | Default | Description  |
|-----------|------|----------|---------|--|
|           |      |          |         | When <code>false</code> , block all connections (fail closed). |

## Access Control Modes

### Whitelist Mode (Recommended for WiFi Calling)

Only allow connections from specified countries. All other countries are blocked.

```
config :omniepdg,
  geoip_enabled: true,
  geoip_mode: :whitelist,
  geoip_countries: ["AU", "NZ", "FJ"] # Australia, New Zealand,
  Fiji
```

**How it works:** Only UEs connecting from Australian, New Zealand, or Fijian IP addresses can authenticate. All other countries are rejected.

**Use case:** Operators who want to restrict WiFi calling to their licensed service areas.

### Blacklist Mode

Block connections from specified countries. All other countries are allowed.

```
config :omniepdg,
  geoip_enabled: true,
  geoip_mode: :blacklist,
  geoip_countries: ["CN", "RU", "KP", "IR"] # China, Russia,
  North Korea, Iran
```

**How it works:** UEs connecting from the listed countries are rejected. All other countries can authenticate.

**Use case:** Blocking high-risk regions while allowing global roaming.

## Handling Unknown Countries

Some IP addresses cannot be geolocated:

- Private IP ranges (10.x.x.x, 192.168.x.x, etc.)
- Newly allocated IP blocks not yet in the database
- Tor exit nodes and some VPNs

The `geoup_allow_unknown` parameter controls behavior:

| Mode      | <code>geoup_allow_unknown</code><br>Default | Behavior                             |
|-----------|---|--------------------------------------|
| Whitelist | <code>false</code>                          | Unknown = not in whitelist = blocked |
| Blacklist | <code>true</code>                           | Unknown = not in blacklist = allowed |

To override the default:

```
config :omniepdg,  
  geoup_mode: :whitelist,  
  geoup_allow_unknown: true # Allow unknown IPs even in whitelist  
mode
```

## Database Updates

MaxMind updates the GeoLite2 database weekly. To update:

1. Download the new `GeoLite2-Country.mmdb` file
2. Replace the existing file at the configured path
3. The database is automatically reloaded on the next lookup (no restart required)

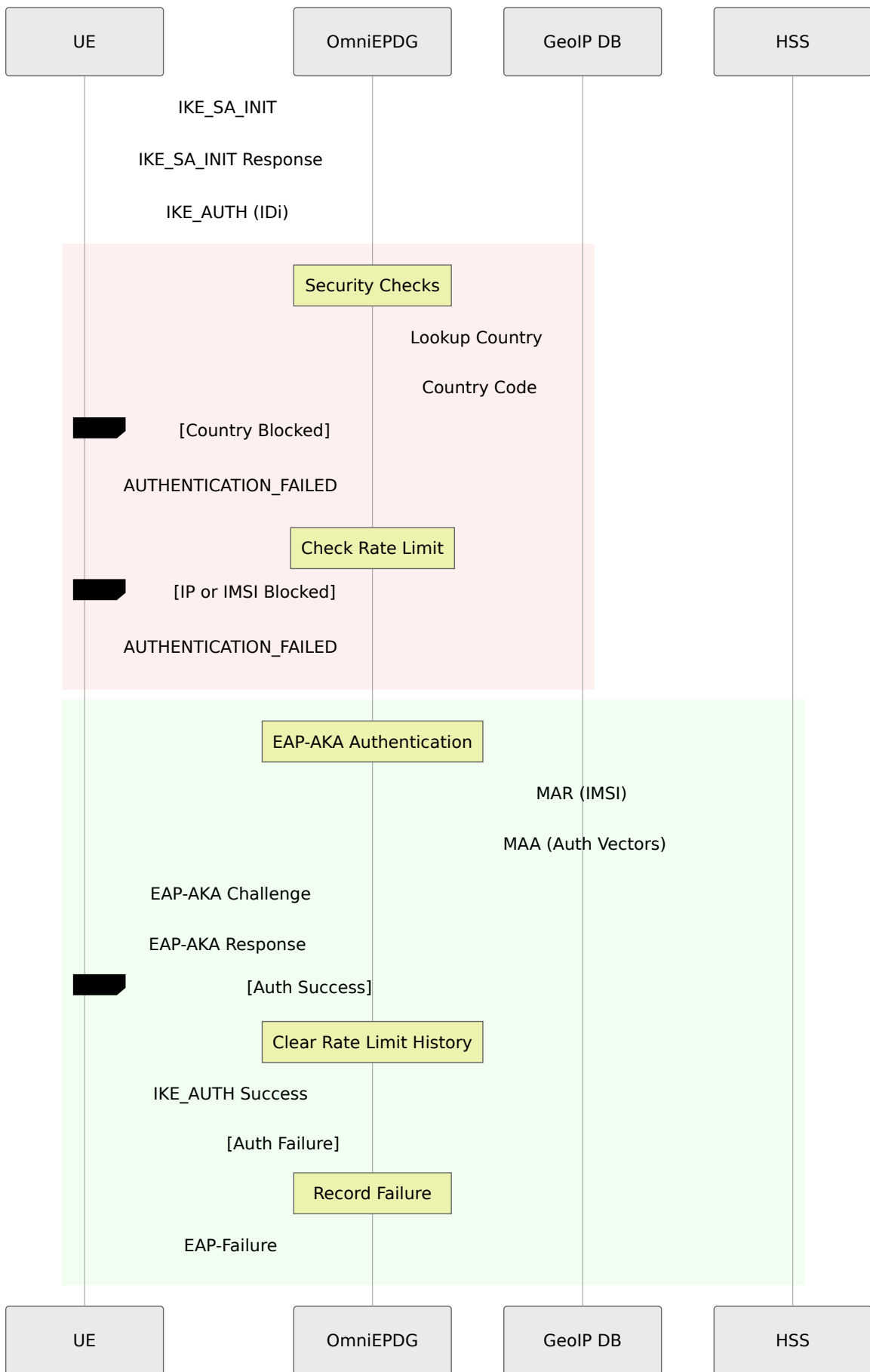
## Common Country Codes

| Code | Country     | Code | Country        |
|------|-------------|------|----------------|
| AU   | Australia   | US   | United States  |
| NZ   | New Zealand | GB   | United Kingdom |
| CA   | Canada      | DE   | Germany        |
| FR   | France      | JP   | Japan          |
| SG   | Singapore   | HK   | Hong Kong      |
| IN   | India       | CN   | China          |

Full list: [ISO 3166-1 alpha-2](#)

## Security Flow

The complete authentication security flow:



# Metrics

## Rate Limiting Metrics

**Metric:** `epdg_auth_rate_limited_count` **Type:** Counter **Description:** Number of authentication attempts blocked by rate limiting **Labels:**

- `type` - Blocking reason: `ip` (IP threshold exceeded) or `imsi` (IMSI threshold exceeded)

### Example queries:

```
# Rate limited attempts per minute
rate(epdg_auth_rate_limited_count[1m])

# Rate limited by type
sum by (type) (rate(epdg_auth_rate_limited_count[5m]))

# Alert: High rate limiting activity
rate(epdg_auth_rate_limited_count[5m]) > 10
```

## GeoIP Metrics

**Metric:** `epdg_auth_geoip_blocked_count` **Type:** Counter **Description:** Number of authentication attempts blocked by GeoIP **Labels:**

- `country` - ISO 3166-1 alpha-2 country code, or `UNKNOWN` for unresolvable IPs

### Example queries:

```
# GeoIP blocks per minute
rate(epdg_auth_geoip_blocked_count[1m])

# Top blocked countries
topk(10, sum by (country) (epdg_auth_geoip_blocked_count))

# Alert: Unusual country attempting access
increase(epdg_auth_geoip_blocked_count{country="XX"}[1h]) > 100
```

# Troubleshooting

## Rate Limiting Issues

### Legitimate Users Being Blocked

**Symptoms:** Users report being unable to connect after failed attempts

**Possible causes:**

- User entered wrong credentials multiple times
- Network issues caused authentication timeouts counted as failures
- Thresholds set too low for the environment

**Resolution:**

1. Check metrics for the affected IP/IMSI
2. Consider increasing thresholds if false positives are common
3. After fixing root cause, the block will expire automatically

### High Rate of Blocked Attempts

**Symptoms:** `epdg_auth_rate_limited_count` increasing rapidly

**Possible causes:**

- Brute-force attack in progress
- Misconfigured UE repeatedly failing authentication

- Credential stuffing attack

**Resolution:**

1. Review source IPs in logs for patterns
2. Consider implementing IP-level firewall rules for persistent attackers
3. Verify HSS connectivity if legitimate users are affected

## GeoIP Issues

### All Connections Being Blocked

**Symptoms:** No UEs can connect after enabling GeoIP

**Possible causes:**

- Database file not found or corrupt
- Wrong country codes in configuration
- `geoip_allow_unknown: false` blocking private IPs in lab environment

**Resolution:**

1. Verify database file exists at configured path
2. Check country codes are correct (uppercase, 2 letters)
3. For lab/development, set `geoip_allow_unknown: true`
4. Check logs for GeoIP-related warnings

### GeoIP Database Not Loading

**Symptoms:** Warning in logs: "GeoIP database not found"

**Possible causes:**

- File path incorrect
- File permissions prevent reading
- File is not valid MMDB format

**Resolution:**

1. Verify file exists: `ls -la /etc/omniepdg/GeoLite2-Country.mmdb`
2. Check permissions: `chmod 644 /etc/omniepdg/GeoLite2-Country.mmdb`
3. Verify file integrity by downloading a fresh copy from MaxMind

## **Unexpected Country Blocks**

**Symptoms:** Users from allowed countries being blocked

### **Possible causes:**

- VPN/proxy making IP appear from different country
- Outdated GeoIP database
- Corporate network egress in unexpected location

### **Resolution:**

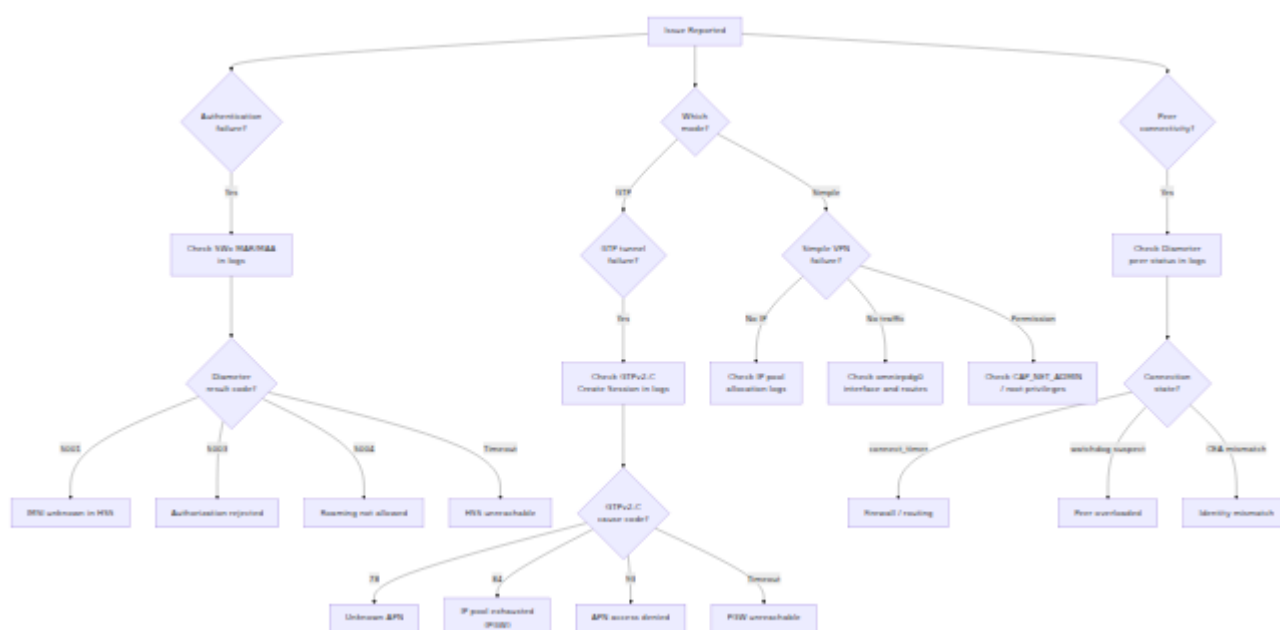
1. Update GeoIP database to latest version
2. Check user's actual egress IP vs expected country
3. Consider adding additional countries if users roam through corporate networks

# OmniEPDG

## Troubleshooting

This guide covers common operational issues, diagnostic procedures, and resolution steps for OmniEPDG.

### Diagnostic Overview



### Log Files

OmniEPDG writes logs to the `log/` directory relative to the application working directory. See the [Configuration Reference](#) for log configuration details.

| File                         | Purpose                                 | When to Check                              |
|------------------------------|---|--|
| <code>log/console.log</code> | All application messages at debug level | First point of investigation for any issue |
| <code>log/error.log</code>   | Errors only                             | Quick scan for active problems             |
| <code>log/crash.log</code>   | OTP process crashes                     | When processes are restarting unexpectedly |
| <code>log/erlang.log</code>  | Erlang kernel logger                    | Low-level Erlang/OTP issues                |

## Key Log Patterns

### Diameter peer connection events:

- `peer_up` - Diameter peer connected and capabilities exchanged
- `peer_down` - Diameter peer disconnected

### UE FSM state transitions:

- `ue_fsm_state_<name> event=<event>` - FSM processing an event in a given state
- `ue_fsm_init(&lt;IMSI>)` - New FSM instance created for subscriber
- `terminating epdg_ue_fsm with reason <reason>` - FSM shutting down

### Timeout events:

- `Timeout swm_der_timeout` - SWm DER response timed out
- `Timeout create_session_timeout` - GTPv2-C Create Session response timed out
- `Timeout s2b_delete_session_timeout` - GTPv2-C Delete Session response timed out
- `Timeout cancel_location_timeout` - Cancel Location response timed out

# Diameter Connectivity Issues

## HSS Connection Failure (SWx)

**Symptoms:** No subscribers can authenticate. Logs show repeated connection attempts to the HSS.

**Possible causes:**

- Firewall blocking SCTP port 3868 between OmniEPDG and HSS
- Incorrect `dia_swx_remote_ip` or `dia_swx_remote_port` in configuration
- HSS not running or not accepting Diameter connections
- SCTP not enabled on the network path (some firewalls block SCTP by default)
- Origin-Host or Origin-Realm mismatch causing CEA rejection

**Resolution:**

1. Verify network connectivity to the HSS IP and port
2. Confirm `dia_swx_remote_ip` and `dia_swx_remote_port` match the HSS configuration
3. Check that SCTP traffic is permitted through all firewalls. If SCTP is blocked, set `dia_swx_proto` to `tcp` as a fallback
4. Verify `dia_swx_origin_host` is a resolvable FQDN and matches what the HSS expects
5. Check HSS logs for Diameter CER/CEA negotiation failures

## PGW Connection Failure (S6b)

**Symptoms:** Authentication succeeds but GTP tunnel creation fails or S6b AAR never arrives from PGW. Logs show no S6b peer\_up event.

**Possible causes:**

- PGW not configured to connect to OmniEPDG's S6b listener
- Firewall blocking SCTP port 3868 on OmniEPDG's S6b bind address

- `dia_s6b_local_ip` not reachable from the PGW
- Origin-Host or Origin-Realm mismatch

### Resolution:

1. Confirm the PGW is configured to connect to OmniEPDG at `dia_s6b_local_ip:dia_s6b_local_port`
2. Verify the S6b bind address is reachable from the PGW network
3. Check firewall rules allow inbound SCTP on port 3868 at the S6b address
4. Verify `dia_s6b_origin_host` and `dia_s6b_origin_realm` match what the PGW expects

## Diameter Watchdog Failures

**Symptoms:** Established Diameter connections intermittently drop. Logs show watchdog transitions to SUSPECT or DOWN state.

### Possible causes:

- Network path instability or packet loss
- Peer overloaded and not responding to DWR within `dia_swx_watchdog_timer`
- Aggressive watchdog configuration (too few retries before declaring suspect)

### Resolution:

1. Check network path quality (packet loss, latency) between OmniEPDG and the peer
2. If packet loss is expected, increase `dia_swx_watchdog_config` / `dia_s6b_watchdog_config` thresholds (e.g., `[{okay, 5}, {suspect, 3}]`)
3. Check peer system health (CPU, memory, connection count)

# IKEv2 Negotiation Failures

## No Proposal Chosen

**Symptoms:** The UE's IKE\_SA\_INIT is rejected with `NO_PROPOSAL_CHOSEN`; logs show `exchange error: :no_proposal_chosen`. The UE never gets past IKE\_SA\_INIT.

### Possible causes:

- The UE only offers crypto transforms OmniEPDG does not support.
- A scanner or misconfigured client probing the public ports.

**Background:** OmniEPDG accepts AES-CBC and AES-GCM encryption; HMAC-SHA2, HMAC-SHA1 and **AES-XCBC-96** integrity; HMAC-SHA2, HMAC-SHA1 and **PRF-AES128-XCBC** PRFs; and MODP/ECP/Curve25519/448 DH groups. See [Cryptographic Algorithms](#) for the full list. Some handsets (notably certain Samsung VoWiFi clients) offer only `AES-CBC-256 / AUTH_AES_XCBC_96 / PRF_AES128_XCBC / MODP-2048` — all supported.

### Resolution:

1. Enable `:debug` logging and inspect the `IKEv2 packet` event for the UE's SA payload — the `payloads[].proposals[]` fields list the exact transforms offered.
2. Confirm the offered encryption / integrity / PRF / DH transforms appear as Supported in the algorithm tables.
3. If a genuinely unsupported transform is required, raise it with engineering.

## Connection Establishes Then Immediately Drops (Child SA Deleted)

**Symptoms:** IKE\_AUTH completes, the session is briefly established, then the UE sends an INFORMATIONAL `DELETE` within ~100 ms. No media flows. Repeats on every attempt.

### Possible causes:

- The Child SA (ESP) transforms in the response don't match what the UE offered, so the UE tears the SA down.
- An ESP integrity/encryption algorithm the data plane can't process.

**Background:** OmniEPDG negotiates the ESP Child SA from the UE's offered proposal (including AES-XCBC-96 and AES-CBC-128/192/256) rather than forcing a fixed suite. A response selecting a transform the UE did not offer is rejected per RFC 7296.

### **Resolution:**

1. In `:debug`, check the `child SA proposal selected` log line — the `esp_offered`, `esp_encr` and `esp_integ` fields show what was offered and chosen.
2. Verify the selected ESP encryption key length matches the cipher (a mismatch surfaces as `Bad key size` and a dropped packet).
3. Confirm the UE's offered ESP integrity is one OmniEPDG supports (see ESP Child SA Algorithms).

# Authentication Failures

## IMSI Unknown (Diameter 5001)

**Symptoms:** Specific subscribers fail EAP-AKA authentication. Logs show SWx MAA with result code 5001 (DIAMETER\_ERROR\_USER\_UNKNOWN).

### **Possible causes:**

- Subscriber not provisioned in the HSS
- IMSI mismatch between UE SIM and HSS database
- NAI format incorrect, causing IMSI extraction to fail

### **Resolution:**

1. Verify the subscriber IMSI exists in the HSS database
2. Check the NAI format in logs matches the expected pattern:

```
0<<IMSI>@nai.epc.mnc<<MNC>.mcc<<MCC>.3gppnetwork.org
```

3. Confirm the SIM card IMSI matches the HSS provisioned value

## **Authorization Rejected (Diameter 5003)**

**Symptoms:** Subscriber authenticates but is rejected during server assignment. Logs show SWx SAA with result code 5003.

**Possible causes:**

- Subscriber not authorized for WiFi calling service
- APN not permitted for this subscriber
- Subscription profile restrictions

**Resolution:**

1. Check the subscriber's service profile in the HSS
2. Verify WiFi calling / ePDG access is enabled for the subscriber
3. Confirm the requested APN is in the subscriber's allowed APN list

## **Roaming Not Allowed (Diameter 5004)**

**Symptoms:** Roaming subscribers fail authentication. Logs show SWx MAA or SAA with result code 5004.

**Possible causes:**

- HSS roaming policy rejects the subscriber's current location
- WiFi calling not permitted for roaming subscribers

**Resolution:**

1. Review HSS roaming policies for the subscriber's HPLMN/VPLMN combination
2. Check if WiFi calling is permitted under roaming agreements

# Authentication Timeout

**Symptoms:** Authentication hangs and then fails after 10 seconds. Logs show `Timeout swm_der_timeout` in `state_wait_auth_resp`.

## Possible causes:

- HSS not responding to SWx MAR within 10 seconds
- SWx Diameter connection dropped during the request
- HSS overloaded

## Resolution:

1. Check HSS responsiveness and load
2. Verify SWx Diameter peer is in OKAY state (not SUSPECT or DOWN)
3. Check `dia_swx_transmit_timer` is adequate for the network latency to HSS

# EAP-AKA Type Mismatch

**Symptoms:** Authentication fails with "type\_mismatch" error in logs. The UE identity prefix doesn't match the EAP method used.

## Possible causes:

- UE sends identity with prefix `0` (EAP-AKA) but network expects EAP-AKA', or vice versa
- HSS returns authentication vectors for wrong EAP type

**Background:** Per 3GPP TS 23.003, the NAI identity prefix indicates the expected authentication type:

- Prefix `0` indicates EAP-AKA
- Prefix `6` indicates EAP-AKA'

OmniEPDG automatically selects the authentication method based on the UE's identity prefix. Most WiFi calling UEs use prefix `0` (EAP-AKA).

## Resolution:

1. Check the UE's NAI identity in logs to verify the prefix
2. Ensure the HSS is configured to return appropriate authentication vectors
3. Verify the SIM card is provisioned correctly for the expected authentication type

## **EAP-AKA RES Mismatch**

**Symptoms:** Authentication fails after challenge/response. Logs show "RES mismatch" or "res\_mismatch" error.

### **Possible causes:**

- SIM card authentication failure
- Key derivation mismatch between UE and network
- Corrupted authentication vectors from HSS

### **Resolution:**

1. Verify the SIM card is valid and not damaged
2. Check that the HSS returned valid authentication vectors (RAND, AUTN, XRES, CK, IK)
3. Enable debug logging to compare the expected XRES with received RES
4. If using test SIMs, verify the Ki and OP/OPc values match between SIM and HSS

## **GTP Tunnel Failures (GTP Mode Only)**

### **Create Session Rejected by PGW**

**Symptoms:** Authentication succeeds but tunnel creation fails. Logs show GTPv2-C Create Session Response with error cause.

### **Common cause codes and actions:**

| Cause Code | Name                           | Action   |
|------------|--------------------------------|--|
| 78         | Missing or Unknown APN         | Verify APN is configured on the PGW and matches subscriber profile |
| 82         | Denied in RAT                  | Check PGW policy allows WiFi (non-3GPP) access type                |
| 84         | All Dynamic Addresses Occupied | PGW IP pool exhausted; expand pool or investigate leaks            |
| 92         | User Authentication Failed     | PGW-side auth failure; check S6b session authorization             |
| 93         | APN Access Denied              | Subscriber not authorized for APN on PGW                           |
| 96         | IMSI/IMEI Not Known            | Subscriber unknown to PGW; verify S6b session was authorized       |
| 113        | APN Congestion                 | APN overloaded; retry or investigate PGW capacity                  |
| 120        | GTP-C Entity Congestion        | PGW control plane overloaded                                       |

## Create Session Timeout

**Symptoms:** Tunnel creation hangs for 10 seconds then fails. Logs show `Timeout create_session_timeout` in `state_wait_create_session_resp`.

### Possible causes:

- PGW not reachable at `gtpc_remote_ip: gtpc_remote_port`
- Firewall blocking UDP port 2123 between OmniEPDG and PGW
- PGW overloaded and not responding to GTPv2-C requests

## Resolution:

1. Verify network connectivity to PGW on UDP port 2123
2. Check firewall rules allow UDP 2123 between OmniEPDG and PGW
3. Check PGW health and GTPv2-C processing capacity

## GTP-U Tunnel Not Passing Traffic

**Symptoms:** Tunnel is established (Create Session succeeds) but subscriber traffic does not flow.

### Possible causes:

- GTP-U kernel module not loaded
- `gtp_u_kmod` socket IP does not match the GTP-U tunnel endpoint address signaled to PGW
- Routing not configured for the GTP tunnel device
- Firewall blocking UDP port 2152 (GTP-U)

### Resolution:

1. Verify the Linux kernel GTP module is loaded (`lsmod | grep gtp`)
2. Confirm the GTP tunnel device exists (`ip link show gtp0`)
3. Verify `gtp_u_kmod` `ip` matches `gtpc_local_ip` or the address signaled in Create Session Request
4. Check routing table includes routes through the GTP tunnel device
5. Verify firewall allows UDP port 2152 between OmniEPDG and PGW

## Simple VPN Failures (Simple VPN Mode Only)

### TUN Interface Not Created

**Symptoms:** OmniEPDG starts but no `omniepdg0` interface appears. Sessions fail at tunnel setup. Logs may show errors from `simple_vpn_route` during

startup.

### **Possible causes:**

- OmniEPDG process lacks `CAP_NET_ADMIN` capability or is not running as root
- TUN/TAP kernel module not loaded
- Another process has already created an interface named `omniepdg0`

### **Resolution:**

1. Verify the TUN kernel module is available (`lsmod | grep tun`)
2. Confirm OmniEPDG is running with sufficient privileges to create TUN interfaces
3. Check if `omniepdg0` already exists from a previous instance (`ip link show omniepdg0`)
4. Check `log/crash.log` for errors from the route manager process

## **IP Pool Exhausted**

**Symptoms:** Authentication succeeds but tunnel setup fails. Logs show IP allocation failure from `simple_vpn_pool`.

### **Possible causes:**

- All addresses in the configured CIDR pool are allocated to active sessions
- IP addresses not being released after session teardown (leak)
- Pool size too small for the number of concurrent subscribers

### **Resolution:**

1. Check the number of active `epdg_ue_fsm` processes against the pool size
2. Verify sessions are being torn down properly (check for `terminating` log messages)
3. If the pool is genuinely full, expand it by using a larger CIDR prefix in `simple_vpn_pool_ipv4` (requires restart)
4. Check for FSM crashes during teardown in `log/crash.log` that may have prevented IP release

# Subscriber Traffic Not Flowing

**Symptoms:** Session is established and the UE receives an IP address, but traffic does not flow through the TUN interface.

## Possible causes:

- Host route not added for the subscriber IP on `omniepdg0`
- IP forwarding not enabled on the OmniEPDG host
- Firewall rules blocking traffic on the `omniepdg0` interface
- Missing NAT/masquerade rules for outbound traffic from the subscriber IP range

## Resolution:

1. Verify the host route exists (`ip route show` and look for the subscriber's /32 route via `omniepdg0`)
2. Confirm IP forwarding is enabled (`sysctl net.ipv4.ip_forward`)
3. Check iptables/nftables rules allow forwarding through `omniepdg0`
4. If subscribers need internet access, verify NAT/masquerade is configured for the subscriber IP range (e.g., `iptables -t nat -A POSTROUTING -s 10.45.0.0/16 -o <wan-interface> -j MASQUERADE`)

# Stale Routes After Crash

**Symptoms:** Host routes for subscriber IPs remain in the routing table after OmniEPDG restarts or after sessions terminate abnormally.

## Possible causes:

- FSM crashed before the route could be removed
- OmniEPDG process was killed without graceful shutdown

## Resolution:

1. Check `log/crash.log` for process crashes during teardown
2. Manually remove stale routes (`ip route del <subscriber-ip>/32 dev omniepdg0`)

3. Restarting OmniEPDG will recreate the `omniepdg0` interface, which removes all associated routes

# Session Teardown Issues

## Teardown Hangs During Deregistration

**Symptoms:** Session teardown does not complete. UE FSM stuck in a `dereg_*` or `wait_*` state.

**Possible causes:**

- PGW not responding to Delete Session Request
- Diameter peer not responding to STR or ASR
- Timeout cascading not completing due to multiple timeouts stacking

**Resolution:**

1. Check logs for timeout messages in the relevant state
2. Verify PGW and HSS connectivity
3. After 10 seconds, the FSM should time out and proceed to the next teardown step or terminate. If it does not, check for unexpected events logged as `Unexpected call event`

## Orphaned GTP-U PDP Contexts

**Symptoms:** GTP-U tunnel entries remain in the kernel after sessions terminate. `ip link show gtp0` shows the device still has active PDP contexts.

**Possible causes:**

- FSM terminated abnormally before deleting the PDP context
- Crash during teardown sequence

**Resolution:**

1. Check `log/crash.log` for process crashes during teardown

2. The FSM's `terminate/3` callback attempts to clean up the PDP context. If the FSM was killed (e.g., supervisor restart), the cleanup may have been skipped
3. Restarting OmniEPDG will recreate the GTP-U socket and clear stale contexts

# Process and System Issues

## Supervisor Restart Loops

**Symptoms:** OmniEPDG processes restart repeatedly. Logs show supervisor restart messages and crash reports.

**Possible causes:**

- Persistent configuration error causing a handler to crash on startup
- External dependency unavailable (e.g., `gen_socket` library not found)
- Diameter peer sending malformed messages causing handler crashes

**Resolution:**

1. Check `log/crash.log` for the root cause of the crash
2. Verify `gen_socket` `libdir` path is correct and the library files exist
3. Check all required configuration parameters are present in `config/runtime.exs`
4. Look for malformed Diameter messages in the crash report

## High Memory Usage

**Symptoms:** Erlang VM memory consumption grows over time.

**Possible causes:**

- UE FSM processes not being cleaned up after session teardown
- Log message accumulation in mailboxes
- Large number of concurrent sessions

**Resolution:**

1. Check the number of running `epdg_ue_fsm` and `aaa_ue_fsm` processes (these should match active subscriber count)
2. Verify FSMs are terminating properly after session teardown (check for `terminating` log messages)
3. Review log rotation settings to ensure log files are being rotated