Integration of Wi-Fi-Only Devices in 5G Core Networks: Addressing Authentication and Identity Management Challenges

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The Core Problem and Its Significance

The Challenge

Current 3GPP standards don't fully address integrating **Wi-Fi-only devices lacking 5G credentials** into the 5G network, preventing standard 5G authentication.

Impact

A significant hurdle for enterprise/residential environments with many such devices.

Motivation

Solving this is crucial for 5G's success, enabling true **5G-Wi-Fi convergence** and extending 5G benefits (eMBB, mMTC, URLLC) to this vast device ecosystem.

Research Objectives

To address this problem, this research aimed to:

1. **Investigate Secure Authentication:** Design a robust local authentication mechanism.
2. **Develop Device Identity Management:** Propose a method for 5GC to recognize and manage these device connections individually.
3. **Propose an Integrated Solution:** Develop a framework for seamless, secure integration with minimal impact.

State of the Art

The Gap

Device Types

- **3GPP:** Have credentials and connect to the cellular network.
- **Non-3GPP:** Use technologies other than cellular and may or may not have 5G credentials.

WiFi-only ➜ Non-Authenticable Non-3GPP (NAUN3)

A robust mechanism for **individualized**, **secure authentication** of these devices and their subsequent per-device management within the 5GC is the focus of this project.

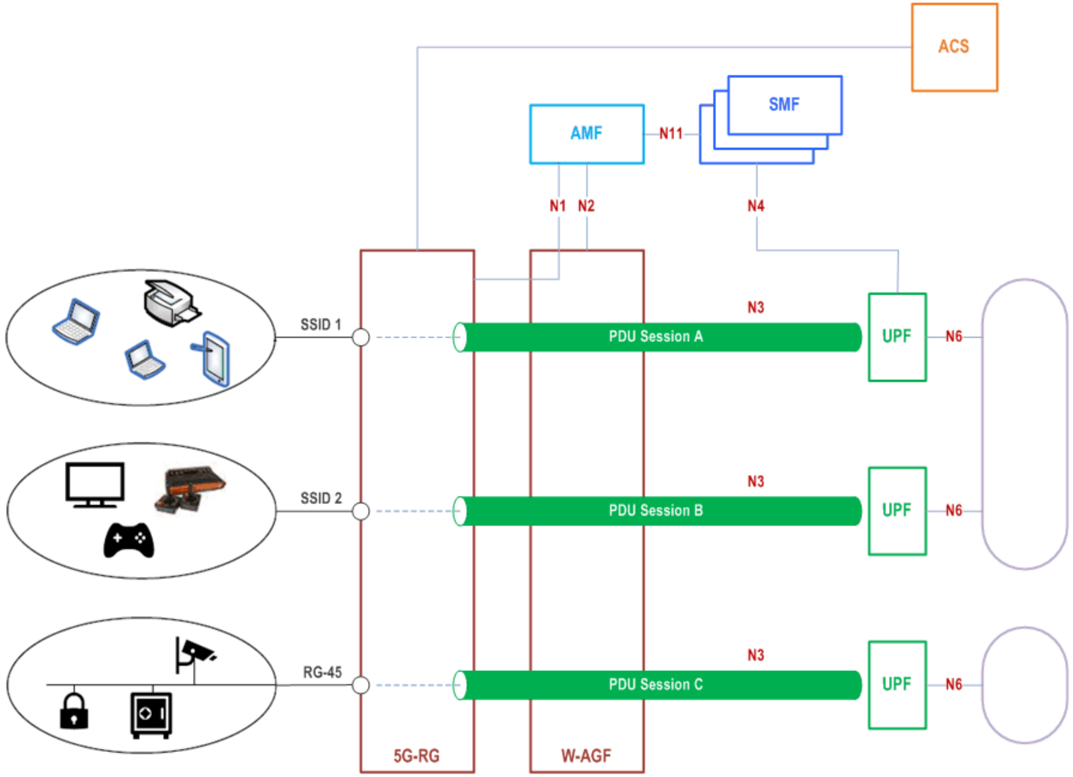
State of the Art

Managing Device Groups (CGID)

Connectivity Group ID (CGID) can manage **groups of devices behind** a 5G-RG with one PDU Session.

This does not provide per-device traffic management granularity.

Later developments envision a **network capable of distinguishing traffic from specific devices** behind an RG.



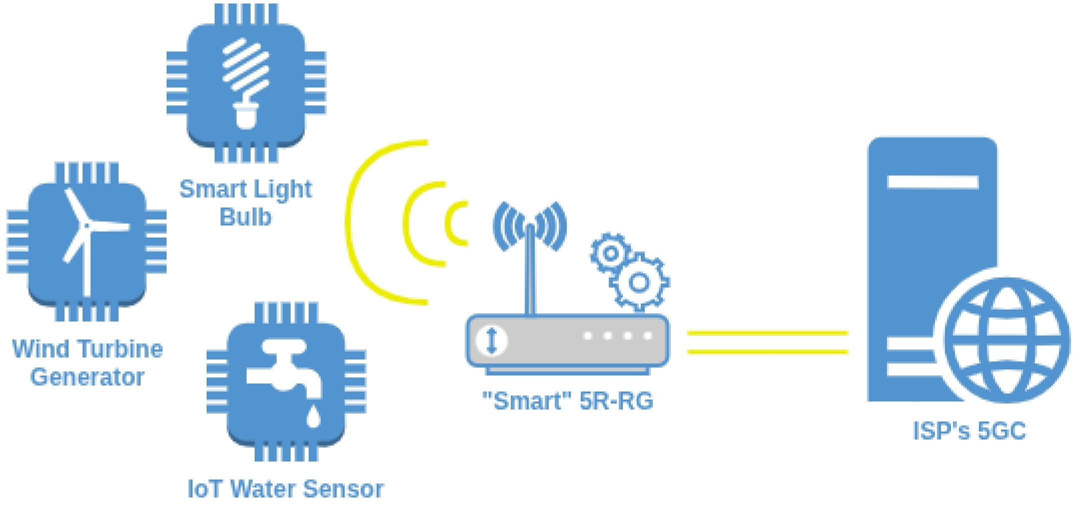
Framework Concept and Architecture

Overview and Guiding Principles

A *smart* 5G Residential Gateway (5G-RG) capable of mediating the secure integration.

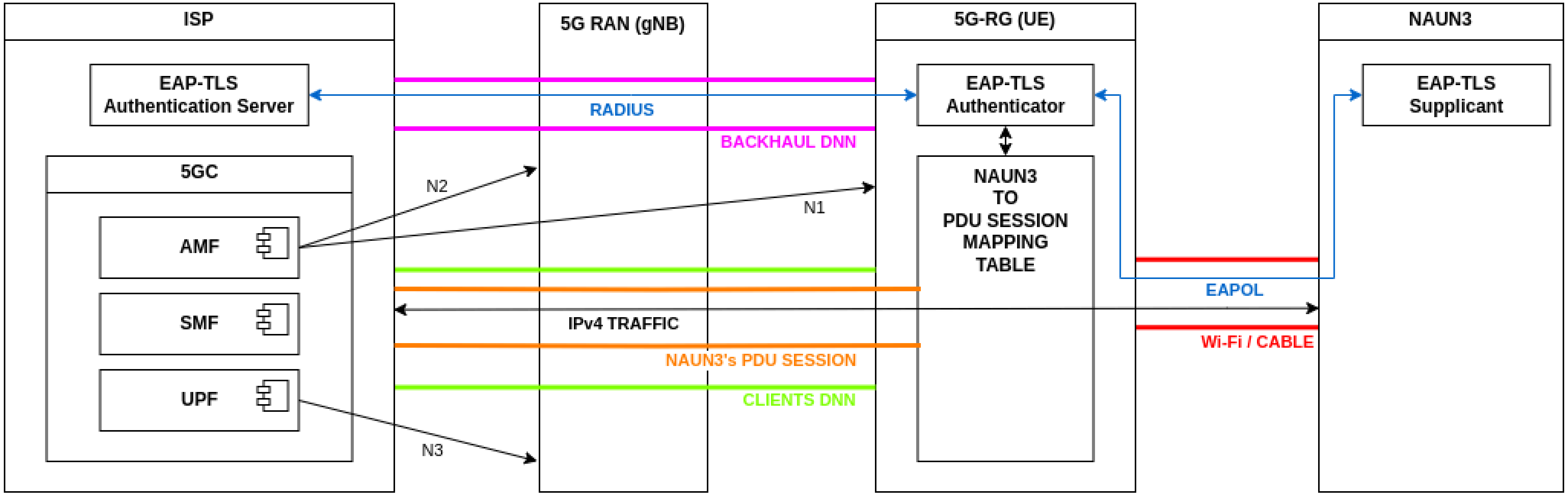
Key Design Principles

- Adaptation logic centralized at the 5G-RG.
- Minimal impact on end-devices and 5GC.



Framework Concept and Architecture

Overall Architecture

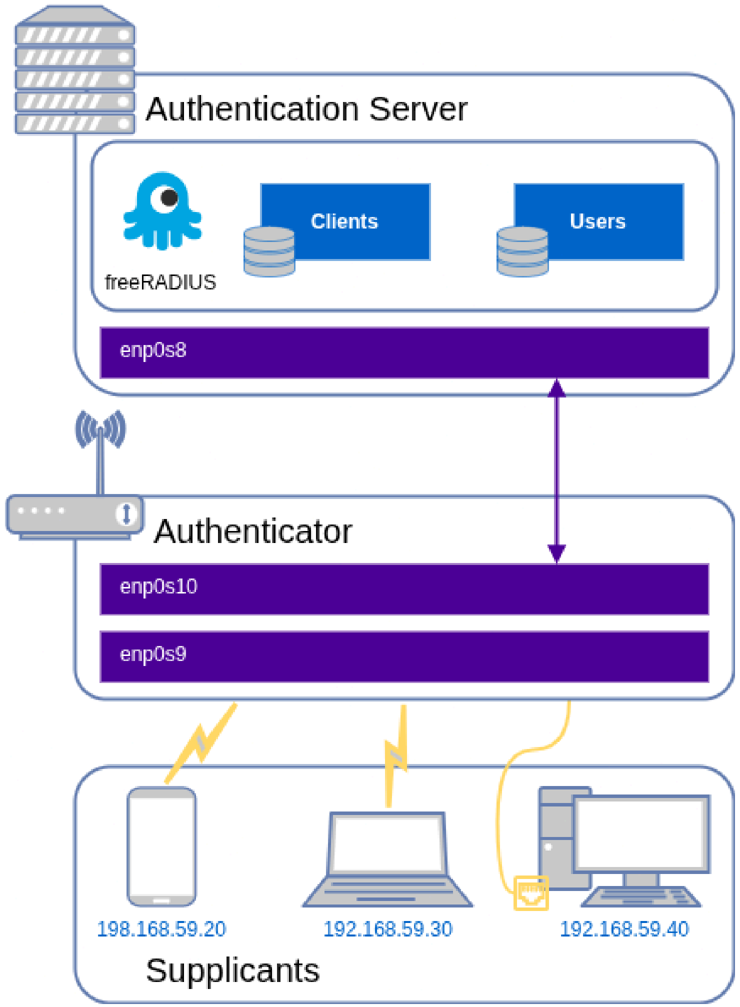


Framework Concept and Architecture

Authentication Mechanism

EAP-TLS is used for mutual, certificate-based local authentication.

- NAUN3 Device (**Supplicant**): Holds a client certificate.
- 5G-RG (**Authenticator**/Relay): Uses hostapd to relay EAP messages.
- RADIUS **Authentication Server**: ISP-operated, validates the device's certificate.

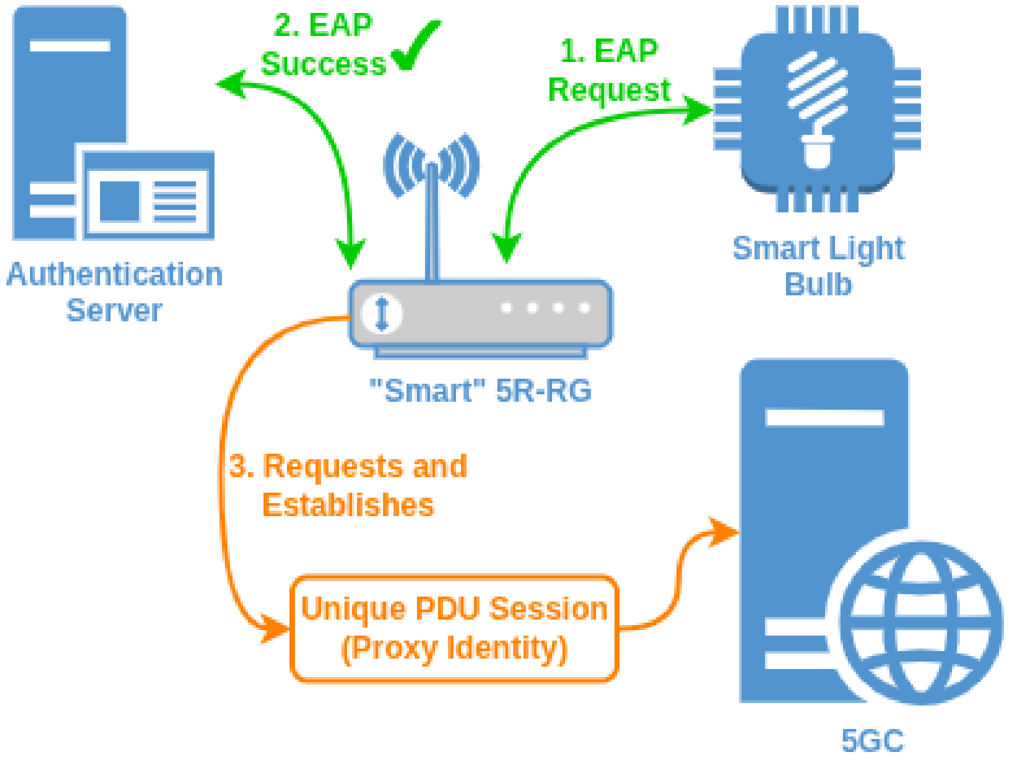


Framework Concept and Architecture

Identity Management (PDU Session as Proxy)

After successful EAP-TLS authentication:

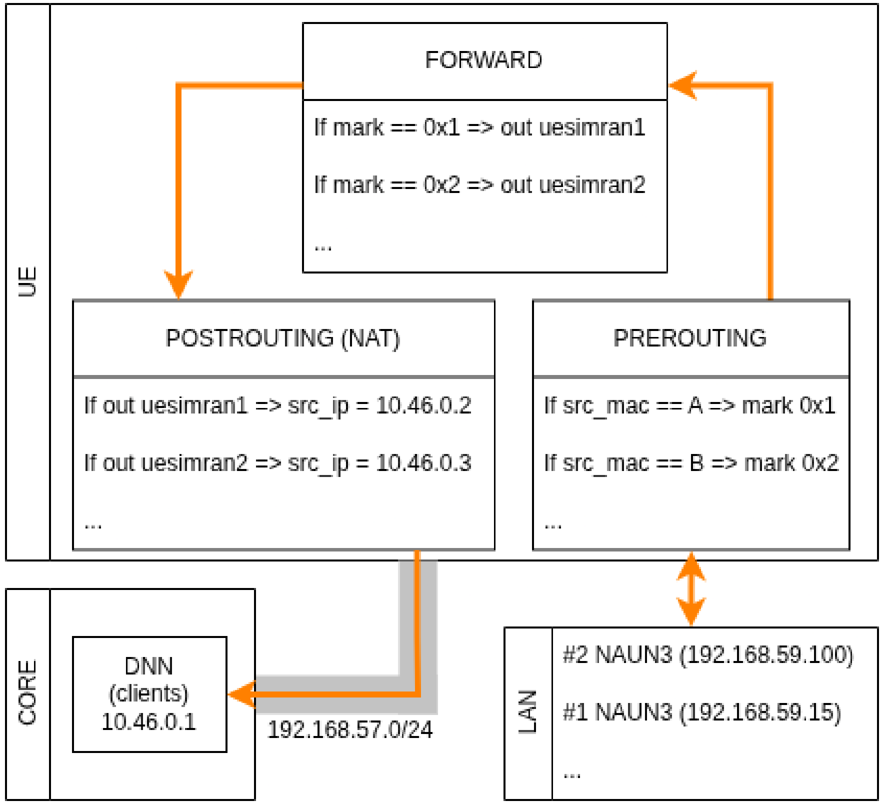
1. The 5G-RG requests a **new, dedicated** PDU Session.
2. This PDU Session becomes the **dynamic proxy identity** for the NAUN3.
3. The 5G-RG maintains a **mapping table** with NAUN3 MAC Addresses to PDU Session ID.



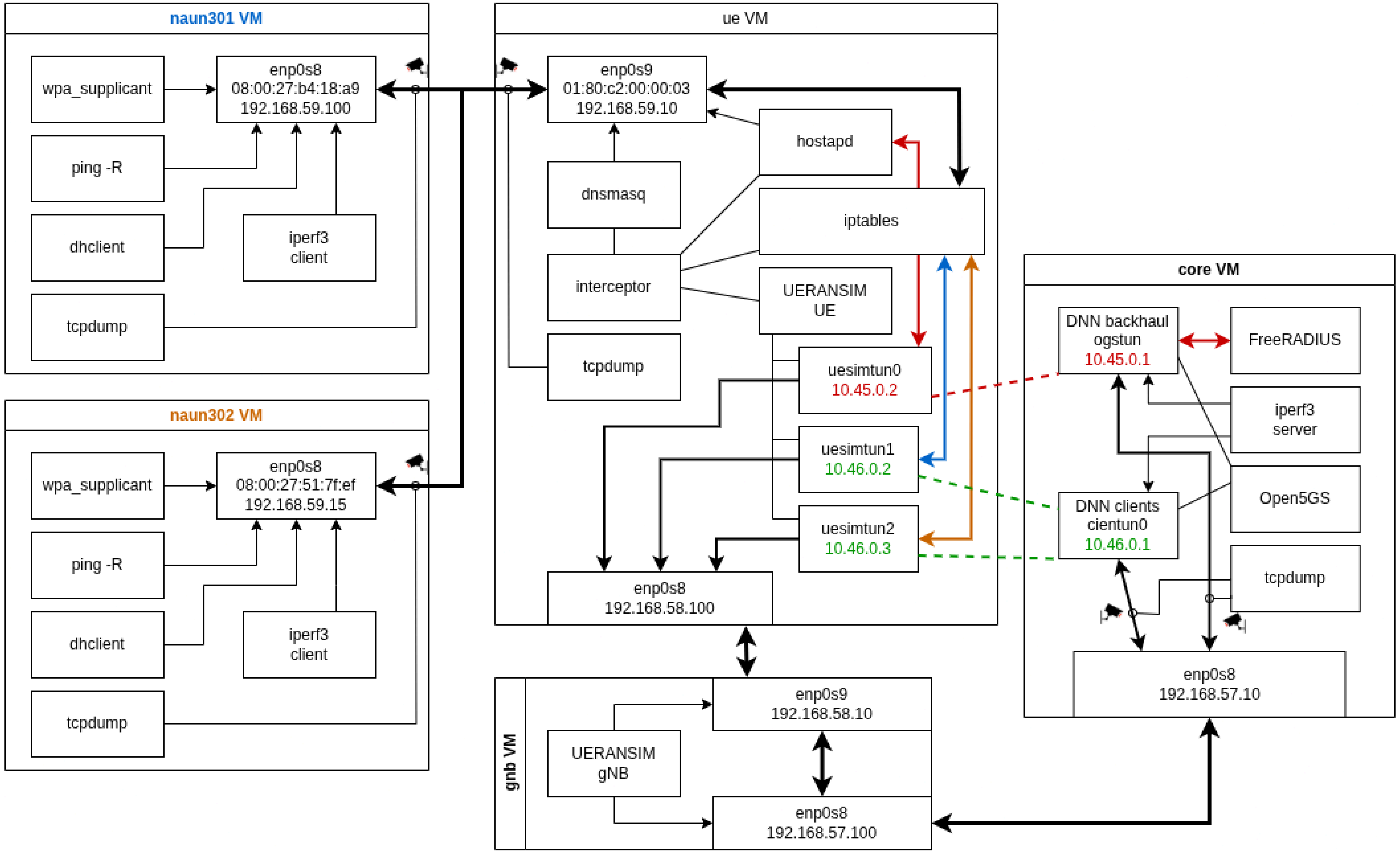
Framework Concept and Architecture

Traffic Management and Policy-Based Routing

1. **Packet Marking:** Incoming packets from the NAUN3's MAC are marked.
2. **Policy Routing:** Marked packets are directed to a specific table.
3. **Dedicated Route:** Traffic is routed via to a unique PDU interface.
4. **NAT:** Traffic is then masqueraded using the PDU session's 5GC-assigned IP address.



Testbed and *Interceptor*: Central Orchestrator

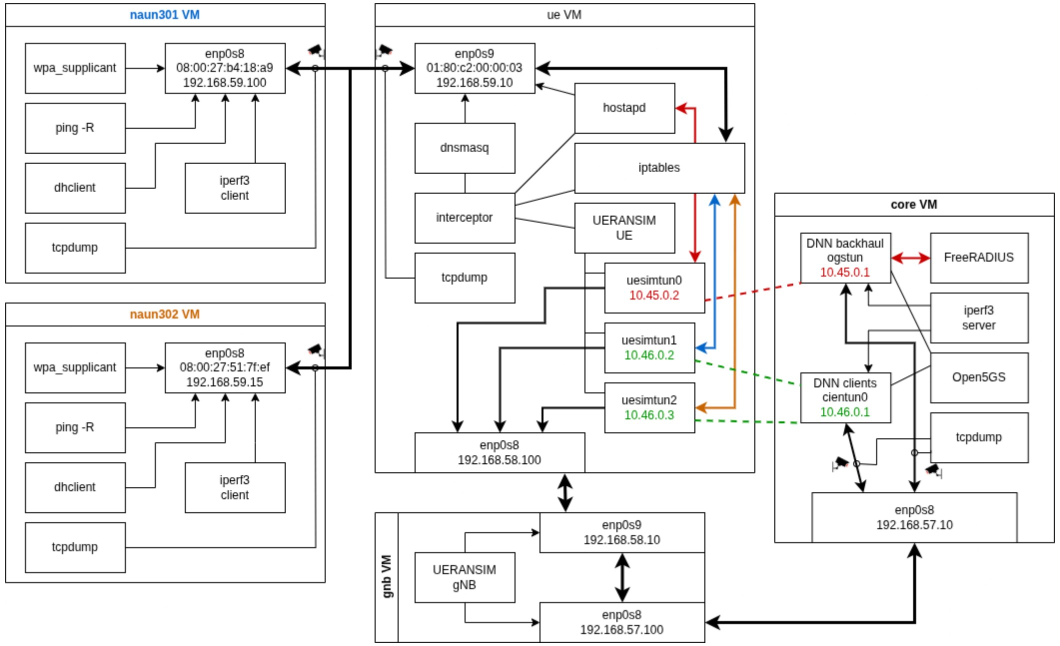


Testbed and *Interceptor*: Central Orchestrator

Virtualized testing environment with Vagrant, Open5GS, UERANSIM, FreeRADIUS, `hostapd`, and `wpa_supplicant`.

The custom logic developed, ***Interceptor***, is the **brain of the solution**, responsible for:

- ☑ Monitor `hostapd`
- ☑ Trigger new PDU Sessions
- ☑ Configure DHCP and routing
- ☑ Clean up on disconnect



Validation

Successful Onboarding and PDU Creation

Local EAP-TLS authentication was consistently successful.

Each authenticated NAUN3 device triggered the 5G-RG to establish a unique, **dedicated PDU session in "clients" DNN**, and the 5GC assigned a **unique IP to each session**.

```
PDU Session2:
 state: PS-ACTIVE
 session-type: IPv4
 apn: clients
 s-nssai:
  sst: 0x01
  sd: null
 emergency: false
 address: 10.46.0.2
 ambr: up[1000000Kb/s] down[1000000Kb/s]
 data-pending: false
```

Validation

End-to-End Connectivity and Traffic Isolation

```
PING 10.46.0.1 (10.46.0.1) 56(124) bytes of data .
64 bytes from 10.46.0.1: icmp_seq =1 ttl =63 time =1.52 ms
RR :    192.168.59.100
    10.46.0.2
    10.46.0.1
    10.46.0.1
    192.168.59.10
    192.168.59.100
(...)
```

```
PING 10.46.0.1 (10.46.0.1) 56(124) bytes of data .
64 bytes from 10.46.0.1: icmp_seq =1 ttl =63 time =2.31 ms
RR :    192.168.59.15
    10.46.0.3
    10.46.0.1
    10.46.0.1
    192.168.59.10
    192.168.59.15
(...)
```

Using `ping -R` and `iperf3` we can confirm that traffic from different NAUN3 devices was **correctly and separately routed through their respective PDU session IPs**, confirming successful **traffic isolation** and NAT.

Validation

Lifecycle Management and Onboarding Delay

Onboarding Delay: The average time for the full process (EAP auth, PDU setup, local IP) was approximately 33 (± 5) seconds in the testbed.

Lifecycle: When a device disconnected, the system correctly deauthenticated it, cleaned up all routing rules and DHCP permissions, and terminated the dedicated PDU session.

1. ☑️ Deauthenticate
2. ☑️ Disallow DHCP lease
3. ☑️ Release dedicated PDU Session
4. ☑️ Remove routing table

Key Contributions

1. A practical, end-to-end framework for integrating *5G-credential-less* Wi-Fi-only devices into 5G.
2. The innovative use of **per-device PDU Sessions as dynamic proxy identities**, orchestrated by an intelligent 5G-RG.
3. The tight coupling of strong, local EAP-TLS authentication with 5G PDU session management at the network edge.
4. A working proof-of-concept validating the architecture with open-source tools and custom logic.

Limitations

- **Physical Hardware Integration:** Physical 5G modem integration is an ongoing challenge. Proprietary drivers, kernel dependencies, and lack of documentation for multi-PDU session management.
- **Implementation Specifics:** The simulated PoC relies on CLI-based orchestration (`nr-cli`), which is not ideal for performance. The onboarding delay of ~33 (±5) seconds reflects this.
- **NAT Implications:** Inbound connection initiation to NAUN3 devices is restricted.

Future Work

- **Modem Interface Adaptation:** The *Interceptor* logic must be adapted to interface with modem-specific APIs, such as AT commands or QMI, replacing the UERANSIM CLI used in the simulation.
- **Performance and Scalability Analysis:** Rigorous testing and exploring alternatives like eBPF.
- **Enhanced Robustness:** Harden the *Interceptor* and secure RADIUS transport (e.g., with IPSec).
- **Address NAT:** Investigate solutions like Framed-Routing.

Thank You and Q&A

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