CSCE 5585 – Part-B Secure Network Design and Implementation

Project By:
Group 9
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1. INTRODUCTION

This project is about creating a secure virtual enterprise with multiple layers of security using GNS3, pfSense, VirtualBox, Suricata, and OpenVPN. The goal is to create a simulated enterprise network that will demonstrate important security principles including segmentation, perimeter security, intrusion detection, and secure remote connections.

The network has four segments: an internal LAN, a DMZ, a WAN connection, and a VPN segment. All these segments are connected together via a virtual switch, and multiple virtual machines (Ubuntu Server, Kali Linux, and Windows 10) are connected to this virtual switch and routed through a pfSense firewall. The pfSense firewall performs many functions and provides many security features, including routing, NAT, firewalling, and VPN services.

One of the most important aspects of this design is the DMZ segment, which includes an Ubuntu-based Apache web server. The web server can be accessed by the LAN workstations and by VPN users, however, it cannot communicate back into the LAN. This is typical of what you would find in an enterprise network. The LAN segment has two types of hosts on it, workstation hosts and an "attacker" host (the Kali Linux VM). These workstation hosts are used to simulate scanning, enumerating, and flooding the network with traffic. A Suricata IPS sensor is placed in inline IPS mode on both the LAN and DMZ segments to provide real-time intrusion detection and prevention.

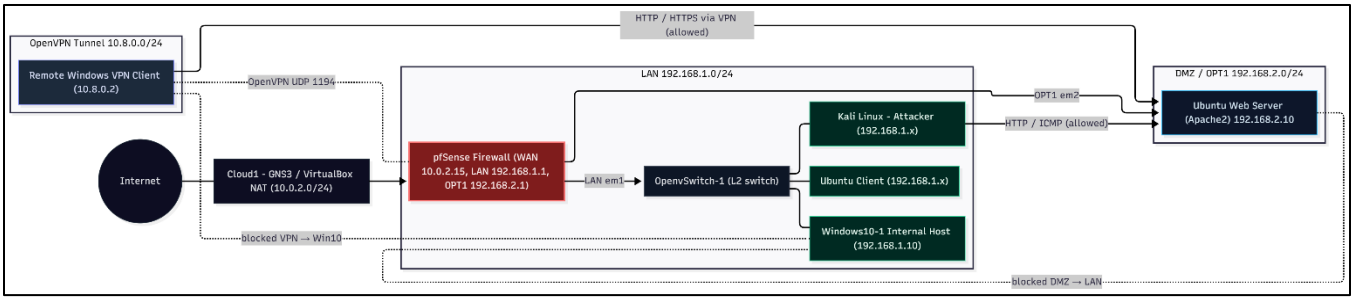
In general terms, the overall purpose of this project was to build and test a multi-layered security architecture, and validate the effectiveness of each layer through the use of a series of controlled attacks against the network. Through this process, all configuration steps, firewall rules, NAT configurations, VPN connections, and IPS alerts and responses have demonstrated how a secure network can be designed and protected.

2. NETWORK TOPOLOGY OVERVIEW

This network was created in GNS3 using pfSense for centralized firewall and routing functionality. It has been segmented into three distinct security zones:

1. WAN (external) representing the Internet;
2. LAN which contains internal hosts such as Windows, Ubuntu, and the Kali;
3. DMZ (OPT1) hosts the Apache web service.

Each of the LAN devices are connected via an Open vSwitch while the DMZ server connects directly to the OPT1 port on pfSense. VPN remote users are able to connect to this network through an OpenVPN tunnel providing secure connectivity, however this is not considered another network zone. In addition to segmentation, it allows the ability for LAN hosts to be able to communicate with DMZ services, DMZ is restricted from making connections to the LAN, and VPN remote users are allowed to communicate with the network, although with controlled access to certain areas.



This design replicates a typical enterprise defensive posture by including multiple layers of defense, Network Address Translation (NAT), Firewall filtering, and IPS inspection utilizing Suricata.

Segment / Interface	Device / Role	IP Address	Description
WAN (em0)	pfSense WAN Interface	**10.0.3.16/24** (DHCP from Cloud1)	Connected to VirtualBox NAT (Internet edge)
LAN (em1) – 192.168.1.0/24	pfSense Gateway	**192.168.1.1**	Default gateway for internal hosts
	Windows10-1 Internal Host	**192.168.1.10**	LAN workstation used for testing
	Ubuntu LAN Client	**192.168.1.x**	Internal workstation
	Kali Linux (Attacker)	**192.168.1.x**	Used for scans, DoS, brute-force attacks
DMZ / OPT1 (em2) – 192.168.2.0/24	pfSense OPT1 Gateway	**192.168.2.1**	DMZ gateway
	Ubuntu Web Server (Apache2)	**192.168.2.10**	Public-facing DMZ web server
VPN Tunnel – 10.8.0.0/24	OpenVPN Windows Client	**10.8.0.2**	Assigned by pfSense OpenVPN server
	pfSense OpenVPN Server	(No static IP)	Terminates remote-access VPN tunnel

3. CONFIGURATION STEPS

This section summarizes the essential configuration elements required to build the project environment. These include GNS3 topology creation, pfsense interface assignment, firewall rule creation, and how NAT behaves. To provide a full visual representation of the steps described in this paper screenshots of each step are included in the appendix.

3.1 GNS3 ENVIRONMENT SETUP

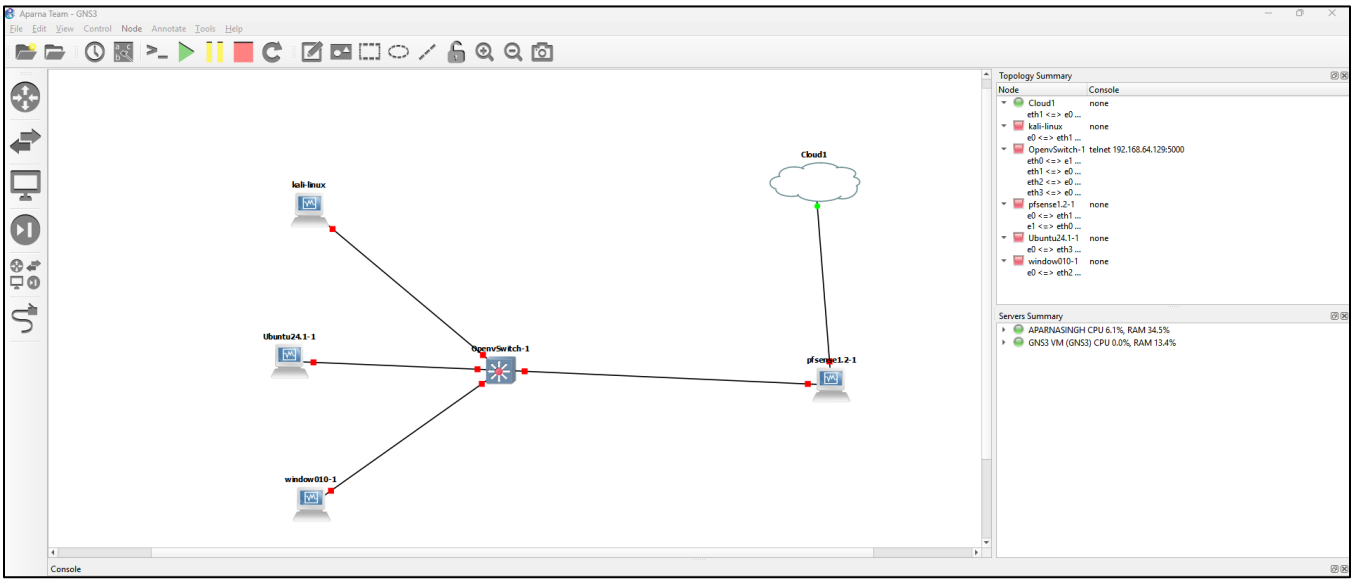
To create the GNS3 network, virtual machines running on VirtualBox were created using the Open vSwitch as the LAN switch. As the NAT network the "Cloud" node in the topology represents the VirtualBox NAT network, which provides the Internet connection to pfSense through its WAN interface. All of the internal hosts (Kali Linux, Windows 10, and Ubuntu client) were attached to the Open vSwitch to form the LAN segment (192.168.1.0/24). A dedicated network adapter was assigned to the

DMZ web server (ubuntu apache2), and it is directly connected to pfSense OPT1. In this way the layout models a segmented enterprise (WAN > Firewall > LAN/DMZ) and matches the topology shown.

Virtual Machine Images Used:

- pfSense 2.8.1 – pfSense amd64 ISO - netgate-installer-v1.1-RELEASE-amd64.iso
- Ubuntu 24.04 LTS – ubuntu-24.04.3-desktop-amd64.iso
- Windows 10 (x64) – Microsoft Windows 10 ISO
- Kali Linux 2025.3 – kali-linux-2025.3-installer-amd64.iso

Below is the proof of Network topology implementation using GNS3:



Key Steps:

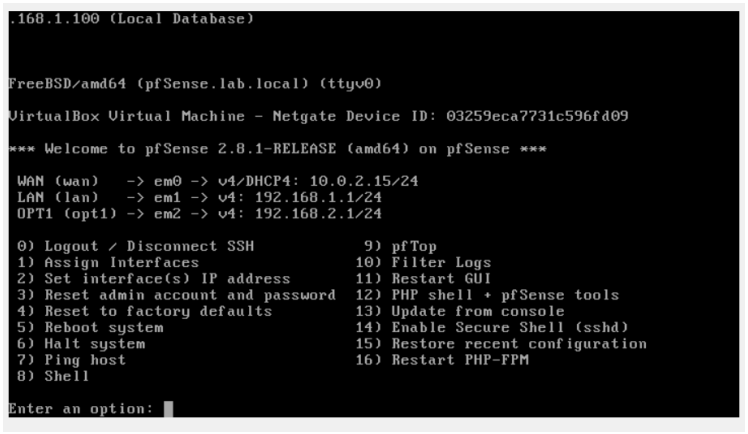
1. Installed new devices in GNS3: pfSense, Kali Linux, Ubuntu, and a Windows10-1 device.
2. All LAN VMs was connected to an internal network through Open vSwitch with an IP address of 192.168.1.0/24.
3. pfSense LAN (em1) was connected to the switch; WAN (em0) was connected to the Cloud NAT and OPT1 (em2) was connected to the DMZ server.
4. The connection of all topology elements is verified by the GNS3 Topology Summary Panel.
5. pfSense was booted first to allow interface identification and IP assignment.

Traffic Flow Summary:

- Internet <> WAN:
  - Internet host > Cloud1 (VirtualBox NAT 10.0.2.0/24) > pfSense WAN (em0) > internal networks (only VPN/allowed traffic).
  - LAN host > pfSense > WAN (em0) > Cloud1 (NAT) > Internet.
- LAN > DMZ:
  - LAN host (192.168.1.0/24) > pfSense LAN (em1) > pfSense OPT1 (em2) > Apache web server 192.168.2.10
  - (HTTP/HTTPS/ICMP allowed).
- DMZ > LAN (blocked):
  - DMZ host 192.168.2.10 > pfSense OPT1 (em2) > blocked from reaching 192.168.1.0/24 LAN.
- VPN > DMZ / LAN:
  - VPN client 10.8.0.2 > pfSense OpenVPN interface > DMZ 192.168.2.10 allowed
  - VPN > LAN 192.168.1.0/24 blocked (by firewall/IPS policy).

3.2 PFSENSE INTERFACE CONFIGURATION

The pfSense firewall automatically detected three interfaces WAN (em0), LAN (em1), and OPT1 (em2) during boot. Interface assignments and IPs were configured as seen in the below pfSense console output:

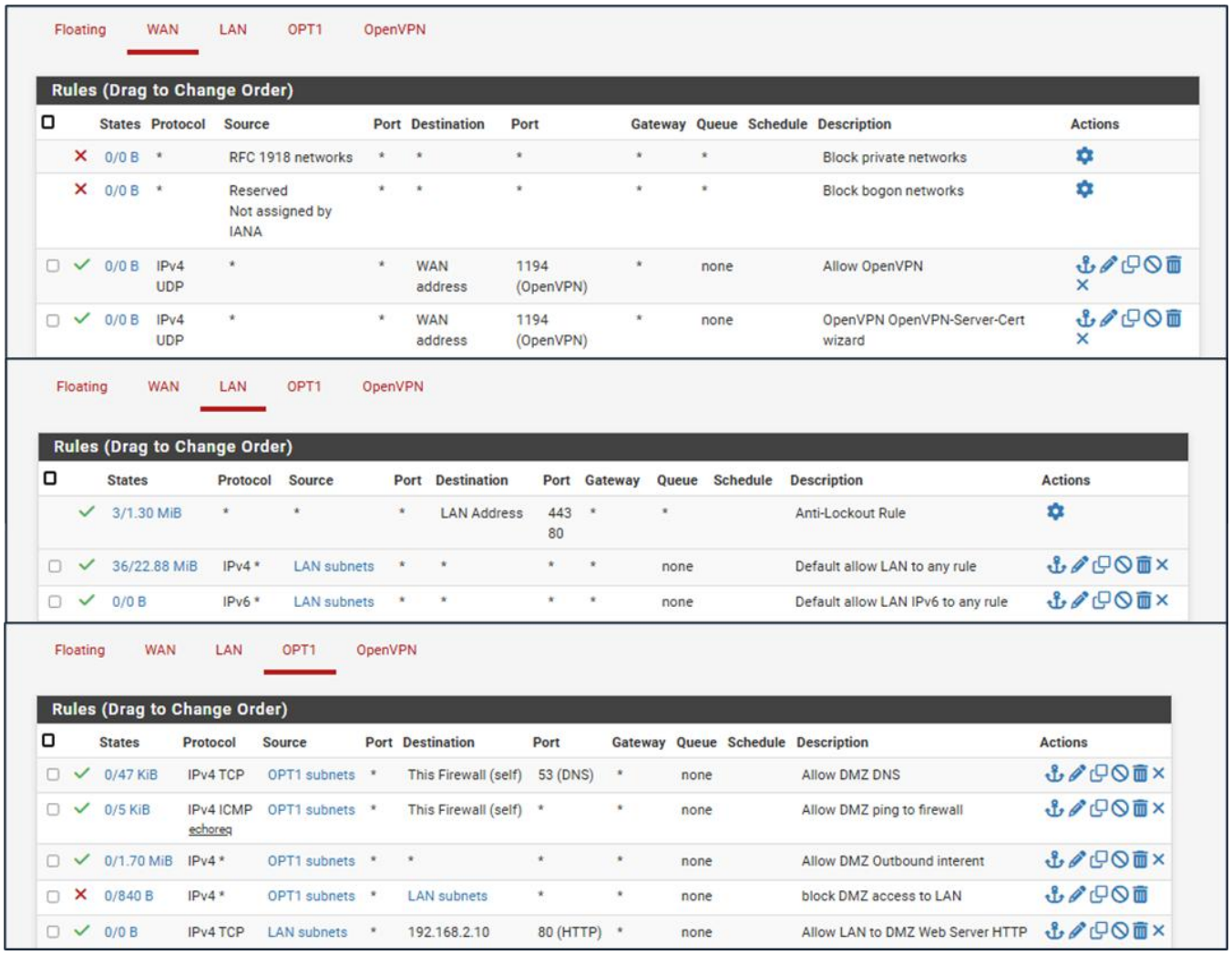


3.3 FIREWALL RULES

After verifying that the pfSense VM had initialized correctly and all interfaces were assigned, the pfSense web GUI was accessed from the Windows10-1 LAN machine using https://192.168.1.100. From the dashboards, we configured necessary firewall policies were created for the WAN, LAN, and OPT1 (DMZ) interfaces as shown in this chart. This chart outlines the overall rules that will be used to segment networks, provide VPN access to users on the DMZ network, and govern how traffic flows between the WAN, LAN, and DMZ networks.

Rule for	Rule	Traffic	Action	Purpose / What Happens
WAN	Block Private Networks	RFC1918 ranges > WAN	Block	Prevents spoofed private-IP traffic from appearing on the WAN interface; default pfSense protection.
	Block Bogon Networks	Unassigned/Reserved IP ranges > WAN	Block	Blocks traffic from IP ranges that should never originate on the public internet to reduce scanning/spoofing attempts.
	Allow OpenVPN (1194/UDP)	Any > WAN Address:1194	Allow	Allows legitimate VPN clients to reach the OpenVPN server on the firewall.
	OpenVPN Wizard Rule	Any > WAN Address:1194	Allow	Auto-generated rule required for the OpenVPN server configuration and tunnel establishment.
LAN	Anti-Lockout Rule	LAN > Firewall LAN IP (TCP/443)	Allow	Ensures continuous admin access to the pfSense web interface; auto-generated by pfSense.
	Default IPv4 LAN Rule	LAN subnets > Any (IPv4)	Allow	Allows unrestricted outbound IPv4 traffic from LAN hosts for initial routing/NAT and connectivity testing.
	Default IPv6 LAN Rule	LAN subnets > Any (IPv6)	Allow	Allows unrestricted outbound IPv6 traffic from LAN hosts for testing and basic functionality validation.
OPT1	Allow DNS to Firewall	OPT1 > Firewall (TCP/53)	Allow	We enabled DNS queries from DMZ hosts for name resolution.
	Allow ICMP to Firewall	OPT1 > Firewall (ICMP echo)	Allow	We allowed DMZ hosts to ping the gateway for connectivity diagnostics.
	Allow DMZ Outbound Internet	OPT1 > Any	Allow	We allowed DMZ outbound traffic to the internet as required for updates/testing.
	Block DMZ to LAN	OPT1 > LAN subnets	Block	We enforced strict isolation by blocking all DMZ-to-LAN access.

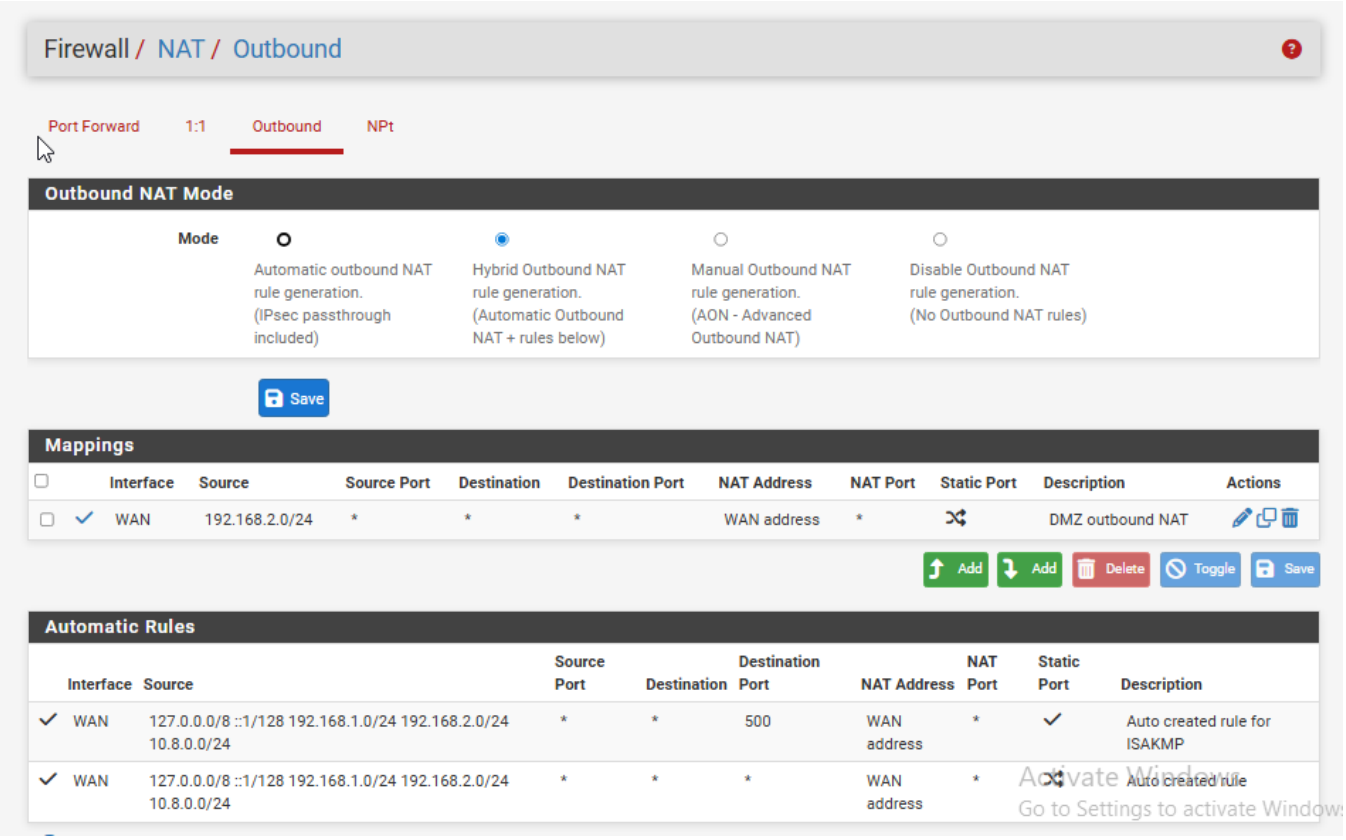
	Allow LAN to DMZ Web Server	LAN subnets > 192.168.2.10:80	Allow	We permitted controlled LAN access to the DMZ web server over HTTP.



3.3 NAT CONFUGIRATION

Hybrid Outbound NAT was enabled with a custom NAT rule for the DMZ to ensure secure outbound connectivity.

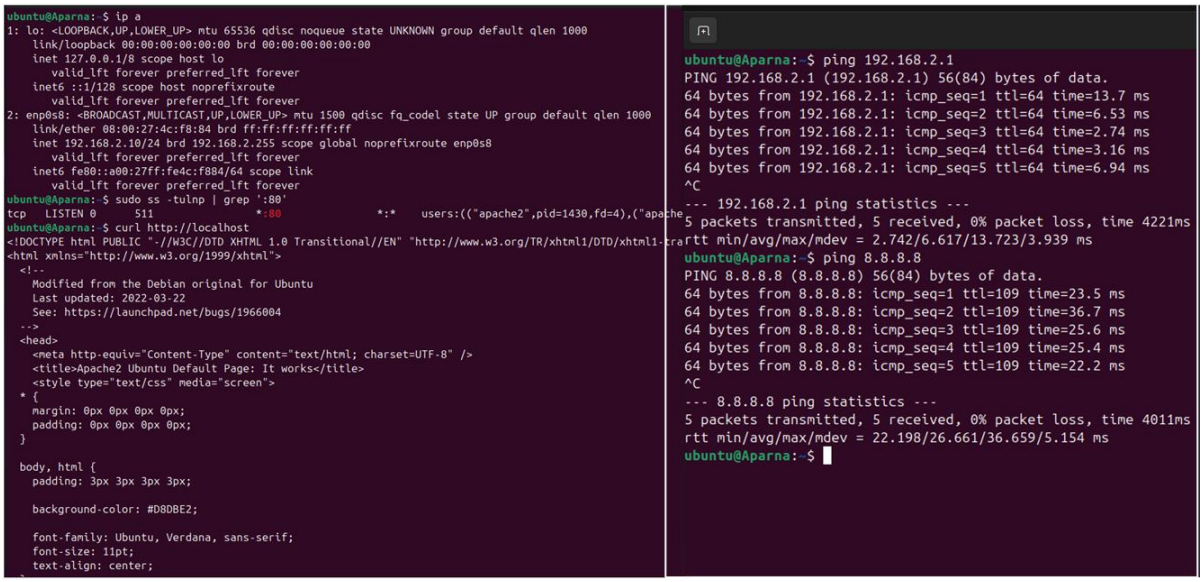
Component	Configuration / Traffic	Purpose / What We Did
NAT Mode	**Hybrid Outbound NAT**	We enabled Hybrid Mode to use both auto-generated NAT rules and custom mappings for specific subnets (e.g., DMZ 192.168.2.0/24).
Custom NAT Mapping	**DMZ (192.168.2.0/24) > WAN Address**	We created a manual rule, so all outbound DMZ traffic is translated to the WAN public IP, enabling DMZ systems to access the internet while staying behind NAT.
Automatic NAT Rules	**LAN + VPN subnets > WAN Address**	pfSense automatically created NAT rules for internal LAN and VPN networks to ensure proper outbound connectivity without manual configuration.
Security Effect	**NAT boundary for LAN + DMZ**	Ensure that internal addressing is hidden externally and unsolicited inbound traffic cannot reach DMZ/LAN hosts.



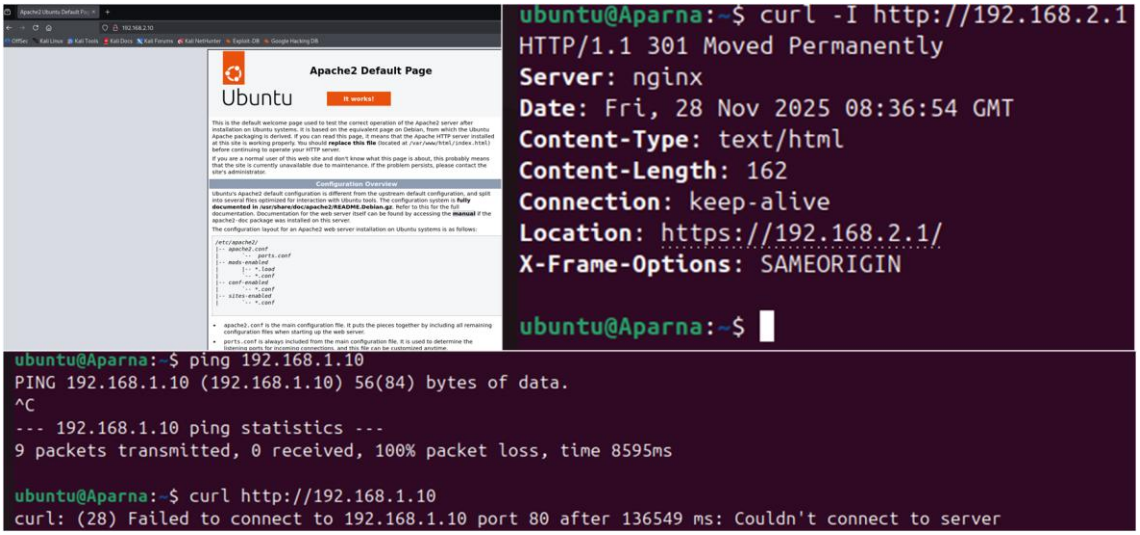
3.5 BEHAVIOR VALIDATION

We validated the expected LAN, DMZ, VPN, and WAN behavior using a series of connectivity tests including ping, curl, and Nmap-based checks, as demonstrated below:

- Verified Apache web server by checking localhost page and confirming port 80 is listening.
- Confirmed DMZ server can reach OPT1 gateway and the internet (ping 192.168.2.1, ping 8.8.8.8).
- Validated LAN access to DMZ web server using ping and curl from Kali and browser access from Windows.
- Confirmed DMZ isolation by blocking access to LAN host (failed ping and curl to 192.168.1.10).
- Verified pfSense redirect and web portal protection using curl -I to 192.168.2.1.



```
kali@kali: ~
Session  Actions  Edit  View  Help

┌──(kali㉿kali)-[~]
└─$ ping 192.168.2.10

PING 192.168.2.10 (192.168.2.10) 56(84) bytes of data.
64 bytes from 192.168.2.10: icmp_seq=1 ttl=63 time=6.36 ms
64 bytes from 192.168.2.10: icmp_seq=2 ttl=63 time=6.20 ms
64 bytes from 192.168.2.10: icmp_seq=3 ttl=63 time=7.26 ms
64 bytes from 192.168.2.10: icmp_seq=4 ttl=63 time=9.73 ms
64 bytes from 192.168.2.10: icmp_seq=5 ttl=63 time=6.43 ms
^C
── 192.168.2.10 ping statistics ──
5 packets transmitted, 5 received, 0% packet loss, time 4010ms
rtt min/avg/max/mdev = 6.204/7.196/9.731/1.319 ms

┌──(kali㉿kali)-[~]
└─$ curl -v http://192.168.2.10

*   Trying 192.168.2.10:80 ...
* Connected to 192.168.2.10 (192.168.2.10) port 80
* using HTTP/1.x
> GET / HTTP/1.1
> Host: 192.168.2.10
> User-Agent: curl/8.15.0
> Accept: */*
>
* Request completely sent off
< HTTP/1.1 200 OK
< Date: Fri, 28 Nov 2025 08:13:38 GMT
< Server: Apache/2.4.58 (Ubuntu)
< Last-Modified: Thu, 27 Nov 2025 23:16:14 GMT
< ETag: "29af-6449bb302d469"
< Accept-Ranges: bytes
< Content-Length: 10671
< Vary: Accept-Encoding
< Content-Type: text/html
<
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Transitional//EN" "http://www.w3.org/TR/xhtml1/DTD/xhtml1-transitional.dtd">
<html xmlns="http://www.w3.org/1999/xhtml">
  <!--
    Modified from the Debian original for Ubuntu
    Last updated: 2022-03-22
    See: https://launchpad.net/bugs/1966004
  -->
  <head>
    <meta http-equiv="Content-Type" content="text/html; charset=UTF-8" />
    <title>Apache2 Ubuntu Default Page: It works</title>
    <style type="text/css" media="screen">
  * {
    margin: 0px 0px 0px 0px;
    padding: 0px 0px 0px 0px;
  }

  body, html {
```



Commands used:

Command	Purpose
ip a	Check interface & IPs
sudo ss -tulnp | grep ':80'	Check Apache listening
curl http://localhost	Test Apache locally
ping 192.168.2.1	Ping pfSense DMZ gateway
ping 8.8.8.8	Test DMZ outbound internet
ping 192.168.2.10	Ping DMZ server from Kali
curl -v http://192.168.2.10	Test HTTP access from Kali

4. VPN CONFIGURATION

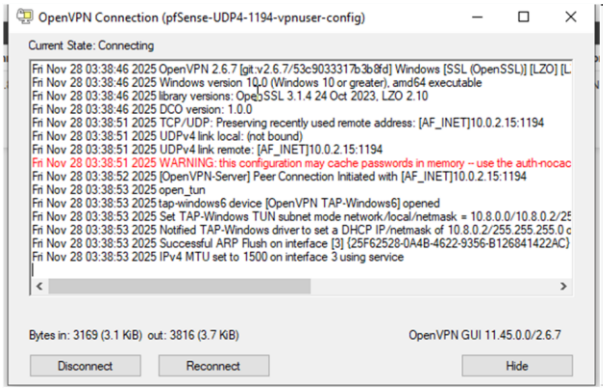
To validate secure remote access, we configured pfSense as an OpenVPN server (UDP/1194), exported a client profile, and connected from a Windows machine. Upon establishing a VPN tunnel, the client was assigned an IP from the 10.8.0.0/24 network and could then securely connect to the web server in the DMZ while at the same time being restricted from connecting to the LAN. This testing validated that all aspects of the OpenVPN service including certificates, routing and the firewalls segmenting policies functioned as intended.

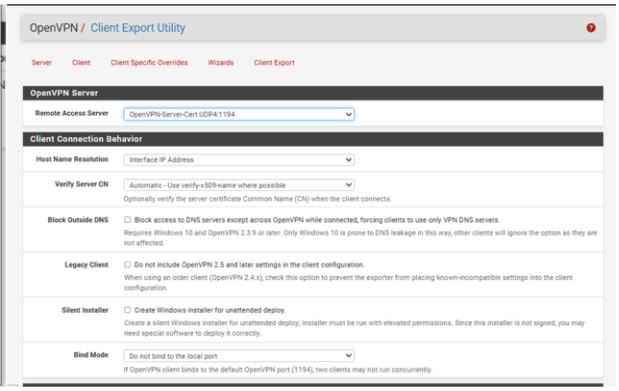
Key Validation Steps:

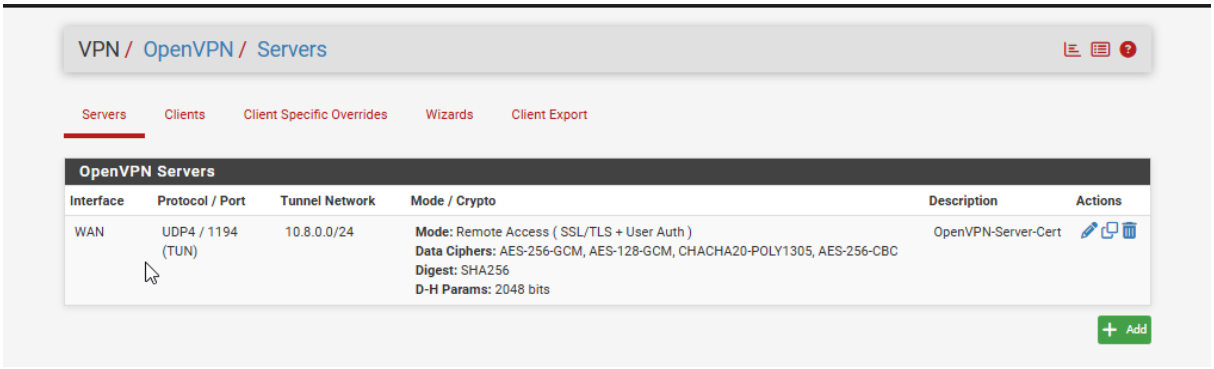
- Establishment of a working VPN connection (OpenVPN client on Windows, IP address assigned as 10.8.0.2).
- Web access via the DMZ Web Server (192.168.2.10) was possible via the VPN (HTTP web pages were accessed).
- The test pings/curls were completed confirming that VPN-to-DMZ is enabled while VPN-to-LAN is disabled.
- pfSense routing/firewall configuration is enforced by the OpenVPN rules page.
- LAN device separation from VPN clients was confirmed to be in place as required for security.

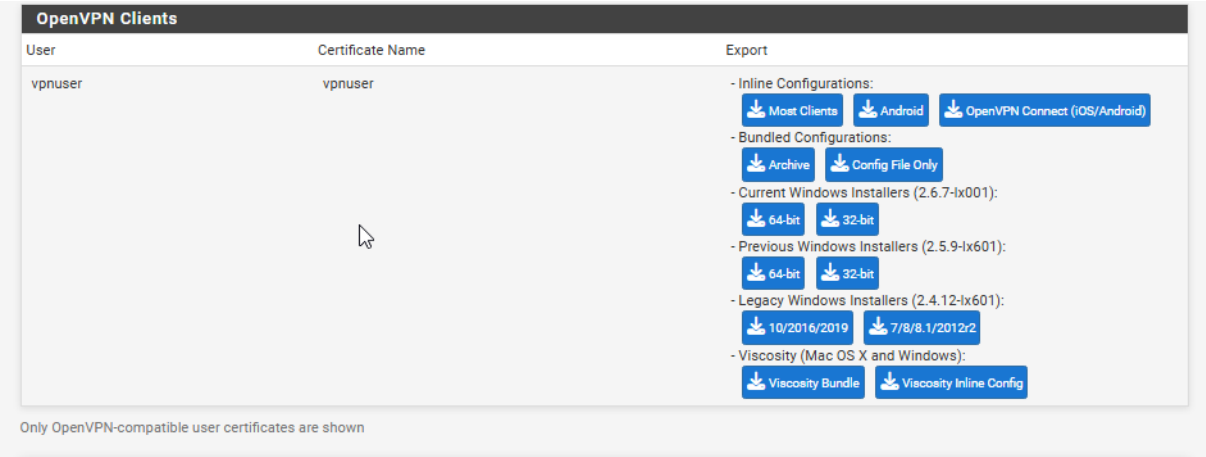
Commands used:

- ping 192.168.2.10 – succeeds - Traffic from the VPN tunnel can reach the DMZ network
- ping 192.168.1.10 – fails - VPN users cannot reach the internal LAN










```
Aparna>ping 192.162.2.10

Pinging 192.162.2.10 with 32 bytes of data:
Reply from 192.162.2.10: bytes=32 time=467ms TTL=229
Reply from 192.162.2.10: bytes=32 time=500ms TTL=229
Reply from 192.162.2.10: bytes=32 time=331ms TTL=229
Reply from 192.162.2.10: bytes=32 time=289ms TTL=229

Ping statistics for 192.162.2.10:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 289ms, Maximum = 500ms, Average = 396ms

Aparna>
Aparna>ping 192.162.1.10

Pinging 192.162.1.10 with 32 bytes of data:
Request timed out.
Request timed out.
Request timed out.
Request timed out.

Ping statistics for 192.162.1.10:
    Packets: Sent = 4, Received = 0, Lost = 4 (100% loss),

Aparna>
```

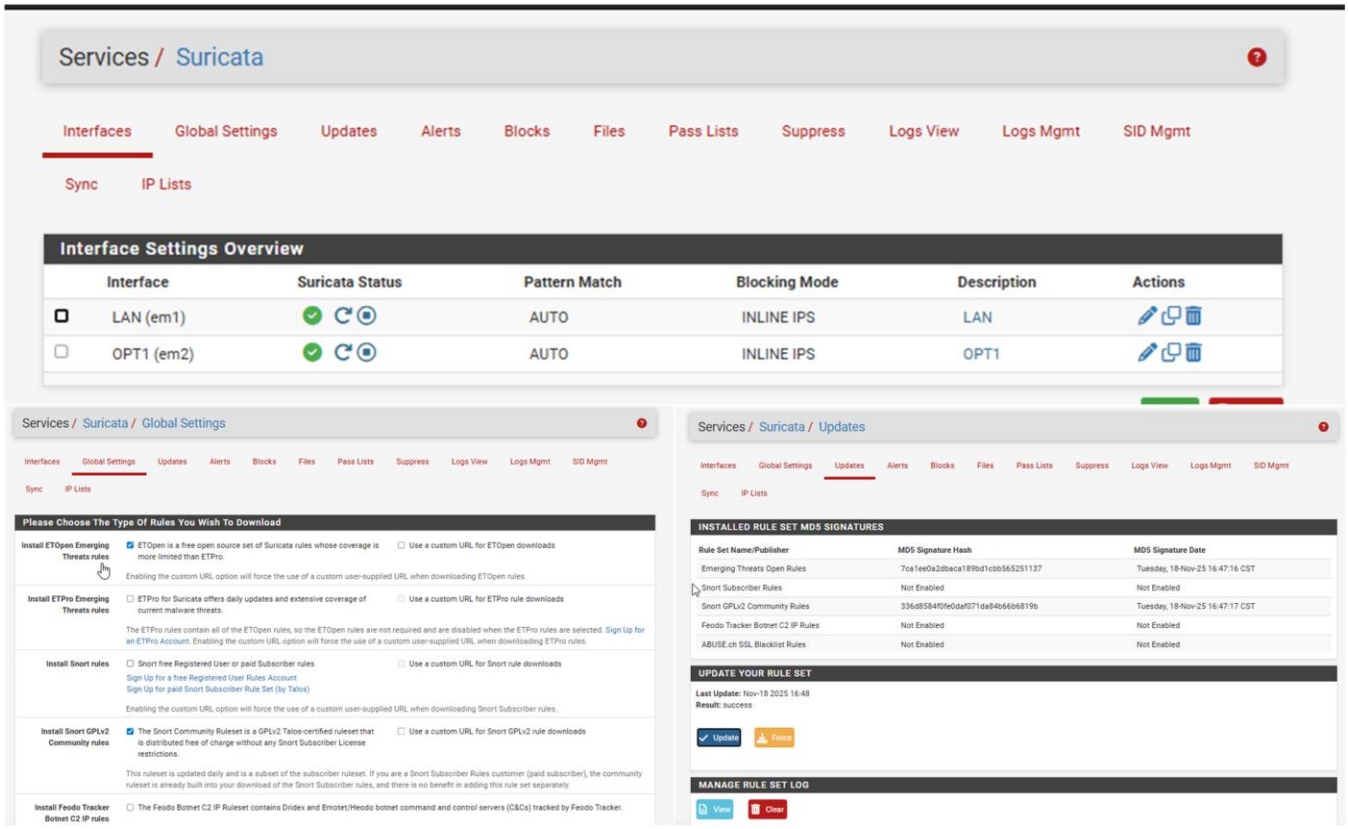
```
Aparna>ipconfig

Windows IP Configuration


Unknown adapter OpenVPN Wintun:

   Media State . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :

Ethernet adapter Ethernet:

   Connection-specific DNS Suffix  . : lab.local
   Link-local IPv6 Address . . . . . : fe80::fd56:f43b:ec58:4df5%6
   IPv4 Address. . . . . . . . . . . : 192.168.1.100
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Default Gateway . . . . . . . . . : 192.168.1.1

Unknown adapter OpenVPN TAP-Windows6:

   Connection-specific DNS Suffix  . :
   Link-local IPv6 Address . . . . . : fe80::23d2:64df:a96a:685c%3
   IPv4 Address. . . . . . . . . . . : 10.8.0.2
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Default Gateway . . . . . . . . . :

Unknown adapter OpenVPN Data Channel Offload:

   Media State . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :
```

5. SURICATA SETUP

1. Enabled Suricata in inline IPS mode on LAN and OPT1 for real-time blocking.
2. Activated ET Open Ruleset, providing updated signatures for malware, scans, and anomalies.
3. Verified successful rules download and updates via the Suricata Updates tab.
4. Confirmed Suricata service was running and inspecting live traffic on both interfaces.
5. Ensured IPS blocked malicious activity during test scans and attack simulations.

Category	Technical Details
Mode	Inline IPS Mode (netmap)
Enabled Interfaces	LAN (em1), OPT1/DMZ (em2)
Rule Source	Emerging Threats Open (ET Open)
Ruleset Update	Updated successfully; MD5 verified
Blocking Mode	Enabled (drops malicious packets)
Engine Features	HTTP parser (libhtp), TCP stream reassembly, IP defrag, checksum validation
Pattern Matcher	Hyperscan

Drop/Alert Events Observed	SYN flood, ICMP flood, UDP flood, Nmap scan, DIRB brute-force, Slowloris, SQL injection attempts
Common Alert Types	TCP anomaly, ICMP anomaly, HTTP directory brute force, Slowloris detection, SQL injection signatures
Log Output	/var/log/suricata/eve.json
Verification	Rules loaded, Suricata running, attacks detected/blocked on LAN & DMZ



6. ATTACK SIMULATION & SECURITY CONTROLS VALIDATION

To validate the security controls, multiple attacks were launched from the Kali attacker system toward the DMZ web server (192.168.2.10) and the protected LAN host (192.168.1.10). Wireshark captures were taken on the target interfaces to observe real packet-level behavior, and Suricata alerts were reviewed to verify IPS action.

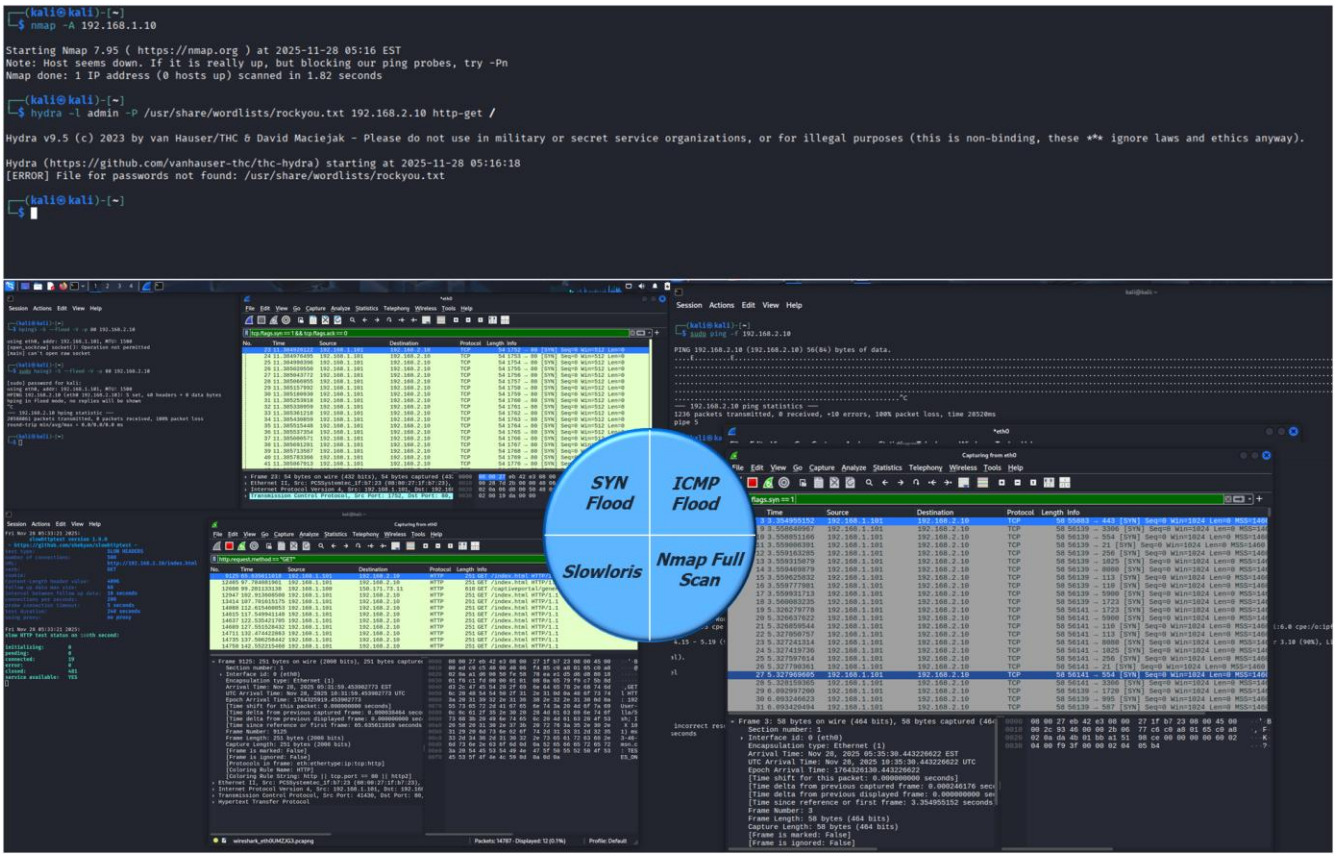
Attacks Performed Summary:

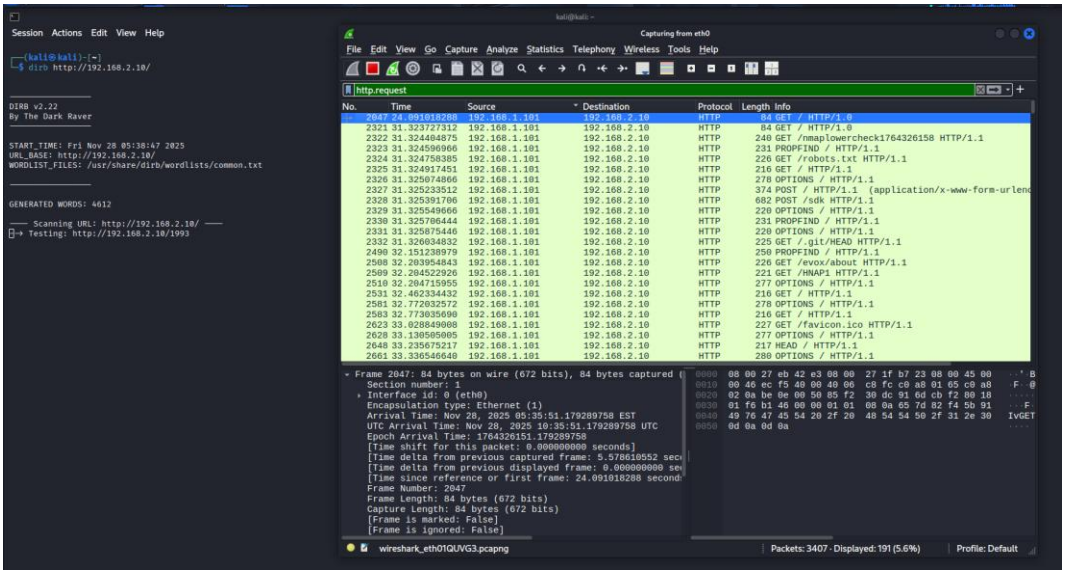
- A reconnaissance NMAP scan was conducted on the DMZ web server (192.168.2.10); it is apparent that port 80 is active, and Apache was indicated via NMAP.
- Full NMAP Scan of the LAN host (192.168.1.10) - It appears the LAN host is unresponsive (PfSense+Suricata are rejecting all incoming packets).
- SYN Flood with Hping3 - Wireshark displays a never-ending stream of SYN packets directed at the DMZ Interface.
- UDP/ICMP floods - high-rate packets are visible in Wireshark showing that packets were generated at a high rate.
- Slowloris (http dos) sent to the DMZ webserver - Wireshark capture shows slow get requests (multiple http get requests made slowly over time).
- Directory brute-force (DIRB) against /index.html - http get requests are visible in Wireshark.

- SQL-injection attempts (http requests with malicious payload) are visible in Wireshark.

What the Wireshark captures showed:

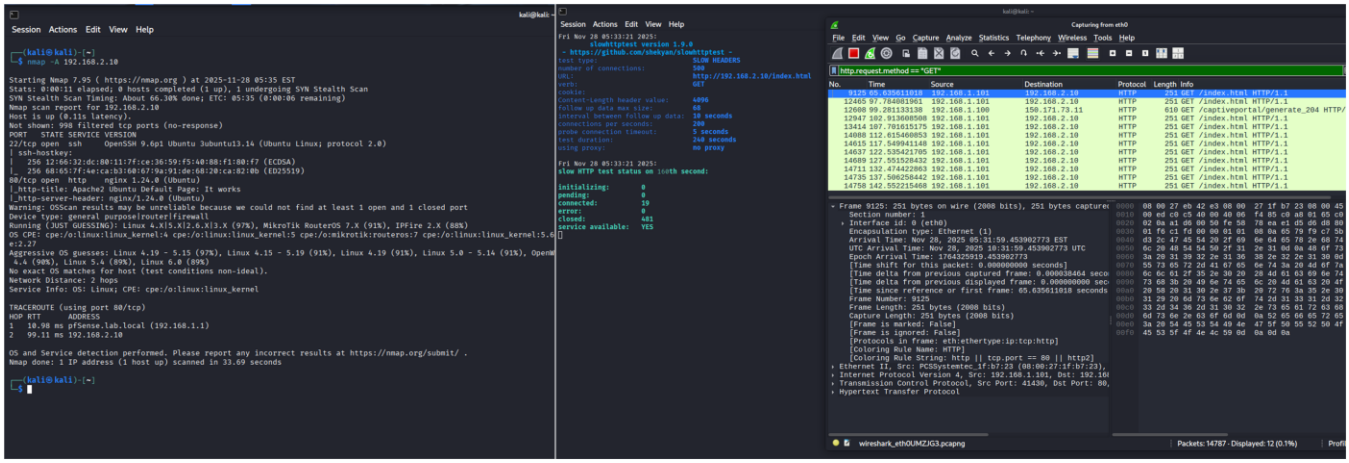
- Continuous ICMP, UDP, TCP, SYN packets hitting the DMZ interface (showing flood behavior).
- Bursts of http get/post requests from dirb, Slowloris and other enumeration tools.
- No response packets when attempting to communicate with the lan host that has been blocked by the firewall (proving the firewall is working as expected).
- Patterns of behavior seen in Wireshark that match Suricata's detections (e.g., malformed TCP, flood anomaly).

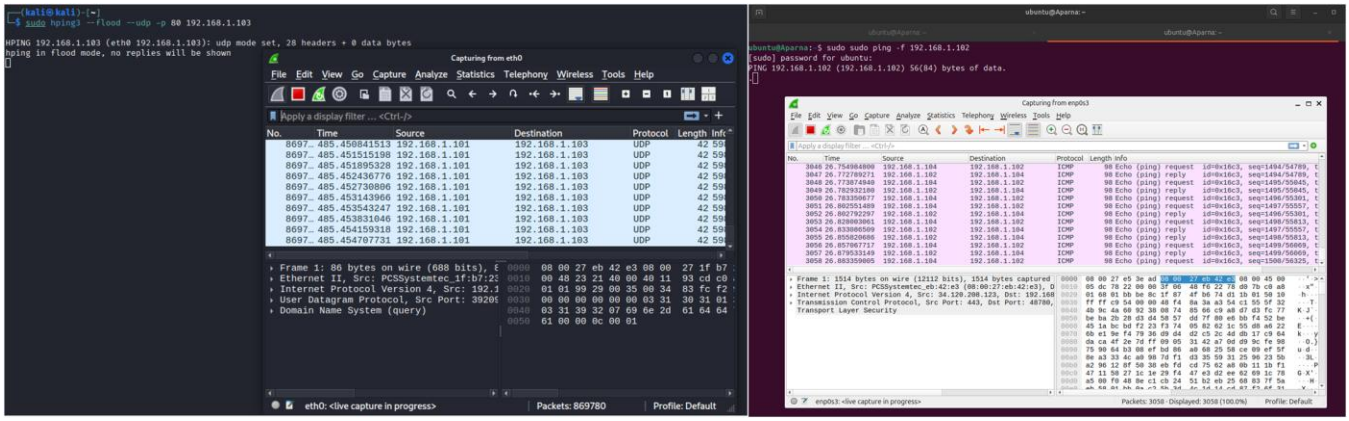


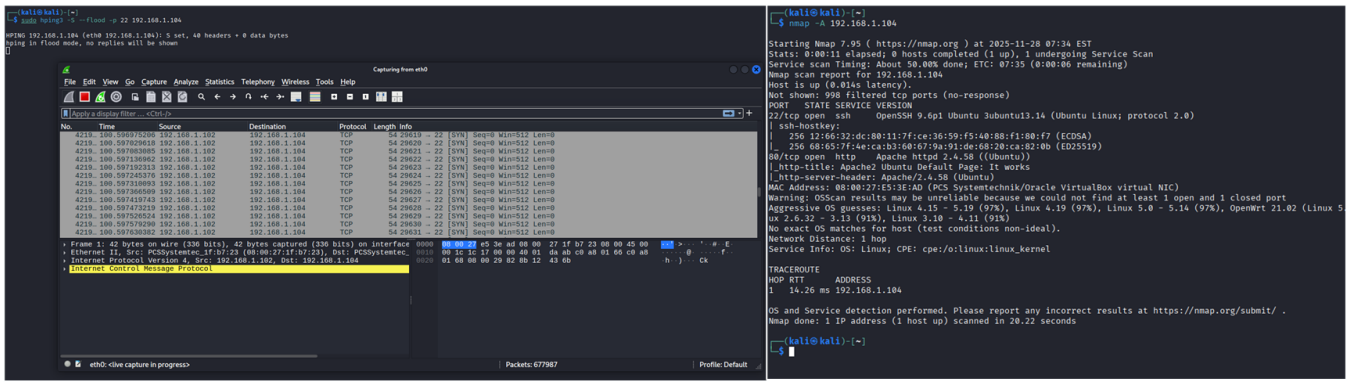


Commands used for Attack:

Command	Attack Type / Purpose
nmap -sS 192.168.2.10	Reconnaissance (Port Scanning)
nmap -A 192.168.2.10	Reconnaissance (Deep Enumeration)
nmap -A 192.168.1.10	Reconnaissance (Service Enumeration)
hydra -l admin -p /usr/share/wordlists/rockyou.txt 192.168.2.10 http-get /	Brute Force Attack
dirb http://192.168.2.10/	Directory Enumeration
sudo hping3 -S --flood -p 80 192.168.2.10	SYN Flood (DoS Attack)
sudo ping -f 192.168.2.10	ICMP Flood (DoS Attack)
sudo hping3 --flood -V 192.168.2.10	ICMP Flood (DoS Attack)
sudo hping3 -S --flood -p 22 192.168.1.104	SYN Flood (DoS Attack)
sudo hping3 --flood -V 192.168.1.104	ICMP Flood (DoS Attack)
slowhttptest -c 500 -H -g -o slowhttptest -u http://192.168.2.10/index.html	Slowloris (Application Layer DoS)
sudo hping3 --flood --udp -p 80 192.168.1.103	UDP Flood Attack
sudo ping -f 192.168.1.102	ICMP Flood (Ping Flood)







7. SURICATA ALERTS

The Suricata intrusion detection system successfully detected and blocked traffic generated by simulated attacks using a number of different alert types; validating that Suricata can be used as an inline intrusion prevention system (IPS).

Key Inline IPS Observations:

- Suricata was able to stop the TCP SYN flood traffic, the UDP burst traffic, and the ICMP anomaly traffic.
- Suricata reported on the following events:
  - Generic protocol commands in TCP
  - Flood/echo anomalies in ICMP
  - Anomalous HTTP activity
  - Possible patterns of a brute force attempt against directories
- The traffic being sent by the attacker was stopped by Suricata as the attacker attempted to send traffic to a LAN host, which allowed for firewalls to maintain segmentation of networks.
- Suricata also blocked several malicious packets that were produced during the high-rate flooding testing from reaching the DMZ server.

Alert Log View Filter

Last 250 Alert Entries. (Most recent entries are listed first)

Note: Alerts triggered by DROP rules that resulted in dropped (blocked) packets are shown with highlighted rows below.

Date	Action	Pri	Proto	Class	Src	SPort	Dst	DPort	GID:SID	Description
11/28/2025 04:16:59	⚠	3	TCP	Generic Protocol Command Decode	192.168.2.10	80	192.168.1.101	34054	1:2260002	SURICATA Applayer Detect protocol only one direction
11/28/2025 04:16:57	⚠	3	ICMP	Generic Protocol Command Decode	192.168.2.10	0	192.168.1.101	9	1:2200025	SURICATA ICMPv4 unknown code
11/28/2025 04:16:57	⚠	3	ICMP	Generic Protocol Command Decode	192.168.1.101	8	192.168.2.10	9	1:2200025	SURICATA ICMPv4 unknown code
11/28/2025 04:16:55	⚠	3	ICMP	Generic Protocol Command Decode	192.168.2.10	0	192.168.1.101	9	1:2200025	SURICATA ICMPv4 unknown code
11/28/2025 04:16:55	⚠	3	ICMP	Generic Protocol Command Decode	192.168.1.101	8	192.168.2.10	9	1:2200025	SURICATA ICMPv4 unknown code
11/28/2025 04:10:44	⚠	3	TCP	Generic Protocol Command Decode	20.25.227.174	443	192.168.1.100	49843	1:2210038	SURICATA STREAM FIN out of window
11/28/2025 04:10:32	⚠	3	TCP	Generic Protocol Command Decode	20.25.227.174	443	192.168.1.100	49843	1:2210038	SURICATA STREAM FIN out of window

8. CONCLUSION

This project effectively demonstrated a well-structured, multi-zone network utilizing current industry best practice. pfSense proved to be a strong firewall enforcer; NAT (Network Address Translation) correctly routed and maintained privacy for the internal network; and the DMZ segmented the internal network from external networks thus preventing unauthorized access to internal resources. Only the appropriate networks had access to the Apache Server; therefore, it was secure. A VPN was optionally configured to provide additional secure remote access. An IDS/IPS system (Suricata) was also configured to monitor for malicious activity at all times.

The environment is a good representation of what can be found in a production environment that uses multiple defense-in-depth strategies. Therefore, it reinforces concepts such as segmentation, least privilege access, intrusion detection, and securely accessing a remote location. Implementing this project reinforced my knowledge of how I would perform many tasks in today's network security environment.