

Implementation of IPSec Tunnel Between VMs Using LibreSwan

Network and Systems Security - Winter 2025 Exercise 3, Part 2 Report

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Introduction

This report details the implementation of an IPSec/IKE tunnel between two gateway virtual machines (VMs) using LibreSwan, as specified in Part 2 of the Winter 2025 Networks and Systems Security II Exercise 3. The setup comprises four VMs: two gateway VMs (VM2 and VM3) running Ubuntu, and two endpoint VMs (VM1 and VM4) running Alpine Linux. The primary objective is to establish a secure, encrypted tunnel between VM2 and VM3, enabling VM1 to communicate with VM4 without modifying their routing tables. Authentication is achieved using X.509 certificates, and the traffic egressing VM3 to VM4 bears VM3's source address. This report outlines the configuration process, validation steps, and security analysis, supported by illustrative screenshots.

Network Architecture

The network topology consists of four VMs configured in VMware Workstation with the following specifications:

- **VM1 (Alpine Linux - Client)**
 - Interface 1: NAT (Internet access)
 - Interface 2: Host-only (10.0.0.0/24 network)
 - IP: 10.0.0.10/24
- **VM2 (Ubuntu - Gateway 1)**
 - Interface 1: Host-only (10.0.0.0/24 network)
 - Interface 2: Host-only (20.0.0.0/24 network)
 - IPs: 10.0.0.1/24, 20.0.0.1/24
- **VM3 (Ubuntu - Gateway 2)**

- Interface 1: Host-only (20.0.0.0/24 network)
- Interface 2: Host-only (30.0.0.0/24 network)
- IPs: 20.0.0.2/24, 30.0.0.1/24
- **VM4 (Alpine Linux - Server)**
 - Interface 1: NAT (Internet access)
 - Interface 2: Host-only (30.0.0.0/24 network)
 - IP: 30.0.0.10/24

Figure 1: Virtual network topology showing gateway VMs and protected subnets

Implementation Steps

1. VMware Network Setup

1. Configured three host-only networks in VMware Virtual Network Editor:
 - vmnet1: 10.0.0.0/24
 - vmnet2: 20.0.0.0/24
 - vmnet3: 30.0.0.0/24
2. Assigned network adapters to each VM as per the topology.

Figure 2: VMware network adapter configuration

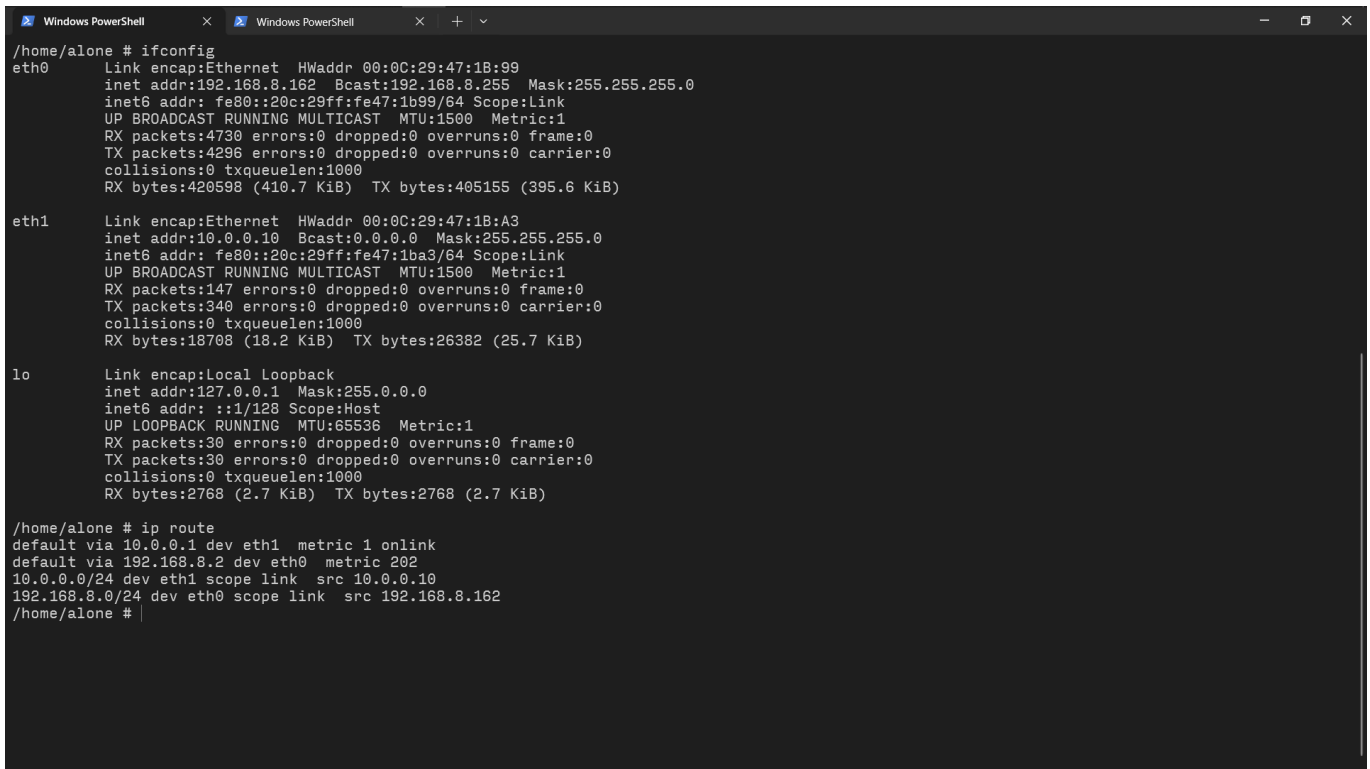
2. VM1 Configuration (Alpine Linux)

- Installed Alpine Linux and configured networking:

```
cat > /etc/network/interfaces << EOF
auto lo
iface lo inet loopback

auto eth0
iface eth0 inet dhcp

auto eth1
iface eth1 inet static
    address 10.0.0.10
    netmask 255.255.255.0
    gateway 10.0.0.1
EOF
/etc/init.d/networking restart
ip route add 30.0.0.0/24 via 10.0.0.1
```



```

/home/alone # ifconfig
eth0      Link encap:Ethernet  HWaddr 00:0C:29:47:1B:99
          inet addr:192.168.8.162  Bcast:192.168.8.255  Mask:255.255.255.0
          inet6 addr: fe80::20c:29ff:fe47:1b99/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:4730 errors:0 dropped:0 overruns:0 frame:0
          TX packets:4296 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:420598 (410.7 KiB)  TX bytes:405155 (395.6 KiB)

eth1      Link encap:Ethernet  HWaddr 00:0C:29:47:1B:A3
          inet addr:10.0.0.10  Bcast:0.0.0.0  Mask:255.255.255.0
          inet6 addr: fe80::20c:29ff:fe47:1ba3/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:147 errors:0 dropped:0 overruns:0 frame:0
          TX packets:340 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:18708 (18.2 KiB)  TX bytes:26382 (25.7 KiB)

lo        Link encap:Local Loopback
          inet addr:127.0.0.1  Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING  MTU:65536  Metric:1
          RX packets:30 errors:0 dropped:0 overruns:0 frame:0
          TX packets:30 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:2768 (2.7 KiB)  TX bytes:2768 (2.7 KiB)

/home/alone # ip route
default via 10.0.0.1 dev eth1 metric 1 onlink
default via 192.168.8.2 dev eth0 metric 202
10.0.0.0/24 dev eth1 scope link src 10.0.0.10
192.168.8.0/24 dev eth0 scope link src 192.168.8.162
/home/alone #

```

Figure 3: VM1 network configuration

3. VM2 Configuration (Ubuntu - Gateway 1)

- Configured network interfaces:

```

sudo cat > /etc/netplan/01-netcfg.yaml << EOF
network:
  version: 2
  renderer: networkd
  ethernets:
    ens33:
      addresses:
        - 10.0.0.1/24
      dhcp4: no
    ens37:
      addresses:
        - 20.0.0.1/24
      dhcp4: no
      routes:
        - to: 30.0.0.0/24
          via: 20.0.0.2
EOF
sudo netplan apply

```

```

~ : bash — Konsole
New Tab Split View
Copy Paste Find
techng@techng:~$ ls
certs Desktop Downloads Music Pictures Public Templates Videos
techng@techng:~$ ifconfig
ens33: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
    inet 10.0.0.1 netmask 255.255.255.0 broadcast 10.0.0.255
    inet6 fe80::20c:29ff:fe0b:233 prefixlen 64 scopeid 0x20<link>
    ether 00:0c:29:0b:02:33 txqueuelen 1000 (Ethernet)
    RX packets 399 bytes 34096 (34.0 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 231 bytes 29955 (29.9 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

ens37: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
    inet 20.0.0.1 netmask 255.255.255.0 broadcast 20.0.0.255
    inet6 fe80::20c:29ff:fe0b:23d prefixlen 64 scopeid 0x20<link>
    ether 00:0c:29:0b:02:3d txqueuelen 1000 (Ethernet)
    RX packets 90 bytes 17108 (17.1 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 80 bytes 8639 (8.6 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

lo: flags=73<UP,LOOPBACK,RUNNING> mtu 65536
    inet 127.0.0.1 netmask 255.0.0.0
    inet6 ::1 prefixlen 128 scopeid 0x10<host>
    loop txqueuelen 1000 (Local Loopback)
    RX packets 8164 bytes 581217 (581.2 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 8164 bytes 581217 (581.2 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

techng@techng:~$ ip route
10.0.0.0/24 dev ens33 proto kernel scope link src 10.0.0.1
20.0.0.0/24 dev ens37 proto kernel scope link src 20.0.0.1
30.0.0.0/24 via 20.0.0.2 dev ens37 proto static
techng@techng:~$

```

- Enabled IP forwarding:

```

echo 1 | sudo tee /proc/sys/net/ipv4/ip_forward
echo "net.ipv4.ip_forward = 1" | sudo tee -a /etc/sysctl.conf
sudo sysctl -p

```

- Installed LibreSwan and OpenSSL:

```

sudo apt update
sudo apt install -y libreswan openssl

```

- Generated certificates:

```

sudo mkdir -p /etc/ipsec.d/certs /etc/ipsec.d/private /etc/ipsec.d/cacerts
sudo openssl genrsa -out /etc/ipsec.d/private/ca-key.pem 4096
sudo openssl req -new -x509 -key /etc/ipsec.d/private/ca-key.pem -out
/etc/ipsec.d/cacerts/ca-cert.pem -days 3650 -subj "/CN=VPN CA"
sudo chmod 600 /etc/ipsec.d/private/ca-key.pem
sudo openssl genrsa -out /etc/ipsec.d/private/vm2-key.pem 4096
sudo openssl req -new -key /etc/ipsec.d/private/vm2-key.pem -out
/tmp/vm2.csr -subj "/CN=VM2"
sudo openssl x509 -req -in /tmp/vm2.csr -CA /etc/ipsec.d/cacerts/ca-cert.pem
-CAkey /etc/ipsec.d/private/ca-key.pem -CAcreateserial -out
/etc/ipsec.d/certs/vm2-cert.pem -days 1825
sudo rm /tmp/vm2.csr

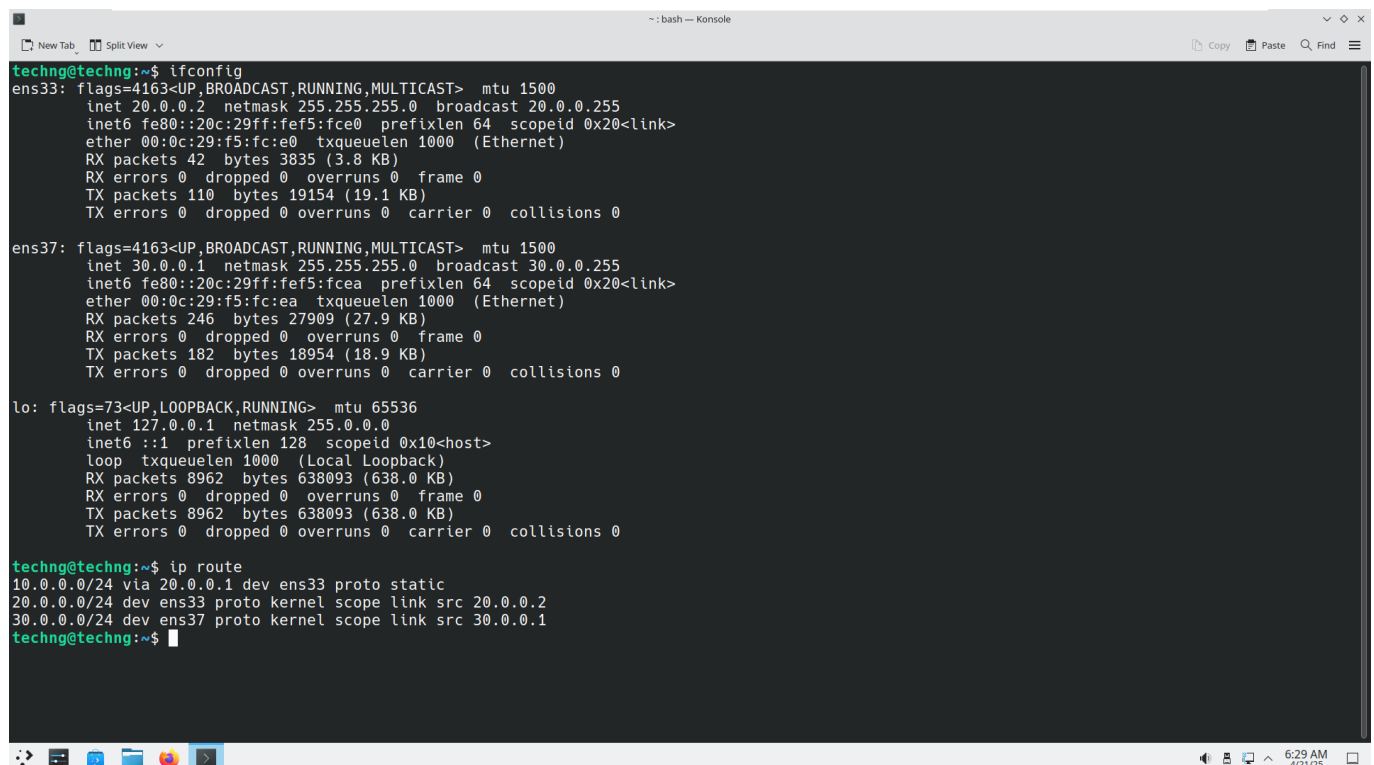
```

Figure 4: Certificate generation process on VM2

4. VM3 Configuration (Ubuntu - Gateway 2)

- Configured network interfaces and NAT:

```
sudo cat > /etc/netplan/01-netcfg.yaml << EOF
network:
  version: 2
  renderer: networkd
  ethernets:
    ens33:
      addresses:
        - 20.0.0.2/24
      dhcp4: no
      routes:
        - to: 10.0.0.0/24
          via: 20.0.0.1
    ens37:
      addresses:
        - 30.0.0.1/24
      dhcp4: no
EOF
sudo netplan apply
sudo iptables -t nat -A POSTROUTING -s 10.0.0.0/24 -d 30.0.0.0/24 -j
MASQUERADE
sudo apt install -y iptables-persistent
```



```
techng@techng:~$ ifconfig
ens33: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
    inet 20.0.0.2 netmask 255.255.255.0 broadcast 20.0.0.255
    inet6 fe80::20c:29ff:fef5:fce0 prefixlen 64 scopeid 0x20<link>
    ether 00:0c:29:f5:fc:e0 txqueuelen 1000 (Ethernet)
    RX packets 42 bytes 3835 (3.8 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 110 bytes 19154 (19.1 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

ens37: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
    inet 30.0.0.1 netmask 255.255.255.0 broadcast 30.0.0.255
    inet6 fe80::20c:29ff:fef5:fcea prefixlen 64 scopeid 0x20<link>
    ether 00:0c:29:f5:fc:ea txqueuelen 1000 (Ethernet)
    RX packets 246 bytes 27909 (27.9 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 182 bytes 18954 (18.9 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

lo: flags=73<UP,LOOPBACK,RUNNING> mtu 65536
    inet 127.0.0.1 netmask 255.0.0.0
    inet6 ::1 prefixlen 128 scopeid 0x10<host>
    loop txqueuelen 1000 (Local Loopback)
    RX packets 8962 bytes 638093 (638.0 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 8962 bytes 638093 (638.0 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

techng@techng:~$ ip route
10.0.0.0/24 via 20.0.0.1 dev ens33 proto static
20.0.0.0/24 dev ens33 proto kernel scope link src 20.0.0.2
30.0.0.0/24 dev ens37 proto kernel scope link src 30.0.0.1
techng@techng:~$
```

- Installed LibreSwan and configured certificates (transferred CA cert from VM2):

```
sudo apt update
sudo apt install -y libreswan openssl
sudo mkdir -p /etc/ipsec.d/certs /etc/ipsec.d/private /etc/ipsec.d/cacerts
sudo openssl genrsa -out /etc/ipsec.d/private/vm3-key.pem 4096
sudo openssl req -new -key /etc/ipsec.d/private/vm3-key.pem -out
/tmp/vm3.csr -subj "/CN=VM3"
# On VM2: Sign VM3's CSR
sudo openssl x509 -req -in /tmp/vm3.csr -CA /etc/ipsec.d/cacerts/ca-cert.pem
-CAkey /etc/ipsec.d/private/ca-key.pem -CAcreateserial -out /tmp/vm3-
cert.pem -days 1825
```

5. VM4 Configuration (Alpine Linux)

- Configured networking and web server:

```
cat > /etc/network/interfaces << EOF
auto lo
iface lo inet loopback

auto eth0
iface eth0 inet dhcp

auto eth1
iface eth1 inet static
    address 30.0.0.10
    netmask 255.255.255.0
    gateway 30.0.0.1
EOF
/etc/init.d/networking restart
apk add lighttpd
rc-service lighttpd start
echo "<html><body><h1>This is VM4 at 30.0.0.10</h1></body></html>" >
/var/www/localhost/htdocs/index.html
```

```
Windows PowerShell
/home/altwo # ifconfig
eth0      Link encap:Ethernet  HWaddr 00:0C:29:0A:ED:F9
          inet addr:192.168.8.163  Bcast:192.168.8.255  Mask:255.255.255.0
          inet6 addr: fe80::20c:29ff:fe0a:edf9/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:3544 errors:0 dropped:0 overruns:0 frame:0
          TX packets:3177 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:318683 (311.2 KiB)  TX bytes:305789 (298.6 KiB)

eth1      Link encap:Ethernet  HWaddr 00:0C:29:0A:ED:03
          inet addr:30.0.0.10  Bcast:0.0.0.0  Mask:255.255.255.0
          inet6 addr: fe80::20c:29ff:fe0a:ed03/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:120 errors:0 dropped:0 overruns:0 frame:0
          TX packets:171 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:16143 (15.7 KiB)  TX bytes:13332 (13.0 KiB)

lo        Link encap:Local Loopback
          inet addr:127.0.0.1  Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING  MTU:65536  Metric:1
          RX packets:46 errors:0 dropped:0 overruns:0 frame:0
          TX packets:46 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:4432 (4.3 KiB)  TX bytes:4432 (4.3 KiB)

/home/altwo # ip route
default via 30.0.0.1 dev eth1 metric 1 onlink
default via 192.168.8.2 dev eth0 metric 202
30.0.0.0/24 dev eth1 scope link src 30.0.0.10
192.168.8.0/24 dev eth0 scope link src 192.168.8.163
/home/altwo #
```

```
Windows PowerShell
/home/alone # wget http://30.0.0.10
Connecting to 30.0.0.10 (30.0.0.10:80)
saving to 'index.html'
index.html 100% |*****| 60 0:00:00 ETA
'index.html' saved
/home/alone # ls
Desktop  Documents  Downloads  Music  Pictures  Public  Templates  Videos  core  index.html
/home/alone # cat index.html
<html><body><h1>This is VM4 at 30.0.0.10</h1></body></html>
/home/alone #
```

Configuration Details

VM2 IPSec Configuration

```
sudo cat > /etc/ipsec.conf << EOF
config setup
    logfile=/var/log/pluto.log
    logtime=yes
    logappend=yes
    plutodebug=all
```

```
dumpdir=/var/run/pluto/
virtual-private=%v4:10.0.0.0/24,%v4:30.0.0.0/24

conn gateway-tunnel
    authby=rsasig
    left=20.0.0.1
    leftsubnet=10.0.0.0/24
    leftcert=vm2-cert.pem
    leftsendcert=always
    leftid="CN=VM2"
    right=20.0.0.2
    rightsubnet=30.0.0.0/24
    rightid="CN=VM3"
    ike=aes256-sha2_256-modp2048!
    esp=aes256-sha2_256!
    auto=start
    type=tunnel
EOF
sudo cat > /etc/ipsec.secrets << EOF
: RSA vm2-key.pem
EOF
sudo systemctl restart ipsec
```

Figure 5: IPSec configuration on VM2

VM3 IPSec Configuration

```
sudo cat > /etc/ipsec.conf << EOF
config setup
    logfile=/var/log/pluto.log
    logtime=yes
    logappend=yes
    plutodebug=all
    dumpdir=/var/run/pluto/
    virtual-private=%v4:10.0.0.0/24,%v4:30.0.0.0/24

conn gateway-tunnel
    authby=rsasig
    left=20.0.0.2
    leftsubnet=30.0.0.0/24
    leftcert=vm3-cert.pem
    leftsendcert=always
    leftid="CN=VM3"
    right=20.0.0.1
    rightsubnet=10.0.0.0/24
    rightid="CN=VM2"
    ike=aes256-sha2_256-modp2048!
    esp=aes256-sha2_256!
    auto=start
    type=tunnel
```



```
EOF
sudo cat > /etc/ipsec.secrets << EOF
: RSA vm3-key.pem
EOF
sudo systemctl restart ipsec
```

Testing and Validation

1. IPSec Tunnel Status

- Verified tunnel establishment:

```
sudo ipsec status
sudo ipsec verify
```

Figure 6: IPSec tunnel status verification

2. Traffic Capture

- Captured IKE negotiation and ESP packets using Wireshark on the 20.0.0.0/24 network:
 - Filter: `isakmp` for IKE
 - Filter: `esp` for encrypted packets

Figure 7: Successful IKEv2 key exchange process

Figure 8: Wireshark capture showing encrypted ESP packets

3. End-to-End Connectivity

- Tested connectivity from VM1 to VM4:

```
ping 30.0.0.10
busybox wget -O - http://30.0.0.10
```

- Confirmed VM3's IP as the source address on VM4.

Figure 9: End-to-end connectivity test results

Troubleshooting

Common Issues and Resolutions

1. ARP Resolution Failures

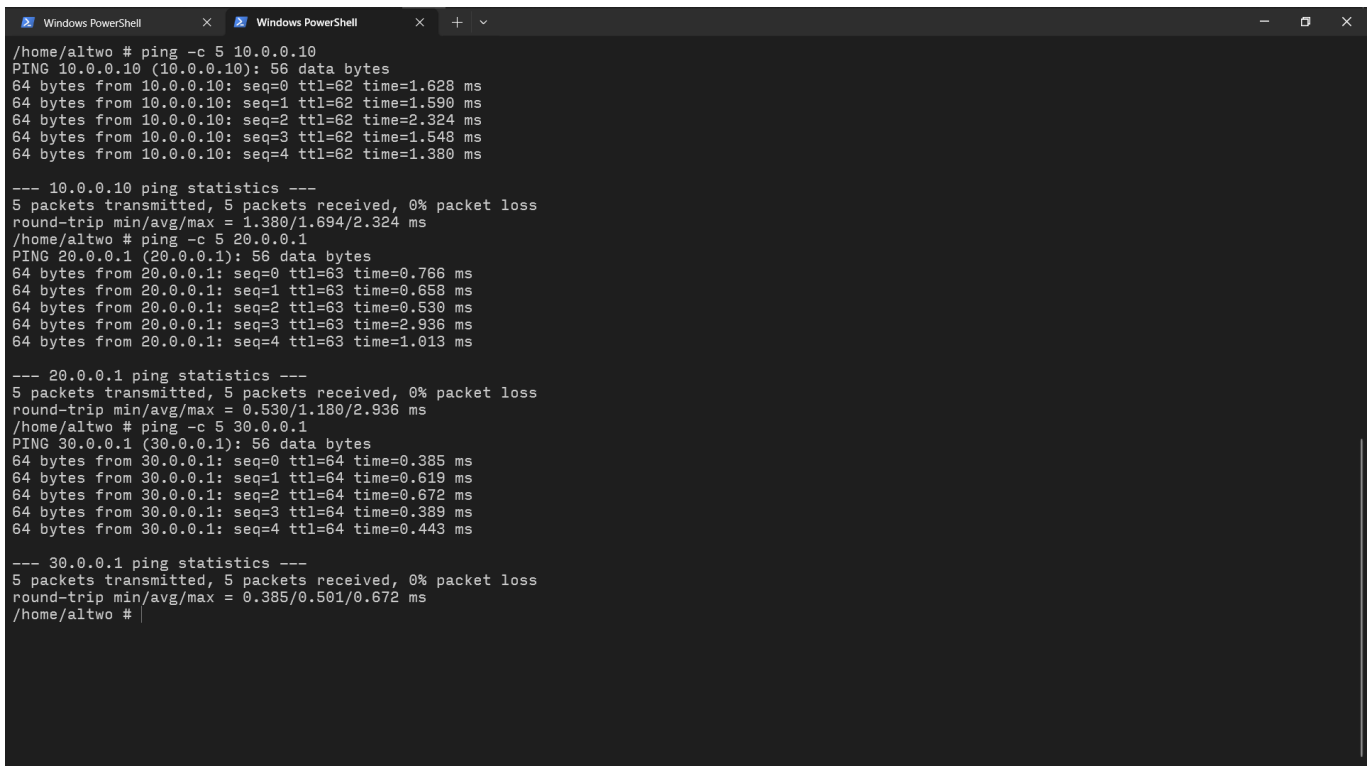
- Symptom: `<incomplete>` ARP entries
- Resolution: Added static ARP entries:

```
# On VM1
arp -s 10.0.0.1 <VM2_MAC>
# On VM2
sudo arp -s 10.0.0.10 <VM1_MAC>
```

2. Package Installation Errors

- Symptom: IO ERROR on `apk add`
- Resolution: Updated Alpine repositories:

```
echo "http://dl-cdn.alpinelinux.org/alpine/v3.19/main" >
/etc/apk/repositories
apk update
```



```
Windows PowerShell
/home/altwo # ping -c 5 10.0.0.10
PING 10.0.0.10 (10.0.0.10): 56 data bytes
64 bytes from 10.0.0.10: seq=0 ttl=62 time=1.628 ms
64 bytes from 10.0.0.10: seq=1 ttl=62 time=1.590 ms
64 bytes from 10.0.0.10: seq=2 ttl=62 time=2.324 ms
64 bytes from 10.0.0.10: seq=3 ttl=62 time=1.548 ms
64 bytes from 10.0.0.10: seq=4 ttl=62 time=1.380 ms

--- 10.0.0.10 ping statistics ---
5 packets transmitted, 5 packets received, 0% packet loss
round-trip min/avg/max = 1.380/1.694/2.324 ms
/home/altwo # ping -c 5 20.0.0.1
PING 20.0.0.1 (20.0.0.1): 56 data bytes
64 bytes from 20.0.0.1: seq=0 ttl=63 time=0.766 ms
64 bytes from 20.0.0.1: seq=1 ttl=63 time=0.658 ms
64 bytes from 20.0.0.1: seq=2 ttl=63 time=0.530 ms
64 bytes from 20.0.0.1: seq=3 ttl=63 time=2.936 ms
64 bytes from 20.0.0.1: seq=4 ttl=63 time=1.013 ms

--- 20.0.0.1 ping statistics ---
5 packets transmitted, 5 packets received, 0% packet loss
round-trip min/avg/max = 0.530/1.180/2.936 ms
/home/altwo # ping -c 5 30.0.0.1
PING 30.0.0.1 (30.0.0.1): 56 data bytes
64 bytes from 30.0.0.1: seq=0 ttl=64 time=0.385 ms
64 bytes from 30.0.0.1: seq=1 ttl=64 time=0.619 ms
64 bytes from 30.0.0.1: seq=2 ttl=64 time=0.672 ms
64 bytes from 30.0.0.1: seq=3 ttl=64 time=0.389 ms
64 bytes from 30.0.0.1: seq=4 ttl=64 time=0.443 ms

--- 30.0.0.1 ping statistics ---
5 packets transmitted, 5 packets received, 0% packet loss
round-trip min/avg/max = 0.385/0.501/0.672 ms
/home/altwo #
```

```
Windows PowerShell
/home/alone # ping -c 5 10.0.0.1
PING 10.0.0.1 (10.0.0.1): 56 data bytes
64 bytes from 10.0.0.1: seq=0 ttl=64 time=0.439 ms
64 bytes from 10.0.0.1: seq=1 ttl=64 time=0.501 ms
64 bytes from 10.0.0.1: seq=2 ttl=64 time=0.593 ms
64 bytes from 10.0.0.1: seq=3 ttl=64 time=0.555 ms
64 bytes from 10.0.0.1: seq=4 ttl=64 time=0.608 ms

--- 10.0.0.1 ping statistics ---
5 packets transmitted, 5 packets received, 0% packet loss
round-trip min/avg/max = 0.439/0.539/0.608 ms
/home/alone # ping -c 5 30.0.0.10
PING 30.0.0.10 (30.0.0.10): 56 data bytes
64 bytes from 30.0.0.10: seq=0 ttl=62 time=1.525 ms
64 bytes from 30.0.0.10: seq=1 ttl=62 time=1.622 ms
64 bytes from 30.0.0.10: seq=2 ttl=62 time=1.397 ms
64 bytes from 30.0.0.10: seq=3 ttl=62 time=1.482 ms
64 bytes from 30.0.0.10: seq=4 ttl=62 time=1.531 ms

--- 30.0.0.10 ping statistics ---
5 packets transmitted, 5 packets received, 0% packet loss
round-trip min/avg/max = 1.397/1.511/1.622 ms
/home/alone # ping -c 5 20.0.0.1
PING 20.0.0.1 (20.0.0.1): 56 data bytes
64 bytes from 20.0.0.1: seq=0 ttl=64 time=1.129 ms
64 bytes from 20.0.0.1: seq=1 ttl=64 time=0.507 ms
64 bytes from 20.0.0.1: seq=2 ttl=64 time=0.648 ms
64 bytes from 20.0.0.1: seq=3 ttl=64 time=0.486 ms
64 bytes from 20.0.0.1: seq=4 ttl=64 time=0.539 ms

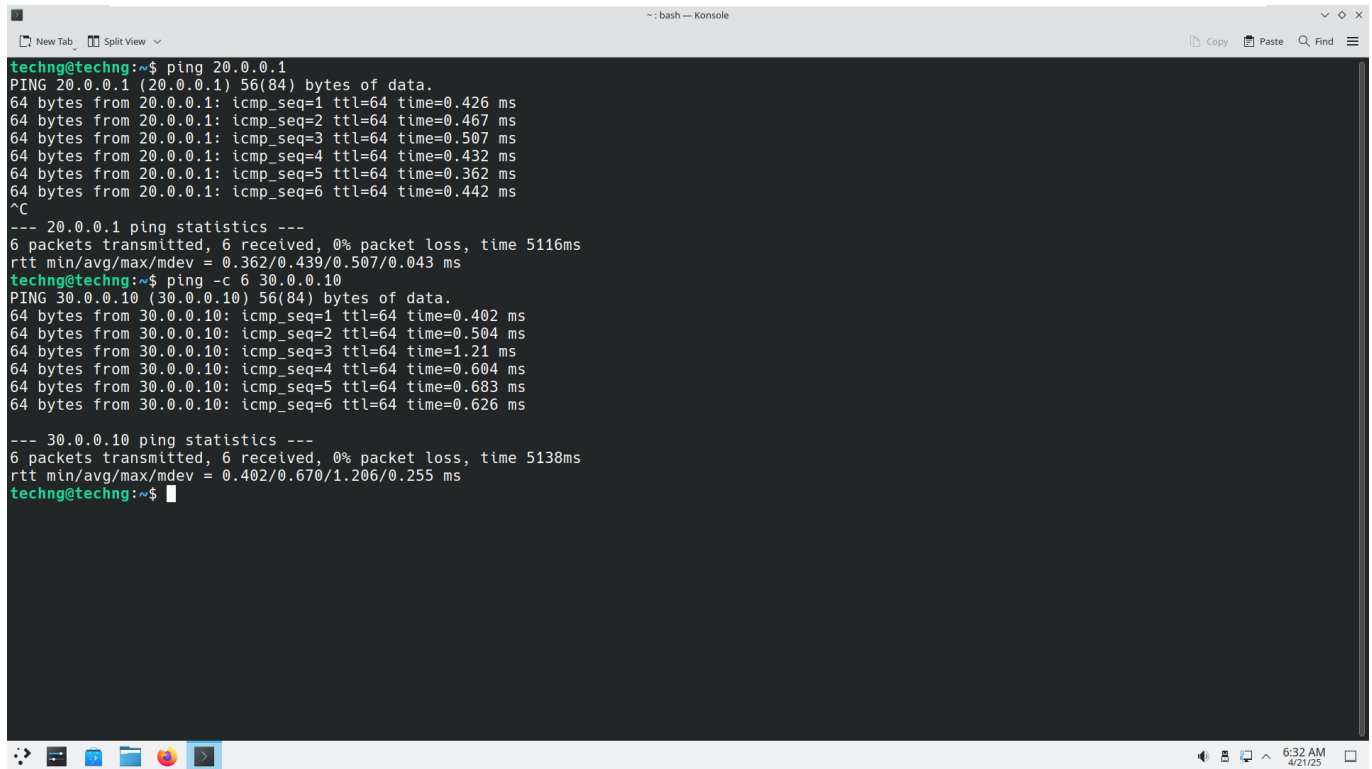
--- 20.0.0.1 ping statistics ---
5 packets transmitted, 5 packets received, 0% packet loss
round-trip min/avg/max = 0.486/0.661/1.129 ms
/home/alone # |
```

```
~: bash -- Konsole
techn@techn:~$ ifconfig
ens33: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
    inet 20.0.0.2 netmask 255.255.255.0 broadcast 20.0.0.255
    inet6 fe80::20c:29ff:fe5:fce0 prefixlen 64 scopeid 0x20<link>
    ether 00:0c:29:f5:fc:e0 txqueuelen 1000 (Ethernet)
    RX packets 42 bytes 3835 (3.8 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 110 bytes 19154 (19.1 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

ens37: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
    inet 30.0.0.1 netmask 255.255.255.0 broadcast 30.0.0.255
    inet6 fe80::20c:29ff:fe5:fcea prefixlen 64 scopeid 0x20<link>
    ether 00:0c:29:f5:fc:ea txqueuelen 1000 (Ethernet)
    RX packets 246 bytes 27909 (27.9 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 182 bytes 18954 (18.9 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

lo: flags=73<UP,LOOPBACK,RUNNING> mtu 65536
    inet 127.0.0.1 netmask 255.0.0.0
    inet6 ::1 prefixlen 128 scopeid 0x10<host>
    loop txqueuelen 1000 (Local Loopback)
    RX packets 8962 bytes 638093 (638.0 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 8962 bytes 638093 (638.0 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

techn@techn:~$ ip route
10.0.0.0/24 via 20.0.0.1 dev ens33 proto static
20.0.0.0/24 dev ens33 proto kernel scope link src 20.0.0.2
30.0.0.0/24 dev ens37 proto kernel scope link src 30.0.0.1
techn@techn:~$
```

A screenshot of a terminal window titled '~: bash -- Konsole'. The terminal shows two ping commands being executed. The first command is 'ping 20.0.0.1', which results in 6 successful pings with varying response times (0.362ms to 0.507ms) and a summary showing 0% packet loss and a total time of 5116ms. The second command is 'ping -c 6 30.0.0.10', which also results in 6 successful pings with response times (0.402ms to 1.21ms) and a summary showing 0% packet loss and a total time of 5138ms. The terminal interface includes a top bar with window controls and a bottom taskbar with various application icons and a system clock showing 6:32 AM on 4/21/25.

```
techng@techng:~$ ping 20.0.0.1
PING 20.0.0.1 (20.0.0.1) 56(84) bytes of data:
64 bytes from 20.0.0.1: icmp_seq=1 ttl=64 time=0.426 ms
64 bytes from 20.0.0.1: icmp_seq=2 ttl=64 time=0.467 ms
64 bytes from 20.0.0.1: icmp_seq=3 ttl=64 time=0.507 ms
64 bytes from 20.0.0.1: icmp_seq=4 ttl=64 time=0.432 ms
64 bytes from 20.0.0.1: icmp_seq=5 ttl=64 time=0.362 ms
64 bytes from 20.0.0.1: icmp_seq=6 ttl=64 time=0.442 ms
^C
--- 20.0.0.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5116ms
rtt min/avg/max/mdev = 0.362/0.439/0.507/0.043 ms
techng@techng:~$ ping -c 6 30.0.0.10
PING 30.0.0.10 (30.0.0.10) 56(84) bytes of data:
64 bytes from 30.0.0.10: icmp_seq=1 ttl=64 time=0.402 ms
64 bytes from 30.0.0.10: icmp_seq=2 ttl=64 time=0.504 ms
64 bytes from 30.0.0.10: icmp_seq=3 ttl=64 time=1.21 ms
64 bytes from 30.0.0.10: icmp_seq=4 ttl=64 time=0.604 ms
64 bytes from 30.0.0.10: icmp_seq=5 ttl=64 time=0.683 ms
64 bytes from 30.0.0.10: icmp_seq=6 ttl=64 time=0.626 ms
^C
--- 30.0.0.10 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5138ms
rtt min/avg/max/mdev = 0.402/0.670/1.206/0.255 ms
techng@techng:~$
```

Figure 10: Troubleshooting network connectivity