Communication Architectures Project

Perform the technical design, configure and test a CDN network with multiple enterprise clients. Authors:

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Interconnection Network

For the interconnection network, we subdivided it into two masks:

- Point-to-point connections, are defined with **/30** or **255.255.255.252** mask
- Loopback interface have **/32** or **255.255.255.255** mask assigned

The division of point-to-point networks can be viewed in the following table:

Subnet	Network IP	Usable Range	Broadcast IP	Mask
1	10.1.0.0	10.1.0.1 - 10.1.0.2	10.1.0.3	30
2	10.1.0.4	10.1.0.5 - 10.1.0.6	10.1.0.7	30
3	10.1.0.8	10.1.0.9 - 10.1.0.10	10.1.0.11	30
4	10.1.0.12	10.1.0.13 - 10.1.0.14	10.1.0.15	30
5	10.1.0.16	10.1.0.17 - 10.1.0.18	10.1.0.19	30
6	10.1.0.20	10.1.0.21 - 10.1.0.22	10.1.0.23	30
7	10.1.0.24	10.1.0.25 - 10.1.0.26	10.1.0.27	30
8	10.1.0.28	10.1.0.29 - 10.1.0.30	10.1.0.31	30
9	10.1.0.32	10.1.0.33 - 10.1.0.34	10.1.0.35	30
10	10.1.0.36	10.1.0.37 - 10.1.0.38	10.1.0.39	30
11	10.1.0.40	10.1.0.41 - 10.1.0.42	10.1.0.43	32
12	10.1.0.44	10.1.0.45 - 10.1.0.46	10.1.0.47	32
13	10.1.0.48	10.1.0.49 - 10.1.0.50	10.1.0.51	32
14	10.1.0.52	10.1.0.53 - 10.1.0.54	10.1.0.55	32
15	10.1.0.56	10.1.0.57 - 10.1.0.58	10.1.0.59	32
16	10.1.0.60	10.1.0.61 - 10.1.0.62	10.1.0.63	33
...	...	...	...	...

The division of loopback networks can be viewed in the following table (they all start after address 100):

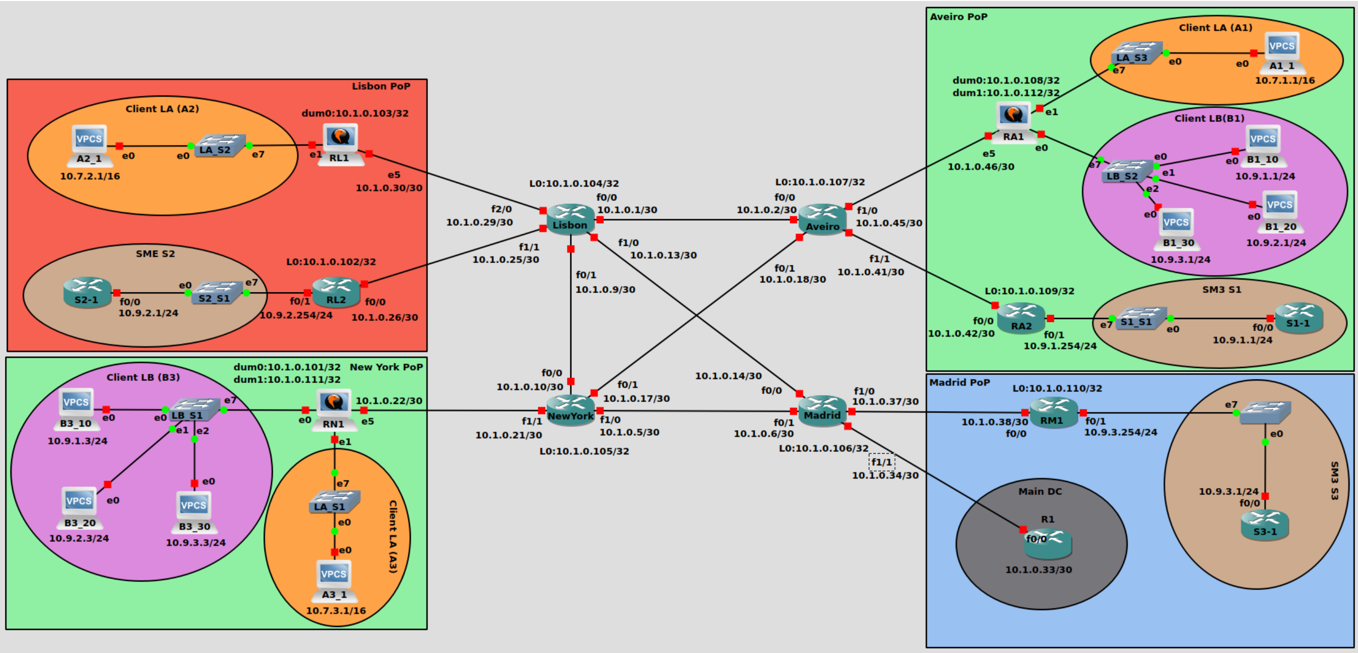
Subnet	Network IP	Usable Range	Mask
1	10.1.0.101	10.1.0.101	32
2	10.1.0.102	10.1.0.102	32
3	10.1.0.103	10.1.0.103	32
4	10.1.0.104	10.1.0.104	32
5	10.1.0.105	10.1.0.105	32
6	10.1.0.106	10.1.0.106	32
7	10.1.0.107	10.1.0.107	32
8	10.1.0.108	10.1.0.108	32
9	10.1.0.109	10.1.0.109	32
10	10.1.0.110	10.1.0.110	32
11	10.1.0.111	10.1.0.111	32
12	10.1.0.112	10.1.0.112	32
13	10.1.0.113	10.1.0.113	32
...	...	...	...

Configuring the network

In this section, we'll be approaching the configuration of IP addresses and base routing protocols to achieve connectivity. Specific network and devices, including VPC's will be approached later.

IP's

The layout of the network, as well as the assigned IP addresses for each interface and device can be viewed in the following image:



The IP addresses of the interconnection and loopback interfaces are derived from the division in the table above, and in the case of private or reserved network, only one address was needed to be assigned to one terminal (router or VPC).

To configure an interface IP address in a Cisco C7200, the following commands can be used:

- For serial interfaces:

```
interface <interface-type>/<interface-number>
ip addr <ip_address> <mask>
```

- For Loopback interfaces:

```
interface loopback <N>
ip addr <ip_address> <mask>
```

In the case of VyOS routers, the configuration is a bit different. When `N` is present in the command, it means that a number needs to be assigned to the interface:

- For serial interfaces:

```
configure
set interfaces ethernet ethN address <ip_address>/<mask>
set system host-name <router_name>
commit
save
```

- For Loopback interfaces:

```
configure
# Loopback/dummy interfaces need to be named dumN
set interfaces dummy dumN address <ip_address>/<maks>
commit
```

NOTE: Before configuring interfaces, check correct interfaces which are **eht0** - **eth5**, with the following command:

```
ip addr
```

If some of those interfaces aren't present, use the next command to load them:

```
sudo cp /opt/vyatta/etc/config.boot.default /config/config.boot
reboot
```

OSPF

OSPF is used in the interconnection of all routers, especially to announce the loopback interfaces of the routers, which are then used to establish connection with other protocols (BGP). The following sub-sections will describe how to create the OSPF process and add the interfaces, both for Cisco C7200 routers, as well as VyOS:

Cisco C7200

Use the following command to configure the serial interfaces:

```
interface f0/0
ip ospf 1 area 0
```

Execute the following command and use the loopback ip of the router as the `router-id`:

```
router ospf 1
router-id <loopback-ip>

## Add a specific network, if needed
network <network-ip> <mask> area 0
```

To verify connection with neighbors, use the following command:

```
show ip ospf neighbors
```

VyOS

Execute the following commands for every interface and use the loopback ip of the router as the `router-id`:

```
configure
# Sets the router-id of the ospf process
set protocols ospf parameters router-id <loopback-ip>
# Explicitly add a network to the process
set protocols ospf area 0 network <network-IP>/<subnet-mask>
commit
save
```

Analysis

With the system configured, networks are being exchanged throughout the system, making so that every router has access to and only to the interconnection networks. We can observe that in the following images, which show the **Lisbon** router *ip route* table and ospf neighbors:

```
Lisbon#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      10.0.0.0/8 is variably subnetted, 27 subnets, 2 masks
C        10.1.0.0/30 is directly connected, FastEthernet0/0
L        10.1.0.1/32 is directly connected, FastEthernet0/0
O        10.1.0.4/30 [110/2] via 10.1.0.14, 00:07:11, FastEthernet1/0
                     [110/2] via 10.1.0.10, 00:07:11, FastEthernet0/1
C        10.1.0.8/30 is directly connected, FastEthernet0/1
L        10.1.0.9/32 is directly connected, FastEthernet0/1
C        10.1.0.12/30 is directly connected, FastEthernet1/0
L        10.1.0.13/32 is directly connected, FastEthernet1/0
O        10.1.0.16/30 [110/2] via 10.1.0.10, 00:07:11, FastEthernet0/1
                      [110/2] via 10.1.0.2, 00:07:11, FastEthernet0/0
O        10.1.0.20/30 [110/2] via 10.1.0.10, 00:07:21, FastEthernet0/1
C        10.1.0.24/30 is directly connected, FastEthernet1/1
L        10.1.0.25/32 is directly connected, FastEthernet1/1
C        10.1.0.28/30 is directly connected, FastEthernet2/0
L        10.1.0.29/32 is directly connected, FastEthernet2/0
O        10.1.0.32/30 [110/2] via 10.1.0.14, 00:07:11, FastEthernet1/0
O        10.1.0.36/30 [110/2] via 10.1.0.14, 00:07:11, FastEthernet1/0
O        10.1.0.40/30 [110/2] via 10.1.0.2, 00:07:11, FastEthernet0/0
O        10.1.0.44/30 [110/2] via 10.1.0.2, 00:07:11, FastEthernet0/0
O        10.1.0.101/32 [110/3] via 10.1.0.10, 00:07:11, FastEthernet0/1
O        10.1.0.102/32 [110/2] via 10.1.0.26, 00:07:11, FastEthernet1/1
O        10.1.0.103/32 [110/2] via 10.1.0.30, 00:07:11, FastEthernet2/0
C        10.1.0.104/32 is directly connected, Loopback0
O        10.1.0.105/32 [110/2] via 10.1.0.10, 00:07:21, FastEthernet0/1
O        10.1.0.106/32 [110/2] via 10.1.0.14, 00:07:11, FastEthernet1/0
O        10.1.0.107/32 [110/2] via 10.1.0.2, 00:07:11, FastEthernet0/0
O        10.1.0.108/32 [110/3] via 10.1.0.2, 00:07:11, FastEthernet0/0
O        10.1.0.109/32 [110/3] via 10.1.0.2, 00:07:11, FastEthernet0/0
O        10.1.0.110/32 [110/3] via 10.1.0.14, 00:07:11, FastEthernet1/0
```

```
Lisbon#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
10.1.0.103        1   FULL/BDR        00:00:33    10.1.0.30       FastEthernet2/0
10.1.0.102        1   FULL/BDR        00:00:32    10.1.0.26       FastEthernet1/1
10.1.0.106        1   FULL/DR         00:00:31    10.1.0.14       FastEthernet1/0
10.1.0.105        1   FULL/DR         00:00:33    10.1.0.10       FastEthernet0/1
10.1.0.107        1   FULL/DR         00:00:36    10.1.0.2        FastEthernet0/0
```

BGP

All routers use the loopback interfaces to establish BGP connection (router-id) between them. This was done as to guarantee that if an interface was disconnected, BGP would still work, with the traffic being routed by another interface connected to the core-router. Our BGP network structure relies on a **spine** and

leaf architecture, with all core-routers interconnected (spines), establishing a *Full-mesh*. The remaining routers in each POP are leafs or **route-reflector-client**'s.

Configuring BGP in the core-routers can be done the following way:

```
router bgp 33900
bgp router-id [loopback_ip]

# Adding another core or POP as neighbor
neighbor [neighbor-ip] remote-as [same-AS-number]

address-family ipv4 unicast

# Make OSPF routes available in BGP
redistribute ospf 1

# Explicitly add a network, if needed
network [network_address] mask [mask]

# Force source address to be loopback in the connection
neighbor [neighbor-ip] update-source lO

# Core routers should configure PoP routers asLeafs
neighbor [neighbor-ip] route-reflector-client
```

Configuration of BGP in the POP routers:

```
router bgp 33900
bgp router-id [interface_coreRouter_ip]

# Adding core as neighbor
neighbor [neighbor-ip] remote-as [same-AS-number]
# Force source address to be loopback in the connection
neighbor [neighbor-ip] update-source lO
```

The configuration for BGP in the VyOS routers located in the POP's is done with the use of a specific peer-group, as to not interfere with future additions. The commands are as follows:

```
set protocols bgp system-as 33900
# Configure router-id
set protocols bgp parameters router-id <loopback_ip>
# Add a core-router neighbor
set protocols bgp neighbor <neighbor_ip|interface> peer-group core
# Configuration the peer-group settings
# Important step to make the source of the traffic ethN
set protocols bgp peer-group core update-source dumN
set protocols bgp peer-group core remote-as 33900
```

```
set protocols bgp peer-group core address-family ipv4-unicast nexthop-self
set protocols bgp address-family ipv4-unicast redistribute ospf
```

Testing

After using the above steps, use the following commands to check if the BGP neighbors are up and exchanging routing information:

```
# Check BGP neighbors
show bgp summary

# Check if all routes are appearing in the routing table
Show ip routes
```

Analysis

Having the system configured, IPV4 unicast routes exchanging should be working, between all the routers configured. The following image shows the `bgp summary` of **New York** router. In there we can see that the BGP connection is established and working between loopback interfaces, with router **RN1** (*leaf*) and the remaining core routers (*spines*)

```
NewYork#show bgp summary
BGP router identifier 10.1.0.105, local AS number 33900
BGP table version is 23, main routing table version 23
22 network entries using 2992 bytes of memory
90 path entries using 5040 bytes of memory
8/4 BGP path/bestpath attribute entries using 1024 bytes of memory
0 BGP route-map cache entries using 0 bytes of memory
0 BGP filter-list cache entries using 0 bytes of memory
BGP using 9056 total bytes of memory
BGP activity 22/0 prefixes, 90/0 paths, scan interval 60 secs

Neighbor        V           AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
10.1.0.101      4        33900      25      28       23    0    0 00:15:37       20
10.1.0.104      4        33900      29      29       23    0    0 00:15:45       18
10.1.0.106      4        33900      27      29       23    0    0 00:15:37       12
10.1.0.107      4        33900      27      28       23    0    0 00:15:39       18
```

Layer 2 point-to-point (vxlan)

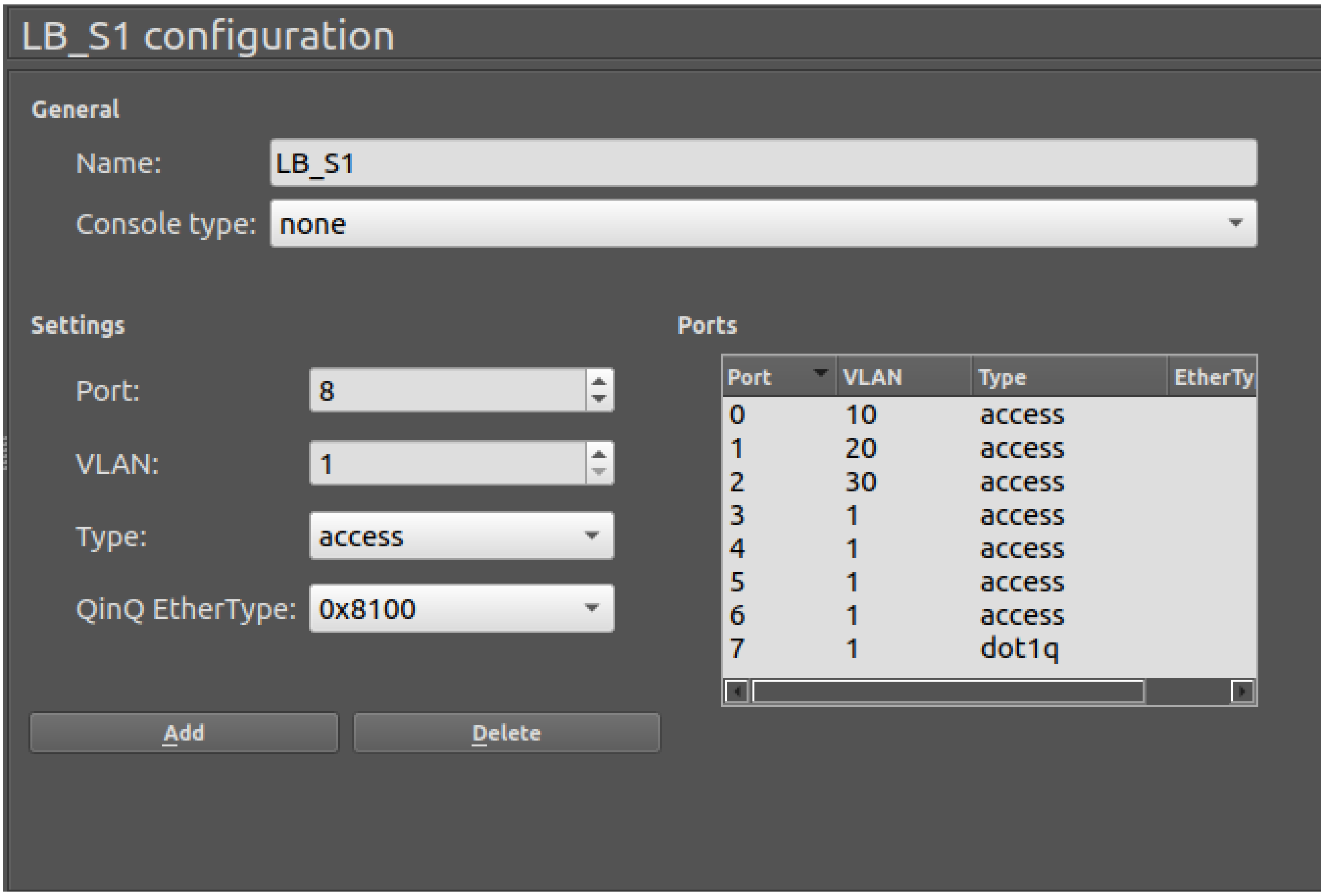
Layer 2 point-to-point is configured to provide connectivity and serve the Client B needs. For that, the respective VPC's and Switches need to be configure, as well as the VyOS routers **RN1** and **RA1**.

VPC's

In the VPC's there's only the need to configure their respective IP addresses and masks. **Don't** configure a gateway.

Layer 2 Switches

Each switch is connected to three VPC's in different VXLAN's. Their connection with the VyOS routers is done using a **802.1Q trunk** (dot1q). The configuration in the switches can be seen in the following image:



VyOS

At the VyOS routers start by creating a new loopback interface l1 and add it to OSPF only used to carry VXLAN traffic:

```
configure
# Loopback/dummy interfaces need to be named dumN
set interfaces dummy dum1 address <ip_address>/<maks>
set protocols ospf area 0 network <network-IP>/<subnet-mask>
commit
```

configure sub-interfaces for VLAN 10, 20 and 30 using the following commands:

```
configure

# N in ethN should be the number of the interface connected to the switch
set interfaces ethernet ethN vif 10
set interfaces ethernet ethN vif 20
set interfaces ethernet ethN vif 30
commit
save
```

Create three VXLAN connections between the VyOS, to carry data for each LAN:

```
set interfaces vxlan vxlan110 vni 110
set interfaces vxlan vxlan110 mtu 1500
set interfaces vxlan vxlan110 remote <remoteRouter_loopback_l1_ip>

set interfaces vxlan vxlan120 vni 120
set interfaces vxlan vxlan120 mtu 1500
set interfaces vxlan vxlan120 remote <remoteRouter_loopback_l1_ip>

set interfaces vxlan vxlan130 vni 130
set interfaces vxlan vxlan130 mtu 1500
set interfaces vxlan vxlan130 remote <remoteRouter_loopback_l1_ip>

commit
save
```

Create three virtual bridges and add to each one the respective VXLAN interface and Ethernet sub-interface:

```
# Watch the interface used, they start with 0, because the connected
#  interface is eth0
set interfaces bridge br010 member interface 'eth0.10'
set interfaces bridge br010 member interface 'vxlan110'

set interfaces bridge br020 member interface 'eth0.20'
set interfaces bridge br020 member interface 'vxlan120'

set interfaces bridge br030 member interface 'eth0.30'
set interfaces bridge br030 member interface 'vxlan130'

commit
save
```

Analysis

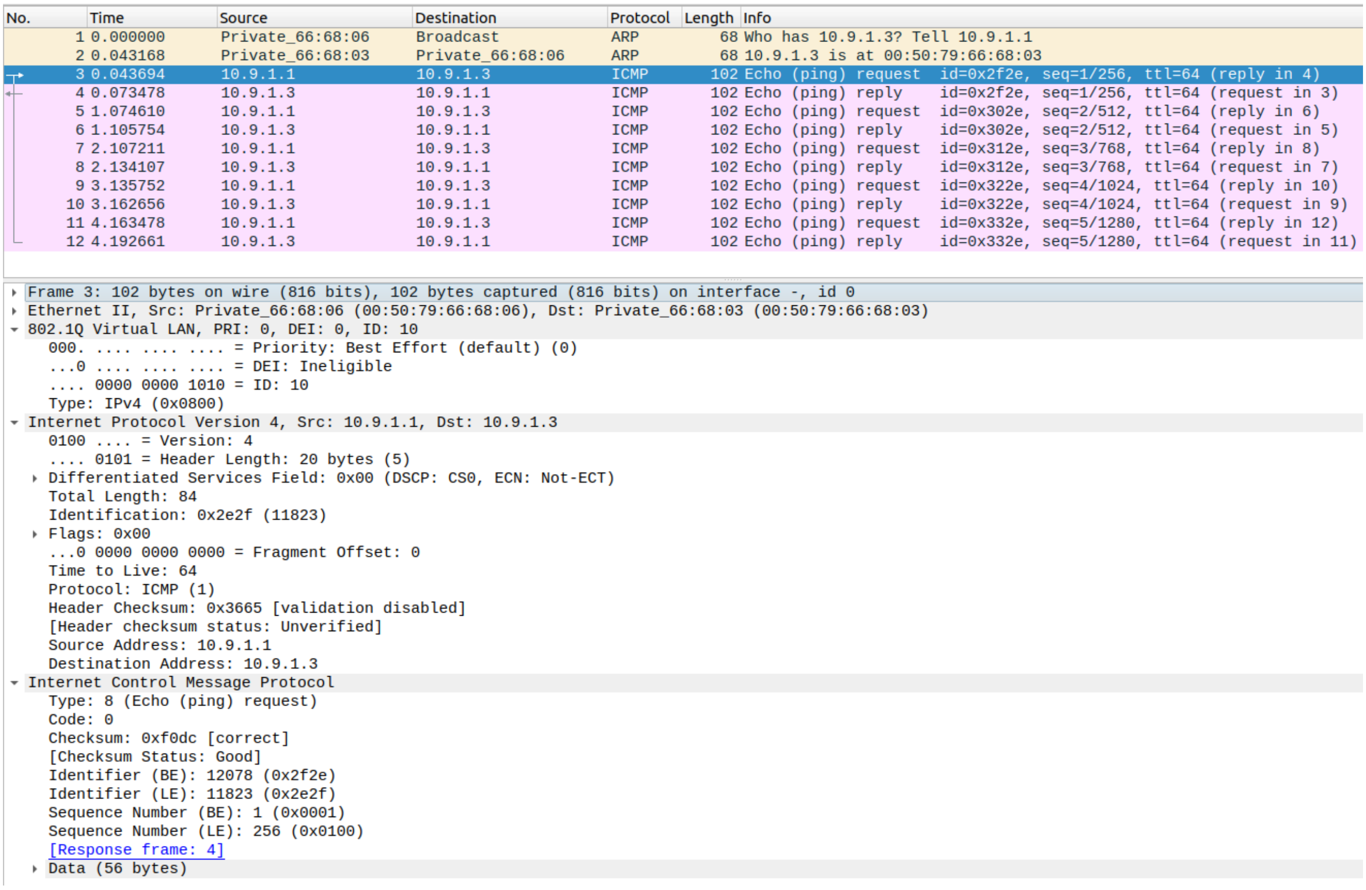
With the system configured, we made a `ping` test with Client LB *B1_10* VPC, to *B3_10* VPC, with addresses `10.9.1.1` and `10.9.1.3` respectively. The terminal output with the successful connection can be seen in the following image:

```
B1_10> ping 10.9.1.3

84 bytes from 10.9.1.3 icmp_seq=1 ttl=64 time=29.978 ms
84 bytes from 10.9.1.3 icmp_seq=2 ttl=64 time=31.495 ms
84 bytes from 10.9.1.3 icmp_seq=3 ttl=64 time=27.462 ms
84 bytes from 10.9.1.3 icmp_seq=4 ttl=64 time=27.320 ms
84 bytes from 10.9.1.3 icmp_seq=5 ttl=64 time=29.751 ms
```

To analyze the exchanged data, we set-up two Wireshark captures, one between **RN1** and **NewYork**, before the data is de-capsulated by **RN1** and another between **RA1** and **LA_S2** switch, so that the VXLAN original traffic can be seen

No.	Time	Source	Destination	Protocol	Length	Info
4	9.206148	10.1.0.46	10.1.0.101	UDP	114	36542 → 8472 Len=72
5	9.209257	10.1.0.22	10.1.0.46	UDP	114	51284 → 8472 Len=72
6	9.246548	10.1.0.46	10.1.0.22	UDP	148	38766 → 8472 Len=106
7	9.247262	10.1.0.22	10.1.0.46	UDP	148	51511 → 8472 Len=106
13	10.276530	10.1.0.46	10.1.0.101	UDP	148	38766 → 8472 Len=106
14	10.279870	10.1.0.22	10.1.0.46	UDP	148	51511 → 8472 Len=106
16	11.306662	10.1.0.46	10.1.0.22	UDP	148	38766 → 8472 Len=106
17	11.309082	10.1.0.22	10.1.0.46	UDP	148	51511 → 8472 Len=106
22	12.337046	10.1.0.46	10.1.0.22	UDP	148	38766 → 8472 Len=106
23	12.338261	10.1.0.22	10.1.0.46	UDP	148	51511 → 8472 Len=106
24	13.366864	10.1.0.46	10.1.0.22	UDP	148	38766 → 8472 Len=106
25	13.369427	10.1.0.22	10.1.0.46	UDP	148	51511 → 8472 Len=106

```
▸ Frame 4: 114 bytes on wire (912 bits), 114 bytes captured (912 bits) on interface -, id 0
▸ Ethernet II, Src: ca:03:ae:ad:00:1d (ca:03:ae:ad:00:1d), Dst: 0c:af:cc:89:00:05 (0c:af:cc:89:00:05)
▾ Internet Protocol Version 4, Src: 10.1.0.46, Dst: 10.1.0.101
    0100 .... = Version: 4
    .... 0101 = Header Length: 20 bytes (5)
  ▸ Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
    Total Length: 100
    Identification: 0xb676 (46710)
  ▸ Flags: 0x00
    ...0 0000 0000 0000 = Fragment Offset: 0
    Time to Live: 14
    Protocol: UDP (17)
    Header Checksum: 0xe17e [validation disabled]
    [Header checksum status: Unverified]
    Source Address: 10.1.0.46
    Destination Address: 10.1.0.101
▾ User Datagram Protocol, Src Port: 36542, Dst Port: 8472
    Source Port: 36542
    Destination Port: 8472
    Length: 80
    Checksum: 0xd546 [unverified]
    [Checksum Status: Unverified]
    [Stream index: 0]
  ▸ [Timestamps]
    UDP payload (72 bytes)
▾ Data (72 bytes)
    Data: 0800000000006e00ffffffffffff00507966680608060001080006040001005079666806…
    [Length: 72]
```



As we can see *ICMP* packets are encapsulated in **UDP** packets, operating in port 8472. This port isn't the standard 4789, because it's the standard designated by VyOS. Analyzing, we can also see the 802.1Q VLAN tag ID present in the de-capsulated *ICMP* packet, in this case it's **VLAN 10**

VXLAN Bandwidth reservation and usage/routing

To fulfill the requirement demanded by client LB of 10 Mbps of guaranteed bandwidth and priority, we started by creating an MPLS traffic-eng tunnel between New York and Aveiro. This tunnel is used so that any VXLAN traffic by Client LB is routed with priority through it. Naturally this also requires configurations on the remaining routers to be able to communicate traffic engineering information.

Initial configuration in core-routers

Firstly, we'll configure the interfaces connected between the core-routers to have a guaranteed bandwidth of 10 Mbps, enabling the support of the expected traffic. The commands are as follows:

```
# enable mpls tunnels globally
mpls traffic-eng tunnels

interface <interface-type>/<interface-number>
mpls traffic-eng tunnels
ip rsvp bandwidth 10000
```

Creating the tunnel

Since Client LB is only present present in routers **RN1** and **RA1**, which connect to *NewYork* and *Aveiro* routers, only one tunnel needs to be established between this two core-routers, which will do Load Balancing and place higher priority in VXLAN traffic.

For creating the tunnel, the following commands can be used:

```
interface Tunnel1
ip unnumbered Loopback0
tunnel source Loopback0
# target should be loopback of New York or Aveiro routers
tunnel destination <loopback_target-ip>
tunnel mode mpls traffic-eng
# announce the tunnel to the routing table
#tunnel mpls traffic-eng autoroute announce
tunnel mpls traffic-eng priority 7 7
tunnel mpls traffic-eng bandwidth 10000
tunnel mpls traffic-eng path-option 1 dynamic # use dynamic routing
```

Use the next commands to enable OSPF for Routing Updates and Path Discovery:

```
router ospf 1
mpls traffic-eng router-id Loopback0
mpls traffic-eng area 0
```

Forwarding traffic through the tunnel

Since dynamic routing of traffic was opted, using *Access-control lists* and *route-maps* is possible to isolate client LB traffic from other traffic flows, ensuring that their data is routed by the tunnel.

First we need to create the *access-list* 100 to allow traffic coming from **RN1** to **RA1** and vice-versa. Since client LB only uses VXLAN, which in VyOS uses the port **8472**, makes the rule easier to configure. Since we also divided the VxLAN and L2VPN in one using dum1 and the other dum0 respectively, it's easier to filter the data now, by using the correct dummy interface. Use The following commands to create the *access-list*:

```
# source and dest ip should be RN1 interface to core and RA1 loopback or
vice-versa
access-list 100 permit udp host <source_ip> host <dest__dum1_ip> eq 8472
```

Next, a *route-map* is needed to filter the traffic and see which applies to the *access-list*. For that, we created the **routeXPRESS** which will *match* the traffic to the **ACL 100** and forward them to *Tunnel 1*. Use the following commands:

```
route-map routeXPRESS permit 10
match ip address 100
```

```
set interface Tunnel1
```

The last step is to apply the *route-map* as a policy to the interface connected to **RN1** and **RA1**, so that the traffic coming originating from those routers is filtered with **routeXPRESS**. The following commands can be used

```
interface <interface-type>/<interface-number>
ip policy route-map routeXPRESS
```

Testing

The following commands can be used to debug if the tunnel is established and working:

```
show mpls forwarding
show ip interface brief
# Next command should show ...Oper: Up...
show mpls traffic-eng tunnels
show access-list 100
show route-map routeXPRESS
show interface tunnel1
# See tunnel path
show mpls traffic-eng tunnels brief
```

Analysis

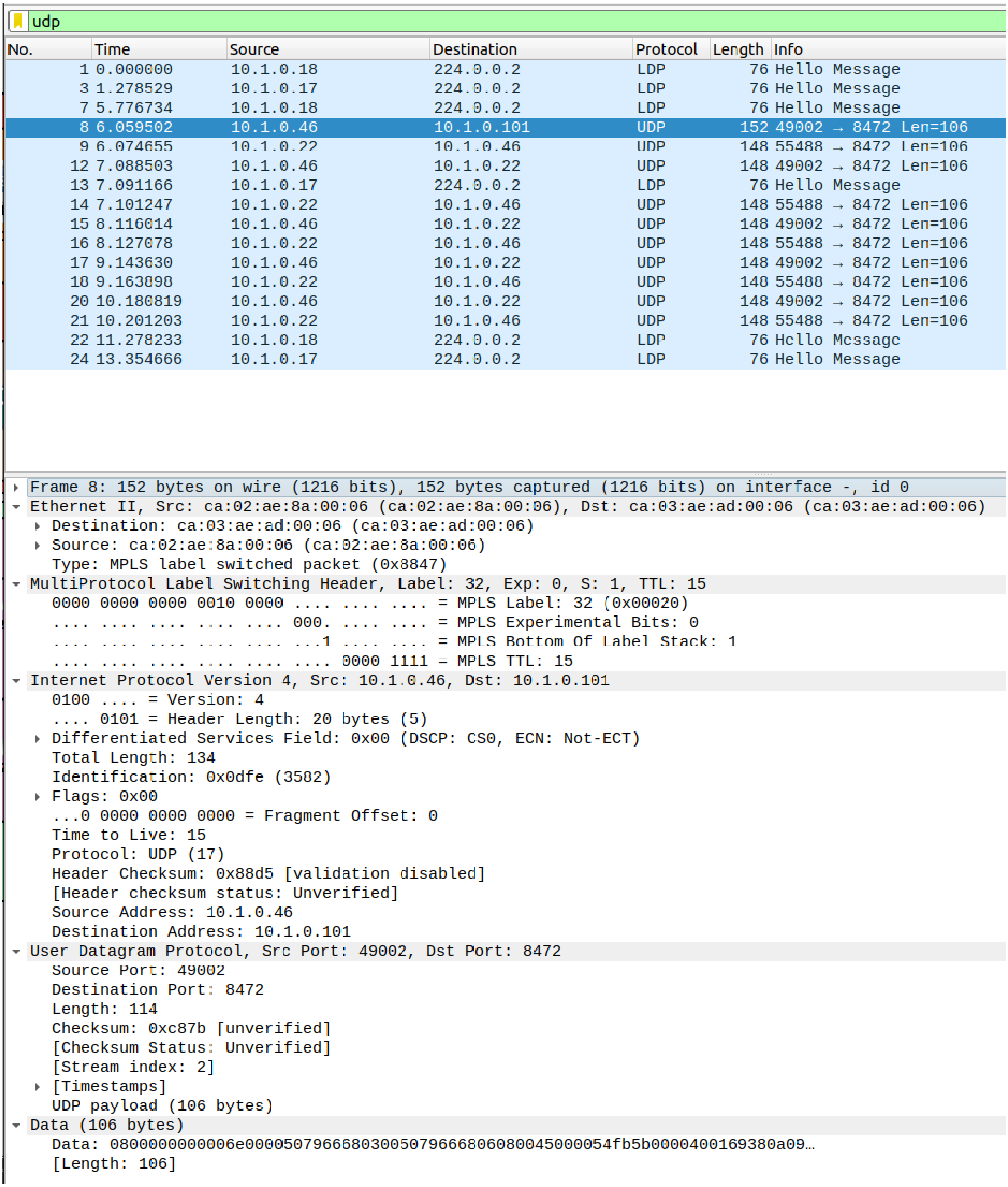
The following image contains the forwarding labels and Pop actions present in **Aveiro** router:

```
Aveiro#show mpls forwarding
Local      Outgoing   Prefix           Bytes Label   Outgoing   Next Hop
Label      Label      or Tunnel Id     Switched      interface
20         24         10.1.0.106/32    0             Fa0/0      10.1.0.1
           25         10.1.0.106/32    0             Fa0/1      10.1.0.17
21         Pop Label  10.1.0.105/32    0             Fa0/1      10.1.0.17
22         Pop Label  10.1.0.104/32    0             Fa0/0      10.1.0.1
23         28         10.1.0.32/30     0             Fa0/0      10.1.0.1
           29         10.1.0.32/30     0             Fa0/1      10.1.0.17
24         Pop Label  10.1.0.28/30     0             Fa0/0      10.1.0.1
25         Pop Label  10.1.0.20/30     0             Fa0/1      10.1.0.17
26         29         10.1.0.36/30     0             Fa0/0      10.1.0.1
           31         10.1.0.36/30     0             Fa0/1      10.1.0.17
27         Pop Label  10.1.0.12/30     0             Fa0/0      10.1.0.1
28         Pop Label  10.1.0.4/30      0             Fa0/1      10.1.0.17
29         Pop Label  10.1.0.8/30      0             Fa0/0      10.1.0.1
           Pop Label  10.1.0.8/30      0             Fa0/1      10.1.0.17
30         Pop Label  10.1.0.24/30     0             Fa0/0      10.1.0.1
31         20         10.1.0.110/32    5778          Fa0/0      10.1.0.1
           21         10.1.0.110/32    0             Fa0/1      10.1.0.17
32         Pop Label  10.1.0.109/32    10543         Fa1/1      10.1.0.42
33         No Label   10.1.0.108/32    8832          Fa1/0      10.1.0.46
34         25         10.1.0.103/32    0             Fa0/0      10.1.0.1
35         26         10.1.0.102/32    5598          Fa0/0      10.1.0.1
Local      Outgoing   Prefix           Bytes Label   Outgoing   Next Hop
Label      Label      or Tunnel Id     Switched      interface
36         28         10.1.0.101/32    0             Fa0/1      10.1.0.17
```

After setting up the system, we check the status of the tunnels, as present in the following image, which shows that they are operating since `oper` is `up`:

```
Aveiro#show mpls traffic-eng tunnels

Name: Aveiro_t1                          (Tunnel1) Destination: 10.1.0.105
  Status:
    Admin: up         Oper: up     Path: valid       Signalling: connected
    path option 1, type dynamic (Basis for Setup, path weight 1)

  Config Parameters:
    Bandwidth: 10000    kbps (Global)  Priority: 7  7   Affinity: 0x0/0xFFFF
    Metric Type: TE (default)
    AutoRoute:  disabled  LockDown: disabled  Loadshare: 10000    bw-based
    auto-bw: disabled
  Active Path Option Parameters:
    State: dynamic path option 1 is active
    BandwidthOverride: disabled  LockDown: disabled  Verbatim: disabled


  InLabel  :  -
  OutLabel : FastEthernet0/1, implicit-null
  RSVP Signalling Info:
       Src 10.1.0.107, Dst 10.1.0.105, Tun_Id 1, Tun_Instance 9
    RSVP Path Info:
      My Address: 10.1.0.18
      Explicit Route: 10.1.0.17 10.1.0.105
      Record   Route:   NONE
      Tspec: ave rate=10000 kbits, burst=1000 bytes, peak rate=10000 kbits
    RSVP Resv Info:
      Record   Route:   NONE
      Fspec: ave rate=10000 kbits, burst=1000 bytes, peak rate=10000 kbits
  History:
    Tunnel:
      Time since created: 32 minutes, 37 seconds
      Time since path change: 31 minutes, 55 seconds
      Number of LSP IDs (Tun_Instances) used: 9
    Current LSP:
      Uptime: 31 minutes, 55 seconds

LSP Tunnel NewYork_t1 is signalled, connection is up
  InLabel  : FastEthernet0/1, implicit-null
  OutLabel :  -
  RSVP Signalling Info:
       Src 10.1.0.105, Dst 10.1.0.107, Tun_Id 1, Tun_Instance 11
    RSVP Path Info:
      My Address: 10.1.0.107
      Explicit Route:  NONE
      Record   Route:   NONE
      Tspec: ave rate=10000 kbits, burst=1000 bytes, peak rate=10000 kbits
    RSVP Resv Info:
      Record   Route:   NONE
      Fspec: ave rate=10000 kbits, burst=1000 bytes, peak rate=10000 kbits
```

As executed above, we made a `ping` test with Client LB *B1_10* VPC, to *B3_10* VPC, with addresses `10.9.1.1` and `10.9.1.3` respectively, then place a Wireshark capture between routers **NewYork** and **Aveiro**. The result of this capture can be seen below:



In this capture, we can see that the **UDP VxLAN** packet operating in port 8472 is being routed by the *MPLS* tunnel traffic-eng tunnel.

L2-VPN

The Layer 2 multi-point VPN is configured to provide connectivity and serve Client A needs. For that end, The respective VPC's need to be configured, as well as VyOS routers **RN1**, **RL1** and **RA1**.

VPC's

In the VPC's there's only the need to configure their respective IP addresses and masks. **Don't** configure a gateway.

VyOS

The routers handling **L2-VPN** can't be Cisco C7200, because this ones don't support *l2vpn*, so the only option are VyOS routers. From the base network configuration, we stated that VyOS routers located in the POP's establish BGP *ipv4 unicast* exchange with core-routers. However, in this case they need to establish BGP connection between themselves, as to exchange *l2vpn* data. Using the previous configuration with `peer-group core` is easy to now establish a new peer-group to communicate over **EVPN**.

In the topology of this network, the **RL1** is the Spine router, while **RA1** and **RN1** are Leafs or *route-reflector-client*'s. To configure the *l2vpn address-family*, in this topology, use the following commands:

```
# The following two configs. were already done before
set protocols bgp system-as 33900
set protocols bgp parameters router-id <loopback_ip>

set protocols bgp address-family l2vpn-evpn advertise-all-vni

# only for Router RL1 to add both neighbor
set protocols bgp neighbor 10.1.0.101 peer-group evpn # Add RN1
set protocols bgp neighbor 10.1.0.108 peer-group evpn # Add RA1

# only RN1 and RA1 should add RL1 as their neighbor
set protocols bgp neighbor 10.1.0.103 peer-group evpn


# Important step to configure dum0 as the source of the data
set protocols bgp peer-group evpn update-source dum0
set protocols bgp peer-group evpn remote-as 33900
set protocols bgp peer-group evpn address-family l2vpn-evpn nexthop-self

# Only for RL1 router
set protocols bgp peer-group evpn address-family l2vpn-evpn route-
reflector-client
```

Configure VXLAN and bridge interfaces in each router:

```
set interfaces vxlan vxlan101 source-address <loopback_ip>
set interfaces vxlan vxlan101 vni 101
set interfaces vxlan vxlan101 mtu 1500

set interfaces bridge br101 address 10.7.<Area>.254/16
set interfaces bridge br101 description 'VLAN101'

# With N in ethN being the interface connected to the network
set interfaces bridge br101 member interface ethN
set interfaces bridge br101 member interface vxlan101
```

Analysis

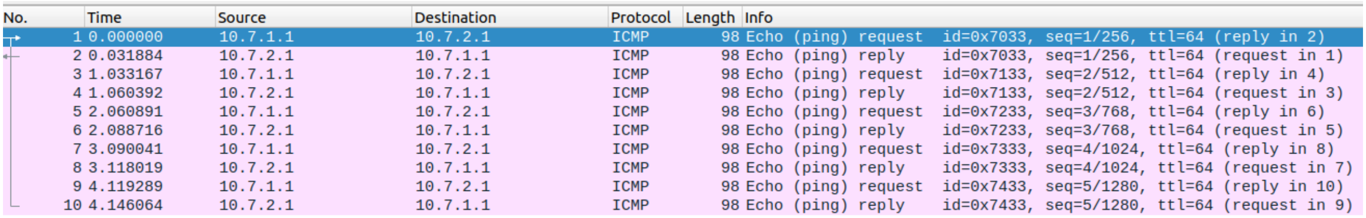
The following captures demonstrate a `ping` test made between VPCs *a1_1* and *a2_1*, with addresses `10.7.1.1` and `10.7.2.1`, respectively. The result was successful and the terminal output can be seen in the following image:

```
A1_1> ping 10.7.2.1

84 bytes from 10.7.2.1 icmp_seq=1 ttl=64 time=32.134 ms
84 bytes from 10.7.2.1 icmp_seq=2 ttl=64 time=27.421 ms
84 bytes from 10.7.2.1 icmp_seq=3 ttl=64 time=28.040 ms
84 bytes from 10.7.2.1 icmp_seq=4 ttl=64 time=28.391 ms
84 bytes from 10.7.2.1 icmp_seq=5 ttl=64 time=27.231 ms
```

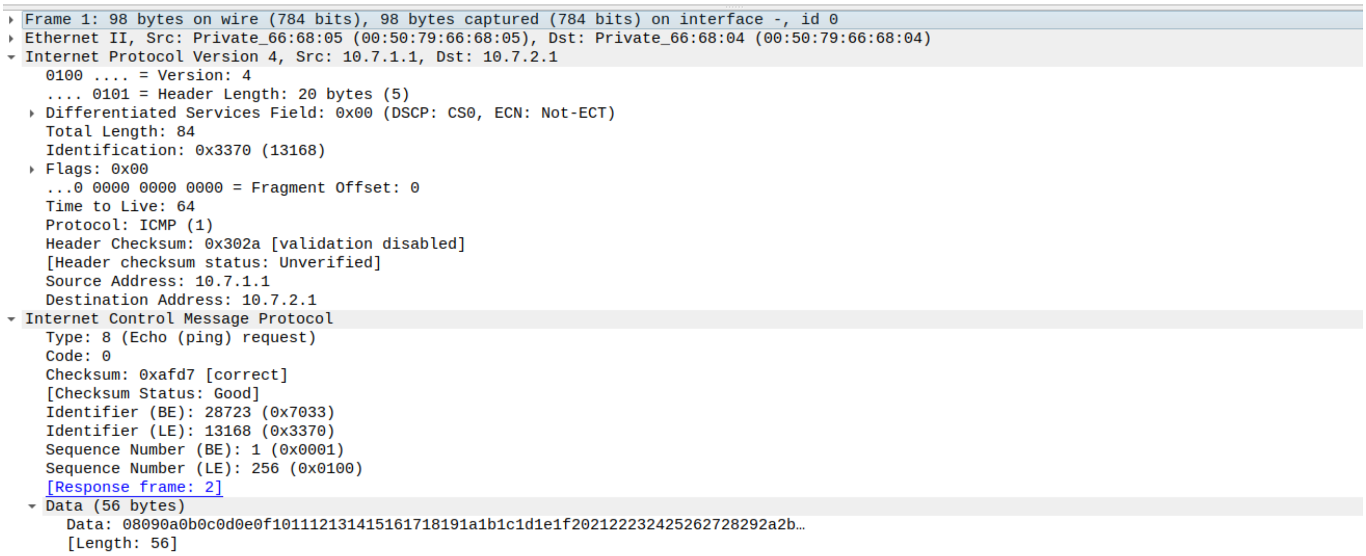
A packet capture was placed using Wireshark, between **Lisbon** and **RL1**, where the data is still encapsulated in **UDP** packets, with port 8472 and another capture between router **RA1** and Switch **LA_S3**, where the *ICMP* packets originate, before being encapsulated.

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	10.1.0.29	224.0.0.5	OSPF	94	Hello Packet
2	0.624054	ca:01:ad:2a:00:38	ca:01:ad:2a:00:38	LOOP	60	Reply
3	2.034215	10.1.0.108	10.1.0.103	UDP	148	33523 → 8472 Len=106
4	2.035469	10.1.0.103	10.1.0.108	UDP	148	33687 → 8472 Len=106
5	3.063862	10.1.0.108	10.1.0.103	UDP	148	33523 → 8472 Len=106
6	3.064790	10.1.0.103	10.1.0.108	UDP	148	33687 → 8472 Len=106
7	4.092996	10.1.0.108	10.1.0.103	UDP	148	33523 → 8472 Len=106
8	4.093715	10.1.0.103	10.1.0.108	UDP	148	33687 → 8472 Len=106
9	5.047780	10.1.0.30	224.0.0.5	OSPF	82	Hello Packet
10	5.122757	10.1.0.108	10.1.0.103	UDP	148	33523 → 8472 Len=106
11	5.125304	10.1.0.103	10.1.0.108	UDP	148	33687 → 8472 Len=106
12	6.152202	10.1.0.108	10.1.0.103	UDP	148	33523 → 8472 Len=106
13	6.154541	10.1.0.103	10.1.0.108	UDP	148	33687 → 8472 Len=106

```
Frame 3: 148 bytes on wire (1184 bits), 148 bytes captured (1184 bits) on interface -, id 0
Ethernet II, Src: ca:01:ad:2a:00:38 (ca:01:ad:2a:00:38), Dst: 0c:24:b4:be:00:05 (0c:24:b4:be:00:05)
Internet Protocol Version 4, Src: 10.1.0.108, Dst: 10.1.0.103
  0100 .... = Version: 4
  .... 0101 = Header Length: 20 bytes (5)
  Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
  Total Length: 134
  Identification: 0xc227 (49703)
  Flags: 0x00
  ...0 0000 0000 0000 = Fragment Offset: 0
  Time to Live: 14
  Protocol: UDP (17)
  Header Checksum: 0xd56b [validation disabled]
  [Header checksum status: Unverified]
  Source Address: 10.1.0.108
  Destination Address: 10.1.0.103
User Datagram Protocol, Src Port: 33523, Dst Port: 8472
  Source Port: 33523
  Destination Port: 8472
  Length: 114
  Checksum: 0x0db3 [unverified]
  [Checksum Status: Unverified]
  [Stream index: 0]
  [Timestamps]
  UDP payload (106 bytes)
Data (106 bytes)
  Data: 0800000000000650000507966680400507966680508004500005433700000400130 2a0a07…
  [Length: 106]
```



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	10.7.1.1	10.7.2.1	ICMP	98	Echo (ping) request id=0x7033, seq=1/256, ttl=64 (reply in 2)
2	0.031884	10.7.2.1	10.7.1.1	ICMP	98	Echo (ping) reply id=0x7033, seq=1/256, ttl=64 (request in 1)
3	1.033167	10.7.1.1	10.7.2.1	ICMP	98	Echo (ping) request id=0x7133, seq=2/512, ttl=64 (reply in 4)
4	1.060392	10.7.2.1	10.7.1.1	ICMP	98	Echo (ping) reply id=0x7133, seq=2/512, ttl=64 (request in 3)
5	2.060891	10.7.1.1	10.7.2.1	ICMP	98	Echo (ping) request id=0x7233, seq=3/768, ttl=64 (reply in 6)
6	2.088716	10.7.2.1	10.7.1.1	ICMP	98	Echo (ping) reply id=0x7233, seq=3/768, ttl=64 (request in 5)
7	3.090041	10.7.1.1	10.7.2.1	ICMP	98	Echo (ping) request id=0x7333, seq=4/1024, ttl=64 (reply in 8)
8	3.118019	10.7.2.1	10.7.1.1	ICMP	98	Echo (ping) reply id=0x7333, seq=4/1024, ttl=64 (request in 7)
9	4.119289	10.7.1.1	10.7.2.1	ICMP	98	Echo (ping) request id=0x7433, seq=5/1280, ttl=64 (reply in 10)
10	4.146064	10.7.2.1	10.7.1.1	ICMP	98	Echo (ping) reply id=0x7433, seq=5/1280, ttl=64 (request in 9)



```
Frame 1: 98 bytes on wire (784 bits), 98 bytes captured (784 bits) on interface -, id 0
Ethernet II, Src: Private_66:68:05 (00:50:79:66:68:05), Dst: Private_66:68:04 (00:50:79:66:68:04)
Internet Protocol Version 4, Src: 10.7.1.1, Dst: 10.7.2.1
  0100 .... = Version: 4
  .... 0101 = Header Length: 20 bytes (5)
  Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
  Total Length: 84
  Identification: 0x3370 (13168)
  Flags: 0x00
  ...0 0000 0000 0000 = Fragment Offset: 0
  Time to Live: 64
  Protocol: ICMP (1)
  Header Checksum: 0x302a [validation disabled]
  [Header checksum status: Unverified]
  Source Address: 10.7.1.1
  Destination Address: 10.7.2.1
Internet Control Message Protocol
  Type: 8 (Echo (ping) request)
  Code: 0
  Checksum: 0xafd7 [correct]
  [Checksum Status: Good]
  Identifier (BE): 28723 (0x7033)
  Identifier (LE): 13168 (0x3370)
  Sequence Number (BE): 1 (0x0001)
  Sequence Number (LE): 256 (0x0100)
  [Response frame: 2]
  Data (56 bytes)
    Data: 08090a0b0c0d0e0f101112131415161718191a1b1c1d1e1f202122232425262728292a2b…
    [Length: 56]
```

MPLS Layer 3 VPN

In terms of MPLS Layer 3 VPN, this one is configured to provide connectivity and address SMEx client needs, all while keeping an isolated virtual routing table. For that, the respective VPC's needed to be configured, as well as the core-routers and POP routers connected to the network.

Terminals

To simulate a user device, a Cisco C7200 router was used in each SME network. To configure the router properly, the following commands should be used:

```
no ip routing
ip default gateway <ip_address>
int <interface-type>/<interface-number>
ip address <ip_address> <mask>
no sh
```

Core-Routers

In the core-routers, mpls needs to be enabled in each interface to other core routers and to router **RM1**, **RA2** or **RL2**. Use the following command:

```
interface <interface-type>/<interface-number>
mpls ip
```

In our case, core-routers continue to establish OSPF and BGP IPV4 connection with this routers, for route exchange, however, they are still *leafs*.

PoP-Routers

The POP routers addressed in this subsection are **RM1**, **RA2** and **RL2**. They need to be configured to handle `address-family vpnv4`. The following commands can be used:

```
router bgp 33900
address-family vpnv4
# Use the router-ids of the other routers
neighbor <pop_router_ip> activate
neighbor <pop_router_ip> send-community both
```

In this connection, no route-reflector is used, because there are only 3 routers and this way, we can improve redundancy where if one of the routers fail, the others can still communicate effectively, without having one which can't fail.

Configure VRF

The first step in their configuration is to create a single VRF for **one** VPN instance:

```
ip vrf VPN-1
rd 200:1
route-target export 200:1
route-target import 200:1
```

Next step is to enable MPLS in the interface connected to the core-router. In this networks case:

```
interface FastEthernet0/0
ip address <ip-address> <subnet-mask>
mpls ip
no shutdown
```

After, vrf forwarding needs to be enabled in the interface connected do the SMEx network. Use the following commands:

```
interface FastEthernet0/1
ip vrf forwarding VPN-1
```

```
ip address <ip-address> <subnet-mask>
no shutdown
```

Configure BGP

Check previous router configuration (`show run`) and execute the necessary following commands to attain a similar configuration:

```
router bgp 33900

# Configure router id, if not before
bgp router-id <loopback_ip>

# Add core router as neighbor
neighbor <neighbor_id> remote-as 33900
neighbor <neighbor_id> update-source lo

# Configure IPV4 route address-family
address-family ipv4
neighbor <coreRouter_neighbor> activate
exit

# Configure vpnv4 route address-family
address-family vpnv4
neighbor <pop_router_target_ip> activate
neighbor <pop_router_target_ip> send-community both
exit

# enable vrf
address-family ipv4 vrf VPN-1
redistribute connected
exit
```

Debugging

Until now, the router has two separate routing table which are isolated from each other. This can be observed by executing two commands:

```
show ip route # Should only appear the interconnection networks
show ip route vrf VPN-1 # should only appear the SME networks
```

Analysis

After configuring our system, we conducted a `ping` test between terminals `S3_1` and `S2_1`, which have the respective ip address `10.9.3.1` and `10.9.2.1`. The terminal output and connectivity of this test can be seen the following image:

```
S3-1#ping 10.9.2.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.9.2.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 68/85/92 ms
```

To analyze the traffic, we configured Wireshark packet capture between routers **RL2** and **Lisbon**, before the traffic arrived at the destination router at the edge of the client network and between router **RM1** and Switch **S3_S1**, capturing the originating *ICMP* packets.

icmp

No.	Time	Source	Destination	Protocol	Length	Info
4	0.990323	10.9.3.1	10.9.2.1	ICMP	118	Echo (ping) request id=0x0002, seq=0/0, ttl=254 (reply in 5)
5	1.014644	10.9.2.1	10.9.3.1	ICMP	122	Echo (ping) reply id=0x0002, seq=0/0, ttl=254 (request in 4)
6	1.071409	10.9.3.1	10.9.2.1	ICMP	118	Echo (ping) request id=0x0002, seq=1/256, ttl=254 (reply in 7)
7	1.095557	10.9.2.1	10.9.3.1	ICMP	122	Echo (ping) reply id=0x0002, seq=1/256, ttl=254 (request in 6)
8	1.152505	10.9.3.1	10.9.2.1	ICMP	118	Echo (ping) request id=0x0002, seq=2/512, ttl=254 (reply in 9)
9	1.176435	10.9.2.1	10.9.3.1	ICMP	122	Echo (ping) reply id=0x0002, seq=2/512, ttl=254 (request in 8)
10	1.233348	10.9.3.1	10.9.2.1	ICMP	118	Echo (ping) request id=0x0002, seq=3/768, ttl=254 (reply in 11)
11	1.257248	10.9.2.1	10.9.3.1	ICMP	122	Echo (ping) reply id=0x0002, seq=3/768, ttl=254 (request in 10)
12	1.314370	10.9.3.1	10.9.2.1	ICMP	118	Echo (ping) request id=0x0002, seq=4/1024, ttl=254 (reply in 13)
13	1.328123	10.9.2.1	10.9.3.1	ICMP	122	Echo (ping) reply id=0x0002, seq=4/1024, ttl=254 (request in 12)

```
Frame 4: 118 bytes on wire (944 bits), 118 bytes captured (944 bits) on interface -, id 0
Ethernet II, Src: ca:01:ad:2a:00:1d (ca:01:ad:2a:00:1d), Dst: ca:06:ba:83:00:08 (ca:06:ba:83:00:08)
  Destination: ca:06:ba:83:00:08 (ca:06:ba:83:00:08)
  Source: ca:01:ad:2a:00:1d (ca:01:ad:2a:00:1d)
  Type: MPLS label switched packet (0x8847)
MultiProtocol Label Switching Header, Label: 37, Exp: 0, S: 1, TTL: 252
  0000 0000 0000 0010 0101 .... .... .... = MPLS Label: 37 (0x00025)
  .... .... .... .... .... 000. .... .... = MPLS Experimental Bits: 0
  .... .... .... .... .... ...1 .... .... = MPLS Bottom Of Label Stack: 1
  .... .... .... .... .... .... 1111 1100 = MPLS TTL: 252
Internet Protocol Version 4, Src: 10.9.3.1, Dst: 10.9.2.1
  0100 .... = Version: 4
  .... 0101 = Header Length: 20 bytes (5)
  Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
  Total Length: 100
  Identification: 0x000a (10)
  Flags: 0x00
  ...0 0000 0000 0000 = Fragment Offset: 0
  Time to Live: 254
  Protocol: ICMP (1)
  Header Checksum: 0xa37b [validation disabled]
  [Header checksum status: Unverified]
  Source Address: 10.9.3.1
  Destination Address: 10.9.2.1
Internet Control Message Protocol
  Type: 8 (Echo (ping) request)
  Code: 0
  Checksum: 0x73c5 [correct]
  [Checksum Status: Good]
  Identifier (BE): 2 (0x0002)
  Identifier (LE): 512 (0x0200)
  Sequence Number (BE): 0 (0x0000)
  Sequence Number (LE): 0 (0x0000)
  [Response frame: 5]
  Data (72 bytes)
    Data: 00000000002b0a58abcdabcdabcdabcdabcdabcdabcdabcdabcdabcdabcdabcdabcdabcd…
    [Length: 72]
```

icmp

No.	Time	Source	Destination	Protocol	Length	Info
5	24.882285	10.9.3.1	10.9.2.1	ICMP	114	Echo (ping) request id=0x0000, seq=0/0, ttl=255 (no response found!)
6	26.344555	10.9.3.1	10.9.2.1	ICMP	114	Echo (ping) request id=0x0000, seq=1/256, ttl=255 (reply in 7)
7	26.435398	10.9.2.1	10.9.3.1	ICMP	114	Echo (ping) reply id=0x0000, seq=1/256, ttl=251 (request in 6)
8	26.445607	10.9.3.1	10.9.2.1	ICMP	114	Echo (ping) request id=0x0000, seq=2/512, ttl=255 (reply in 9)
9	26.536359	10.9.2.1	10.9.3.1	ICMP	114	Echo (ping) reply id=0x0000, seq=2/512, ttl=251 (request in 8)
10	26.546389	10.9.3.1	10.9.2.1	ICMP	114	Echo (ping) request id=0x0000, seq=3/768, ttl=255 (reply in 11)
11	26.637190	10.9.2.1	10.9.3.1	ICMP	114	Echo (ping) reply id=0x0000, seq=3/768, ttl=251 (request in 10)
12	26.647288	10.9.3.1	10.9.2.1	ICMP	114	Echo (ping) request id=0x0000, seq=4/1024, ttl=255 (reply in 13)
13	26.738120	10.9.2.1	10.9.3.1	ICMP	114	Echo (ping) reply id=0x0000, seq=4/1024, ttl=251 (request in 12)
15	28.836423	10.9.3.1	10.9.2.1	ICMP	114	Echo (ping) request id=0x0001, seq=0/0, ttl=255 (reply in 16)
16	28.927100	10.9.2.1	10.9.3.1	ICMP	114	Echo (ping) reply id=0x0001, seq=0/0, ttl=251 (request in 15)
17	28.937218	10.9.3.1	10.9.2.1	ICMP	114	Echo (ping) request id=0x0001, seq=1/256, ttl=255 (reply in 18)
18	29.028023	10.9.2.1	10.9.3.1	ICMP	114	Echo (ping) reply id=0x0001, seq=1/256, ttl=251 (request in 17)
19	29.038072	10.9.3.1	10.9.2.1	ICMP	114	Echo (ping) request id=0x0001, seq=2/512, ttl=255 (reply in 20)
20	29.128957	10.9.2.1	10.9.3.1	ICMP	114	Echo (ping) reply id=0x0001, seq=2/512, ttl=251 (request in 19)
21	29.139063	10.9.3.1	10.9.2.1	ICMP	114	Echo (ping) request id=0x0001, seq=3/768, ttl=255 (reply in 22)
22	29.219561	10.9.2.1	10.9.3.1	ICMP	114	Echo (ping) reply id=0x0001, seq=3/768, ttl=251 (request in 21)
23	29.229528	10.9.3.1	10.9.2.1	ICMP	114	Echo (ping) request id=0x0001, seq=4/1024, ttl=255 (reply in 24)

```
Frame 7: 114 bytes on wire (912 bits), 114 bytes captured (912 bits) on interface -, id 0
Ethernet II, Src: ca:05:ba:64:00:06 (ca:05:ba:64:00:06), Dst: ca:0a:88:79:00:08 (ca:0a:88:79:00:08)
  Destination: ca:0a:88:79:00:08 (ca:0a:88:79:00:08)
  Source: ca:05:ba:64:00:06 (ca:05:ba:64:00:06)
  Type: IPv4 (0x0800)
Internet Protocol Version 4, Src: 10.9.2.1, Dst: 10.9.3.1
  0100 .... = Version: 4
  .... 0101 = Header Length: 20 bytes (5)
  Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
  Total Length: 100
  Identification: 0x0001 (1)
  Flags: 0x00
  ...0 0000 0000 0000 = Fragment Offset: 0
  Time to Live: 251
  Protocol: ICMP (1)
  Header Checksum: 0xa684 [validation disabled]
  [Header checksum status: Unverified]
  Source Address: 10.9.2.1
  Destination Address: 10.9.3.1
Internet Control Message Protocol
  Type: 0 (Echo (ping) reply)
  Code: 0
  Checksum: 0x7413 [correct]
  [Checksum Status: Good]
  Identifier (BE): 0 (0x0000)
  Identifier (LE): 0 (0x0000)
  Sequence Number (BE): 1 (0x0001)
  Sequence Number (LE): 256 (0x0100)
  [Request frame: 6]
  [Response time: 90,843 ms]
  Data (72 bytes)
    Data: 00000000002a120cabcdabcdabcdabcdabcdabcdabcdabcdabcdabcdabcdabcdabcdabcd…
    [Length: 72]
```

In this packets, we can see that the packets are forwarded through the networks using the **MPLS** protocol, operating in Layer 3.

The following images also show the terminal of **RM1** router, where it's possible to see the `ip route` of the psychical routing table and virtual `vrf VPN-1` routing table, where the physical table only contains the interconnection network and the virtual only the client **SME** networks. This way the client get's an isolated routing table.

```
RM1#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      10.0.0.0/8 is variably subnetted, 25 subnets, 2 masks
O        10.1.0.0/30 [110/3] via 10.1.0.37, 01:36:46, FastEthernet0/0
O        10.1.0.4/30 [110/2] via 10.1.0.37, 01:36:46, FastEthernet0/0
O        10.1.0.8/30 [110/3] via 10.1.0.37, 01:36:46, FastEthernet0/0
O        10.1.0.12/30 [110/2] via 10.1.0.37, 01:36:46, FastEthernet0/0
O        10.1.0.16/30 [110/3] via 10.1.0.37, 01:36:46, FastEthernet0/0
O        10.1.0.20/30 [110/3] via 10.1.0.37, 01:36:46, FastEthernet0/0
O        10.1.0.24/30 [110/3] via 10.1.0.37, 01:36:46, FastEthernet0/0
O        10.1.0.28/30 [110/3] via 10.1.0.37, 01:36:46, FastEthernet0/0
O        10.1.0.32/30 [110/2] via 10.1.0.37, 01:36:46, FastEthernet0/0
C        10.1.0.36/30 is directly connected, FastEthernet0/0
L        10.1.0.38/32 is directly connected, FastEthernet0/0
O        10.1.0.40/30 [110/4] via 10.1.0.37, 01:36:36, FastEthernet0/0
O        10.1.0.44/30 [110/4] via 10.1.0.37, 01:36:36, FastEthernet0/0
O        10.1.0.101/32 [110/4] via 10.1.0.37, 01:36:36, FastEthernet0/0
O        10.1.0.102/32 [110/4] via 10.1.0.37, 01:36:36, FastEthernet0/0
O        10.1.0.103/32 [110/4] via 10.1.0.37, 01:36:36, FastEthernet0/0
O        10.1.0.104/32 [110/3] via 10.1.0.37, 01:36:46, FastEthernet0/0
O        10.1.0.105/32 [110/3] via 10.1.0.37, 01:36:46, FastEthernet0/0
O        10.1.0.106/32 [110/2] via 10.1.0.37, 01:36:46, FastEthernet0/0
O        10.1.0.107/32 [110/4] via 10.1.0.37, 01:36:46, FastEthernet0/0
O        10.1.0.108/32 [110/5] via 10.1.0.37, 01:36:36, FastEthernet0/0
O        10.1.0.109/32 [110/5] via 10.1.0.37, 01:36:37, FastEthernet0/0
C        10.1.0.110/32 is directly connected, Loopback0
O        10.1.0.111/32 [110/4] via 10.1.0.37, 01:23:14, FastEthernet0/0
O        10.1.0.112/32 [110/5] via 10.1.0.37, 01:24:49, FastEthernet0/0
```

```
RM1#show ip route vrf VPN-1

Routing Table: VPN-1
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      10.0.0.0/8 is variably subnetted, 4 subnets, 2 masks
B        10.9.1.0/24 [200/0] via 10.1.0.109, 01:35:49
B        10.9.2.0/24 [200/0] via 10.1.0.102, 01:35:48
C        10.9.3.0/24 is directly connected, FastEthernet0/1
L        10.9.3.254/32 is directly connected, FastEthernet0/1
```

Geographic based service routing

This section will attend to client SMEx needs of geographic based service routing for its servers/services. In practice this translates to a DNS server located in main DC which will be the target of client requests and supply them with a dummy or the gateway IP address associated to their respective PoP.

Terminals

For increased reliability with DNS requests, we'll be using Cisco C7200 routers as the client (already configured in MPLS section), with routing disabled. To configure the terminal routers, use the following commands:

```
# Already done before
no ip routing
ip default-gateway <gateway_ip>
int <interface-type>/<interface-number>
ip address <ip_address> <mask>
no shutdown

# New commands
ip name-server 10.1.0.33
ip domain lookup
```

DNS Server

Using Qemu and `labcom`, we started by defining the GeoLocation of the respective IP addresses associated to the PoP. The ACL list is as follows:

```
acl Aveiro {
    10.9.1.0/24;
};

acl Lisbon {
    10.9.2.0/24;
};

acl Madrid {
    10.9.3.0/24;
};
```

This file should be named `GeoIP.acl` and present in the directory `/etc/bind/`. Next, create bind the ip address and gateway to the connection:

```
# Bind the ip address to the ens3 interface
sudo ip addr add 10.1.0.33/30 dev ens3
```

```
# Assign a gateway
sudo ip route add default via 10.1.0.34
```

On the DNS server, load the **ACL** file to *BIND* the configuration by adding the following line to `/etc/bind/named.conf` (If present, comment the line `include "/etc/bind/named.conf.default-zones";`):

```
include "/etc/bind/GeoIP.acl";
```

The file will have the following structure:

```
// This is the primary configuration file for the BIND DNS server named.
//
// Please read /usr/share/doc/bind9/README.Debian.gz for information on the
// structure of BIND configuration files in Debian, *BEFORE* you customize
// this configuration file.
//
// If you are just adding zones, please do that in /etc/bind/named.conf.local

include "/etc/bind/named.conf.options";
include "/etc/bind/named.conf.local";
//include "/etc/bind/named.conf.default-zones";
include "/etc/bind/GeoIP.acl";
~
~
~
~
~
~
~
```

Then restart the DNS server with the command:

```
service bind9 restart or systemctl restart bind9.
# check it's status
service bind9 status
systemctl status bind9
```

Modify file `/etc/bind/named.conf.local` by creating the definition of *zones* conditioned by *views*, dependent on the geographic location obtained from the **ACL**. The additions are present in the following image:

```
view "aveiro" {
 match-clients { Aveiro; };
 recursion no;
 zone "cdnglobal.com" {
  type master;
  file "/etc/bind/cdnglobal.com-aveiro.db";
 };
};

view "lisbon" {
 match-clients { Lisbon; };
 recursion no;
 zone "cdnglobal.com" {
  type master;
  file "/etc/bind/cdnglobal.com-lisbon.db";
 };
};

view "madrid" {
 match-clients { Madrid; };
 recursion no;
 zone "cdnglobal.com" {
  type master;
  file "/etc/bind/cdnglobal.com-madrid.db";
 };
};

view "other" {
 match-clients { any; };
 recursion no;
 zone "cdnglobal.com" {
  type master;
  file "/etc/bind/cdnglobal.com-other.db";
 };
};
```

To create the IP addresses of the servers present in each location, we created one `.db` file for each location and another for open access. In our case, since we don't have a dedicated copy server (not in scope), we just simply returned the address of the gateway present in this network. In the following images, we have present the configuration of each file:

- DNS database file of Aveiro SME1 network:

```
$TTL    604800
$ORIGIN cdnglobal.com.
@ IN SOA ns1.cdnglobal.com. adm.cdnglobal.com. (
    2         ; Serial
    604800    ; Refresh
    86400     ; Retry
    2419200   ; Expire
    604800    ; Negative Cache TTL
)
@   IN NS ns1.cdnglobal.com.
@   IN A  10.9.1.254
ns1 IN A  10.1.0.33
```

- DNS database file of Lisbon SME2 network:

```
$TTL    604800
$ORIGIN cdnglobal.com.
@ IN SOA ns1.cdnglobal.com. adm.cdnglobal.com. (
        2         ; Serial
        604800    ; Refresh
        86400     ; Retry
        2419200   ; Expire
        604800    ; Negative Cache TTL
)
@    IN NS ns1.cdnglobal.com.
@    IN A  10.9.2.254
ns1  IN A  10.1.0.33
```

- DNS database file of Madrid SME3 network:

```
$TTL    604800
$ORIGIN cdnglobal.com.
@ IN SOA ns1.cdnglobal.com. adm.cdnglobal.com. (
        2         ; Serial
        604800    ; Refresh
        86400     ; Retry
        2419200   ; Expire
        604800    ; Negative Cache TTL
)
@    IN NS ns1.cdnglobal.com.
@    IN A  10.9.3.254
ns1  IN A  10.1.0.33
```

- DNS database file for any access:

```
$TTL    604800
$ORIGIN cdnglobal.com.
@ IN SOA ns1.cdnglobal.com. adm.cdnglobal.com. (
        2         ; Serial
        604800    ; Refresh
        86400     ; Retry
        2419200   ; Expire
        604800    ; Negative Cache TTL
)
@    IN NS ns1.cdnglobal.com.
@    IN A  10.1.0.254
ns1  IN A  10.1.0.33
```

To check the successful configuration of the addresses, use the command:

```
named-checkzone cdnglobal.com /etc/bind/cdnglobal.com-<zone>.db
```

Finally, restart the server and the system is configured.

Other routers

Since SMEx network operate in a MPLS Layer3 network with isolated routing, they can't natively access devices outside of their network. However, in this case, they need to access the DNS server in order to resolute the address of the website `cdnglobal.com`. For that, in routers **RM1**, **RL2** and **RA2**, a static default route needed to be created in the virtual routing table (`vrf VPN-1`) as to give the ability of this network to access the global physical routing table. The command used is as follows:

```
# Add a default route from the VPN-1 to core-router using the global
#  routing table to find the next-hop
ip route vrf VPN-1 0.0.0.0 0.0.0.0 <coreRouter_interface_ip> global
```

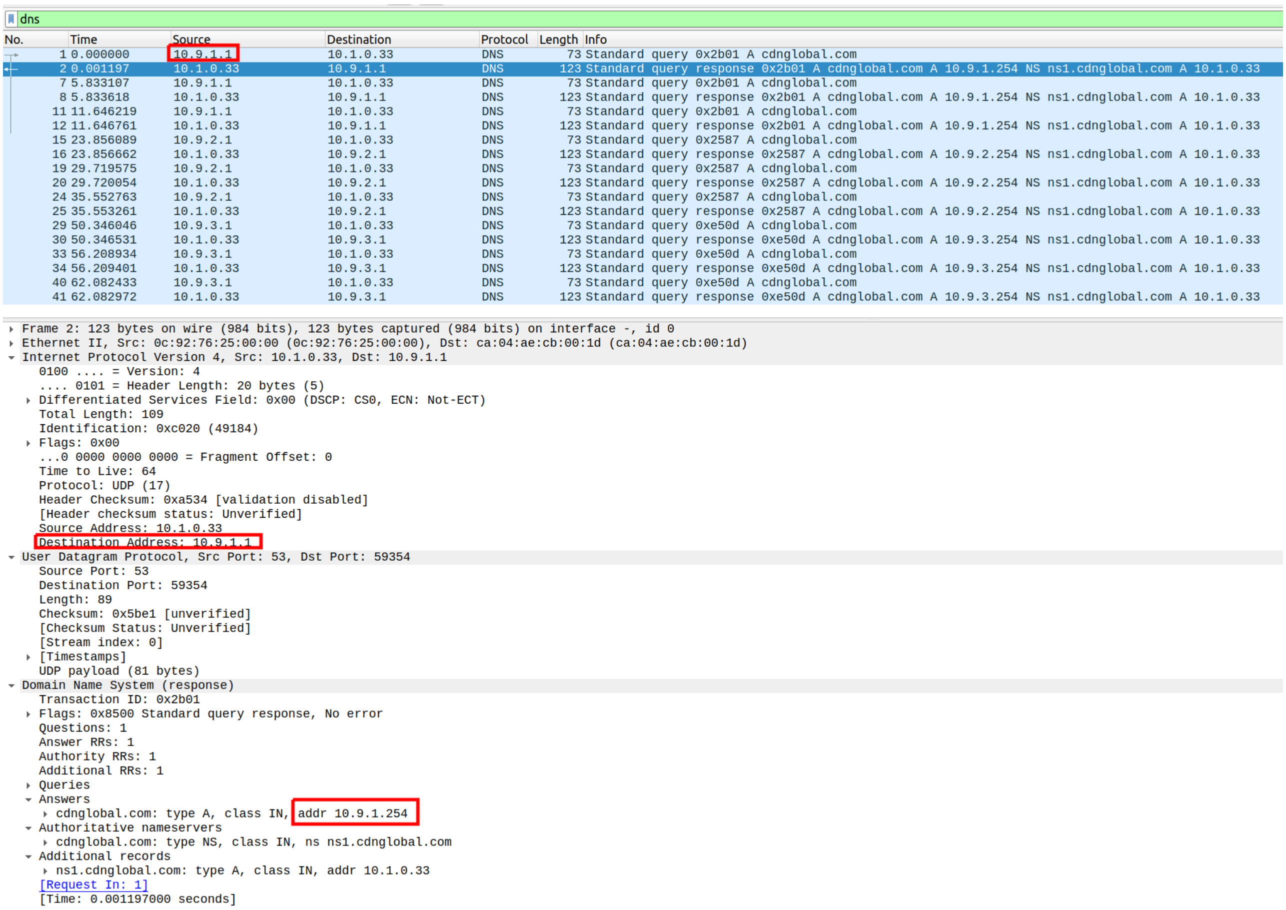
Since the scope of this sections was just to have the address resolved and seen by Wireshark, a return path wasn't configured, which means that the terminals are able to reach the **DNS** server, however, the server doesn't have the routes to their network, so they won't be able to see the resolution. Still, that resolution can be observed in the Wireshark packets as we'll be approaching in the next section.

Static routes from the global routing table to the virtual, distributed by OSPF could be configured ot solve this issue, however this would quickly prove to be a bad idea, because the SMEx networks would start to be seen as internal to the AS infrastructure, allowing other users or bad actors access. Of course other measures could be used, such as only allowing DNS traffic with **ACL**'s, or using another dedicated *VPN* to carry only traffic outside of the clients networks and back. This and other approaches could be used, however, as stated before this part of the work falls out-of-scope of this project.

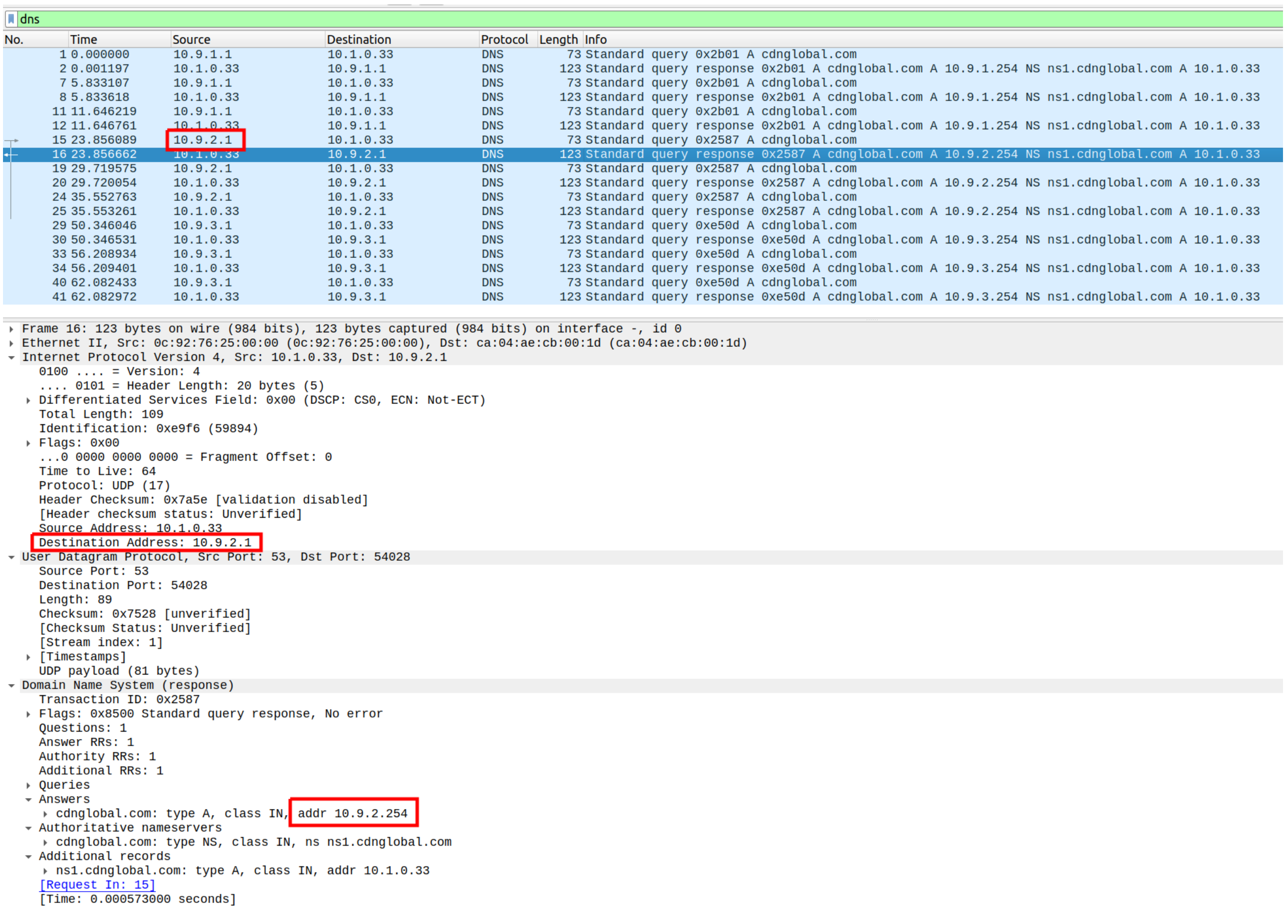
Analysis

To test the successful implementation of our DNS system, we performed a packet capture using Wireshark in the link between **Madrid** router and the **DNS** server. Next, we made a `ping` test to address `cdnglobal.com`, filtered by the **DNS** response packet and checked the `Answers` field, which contains the address returned by the **DNS** server. As present in the following images, our system performed as expected, returning the correct server address for all requests.

- Test from Aveiro:



- Test from Lisbon:



- Test from Madrid: