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Introduction

This report documents the procedures in LAB3 of NWEN302 where a software based emulator called Marionnet developed by Jean-Vincent Loddo and Luca Saiu at the Universite Paris 13 was used to gain practical experience of configuring both IPv4 and IPv6 networks. This included creating a network topology in Marionnet where all the interfaces of each machine and router were configured, static routing implemented and then dynamic routing implemented in the form of OSPF and OSPF6 respectively. During and after these steps, testing was performed to make sure all devices were working and communicating correctly by using common Linux and UNIX style command line tools found on computers and routers, thus giving a great deal of experience of how real life networks are tested and debugged.

Apparatus

A capable computer running.

1) Marionnet Version: 0.90.6
   Copyright © 2007, 2008, 2009, 2010, 2011 Jean-Vincent Loddo, Luca Saiu, Université Paris 13.
   http://www.marionnet.org/EN/
2) GNU/Linux Distribution (Debian based, Red Hat based or OpenSuse)
   (Arch Linux 3.7.5-1 licensed under the GNU GPLv2 used)

Procedures

Creating an initial setup

The topology shown in Appendix 1, page 11 was created in Marionnet by adding devices using the device buttons on the left hand side of the screen. When added, each router was given a name of R1 through R8 as shown in the topology. The amount of ports was set, the port 0 address set as 0.0.0.0/0 and the "Show unix terminal" checkbox ticked with all other fields left as default. All machines were labeled M1 through M4 as in the topology, with all other fields left as default.

Numbering the interfaces

Each interface of all routers created in Marionnet were linked together with the Crossover cable as in the topology. When doing this, the ports allocated to each link were recorded in a table. See Appendix 2, page 12 for the completed table and Appendix 3, page 13 for the network diagram.

Configuring the router interfaces

As Marionnet uses virtual Linux hosts as Routers and Machines, actual Linux based software is installed on them. These are the command line tools such as ping, ping6, route, nano and a software package called Quagga that handles different routing protocols, this effectively turning a Linux machine into a router.

Using the Quagga package and connecting to the Zebra process, each routers interface, IPv4 and IPv6 addresses were set. This was done by being logged on to the router and doing the following:

1) Using ***chown quagga.quagga /etc/quagga*** at first startup of the router to change the ownership of the quagga directory so quagga changes can be saved.

2) ***telnet localhost 2601*** used to start the Zebra process. Then logging in with the password ***zebra***, and using ***enable*** to allow administrator privileges. This asked for the administrator password which was ***zebra***.

3) Next ***configure terminal*** was used to change the configuration of the router.

4) Then a router interface was selected to be modified, for example ***interface eth0*** to set eth0 as the interface to modify.

5) The IPv4 and IPv6 addresses were now set for the interface. For example the IPv4 address set to 10.10.1.1/24 is ***ip address 10.10.1.1/24*** the IPv6 address set, ***ipv6 address 2404:2000:2002:101::1/64.***

6) ***exit*** was used to stop modifying the interface and step 4 and 5 were repeated for all interfaces on the router. Once all interfaces were configured, ***exit*** was used again to exit the router configuration, ***write memory*** used to save the changes and finally ***exit*** used again to quit the Zebra process.

Once this process was achieved for all routers, communication between neighboring routers existed. To test this, ***ping*** and ***ping6*** were used to show the communication on the same subnets between routers. The successful results are shown in Appendix 4, page 14 for all routers.

Configuring the Unix hosts

The hosts were then configured so they could communicate to the neighbouring router. To achieve this, the IP addresses and subnet masks were set, as well as the default gateway.

A default gateway is the default address a device sends a packet to if the device has no entry in its routing table for the destination. For example, if m4 in the network wants to send a packet to m2, then since 10.10.11.2 is not on its local subnet, the packet will be forwarded out its default gateway and be routed to m2, that is assuming somesort of routing is set up in the network.

The procedure in doing this involved adding the following lines to the file */etc/network/interface* like in the example for m1 below.

```
iface eth0 inet static
        address 10.10.10.2
        netmask 255.255.255.0
        gateway 10.10.10.1

iface eth0 inet6 static
        address 2404:2000:2002:110::2
        netmask 64
        gateway 2404:2000:2002:110::1
```

Once the interface file was saved, eth0 had to be initialised on every startup of the machine by using ***ifup --force eth0.*** It was now possible for the machines to communicate to their neighbouring router and that machine could also communicate with any other machines connected to its neighbouring router. For example, in the network topology, m1 can communicate with m2 because m1 will send a packet out its default gateway, this is received by router R1. R1 knows the address of m2 so it can forward the packet to m2. When m2 receives the packet it can send a reply through its default gateway and the packet will be forwarded by R1 to m1. This was tested by using the ***ping*** and ***ping6*** command, and the results showing this and the communication to the neighbouring router are shown in Appendix 5, page 23.

Static Routing

Static routing is the process of adding routes to a routers forwarding table manually to achieve a path through a network. A route/path between R2 and R6 that went through R3 was implemented in the network with static routing. This was done by adding static routes in the Zebra process. Once logged in and the configuration enabled, R2 was setup by running:

ip route 10.10.7.0/24 10.10.9.2
ipv6 route 2404:2000:2002:107::/64 2404:2000:2002:109::2

and R6 setup by running:

ip route 10.10.9.0/24 10.10.7.1
ipv6 route 2404:2000:2002:109::/64 2404:2000:2002:107::1

The R2 static route will forward any packets with the destination of subnet 10.10.7.0/24 or 2404:2000:2002:107::/64 to the 10.10.9.2 gateway or 2404:2000:2002:109::2 gateway respectivly. When doing this the router would be using the Address Resolution Protocol (ARP) protocol to to find out what MAC address to send the packet out to for IPv4 and the Network Discovery Protocol (NDP) to resolve IPv6 addresses. The NDP protocol is very similar to the ARP protocol where the device wanting to send a packet to an IPv6 address will send a broadcast packet to its neighbouring nodes which will respond with a MAC address if they know the IPv6 address the device wants to send to and the NDP table will be updated for future requests to the same IP address. R3 does not require any static routes because it already knows both the subnets that it can forward to. The route was tested using the ***ping*** command to show if the routers could communicate and the results are shown in Appendix 6, page 27.

If communication was needed between m1, m2, m3 and m4 then 8 static routes would be needed to give full communication between all machines using routers R1, R3 and R4. More specifically R1 would require 2 static routes to forward packets to R3 for the 10.10.13.0/24 and 10.10.12.0/24 subnets as it doesn't know where those subnets are. R4 would require 2 static routes to forward packets to R3 for the 10.10.10.0/24 and 10.10.11.0/24 subnets similiely. R3 would require 2 static routes to forward packets to R1 and 2 static routes to forward packets to R4 for the respective subnets. R1 and R4 don't require static routing to the connected machines because they already know where to send packets because they belong on the same subnet. This route was chosen because it was the shortest path and if any links or routers failed the machines would not be able to communicate. To fix this, static routes would have to be added to other routers when a failure occured to bypass the problem.

f another router was added in between routers R1 and R4 then that router would need 4 static routes to forward traffic both ways for all 4 subnets. If the router was placed before R1 or R4 then that router would need two static routes to forward packets on. R1 and R4 would need two more static routes added to forward packets to the new router.

Dynamic Routing using OSPF and OSPF6

Dynamic routing is the alternative to static routing. It is implemented on routers as protocols to achieve dynamic learning of network destinations in a local area network. Dynamic routing has the advantages that it is easy and fast to set up a network as each device knows where to forward packets. If a link or router fails then a dynamic protocol can adapt automatically to find an alternative route.

OSPF and OSPF6 are such dynamic routing protocols that were implemented in the network to allow communication between all nodes in the network.

Before implementing OSPF the old static routes had to be manually removed using the ***no ip route*** and ***no ipv6 route*** commands in the Zebra process. For example, removing the static routes for R2 is shown below:

```
no ip route 10.10.7.0/24 10.10.9.2
no ipv6 route 2404:2000:2002:107::/64 2404:2000:2002:109::2
```

To implement OSPF (IPv4) the following structure was used after logging in the the OSPF process on port 2604 and enabling the configuration terminal:

```
router ospf
 redistribute connected
 network 10.10.0.0/8 area 0.0.0.0
```

This was done for every router in the network. Appendix 7, page 28 shows the successful communication between nodes in the network using the traceroute tool.

OSPF6 was now implemented in the network so all devices could communicate using IPv6 addresses. This was done by using the following structure once logged in to the OSPF6 process on port 2606 and enable the configuration terminal:

```
router ospf6
 router-id 10.10.1.1
 redistribute connected
 interface eth0 area 0.0.0.0
 interface eth1 area 0.0.0.0
```

This example shows the OSPF6 setup for R1 in the network. The router-id is the ip address of port 0. R1 has interface eth0 and eth1 because that is the two interfaces that connect to other routers. OSPF6 was set up on every router following the same structure where the port 0 address will vary and the interfaces connected to other routers will vary.

Before IPv6 could be tested IPv6 forwarding had to be enabled on each router by adding ***net.ipv6.conf.all.forwarding=1*** to the /etc/sysctl.conf file and the router rebooted. To test that this change worked and OSPF6 worked the **traceroute** tool was used with link c2 disconnected.

When using traceroute the -n flag was used so it prevented the program from resolving the numeric address to a symbolic name. The OSPF protocol takes a while to get its forwarding tables set up, so the first attempt at traceroute was unsuccessful as some routers were busy and timed out. After a while the traceroute attempt was successful and the results can be seen in Appendix 8 on page 29. After c2 was reconnected the OSPF table took a while to adjust and the old route was taken by a traceroute packet. Once it adjusted itself OSPF reverted back to the shortest path as shown in Appendix 8, page 29. This process took about 4 - 5 seconds, which was worked out by traceroute attempts which each one took just over one second.

The following table is R7's completed OSPF routing table. This is because all packets sent to all subnets are forwarded to gateway 10.10.6.2. This can only be R7 because 10.10.6.2 is assigned to R5 on port 0 and it is connected via Ethernet crossover cable to R7.

```
Router# sh ip ospf route
============ OSPF network routing table ============
N    10.10.1.0/24         [30] area: 0.0.0.0
                     via 10.10.6.2, eth0
N    10.10.2.0/24         [40] area: 0.0.0.0
                     via 10.10.6.2, eth0
N    10.10.3.0/24         [30] area: 0.0.0.0
                     via 10.10.6.2, eth0
N    10.10.4.0/24         [20] area: 0.0.0.0
                     via 10.10.6.2, eth0
N    10.10.5.0/24         [20] area: 0.0.0.0
                     via 10.10.6.2, eth0
N    10.10.6.0/24         [10] area: 0.0.0.0
                     directly attached to eth0
N    10.10.7.0/24         [30] area: 0.0.0.0
                     via 10.10.6.2, eth0
N    10.10.8.0/24         [20] area: 0.0.0.0
                     via 10.10.6.2, eth0
N    10.10.9.0/24         [30] area: 0.0.0.0
                     via 10.10.6.2, eth0
N    10.10.10.0/24        [40] area: 0.0.0.0
                     via 10.10.6.2, eth0
N    10.10.11.0/24        [40] area: 0.0.0.0
                     via 10.10.6.2, eth0
N    10.10.12.0/24        [30] area: 0.0.0.0
                     via 10.10.6.2, eth0
N    10.10.13.0/24        [30] area: 0.0.0.0
                     via 10.10.6.2, eth0

============ OSPF router routing table =============
R    10.10.2.1            [30] area: 0.0.0.0, ASBR
                     via 10.10.6.2, eth0
R    10.10.6.2            [10] area: 0.0.0.0, ASBR
                     via 10.10.6.2, eth0
R    10.10.7.2            [20] area: 0.0.0.0, ASBR
                     via 10.10.6.2, eth0
R    10.10.9.1            [20] area: 0.0.0.0, ASBR
                     via 10.10.6.2, eth0
R    10.10.9.2            [30] area: 0.0.0.0, ASBR
                     via 10.10.6.2, eth0
R    10.10.13.1           [20] area: 0.0.0.0, ASBR
                     via 10.10.6.2, eth0

============ OSPF external routing table ===========
N E2 172.23.0.0/16        [10/20] tag: 0
                     via 10.10.6.2, eth0
```

The OSPF tables of each router will be similar but not the same. They will contain all the same entries for subnets in the network but the output addresses will be different as neighbouring routers will be connected on different interfaces and each table will contain different directly connected interfaces to local subnets. Another example of an OSPF routing table is shown in Appendix 9, page 30.

The following table is a routing table for R1 once the OSPF process has been enabled on it. It can be seen in the routing table that it contains the entries for all local subnets and where to forward the packets to. Before OSPF was enabled this table would only contain local subnet entries 10.10.20/24, 10.10.1.0/24, 10.10.10.0/24, 10.10.11.0/24 and any manually static entries.

R1:~# route
Kernel IP routing table

Destination	*Gateway*	*Genmask*	*Flags*	*Metric*	*Ref*	*Use*	*Iface*
10.10.6.0	*10.10.1.2*	*255.255.255.0*	*UG*	*30*	*0*	*0*	*eth0*
10.10.7.0	*10.10.2.2*	*255.255.255.0*	*UG*	*20*	*0*	*0*	*eth1*
10.10.4.0	*10.10.1.2*	*255.255.255.0*	*UG*	*30*	*0*	*0*	*eth0*
10.10.5.0	*10.10.1.2*	*255.255.255.0*	*UG*	*30*	*0*	*0*	*eth0*
10.10.2.0	*	*255.255.255.0*	*U*	*0*	*0*	*0*	*eth1*
10.10.3.0	*10.10.2.2*	*255.255.255.0*	*UG*	*20*	*0*	*0*	*eth1*
10.10.1.0	*	*255.255.255.0*	*U*	*0*	*0*	*0*	*eth0*
10.10.12.0	*10.10.2.2*	*255.255.255.0*	*UG*	*30*	*0*	*0*	*eth1*
10.10.13.0	*10.10.2.2*	*255.255.255.0*	*UG*	*30*	*0*	*0*	*eth1*
10.10.10.0	*	*255.255.255.0*	*U*	*0*	*0*	*0*	*eth2*
10.10.11.0	*	*255.255.255.0*	*U*	*0*	*0*	*0*	*eth3*
10.10.8.0	*10.10.1.2*	*255.255.255.0*	*UG*	*20*	*0*	*0*	*eth0*
10.10.9.0	*10.10.1.2*	*255.255.255.0*	*UG*	*20*	*0*	*0*	*eth0*

Exploring the network from the core

The OSPF protocol was examined more closely by turning on debugging in the OSPF process in R3 using:

terminal monitor
debug ospf lsa

Once the debugging was started, link C2 was disconnected from the network and the output from the OSPF debugger was monitored and the following shows the important parts of the output with explanation of what is happening:

A new Link State Advertisement is being created because the rest of the network must be informed that R3 can't forward to R1 through C2 now because C2 is down.
OSPF: LSA[Type1]: Create router-LSA instance
OSPF: LSA[Type1,id(10.10.9.2),ar(10.10.9.2)]: Install router-LSA to Area 0.0.0.0

LSA destined for other routers, sent from R2 (10.10.9.2) flooding the network.
OSPF: RXmtL(0)++, NBR(10.10.7.2), LSA[Type1,id(10.10.9.2),ar(10.10.9.2)]
OSPF: RXmtL(0)++, NBR(10.10.12.1), LSA[Type1,id(10.10.9.2),ar(10.10.9.2)]
OSPF: RXmtL(0)++, NBR(10.10.9.1), LSA[Type1,id(10.10.9.2),ar(10.10.9.2)]

Showing the LSA of R3.
OSPF: LSA[Type1:10.10.9.2]: router-LSA refresh
OSPF: LSA Header
OSPF: LS age 0
OSPF: Options 2 (*|-|-|-|-|-|E|*)
OSPF: LS type 1 (router-LSA)
OSPF: Link State ID 10.10.9.2
OSPF: Advertising Router 10.10.9.2
OSPF: LS sequence number 0x80000005
OSPF: LS checksum 0xec0f
OSPF: length 72

More flooding on the network of LSAs from all the routers. -- to remove old LSA, ++ to add LSA.
OSPF: RXmtL(1)--, NBR(10.10.7.2), LSA[Type1,id(10.10.9.2),ar(10.10.9.2)]
OSPF: RXmtL(1)--, NBR(10.10.9.1), LSA[Type1,id(10.10.9.2),ar(10.10.9.2)]
OSPF: RXmtL(0)++, NBR(10.10.7.2), LSA[Type2,id(10.10.2.1),ar(10.10.11.1)]
OSPF: RXmtL(1)++, NBR(10.10.12.1), LSA[Type2,id(10.10.2.1),ar(10.10.11.1)]
OSPF: RXmtL(1)--, NBR(10.10.7.2), LSA[Type2,id(10.10.2.1),ar(10.10.11.1)]

OSPF: RXmtL(2)--, NBR(10.10.12.1), LSA[Type2,id(10.10.2.1),ar(10.10.11.1)]
OSPF: RXmtL(0)++, NBR(10.10.7.2), LSA[Type1,id(10.10.11.1),ar(10.10.11.1)]
OSPF: RXmtL(1)++, NBR(10.10.12.1), LSA[Type1,id(10.10.11.1),ar(10.10.11.1)]
OSPF: RXmtL(0)++, NBR(10.10.7.2), LSA[Type2,id(10.10.2.1),ar(10.10.11.1)]
OSPF: RXmtL(0)++, NBR(10.10.12.1), LSA[Type2,id(10.10.2.1),ar(10.10.11.1)]
OSPF: RXmtL(0)++, NBR(10.10.9.1), LSA[Type2,id(10.10.2.1),ar(10.10.11.1)]
OSPF: RXmtL(1)--, NBR(10.10.7.2), LSA[Type2,id(10.10.2.1),ar(10.10.11.1)]
OSPF: RXmtL(1)--, NBR(10.10.12.1), LSA[Type2,id(10.10.2.1),ar(10.10.11.1)]
OSPF: RXmtL(1)--, NBR(10.10.9.1), LSA[Type2,id(10.10.2.1),ar(10.10.11.1)

After the flooding, each router can update their routing tables so they can send packet to the destination via the shortest possible path.

References

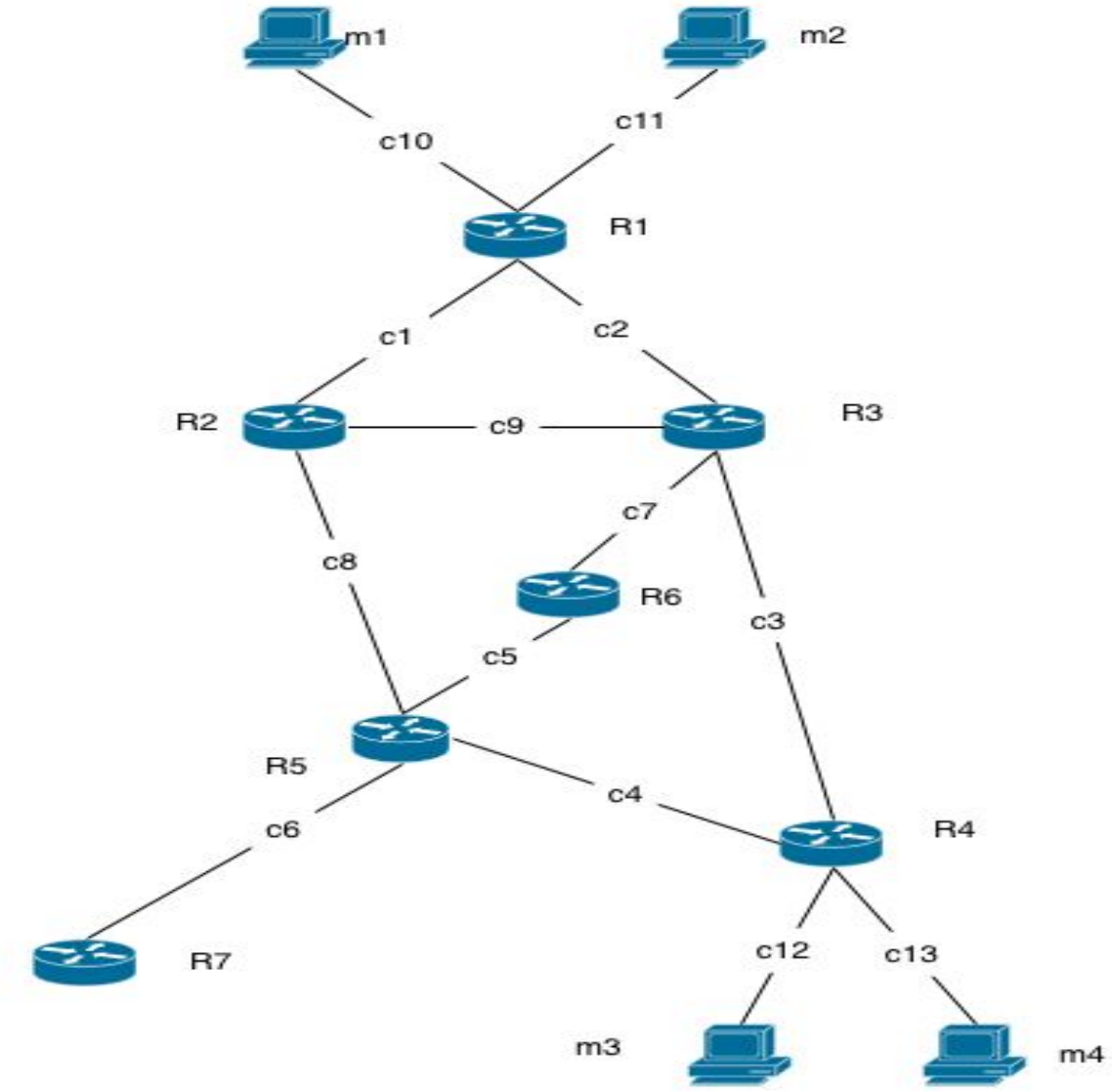
Quagga - http://www.nongnu.org/quagga/
Marionnet - http://www.marionnet.org/EN/
Routing Protocols, Prof Winston Seah, NWEN302, Victoria University of Wellington - http://ecs.victoria.ac.nz/foswiki/pub/Courses/NWEN302_2013T2/LectureSchedule/Week08-Routing_Protocols.pdf

Conclusion

Marionnet was an extremely valuable resource that along with the lab instructions gave good experience at configuring networks at the network layer level. It helped gain a better understanding of the network layer principles and show the differences in implementing IPv4 and IPv6 networks.

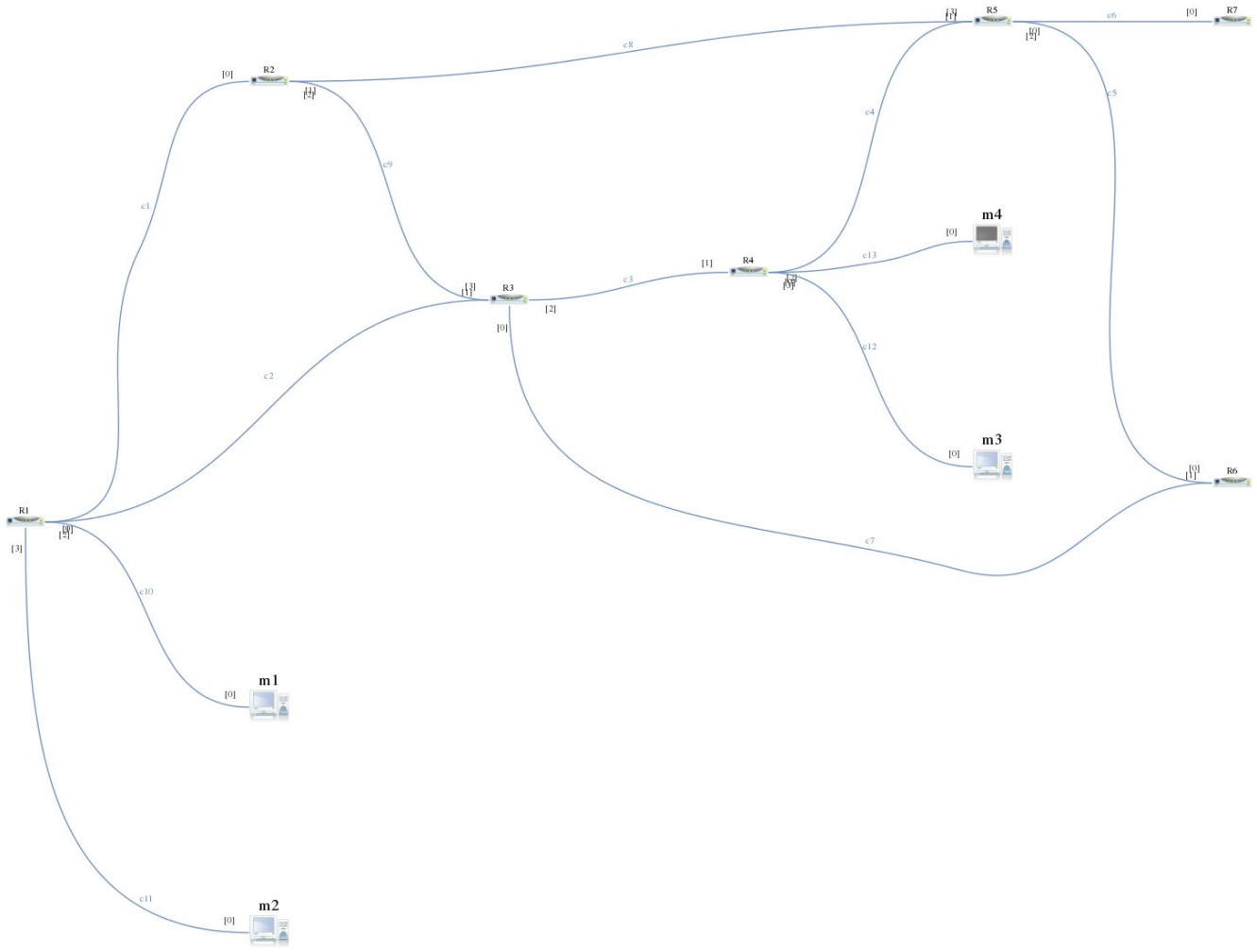
Appendices

Appendix 1 - Network Topology



NWEN302 Routing Lab

Appendix 2 - Network Diagram


R1
R2
R3
R4
R5
R6
R7
m1
m2
m3
m4
c1
c2
c3
c4
c5
c6
c7
c8
c9
c10
c11
c12
c13

Appendix 3 - Router Address Table

Router	Port	Cable	IPv4 Address	IPv4 Netmask	IPv6 Address
R1	eth0	C1	10.10.1.1	255.255.255.0	2404:2000:2002:101::1/64
R1	eth1	C2	10.10.2.1	255.255.255.0	2404:2000:2002:102::1/64
R1	eth2	C10	10.10.10.1	255.255.255.0	2404:2000:2002:110::1/64
R1	eth3	C11	10.10.11.1	255.255.255.0	2404:2000:2002:111::1/64
R2	eth0	C1	10.10.1.2	255.255.255.0	2404:2000:2002:101::2/64
R2	eth1	C8	10.10.8.1	255.255.255.0	2404:2000:2002:108::1/64
R2	eth2	C9	10.10.9.1	255.255.255.0	2404:2000:2002:109::1/64
R3	eth0	C7	10.10.7.1	255.255.255.0	2404:2000:2002:107::1/64
R3	eth1	C2	10.10.2.2	255.255.255.0	2404:2000:2002:102::2/64
R3	eth2	C3	10.10.3.1	255.255.255.0	2404:2000:2002:103::1/64
R3	eth3	C9	10.10.9.2	255.255.255.0	2404:2000:2002:109::2/64
R4	eth0	C13	10.10.13.1	255.255.255.0	2404:2000:2002:113::1/64
R4	eth1	C3	10.10.3.2	255.255.255.0	2404:2000:2002:103::2/64
R4	eth2	C4	10.10.4.1	255.255.255.0	2404:2000:2002:104::1/64
R4	eth3	C12	10.10.12.1	255.255.255.0	2404:2000:2002:112::1/64
R5	eth0	C6	10.10.6.2	255.255.255.0	2404:2000:2002:106::2/64
R5	eth1	C4	10.10.4.2	255.255.255.0	2404:2000:2002:104::2/64
R5	eth2	C5	10.10.5.1	255.255.255.0	2404:2000:2002:105::1/64
R5	eth3	C8	10.10.8.2	255.255.255.0	2404:2000:2002:108::2/64
R6	eth0	C5	10.10.5.2	255.255.255.0	2404:2000:2002:105::2/64
R6	eth1	C7	10.10.7.2	255.255.255.0	2404:2000:2002:107::2/64
R7	eth0	C6	10.10.6.1	255.255.255.0	2404:2000:2002:106::1/64
m1	eth0	C10	10.10.10.2	255.255.255.0	2404:2000:2002:110::2/64
m2	eth0	C11	10.10.11.2	255.255.255.0	2404:2000:2002:111::2/64
m3	eth0	C12	10.10.12.2	255.255.255.0	2404:2000:2002:112::2/64
m4	eth0	C13	10.10.13.2	255.255.255.0	2404:2000:2002:113::2/64

Appendix 4 - *ping* and *ping6* results between router links

(ping6 results start on page 19)

R1

Checking 10.10.1.2 on link C1

```
R1:~# ping -c 3 10.10.1.2
PING 10.10.1.2 (10.10.1.2) 56(84) bytes of data.
64 bytes from 10.10.1.2: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.1.2: icmp_seq=2 ttl=64 time=0.344 ms
64 bytes from 10.10.1.2: icmp_seq=3 ttl=64 time=1.19 ms

--- 10.10.1.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2025ms
rtt min/avg/max/mdev = 0.344/7.362/20.550/9.331 ms
```

Checking 10.10.2.2 on link C2

```
R1:~# ping -c 3 10.10.2.2
PING 10.10.2.2 (10.10.2.2) 56(84) bytes of data.
64 bytes from 10.10.2.2: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.2.2: icmp_seq=2 ttl=64 time=0.451 ms
64 bytes from 10.10.2.2: icmp_seq=3 ttl=64 time=0.435 ms

--- 10.10.2.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2026ms
rtt min/avg/max/mdev = 0.435/7.158/20.588/9.496 ms
```

R2

Checking 10.10.1.1 on link C1

```
R2:~# ping -c 3 10.10.1.1
PING 10.10.1.1 (10.10.1.1) 56(84) bytes of data.
64 bytes from 10.10.1.1: icmp_seq=1 ttl=64 time=20.6 ms
64 bytes from 10.10.1.1: icmp_seq=2 ttl=64 time=0.565 ms
64 bytes from 10.10.1.1: icmp_seq=3 ttl=64 time=1.50 ms

--- 10.10.1.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2014ms
rtt min/avg/max/mdev = 0.565/7.565/20.621/9.240 ms
```

Checking 10.10.8.2 on link C8

R2:~# ping -c 3 10.10.8.2
PING 10.10.8.2 (10.10.8.2) 56(84) bytes of data.
64 bytes from 10.10.8.2: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.8.2: icmp_seq=2 ttl=64 time=0.515 ms
64 bytes from 10.10.8.2: icmp_seq=3 ttl=64 time=0.496 ms

--- 10.10.8.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2025ms
rtt min/avg/max/mdev = 0.496/7.199/20.588/9.467 ms

Checking 10.10.9.2 on link C9
R2:~# ping -c 3 10.10.9.2
PING 10.10.9.2 (10.10.9.2) 56(84) bytes of data.
64 bytes from 10.10.9.2: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.9.2: icmp_seq=2 ttl=64 time=0.479 ms
64 bytes from 10.10.9.2: icmp_seq=3 ttl=64 time=1.22 ms

--- 10.10.9.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2024ms
rtt min/avg/max/mdev = 0.479/7.431/20.593/9.311 ms

R3

Checking 10.10.7.2 on link C7
R3:~# ping -c 3 10.10.7.2
PING 10.10.7.2 (10.10.7.2) 56(84) bytes of data.
64 bytes from 10.10.7.2: icmp_seq=1 ttl=64 time=21.8 ms
64 bytes from 10.10.7.2: icmp_seq=2 ttl=64 time=0.366 ms
64 bytes from 10.10.7.2: icmp_seq=3 ttl=64 time=0.824 ms
--- 10.10.7.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2016ms
rtt min/avg/max/mdev = 0.366/7.688/21.874/10.032 ms

Checking 10.10.2.1 on link C2
R3:~# ping -c 3 10.10.2.1
PING 10.10.2.1 (10.10.2.1) 56(84) bytes of data.
64 bytes from 10.10.2.1: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.2.1: icmp_seq=2 ttl=64 time=0.438 ms
64 bytes from 10.10.2.1: icmp_seq=3 ttl=64 time=0.424 ms
--- 10.10.2.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2014ms
rtt min/avg/max/mdev = 0.424/7.129/20.526/9.473 ms

Checking 10.10.3.2 on link C3

```
R3:~# ping -c 3 10.10.3.2
PING 10.10.3.2 (10.10.3.2) 56(84) bytes of data.
64 bytes from 10.10.3.2: icmp_seq=1 ttl=64 time=21.5 ms
64 bytes from 10.10.3.2: icmp_seq=2 ttl=64 time=0.400 ms
64 bytes from 10.10.3.2: icmp_seq=3 ttl=64 time=0.384 ms
--- 10.10.3.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2026ms
rtt min/avg/max/mdev = 0.384/7.431/21.509/9.954 ms
```

Checking 10.10.9.1 on link C9

```
R3:~# ping -c 3 10.10.9.1
PING 10.10.9.1 (10.10.9.1) 56(84) bytes of data.
64 bytes from 10.10.9.1: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.9.1: icmp_seq=2 ttl=64 time=0.357 ms
64 bytes from 10.10.9.1: icmp_seq=3 ttl=64 time=0.375 ms
--- 10.10.9.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2024ms
rtt min/avg/max/mdev = 0.357/7.108/20.592/9.534 ms
```

R4

Checking 10.10.3.1 on link C3

```
R4:~# ping -c 3 10.10.3.1
PING 10.10.3.1 (10.10.3.1) 56(84) bytes of data.
64 bytes from 10.10.3.1: icmp_seq=1 ttl=64 time=20.6 ms
64 bytes from 10.10.3.1: icmp_seq=2 ttl=64 time=0.354 ms
64 bytes from 10.10.3.1: icmp_seq=3 ttl=64 time=0.414 ms

--- 10.10.3.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2024ms
rtt min/avg/max/mdev = 0.354/7.125/20.607/9.533 ms
```

Checking 10.10.4.2 on link C4

```
R4:~# ping -c 3 10.10.4.2
PING 10.10.4.2 (10.10.4.2) 56(84) bytes of data.
64 bytes from 10.10.4.2: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.4.2: icmp_seq=2 ttl=64 time=0.492 ms
64 bytes from 10.10.4.2: icmp_seq=3 ttl=64 time=1.22 ms

--- 10.10.4.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2024ms
rtt min/avg/max/mdev = 0.492/7.427/20.568/9.296 ms
```

R5

Checking 10.10.6.1 on link C6
R5:~# ping -c 3 10.10.6.1
PING 10.10.6.1 (10.10.6.1) 56(84) bytes of data.
64 bytes from 10.10.6.1: icmp_seq=1 ttl=64 time=21.1 ms
64 bytes from 10.10.6.1: icmp_seq=2 ttl=64 time=1.48 ms
64 bytes from 10.10.6.1: icmp_seq=3 ttl=64 time=1.16 ms

--- 10.10.6.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2015ms
rtt min/avg/max/mdev = 1.163/7.920/21.108/9.326 ms

Checking 10.10.4.1 on link C4
R5:~# ping -c 3 10.10.4.1
PING 10.10.4.1 (10.10.4.1) 56(84) bytes of data.
64 bytes from 10.10.4.1: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.4.1: icmp_seq=2 ttl=64 time=0.421 ms
64 bytes from 10.10.4.1: icmp_seq=3 ttl=64 time=1.18 ms

--- 10.10.4.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2025ms
rtt min/avg/max/mdev = 0.421/7.394/20.578/9.327 ms

Checking 10.10.5.2 on link C5
R5:~# ping -c 3 10.10.5.2
PING 10.10.5.2 (10.10.5.2) 56(84) bytes of data.
64 bytes from 10.10.5.2: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.5.2: icmp_seq=2 ttl=64 time=0.352 ms
64 bytes from 10.10.5.2: icmp_seq=3 ttl=64 time=0.416 ms
--- 10.10.5.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2015ms
rtt min/avg/max/mdev = 0.352/7.111/20.567/9.514 ms

Checking 10.10.8.1 on link C8
R5:~# ping -c 3 10.10.8.1
PING 10.10.8.1 (10.10.8.1) 56(84) bytes of data.
64 bytes from 10.10.8.1: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.8.1: icmp_seq=2 ttl=64 time=0.334 ms
64 bytes from 10.10.8.1: icmp_seq=3 ttl=64 time=0.409 ms
--- 10.10.8.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2026ms
rtt min/avg/max/mdev = 0.334/7.112/20.593/9.532 ms

R6

Checking 10.10.5.1 on link C5
R6:~# ping -c 3 10.10.5.1
PING 10.10.5.1 (10.10.5.1) 56(84) bytes of data.
64 bytes from 10.10.5.1: icmp_seq=1 ttl=64 time=1.33 ms
64 bytes from 10.10.5.1: icmp_seq=2 ttl=64 time=1.23 ms
64 bytes from 10.10.5.1: icmp_seq=3 ttl=64 time=1.23 ms

--- 10.10.5.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2012ms
rtt min/avg/max/mdev = 1.232/1.268/1.336/0.048 ms

Checking 10.10.7.1 on link C7
R6:~# ping -c 3 10.10.7.1
PING 10.10.7.1 (10.10.7.1) 56(84) bytes of data.
64 bytes from 10.10.7.1: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.7.1: icmp_seq=2 ttl=64 time=1.19 ms
64 bytes from 10.10.7.1: icmp_seq=3 ttl=64 time=0.395 ms

--- 10.10.7.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2026ms
rtt min/avg/max/mdev = 0.395/7.388/20.577/9.331 ms

Checking 10.10.6.2 on link C6
R7:~# ping -c 3 10.10.6.2
PING 10.10.6.2 (10.10.6.2) 56(84) bytes of data.
64 bytes from 10.10.6.2: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.6.2: icmp_seq=2 ttl=64 time=0.322 ms
64 bytes from 10.10.6.2: icmp_seq=3 ttl=64 time=1.22 ms

--- 10.10.6.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2015ms
rtt min/avg/max/mdev = 0.322/7.371/20.564/9.336 ms

IPV6 PING Tests between Routers

R1
C1
```
R1:~# ping6 -c 3 2404:2000:2002:101::2
PING 2404:2000:2002:101::2(2404:2000:2002:101::2) 56 data bytes
64 bytes from 2404:2000:2002:101::2: icmp_seq=1 ttl=64 time=21.6 ms
64 bytes from 2404:2000:2002:101::2: icmp_seq=2 ttl=64 time=0.450 ms
64 bytes from 2404:2000:2002:101::2: icmp_seq=3 ttl=64 time=0.395 ms

--- 2404:2000:2002:101::2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2015ms
rtt min/avg/max/mdev = 0.395/7.510/21.687/10.024 ms
```

C2
```
R1:~# ping6 -c 3 2404:2000:2002:102::2
PING 2404:2000:2002:102::2(2404:2000:2002:102::2) 56 data bytes
64 bytes from 2404:2000:2002:102::2: icmp_seq=1 ttl=64 time=21.8 ms
64 bytes from 2404:2000:2002:102::2: icmp_seq=2 ttl=64 time=1.01 ms
64 bytes from 2404:2000:2002:102::2: icmp_seq=3 ttl=64 time=1.05 ms

--- 2404:2000:2002:102::2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2016ms
rtt min/avg/max/mdev = 1.013/7.957/21.803/9.790 ms
```

R2
C1
```
R2:~# ping6 -c 3 2404:2000:2002:101::1
PING 2404:2000:2002:101::1(2404:2000:2002:101::1) 56 data bytes
64 bytes from 2404:2000:2002:101::1: icmp_seq=1 ttl=64 time=21.6 ms
64 bytes from 2404:2000:2002:101::1: icmp_seq=2 ttl=64 time=0.497 ms
64 bytes from 2404:2000:2002:101::1: icmp_seq=3 ttl=64 time=0.326 ms

--- 2404:2000:2002:101::1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2025ms
rtt min/avg/max/mdev = 0.326/7.491/21.651/10.012 ms
```

C8
```
R2:~# ping6 -c 3 2404:2000:2002:108::2
PING 2404:2000:2002:108::2(2404:2000:2002:108::2) 56 data bytes
64 bytes from 2404:2000:2002:108::2: icmp_seq=1 ttl=64 time=21.5 ms
64 bytes from 2404:2000:2002:108::2: icmp_seq=2 ttl=64 time=0.293 ms
64 bytes from 2404:2000:2002:108::2: icmp_seq=3 ttl=64 time=0.346 ms

--- 2404:2000:2002:108::2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2015ms
rtt min/avg/max/mdev = 0.293/7.402/21.568/10.016 ms
```
C9
```
R2:~# ping6 -c 3 2404:2000:2002:109::2
```

PING 2404:2000:2002:109::2(2404:2000:2002:109::2) 56 data bytes
64 bytes from 2404:2000:2002:109::2: icmp_seq=1 ttl=64 time=21.7 ms
64 bytes from 2404:2000:2002:109::2: icmp_seq=2 ttl=64 time=0.405 ms
64 bytes from 2404:2000:2002:109::2: icmp_seq=3 ttl=64 time=1.41 ms

--- 2404:2000:2002:109::2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2025ms
rtt min/avg/max/mdev = 0.405/7.868/21.791/9.853 ms

R3

C7
R3:~# ping6 -c 3 2404:2000:2002:107::2
PING 2404:2000:2002:107::2(2404:2000:2002:107::2) 56 data bytes
64 bytes from 2404:2000:2002:107::2: icmp_seq=1 ttl=64 time=21.4 ms
64 bytes from 2404:2000:2002:107::2: icmp_seq=2 ttl=64 time=0.396 ms
64 bytes from 2404:2000:2002:107::2: icmp_seq=3 ttl=64 time=0.331 ms

--- 2404:2000:2002:107::2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2025ms
rtt min/avg/max/mdev = 0.331/7.382/21.421/9.927 ms

C2
R3:~# ping6 -c 3 2404:2000:2002:102::1
PING 2404:2000:2002:102::1(2404:2000:2002:102::1) 56 data bytes
64 bytes from 2404:2000:2002:102::1: icmp_seq=1 ttl=64 time=21.6 ms
64 bytes from 2404:2000:2002:102::1: icmp_seq=2 ttl=64 time=0.997 ms
64 bytes from 2404:2000:2002:102::1: icmp_seq=3 ttl=64 time=0.337 ms

--- 2404:2000:2002:102::1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2015ms
rtt min/avg/max/mdev = 0.337/7.656/21.636/9.889 ms

C3
R3:~# ping6 -c 3 2404:2000:2002:103::2
PING 2404:2000:2002:103::2(2404:2000:2002:103::2) 56 data bytes
64 bytes from 2404:2000:2002:103::2: icmp_seq=1 ttl=64 time=21.9 ms
64 bytes from 2404:2000:2002:103::2: icmp_seq=2 ttl=64 time=0.439 ms
64 bytes from 2404:2000:2002:103::2: icmp_seq=3 ttl=64 time=0.531 ms

--- 2404:2000:2002:103::2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2016ms
rtt min/avg/max/mdev = 0.439/7.653/21.990/10.137 ms

C9
R3:~# ping6 -c 3 2404:2000:2002:109::1

PING 2404:2000:2002:109::1(2404:2000:2002:109::1) 56 data bytes
64 bytes from 2404:2000:2002:109::1: icmp_seq=1 ttl=64 time=21.8 ms
64 bytes from 2404:2000:2002:109::1: icmp_seq=2 ttl=64 time=1.10 ms
64 bytes from 2404:2000:2002:109::1: icmp_seq=3 ttl=64 time=0.811 ms

--- 2404:2000:2002:109::1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2026ms
rtt min/avg/max/mdev = 0.811/7.937/21.897/9.871 ms

R4

C3
R4:~# ping6 -c 3 2404:2000:2002:103::1
PING 2404:2000:2002:103::1(2404:2000:2002:103::1) 56 data bytes
64 bytes from 2404:2000:2002:103::1: icmp_seq=1 ttl=64 time=1.09 ms
64 bytes from 2404:2000:2002:103::1: icmp_seq=2 ttl=64 time=0.278 ms
64 bytes from 2404:2000:2002:103::1: icmp_seq=3 ttl=64 time=1.07 ms

--- 2404:2000:2002:103::1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2000ms
rtt min/avg/max/mdev = 0.278/0.812/1.090/0.379 ms

C4
R4:~# ping6 -c 3 2404:2000:2002:104::2
PING 2404:2000:2002:104::2(2404:2000:2002:104::2) 56 data bytes
64 bytes from 2404:2000:2002:104::2: icmp_seq=1 ttl=64 time=21.7 ms
64 bytes from 2404:2000:2002:104::2: icmp_seq=2 ttl=64 time=0.362 ms
64 bytes from 2404:2000:2002:104::2: icmp_seq=3 ttl=64 time=1.38 ms

--- 2404:2000:2002:104::2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2025ms
rtt min/avg/max/mdev = 0.362/7.831/21.747/9.848 ms

R5

C6
R5:~# ping6 -c 3 2404:2000:2002:106::1
PING 2404:2000:2002:106::1(2404:2000:2002:106::1) 56 data bytes
64 bytes from 2404:2000:2002:106::1: icmp_seq=1 ttl=64 time=21.4 ms
64 bytes from 2404:2000:2002:106::1: icmp_seq=2 ttl=64 time=1.45 ms
64 bytes from 2404:2000:2002:106::1: icmp_seq=3 ttl=64 time=0.338 ms

--- 2404:2000:2002:106::1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2016ms
rtt min/avg/max/mdev = 0.338/7.731/21.401/9.676 ms
C4
R5:~# ping6 -c 3 2404:2000:2002:104::1

PING 2404:2000:2002:104::1(2404:2000:2002:104::1) 56 data bytes
64 bytes from 2404:2000:2002:104::1: icmp_seq=1 ttl=64 time=20.6 ms
64 bytes from 2404:2000:2002:104::1: icmp_seq=2 ttl=64 time=0.334 ms
64 bytes from 2404:2000:2002:104::1: icmp_seq=3 ttl=64 time=0.968 ms

--- 2404:2000:2002:104::1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2024ms
rtt min/avg/max/mdev = 0.334/7.311/20.633/9.423 ms

C5
R5:~# ping6 -c 3 2404:2000:2002:105::2
PING 2404:2000:2002:105::2(2404:2000:2002:105::2) 56 data bytes
64 bytes from 2404:2000:2002:105::2: icmp_seq=1 ttl=64 time=21.9 ms
64 bytes from 2404:2000:2002:105::2: icmp_seq=2 ttl=64 time=0.427 ms
64 bytes from 2404:2000:2002:105::2: icmp_seq=3 ttl=64 time=0.367 ms

--- 2404:2000:2002:105::2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2025ms
rtt min/avg/max/mdev = 0.367/7.566/21.906/10.139 ms
C8
R5:~# ping6 -c 3 2404:2000:2002:108::1
PING 2404:2000:2002:108::1(2404:2000:2002:108::1) 56 data bytes
64 bytes from 2404:2000:2002:108::1: icmp_seq=1 ttl=64 time=21.9 ms
64 bytes from 2404:2000:2002:108::1: icmp_seq=2 ttl=64 time=0.404 ms
64 bytes from 2404:2000:2002:108::1: icmp_seq=3 ttl=64 time=0.348 ms

--- 2404:2000:2002:108::1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2015ms
rtt min/avg/max/mdev = 0.348/7.573/21.968/10.178 ms

R6

C5
R6:~# ping6 -c 3 2404:2000:2002:105::1
PING 2404:2000:2002:105::1(2404:2000:2002:105::1) 56 data bytes
64 bytes from 2404:2000:2002:105::1: icmp_seq=1 ttl=64 time=21.8 ms
64 bytes from 2404:2000:2002:105::1: icmp_seq=2 ttl=64 time=0.383 ms
64 bytes from 2404:2000:2002:105::1: icmp_seq=3 ttl=64 time=0.349 ms

--- 2404:2000:2002:105::1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2025ms
rtt min/avg/max/mdev = 0.349/7.515/21.813/10.110 ms

C7
R6:~# ping6 -c 3 2404:2000:2002:107::1

PING 2404:2000:2002:107::1(2404:2000:2002:107::1) 56 data bytes
64 bytes from 2404:2000:2002:107::1: icmp_seq=1 ttl=64 time=21.3 ms
64 bytes from 2404:2000:2002:107::1: icmp_seq=2 ttl=64 time=0.393 ms
64 bytes from 2404:2000:2002:107::1: icmp_seq=3 ttl=64 time=0.412 ms

--- 2404:2000:2002:107::1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2024ms
rtt min/avg/max/mdev = 0.393/7.399/21.392/9.894 ms

R7

C6
R7:~# ping6 -c 3 2404:2000:2002:106::2
PING 2404:2000:2002:106::2(2404:2000:2002:106::2) 56 data bytes
64 bytes from 2404:2000:2002:106::2: icmp_seq=1 ttl=64 time=21.8 ms
64 bytes from 2404:2000:2002:106::2: icmp_seq=2 ttl=64 time=1.23 ms
64 bytes from 2404:2000:2002:106::2: icmp_seq=3 ttl=64 time=0.381 ms

--- 2404:2000:2002:106::2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2026ms
rtt min/avg/max/mdev = 0.381/7.812/21.826/9.915 ms

Appendix 5 PING Between Hosts and Routers

R1 to M1
IPv4
R1:~# ping -c 3 10.10.10.2
PING 10.10.10.2 (10.10.10.2) 56(84) bytes of data.
64 bytes from 10.10.10.2: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.10.2: icmp_seq=2 ttl=64 time=0.354 ms
64 bytes from 10.10.10.2: icmp_seq=3 ttl=64 time=0.781 ms

--- 10.10.10.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2016ms
rtt min/avg/max/mdev = 0.354/7.242/20.593/9.442 ms
IPv6
R1:~# ping6 -c 3 2404:2000:2002:110::2
PING 2404:2000:2002:110::2(2404:2000:2002:110::2) 56 data bytes
64 bytes from 2404:2000:2002:110::2: icmp_seq=1 ttl=64 time=21.3 ms
64 bytes from 2404:2000:2002:110::2: icmp_seq=2 ttl=64 time=0.317 ms
64 bytes from 2404:2000:2002:110::2: icmp_seq=3 ttl=64 time=0.761 ms

--- 2404:2000:2002:110::2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2015ms
rtt min/avg/max/mdev = 0.317/7.470/21.333/9.804 ms

M1 to R1
IPv4

```
m1:~# ping -c 3 10.10.10.1
PING 10.10.10.1 (10.10.10.1) 56(84) bytes of data.
64 bytes from 10.10.10.1: icmp_seq=1 ttl=64 time=0.334 ms
64 bytes from 10.10.10.1: icmp_seq=2 ttl=64 time=0.359 ms
64 bytes from 10.10.10.1: icmp_seq=3 ttl=64 time=0.350 ms

--- 10.10.10.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2004ms
rtt min/avg/max/mdev = 0.334/0.347/0.359/0.023 ms
```

IPv6

```
m1:~# ping6 -c 3 2404:2000:2002:110::1
PING 2404:2000:2002:110::1(2404:2000:2002:110::1) 56 data bytes
64 bytes from 2404:2000:2002:110::1: icmp_seq=1 ttl=64 time=21.5 ms
64 bytes from 2404:2000:2002:110::1: icmp_seq=2 ttl=64 time=0.356 ms
64 bytes from 2404:2000:2002:110::1: icmp_seq=3 ttl=64 time=0.768 ms

--- 2404:2000:2002:110::1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2015ms
rtt min/avg/max/mdev = 0.356/7.555/21.541/9.891 ms
```

R1 to M2

IPv4

```
R1:~# ping -c 3 10.10.11.2
PING 10.10.11.2 (10.10.11.2) 56(84) bytes of data.
64 bytes from 10.10.11.2: icmp_seq=1 ttl=64 time=15.2 ms
64 bytes from 10.10.11.2: icmp_seq=2 ttl=64 time=0.839 ms
64 bytes from 10.10.11.2: icmp_seq=3 ttl=64 time=0.321 ms

--- 10.10.11.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2019ms
rtt min/avg/max/mdev = 0.321/5.466/15.239/6.913 ms
```

IPv6

```
R1:~# ping6 -c 3 2404:2000:2002:111::2
PING 2404:2000:2002:111::2(2404:2000:2002:111::2) 56 data bytes
64 bytes from 2404:2000:2002:111::2: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 2404:2000:2002:111::2: icmp_seq=2 ttl=64 time=0.357 ms
64 bytes from 2404:2000:2002:111::2: icmp_seq=3 ttl=64 time=0.945 ms

--- 2404:2000:2002:111::2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2015ms
rtt min/avg/max/mdev = 0.357/7.292/20.574/9.394 ms
```

M2 to R1
IPv4
m2:~# ping -c 3 10.10.11.1
PING 10.10.11.1 (10.10.11.1) 56(84) bytes of data.
64 bytes from 10.10.11.1: icmp_seq=1 ttl=64 time=21.2 ms
64 bytes from 10.10.11.1: icmp_seq=2 ttl=64 time=0.759 ms
64 bytes from 10.10.11.1: icmp_seq=3 ttl=64 time=0.800 ms

--- 10.10.11.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2016ms
rtt min/avg/max/mdev = 0.759/7.613/21.281/9.664 ms

IPv6
m2:~# ping6 -c 3 2404:2000:2002:111::1
PING 2404:2000:2002:111::1(2404:2000:2002:111::1) 56 data bytes
64 bytes from 2404:2000:2002:111::1: icmp_seq=1 ttl=64 time=20.9 ms
64 bytes from 2404:2000:2002:111::1: icmp_seq=2 ttl=64 time=0.239 ms
64 bytes from 2404:2000:2002:111::1: icmp_seq=3 ttl=64 time=0.235 ms

--- 2404:2000:2002:111::1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2015ms
rtt min/avg/max/mdev = 0.235/7.130/20.916/9.748 ms

R4 to M3
IPv4
R4:~# ping -c 3 10.10.12.2
PING 10.10.12.2 (10.10.12.2) 56(84) bytes of data.
64 bytes from 10.10.12.2: icmp_seq=1 ttl=64 time=0.424 ms
64 bytes from 10.10.12.2: icmp_seq=2 ttl=64 time=0.271 ms
64 bytes from 10.10.12.2: icmp_seq=3 ttl=64 time=0.783 ms

--- 10.10.12.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2002ms
rtt min/avg/max/mdev = 0.271/0.492/0.783/0.216 ms

IPv6
R4:~# ping6 -c 3 2404:2000:2002:112::2
PING 2404:2000:2002:112::2(2404:2000:2002:112::2) 56 data bytes
64 bytes from 2404:2000:2002:112::2: icmp_seq=1 ttl=64 time=21.2 ms
64 bytes from 2404:2000:2002:112::2: icmp_seq=2 ttl=64 time=0.330 ms
64 bytes from 2404:2000:2002:112::2: icmp_seq=3 ttl=64 time=0.354 ms

--- 2404:2000:2002:112::2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2025ms
rtt min/avg/max/mdev = 0.330/7.321/21.281/9.871 ms

M3 to R4

IPv4

```
m3:~# ping -c 3 10.10.12.1
PING 10.10.12.1 (10.10.12.1) 56(84) bytes of data.
64 bytes from 10.10.12.1: icmp_seq=1 ttl=64 time=0.344 ms
64 bytes from 10.10.12.1: icmp_seq=2 ttl=64 time=0.265 ms
64 bytes from 10.10.12.1: icmp_seq=3 ttl=64 time=0.873 ms

--- 10.10.12.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2000ms
rtt min/avg/max/mdev = 0.265/0.494/0.873/0.269 ms
```

IPv6

```
m3:~# ping6 -c 3 2404:2000:2002:112::1
PING 2404:2000:2002:112::1(2404:2000:2002:112::1) 56 data bytes
64 bytes from 2404:2000:2002:112::1: icmp_seq=1 ttl=64 time=21.4 ms
64 bytes from 2404:2000:2002:112::1: icmp_seq=2 ttl=64 time=0.434 ms
64 bytes from 2404:2000:2002:112::1: icmp_seq=3 ttl=64 time=0.364 ms

--- 2404:2000:2002:112::1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2025ms
rtt min/avg/max/mdev = 0.364/7.406/21.422/9.910 ms
```

R4 to M4

IPv4

```
R4:~# ping -c 3 10.10.13.2
PING 10.10.13.2 (10.10.13.2) 56(84) bytes of data.
64 bytes from 10.10.13.2: icmp_seq=1 ttl=64 time=20.5 ms
64 bytes from 10.10.13.2: icmp_seq=2 ttl=64 time=0.328 ms
64 bytes from 10.10.13.2: icmp_seq=3 ttl=64 time=0.822 ms

--- 10.10.13.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2025ms
rtt min/avg/max/mdev = 0.328/7.235/20.556/9.421 ms
```

IPv6

```
R4:~# ping6 -c 3 2404:2000:2002:113::2
PING 2404:2000:2002:113::2(2404:2000:2002:113::2) 56 data bytes
64 bytes from 2404:2000:2002:113::2: icmp_seq=1 ttl=64 time=21.3 ms
64 bytes from 2404:2000:2002:113::2: icmp_seq=2 ttl=64 time=0.851 ms
64 bytes from 2404:2000:2002:113::2: icmp_seq=3 ttl=64 time=0.384 ms

--- 2404:2000:2002:113::2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2016ms
rtt min/avg/max/mdev = 0.384/7.530/21.355/9.777 ms
```

M4 to R4

IPv4

```
m4:~# ping -c 3 10.10.13.1
PING 10.10.13.1 (10.10.13.1) 56(84) bytes of data.
64 bytes from 10.10.13.1: icmp_seq=1 ttl=64 time=16.3 ms
64 bytes from 10.10.13.1: icmp_seq=2 ttl=64 time=0.344 ms
64 bytes from 10.10.13.1: icmp_seq=3 ttl=64 time=0.908 ms

--- 10.10.13.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2019ms
rtt min/avg/max/mdev = 0.344/5.877/16.381/7.431 ms
```

IPv6

```
m4:~# ping6 -c 3 2404:2000:2002:113::1
PING 2404:2000:2002:113::1(2404:2000:2002:113::1) 56 data bytes
64 bytes from 2404:2000:2002:113::1: icmp_seq=1 ttl=64 time=20.9 ms
64 bytes from 2404:2000:2002:113::1: icmp_seq=2 ttl=64 time=0.322 ms
64 bytes from 2404:2000:2002:113::1: icmp_seq=3 ttl=64 time=0.365 ms

--- 2404:2000:2002:113::1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2024ms
rtt min/avg/max/mdev = 0.322/7.197/20.906/9.693 ms
```

Appendix 6 - Static Routing

IPv4

```
R2:~# ping -c 3 10.10.7.2
PING 10.10.11.2 (10.10.11.2) 56(84) bytes of data.
64 bytes from 10.10.11.2: icmp_seq=1 ttl=63 time=33.1 ms
64 bytes from 10.10.11.2: icmp_seq=2 ttl=63 time=0.572 ms
64 bytes from 10.10.11.2: icmp_seq=3 ttl=63 time=1.28 ms
```

Appendix 7 - Traceroute across network OSPF IPv4 and IPv6

M4 to M2

```
m4:~# traceroute  -n 10.10.11.2
traceroute to 10.10.11.2 (10.10.11.2), 30 hops max, 40 byte packets
 1  10.10.13.1  2.436 ms  2.251 ms  2.076 ms
 2  10.10.3.1  1.889 ms  1.714 ms  1.538 ms
 3  10.10.2.1  4.706 ms  5.894 ms  9.062 ms
 4  10.10.11.2  10.364 ms  12.120 ms  12.171 ms

m4:~# traceroute  -n 2404:2000:2002:111::2
traceroute to 2404:2000:2002:111::2 (2404:2000:2002:111::2), 30 hops max, 40 byte
packets
 1  2404:2000:2002:113::1  1.380 ms  1.225 ms  1.048 ms
 2  2404:2000:2002:103::1  2.100 ms  1.923 ms  1.709 ms
 3  2404:2000:2002:102::1  1.476 ms  2.861 ms  4.748 ms
 4  2404:2000:2002:111::2  10.805 ms  10.665 ms  11.141 ms
```

M4 to M2 C2 **cable removed**

```
m4:~# traceroute  -n 10.10.11.2
traceroute to 10.10.11.2 (10.10.11.2), 30 hops max, 40 byte packets
 1  10.10.13.1  1.065 ms  0.744 ms  0.616 ms
 2  10.10.4.2  0.595 ms  0.372 ms  1.858 ms
 3  10.10.8.1  1.655 ms  1.523 ms  1.332 ms
 4  10.10.1.1  0.756 ms  3.986 ms  4.018 ms
 5  10.10.11.2  4.513 ms  5.332 ms  6.465 ms

m4:~# traceroute  -n 2404:2000:2002:111::2
traceroute to 2404:2000:2002:111::2 (2404:2000:2002:111::2), 30 hops max, 40 byte
packets
 1  2404:2000:2002:113::1  1.081 ms  0.215 ms  0.205 ms
 2  2404:2000:2002:104::2  0.583 ms  0.584 ms  3.711 ms
 3  2404:2000:2002:108::1  3.477 ms  3.229 ms  4.915 ms
 4  2404:2000:2002:101::1  6.036 ms  9.767 ms  7.889 ms
 5  2404:2000:2002:111::2  9.507 ms  12.228 ms  13.365 ms
```

Appendix 8 - OSPF Routing table for R3

```
Router# sh ip ospf route

============ OSPF network routing table ============
N        10.10.1.0/24        [20] area: 0.0.0.0
                   via 10.10.9.1, eth3
                   via 10.10.2.1, eth1
N        10.10.2.0/24       [10] area: 0.0.0.0
                   directly attached to eth1
N        10.10.3.0/24       [10] area: 0.0.0.0
                   directly attached to eth2
N        10.10.4.0/24       [20] area: 0.0.0.0
                   via 10.10.3.2, eth2
N        10.10.5.0/24       [20] area: 0.0.0.0
                   via 10.10.7.2, eth0
N        10.10.6.0/24       [30] area: 0.0.0.0
                   via 10.10.7.2, eth0
                   via 10.10.3.2, eth2
                   via 10.10.9.1, eth3
N        10.10.7.0/24       [10] area: 0.0.0.0
                   directly attached to eth0
N        10.10.8.0/24       [20] area: 0.0.0.0
                   via 10.10.9.1, eth3
N        10.10.9.0/24       [10] area: 0.0.0.0
                   directly attached to eth3
N        10.10.10.0/24              [20] area: 0.0.0.0
                  via 10.10.2.1, eth1
N        10.10.11.0/24              [20] area: 0.0.0.0
                   via 10.10.2.1, eth1
N        10.10.12.0/24              [20] area: 0.0.0.0
                   via 10.10.3.2, eth2
N        10.10.13.0/24        [20] area: 0.0.0.0
                   via 10.10.3.2, eth2
============ OSPF router routing table =============
R        10.10.6.1          [30] area: 0.0.0.0, ASBR
                   via 10.10.7.2, eth0
                   via 10.10.3.2, eth2
                   via 10.10.9.1, eth3
R        10.10.7.2          [10] area: 0.0.0.0, ASBR
                   via 10.10.7.2, eth0
R        10.10.8.2          [20] area: 0.0.0.0, ASBR
                   via 10.10.7.2, eth0
                   via 10.10.3.2, eth2
                   via 10.10.9.1, eth3
R        10.10.9.1          [10] area: 0.0.0.0, ASBR
                   via 10.10.9.1, eth3
R        10.10.11.1         [10] area: 0.0.0.0, ASBR
                   via 10.10.2.1, eth1
R        10.10.12.1         [10] area: 0.0.0.0, ASBR
                   via 10.10.3.2, eth2
 ============ OSPF external routing table ===========
N E2 172.23.0.0/16         [10/20] tag: 0
                  via 10.10.7.2, eth0
                   via 10.10.9.1, eth3
                   via 10.10.2.1, eth1
                   via 10.10.3.2, eth2
```

Appendix 9 - OSPF Routing table for R3 with C2 disconnected

Router# sh ip ospf route

```
============ OSPF network routing table ============
N        10.10.1.0/24      [20] area: 0.0.0.0
                   via 10.10.9.1, eth3
N        10.10.2.0/24      [10] area: 0.0.0.0
                   directly attached to eth1
N        10.10.3.0/24        [10] area: 0.0.0.0
                   directly attached to eth2
N        10.10.4.0/24      [20] area: 0.0.0.0
                   via 10.10.3.2, eth2
N        10.10.5.0/24      [20] area: 0.0.0.0
                   via 10.10.7.2, eth0
N        10.10.6.0/24      [30] area: 0.0.0.0
                   via 10.10.7.2, eth0
                   via 10.10.3.2, eth2
                   via 10.10.9.1, eth3
N        10.10.7.0/24      [10] area: 0.0.0.0
                    directly attached to eth0
N        10.10.8.0/24      [20] area: 0.0.0.0
                   via 10.10.9.1, eth3
N        10.10.9.0/24      [10] area: 0.0.0.0
                   directly attached to eth3
N        10.10.10.0/24       [30] area: 0.0.0.0
                   via 10.10.9.1, eth3
N        10.10.11.0/24             [30] area: 0.0.0.0
                   via 10.10.9.1, eth3
N        10.10.12.0/24             [20] area: 0.0.0.0
                   via 10.10.3.2, eth2
N        10.10.13.0/24             [20] area: 0.0.0.0
                   via 10.10.3.2, eth2

============ OSPF router routing table =============
R        10.10.6.1         [30] area: 0.0.0.0, ASBR
                   via 10.10.7.2, eth0
                     via 10.10.3.2, eth2
                   via 10.10.9.1, eth3
R        10.10.7.2         [10] area: 0.0.0.0, ASBR
                   via 10.10.7.2, eth0
R        10.10.8.2         [20] area: 0.0.0.0, ASBR
                      via 10.10.7.2, eth0
                   via 10.10.3.2, eth2
                   via 10.10.9.1, eth3
R        10.10.9.1         [10] area: 0.0.0.0, ASBR
                   via 10.10.9.1, eth3
R        10.10.11.1        [20] area: 0.0.0.0, ASBR
                   via 10.10.9.1, eth3
R        10.10.12.1        [10] area: 0.0.0.0, ASBR
                   via 10.10.3.2, eth2
```