Exercise 4
MPLS router configuration

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Preliminary note

For this exercise you have to use the virtual routing environment prepared in the virtual machine that can be downloaded from the netgroup cloud. Follow the GNS3 VM instructions before proceeding.

http://netgroup.polito.it/teaching/cnts/Instruction.pdf

1 Network topology and base configuration

It is suggested that the network topology in Figure 1 is used; it can be recreated with the GNS3 interface.

In the network at least two routers shall be customer edge (CE) routers, (R0 and R5 in the suggested topology in Figure 1), i.e., not deploying MPLS, but connected to an MPLS network. At least two routers shall be forwarding labeled packets on at least 2 of their interfaces (R2 and R3 in Figure 1). Finally, at least two provider edge (PE) routers shall connected to the CE routers and receive plain IP packets on one interface and forward them with an MPLS label on another interface (R1 and R4 in the suggested topology in Figure 1).

1.1 Addressing

As a prerequisite for the network to work, an addressing plan shall be designed and addresses (IPv4 or IPv6, according to personal preference) assigned to all router interfaces. In the case of IPv4 routing, this can be done using the interface level command

```
ip address address netmask
```

In order to better differentiate between information related to the MPLS network and information related to the peripheral networks (representing ”customers” of a service provider operating the MPLS backbone), it is suggested that very different prefixes be used for the two parts of the network. For example, in an IPv4 network address plan, the prefix 10.0.0.0/8 could be used on the MPLS backbone, while prefixes 192.168.x.0/24 could be used for peripheral networks.
In order to have at least 2 destination networks that do not have anything to do with the MPLS backbone (i.e., do not include any "provider" node), it is suggested that the loopback interfaces of the CE routers (R0 and R5) are configured with the previously mentioned "customer" prefixes and used as traffic sources and destinations (e.g., in ping commands) when checking the operation of the network. The loopback interface is a special "virtual" interface (i.e., not actually corresponding to a port connected to a transmission medium) that once configured is always operational, i.e., usable for generating and receiving packets.

1.2 Enabling MPLS

In order for routers to deploy MPLS labels on an interface, the following interface level configuration command must be used:

mpls ip

For example, in R2 the command must be included in the configuration of the interface connecting it to R3, as well as the interface connecting it to R4.

Please note that in Cisco routers this will automatically activate LDP (Label Distribution Protocol) on the interface.

2 Dynamic configuration

Firstly, let’s configure LSRs to automatically figure out how to reach destinations, choose labels, and create their mappings in the forwarding table. In order for LSRs to be able to create bindings and mappings, they need to know how to reach destinations. This can be automatically done through routing protocols. It is suggested that the RIP routing protocol be used here for this purpose, as its configuration is straightforward.

On each of the routers the routing protocol should be activated by means of the following configuration commands:

router rip
network prefix
Where *prefix* is the natural prefix used on one or more of the router interfaces. The command is telling to the router to (i) announce *prefix* as one of the destinations it can reach as directly connected to it, and (ii) exchange RIP messages through each of the interfaces configured with an address beginning with *prefix*.

If more than one prefix is configured on the router interfaces, the `network` command shall be repeated. For example, if a router has the addresses 10.1.1.1/24, 10.2.2.1/24 and 192.168.4.1/24 on three of its interfaces, the RIP routing protocol can be configured as follows:

```
routing rip
network 10.0.0.0
network 192.168.4.0
```

Once the network is configured, test its operation, as explained in Section 3, by performing the following actions and carefully analyzing the obtained results:

1. Execute a `ping` between "customer" (i.e., non-MPLS) addresses.
2. Execute a `traceroute` between "customer" (i.e., non-MPLS) addresses.
3. Verify the routing table of at least one of the CE and one of the provider routers.
4. Verify the MPLS forwarding table of at least one PE (i.e., LER) router and at least two LSRs.
   (a) What is different in the table of an LSR and LER?
   (b) What is the relationship between the forwarding tables of the two LSRs?
5. Capture packets, generated with a `ping` or `traceroute` command, on at least a link between a CE and a PE (e.g., L4 in Figure 1) and a link between a PE and an internal router (e.g., L4 in Figure 1).
   (a) How do packets captured on each link differ?
   (b) How do MPLS labels seen on the link compare to the ones in the MPLS forwarding table?
6. Visualize the label mappings of at least one PE (i.e., LER) router and at least one LSR. Are there any differences? Why?
7. Capture LDP messages on some of the links and compare information found in those messages with the one found in the label binding information base in routers. Please note that in order to see label distribution interfaces might need to be taken down (interface level `shutdown` configuration command) and up again (interface level `no shutdown` configuration command).
8. Do packets forwarded from an internal LSR to an egress LSR (e.g., from R2 to R1 in Figure 1) have a label? Why? How is this reflected in the MPLS forwarding tables and label binding databases of the 2 routers?
3 Verification of proper operation

3.1 Traffic generation

One way to verify that the MPLS backbone is operating properly is to generate traffic between external networks, e.g., from R0 and R5 in Figure 1, using the ping and traceroute commands. It is suggested that the source option of the commands are used to ensure that packets are generated with the wanted interface address so that the backbone will be able to properly route back response packets. For example, ping 192.168.1.11 source 192.168.2.22 generates ICMP echo request packets to 192.168.1.11 from 192.168.2.22, which the target will respond to.

Please keep in mind that since routers in the MPLS backbone are able to forward plain IP packets, reachability (i.e., successful ping and traceroute execution) does not imply proper MPLS operation. Traffic must be observed in the MPLS backbone to make sure that packets are indeed forwarded using the technology.

3.2 Traffic observation

Traffic should be captured on both CE-PE links, where plain IP packets, without MPLS labels shall be expected, and on internal links, where MPLS headers and LDP messages can be observed.

Please notice that GNS3 can perform and visualize captures, however, MPLS headers and MPLS related protocols (such as LDP) are not properly interpreted. Hence, captures must be downloaded and visualized with an external packet analyzer, such as for example wireshark that can be freely downloaded. If admin privileges cannot be obtained, such as on the lab PCs, wireshark make sure to download the version that can be executed in user mode without installation.

3.3 Router information inspection

Gaining access to the data available to each LSR is key to troubleshoot a malfunctioning network or, as in our case, to fully understand the mechanisms underlying MPLS. The following commands can be useful to this purpose.

*show ip route* - visualize IP routing table; useful to understand what destinations (i.e., IP prefixes) a router is able to route packets to and the next hop it would forward packets to. Please note that having routing information is key for routers to be able to build their mapping in their forwarding table.

*show mpls forwarding-table* - visualize the forwarding table mapping input labels to output ports (and next hops) and output labels. It enables figuring out how the router will handle labeled packets and how it will possibly label packets that are received without label.

*show mpls ip binding* - visualize binding of labels to FECs (forward equivalence classes), which in this simple examples will be prefixes. It is useful to observe information used to build the forwarding table or ignored when building the forwarding table.

*show mpls ldp binding* - visualize binding information exchanged and received through LDP.
4 Dynamic label binding with static routing

After disabling RIP on each of the routers (with the general configuration command `no router rip`), observe whether the network is still working. Specifically, after wait several minutes to ensure that routers have removed all of the stale information on destinations learned while RIP was being used, go through the following steps.

1. Test reachability of external (“customer”) destinations.

2. Since they are not reachable, verify in routing tables that router in the MPLS backbone have no information on such destinations. Do they have bindings only for certain destinations?

3. Verify label binding information. Do routers have bindings? Why?

4. Check out the MPLS forwarding table. Is it empty? Why is that expected based on what you have observed so far?

At this point, starting from one of the CEs, configure a static route to one of the external destinations. In the case of IPv4 routers, this can be done with the global configuration command

`ip route address netmask next_hop`

For example, if the loopback interface of router R5 in Figure 1 was configured with the address 192.168.2.22, the following static route can be provided to R4:

`ip route 192.168.2.0 255.255.255.0 10.0.4.5`

assuming 10.0.4.5 is the address of R5 on link L4.

Capture LDP messages on some of the links while providing static routes and compare information found in those messages with the one found in the label binding information base in routers. When are label distribution messages triggered?

At this point repeat the steps listed above and notice how the information available to the router you have configured with the static route and to its neighbors has changed.

Add similar static routes to each of the other routers, one by one, repeating all the steps above after a static route is added to each router. Notice how information change. Remember to add routing information for both external destinations involved in the `ping` command; reachability will be restored only when all routers will have a route to both destinations.

Please note that in order for the network to properly operate, routers do not need to have routes for destinations within the MPLS network. For example, with the addressing solution suggested in Section 1.1, external destinations will be able to successfully reach each other even though provider routers do not have in their routing tables routes for 10.0.0.0/8 destinations (although they will anyway know how to reach the destinations directly connected to their interfaces).

5 Static label binding with static routing

In order to make sure we fully understand what information MPLS routers need to properly operate, we now manually provide each piece of such information by manually configuring label bindings.
First off, we need to disable label distribution with the general configuration command:

```
no mpls ldp advertise-labels
```

Please note that since routers might keep previous binding information, it might be necessary to restart the router (after having saved the configuration with the command `write`).

Part of the label space must be reserved for manually binding labels to FECs with the general configuration command

```
mpls label range min_dym max_dym static min_man max_man
```

For example, in order to reserve labels from 50 to 90 for manual (static) assignment, while keeping labels from 100 to 100000 for dynamic binding, we can include in the configuration

```
mpls label range 100 100000 static 50 90
```

Finally, we can create a static local binding with the general configuration command:

```
mpls static binding ipv4 address netmask label
```

where `label` is the label the router is expecting attached to incoming packets whose destination address has the prefix specified by the `address netmask` pair (i.e., FEC). For example,

```
mpls static binding ipv4 192.168.1.0 255.255.255.0 71
```

A remote binding, i.e., the binding expected by a neighbor, can be configured as

```
mpls static binding ipv4 address netmask output neighbor label
```

Where `neighbor` is a directly connected router that expects packets to the destination specified by the `address netmask` pair to arrive with label `label`. This implied that `neighbor` must have chosen `label` in its local binding for FEC `address netmask`.

For example,

```
mpls static binding ipv4 192.168.1.0 255.255.255.0 output 10.0.2.2 61
```

Please note that in order for a router to use a local binding and a remote binding to create a mapping in its MPLS forwarding table, the router must have a route indicating which neighbor should be used as a next hop for the destination. In the examples above, only if the router has a route that indicates 10.0.2.2 as the next hop for the destination 192.168.1.0 255.255.255.0, will it create a mapping between the input label 71, the output label 61 and the next hop 10.0.2.2.

The LSR that is supposed to perform penultimate hop popping, can be configured to know that a neighbor is expecting a null label using the special keyword `explicit-null`. For example,

```
mpls static binding ipv4 192.168.2.0 255.255.255.0 output 10.0.3.4 explicit-null
```

After configuring static bindings and static routers in each of the provider routers (i.e., R1, R2, R3, and R4 in Figure [1]) one at a time, carefully check out at each step

- routing table
- binding database
- MPLS forwarding table

on the configured router and the neighboring ones, noting how they are affected by the configuration, until the point in which the network is capable of forwarding packets among the external destinations.
5.1 Static mapping

As a last experiment to further our understanding and mastering of MPLS, we can manually configure the mappings in the forwarding tables for two internal LSRs (e.g., R3 and R2 in Figure 1), instead of letting them figure out their mappings based on the configured bindings and routes.

Static mappings can be manually created with the general configuration command

`mpls static crossconnect 62 FastEthernet0/1 10.0.2.3 72`

The label `explicit-null` can be used for an LSR that should perform penultimate hop popping.

Sample usages are

`mpls static crossconnect 62 FastEthernet0/1 10.0.2.3 72`
`mpls static crossconnect 61 FastEthernet0/0 10.0.1.1 explicit-null`

Specifically, starting from a blank configuration, we need to

1. Configure IP addresses on each interface
2. Activate MPLS forwarding
3. Disable LDP
4. Define a range for static labels
5. Create static mappings

Notice that no route are required for the LSR to operate.

As with previous experiences it is advised that traffic and router information (label binding database and forwarding table) are observed on a router and its neighbors after each static mapping (crossconnect) configuration command is provided.

Bibliography

Cisco Systems, ”MPLS static labels,”


Cisco Systems, ”MPLS Label Distribution Protocol (LDP),”