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COM-407: TCP/IP NETWORKING

LAB EXERCISES (TP) 1
INTRODUCTION TO MININET

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Abstract

In this TP you deploy a virtual machine that is pre-installed with Mininet, a virtualized environment used to emulate hosts, switches and routers that will be used throughout this course. You will perform basic network configuration tasks and learn to mount a man-in-the-middle attack. For a bonus, you will have the chance to evaluate how the performance of Mininet scales with the number of emulated hosts and routers.

1 OVERVIEW

Most of the labs of this course will run in a virtualized environment that can be installed directly on your own computer. With the virtualized environment, you will be able to operate a network with several hosts, routers, and other communication equipment, all in your own machine. This considerably simplifies the operation of the labs and may prove useful outside this course whenever you have to test a communication system.

The virtualized environment is an emulated[1] environment, i.e. the virtual hosts and routers run the same code as real physical hosts and routers; only their hardware is replaced by the virtualized environment.

The virtualized environment is mainly composed of the following items:

- A virtualization software, like VirtualBox, provides hardware emulation to support virtual routers and standard PCs. Version `5.1.4` was tested for compatibility with the lab, but versions `5.1.x` should all work.
- Next, we need to install the virtual machine in the virtual box. The virtual disk for the virtual machine is available on moodle.
- The virtual machine already has Mininet installed on it, Mininet provides emulation of networks and cables; it will be used to create network topologies.

[1] In contrast, a *simulated* environment such as ns3 replaces hosts and routers with simplified code.

2 VIRTUALBOX: INSTALLATION GUIDE

Download VirtualBox[2] and install it on your computer.

Download the compressed virtual HD image `TCPIPVM.zip` (the link is on Moodle).

IMPORTANT FOR WINDOWS USERS Please use Winrar to uncompress the image, as other uncompressing tools will corrupt it. Also, keep the compressed version stored locally to avoid re-downloading the file in case of issues later on.

NOTE The uncompressed image takes roughly 4GB (and may grow if you want to install additional packages). Thus, you will need about 5GB of free space on your hard drive for the TCP-IP labs.

2.1 YOUR FIRST VIRTUAL PC

We will first now create a virtual machine.

1. Launch the VirtualBox software.
2. Create a new virtual machine, set the name to `MininetVM`, the type to Linux, choose version Other 64bit (and press next).
3. Assign 1GB of RAM (press next).
4. Choose "use an existing virtual hard disk file" and pick the uncompressed file `TCPIPVM.vdi`.

After the machine is created, we will add two features to it. First, we will create a shared folder between the guest machine and the host machine. With this folder you can easily backup and transfer configuration scripts, snapshots and any file you might find useful during your labs. Second, we will enable the "copy to clipboard" functionality between your host machine and the guest machine, and between guest machines as well. Note that you must do these changes when the VM is not launched.

1. **For the shared folder:** In virtualbox go to the machine settings: (`Devices`→ `Shared Folders...`→ `Add`). Point the "Folder Path" to a folder of your choice on your host machine, and in the "Name" field write `share` [3]. Check the box `Auto-mount`.
2. **For the clipboard copy**: Go to the machine settings in `General`→ `Advanced` and set the shared clipboard to "Bidirectional".

Lastly, we will attach a "Host-only network" to the VM from your host machine. Before you can attach a VM to a host-only network you have to create at least one host-only interface. For this, goto "File" $->$ "Preferences" $->$ "Network" $->$ "Host-only network" $->$ "(+)Add host-only network". Next, in the virtual machine, go to machine settings: (`Network`→ `Adapter 2`). Enable the adapter by checking the box "Enable Network Adapter". Next, under the field "Attached to", choose "Host-only Adapter". Press "Ok" to finish.

Congratulations, you have just created a virtual machine!

[2] You can also use a different virtualization software but we will provide support and instructions only for VirtualBox.

[3] There is a link on the Desktop of the VM that doesn't work otherwise, so only change the name if you know what you are doing.

2.2 RUNNING THE VIRTUAL MACHINE

In VirtualBox select `MininetVM` and run it.

The virtual machine is configured to login automatically. In case you need to login again, the username is `lca2` with password `lca2`.

The virtual machine should already be connected to the Internet via the host's connection. Open the Firefox web browser and go to a webpage to check that you are indeed connected.

In case you have issues launching your virtual machine, you may need to activate hardware virtualization. To do this you need to access the `BIOS` menu of your computer. You might need to power off your computer after enabling this option (not just a simple reboot!).

If you have any issues at this point (no Internet connection, cannot launch VM, cannot copy paste, cannot access shared folder) that you cannot resolve yourself, contact a TA for help.

2.3 LINUX CRASH COURSE (OPTIONAL)

This section is meant to provide a brief introduction to Linux commands and best practices. Feel free to skip this section and go directly to Section 2.4, if you are familiar with Linux. Note, however, that these are the basic commands that you will need to be familiar with for all the remaining labs.

2.3.1 LINUX COMMANDS

The Linux distribution of the virtual machine comes with a friendly graphical interface. For configurating network interfaces however, we will use the terminal. Here are a few things you need to know:

Linux is a multi-user system that uses the Extended file system (e.g., ext2, ext3, ext4) to store files. In extfs each file has a unique owner (a user), belongs to a group of users, and has a set of permissions which define access rights to the file (read, write, and/or execute) for the owner, the group, and everyone else.

Each normal user has a home directory, that is referred to by the symbol ~ (tilde). To change directories in the terminal use the command `cd` followed by the name of the directory. This can be a relative name, such as `Documents/tcpip`, or an absolute name, such as `/etc/init.d` (i.e., beginning with the `/`, which is the root of the filesystem). It can also be the home directory (i.e., `cd ~`). To move up in the tree, i.e., out of a directory, use `cd ..` (two dots). The current directory is always represented by a single dot, so `cd .` does nothing. To display the current directory use `pwd` (print working directory).

Try it yourself: open a terminal [4]. Use `pwd` to show the current directory. Then `cd` to `~/Tutorial/`. Use the Tab key for auto-complete.

In the terminal, you can list the files in a directory by using the command `ls`. You can add switches to a command. For example, if you want to see detailed attributes of all the files in a directory (including the permissions), you can use the `-l` switch:

```
$ ls -l
```

You should see something like this:

[4] Tip: The shortcut to open a terminal is `Ctrl+Alt+T`.

```
lca2@TCPIP-VM:~/Tutorial$ ls -ls
total 4
0 -rw-rw-r-- 1 lca2 lca2   0 Aug 18 12:14 emptyFile.txt
4 -rw-rw-r-- 1 lca2 lca2 208 Aug 18 12:16 helloWorld.txt
```

You can output the contents of a file to the terminal by using commands such as `cat` or `less`:

```
$ cat helloWorld.txt
```

You can see above that the permissions of the `helloWorld.txt` file are `-rw-r--r--`, that it belongs to the user `lca2` and the group `lca2`, and that it is `208` bytes long. The permissions string is 10 characters long. The first character is either a dash `-` for regular files, or other letters for special files (a `d` for directories, etc.). The next three characters give the permissions for the owner of the file, in this case `rw-`. This means that the owner has the right to read the file (`r`), to write/modify the file (`w`), but not to execute the file. If the file was executable, in the third position there would be an `x`. The next three characters describe the permissions of the group, and the last three characters the permissions of all the other users in the system. In this case the file is read-only for the group and for everyone else.

A file that the user `lca2` does not want anyone to see but herself would have permissions `-rw-------`, whereas a file with full rights for everybody would have permissions `-rwxrwxrwx`.

A file's permissions can be changed by using the command `chmod`. You need to specify whose access rights to the file you want to alter: of the user who owns it (`u`), of the group (`g`), or of others (`o`), whether you want to add (`+`), or remove (`-`) a right, and which right you mean (`r`, `w`, or `x`).

For example,

```
$ chmod o-r,g+w emptyFile.txt
```

removes the reading right for other users than the owner or the group and adds writing for the group. To change the ownership of the file, use `chown`.

When you issue a command in the terminal, you are in fact running a certain executable file. The command interpreter (or the shell) looks for these executable files in one of the several directories specified in the `PATH` environment variable. To list the contents of this variable, run

```
$ echo $PATH
```

The character `$` indicates that we want to display the contents of the variable `PATH`; without it, the command would simply display the string `PATH`. The directories are separated by semicolons, and they are searched in order. To see which executable you are running, use the command `which` followed by the name of the executable. For example, `which ls` displays `/bin/ls`, the location of the `ls` executable.

Note that the current directory (`.`) is not in the `PATH` for security reasons (a miscreant user might create an executable called `ls` in some directory, which in fact erases the given directory instead of listing it). Therefore, if you really want to execute a file in the current directory, you need to specify the path (the current directory), i.e., to type `./some_script` instead of simply typing `some_script` (the latter results in a "file not found" error).

Normal users cannot alter system configurations files (they do not have permission). For this reason it is safer to use a Linux machine as a normal user, and not as an administrator. This way, you cannot do too much harm.

There is a super-user (administrator) called `root` that has absolute rights (i.e., can do **anything**). In the terminal, the command prompt for a normal user ends with a dollar sign `$`, whereas for the `root` the prompt ends with a hash `#`.

IMPORTANT In these labs, whenever you see the hash `#` sign in front of a command that you are supposed to type, it means that you need `root` access.

There are users called "sudoers" that are allowed to run a single command as `root` (the user `lca2` in our virtual machine is such a user). This is achieved by typing `sudo` followed by the desired command. You will then be prompted for the password of the user.

If you want to run a terminal in `root` mode, type the command `su`. You will then be prompted for the `root` password and you will switch to `root` mode. the password for root is `lca2`.

2.3.2 BEST PRACTICES

In these labs you will often type configuration commands in the terminal, usually one by one, to observe and understand their effects. However, after a reboot, the effects of these commands are usually lost, and you need to type them again, which is cumbersome.

We recommend the following practice:

Keep a text editor open in the virtual machine (for example "Leafpad", located in Accessories, or `nano` in another terminal). Whenever you type a configuration command in the terminal, paste it in the editor. In Linux it suffices to select a text to copy it in the clipboard. For pasting use the middle mouse button. Otherwise use the standard "right-click" + Copy (but be warned that this might not work in all terminals). The shortcuts for copy and paste on the terminal are `Ctrl+Shift+C` and `Ctrl+Shift+V`, respectively.

Save the resulting file in your home directory (for example as `conf.sh`). When you reboot, you can run all the commands in the file as root by

```
# sh conf.sh
```

or as a regular user via `sudo` by

```
$ sudo sh conf.sh
```

2.3.3 ADDITIONAL INFO

There are two main software packages that provide tools for configuring the network: the older, standard `net-tools` (provides `ifconfig`, `route`, `netstat`), and the newer and more powerful `iproute2` (provides `ip`, `ss`). Both are installed on the virtual machine, but we will focus primarily on the second set of tools (here is an angrily argumented viewpoint `http://inai.de/2008/02/19`).

2.4 TEST SOME COMMANDS

Start Wireshark on the virtual machine. To be able to capture packets using wireshark, you need to be a super user. Enter `sudo wireshark` in a new terminal/or a new tab (you will not be able to use this terminal/tab while wireshark is running) to start wireshark.

```
$ ping 10.0.100.200
```

Q1/ Describe and explain your observations in Wireshark

[A1]

To test that the shared folder works, copy three files to the shared folder of your **host** machine and rename them `file.1`, `file.2` and `.file.3` (with a dot at the beginning).

Q2/ On your virtual machine, open a terminal, go to the folder `~/Desktop/shared` and type the command `ls`. What do you observe?

[A2]

3 MININET: A VIRTUALIZED ENVIRONMENT FOR NETWORKING

Mininet "creates a realistic virtual network, running real kernel, switch and application code, on a single machine...". It is a network emulator that can be used to deploy a full network topology on your computer. It runs a collection of hosts, switches, and links on a single Linux kernel. For this, it uses lightweight virtualization to make a single system look like a computer network, running the same kernel and user code.

In this lab, we prefer Mininet to other emulation platforms such as GNS3 due to its light-weight and scalability features. To learn more about the advantages and limitations of Mininet over other emulation platforms, take a look at this seminar from SIGCOMM 2014.

3.1 MININET TUTORIAL: COMMAND LINE INTERFACE

Here is a short tutorial on Mininet. The quickest way to familiarize with Mininet is through its command line interface. The command line interface is used to view the configuration of hosts and switches, and run applications or test on the configured network. It cannot be used to modify the topology, i.e., add or remove nodes or links. To start Mininet, enter:

```
$ sudo mn
```

It starts with the default `minimal` topology that comprises 2 hosts, 1 switch and a software-defined-networking controller (more on this in Lab 4). Alternatively, you could start mininet with one of the standard topologies using the `topo` parameter: `sudo mn --topo=tree`. We will learn about more advanced ways to to create and configure networks in Section 3.2. Once Mininet is started, the command prompt changes from `$` to `mininet>`.

At the Mininet prompt, enter `help` to see a list of acceptable commands. Next, we will go through a few important ones.

To see the nodes, enter `nodes`. You will the following output.

```
mininet> nodes
available nodes are:
c0 h1 h2 s1
```

To see the network connections, enter `net` and to see the information about the nodes, enter `dump`.

Q3/ What are the different links in the network?

[A3]

Q4/ How many interfaces does host h1 have? What is/are its/their IP addresses?

[A4]

The hosts and switches in Mininet share a common UNIX kernel and file system. As a result, any application or script installed on the Mininet VM is accessible by all the devices. Furthermore, the UNIX command line interface can be used for configuration and running applications. This architecture makes using Mininet very intuitive as we shall see. To execute a command on a particular host or a switch, simply append the UNIX command with the name of the device: `<node/switch> <cmd>`. For instance, to check the list of files in the current directory on host `h1`, use

```
mininet> h1 ls -ls
```

As the hosts share the same filesystem, you can verify that the output for the corresponding command on host `h2` is same.

Mininet automatically substitutes IP addresses for host names. So, to ping a host `h2` from host `h1`, use:

```
mininet> h1 ping h2
```

Now, in a different terminal, start Wireshark by using the command `sudo wireshark`. In wireshark, choose the interfaces `s1-eth1` and `s1-eth2` and start a capture.

Q5/ What is the destination IP address of the ICMP echo requests sent from h1 to h2?

[A5]

Besides the traditional ping, Mininet also offers the `pingall` command to check connectivity between all hosts. This is particularly handy in checking if a newly configured network is correctly configured.

To exit, use `mininet> exit`. If Mininet crashes for some reason, you can clean up the topology using the following command.

```
$ sudo mn -c
```

For more information, you can use this walk-through.

3.2 MININET TUTORIAL: PYTHON API

While the command line interface is very useful for configuring a few nodes on-the-fly, it is cumbersome for setting up larger networks. For setting up larger networks, Mininet provides a Python-based API that can be used to create and modify a network with hosts and switches, run tests on the switches and collect results, all with using a single scripts. Next, we shall see how to get started with this API.

NOTE This tutorial will only cover the Python API needed for Mininet. The commands discussed here are sufficient for understanding and modifying a piece of Python code. This level of understanding is sufficient for Lab 1. You will not be able to write a Python code from scratch based on this tutorial. However, we will visit Python in detail again in Lab 3.

Here is a sample code for a Mininet network with two hosts interconnected by a switch. You can also find this code in the file `firstNetwork.py` in the folder `~/lab1`.

The code is annotated with comments for your understanding. Comments in Python starts with `#` (for single line comments) or are enclosed in `"""..."""` (for multi-line comments).

```
#!/usr/bin/python
""" This example shows how to create a Mininet object and add nodes to
it manually.  """

#Importing Libraries
from mininet.net import Mininet
from mininet.node import Controller
from mininet.cli import CLI
from mininet.log import setLogLevel, info
```

```
#Function definition:  This is called from the main function
def firstNetwork():

#Create an empty network and add nodes to it.
net = Mininet()

info( '*** Adding controller\n' )
net.addController( 'c0' )

info( '*** Adding hosts \n' )
h1 = net.addHost( 'h1', ip='10.0.0.1' )
h2 = net.addHost( 'h2')

info( '*** Adding switch\n' )
s12 = net.addSwitch( 's12' )

info( '*** Creating links\n' )
net.addLink( h1, s12 )
net.addLink( h2, s12 )

info( '*** Starting network\n')
net.start()
#This is used to run commands on the hosts
info( '*** Starting terminal on hosts\n' )
h1.cmd('xterm -xrm ŕTerm.vt100.allowTitleOps:  false-T h1 &')
h2.cmd('xterm -xrm ŕTerm.vt100.allowTitleOps:  false-T h2 &')
info( '*** Running the command line interface\n' )
CLI( net )

info( '*** Closing the terminals on the hosts\n' )
h1.cmd("killall xterm ")
h2.cmd("killall xterm ")

info( '*** Stopping network' )
net.stop()

#main Function:  This is called when the Python file is run
if __name__ == '__main__':
setLogLevel( 'info' )
firstNetwork()
```

Note the two ways of adding a host. For adding `h1`, we specify the name of the host and the ip address in the parameters. For adding `h2`, we specify only the name of the host. When the IP address is not specified, Mininet gives it a default IP Address. In this lab, we will use the later approach to create a host. Once we

create a host, we will configure it through standard Linux commands through the terminal.

To start Mininet with the custom topology, nagivate to the directory in which `firstNetwork.py` is present and in the command line enter:

```
$ sudo python firstNetwork.py
```

Besides the output on your terminal, you should see two new terminals, one each for the hosts `h1` and `h2`, respectively. From these terminals, you can access `h1` and `h2` just like normal UNIX hosts. For instance, in the terminal for `h2`, enter `sudo wireshark` to open wireshark.

Q6/ List down the names of the interfaces that are available for capture.

[A6]

To close all the terminals and the network, in Mininet, enter:

```
mininet> exit
```

More information on the Python API can be found here.

4 BASIC CONNECTIVITY WITHIN A LAN

In this section you will learn how to configure machines in order to achieve connectivity in the IP layer within a Local Area Network (LAN). You will also use *Wireshark* to observe which traffic is sent (or not) in some scenarios. This will help you to find what is configured correctly and what has to be configured additionally in order to achieve the connectivity.

4.1 WIRING AND ADDRESSING SCHEME

In Mininet, create a configuration with four hosts PC1, PC2, PC3 and PC4 and three switches s14, s24 and s34 as shown in Figure 1. For this purpose, you use the file `lanTopology.py` in the folder `~/lab1`. Parts of the topology file have already been written for you. Fill in the rest and start the network. Once completed, you should see four terminal windows labeled PC1, PC2, PC3 and PC4. We will use these windows for the remainder of the lab.

4.1.1 IPV4 ADDRESSING

For IPv4 addressing, we will use the private IPv4 address space `10.10.0.0/16`.

- For the local network connecting PC4 to PC1 (LAN1), we will use the IPv4 network address prefix `10.10.14.0/24`. The host identifier (the fourth byte) should be `1` to indicate the PC1 and `4` for PC4.

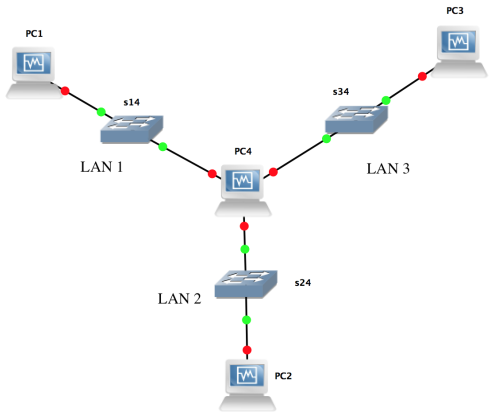


Figure 1: Basic configuration

- For the local network connecting PC4 to PC2 (LAN2), we will use the IPv4 network address prefix `10.10.24.0/24`. The host identifier (the fourth byte) should be `2` to indicate the PC2 and and `4` for PC4.
- For the local network connecting PC4 to PC3 (LAN3), we will use the IPv4 network address prefix `10.10.34.0/24`. The host identifier (the fourth byte) should be `3` to indicate the PC3 and and `4` for PC4.

Q7/ How many IPv4 networks does PC4 belong to? Name the type of the network(s).

[A7]

Q8/ Write down the IPv4 addresses you will use for the interfaces according to this addressing scheme.

[A8.a] PC1-eth0:	[A8.b] PC2-eth0:
[A8.c] PC3-eth0:	[A8.d] PC4-eth0:
[A8.e] PC4-eth1:	[A8.f] PC4-eth2:

4.1.2 IPv6 ADDRESSING

Several IPv6 addresses can be obtained by each interface. In the virtual environment we use private addresses, called Unique Local Addresses (ULAs). Such addresses can be used only inside a private domain and are ignored in the public internet. We will use the prefix `fd24:ec43:12ca::/48`, which is registered to EPFL for the SmartGrid project.

- For LAN 1, we will use the IPv6 subnet `fd24:ec43:12ca:c001:14::/80` and addresses `fd24:ec43:12ca:c001:14::X`, with `X` equal to `1` for PC1 and to `4` for PC4.
- For LAN 2, we will use the IPv6 subnet `fd24:ec43:12ca:c001:24::/80` and the addresses `fd24:ec43:12ca:c001:24::X`, with `X` equal to `2` for PC2 and `4` for PC4.

- For LAN 3, we will use the IPv6 subnet `fd24:ec43:12ca:c001:34::/80` and the addresses `fd24:ec43:12ca:c001:34::X`, with `X` equal to `3` for PC3 and `4` for PC4.

Q9/ Write down the IPv6 addresses you will use for the interfaces according to this addressing scheme.

[A9.a] PC1-eth0: [A9.b] PC2-eth0:
[A9.c] PC3-eth0: [A9.d] PC4-eth0:
[A9.e] PC4-eth1: [A9.f] PC4-eth2:

In addition to the Unique Local Addresses, every IPv6 interface also has a link-local address due to the IPv6 Stateless Address Autoconfiguration (SLAAC). Link local addresses are allocated automatically and do not require any configuration; they can be used only for communication in the same LAN.

Link-local addresses are all in the `fe80::/64` subnet. With this addressing scheme, all the network cards in the world are in the same subnet (you can see that the routing table contains by default this subnet)! For this reason, two machines on the same link can communicate directly without the need to configure routing (the host part is unique because it is derived from the MAC address, which is supposed to be unique).

To determine the MAC address for the `PC1-eth0` interface, look at the `link/ether` field after issuing in a terminal the following command:

```
$ ip link show PC1-eth0
```

Q10/ Write down the MAC address of the interfaces.

[A10.a] PC1-eth0: [A10.b] PC2-eth0:
[A10.c] PC3-eth0: [A10.d] PC4-eth0:
[A10.e] PC4-eth1: [A10.f] PC4-eth2:

The SLAAC IPv6 link-local address is formed as follows. The address prefix is `fe80::/64`. For the host part, we use a 64-bit interface identifier in modified EUI-64 format. It is derived from the interface's MAC address by setting 7th bit to 1 and inserting `ff:fe` in the middle. An illustration is given in Figure 2 adapted from the Wikipedia page dedicated to IPv6 addresses.

Note that for non-virtualized machines, the 7th bit of the MAC address will always be 0. However, as some of you will notice, virtual MAC addresses might have the 7th bit set to 1, which will not happen in reality. The link-local address is still formed by setting the 7th bit to 1, regardless of its original state.

Q11/ Compute the IPv6 link-local addresses for the interfaces below.

[A11.a] PC3:
[A11.b] PC4, LAN3(eth2):

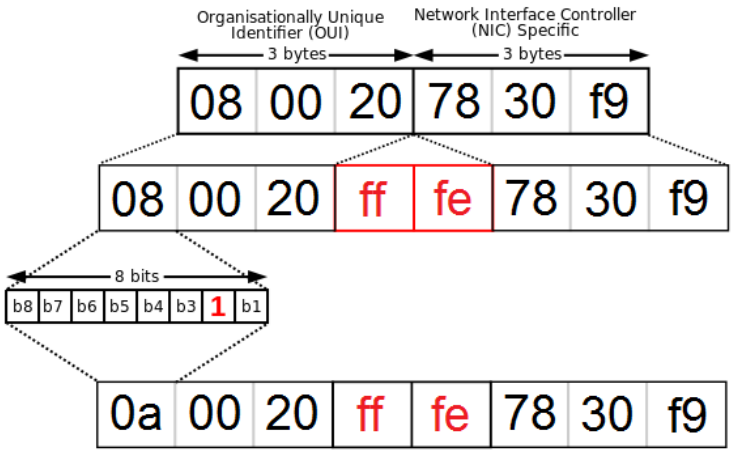


Figure 2: Formation of EUI-64 starting from MAC address of an interface.

4.2 Are you connected? Use Wireshark to see what happens.

In order to have access to the commands that manipulate the network interfaces, you need to be logged in as superuser (root) – see Section 2.3.1.

To see the network interfaces of any PC, type:

```
$ ip link
```

Bring up the interfaces of PC4. Run in a terminal:

```
# ip link set PC4-eth0 up
# ip link set PC4-eth1 up
# ip link set PC4-eth2 up
```

Similarly, bring up the interfaces of PC1, PC2 and PC3.

As seen in Lab0, the `Wireshark` program is used to capture the incomming and outgoing traffic on a network interface. You will now inspect what happens at packet level.

Start a `Wireshark` capture on all interfaces of PC1 and PC4.

We will first test what happens when pinging unassigned addresses.

To test IPv4 connectivity run a *ping* to the unconfigured router from a terminal on the `PC1`:

```
$ ping 10.10.14.4
```

Q12/ Explain what happens.

[A12]

Test IPv6 connectivity by running a *ping* to the link-local IPv6 address of `PC1-eth0` interface (the one that is connected to PC1) from a terminal on PC1.

```
$ ping6 <link_local_address_of_PC1_eth0> -I PC1-eth0
```

Q13/ Describe the traffic you observe with Wireshark.

[A13]

Now ping the link-local IPv6 address of `PC4-eth2` interface (the one that is in LAN 3) from a terminal on PC1.

```
$ ping6 <link_local_address_of_PC4_eth2> -I PC4-eth2
```

Q14/ Describe and explain the differences (if any) between the output from the two ping commands.

[A14]

4.3 CONFIGURING AND TESTING OF THE LAN

In the previous question you observed that there exists only IPv6 connectivity within the LAN. This is a consequence of IPv6 Stateless Address Autoconfiguration. However, these addresses are not globally routable. To obtain full IPv6 connectivity and IPv4 connectivity some additional steps are required.

4.3.1 LAN CONFIGURATION

The first step in order to achieve full connectivity from your machine is to configure its network interface and to assign an IP address to the interface. This is true both for IPv4 and IPv6 as link-local IPv6 addresses are not routable on the Internet.

To visualize the IPv4 and IPv6 routing tables of the machine, on *PC1* type:

```
$ ip route
$ ip -6 route
```

Q15/ Write down and explain the routing table entries.

[A15]

To configure your network interfaces[5] and assign an IPv4 and an IPv6 address to `PC1-eth0` interface, open a `root` terminal (`su`) and type:

```
# ip addr add 10.10.14.1/24 dev PC1-eth0
# ip -6 addr add fd24:ec43:12ca:c001:14::1/80 dev PC1-eth0
```

Make sure to delete any existing IP addresses. You may check for those and delete them with commands similar to the following:

```
# ip addr show
# ip addr del 10.0.0.1 dev PC1-eth0
```

Q16/ Compare the routing table after assigning ip addresses with the one you got from last question. What are the new modifications used for?

[A16]

Q17/ For the IP addresses assigned to PC1-eth0, identify the host and subnetwork portions. Why is it important for the PC to know this information?

[A17]

From PC1, run another `ping` to PC4's IPv4 interface:

```
$ ping 10.10.14.4
```

[5] Tip: To avoid typing this again the next time you boot the PCs save the commands in a script file that you can execute later on. Make use of the `shared` folder and the copy-paste functionality.

Q18/ What do you observe? Has the analyzer captured anything?

[A18]

Configure the interfaces of PC4 and the one of PC2 and PC3 according to the addressing scheme.

To verify the configuration, type:

```
$ ip addr show
```

Try again pinging PC4 from PC1. It should work now. Do the same for PC2 and PC3 to verify connectivity to PC4.

You can see the mapping between IPv4 addresses and MAC addresses. Take a look at the ARP table of the PC1 workstation:

```
$ arp -a
```

At this point you should have both IPv4 and IPv6 connectivity within each LAN.

4.4 ROUTING PACKETS

Try to reach any of the `PC4-eth1` or `PC4-eth2` interfaces of PC4 from PC1 (i.e., anyone that is not directly connected to PC1):

For IPv4:

```
$ ping 10.10.24.4
$ ping 10.10.34.4
```

For IPv6:

```
$ ping fd24:ec43:12ca:c001:24::4
$ ping fd24:ec43:12ca:c001:34::4
```

Q19/ Does it work? Why?

[A19]

On PC1, add an IPv4 default route (i.e., “configure default gateway”) and do the same for IPv6:

```
# ip route add default via 10.10.14.4
# ip -6 route add default via fd24:ec43:12ca:c001:14::4
```

Take the `eth2` interface of PC4 and test again if it is reachable from PC1 (both in IPv4 and IPv6).

In PC4 start a `Wireshark` capture of `PC4-eth2`interface to observe the traffic of the link between the machines belonging to LAN3.

From PC1, try to ping PC3, and observe the traffic on PC4:

```
$ ping 10.10.34.3
```

Frustratingly, it does not work. The ICMP messages do not get sent out by PC4. By default, PC4 does not forward IP traffic from one LAN to another. You need in addition to enable IP forwarding on PC4 by typing the following command (if you use copy-paste from this document, most likely the underscore "_" character will not be copied properly):

```
# echo 1 > /proc/sys/net/ipv4/ip_forward
```

Retry to ping PC3 from PC1. It still does not work, but now you know enough to fix it. *Hint:* Check again the traffic on the two links with Wireshark and see which packets do not get sent.

Q20/ Which command(s) you need to fix the problem?. On which PC did you apply them?

[A20]

Now, configure your network so as to be able to ping PC1, PC2 and PC3 between each other both in IPv4 and IPv6. For that, you will need to enable IPv6 forwarding using:

```
# echo 1 > /proc/sys/net/ipv6/conf/all/forwarding
```

Q21/ Perform the following pings simultaneously: PC2 from PC1, PC3 from PC2, and PC1 from PC3. Comment on the round-trip times that you observe.

[A21]

5 CREATING A MAN-IN-THE-MIDDLE ATTACK WITH IP TABLES

In this section you will have an introduction to `iptables`, which will be useful in the next labs. We will work in IPv4 only, and we will use the same working configuration of section 4.4. We will use a man-in-the-middle (MITM) attack example to illustrate iptables, so let's re-label PCs accordingly to their new function (check fig. 3): PC2 is Alice, the naive internet user who is trying to access her bank account; PC1 plays the role of the bank server; PC4 is Alice's home router, which will be hacked to our malicious purposes; and finally PC3 is the attacker's (your) private server where you will redirect Alice's bank transactions and steal her money.

Let's assume that a successful `ping` between two devices is equivalent to a successful money transfer between them. Your goal (as a hacker) is to make Alice and her bank believe they have a successful and point-to-point connection (blue line in fig. 3) while in reality communication goes all the way to your malicious server (PC3) whenever there is a transaction between Alice and the bank (red line in fig. 3). The rule is we can only make configuration changes in Alice's home router and in our own malicious server (PC4 and PC3 respectively).

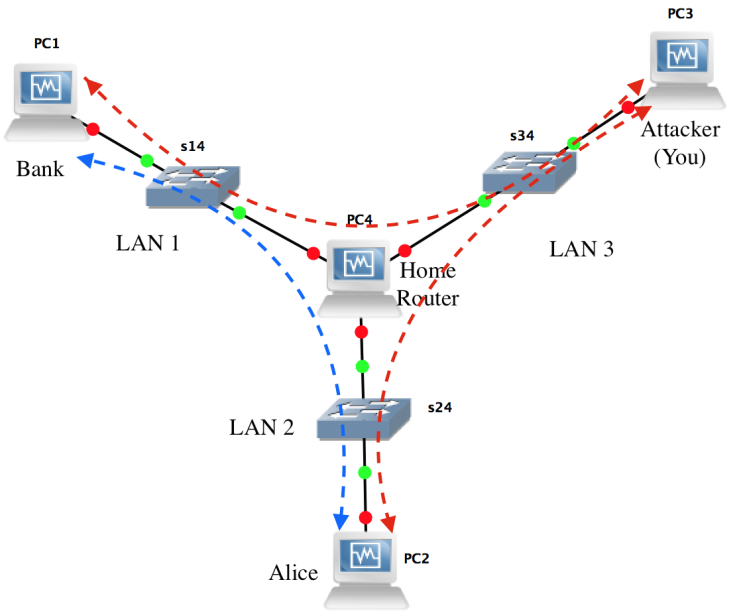


Figure 3: Basic configuration with modified labels

5.1 SETTING UP THE CONFIGURATION

In order for our attack to work properly, we will disable *Reverse path filtering* functionality on Alice's home router. Reverse path filtering (RPF) is a security mechanism where whenever the machine (PC4 in our case) receives a packet, it will first check whether the source IP address of the received packet is reachable through the interface it came in. If it is reachable it will accept the packet; if it is not it will drop it. for more information regarding RPF, here is a link explained by Sarath Pillai (`http://www.slashroot.in/linux-kernel-rpfilter-settings-reverse-path-filtering`):

To disable RPF for IPv4 in all Alice's home router's interfaces, run the script `mitmConfig.sh` script in the folder `~/lab1` as a superuser.

Finally, we will need to enable IPv4 forwarding on the malicious server (PC3). Do this with the command

learnt from previous sections.

5.2 IP TABLES

The Linux kernel contains a packet filter framework called `netfilter` which enables a Linux machine to masquerade source or destination IP addresses. The command used to do this is called `iptables -t nat`, and it manages the table that contains rules regarding address masquerading. This table has two important types of rules:

(i) `PREROUTING`: responsible for packets that just arrived at the network interface, implying rules *before* any routing decision has been made.
(ii) `POSTROUTING`: responsible for packets with a recipient *outside* the linux machine, implying rules before the packet leaves through the network interface (after routing rules).

In this section of the lab, we will learn how to use both rules in order to carry out our MITM attack.

Start a wireshark capture of interface `PC3-eth0` in PC3. Do a ping from Alice's PC (PC2) to the malicious server (PC3). Execute the following command on Alice's home router (PC4):

```
# iptables -t nat -A POSTROUTING -o PC4-eth2 -j MASQUERADE
```

In this command,

- `iptables -t nat` is the command that modifies the masquerade table of the `netfilter`.
- `-A POSTROUTING` says to append a rule to the `POSTROUTING` rules (`-A` stands for `Append`).
- `-o PC4-eth2` states that this rule is valid for packets that leave on interface `PC4-eth2` (`-o` stands for `output`).
- `-j MASQUERADE` states the action that should take place is to "masquerade" or replace source ip address.

Q22/ Do a ping again from Alice to the malicious server and check in wireshark the differences between packets. Write-down any difference in source and destination IP addresses.

[A22]

If you want to remove any configuration from the `iptables` or if you want to flush the mapping or "masquerading" table type the following commands:

```
# iptables -F
# iptables -t nat -F
```

Verify that iptables is disabled by doing another ping from Alice to malicious server.

Execute the following command on Alice's home router (PC4):

```
# iptables -t nat -A PREROUTING -d 10.10.14.1 -j DNAT --to-destination
10.10.34.3
```

Q23/ Do one more ping from Alice to the bank and check in wireshark source and destination IP addresses. Based on your observations, what are the use cases for the "*-j MASQUERADE*" and "*-j DNAT*" configuration options?

[A23]

Flush again the iptables with the commands provided in this section.

5.3 CONFIGURING THE MITM ATTACK

Let's hack Alice's home router. First let's send the traffic targeted to the bank to go to the malicious server. Since Alice may have other internet activity with high bandwidth consumption (e.g. online gaming), and since Alice may have classmates working with her, we want to select only the traffic we are interested in (*ICMP* packets), and coming only from Alice's PC IP address (`10.10.24.2`). Keep the wireshark capture on the malicious server.

Q24/ Write down the command(s) required to this end. If you need help, check the `iptables` howto for masquerading (NAT):
(`http://www.netfilter.org/documentation/HOWTO/NAT-HOWTO-6.html`)

[A24]

Check with wireshark that you have successfully redirected the Bank's traffic from Alice's home router to your private (and malicious) server. Now we need to configure such server (PC3) in order to receive the traffic from Alice's home router, masquerade it, and send it to the bank. To this end, we need to replace the destination IP address of the packet with the IP address of the bank server `10.10.14.1`, and modify the source IP address with your server's IP address `10.10.34.3`.

Start a new wireshark capture on malicious server's `PC3-eth0` interface and on Bank's `PC1-eth0` interface

Q25/ Propose the iptables command(s) that needs to be added to the malicious server in order to complete this task.

[A25]

On the malicious server (PC3) you should see packets from `10.10.24.2` to `10.10.34.3` (and viceversa), and from `10.10.34.3` to `10.10.14.1` (and viceversa).

Additionally, on Bank's server (PC1) you should see packets coming from `10.10.34.3`. Since this is something that the bank could detect as malicious (e.g. it has an access-control list allowing connections only from its customers' IP addresses), propose the iptables command that you need to configure on Alice's home router (PC4), which is required to masquerade the malicious server with Alice's IP address `10.10.24.2`.

Q26/ Write down the command(s) here

[A26]

That's it, you have successfully mounted a man-in-the-middle attack. To conclude the lab just answer the final questions:

Q27/ Can this attack be mounted by just tampering the ip routing table of Alice's home router (PC4)?

[A27]

Q28/ In our lab environment, is there any way (other than checking Alice's empty bank account) that Alice could notice that she is under attack?

[A28]

6 MININET: ANALYZING LATENCY VERSUS NUMBER OF NODES (BONUS)

The following is a bonus section, and is completely optional. It will give you a chance to apply some of what you learned in this lab about Mininet, and it will allow you to gain a better understanding of how Mininet works, in addition to gaining more experience using it, which will be helpful for future labs.

We will be testing how the performance of Mininet scales with the number of nodes. Specifically, as the number of hosts, routers, and switches increases, how is the latency of the communication between these nodes affected?

In order to answer this question, you will need to create several scenarios, each with a Mininet topology in which the number of nodes, and the number of links between them, vary. Of course, this depends on your VM setup, and how much resources (memory, CPU) you assigned to the VM.

One example scenario is a star topology: a router in the center with N interfaces, each interface connected to a switch that is connected to a host. In such a scenario, each host is in a different LAN, and each pair of hosts is separated by the router. How do communication latencies (ping or otherwise) change as the number of hosts N increases from 2 to 5 to 10 to 100?

We ask you to analyze up to two scenarios: either one scenario other than the star topology, or two scenarios including the star topology.

What to submit A PDF file containing a small description of each scenario you analyzed, along with the results (plots, tables) you obtained, and a snippet of the source code used to generate the topology. Put this

PDF file along with the PDF file of this report in the same zip folder `Lab3_Name1_Name2`, and submit this folder.

Grading The bonus part will be graded separately from the lab, and you will receive a grade between 0-10. This grade will be part of your research exercise grade.

Dylan Bourgeois

Antoine Mougeot

6 MININET

ANALYZING LATENCY VERSUS NUMBER OF NODES (BONUS)

Method

We chose 2 different `mininet` topologies to test the influence on performance : **single** and **linear**. For simplicity we decided not to use a custom configuration for the link performances (e.g. delays and bandwiths), using instead the default nodes and predefined topologies provided by `mininet`. This is of course not ideal for performance testing on a real network but should be sufficient to study trends that depend on the number of nodes on the network.

We study two metrics :

- **ping time** : measured from the first to the last host on the network, averaged over 5 pings (`mininet> h1 ping -c5 hn`).
- **bandwidth** : measures the TCP bandwith (`mininet> iperf`)

Again this is out of convenience as these are predefined tests in `mininet` though they are telling indicators of a network's performance.

Single

This topology is `mininet`'s expression of a star network, as requested in the exercise.

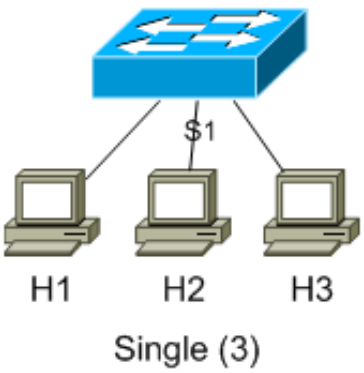


Figure 1 : Single topology Source

The above tree can be created in mininet with the command :

```
sudo mn --topo single,3 -v info
```

Note The same result can be achieved with `mininet`'s tree topology, with `depth=1` and `fanout=<nb_nodes>` .

Linear

This is a simple *bus-like* topology, where nodes are aligned on a single link, with switches in between each.

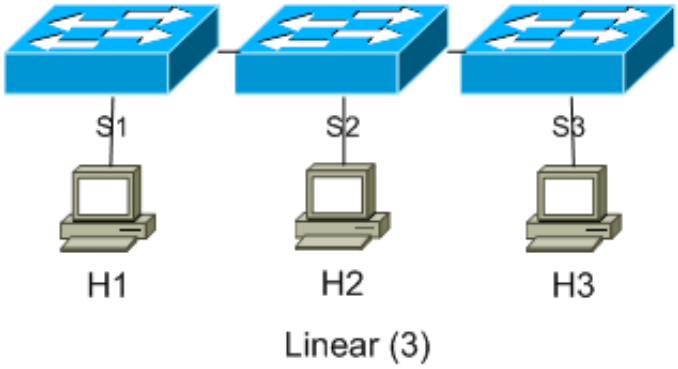


Figure 2 : Linear topology Source

```
sudo mn --topo linear,5 -v info
```

Note unfortunately we weren't able to scale the network to more than 15 hosts, after which the first host wasn't able to ping the last (we checked by manually pinging and using `pingall` which would not be able to reach host 16+).

Results

Table 1 : Network topology and performance

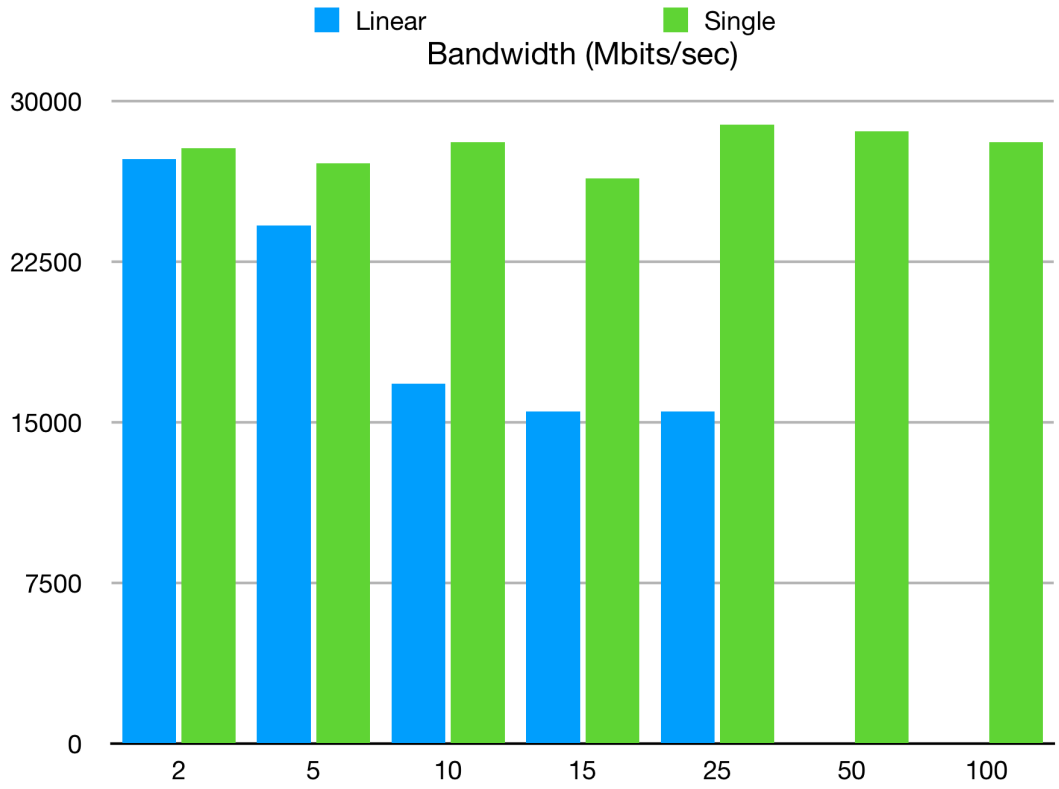
Network Topology	Size	Ping time (ms)	Bandwith (Mbits/s)
Linear	**2**	0.113	27300
	5	0.108	24200
	10	0.179	16800
	15	0.310	15500
	25	0.310	15500
Single	**2**	0.408	27800
	5	0.351	27100
	10	0.424	28100
	15	0.397	26400
	25	0.110	28900
	50	0.078	28600
	100	0.056	28100

The trends can be shown in the following barplots :

Bandwith

We clearly see a downwards trend for the *Linear* network configuration, whereas the *Single* / *Star* network stays constant. This makes sense as the time spent by a packet in a linear network is linear as well (the number of hops is the number of hosts), which means that the longer the network the longer it takes for a TCP packet to confirm its arrival, slowing the bandwith. (*Note* we suppose that this behaviour should not be observed for UDP packets).

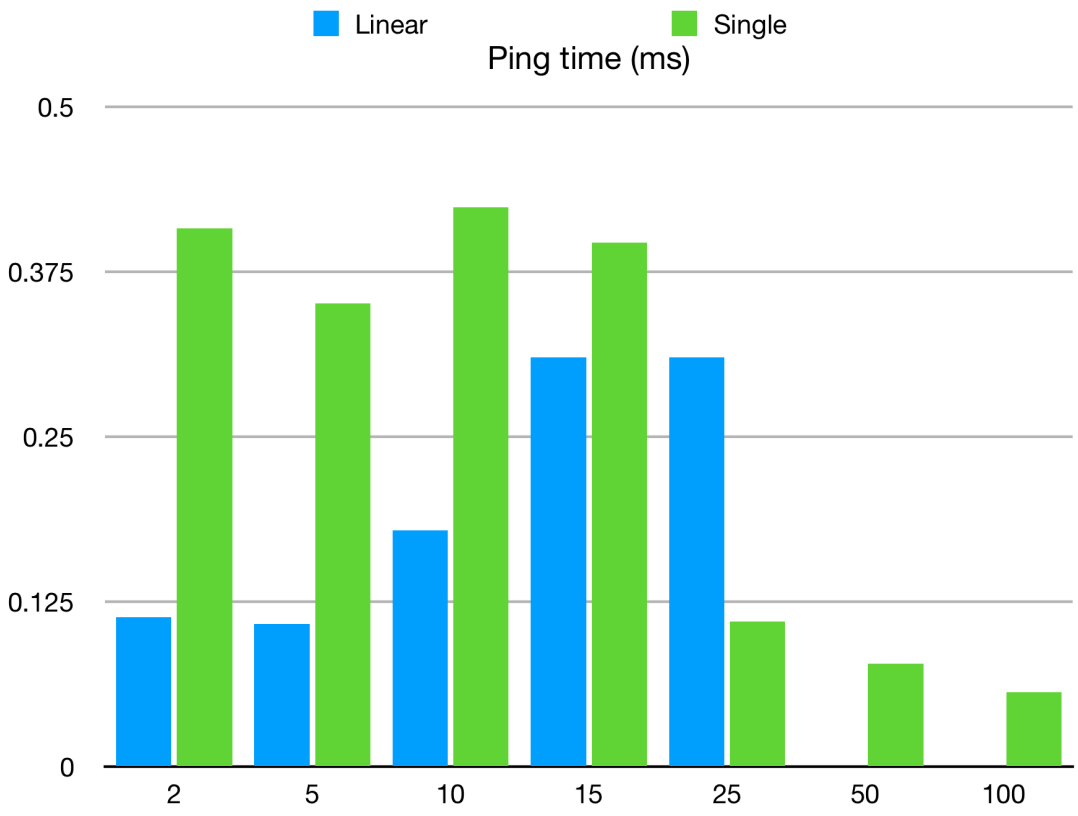
On the other hand, a packet in a star network doesn't have to do more hops to arrive to its destination no matter the amount of hosts in the LAN (its travel time is constant).



Ping time

The same reasoning as above holds for the *ping time* behaviour observed :

- Linear networks grow linearly hence the time spent in the LAN grows linearly as well
- Star networks are time constant. The fact that the ping time is slower than for a linear network for smaller networks would be due to the problem of finding an unknown host, which is linear in a star network.


Linear
Single
Ping time (ms)
0.5
0.375
0.25
0.125
0
2
5
10
15
25
50
100