

# Project 1 - VM Setup, Defining Topologies, and Simulating Networks

## Goals

This project has three goals: to set up the virtual machine that we will be using for the rest of the projects in this course, learn how represent network topologies in Mininet, and how to simulate basic network commands on these topologies in the Mininet command prompt. [Mininet](#) is a network simulator. It runs multiple Linux containers for individual hosts and uses [Open vSwitch](#) for network device emulation.

This project is split into four parts: Setup, Static Topologies, Simulation, and Dynamic Topologies. The Setup stage is reasonably straightforward. You must download and setup a VM in VirtualBox. In the second part, you will learn how to represent static network topologies in Mininet. Third, you will learn how to run basic network commands on these topologies using the Mininet command line interface. Finally, you will use what you have learned to create a dynamic topology that can be defined at runtime using command line parameters and verify it works properly.

## VM Setup Directions

1. Download and install the latest Virtualbox for your platform. You can find Virtualbox [here](#).
2. Download the [CS6250 virtual machine image](#). The download is ~2.2 GB in size so be patient with the download and, if possible, connect your computer to the Internet via a wired connection. If the download is especially slow, setup your computer to download the image overnight.
3. In Virtualbox select File -> Import Appliance and select the .ova you just downloaded. Virtualbox will show you the VM settings and you can then click Import.
4. Start the VM by clicking Start. (If you have errors with the VM at this point, first spend a little time trying to figure it out yourself, but don't spend *too* long. If you continue to have trouble, go to Piazza for help.)
5. Log in to the VM using mininet for the username and password.

6. Open up a terminal in the virtual machine. (Click Activities and then the terminal icon.)
7. Now we will run a test to ensure Mininet is working correctly. Type `sudo mn --test pingpair`.
8. The output should look like Results: 0% dropped (2/2 received).

**Issues with VM** - If there are any questions about the VM, please post them to Piazza. But expect that your environment may require some customization.

## Defining Topologies

1. The starter code required for this project is available on Canvas as Project1.zip. Download this directly on the VM.
2. Use the following command to unzip the files
  - o `tar -xvf Project1.zip`
3. The above command should preserve original file permissions, but if you run into permission errors while working on the project, ensure the permissions match the following:

- o Use the 'ls -l' command to view permissions and 'chmod' command to change them if required.

```
drwxrwxr-x 2 mininet mininet 4096 May 13 19:56 util
-rwxrwxr-x 1 mininet mininet 817 May 13 19:56 topology.sh
-rwxrwxr-x 1 mininet mininet 376 May 13 19:56 plot-rate.sh
-rw-rw-r-- 1 mininet mininet 760 May 13 19:56 ping.py
-rw-rw-r-- 1 mininet mininet 906 May 13 19:56 mntopo.py
-rw-rw-r-- 1 mininet mininet 5709 May 13 19:56 measure.py
-rw-rw-r-- 1 mininet mininet 63 May 13 19:56 __init__.py
-rw-rw-r-- 1 mininet mininet 423 May 13 19:56 complextopo.py
-rw-rw-r-- 1 mininet mininet 2712 May 13 20:10 dynamictopo.py
-rw-rw-r-- 1 mininet mininet 51200 May 14 23:29 cli.py
```

4. You can now run the example topology provided to simulate a host communicating with another host. Change into the project directory and run the topology using the following commands:

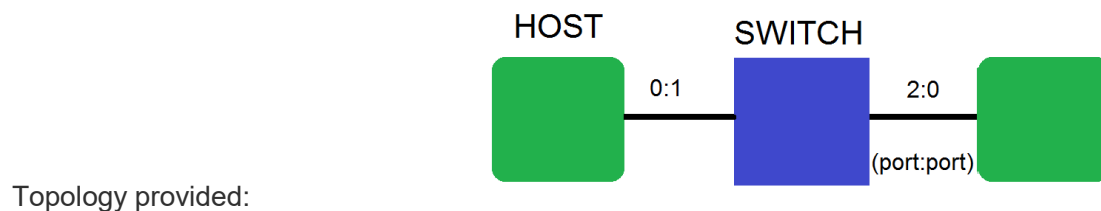
- o `cd Project1`
- o `sudo ./topology.sh`. (This step may take a minute.)

5. The script produces a time-stamped results folder that contains some raw data as well as a couple of graphs. One is the TCP congestion window (`cwnd.png`) and another is the bandwidth in megabits per second (`rate.png`). To view the graphs, use the command:

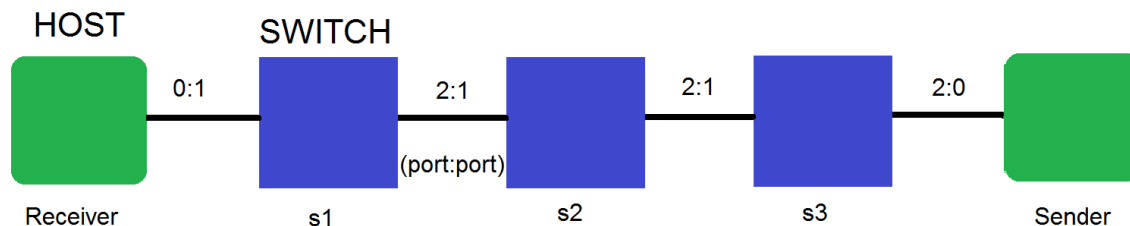
- o `display {image file name}`

The bandwidth graph should show a constant rate of about 10 Mbps, and the congestion window graph should show a familiar pattern if you've had an earlier networking course or are otherwise familiar with TCP (but if you aren't, don't worry - we'll learn about this pattern later in the class!)

6. Now you will modify the Mininet topology to add more switches. The current topology is setup as shown in the first image below (2 hosts, 1 switch, 2 links). You will modify the topology to the second topology shown below (2 hosts, 3 switches, 4 links). To modify the topology, you should edit the Mininet topology file `mntopo.py`. (See if you can understand how this code is creating the hosts, switches, and links in the topology. Refer to the [Mininet documentation](#) to help you piece apart the topology file). You should add two new switches and two new links to the topology. When you have modified the topology, re-run the topology test script (`sudo ./topology.sh`). The graphs should be similar to the graphs produced in your earlier test run. The similarity should come as no surprise because the new switch and links in the topology are adding a slight amount of total latency but have the same bandwidth properties as the other links. NOTE: Be sure not to add or leave extra links in the topology!



Topology you will create:



7. The next two steps involve tweaking topology parameters and observing their outputs. First we will modify the latency of the topology. Before we modify the latency, we will test the current latency using the `ping` command. Run the following from the project folder:

```
o sudo python ./ping.py
```

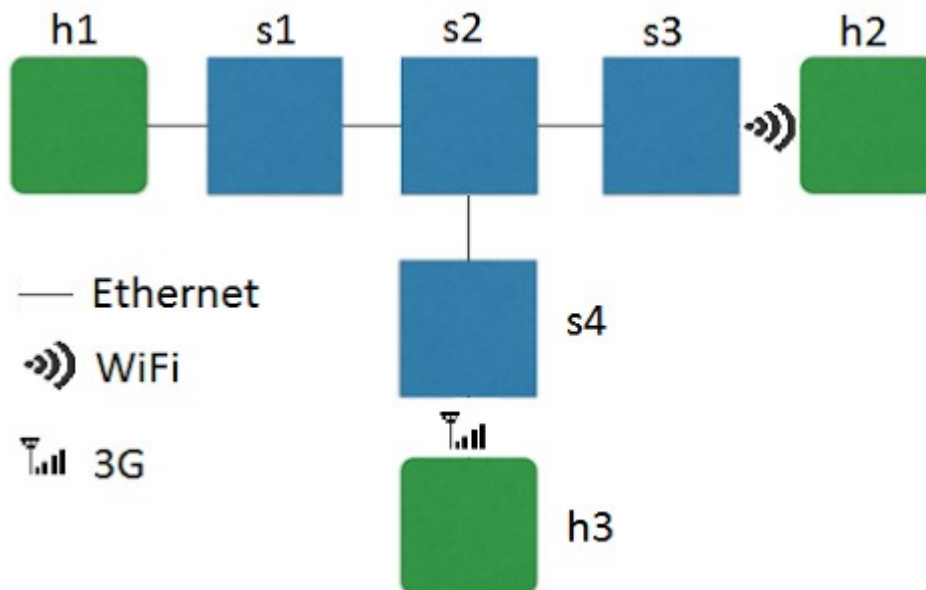
8. You should see results around 8-10 ms. (If the first one is a bit longer, that's normal. It's likely due to time required for ARP to run - if you don't know about ARP yet, that's okay; we'll learn about it later in this course!) To modify the latency we will adjust the delay on the links in the `mntopo.py` file.

Adjust the `delay` parameter in the `linkConfig` dictionary to 10ms. Then run ping script again (`sudo python ./ping.py`). This time you should see pings just a bit over 80 ms. This is the time for one packet to traverse four links to the receiver, and the ping reply to traverse the same four links back to the sender. The beauty of Mininet is these configuration parameters allow us to emulate real network events without modifying common network tools like `ping`.

9. Now we will modify the bandwidth and observe the change in the topology. Adjust the `bw` in the `linkConfig` dictionary to 50 which will adjust the bandwidth along each link to 50 Mbits per second (Mbps). To confirm Mininet emulates this correctly, re-run the topology test script (`sudo ./topology.sh`) and then view the `rate.png` output graph using `display` as in step 5. Does the graph match what you expected to see after you changed the `bw` parameter?

**NOTE:** Make sure you save your output as well as `mntopo.py` after this step, it is a deliverable for this project.

10. To exercise what we have just learned, we will create a new topology representing a more complicated network topology:



11. To create your topology, edit the starter file `complextopo.py` and create three hosts, `h1`, `h2`, and `h3`. Next create four switches, `s1`, `s2`, `s3`, and `s4`. It is important that your hosts and switches use these names for grading purposes. Then add the links between these hosts and switches as depicted above. The properties for each link type are provided below:

- Ethernet: Bandwidth 25 Mbps, Delay 2 ms, and loss rate 0%
- WiFi: Bandwidth 10 Mbps, Delay 6 ms, and loss rate 3%

- 3G: Bandwidth 3 Mbps, Delay 10 ms, and loss rate 8%

NOTE: You can use arbitrary port numbers for each link for this topology, since will not generate any graphs for this topology. We will interact with it in the next section!

## Network Simulation

1. Using our complex topology, let's explore how to simulate basic network commands over our topology. To do this, we will launch Mininet's command line interface, or CLI for short. To launch the simulation, run the following command:

- `sudo python ./cli.py`
- After Mininet loads the complex topology, you should see the Mininet command prompt: `mininet>`

2. Now let's run some commands. To execute a command on one host, type the host name followed by the command. For example, let's test the connection between h1 and h2 by typing the following at the Mininet prompt:

- `h1 ping h2 -c 10`

This will cause h1 to ping h2 with 10 packets of data, and print out results like those in steps 7 and 8 above. Due to the loss rates on the wireless links, you may see some packet loss occur during the ping command execution.

3. Let's perform a casual experiment. Issue a 100 packet ping command from h1 to h2, and then a 100 packet ping command from h1 to h3. How do the reported statistics differ across the two different wireless links?

4. Another useful command provided by Mininet is `pingall`. This command issues ping commands between all hosts on the topology, and can be useful to verify that your topology is connected. Issue this command at the Mininet prompt. A failed ping between two hosts is indicated by an `x`. You may see an X in the results of your `pingall` due to the loss rates on the wireless links, but you can run the command again to confirm the topology is behaving as you intended.

5. We will be explore more complex experiments as the course continues, but for now we are finished! To close the Mininet simulation, type `exit` at the Mininet prompt.

## Dynamic Topologies

Since we are defining our Mininet topologies in a programming language, it may have occurred to you that we can define topologies dynamically prior to the initialization of the network. This is particularly

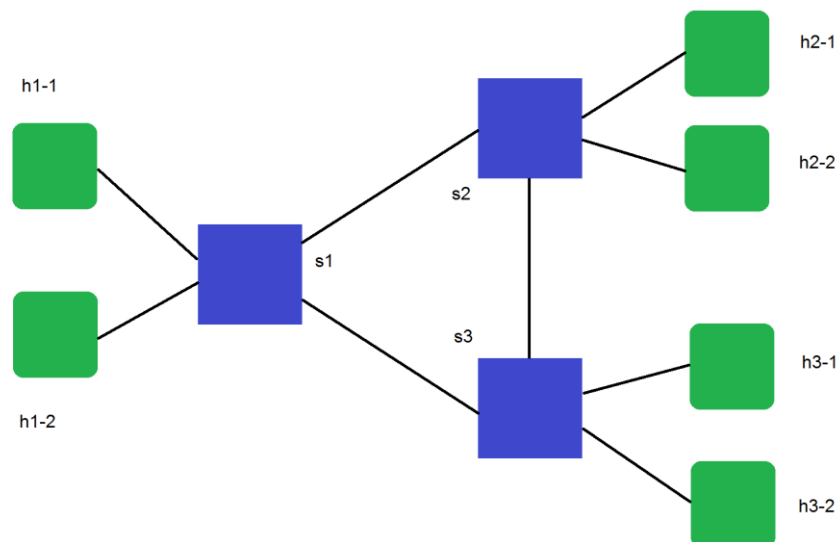
useful for creating large scale topologies and automating network testing. In this last section of the project, you will create a dynamic topology that builds a custom topology and launches the Mininet CLI.

The topology we will create is known as a Ring Topology. Our ring topology will be defined by 4 parameters:

- `z`: The number of distinct zones in the ring topology. A Zone is defined as a single switch and several hosts. The zone switch is connected to precisely two other switches in the ring, the previous and next zone switch. The  $z$ th zone switch is connected to first zone switch to complete the ring.
- `n`: The number of hosts in each zone. The hosts in each zone are connected directly to their respective zone switch.
- `delay`: The latency of all links in the topology.
- `bw`: The bandwidth of all the links in the topology

The user can specify the values of these parameters as command line arguments to the `dynamic topo.py` script. The following is an example of a ring topology with  $z=3$  and  $n=2$  (assume the links are configured properly):

Note: We will only be testing your code with  $z \geq 3$  and  $n \geq 1$ .



It is important for grading purposes that the switches are named `s1`, `s2`, to `sz` and hosts are named `h1-1`, `h1-2`, to `hz-n`. Your code must use this naming convention to receive full credit. To implement your dynamic topology, complete the TODO sections marked in `dynamic topo.py`. Once complete, you should be able to launch your topology and enter the Mininet CLI with the following command: `sudo`

```
python ./dynamictopo.py <args>. For example - sudo python dynamictopo.py --delay 5ms  
--bw 10 --z 3 --n 1
```

You can verify your topology is properly connected using the command line interface. You can print out the network configuration using the `dump` command, as well as using the `pingall` command to verify all hosts can reach each other. **NOTE:** Your first ping commands may be unsuccessful, as it takes the topology a bit to construct its spanning tree (we will explore this in our next project!)

## What to turn in

To complete this project, submit your `mntopo.py` file, `bwm.txt` raw data and `rate.png` image files generated in **Defining Topologies: Step 9**, your `complextopo.py` file from **Defining Topologies: Step 11**, and your `dynamictopo.py` file created in **Dynamic Topologies** to Canvas as five separate files. Do **not** submit tarballs or zip files, and do not modify the names of those files or else grading will be affected and you may receive a zero. The file names must be **exactly** as stated here.

- `mntopo.py`
- `bwm.txt`
- `rate.png`
- `complextopo.py`
- `dynamictopo.py`

## What you can and cannot share

For this project, you are encouraged to share your experience/assistance in setting up the course VM on Piazza. Due to variations in computing platforms, virtualization software, and operating systems, VM setup can be painful for some students. This portion of the project is ungraded, so please don't hesitate to discuss / troubleshoot on Piazza.

You are **not** permitted to share code from `mntopo.py`, `complextopo.py`, or `dynamictopo.py` on Piazza or other platforms. Additionally, you are not permitted to share the contents of your experiment data (`bwm.txt` files) on Piazza or other platforms. You **are** permitted (and encouraged!) to share `rate.png` and `cwnd.png` files on Piazza with other students, and discuss how these simple experiments lined up with your expectations (or didn't!).

## Additional Resources

Project Descriptions will frequently provide additional resources towards the end. These are not required reading so as to not cause the project to become overwhelming, but will often contain helpful tutorials or additional information for completing the project or taking the project one step further.

This [Mininet walkthrough](#) may be helpful for this project.

## Notes

The course VM is this course's common operating platform. It is designed specifically for compatibility with our project code, and as a result uses some packages considered to be legacy, this is an intentional design. Therefore, students are **highly** encouraged to complete and turn in all projects via the course VM (using the provided browser and GUI). All projects are developed and graded in this exact same VM, to ensure consistency and eliminate platform dependency issues. In the interests of maintaining this consistency, students **should not** perform any of the actions throughout the duration of the course:

- Install new software or apply package or OS updates (unless instructed to by the professor or a TA). Students in past semesters have installed IDEs such as PyCharm without issue so you can do that if you prefer.
- Alter the VM's hardware virtualization settings unless necessary. Some changes may improve the VM performance on your system, like increasing available memory, video memory etc. and shouldn't affect the projects, however some changes can affect projects, like adding CPUs for example. If in doubt, undo hardware virtualization setting changes and ensure your project still runs as expected prior to turn in.
- Transfer files to be submitted to Canvas to a different platform (i.e Windows OS) before turn-in. Specifically, do not open code in Windows because this alters the line endings and will cause the files to not run in the VM or to fail to auto-grader.
- Using tabs instead of spaces in Python files. Using tabs frequently causes the autograders to fail.
- Not removing print statements. Leaving unnecessary print statements in your files may affect the autograders.
- Using shared/mounted folders with your host systems. These are unnecessary and sometimes cause issues, particularly with projects involving mininet.



## Grading

15 pt	Correct Submission	For turning in all project files with the correct names, and significant effort has been made in each file towards completing the project.
20 pt	Simple Topology	The topology in <code>mntopo.py</code> is correctly implemented, the output in <code>bwm.txt</code> is correct, and the <code>rate.png</code> file is consistent with the experiment conducted.
25 pt	Complex Topology	The topology in <code>complextopo.py</code> is correctly implemented, and commands issued against the topology run without error and produce the expected output
40 pt	Dynamic Topology	The script created in <code>dynamictopo.py</code> is correctly implemented, and correctly generates topologies according to specified parameters. We will test your script against several different test cases to determine if it correct.