

# CSCI 4211: Introduction to Computer Networks

Spring 2024

PROGRAMMING PROJECT 3: SDN and Mininet

Phase 1: Mininet Setup and Walkthrough

*Due: April 9<sup>th</sup>, 2024 at 11:59 p.m.*

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**Note:** The use of chatGPT and similar bots is strictly prohibited for this project.

## Table of Contents

<b>Table of Contents.....</b>	<b>1</b>
<b>1. Description.....</b>	<b>2</b>
<b>2. Set Up The Project Environment.....</b>	<b>2</b>
2.1 Windows/macOS (Except M1/M2/M3 chips).....	2
2.1.1 Download The Required Software/Tools.....	2
2.1.2 Import The Mininet Virtual Machine Image.....	2
2.1.3 Finish VM Setup.....	5
2.1.4 Start the Mininet VM.....	8
2.1.5 Use An XTerm Terminal Inside Your VM.....	12
2.1.6 Enable and Setup Shared Folder (Optional).....	13
2.2 macOS with M1/M2/M3 chips.....	17
2.2.1 Download The Required Software/Tools.....	17
2.2.2 Enable and Setup A Shared Folder (Optional).....	18
2.3 Linux.....	21
<b>3. SSH and Copy Files (For Windows/macOS Only).....</b>	<b>22</b>
3.1 SSH Into Your Mininet VM.....	22
3.2 Copying Files Between The Local Host and Your Mininet VM.....	27
3.3 Use A Local XTerm Terminal (Optional).....	28
<b>4. Mininet Walkthrough.....</b>	<b>28</b>
<b>5. Helpful Resources and General Advice.....</b>	<b>28</b>
<b>6. Submission Information.....</b>	<b>29</b>
6.1 Rubric.....	29
6.2 What To Submit.....	29

[Back To The Table of Contents](#)

# 1. Description

In this phase, you will learn how to use Mininet and complete a walkthrough of its various features. Sections [2 - 4](#) contain the lists of required tasks that you must complete.

## 2. Set Up The Project Environment

The specific steps necessary to set up your project environment depend on the OS running on the machine that you'll use to complete this project. Follow the correct set of steps from the following sections accordingly.

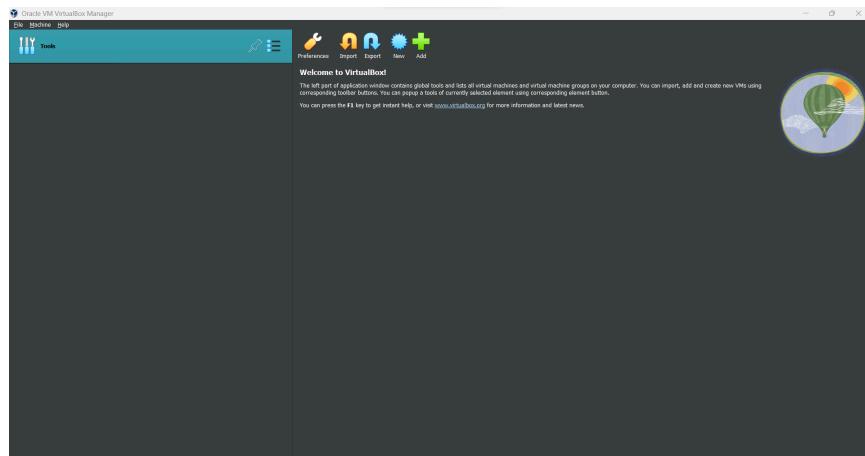
### 2.1 Windows/macOS (*Except M1/M2/M3 chips*)

#### 2.1.1 Download The Required Software/Tools

1. Download a Virtual Machine Manager (“VMM”): You can use any virtualization system of your choice, but we recommend installing [VirtualBox](#) as it is free and easy to use. **OR** You can use [VMWARE Fusion](#) which is free for UMN students.
2. Download a Mininet Virtual Machine (“VM”) image: We recommend that you download the image that was prepared by us containing a lightweight LXDE GUI for XTerm from [here](#). **OR** You can download the original Mininet VM from [here](#). Based on your computer specs, download either the i386.zip or amd64.zip.

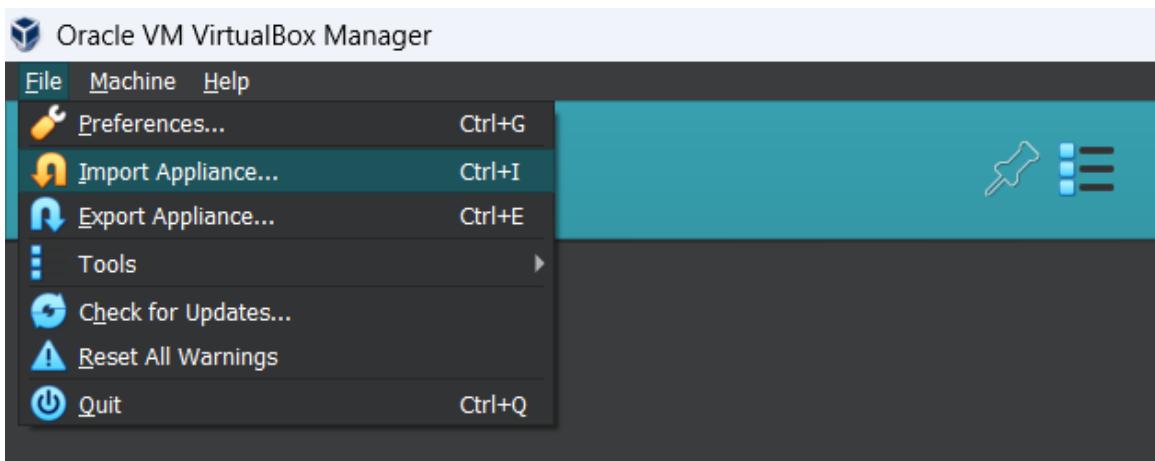
#### 2.1.2 Import The Mininet Virtual Machine Image

1. Start your VMM (i.e., Oracle VirtualBox). Your screen should look like the following screenshot if you’ve just downloaded VirtualBox for the first time onto your machine.

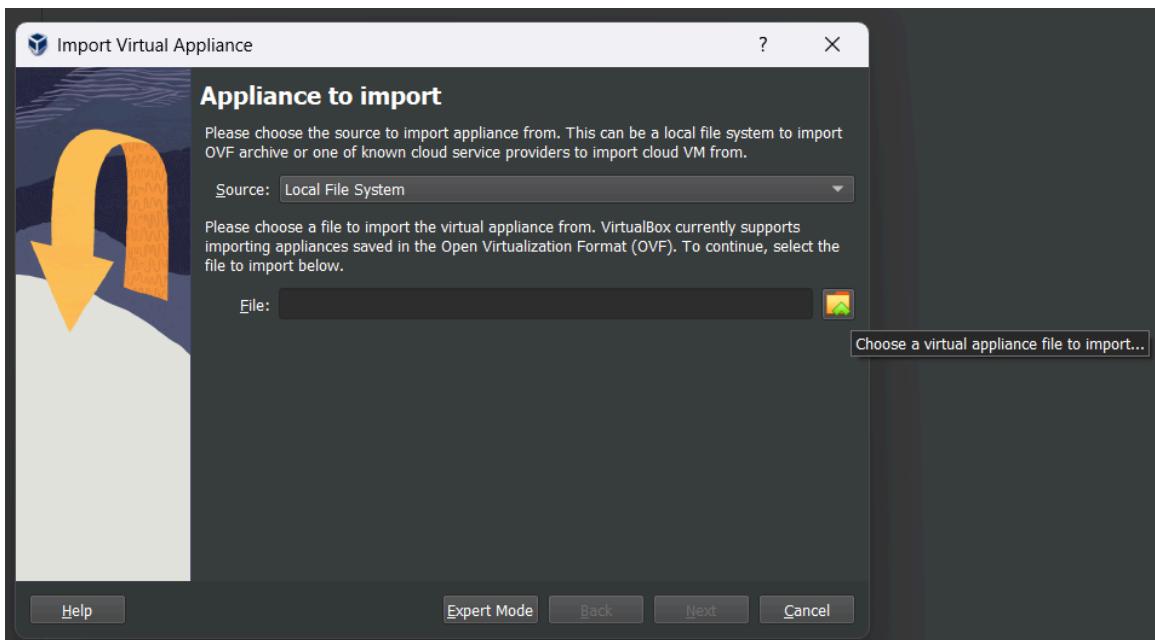


[Back To The Table of Contents](#)

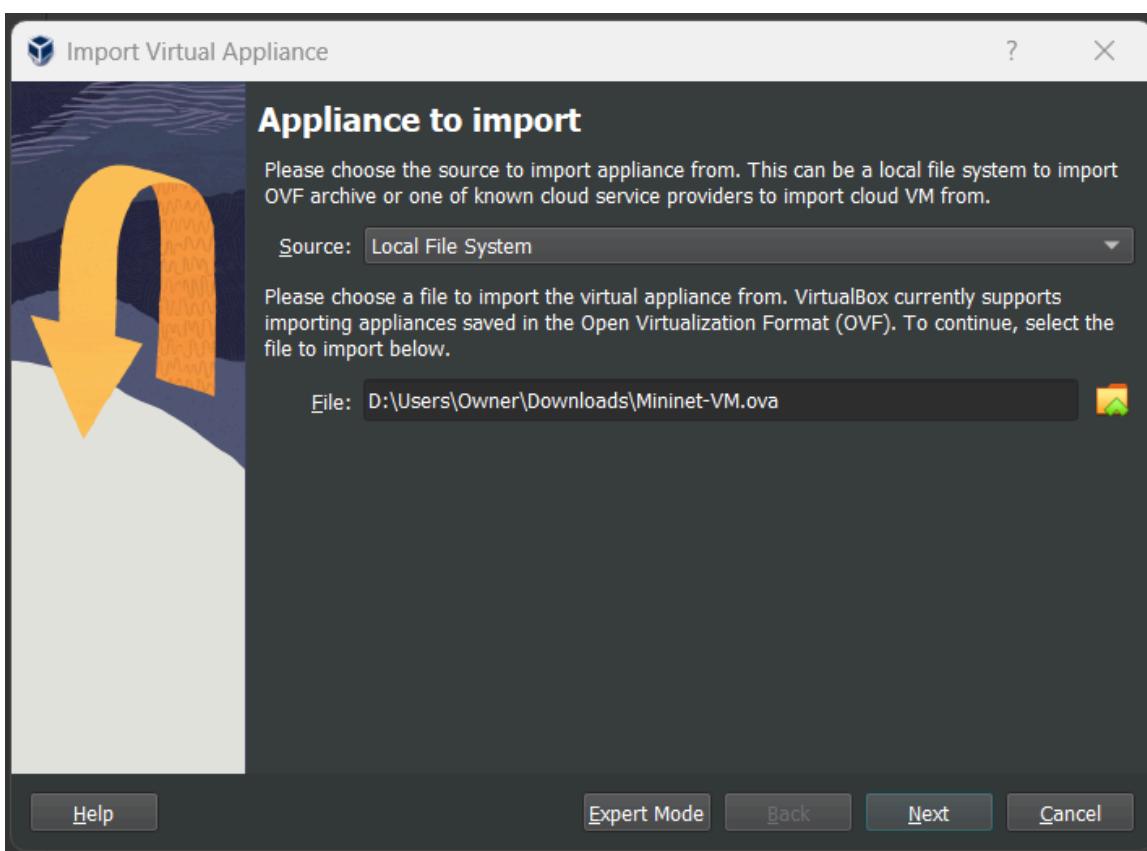
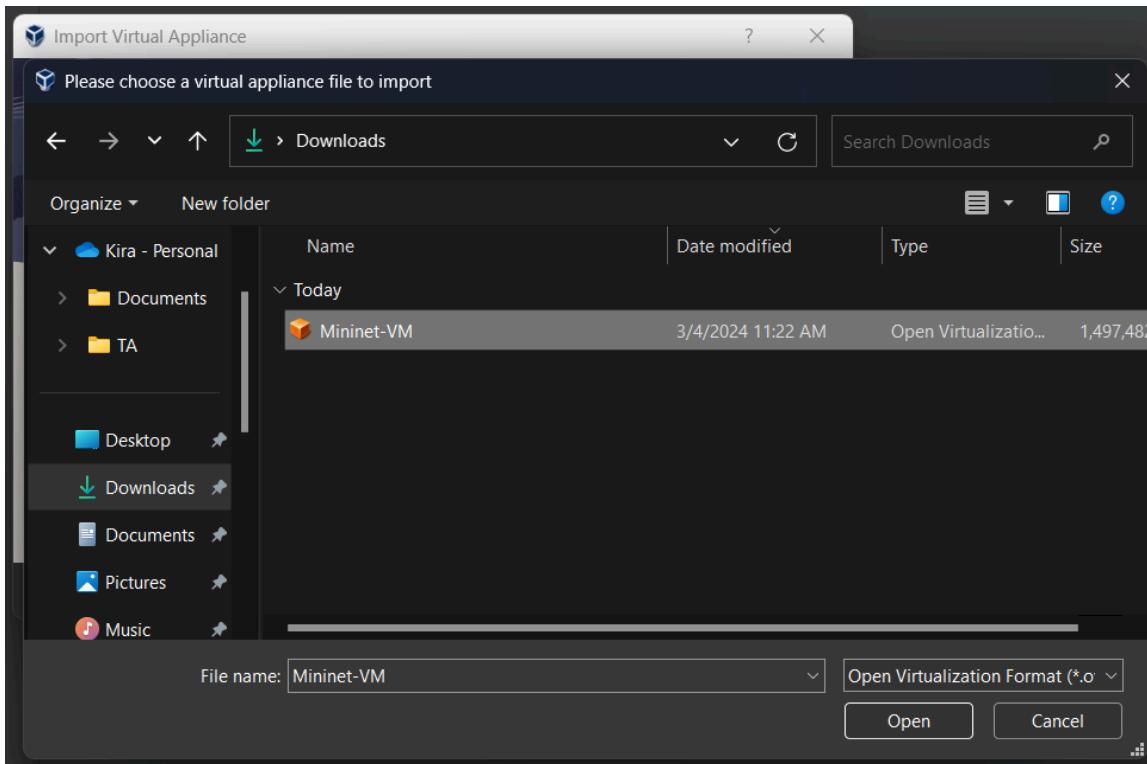
2. Open the File menu by clicking the “File” button at the top-left corner of the screen and select “Import Appliance...”.



3. Click the folder icon with the green up-arrow to the right of the “File:” textbox, navigate to your Downloads folder, and select the Mininet-VM.ova file that you downloaded. Afterward, click “Next”.

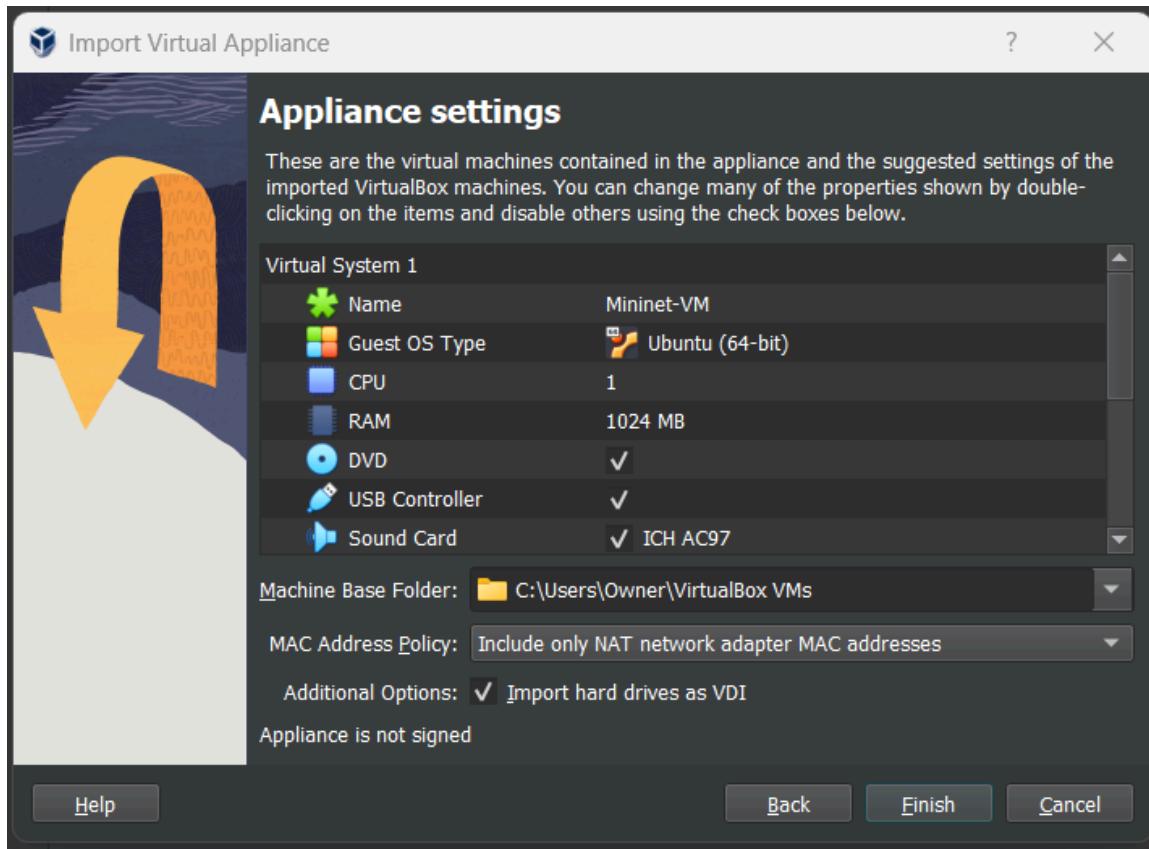


[Back To The Table of Contents](#)

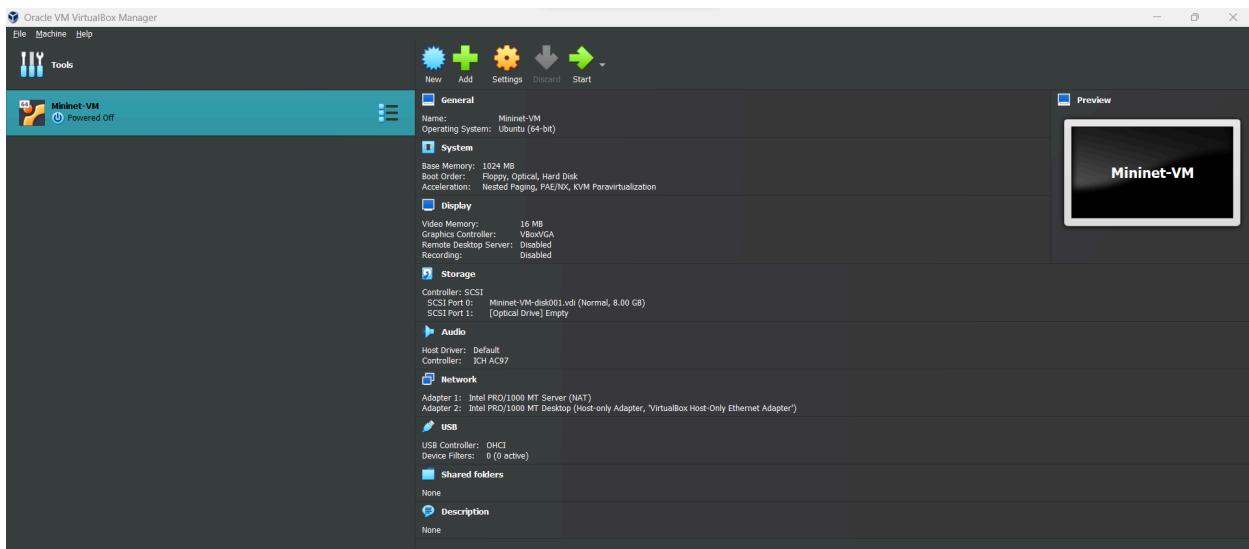


[Back To The Table of Contents](#)

- Leave the default appliance settings as they are and click “Finish”.

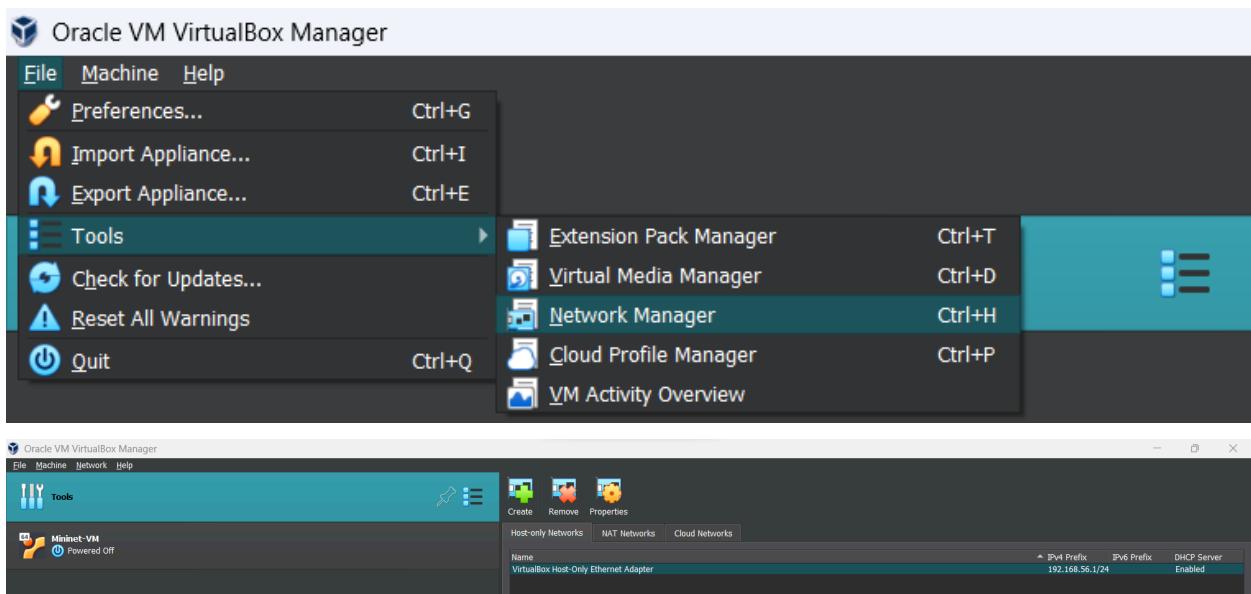


### 2.1.3 Finish VM Setup



[Back To The Table of Contents](#)

1. Open the File menu again, hover over the “Tools” menu, and select “Network Manager”.



2. Click the “Create” button with the green plus symbol at the top of the screen. This will result in a new Ethernet adapter being added to the list of Host-only Networks. You should see a new network named “VirtualBox Host-Only Ethernet Adapter #2”, “HostNetwork2”, or something similar depending on the number of adapters that were previously created and which OS your machine is running.



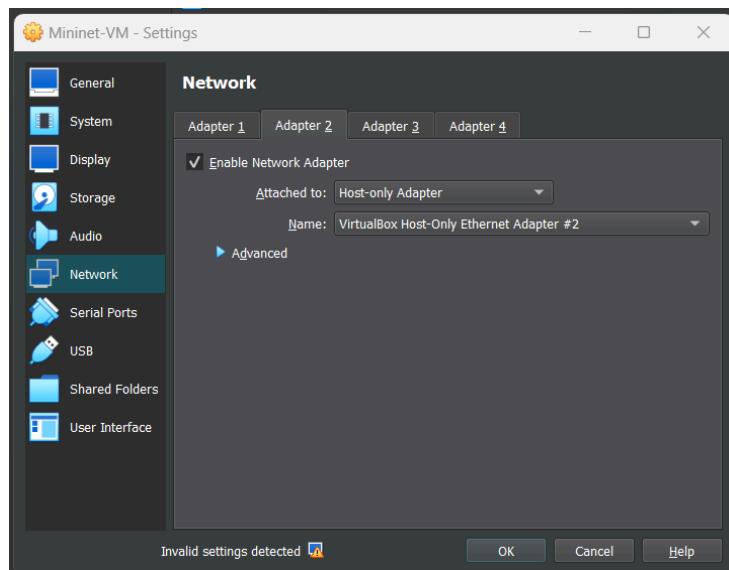
**Note:** Steps 3 and 4 are only for Windows machines. Skip if you’re using a Mac device.

3. Make sure that the new adapter is selected (i.e., highlighted), and then click the “Properties” button at the top of the screen. A new window should appear at the bottom of the right half of the screen.
4. Click the “DHCP Server” tab, check the “Enable Server” checkbox, and click “Apply”.

**Note:** The Host-only interface allows your VM to communicate with the host machine and it is the access point where you can SSH into your VM.

The image consists of three vertically stacked screenshots of a network configuration interface. Each screenshot shows two tabs at the top: 'Adapter' (selected) and 'DHCP Server'. The first screenshot shows the 'Adapter' tab with the 'Configure Adapter Manually' option selected. It displays fields for IPv4 Address (192.168.193.1), IPv4 Network Mask (255.255.255.0), IPv6 Address (fe80::958c:eb5d:7e36:9695), and IPv6 Prefix Length (64). The second screenshot shows the 'DHCP Server' tab with the 'Enable Server' checkbox checked. It displays fields for Server Address (192.168.193.2), Server Mask (255.255.255.0), Lower Address Bound (192.168.193.3), and Upper Address Bound (192.168.193.254). The third screenshot shows the 'Adapter' tab again, with the 'Enable Server' checkbox checked. The fields are identical to the second screenshot.

- Click on the Mininet-VM and then on the “Settings” button. Select the “Network” tab and then the “Adapter 2” tab. Click the “Name:” dropdown, select the option with the name of your newly created Ethernet network, and then click “OK”.



[Back To The Table of Contents](#)

## 2.1.4 Start the Mininet VM

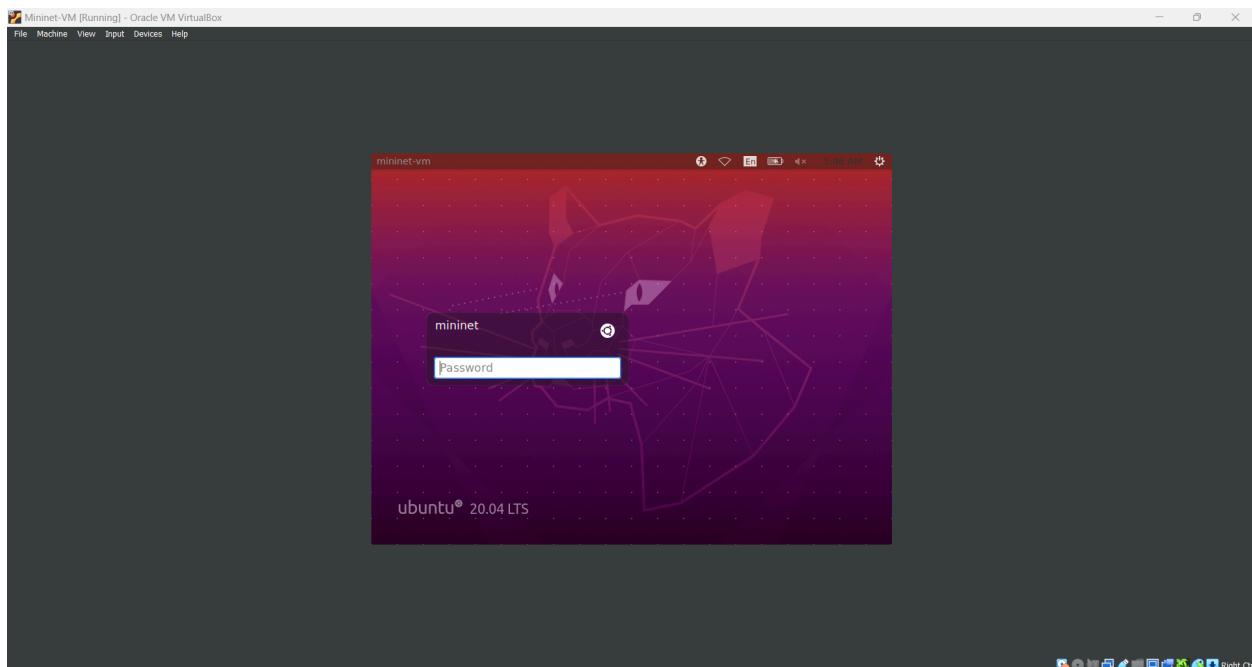
1. The Mininet VM can be started by either double-clicking the Mininet-VM tab or clicking the Mininet-VM tab once and then the “Start” button with the green right-pointing arrow at the top of the screen.

**Note:** If the VM is crashing immediately on startup, then try making the following changes in the VM’s settings to resolve the issue:

- In the “**Motherboard**” tab of the “**System**” settings, increase the VM’s base memory to 4096 MB.
- In the “**Processor**” tab of the “**System**” settings, increase the number of cores for the VM to 2 or 4.
- In the “**Display**” tab, check the “**Enable 3D Acceleration**” checkbox.
- In the “**Display**” tab, change the Graphics Controller to “**VMSVGA**”.

Additionally, if your VM won’t boot to login, check your [BIOS/UEFI](#) settings on your host machine to ensure that virtualization is enabled. To do this, you will need to look up how to access the BIOS for your specific machine. For example, a Lenovo laptop can access its BIOS by restarting and hitting enter as soon as the initial boot screen appears, and from there, the BIOS configuration can be accessed.

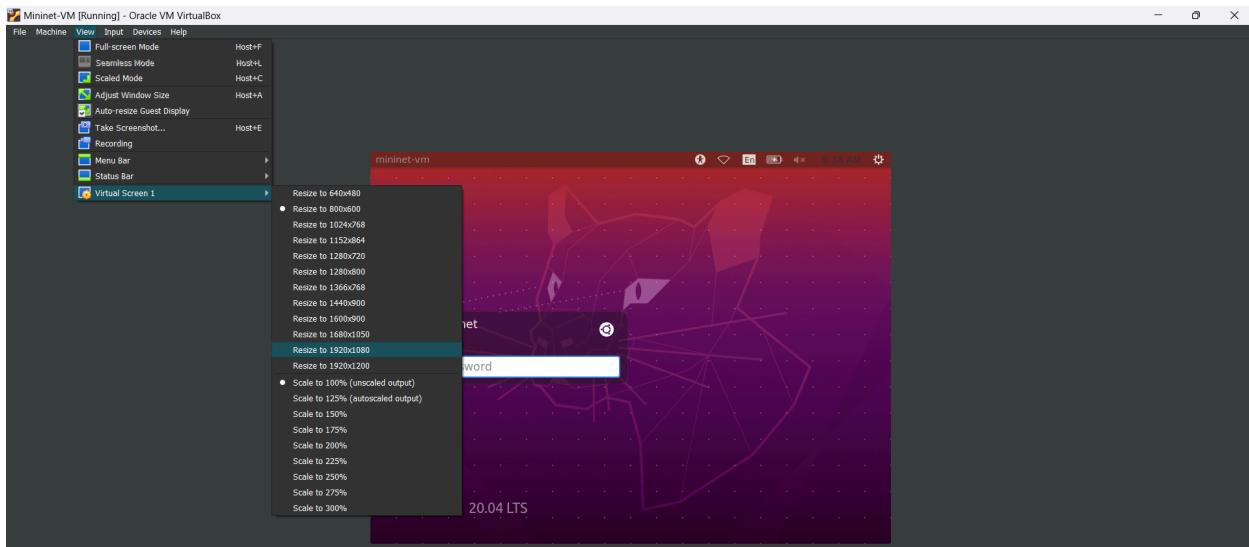
2. Your VirtualBox window should look like the following screenshot once the VM is booted.



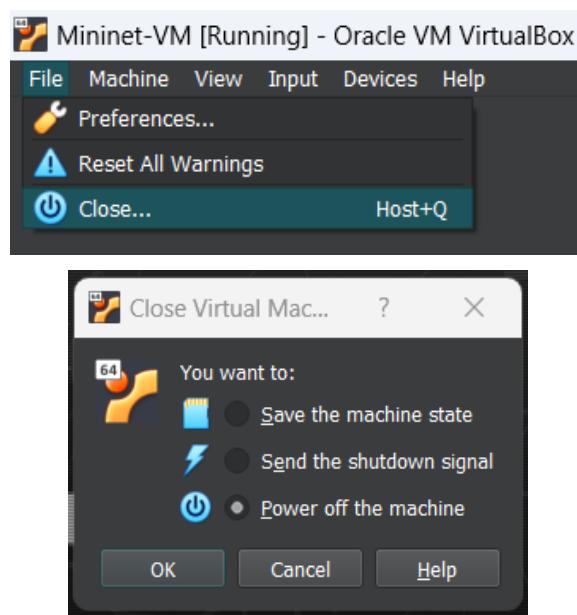
[Back To The Table of Contents](#)

**Note:** Complete steps 3 - 5 if you wish to have the Mininet VM's screen be full size (or any other size). Otherwise, skip them if you're content with using the VM as is.

3. Click the “**View**” menu in the top-left corner, hover over the “**Virtual Screen 1**” option, and click the appropriate resize option according to the specifications of the host machine and your preference. The “**Resize to 1920x1080**” option is a good starting point for most screens.

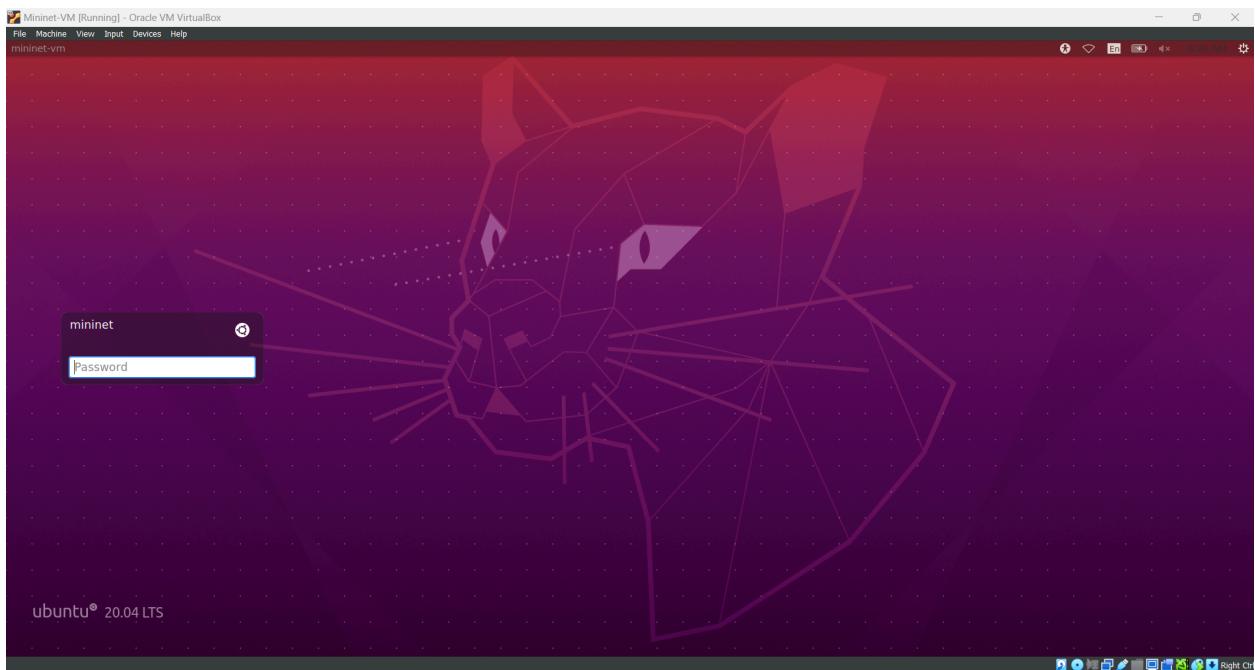


4. For the change to take effect, you will need to shut down the VM by opening the File menu, clicking the “**Close...**” option, selecting the “**Power off the machine**” radio button, and clicking “**OK**”.



[Back To The Table of Contents](#)

5. Restart the Mininet VM and your screen should now look like the following screenshot or something similar depending on your selected resolution.



6. Both the VM's username and password are “**mininet**” (without the quotation marks).

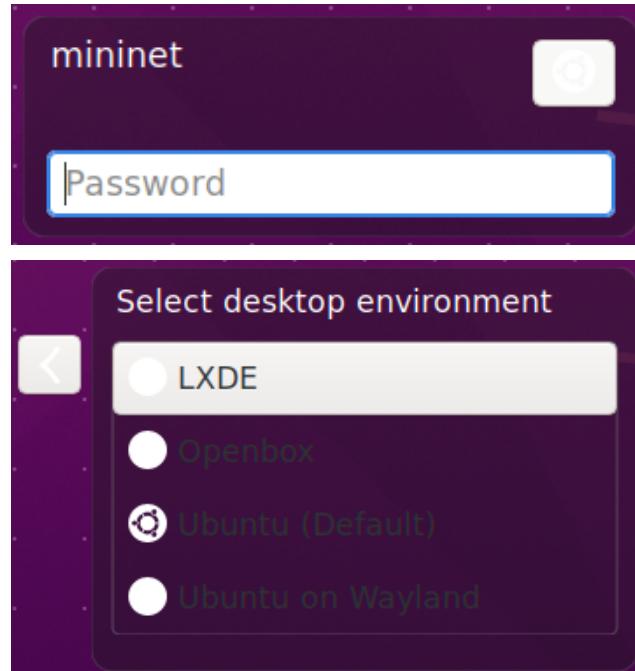
**Note:** The “mininet” user account has **sudo** privileges, so you can execute commands with root permissions by typing **sudo <command>**, where **<command>** is the command you wish to execute with root permissions.

Right now, if you enter the password, then you will get the following error message.

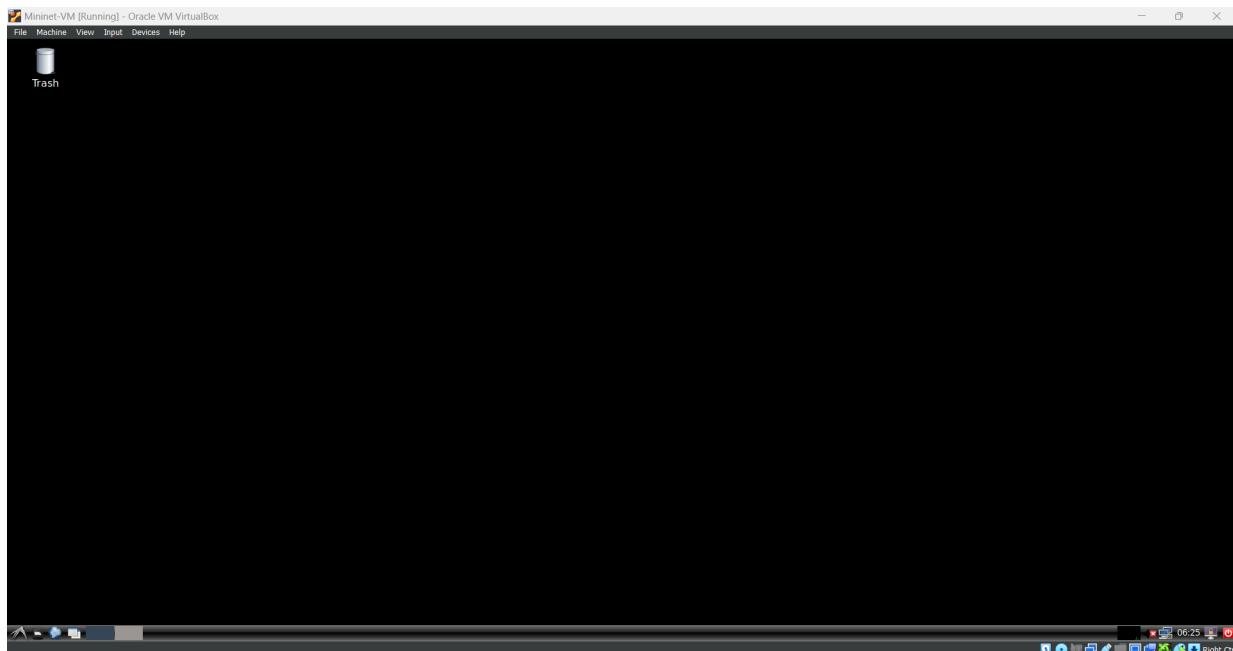


[Back To The Table of Contents](#)

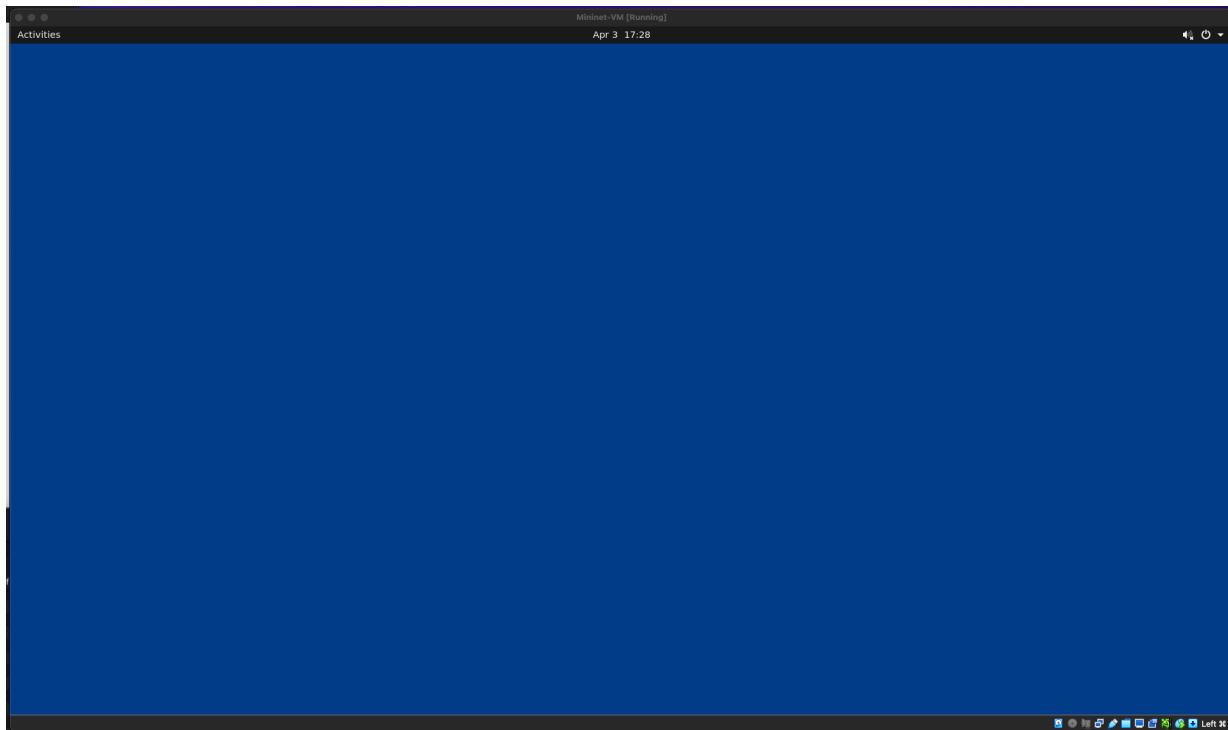
To prevent this from occurring, you will need to click the circular icon in the top-right corner of the password box and change the desktop environment from “Ubuntu (Default)” to “LXDE”.



After changing this, you should now be able to log in without any issues and your screen should look like one of the following screenshots for Windows and Mac machines, respectively:

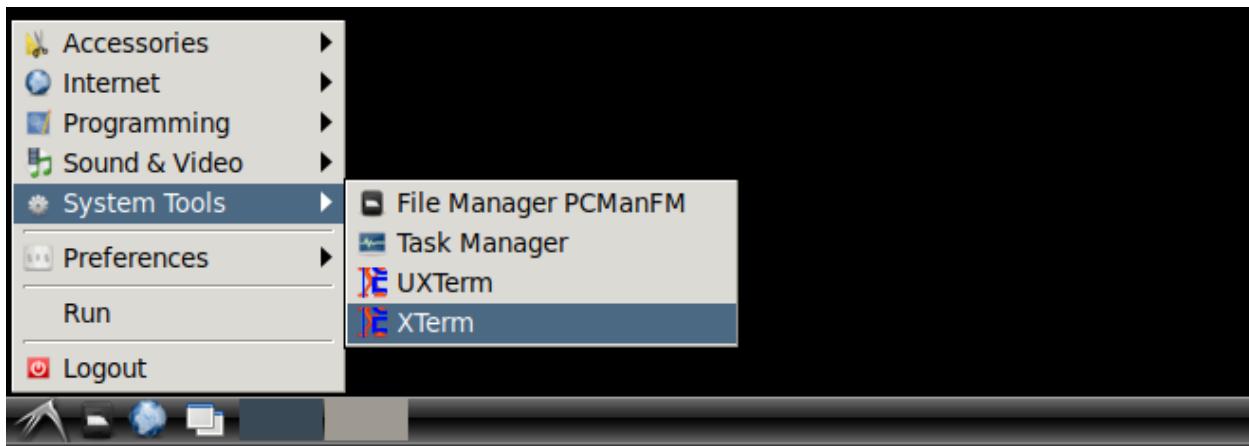


[Back To The Table of Contents](#)

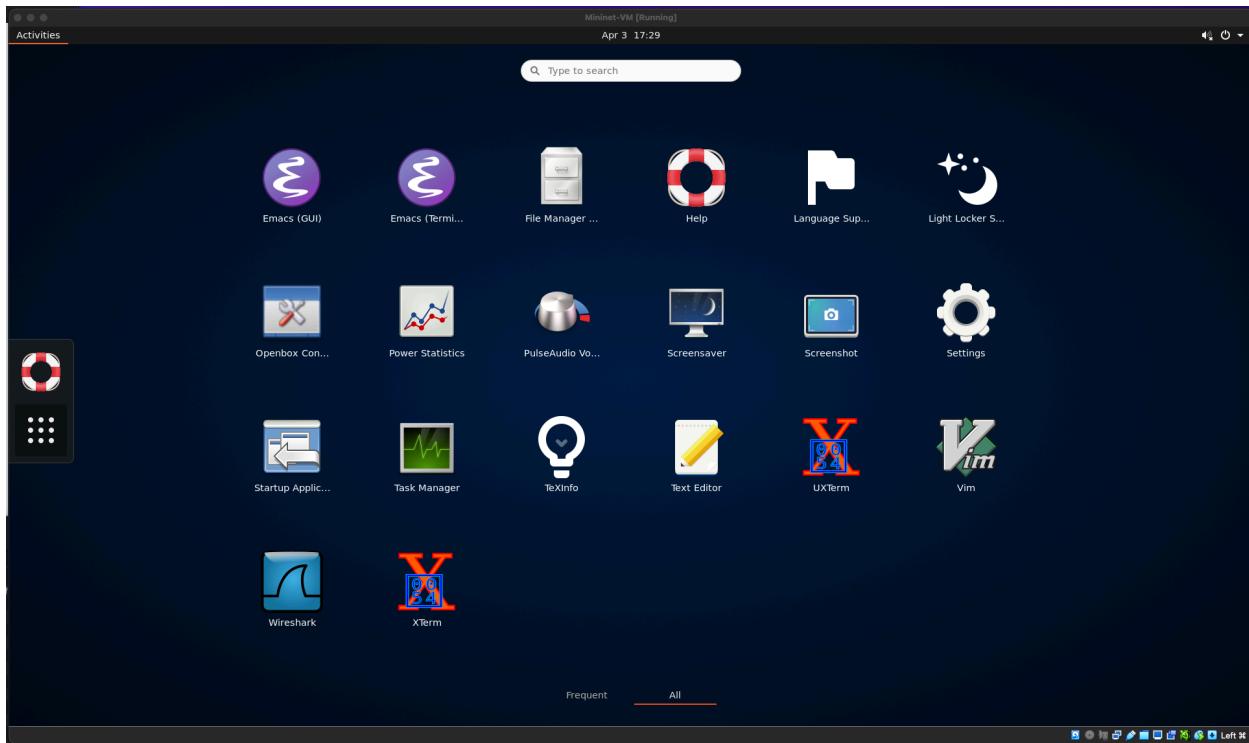


### 2.1.5 Use An XTerm Terminal Inside Your VM

For Windows machines: While your Mininet VM is running, click on the “**Menu**” button at the bottom-left of the screen, hover over the “**System Tools**” option, and click the “**XTerm**” option. This will open an XTerm terminal.



For Mac machines: While your Mininet VM is running, click the “**Activities**” button in the top-left corner. Then click on the 3-by-3 dotted square icon that appears on the left-hand side of the screen to show all of the available applications in the VM. Afterward, click on the XTerm icon to open an XTerm terminal.

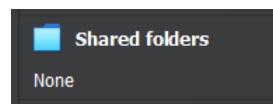


This approach is the simplest and quickest way to have access to an XTerm terminal which you'll need to complete this project.

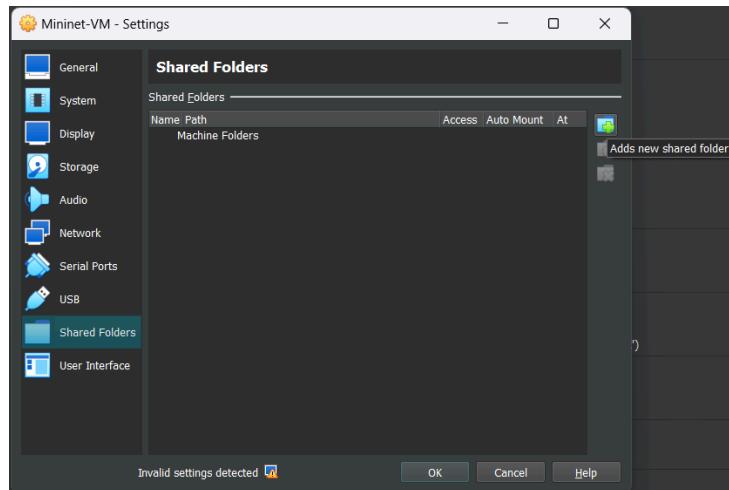
### 2.1.6 Enable and Setup Shared Folder (Optional)

**Note:** Before you start the following steps, you will need to make sure that the Mininet VM is off and was previously closed using the “**Power off the machine**” option (see [Section 2.1.4](#) Step 4). If it was closed using a different option and you try to apply the following (or any) changes to your VM’s settings, then it won’t work and you’ll receive an error message.

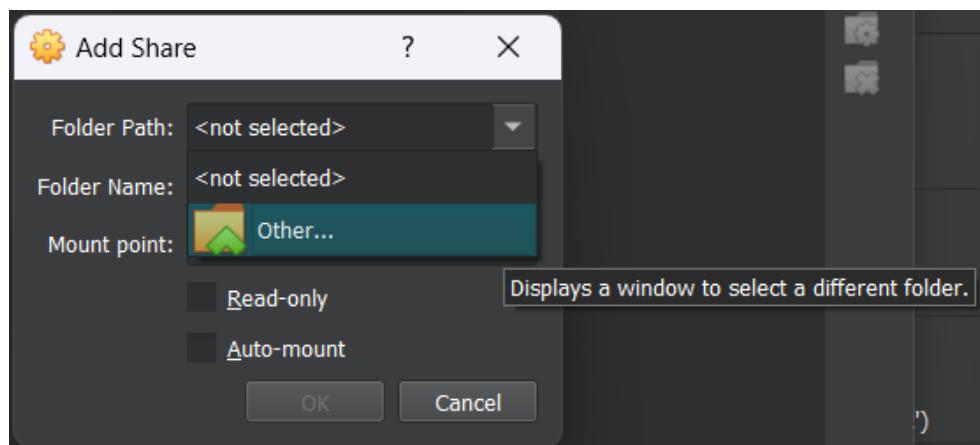
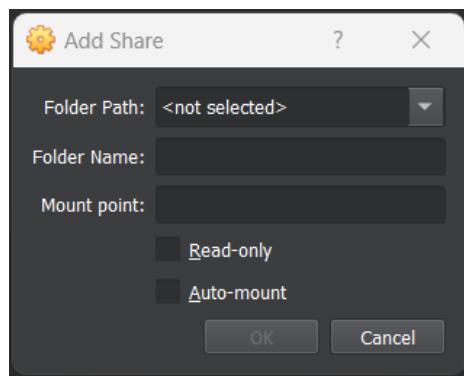
1. By default, your Mininet VM won’t have any shared folders added, and this part of the VM’s configuration should confirm this as shown below.



2. Click on the Mininet-VM and then on the “**Settings**” button. Select the “**Shared Folders**” tab. Click the blue folder icon with the green plus button on the right side of the Settings window.

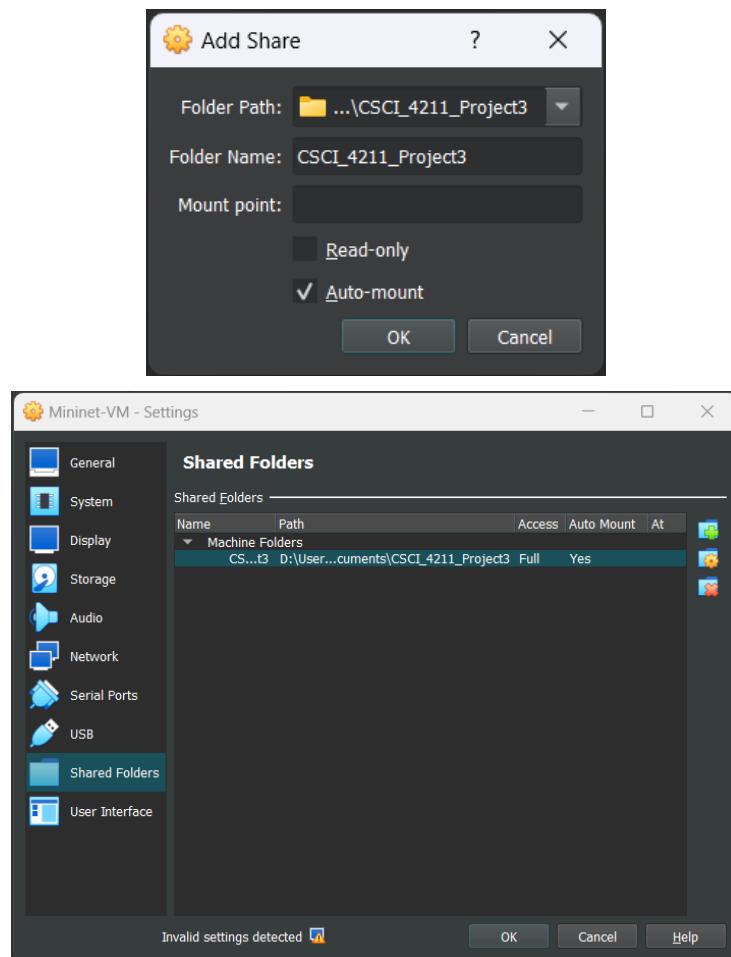


3. In the new window that pops up, click the down-arrow at the end of the “**Folder Path:**” field. Select the “**Other...**” option and navigate to the folder you want to share with the VM.

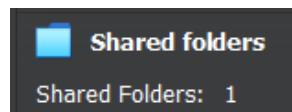


[Back To The Table of Contents](#)

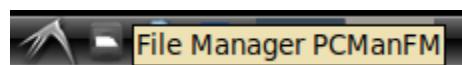
4. Check the “Auto-mount” checkbox so that the guest OS will try to automatically mount the shared folder when it starts up. Click “OK” for both of the following windows.



After applying the changes, you should now see that the VM’s configuration shows that one shared folder has been successfully added.

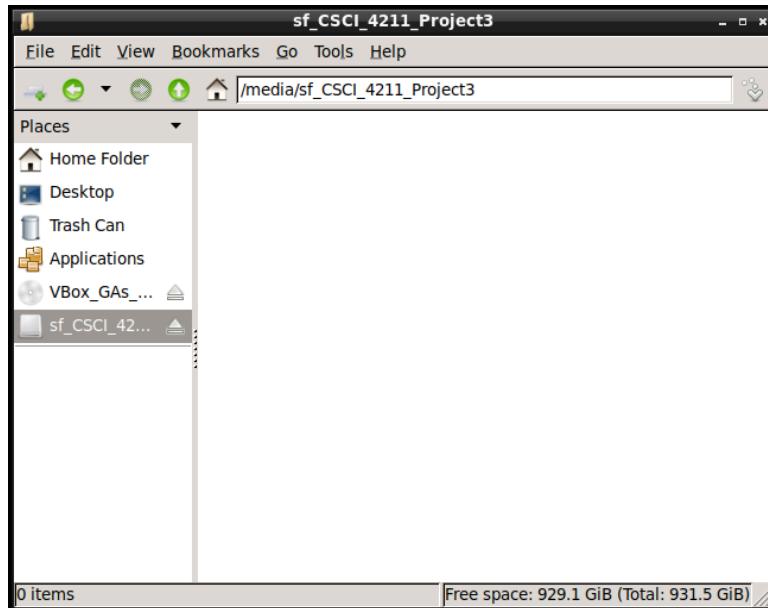


5. To see the true effect of this change, start the VM. Open the File Manager by clicking the second leftmost icon in the taskbar located at the bottom-left of the VM’s screen.



[Back To The Table of Contents](#)

6. In the File Manager, at the bottom of the lefthand column, you should see a tab named `sf_<Shared folder name>` where `<Shared folder name>` is the name of the folder on your local host that you shared with the VM. Click on this tab.



If your shared folder already contained the project files before you shared it, then you should see those files appear in the VM's File Manager. Otherwise, the folder will be empty like in the screenshot above. Also, any files that you place in this folder inside the VM should appear in the shared folder on your local host.

**Note:** To access/run files in this folder in a terminal, you will need to change directories using the following path: `/media/sf_<Shared folder name>`

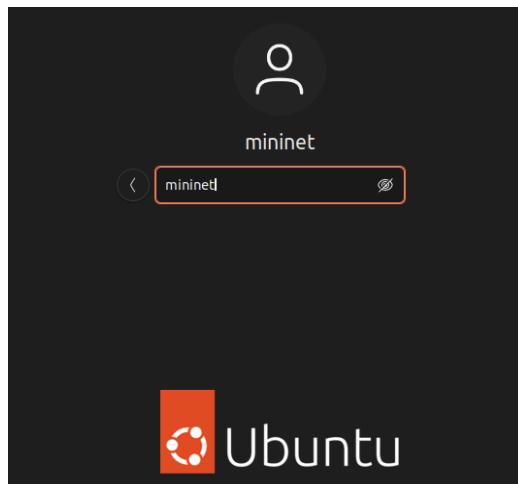
Hopefully, you can see how convenient this approach is and use it to your full advantage.

## 2.2 macOS with M1/M2/M3 chips

For Mininet Installation on Apple Mac M1/M2/M3 machines, please follow these instructions.

### 2.2.1 Download The Required Software/Tools

1. Watch and follow the **first 10 minutes ONLY** of this [YouTube video](#) to install UTM and Ubuntu Server and Desktop:
  - a. [Download](#) UTM to be able to run Linux on your machine.
  - b. [Ubuntu Server for ARM](#):
    - i. Download the version 22.04.4 LTS
    - ii. Follow the Installation Steps according to the YouTube video
    - iii. Once you are done, log in using the following credentials:
      1. Username: mininet
      2. Password: mininet
    - iv. Execute the following commands in the terminal:
      1. `sudo apt update`
      2. `sudo apt upgrade`
    - v. Install the Ubuntu Desktop on top of the Ubuntu Server: `sudo apt install ubuntu-desktop -y`
    - vi. After the installation is done, enter `reboot` in the terminal.
    - vii. You should now see the Linux Desktop login screen: The username and password are still “**mininet**” (without quotation marks).

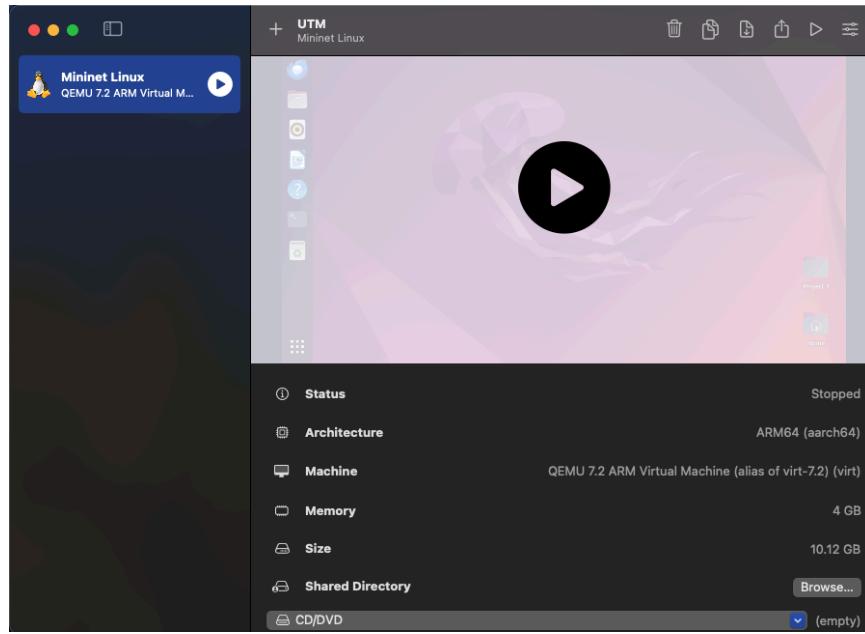


2. To install Mininet, follow the steps listed in [Section 2.3](#).

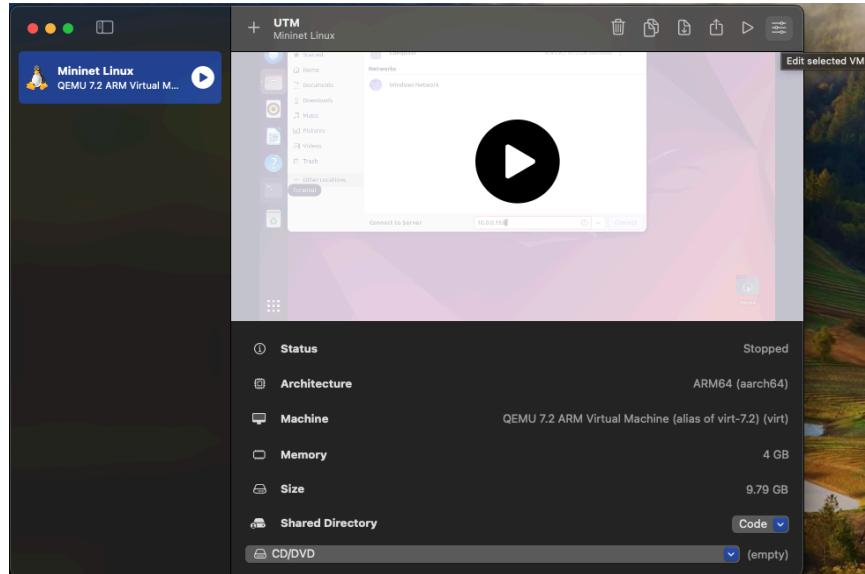
[Back To The Table of Contents](#)

## 2.2.2 Enable and Setup A Shared Folder (Optional)

1. In the UTM, select the Mininet Linux VM. Click on the “**Browse...**” dropdown to the right of the “**Shared Directory**” and navigate to the folder you want to share with the VM.

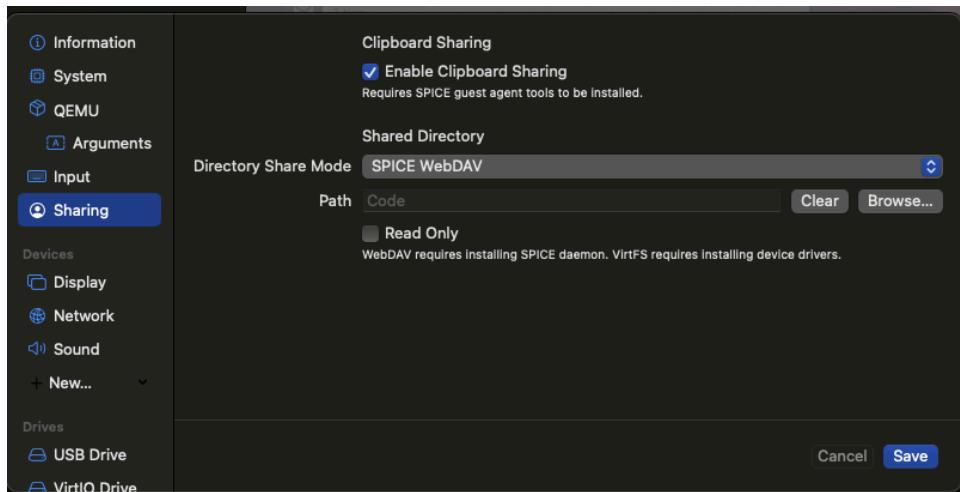


2. Click the “**Edit selected VM**” button in the top-right corner.



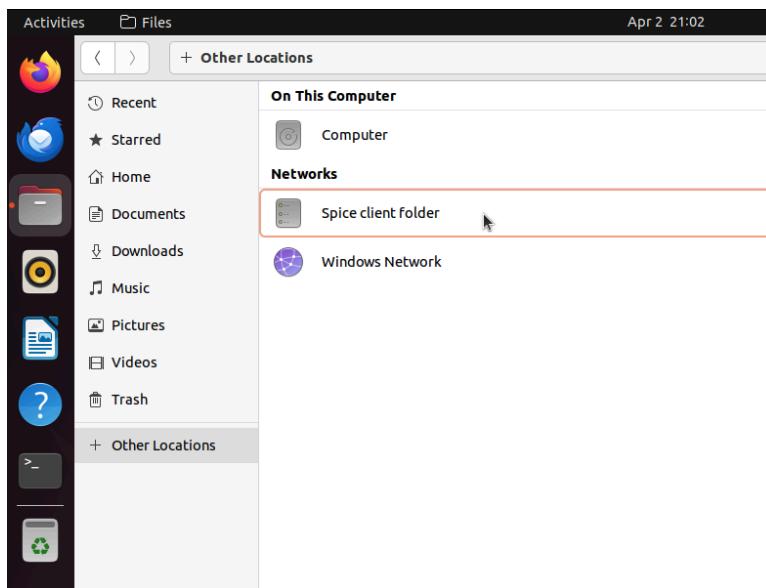
[Back To The Table of Contents](#)

3. Click on the “Sharing” tab and change the settings to match the following screenshot and click “Save”.



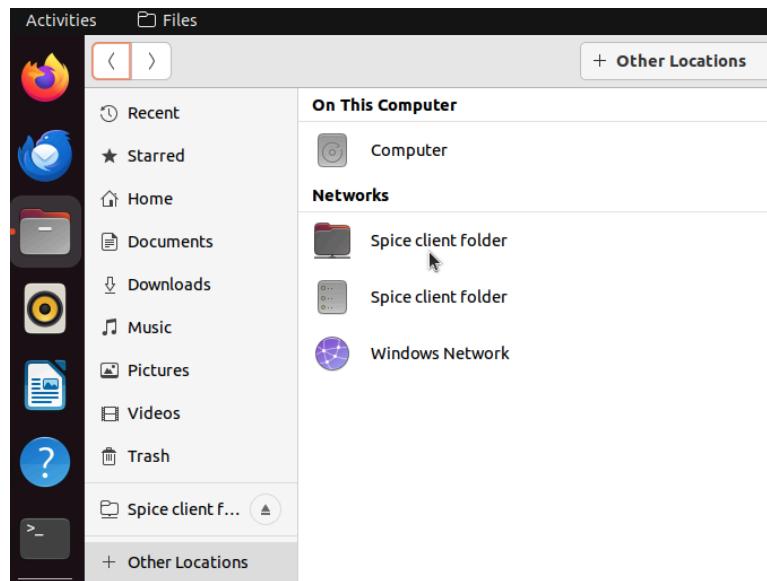
4. Start the VM. Inside a terminal, run the following [commands](#):
  - `sudo apt install spice-vdagent`
  - `sudo apt install qemu-guest-agent`
  - `sudo apt install spice-webavd`
5. Open the file system inside of the VM and click on the “Other Locations” tab. You should be able to see the “Spice client folder” under “Networks”.

**Note:** If you don't see this, then restart the VM.

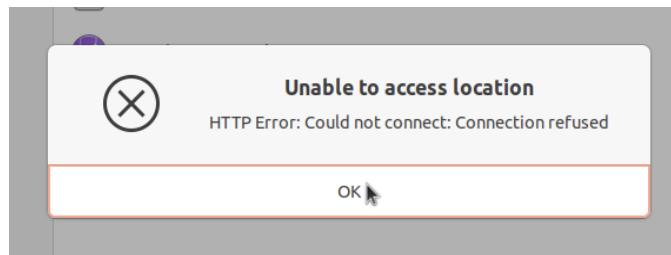


[Back To The Table of Contents](#)

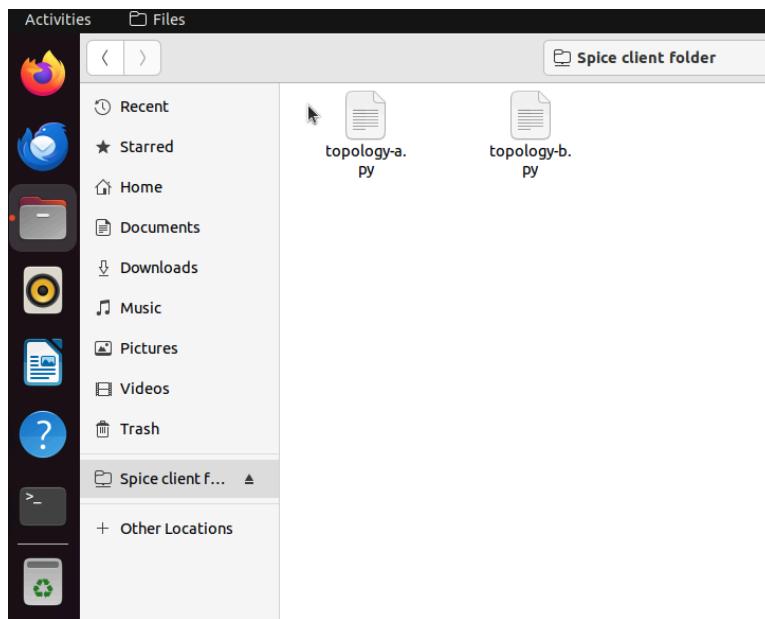
6. Double-click the “**Spice client folder**”. You should see a new folder appear with an eject icon next to it. This is your shared folder from the UTM.



**Note:** If you get the following error, then give the system a few minutes and try again - it takes some time after starting the VM for the shared directory to become accessible.



7. Open this folder. You should now see the contents of the folder from your host machine that you shared with your VM. Now you can share files back and forth with your VM!



8. You can then create a Project 3 folder on your VM desktop and copy these files inside to access them from VSCode.

Note: You will need to copy the files from this new Project 3 directory in your VM back to the “**Spice client folder**” for your local host to be able to access the updated files.

## 2.3 Linux

Mininet can be installed directly onto your machine by following [these](#) instructions (only Option 2). Here are the instructions you need to follow:

1. Open a terminal and install Mininet using this command:
  - `git clone https://github.com/mininet/mininet`
  - `cd mininet`
  - `git tag # list available versions`
  - `git checkout`
  - `cd ..`
  - `mininet/util/install.sh -a`

2. After the installation, test Mininet is working with this command:  
**mininet/util/install.sh -a**
  
3. Everything has now been installed from the original Mininet VM including XTerm and Wireshark.

**Note:** Linux OS has an X Server installed by default.

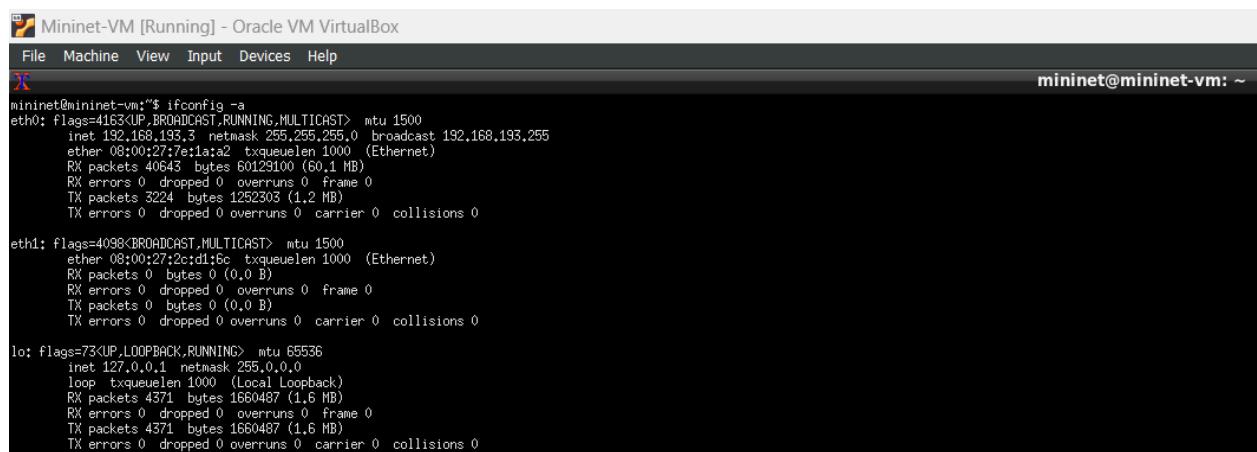
## 3. SSH and Copy Files (For Windows/macOS Only)

### 3.1 SSH Into Your Mininet VM

**Note:** Your Mininet VM must be running first before you can SSH into it.

To SSH into your Mininet VM, you will need the IPv4 address that was assigned to it.

1. Open a terminal inside your VM.
  
2. In this terminal, enter the following command: **ifconfig -a**.
  
3. In the terminal output, look for the IPv4 address with a 192.168.x.y prefix (e.g., 192.168.193.3). This is the IP address that you will use when SSH'ing into your Mininet VM.



```

Mininet-VM [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
mininet@mininet-vm: ~
K

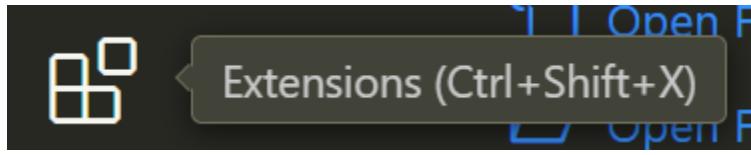
mininet@mininet-vm:~$ ifconfig -a
eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
        inet 192.168.193.3 netmask 255.255.255.0 broadcast 192.168.193.255
              ether 08:00:27:e1:a2 txqueuelen 1000 (Ethernet)
              RX packets 40643 bytes 60129100 (60.1 MB)
              RX errors 0 dropped 0 overruns 0 frame 0
              TX packets 3224 bytes 1252303 (1.2 MB)
              TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

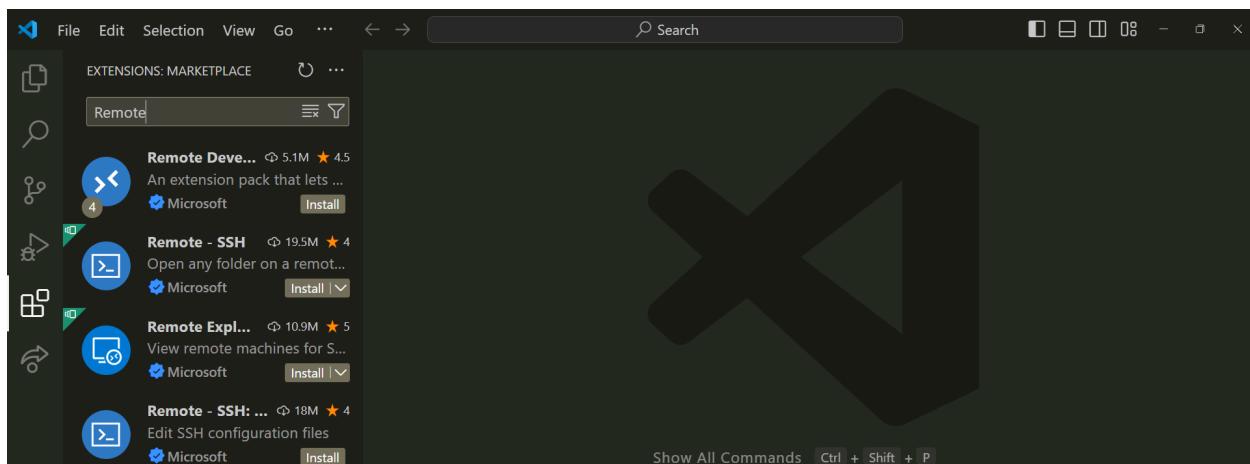
eth1: flags=4098<BROADCAST,MULTICAST> mtu 1500
        ether 08:00:27:2c:d1:b6 txqueuelen 1000 (Ethernet)
        RX packets 0 bytes 0 (0.0 B)
        RX errors 0 dropped 0 overruns 0 frame 0
        TX packets 0 bytes 0 (0.0 B)
        TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

lo: flags=73<UP,LOOPBACK,RUNNING> mtu 65536
        inet 127.0.0.1 netmask 255.0.0.0
          loop txqueuelen 1000 (Local Loopback)
          RX packets 4371 bytes 1660487 (1.6 MB)
          RX errors 0 dropped 0 overruns 0 frame 0
          TX packets 4371 bytes 1660487 (1.6 MB)
          TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0
    
```

**Note:** Before you try to SSH to your Mininet VM, verify that your local host can reach your Mininet VM by Pinging the Mininet VM's IP address that you just found (**ping -c 3 <YOUR\_VM\_IP\_ADDRESS>**).

Two different approaches can be used to do the SSH:

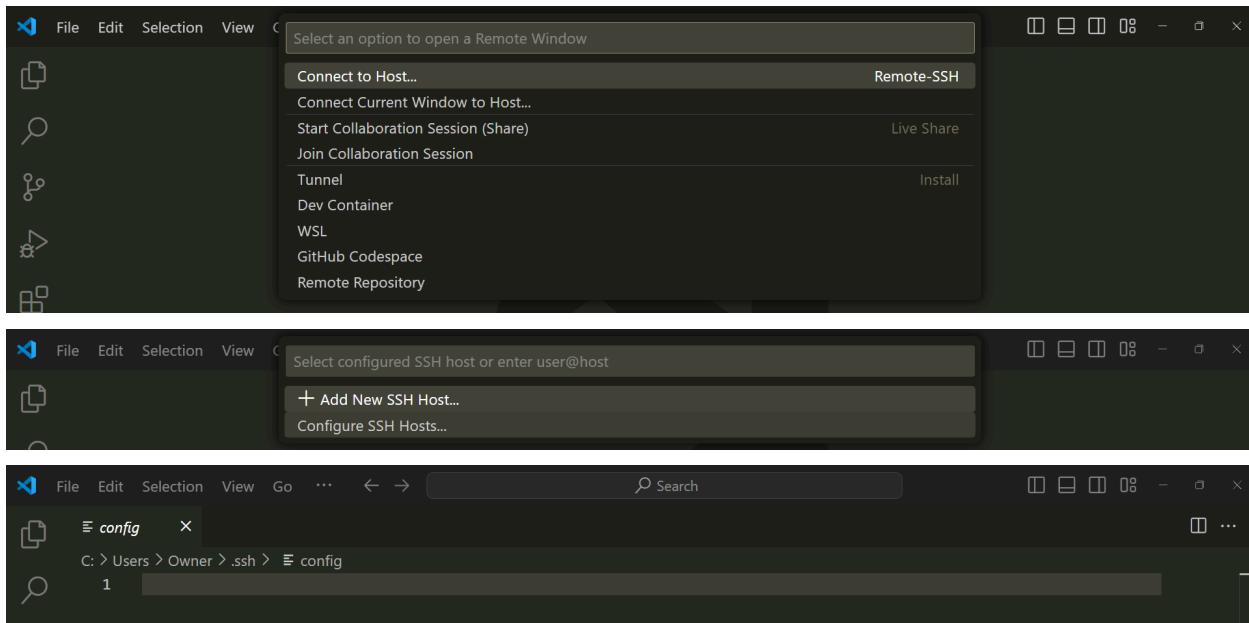
1. **[Recommended Approach]** Use Visual Studio Code (“VSCode”).
  - a. [Download](#) and install VSCode onto your local machine if it's not already installed.
  - b. Start VSCode.
  - c. Click on the “**Extensions**” icon located on the left-hand side of the screen.
  - d. Type the string “**Remote**” into the search bar. You should install the “**Remote - SSH**”, “**Remote Explorer**”, and “**Remote - SSH: Editing Configuration Files**” extensions.



There should now be a “><” icon at the bottom-left corner of the VSCode window.



- e. Click the “><” button, the “**Connect to Host...**” option, and then the “**Configure SSH Hosts...**” option. Depending on whether or not you already had VSCode installed on your local machine and the Remote SSH extensions installed, the configuration file that opens may or may not be populated. Either way is fine for this project.



- f. Add a new entry to the configuration file that looks like the following example. You should replace the IPv4 address in the screenshot with the one that was assigned to your Mininet VM which can be found by following the initial steps listed in this [section](#).

A screenshot of the VSCode code editor showing the "config" file. The file contains the following content:

```

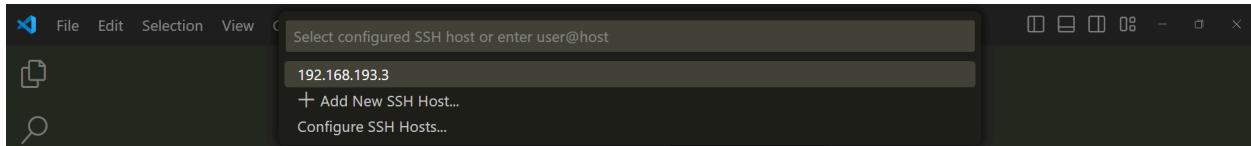
Host 192.168.193.3
HostName 192.168.193.3
ForwardX11 yes
User mininet

```

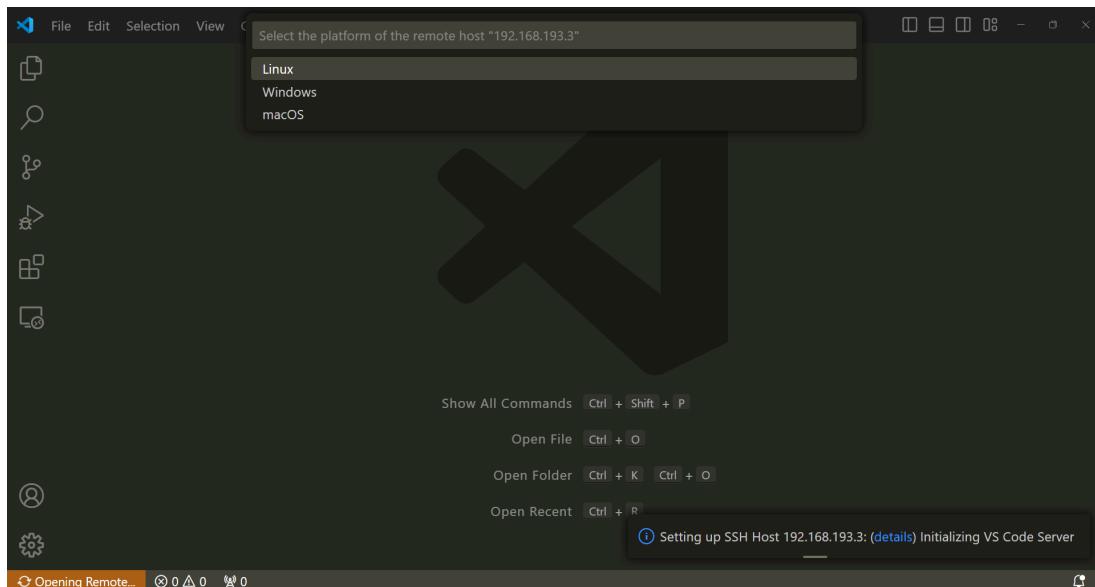
The file path shown in the status bar is "C: > Users > Owner > .ssh > config".

[Back To The Table of Contents](#)

- g. Save the changes made to the configuration file and close it. Click the “><” icon again at the bottom-left corner of the screen and click the “**Connect to Host...**” option. You should now see a new entry in the remote host list whose name is the IPv4 address of your Mininet VM.

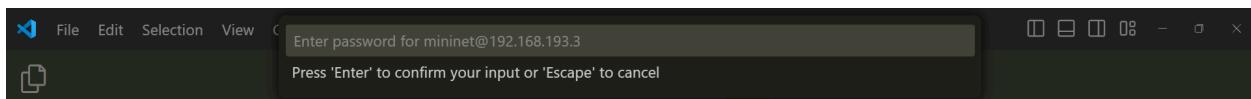


- h. Click on this entry and select Linux as the OS since that's what the Mininet VM uses.



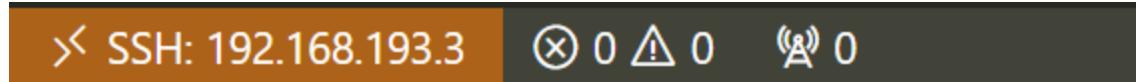
- i. Enter the password “**mininet**” (without the quotation marks) into the textbox that appears.

**Note:** You may need to enter the password multiple times which is okay.

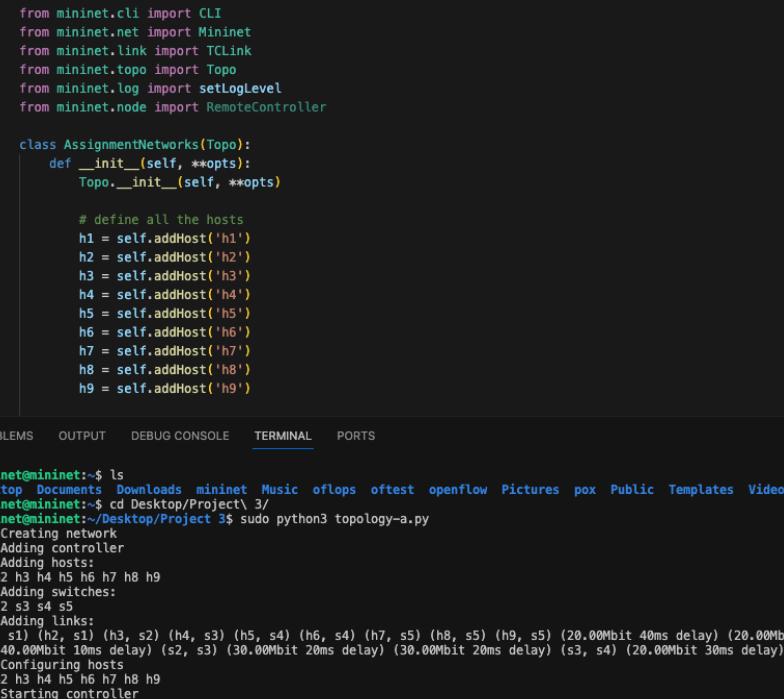


Afterward, you should see that the current window in VSCode has connected to your Mininet VM by looking at the button in the bottom-left corner and seeing that it now contains the IPv4 address of your Mininet VM.

[Back To The Table of Contents](#)



This will allow you the ability to access and edit the VM's files through a more user-friendly UI as shown in the screenshot below:



```
home > mininet > Desktop > Project 3 > topology-a.py ...
 1  #!/usr/bin/env python
 2
 3  from mininet.cli import CLI
 4  from mininet.net import Mininet
 5  from mininet.link import TCLink
 6  from mininet.topo import Topo
 7  from mininet.log import setLogLevel
 8  from mininet.node import RemoteController
 9
10 class AssignmentNetworks(Topo):
11     def __init__(self, **opts):
12         Topo.__init__(self, **opts)
13
14         # define all the hosts
15         h1 = self.addHost('h1')
16         h2 = self.addHost('h2')
17         h3 = self.addHost('h3')
18         h4 = self.addHost('h4')
19         h5 = self.addHost('h5')
20         h6 = self.addHost('h6')
21         h7 = self.addHost('h7')
22         h8 = self.addHost('h8')
23         h9 = self.addHost('h9')
24
PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS
● mininet@mininet:~$ ls
Desktop Documents Downloads mininet Music oflops oftest openflow Pictures pox Public Templates Videos
● mininet@mininet:~$ cd Desktop/Project\ 3/
○ mininet@mininet:~/Desktop/Project\ 3$ sudo python3 topology-a.py
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2 h3 h4 h5 h6 h7 h8 h9
*** Adding switches:
s1 s2 s3 s4 s5
*** Adding links:
(h1, s1) (h2, s1) (h3, s2) (h4, s3) (h5, s4) (h6, s4) (h7, s5) (h8, s5) (h9, s5) (20.00Mbit 40ms delay) (20.00Mbit 40ms delay)
y) (40.00Mbit 10ms delay) (s2, s3) (30.00Mbit 20ms delay) (30.00Mbit 20ms delay) (s3, s4) (20.00Mbit 30ms delay) (20.00Mbit 30ms delay)
*** Configuring hosts
h1 h2 h3 h4 h5 h6 h7 h8 h9
*** Starting controller
c0
*** Starting 5 switches
s1 s2 s3 s4 s5 ... (20.00Mbit 40ms delay) (20.00Mbit 40ms delay) (40.00Mbit 10ms delay) (40.00Mbit 10ms delay) (30.00Mbit 20ms delay)
(30.00Mbit 20ms delay) (20.00Mbit 30ms delay)
*** Starting CLI:
mininet> []
```

2. Use a local terminal (e.g., Command Prompt).

Open a local terminal on your host machine and enter the following command:  
`ssh mininet@<YOUR_VM_IP_ADDRESS>`

You can minimize VirtualBox and mainly interact with your Mininet VM through this terminal if you wish. However, you won't be able to use an XTerm terminal, so you'll still need to use VirtualBox or UTM VM for that.

### *3.2 Copying Files Between The Local Host and Your Mininet VM*

1. **[Recommended Approach]** Add a shared folder to your Mininet VM using the steps defined above:

By using this simple and effective approach, you'll be able to skip all of the tedious manual file copying between your local host and your Mininet VM that will need to occur if you decide to use one of the other approaches.

- a. For Windows and macOS (Except M1/M2/M3 chips), see [Section 2.1.6](#).
  - b. For macOS (with M1/M2/M3 chips), see [Section 2.2.2](#).
2. Manually copy files into and out of VSCode.

While SSH'ed into your Mininet VM through VSCode, you can open the local file you wish to have access to in the VM (e.g., `topology-a.py`), copy its entire contents, open a new file that's stored in the VM, and paste the contents of the file you copied into this new file. If you wish to export the contents of a file from the VM into a file on your local host, then you will need to do this same process but backward.

3. Use the `scp` (Secure Copy) command.

To copy files from your local host to the VM, in a terminal that's connected to your local host, navigate to the directory containing the file you wish to copy and enter a command using the following format: `scp <local file path> <VM user>@<VM machine IP>:<VM file path>`

Examples:

- `scp ~\Desktop\CSCI_4211\Project3\topology-b.py mininet@VM_IP:~/pox/pox/samples/`
- `scp -r ProjectCode mininet@192.168.56.102:/home/mininet`

To copy from the VM to your local host, in a terminal that's connected to your VM through SSH, navigate to the directory containing the file you wish to copy and enter a command using the following format: `scp <VM user>@<VM machine IP>:<VM path> <local file path>`

Example:

- `scp mininet@VM_IP:~/pox/pox/samples/simple_routing.py ~\Desktop\CSCI_4211\Project3\`

### 3.3 Use A Local XTerm Terminal (Optional)

**Note:** This is optional because you can use an XTerm terminal inside the VM as mentioned earlier in [Section 2.1.5](#). Also, this approach is a bit complicated to get working.

If you want to use a local XTerm terminal on your host machine to interact with the VM, then you need to [install an X Server and the appropriate terminal](#) corresponding to your host machine's OS. Follow the instructions at this [link](#) for more detailed information.

## 4. Mininet Walkthrough

Tasks:

1. Follow this [Mininet walkthrough](#) from start to finish.
2. Include your answers to the following questions in a PDF report:
  - a. Summarize your experience with setting up Mininet. Did you face any issues/challenges? If so, then how did you attempt to resolve them and did your attempts succeed?
  - b. Summarize what you have learned from the Mininet walkthrough tutorial.

## 5. Helpful Resources and General Advice

While almost *any* reference can be helpful to you, the following should be particularly useful when completing this project:

- [Introduction to Mininet video](#)
- [Introduction to Mininet](#)
- [scp\(1\) - Linux manual page](#)

**Get Started Early!** Don't wait until the last minute. Starting early will allow you the opportunity to have more time to promptly receive any help that you may require from the instructors and to calmly debug your code if any unexpected and/or difficult problems arise.

# 6. Submission Information

## 6.1 Rubric

Before submitting the project, be sure to verify all of your work by using the following rubric:

Criteria	Approximate % Grade	Excellent (100%)	Adequate (80%)	Poor (60%)	Not Met (0%)
<b>Mininet Setup Experience Summary</b>	30%	Provided a clear summary of their experience with setting up Mininet.	Provided a mostly clear summary of their experience with setting up Mininet.	Provided a somewhat unclear summary of their experience with setting up Mininet.	1.) Provided a completely unclear summary of their experience with setting up Mininet.  OR  2.) Didn't provide a summary of their Mininet experience.
<b>Encountered Issues</b>	10%	1.) Provided a clear explanation of any issues that were encountered and what attempts were made to resolve them.  OR  2.) Explicitly stated that no issues were encountered	Provided a mostly clear explanation of any issues that were encountered and what attempts were made to resolve them.	Provided a somewhat unclear explanation of any issues that were encountered and what attempts were made to resolve them.	1.) Provided a completely unclear explanation of any issues that were encountered and what attempts were made to resolve them.  OR  2.) Didn't mention issues at all in the submission.
<b>Walkthrough Summary</b>	60%	Provided a clear summary of what was learned from the Mininet walkthrough.	Provided a mostly clear summary of what was learned from the Mininet walkthrough.	Provided a somewhat unclear summary of what was learned from the Mininet walkthrough.	1.) Provided a completely unclear summary of what was learned from the Mininet walkthrough.  OR  2.) Didn't provide a summary of what was learned from the Mininet walkthrough.

## 6.2 What To Submit

A PDF, named g<GroupNumber>-project3-phase1-report.pdf where <GroupNumber> is the number of the Mininet Group you joined on Canvas (example: g1-project3-phase1-report.pdf). Refer to [Section 4](#) to see what this report should contain.

[Back To The Table of Contents](#)