Computer Networks
@CS.NCTU

Lab. 3: Route Configuration

Location: EC-114

Instructor: 陸勇盛 (David Lu)

Agenda

- Objectives
- Overview
- Tasks
- Submission
- Grading Policy
- References

Objectives

In this lab, we are going to write a Python program with Ryu SDN framework to build a simple software-defined network and compare the differences between two forwarding rules.

1. Learn how to build a simple software-defined networking with Ryu SDN framework
2. Learn how to add forwarding rules into each OpenFlow switch

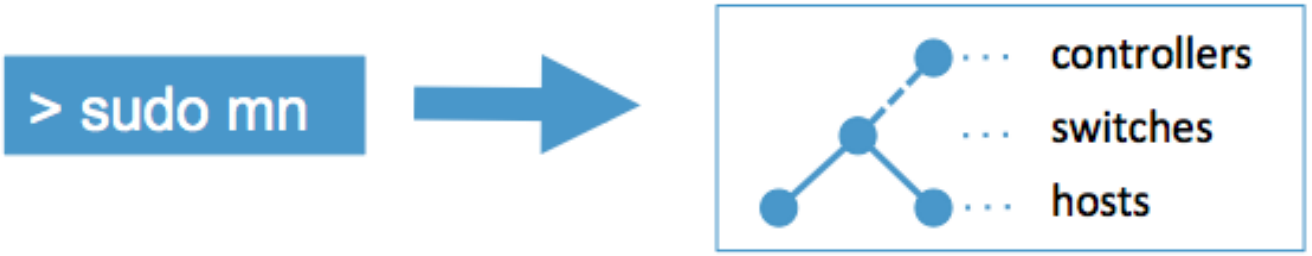
TODO

1. We will give you a Python code (SimpleTopo.py) that includes an example network topology and another Python code (SimpleController.py) that includes Ryu controller
2. We will get you a figure illustrating a topology you should generate
3. Copy the necessary function code from SimpleTopo.py and SimpleController.py to your Python code (topo.py and controller.py) to build your networks with forwarding rules

Overview

Mininet

- Mininet is a network emulator
  - Overview of Mininet - http://mininet.org/overview/
  - We have provided you a container that has installed Mininet
- Create a realistic virtual network, running real kernel, switch and application code, on a single machine (VM, cloud or native)
- Run a collection of end-hosts, switches, routers, and links on a single Linux kernel.

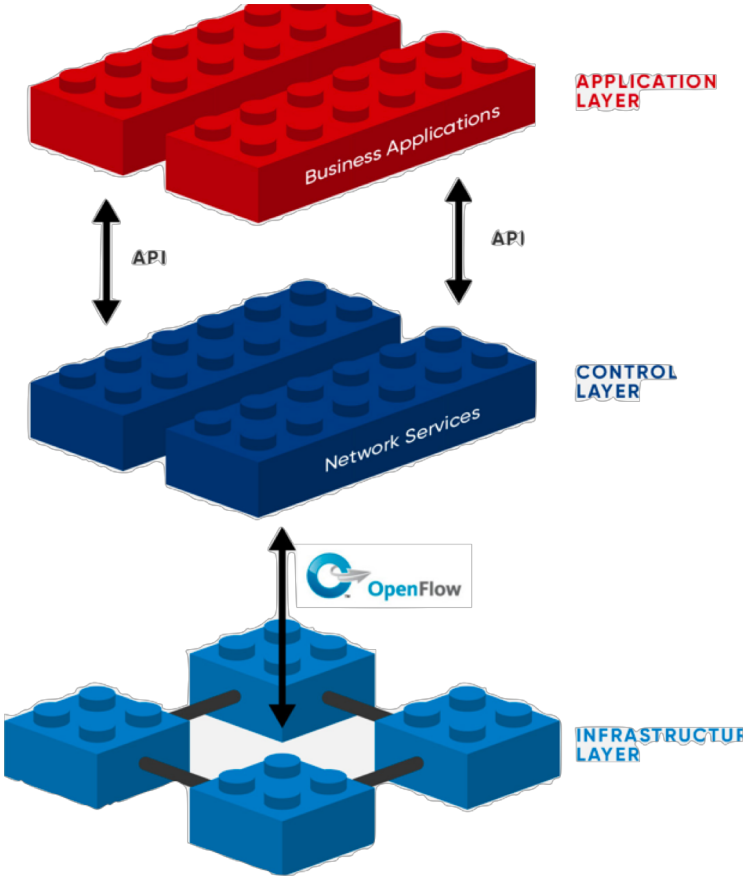


Mininet References

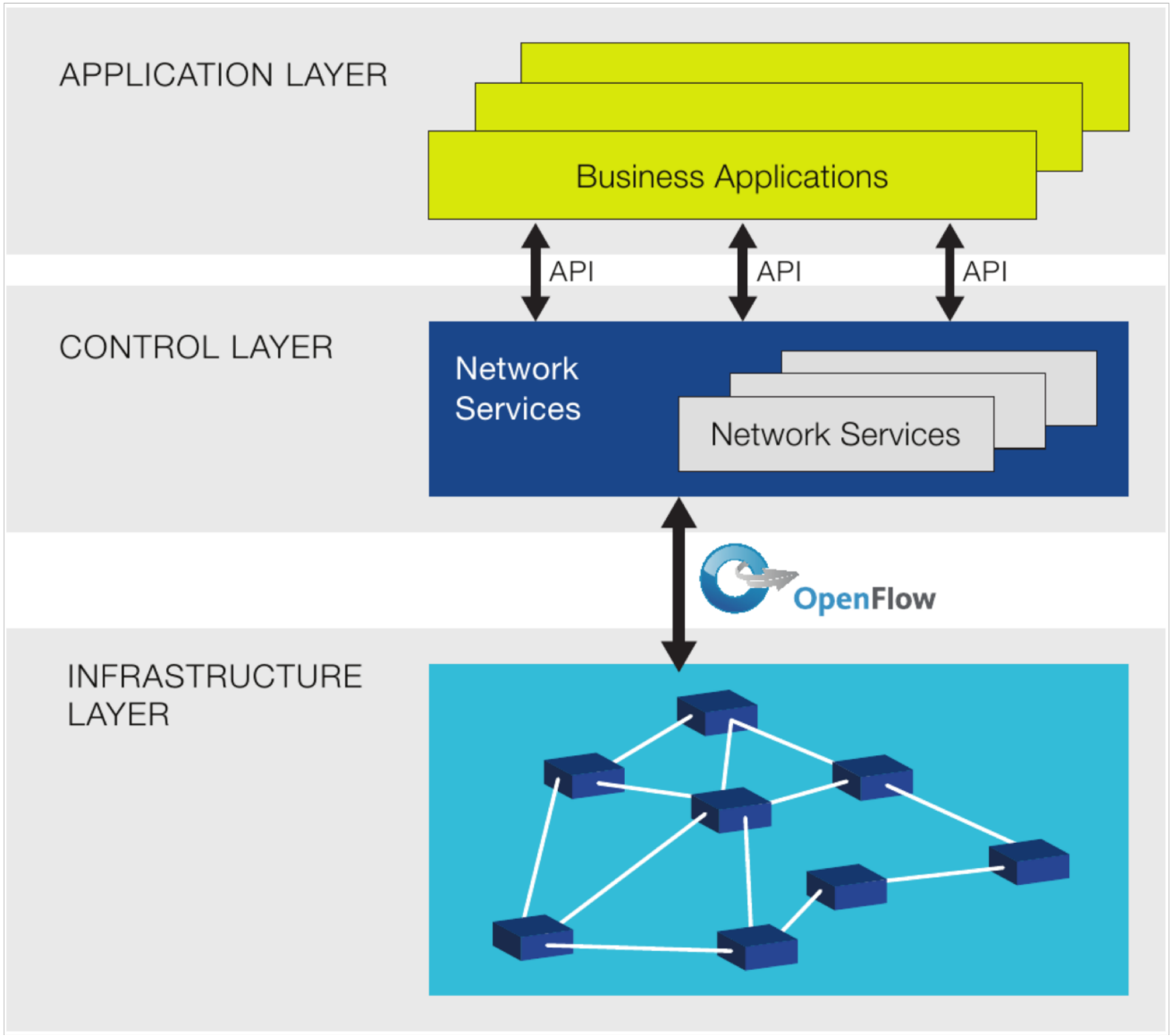
- English
  - Mininet Walkthrough
  - Introduction to Mininet
  - Mininet Python API Reference Manual
  - A Beginner's Guide to Mininet
- Chinese
  - GitHub/OSE-Lab - 熟悉如何使用 Mininet
  - 菸酒生的記事本 – Mininet 筆記
  - Hwchiu Learning Note – 手把手打造仿 mininet 網路
  - 阿寬的實驗室 – Mininet 指令介紹
  - Mininet 學習指南

Software-Defined Networking (SDN)

- Software-defined
  = Programmable
  - Dynamic
  - Manageable
  - Cost-effective
  - Adaptable
- The OpenFlow protocol is a foundational element for building SDN

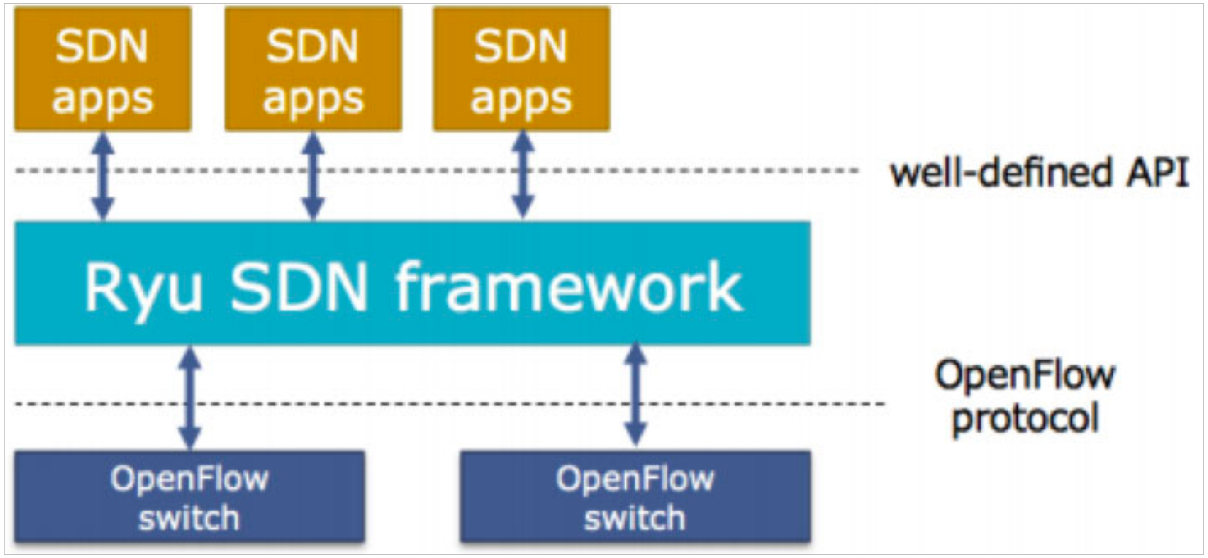


OpenFlow


APPLICATION LAYER
Business Applications
API
API
API
CONTROL LAYER
Network Services
Network Services
OpenFlow
INFRASTRUCTURE LAYER

Ryu SDN

- Ryu is a component-based software defined networking framework
  - Support various protocols for managing network devices, such as OpenFlow, etc
  - We have provided you a container that has installed Ryu



Ryu SDN References

- English
  - Ryubook Documentation
  - Ryubook [PDF]
  - Ryu 4.30 Documentation
  - Ryu Controller Tutorial
  - OpenFlow 1.3 Switch Specification
- Chinese
  - Ryubook 說明文件
  - GitHub - Ryu Controller 教學專案
  - Ryu SDN 指南 – Pengfei Ni
  - OpenFlow 通訊協定

iPerf

- iPerf is a tool for active measurements of the maximum achievable bandwidth on IP networks
- Support tuning of various parameters related to timing, buffers and protocols (TCP, UDP, SCTP with IPv4 and IPv6)

File Structure

```
Route_Configuration/              # This is ./ in this repository
|--- src/                         # Folder of source code
     |--- scripts/                # Folder of scripts
          |--- run_mininet.sh     # Running script of Mininet
          |--- run_ryu.sh         # Running script of Ryu manager
     |--- topo/                   # Folder of topology figure
          |--- topo.png
     |--- out/                    # Output files
          |--- .gitkeep           # For keeping this folder
     |--- SimpleTopo.py           # Example code of topology
     |--- SimpleController.py     # Example code of controller
     |--- controller.py           # Your program should be here!
     |--- topo.py                 # Your program should be here!
|--- LICENSE
|--- README.md                    # Your report of Lab3!
|--- .gitignore                   # For ignoring useless files
```

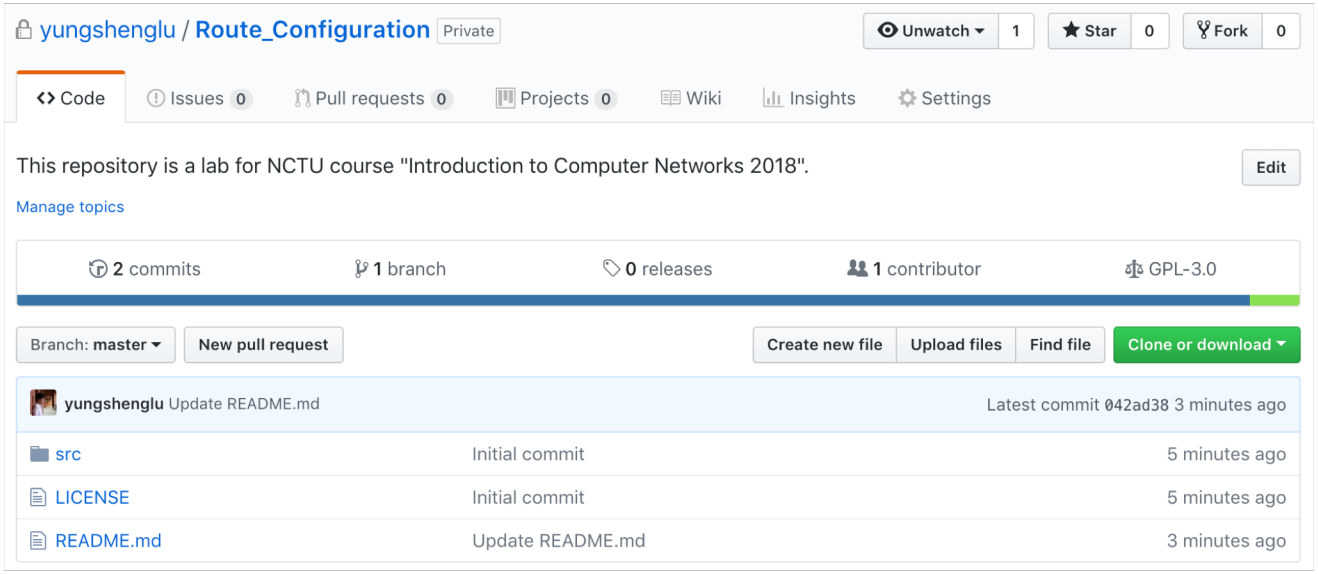
Tasks

Tasks

1. Environment Setup
2. Example of Ryu SDN
3. Mininet Topology
4. Ryu Controller
5. Measurement
6. Report

Task 1. Environment Setup

- **Step 1. Join this lab on GitHub Classroom**
  - Click the following link to join this lab
    - https://classroom.github.com/a/RHNMq4Td
  - Go to our GitHub group to see your repository
    - https://github.com/nctucn
  - You will have an initial repository we prepared



Task 1. Environment Setup (cont.)

- **Step 2. Login to your container using SSH**
  - **For windows**
    - Open the PieTTY and connect to your container
      - IP address: `140.113.195.69`
      - Port: **Last 5 digits of student ID**
    - Login as root

```
Login: root
Password: cn2018
```

  - **For MacOS and Ubuntu Linux**

```
# Open the terminal to connect to your container
$ ssh -p <LAST_5_DIGITS_OF_STUDENT_ID> root@140.113.195.69
Password: cn2018
```

Task 1. Environment Setup (cont.)

- **Step 3. Clone your GitHub repository**

```
# Clone your GitHub repository to "Route_Configuration"
$ git clone https://github.com/nctucn/lab3-<GITHUB_ID>.git
Route_Configuration
Cloning into 'Route_Configuration'...
Username for 'https://github.com': <GITHUB_ID>
Password for 'https://<GITHUB_ID>@github.com':
<GITHUB_PASSWORD>
......

# Show all files in /root/
$ ls /root/
Route_Configuration
```

After cloning the repository from your GitHub to on your container, you will see a folder "Route_Configuration"

Task 1. Environment Setup (cont.)

- **Step 4. Run Mininet for testing**
  - After logging to your container, you may meet the following error when running Mininet

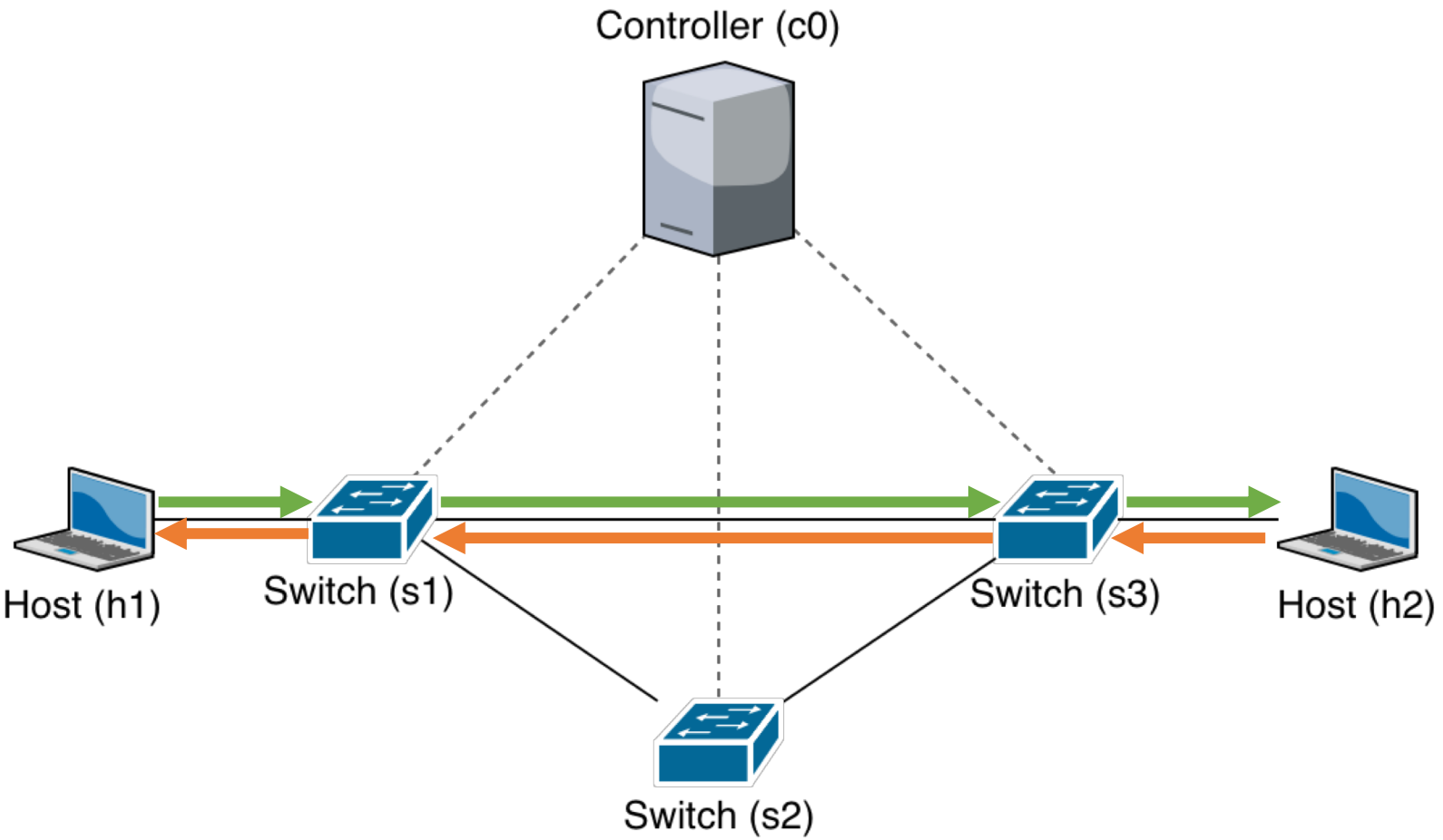
```
# Run Mininet for testing
$ [sudo] mn
......
*** Error connecting to ovs-db with ovs-vsctl
Make sure that Open vSwitch is installed, that ovsdb-
server is running, and that
"ovs-vsctl show" works correctly.
You may wish to try "service openvswitch-switch start".
```

  - **Solution**

```
# Start the service of Open vSwitch
$ [sudo] service openvswitch-switch start
# Run Mininet again!
$ [sudo] mn
```

Task 2. Example of Ryu SDN

- Network topology of SimpleTopo.py



Task 2. Example of Ryu SDN (cont.)

- **Step 1. Login to your container in two terminals**
  - **For windows**
    - Open the PieTTY and connect to your container
      - IP address: `140.113.195.69`
      - Port: **Last 5 digits of student ID**
    - Login as root

```
Login: root
Password: cn2018
```

  - **For MacOS and Ubuntu Linux**

```
# Open the terminal to connect to your container
$ ssh -p <LAST_5_DIGITS_OF_STUDENT_ID> root@140.113.195.69
Password: cn2018
```

Task 2. Example of Ryu SDN (cont.)

- **Step 2. Run Mininet topology**
  - Run SimpleTopo.py in one terminal first

```
# Change the directory into
# /root/Route_Configuration/src/
$ cd /root/Route_Configuration/src/
# Run the SimpleTopo.py with Mininet
$ [sudo] mn --custom SimpleTopo.py --topo topo
--link tc --controller remote
```

Task 2. Example of Ryu SDN (cont.)

- The result after running SimpleTopo.py

```
*** Creating network
*** Adding controller
Unable to contact the remote controller at 127.0.0.1:6653
Unable to contact the remote controller at 127.0.0.1:6633
Setting remote controller to 127.0.0.1:6653
*** Adding hosts:
h1 h2
*** Adding switches:
s1 s2 s3
*** Adding links:
(s1, h1) (s1, s2) (s1, s3) (s3, h2) (s3, s2)
*** Configuring hosts
h1 h2
*** Starting controller
c0
*** Starting 3 switches
s1 s2 s3 ...
*** Starting CLI:
mininet>
```

Task 2. Example of Ryu SDN (cont.)

- **Troubleshooting 1**
  - The following error may occur when you run SimpleTopo.py or Mininet's program

```
# Run the SimpleTopo.py with Mininet (SimpleTopo.py)
$ [sudo] mn --custom SimpleTopo.py --topo topo
--link tc --controller remote
*** Creating network
......
Exception: Error creating interface pair (s1-eth1,s2-
eth1): RTNETLINK answers: File exists
```

  - **Solution:**

```
# If Mininet crashes for some reason, clean it up!
$ [sudo] mn -c
```

Task 2. Example of Ryu SDN (cont.)

- **Troubleshooting 2**
  - The following message which won't affect in this lab may show when you run SimpleTopo.py or your Mininet's program

```
# Run the example code (SimpleTopo.py)
$ [sudo] mn --custom SimpleTopo.py --topo topo
--link tc --controller remote
*** Error setting resource limits. Mininet's
performance may be affected.
*** Creating networkpo --link tc --
controller=remotecusto
......
```

Task 2. Example of Ryu SDN (cont.)

- **Step 3. Run Ryu manager with controller**
  - Run SimpleController.py in another terminal

```
# Change the directory into
# /root/Route_Configuration/src/
$ cd /root/Route_Configuration/src/
# Run the SimpleController.py with Ryu manager
$ [sudo] ryu-manager SimpleController.py --observe-
links
loading app controller.py
loading app ryu.topology.switches
loading app ryu.controller.ofp_handler
instantiating app controller.py of SimpleController
instantiating app ryu.topology.switches of Switches
instantiating app ryu.controller.ofp_handler of
OFPHandler
```

Task 2. Example of Ryu SDN (cont.)

- **Step 4. How to leave the Ryu controller?**
  - Leave SimpleTopo.py in one terminal first

```
# Leave the Mininet CLI
mininet> exit
```

  - Then, leave SimpleController.py in another terminal

```
# Leave the Mininet CLI
Ctrl-z
# Make sure "RTNETLINK" is clean indeed
$ mn -c
```

Task 3. Mininet Topology (cont.)

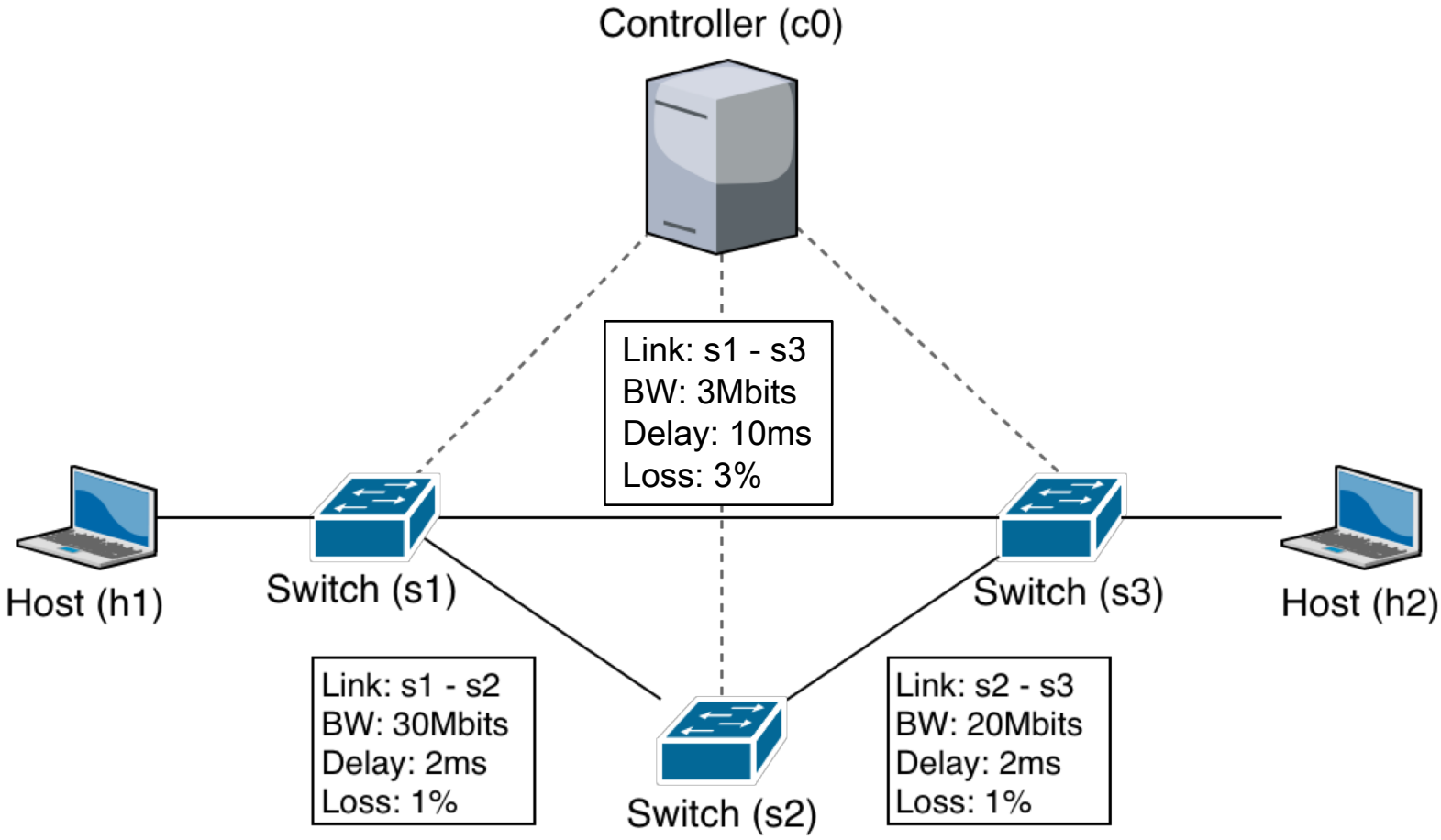
- **Step 1. Build the topology via Mininet**
  - Duplicate the example code SimpleTopo.py and name it topo.py

```
# Make sure the current directory is
# /root/Route_Configuration/src/
$ cp SimpleTopo.py topo.py
```

  - Add the constraints (e.g., bandwidth, delay, and loss rate) by /Route_Configuration/src/topo/topo.png
  - You don't need to set the bandwidth, delay, or loss rate if the figure don't specify.

Task 3. Mininet Topology (cont.)

- Topology of /Route_Configuration/src/topo/topo.png



Task 3. Mininet Topology (cont.)

- **Step 2. Run Mininet topology and controller**
  - Run topo.py in one terminal first

```
# Run the topo.py with Mininet
$ [sudo] mn --custom topo.py --topo topo --link tc
--controller remote
......
mininet>
```

  - Then, run SimpleController.py in another terminal

```
# Run the SimpleController.py with Ryu manager
$ [sudo] ryu-manager SimpleController.py –observe-links
loading app controller.py
loading app ryu.topology.switches
loading app ryu.controller.ofp_handler
instantiating app controller.py of SimpleController
instantiating app ryu.topology.switches of Switches
instantiating app ryu.controller.ofp_handler of
OFPHandler
```

Task 3. Mininet Topology (cont.)

- **Troubleshooting 3**
  - The following message means your controller's program has some error

```
$ ryu-manager SimpleController.py –observe-links
loading app SimpleController.py
Traceback (most recent call last):
  File "/usr/local/bin/ryu-manager", line 9, in
......
ImportError: No module named SimpleController.py
```

  - The following message means your topology's program has some error

```
$ [sudo] mn --custom topo.py --topo topo --link tc
--controller remote
-------------------------------------------------------
Caught exception. Cleaning up...
SyntaxError: invalid syntax (SimpleTopo.py, line 19)
```

Task 3. Mininet Topology (cont.)

- **Troubleshooting 4**
  - You can ping each link respectively by using the following command in the Mininet's CLI mode

```
# Example of testing the connectivity between h1 and h2
mininet> h1 ping h2
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=31.8 ms
......
```

  - Please refer to the **Troubleshooting 1** for solving the following error when running your program

```
# Run the SimpleTopo.py with Mininet (SimpleTopo.py)
$ [sudo] mn --custom SimpleTopo.py --topo topo
--link tc --controller remote
......
Exception: Error creating interface pair (s1-eth1,s2-
eth1): RTNETLINK answers: File exists
```

Task 4. Ryu Controller

- **Step 1. Trace the code of Ryu controller**
  - Trace the example code SimpleController.py

```
class SimpleController(app_manager.RyuApp):
    # Let the Ryu controller running in protocol OpenFlow 1.3
    OFP_VERSIONS = [ofproto_v1_3.OFP_VERSION]
    ......
    # Class constructor (DO NOT MODIFY)
    def __init__(self, *args, **kwargs):
    ......
    # Add a flow into flow table of each switch (DO NOT MODIFY)
    def add_flow(self, datapath, priority, match, actions):
    ......
    # Handle the initial feature of each switch
    def switch_features_handler(self, ev):
    ......
    # Handle the packet-in events (DO NOT MODIFY)
    def packet_in_handler(self, ev):
    ......
    # Show the information of the topology (DO NOT MODIFY)
    def get_topology_data(self, ev):
    ......
```

Your should modify here!

Task 4. Ryu Controller

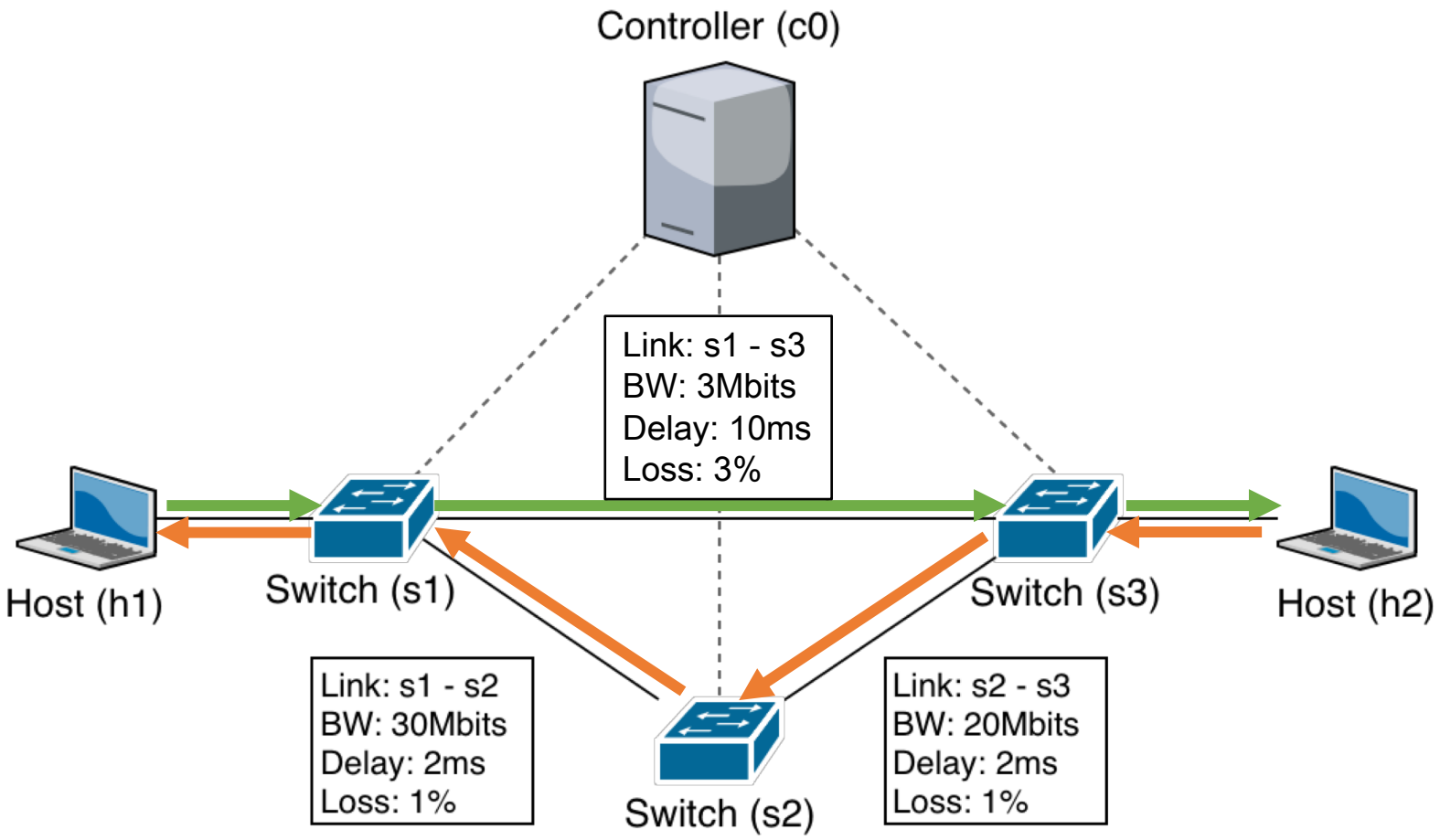
- **Step 2. Write another Ryu controller**
  - Duplicate the example code SimpleController.py and name it controller.py

```
# Make sure the current directory is
# /root/Route_Configuration/src/
$ cp SimpleController.py controller.py
```

  - Follow the the forwarding rules in the next slide and modify controller.py
  - You ONLY need to modify the method `switch_features_handler(self, ev)`

Task 3. Mininet Topology (cont.)

- **Forwarding rules** (for controller.py)



Task 5. Measurement

- **Step 1. Run topology with SimpleController.py**
  - Run topo.py in one terminal first

```
# Run the topo.py with Mininet
$ [sudo] mn --custom topo.py --topo topo --link tc
--controller remote
```

  - Then, run SimpleController.py in another terminal

```
# Run the SimpleController.py with Ryu manager
$ [sudo] ryu-manager SimpleController.py –observe-links
loading app SimpleController.py
loading app ryu.topology.switches
loading app ryu.controller.ofp_handler
instantiating app SimpleController.py of
SimpleController
instantiating app ryu.topology.switches of Switches
instantiating app ryu.controller.ofp_handler of
OFPHandler
```

Task 5. Measurement

- **Step 2. Measure the bandwidth**
  - Use the following iPerf commands to measure the bandwidth in your network

```
# Run in the iPerf command in Mininet CLI
mininet> h1 iperf -s -u -i 1 –p 5566 > ./out/result1 &
mininet> h2 iperf -c 10.0.0.1 -u –i 1 –p 5566
```

  - Leave topo.py in one terminal first

```
# Leave the Mininet CLI
mininet> exit
```

  - Then, leave SimpleController.py in another terminal

```
# Leave the Mininet CLI
Ctrl-z
# Make sure “RTNETLINK” is clean indeed
$ mn -c
```

Task 5. Measurement

- **Step 3. Run topology with controller.py**
  - Run topo.py in one terminal first

```
# Run the topo.py with Mininet
$ [sudo] mn --custom topo.py --topo topo --link tc
--controller remote
```

  - Then, run controller.py in another terminal

```
# Run the controller.py with Ryu manager
$ [sudo] ryu-manager controller.py –observe-links
loading app controller.py
loading app ryu.topology.switches
loading app ryu.controller.ofp_handler
instantiating app controller.py of SimpleController
instantiating app ryu.topology.switches of Switches
instantiating app ryu.controller.ofp_handler of
OFPHandler
```

Task 5. Measurement

- **Step 4. Measure the bandwidth**
  - Use the following iPerf commands to measure the bandwidth in your network

```
# Run in the iPerf command in Mininet CLI
mininet> h1 iperf -s -u -i 1 –p 5566 > ./out/result2 &
mininet> h2 iperf -c 10.0.0.1 -u –i 1 –p 5566
```

  - Leave topo.py in one terminal first

```
# Leave the Mininet CLI
mininet> exit
```

  - Then, leave controller.py in another terminal

```
# Leave the Mininet CLI
Ctrl-z
# Make sure “RTNETLINK” is clean indeed
$ mn -c
```

Task 6. Report

- **Write your report in Markdown format**
  - Cheat Sheet of Markdown Syntax
  - Finish the README.md as your report
- **Your README.md must include**
  - **Execution**
    - How to run your program?
    - What is the meaning of the executing command (both Mininet and Ryu controller)?
    - Screenshot the result of using iPerf command (both SimpleController.py and controller.py)
  - **Description**
    - Describe how you finish this work in detail
    - Which reference you refer to?

Task 6. Report

- **Discussion** (also write in README.md)
  1. Describe the differences between packet-in and packet-out in detail.
  2. What is "table-miss" in SDN?
  3. Why is "`(app_manager.RyuApp)`" adding after the declaration of class in controller.py?
  4. Explain the following code in controller.py.

```
@set_ev_cls(ofp_event.EventOFPPacketIn, MAIN_DISPATCHER)
```

  5. What is the meaning of "`datapath`" in controller.py?
  6. Why need to set "`ip_proto=17`" in the flow entry?
  7. Compare the differences between the iPerf results of SimpleController.py and controller.py in detail.
  8. Which forwarding rule is better? Why?

Task 6. Report (cont.)

- **Notice**
  - Please write your report in detail and do NOT just copy the content in this slide; otherwise, you won't get score
  - You can refer any other materials to help you finish your report but remember to attach the source
  - You can write your report in English or Chinese
  - Make sure your report is named README.md; otherwise, we won't mark your report

Submission

- **Submit your works to your GitHub repository**

```
# Add all files into staging area
$ git add .
# Commit your files
$ git commit -m "YOUR OWN COMMIT MESSAGE"
# Push your files to remote
$ git push origin master
```

- **Notice**
  - You should NOT commit your works only one time; otherwise, your lab may be deemed as plagiarism
  - You should write your commit message clearly
    - How to Write a Git Commit Message
  - Make sure that your final work is on `master` branch

Grading Policy

- **Deadline1 - Dec. 30, 2018. 23:00 (5% bonus)**
- **Deadline2 - Jan. 14, 2019. 23:00**
  - Upload all your works and report to your GitHub repository
  - Make sure the filename of each file is correct; otherwise; we won't mark it.
  - Do NOT attack our server; otherwise, you will get "F" this semester!
  - No delay policy. You cannot submit after 2019/1/14
- **Homework, 100%**
  1. Python programs, 60%
     - topo.py, controller.py
  2. Report, 40%
     - README.md

Grading Policy (cont.)

- **Cheating Policy** (follow syllabus)
  - Academic integrity
  - Homework must be your own – cheaters share the score
  - Both the cheaters and the students who aided the cheater will be held responsible for the cheating

References

- **Ryu SDN**
  - English
    - Ryubook Documentation
    - Ryubook [PDF]
    - Ryu 4.30 Documentation
    - Ryu Controller Tutorial
    - OpenFlow 1.3 Switch Specification
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    - 阿寬的實驗室 – Mininet 指令介紹
    - Mininet 學習指南

References (cont.)

- **Python**
  - Python 2.7.15 Standard Library
  - Python Tutorial - Tutorialspoint
- **Others**
  - iPerf3 User Documentation
  - Cheat Sheet of Markdown Syntax
  - Vim Tutorial – Tutorialspoint
  - 鳥哥的 Linux 私房菜 – 第九章、vim 程式編輯器