Lab 2

OpenFlow Protocol Observation and Flow Rule Installation

Deadline 2024/09/25 (WED) 23:59

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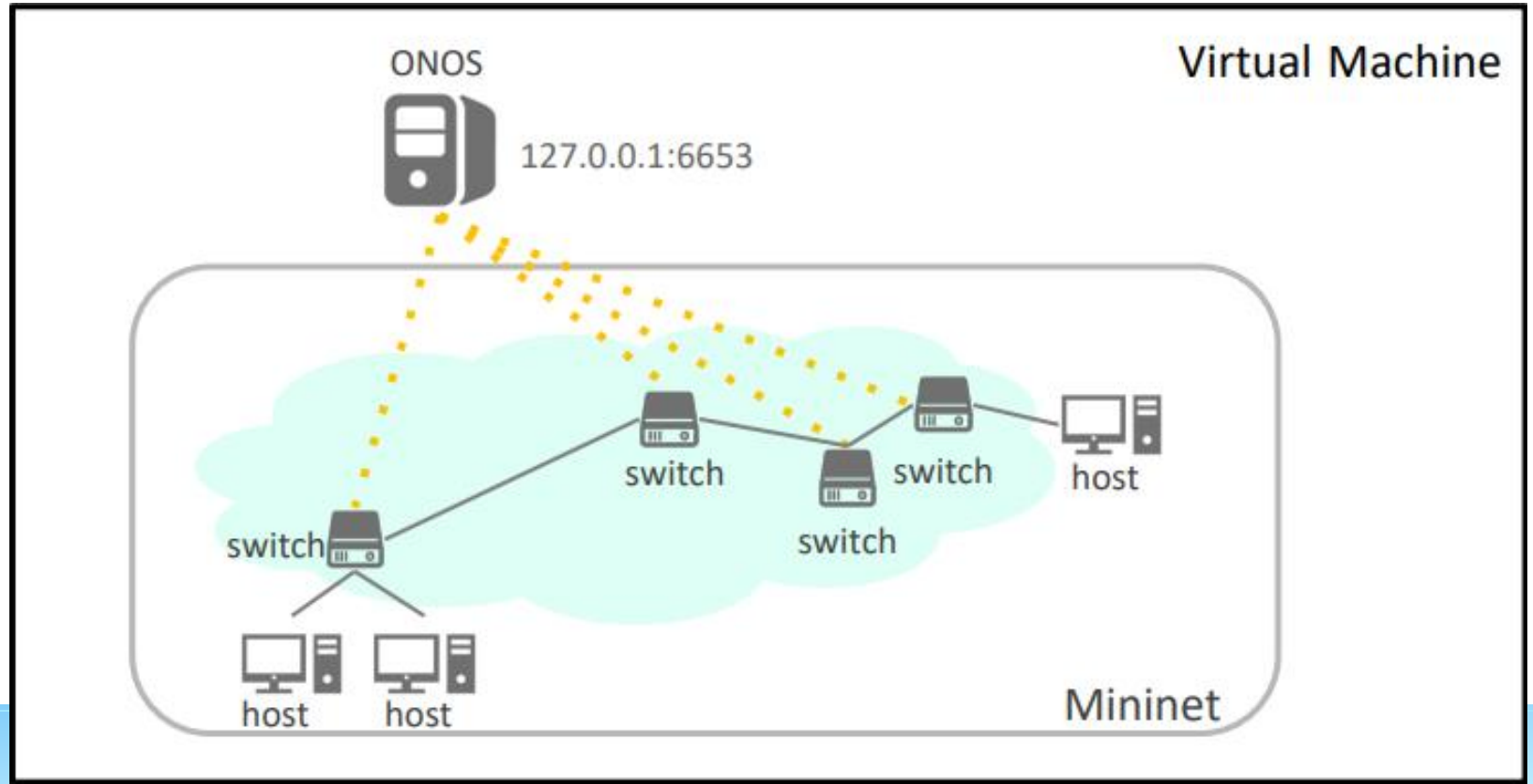
Outline

- OpenFlow Messages
  - Monitor Traffic between ONOS & Switches
  - OpenFlow Message Observation
- Install/Delete Flow Rules
  - Rest, JSON file, and Curl introduction
  - ONOS and Topology Setup
  - Method 1: via Command “curl”
  - Method 2: via ONOS Web GUI
- Lab 2 Requirements
  - Part 1: Answer Questions
  - Part 2: Install Flow Rules
  - Part 3: Create Broadcast Storm
  - Part 4: Trace ReactiveForwarding

OpenFlow Protocol

- OpenFlow is a Software Defined Network (SDN) control protocol
- ONOS SDN controller uses OpenFlow messages to communicate with OVS switches.
  - Hello, Packet-in/out, Flow Install/Remove, etc.



Wireshark Installation

- Wireshark is an open-source and widely-used network packet analyzer
  - Can capture packets on any specified interface
- Installation steps:
  1. Update package information

```
$ sudo apt update          # update all packages information
```

  2. Install Wireshark

```
$ sudo apt install wireshark -y
```

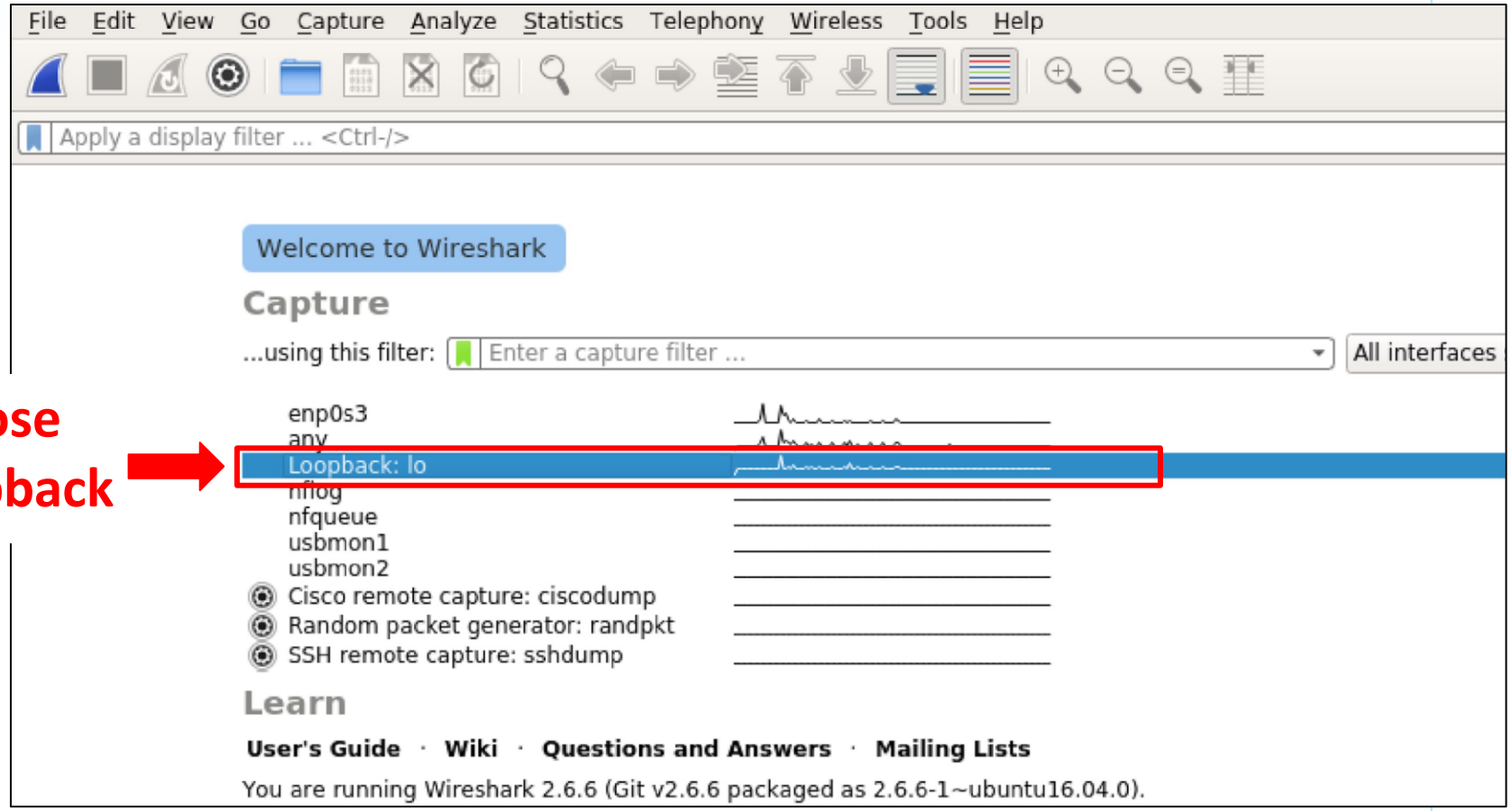
- Start Wireshark

```
$ sudo wireshark
```

Capture Packets in Wireshark

- Both ONOS and Mininet run locally in VM
  - We can capture packets on the Loopback (lo) interface
- Loopback:

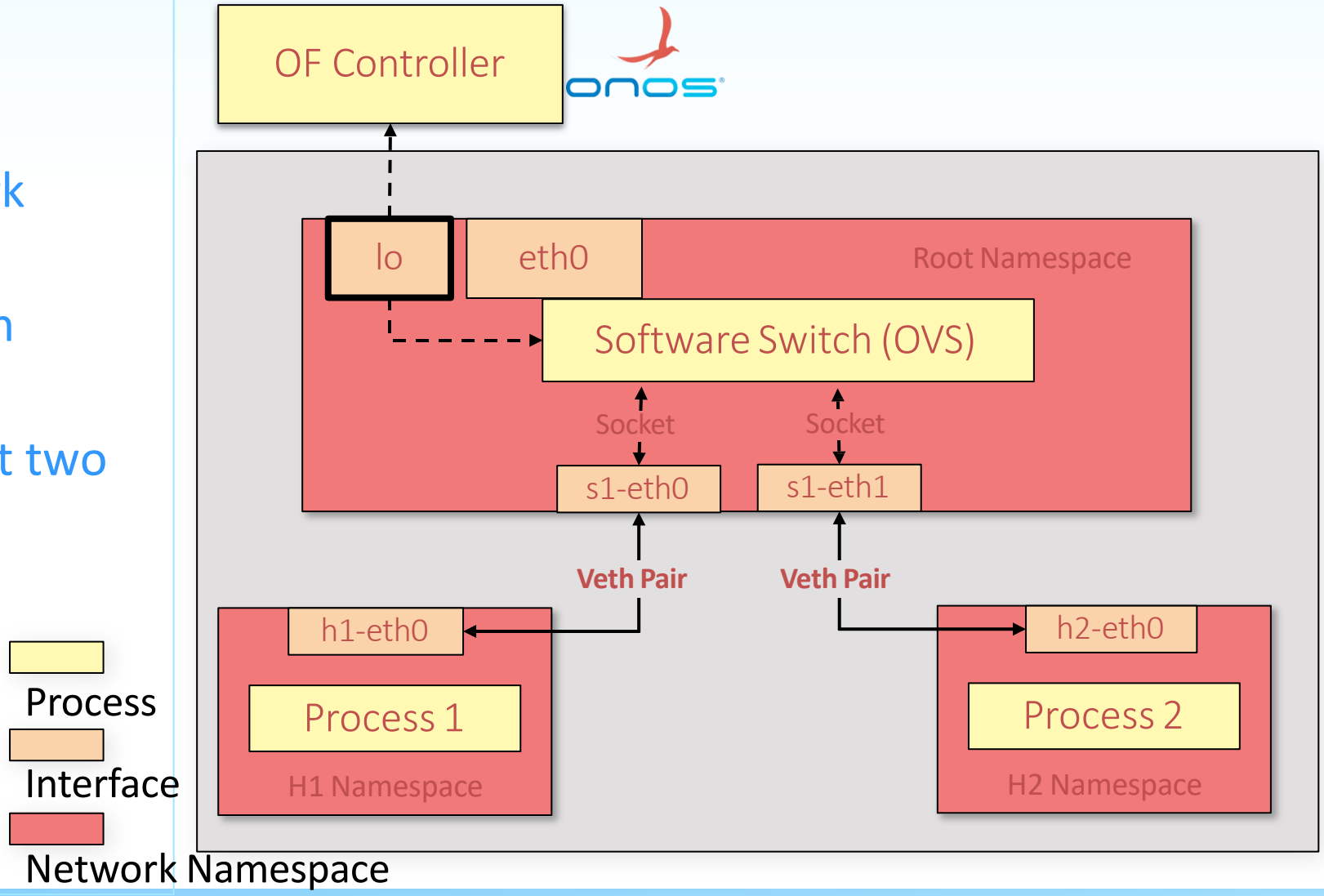
  Route data streams back to the source without intentional processing or modification.



Choose Loopback

Mininet and Network Namespace

- Mininet uses network namespace to emulate networks
- OVS runs in root network namespace
- Each host runs in its own network namespace
- ➢ Use Veth pair to connect two networks of different namespaces



Sending OpenFlow Messages

1. Start ONOS
2. Activate ReactiveForwarding

```
onos> apps -a -s            # (optional) check activated application
onos> app activate fwd      # activate ReactiveForwarding
```

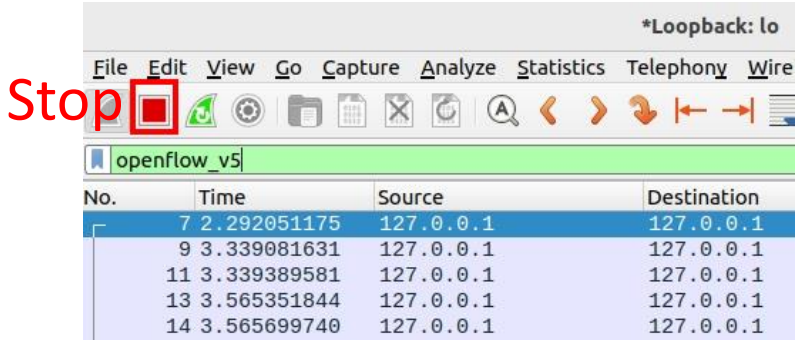
3. Start Mininet with default topology

```
$ sudo mn --controller=remote,127.0.0.1:6653 --switch=ovs,protocols=OpenFlow14
```

4. H1 ping H2 in Mininet

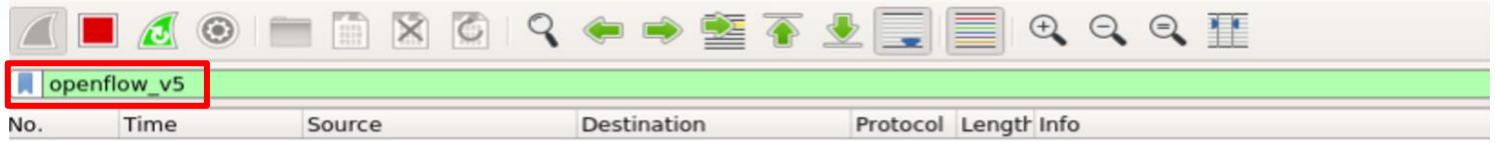
```
mininet> h1 ping h2 -c 5          # send five ICMP echo_request packets
```

5. Exit Mininet when ping terminates
6. Stop capturing packets in Wireshark
7. Observe captured OpenFlow packets

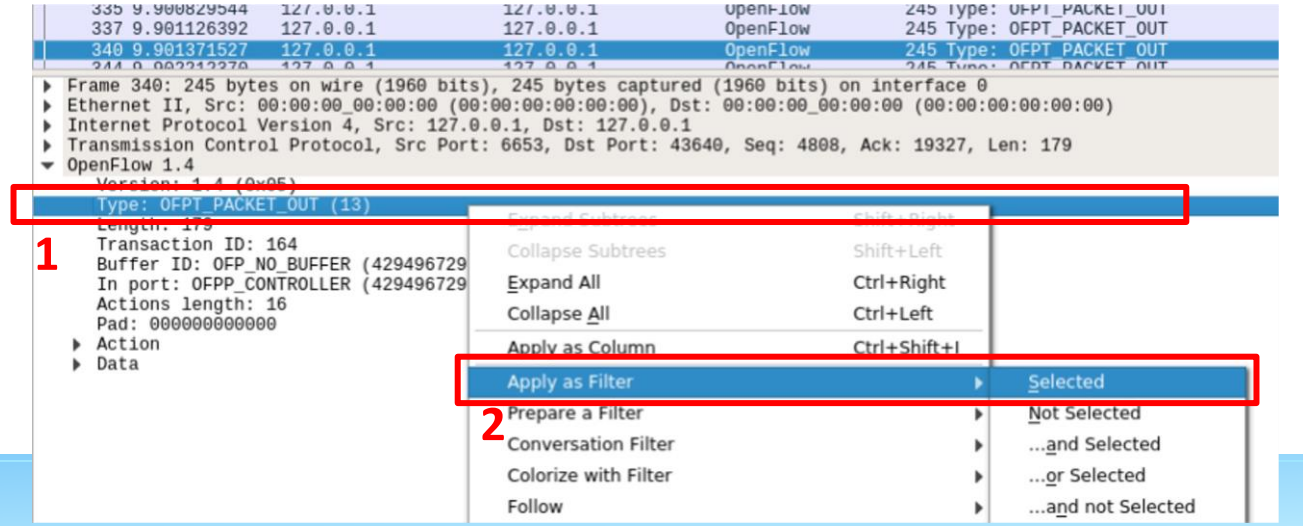


Packet Filtering in Wireshark

- Use keyword “openflow_v5” to filter OpenFlow v1.4.0 packets
  - ONOS v2.2.0 uses Openflow v1.4.0



- Alternatively, apply filter in the following steps:
  1. Right click on the packet header field which you want to apply as filter
  2. Choose “Apply as Filter” and click “Selected”
  3. Wireshark will immediately filter out all the relevant packets



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- OpenFlow Messages
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  - Method 2: via ONOS Web GUI
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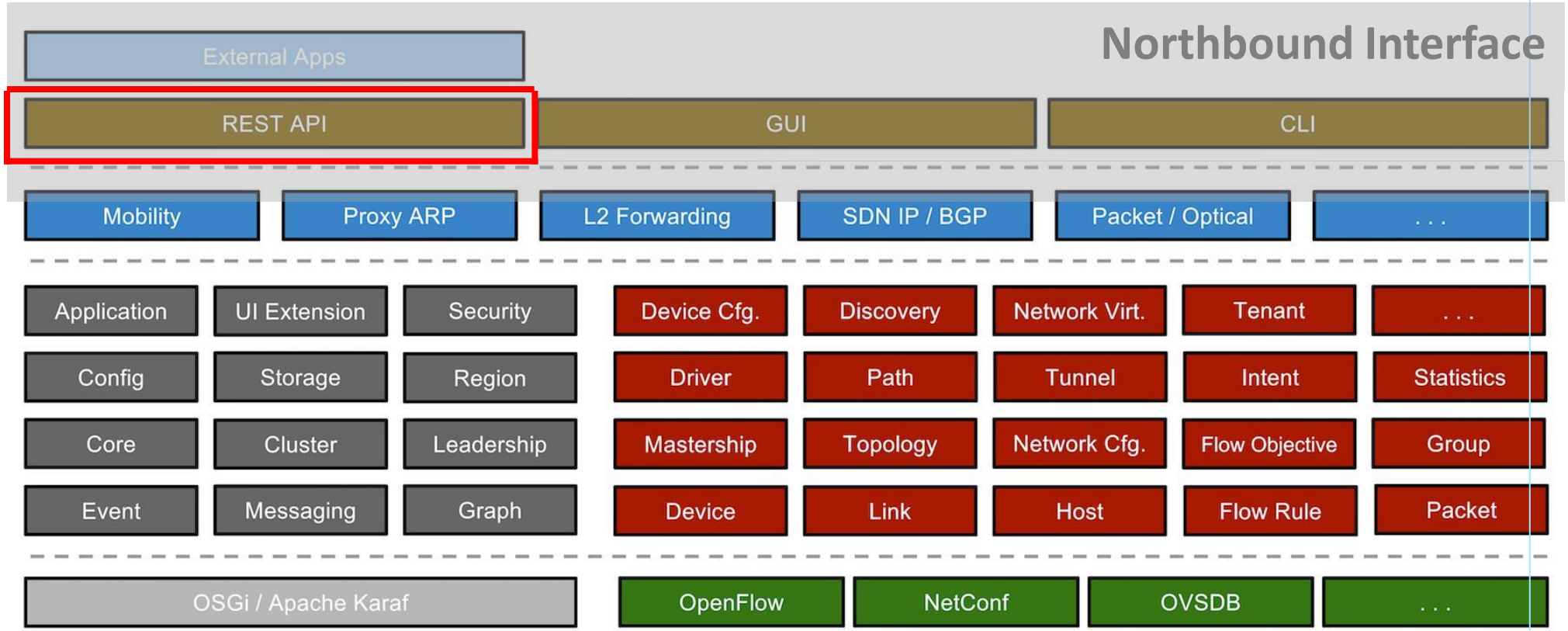
ONOS Northbound Interface

- Northbound Interface of ONOS is the interface that interacts with programmers
- REST is a **software architectural style** for Web services
- We will use the REST API to install/delete flow rules



Create a JSON file of flow rules

- What is a JSON (JavaScript Object Notation)?
  - JSON
    - An open standard file format and data interchange format
    - Uses human-readable text to store and transmit data objects consisting of
      - attribute–value pairs
      - arrays
      - other serializable values
- E.g., flows1.json: JSON file for a flow rule
- Hint:
  - Priority of preinstalled flow rules: 40000
  - The priorities of flow rules **MUST** be 40001 to 65535
- Ref: Flow Rule Criteria & Instructions

flows1.json

```
{
    "priority": 50000,
    "timeout": 0,
    "isPermanent": true,
    "selector": {
        "criteria": [
            {
                "type": "IN_PORT",
                "port": 1
            }
        ]
    },
    "treatment": {
        "instructions": [
            {
                "type": "OUTPUT",
                "port": 2
            }
        ]
    }
}
```

JSON File: Match Fields (criteria)

flows1.json

```
{
    "priority": 50000,
    "timeout": 0,
    "isPermanent": true,
    "selector": {
        "criteria": [
            {
                "type": "IN_PORT",
                "port": 1
            }
        ]
    },
    "treatment": {
        "instructions": [
            {
                "type": "OUTPUT",
                "port": 2
            }
        ]
    }
}
```

- Match fields may have dependency; please refer to OpenFlow spec v1.4.0.

```
"selector": {
    "criteria": [
        {
            "type": "IN_PORT",
            "port": 1
        },
        { … },
        …
    ]
},
```

JSON File: Actions (instructions)

flows1.json

```
{
    "priority": 50000,
    "timeout": 0,
    "isPermanent": true,
    "selector": {
        "criteria": [
            {
                "type": "IN_PORT",
                "port": 1
            }
        ]
    },
    "treatment": {
        "instructions": [
            {
                "type": "OUTPUT",
                "port": 2
            }
        ]
    }
}
```

```
"treatment": {
    "instructions": [
        {
            "type": "OUTPUT",
            "port": 2
        },
        { … },
        …
    ]
}
```

Curl – Command Tool for Transferring Data with URL

- Command format

```
curl [options] [URL...]
```

- Transferring data with URL

```
$ curl -u <user:password> -X <method-type> -H <header> -d <data> [URL...]
      # option "-X" specifies a HTTP request method
      # option “-H” includes extra header in the HTTP request
      # option “-d” sends specified data in a POST request
      # URL (Uniform Resource Locator)
```

  - "<data>" can be a file name with prefix “@”

```
$ curl -u <user:password> -X <method-type> -H <header> -d @<filename> [URL...]
```

- References:
  - “request methods” in HTTP
  - Manpage for command "curl”

Review:

- user: onos
- password: rocks

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ONOS & Topology Setup

1. Restart ONOS
   1. <ctrl+c> in the ONOS log panel to shutdown the ONOS instance
   2. Start ONOS

```
demo@SDN-NFV:~/onos$ ok clean
   # ok is an alias of command “bazel run onos-local -- ”
```

2. Deactivate ReactiveForwarding APP

```
onos> app deactivate fwd    # deactivate ReactiveForwarding
```

3. Start Mininet with default (minimal) topology

```
$ sudo mn --controller=remote,127.0.0.1:6653 --switch=ovs,protocols=OpenFlow14
```

4. Make sure that two hosts CAN NOT ping each other

```
mininet> h1 ping h2
```

```
mininet> h1 ping h2
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.
From 10.0.0.1 icmp_seq=1 Destination Host Unreachable
From 10.0.0.1 icmp_seq=2 Destination Host Unreachable
From 10.0.0.1 icmp_seq=3 Destination Host Unreachable
From 10.0.0.1 icmp_seq=4 Destination Host Unreachable
```

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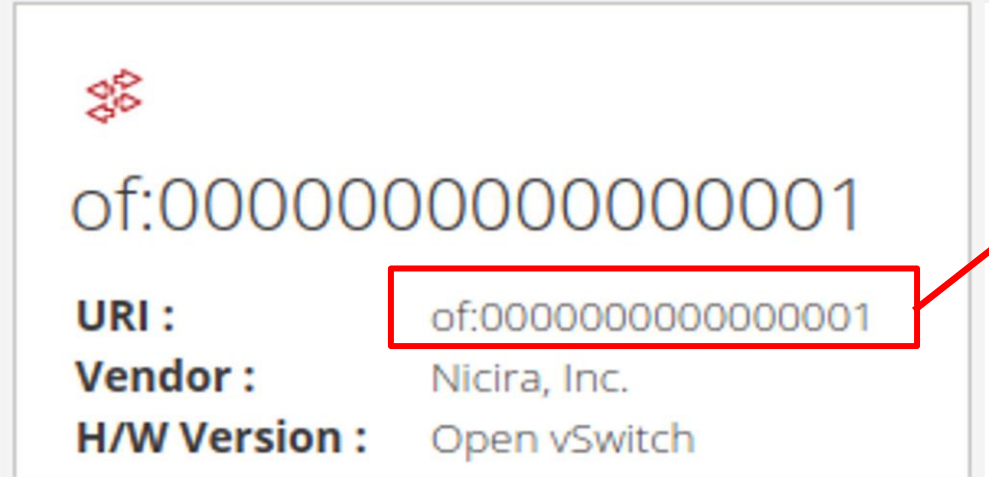
Upload JSON File to ONOS

- Install flow rules on ONOS with JSON file (flows1.json)

```
$ curl -u onos:rocks -X POST \
> -H 'Content-Type: application/json' \
> -d @flow1.json \
> 'http://localhost:8181/onos/v1/flows/of:0000000000000001'
```

```
#Recall command from p.15
$ curl -u <user:password>
-X <method-type>
-H <header>
-d @<filename>
[URL...]
```



Device ID

- DeviceID MUST be the URI shown in the ONOS web GUI
- DeviceID can be set by either ONOS or user specified topology file (i.e. *.py)

Check whether the flow rule is installed (1/2)

1. Go to ONOS web GUI (http://localhost:8181/onos/ui)
2. Left click on  . Then, the panel of switch info will pop out
3. Left click on  .

Flow rules in switch

STATE	PACKETS	DURATION	FLOW PRIORITY	TABLE NAME	SELECTOR	TREATMENT	APP NAME
Added	0	36	50000	0	IN_PORT:1	imm[OUTPUT:2], cleared:false	*rest
Added	0	960	40000	0	ETH_TYPE:bddp	imm[OUTPUT:CONTROLLER], cleared:true	*core
Added	0	960	40000	0	ETH_TYPE:lldp	imm[OUTPUT:CONTROLLER], cleared:true	*core
Added	12	960	40000	0	ETH_TYPE:arp	imm[OUTPUT:CONTROLLER], cleared:true	*core

Check whether the flow rule is installed (2/2)

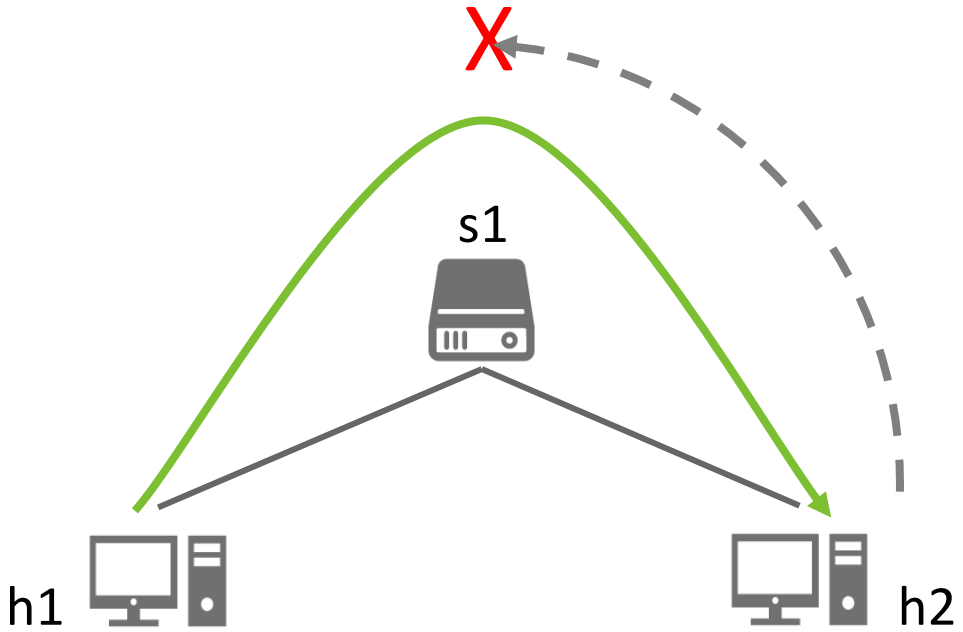
SELECTOR	TREATMENT	APP NAME
IN_PORT:1	imm[OUTPUT:2], cleared:false	*rest

STATE	PACKETS	DURATION ▲	FLOW PRIORITY	TABLE NAME	SELECTOR	TREATMENT	APP NAME
Pending Add	0	0	50000	0	IN_PORT:1	imm[OUTPUT:2], cleared:false	*rest
Added	0	10,485	40000	0	ETH_TYPE:bddp	imm[OUTPUT:CONTROLLER], cleared:true	*core
Added	0	10,485	40000	0	ETH_TYPE:arp	imm[OUTPUT:CONTROLLER], cleared:true	*core
Added	0	10,485	40000	0	ETH_TYPE:lldp	imm[OUTPUT:CONTROLLER], cleared:true	*core

- Flow Rule States:
  - **PENDING_ADD -** ONOS has received a request from the application to install the flow rule, but that flow has NOT yet been observed on the device.
  - **ADDED -** Once the flow rule subsystem observes the flow on the device, it will change to this state.

Why Hosts Still Cannot Ping Each Other?

- Because we have only installed a flow rule for one direction
  - s1 can forward packets from h1 to h2
  - But, s1 CANNOT forward packets from h2 to h1
    - By default, s1 drops a packet if the packet does not match any flow rule
      - i.e. table-miss



Delete Flow Rules (1/2)

- Use URL to find flow rule **IDs in a switch**

  Ex. http://localhost:8181/onos/v1/flows/of:0000000000000001


```
flows:
  0:                {…}
  1:
    groupId:        0
    state:          "ADDED"
    life:           515
    liveType:       "UNKNOWN"
    lastSeen:       1695031088914
    packets:        9
    bytes:          378
    id:             "49539596291667367"
    appId:          "org.onosproject.rest"
    priority:       50000
    timeout:        0
    isPermanent:    true
    deviceId:       "of:0000000000000001"
    tableId:        0
    tableName:      "0"
    treatment:      {…}
    selector:       {…}
  2:                {…}
  3:                {…}
```


```
id:        "49539596291667367"
appId:     "org.onosproject.rest"
```

- ID of the flow we just added is 49539596291667367

- Alternatively, we could use “curl” to get flow information

```
$ curl -u onos:rocks -X GET -H 'Accept: application/json' \
  'http://localhost:8181/onos/v1/flows/of:0000000000000001'
```

Delete Flow Rules (2/2)

- Then, delete the flow rule with flowID: 49539596291667367

```
$ curl -u onos:rocks \
  -X DELETE \
  -H 'Accept: application/json' \
  'http://localhost:8181/onos/v1/flows/of:0000000000000001\
  /49539596291667367'
```

Device ID

Flow ID

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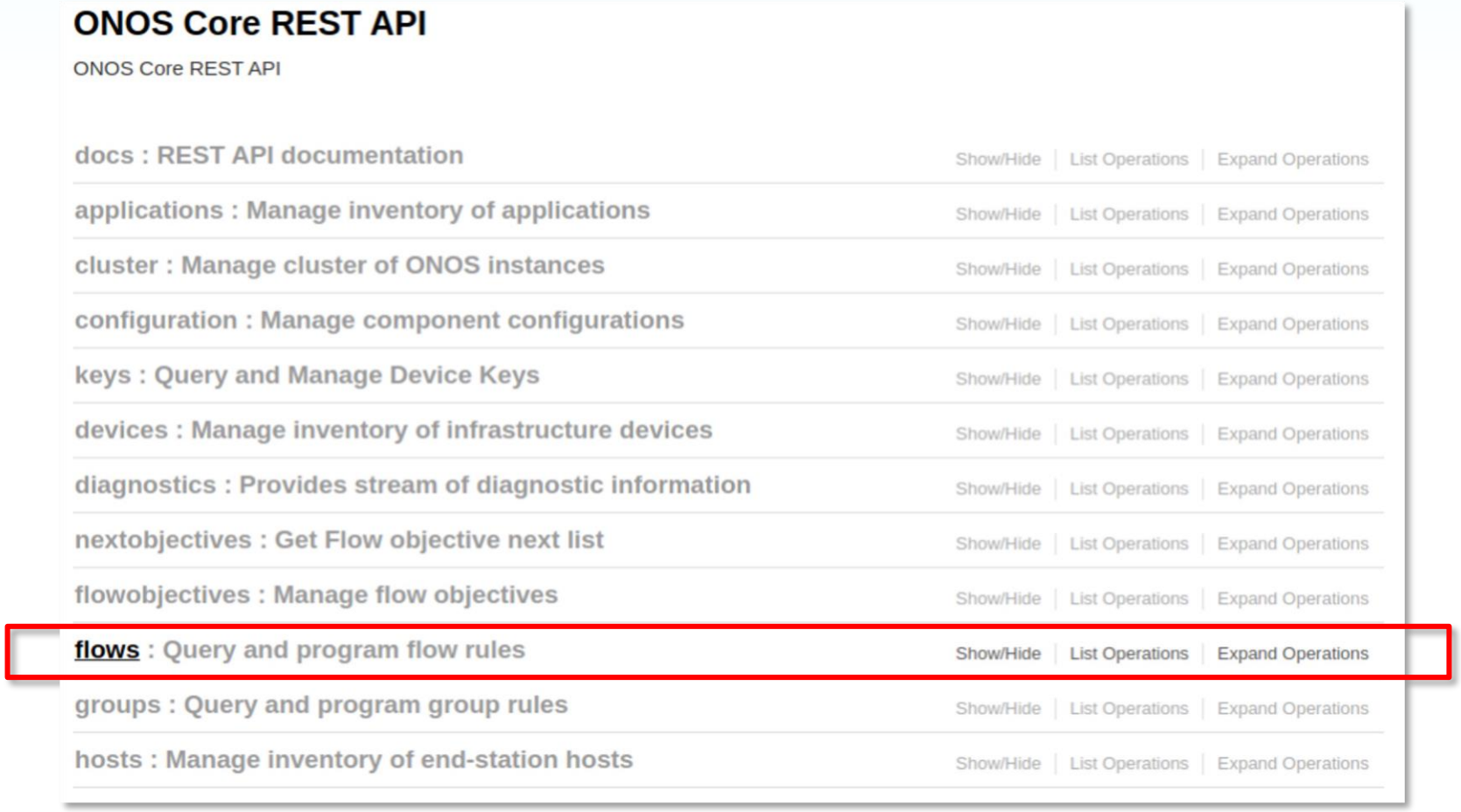
REST API on ONOS Web GUI

- Browse http://localhost:8181/onos/v1/docs



Using Web GUI to Install Flow Rule (1/2)

- Fill out required fields ("appId" could be arbitrary string)

Select

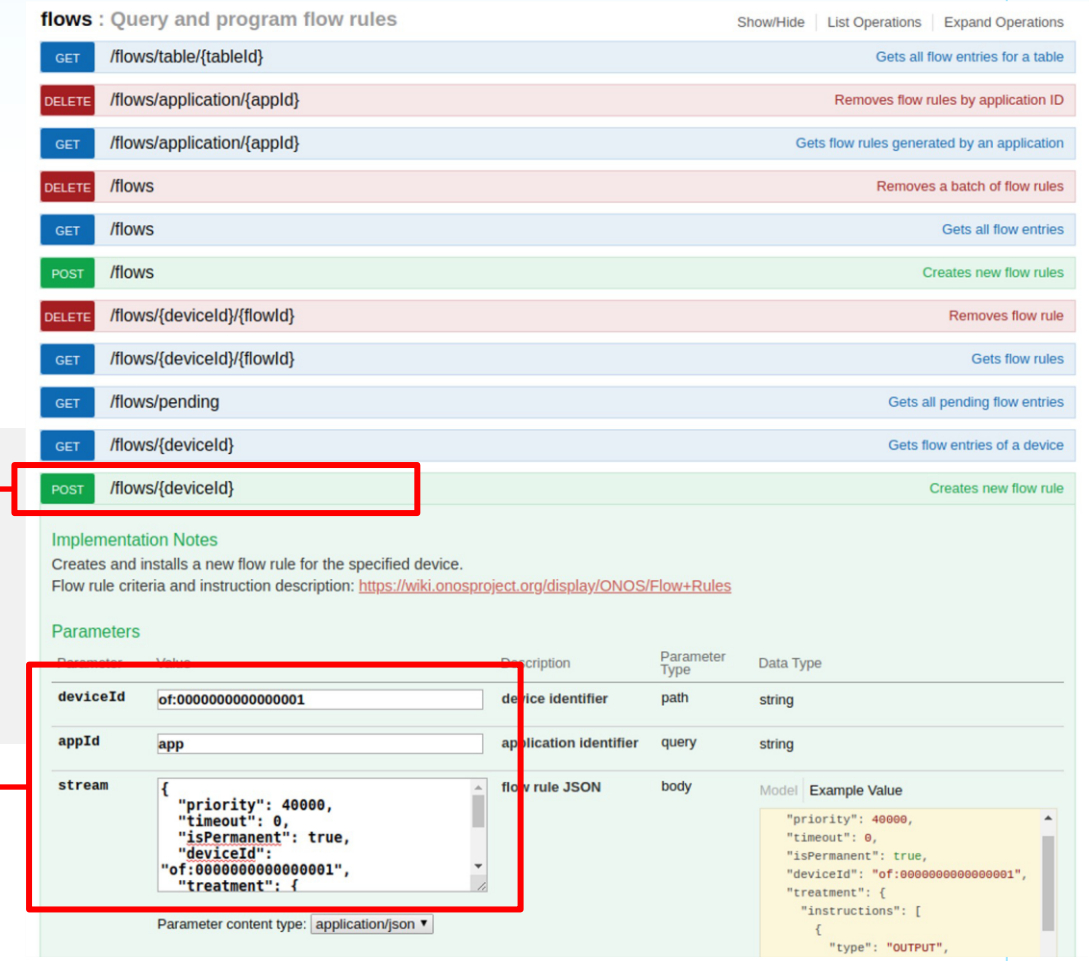
[POST] /flows/{deviceId}

- Corresponding curl command

```
$ curl -u onos:rocks \
  -X POST \
  -H 'Content-Type: application/json' \
  -d @flows1.json \
  'http://localhost:8181/onos/v1/flows/of:0000000000000001'
```

Type In

deviceId
appId
JSON file



Using Web GUI to Install Flow Rule (2/2)

- Click “Try it out!”
  - Web will pass the JSON stream to ONOS
  - Status code 201 represents HTTP Request is granted

HTTP response replied by ONOS

  - In case of “curl”, use “-i” option to include HTTP Response header in the output

Delete Flow Rule via ONOS Web GUI (1/2)

Response Code

```
201
```

Response Headers

```
{
  "content-length": "0",
  "location": "http://localhost:8181/onos/v1/flows/of:0000000000000001/49821071268378023",
  "server": "Jetty(9.4.28.v20200408)",
  "content-type": null
}
```

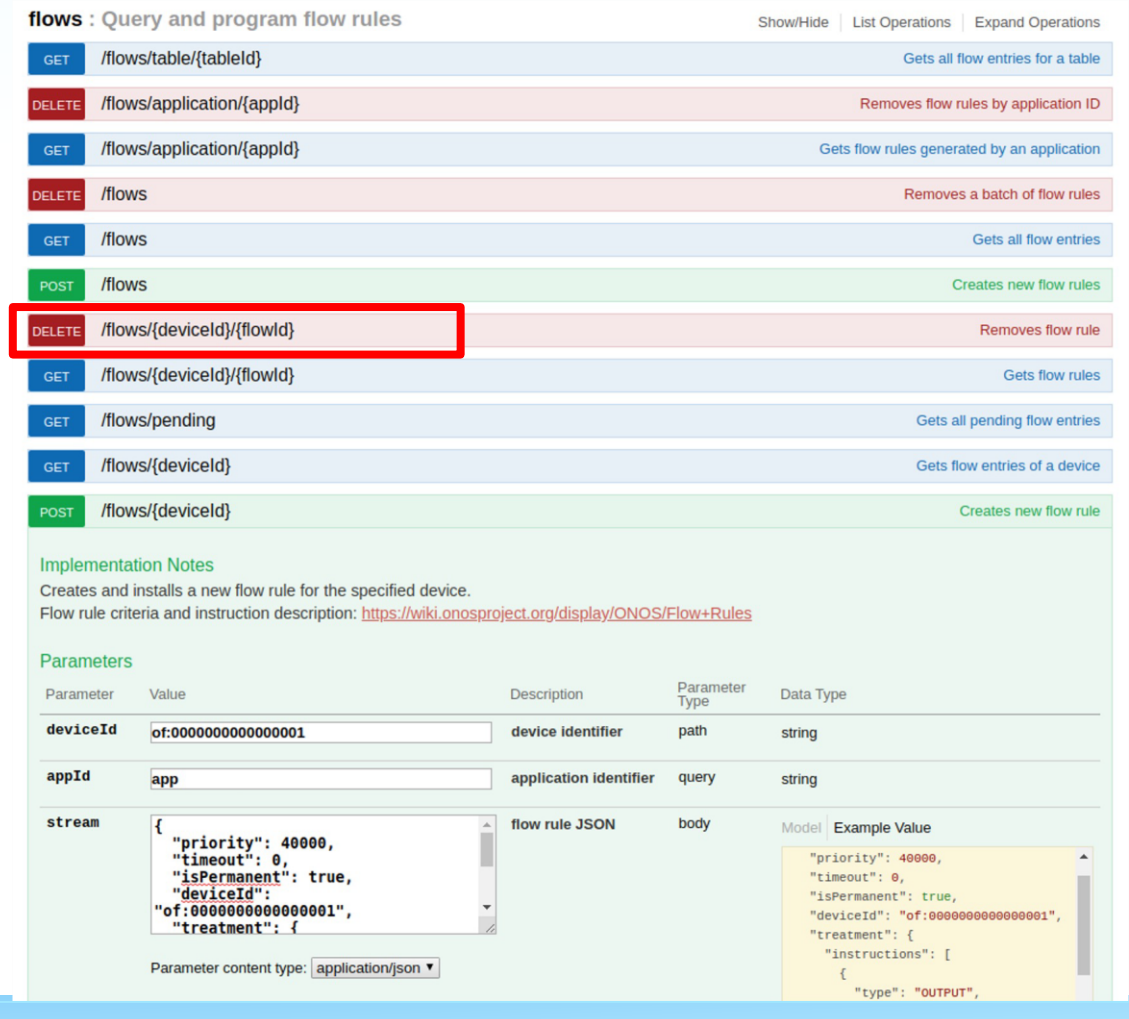
flowId

Delete Flow Rule via ONOS Web GUI (2/2)

- Same procedure as installing flow rules

Select

[DELETE] /flows/{deviceId}/{flowId}



Outline

- OpenFlow Messages
- Install/ Delete Flow Rules
- Lab 2 Requirements
  - Part 1: Answer Questions (15%)
  - Part 2: Install Flow Rules (15%)
  - Part 3: Create Broadcast Storm (20%)
  - Part 4: Trace ReactiveForwarding (10%)
  - Project 2 Demo(40%)

Part 1: Answer Questions (1/2)

- Preparation:

please refer to the commands on p.8

1. Start capturing packets on the loopback interface (lo) with Wireshark.
2. Create a default topology.
3. Activate “org.onosproject.fwd”.
4. Execute command “h1 ping h2 -c 5” in Mininet CLI.
5. Observe the flow rules shown in the GUI.
6. Exit Mininet and stop capturing packets **when the forwarding rules disappear.**

- Questions:

1. How many **OpenFlow headers** with type “OFPT_FLOW_MOD” and command “OFPFC_ADD” are there among all the packets?
2. What are **the match fields** and the corresponding **actions** in each “OFPT_FLOW_MOD” message?
3. What are the **Idle Timeout values** for all flow rules on s1 in **GUI**?

Report format

Ex:There are x distinct “OFPT_FLOW_MOD” headers during the experiment.

Match fields	actions	Timeout values
IN_PORT=1	Output port=4	0
……		

Part 1: Answer Questions (2/2)

- Hints
  - A single OpenFlow packet may contain multiple OpenFlow message headers
  - Only count the number of distinct OpenFlow headers
    - If match fields of two headers are the same, just count once
  - Value of timeout can be zero
  - There will be an `Unknown` type, please refer to ONOS's Source Code to find what it is

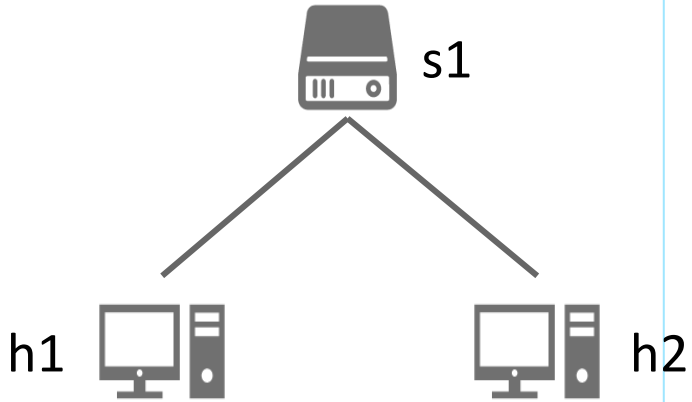
```
▼ OpenFlow 1.4
    Version: 1.4 (0x05)
    Type: OFPT_FLOW_MOD (14)
    Length: 96
    Transaction ID: 7
    Cookie: 0x00010000021b41dc
    Cookie mask: 0x0000000000000000
    Table ID: 0
    Command: OFPFC_ADD (0)
    Idle timeout: 0
    Hard timeout: 0
    Priority: 5
    Buffer ID: OFP_NO_BUFFER (4294967295)
    Out port: OFPP_ANY (4294967295)
    Out group: OFPG_ANY (4294967295)
  ▶ Flags: 0x0001
    Importance: 0
  ▼ Match
      Type: OFPMT_OXM (1)
      Length: 10
    ▼ OXM field
        Class: OFPXMC_OPENFLOW_BASIC (0x8000)
        0000 101. = Field: OFPXMT_OFB_ETH_TYPE (5)
        .... ...0 = Has mask: False
        Length: 2
        Value: IPv4 (0x0800)
      Pad: 000000000000
```

```
Type: OFPT_FLOW_MOD (14)
Length: 96
Transaction ID: 7
Cookie: 0x00010000021b41dc
Cookie mask: 0x0000000000000000
Table ID: 0
Command: OFPFC_ADD (0)
```

```
▼ Match
    Type: OFPMT_OXM (1)
    Length: 10
  ▼ OXM field
      Class: OFPXMC_OPENFLOW_BASIC (0x8000)
      0000 101. = Field: OFPXMT_OFB_ETH_TYPE (5)
      .... ...0 = Has mask: False
      Length: 2
      Value: IPv4 (0x0800)
    Pad: 000000000000
```

Part 2: Install Flow Rules (1/3)

- Please deactivate all the Apps, **except the following Apps** initially activated:
  - “org.onosproject.hostprovider”
  - “org.onosproject.lldpprovider”
  - “org.onosproject.optical-model”
  - “org.onosproject.openflow-base”
  - “org.onosproject.openflow”
  - “org.onosproject.drivers”
  - “org.onosproject.gui2”
- Use the following topology (i.e. h1-s1-h2):




```
$ sudo mn --controller=remote,127.0.0.1:6653 --switch=ovs,protocols=OpenFlow14
```

Part 2: Install Flow Rules (2/3)

1. Install **one** flow rule to forward ARP packets
   - Match Fields
     - Ethernet type (ARP)
   - Actions
     - Forwarding ARP packets to all port in one instruction

- Take screenshot to verify the flow rule you installed

```
mininet> h1 arping h2                # send ARP request
```

```
mininet> h1 arping h2
ARPING 10.0.0.2
42 bytes from 5e:c0:96:3f:8e:ab (10.0.0.2): index=0 time=4.134 msec
42 bytes from 5e:c0:96:3f:8e:ab (10.0.0.2): index=1 time=6.226 usec
42 bytes from 5e:c0:96:3f:8e:ab (10.0.0.2): index=2 time=5.839 usec
42 bytes from 5e:c0:96:3f:8e:ab (10.0.0.2): index=3 time=3.860 usec
42 bytes from 5e:c0:96:3f:8e:ab (10.0.0.2): index=4 time=3.991 usec
42 bytes from 5e:c0:96:3f:8e:ab (10.0.0.2): index=5 time=7.219 usec
```

Part 2: Install Flow Rules (3/3)

2. Install **two** flow rules to forward IPv4 packets
   - Match Fields
     - IPv4 destination address and other required dependencies
   - Actions
     - Forwarding IPv4 packets to the right host

- Take screenshot to verify the flow rules you installed

```
mininet> h1 ping h2          # send ICMP request
```

```
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=0.339 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.056 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.057 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.064 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.055 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=0.054 ms
```

Hint: *Match fields may have dependency; please refer to OpenFlow spec v1.4.0.*

Part 3: Create Topology with Broadcast Storm

- Steps:
  - Create a topology that may cause a “Broadcast Storm”.
  - Install flow rules on switches.
  - Send packets from one host to another host.
  - Observe link status of the network and the CPUs utilization of VM

- **Do NOT** activate any other APPs, except for those initially activated by ONOS
- Describe what you have observed and explain why the broadcast storm occurred
- Take screenshot of CPU’s utilization
- Hand in Topology file (*.py) and flow rule files (*.json)

Hint: ONOS would initially install several flow rules.

Part 4: Trace ReactiveForwarding

- Activate only “org.onosproject.fwd” and other initially activated APPs.
- Use Mininet default topology and let h1 ping h2.
- Observe what happens in control and data planes
  - From the time when h1 pings h2 until h2 receives the first ICMP request
  - Write down every operation made by control and data planes
  - Please refer to the ONOS ReactiveForwarding application
  - Source Code
- Describe what you observed step by step in report
- **Don’t** need to take screenshot

Hint: Tracing Source code with Wireshark to finish this Part

Submission (1/2)

- Files:
  - A report: lab2_<studentID>.pdf
    1. Part 1: Answers to those three questions in **p.31** format
    2. Part 2: Take screenshots of arping/ping result
    3. Part 3: Take screenshots and answer the question
    4. Part 4: Write down what you have observed step by step
    5. What you've learned or solved
  - JSON files for installing flow rules in part 2 and part 3
    - Please follow naming convention
  - A Python script for creating topology in part 3

Naming Convention

- Use the following convention to name the files created in both part 2 and part 3.
  1. Python script for the topology: topo_<studentID>.py
  2. JSON files for flow rules: flows_s<i>-<j>_<studentID>.json
     - "i" is the switch number
     - "j" is the flow rule number, starting from 1, on a switch.

e.g.

File Name	Meaning
flows_s1-1_0748787.json	#1 flow rule to install on s1
flows_s1-2_0748787.json	#2 flow rule to install on s1
flows_s2-1_0748787.json	#1 flow rule to install on s2

Submission (2/2)

- Directory structure:
  - Create root folder: lab2_<studentID>
  - In root folder, create part2 and part3 folders and move files (i.e. *.json, *.py) into the corresponding folders

e.g.

```
project2_0748787/
├── part2
│   ├── flows_s1-1_0748787.json
│   ├── flows_s1-2_0748787.json
│   └── flows_s1-3_0748787.json
├── part3
│   ├── flows_s1-1_0748787.json
│   ├── flows_s1-2_0748787.json
│   ├── flows_s2-1_0748787.json
│   ├── flows_s3-1_0748787.json
│   └── topo_0748787.py
└── project2_0748787.pdf
```

  - Zip root folder: lab2_<studentID>.zip
- Wrong file name or format will result in 10 points deduction

Lab 2 Demo

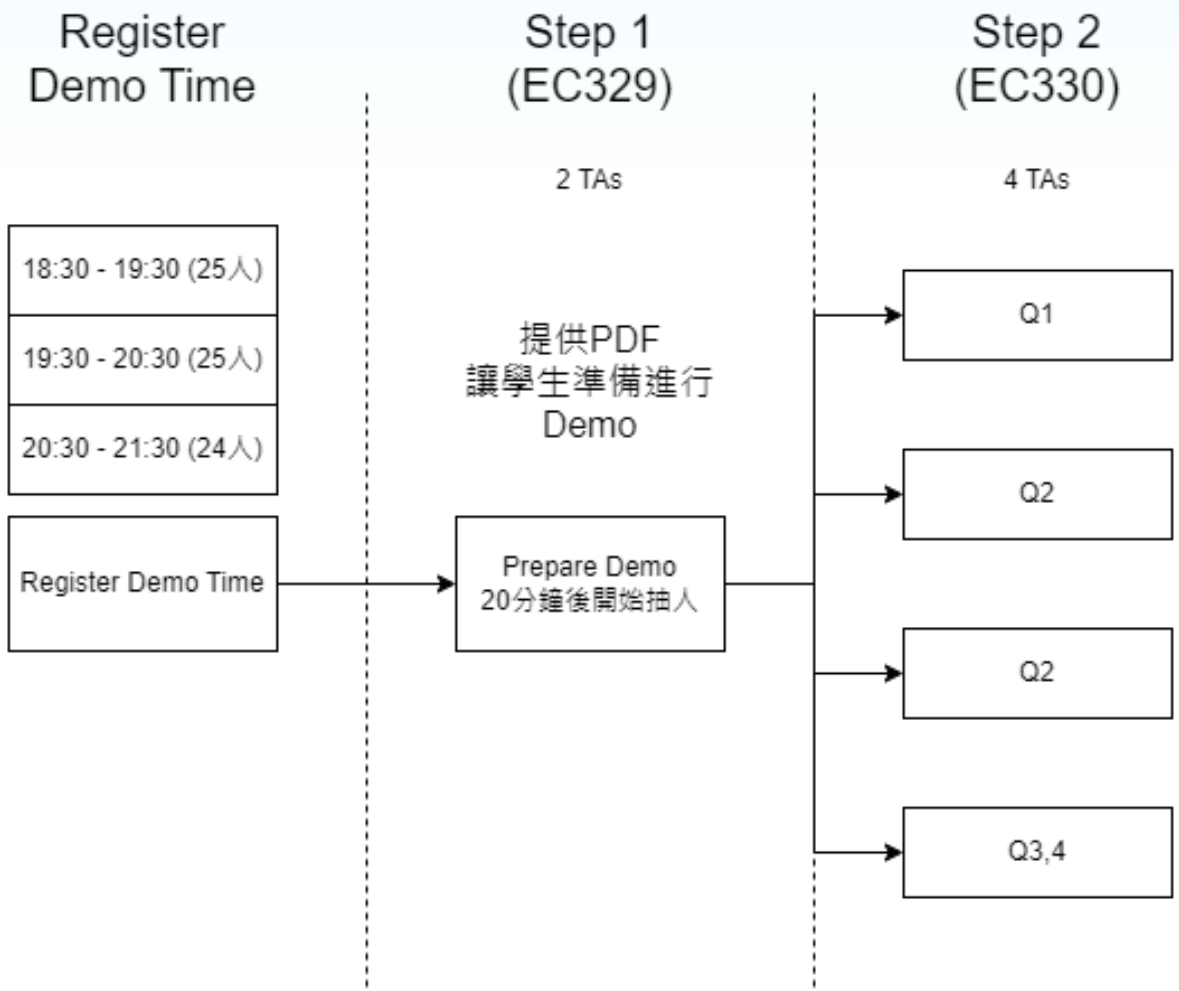
- The demo dates will be in the week after lab 2 deadline.
- Demo question will show when demo start.
- The questions involve modification of the code and the content related to the lecture and the lab

Lab Assign, Due, and Demo Time

		Assign Time	Due Time	Demo Time
Lab 1	ONOS and Mininet Installation	09/05	09/25 (WED) 23:59	-
Lab 2	OpenFlow Protocol Observation & Flow Rule installation	09/12	09/25 (WED) 23:59	09/30 (MON) 18:30 – 21:30
Lab 3	ONOS Application Development: SDN-enabled Learning Bridge and ARP Proxy	09/26	10/16 (WED) 23:59	10/21 (MON) 18:30 – 21:30
Lab 4	Meter Table and Bandwidth Control	10/17	11/06 (WED) 23:59	11/11 (MON) 18:30 – 21:30
Lab 5	Network Function Virtualization: Software Router and Containerization	11/07	11/27 (WED) 23:59	12/02 (MON) 18:30 – 21:30
Final Project	SDN network as vRouter (Group project)	11/28	待定	待定

Lab 2 Demo Flow Chart

- Lab 2 Demo Flow Chart



Lab 2 Demo Time-reserved Table

- Lab 2 Demo Time-reserved Table
  - URL：https://anurl.app/xhDBlb
  - Date of completion: now ~ 9/25 (WED) 23:59

Lab 2 Demo 時段登記

日期: 2024/09/30	學號	姓名	學號	姓名	學號	姓名	學號	姓名	學號	姓名
時段 1 18:30 - 19:30										
時段 2 19:30 - 20:30										
時段 3 20:30 - 21:30									Ex: 313551001	Ex: 王小明

Lab 2 Demo Time-reserved Table

References

- OpenFlow spec v1.4.0
  - https://opennetworking.org/wp-content/uploads/2014/10/openflow-spec-v1.4.0.pdf
- Wireshark wiki
  - https://wiki.wireshark.org/Home
- ONOS REST API
  - https://wiki.onosproject.org/display/ONOS/Appendix+B%3A+REST+API
- JSON Format for Installing Flow Rules
  - https://wiki.onosproject.org/display/ONOS/Flow+Rules

Appendix—REST (REpresentational State Transfer)

- REST is a **software architectural style** for creating Web services
- Architectural constraints:
  - Client-server architecture
  - Stateless
  - Cacheable
  - Uniform interface
  - Layered system
- Allow us to access and manipulate web resources
  - Commonly we use HTTP method
    - Payload could be formatted in HTML, XML, JSON

REST Triangle
of nouns, verbs and content types

Source: Soul & Shell Blog

About help!

- **For lab problem, ask at e3 forum**
  - Ask at the e3 forum
  - TAs will help to clarify Lab contents instead of giving answers!
  - Please describe your questions with sufficient context,
    - , e.g., Environment setup, Input/Output, Screenshots, …
- **For personal problem mail to sdnta@win.cs.nycu.edu.tw**
  - You have special problem and you can’t meet the deadline
  - You got weird score with project
- **No Fixed TA hours**

Q & A