Build basic topo (mininet):

sudo mn --controller=remote,ip=127.0.0.1 --mac --switch=ovsk,protocols=OpenFlow13 --topo=single,4

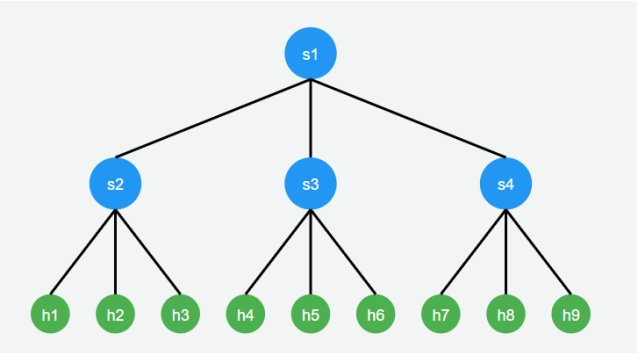
--mac -i (กำหนด ip) 10.1.1.0/24 ..... --topo=linear,4 // Switch 1 ตัว ต่อ Host 1 เครื่อง

-x หลังกำหนด Topo(mininet) = start xterm in all hosts

sudo mn --controller=remote,ip=127.0.0.1:XXXX --mac ... // กำหนด port

options	Description
--controller	type of controller local/remote and remote controller ip.
--mac	mac address starts with 00:00:00:00:00:01
-i	IP Subnets for the Topology
--switch	Switch type (ovsk - openvswitch kernel module), and openflow version.
--topo	topology type(linear,minimal,reversed,single,torus,tree) and params.

--topo=tree,depth=2,fanout=3



Start controller:

ryu-manager ryu.app.simple_switch_13

ryu-manager --ofp-tcp-listen-port 6634 ryu.app.simple_switch_13 //กำหนด port

ryu-manager ryu.app.simple_switch_13 ***ryu.app.ofctl_rest*** *// REST API สำหรับการควบคุมและจัดการสวิตช์*

ryu.app.simple_monitor_13 //statistics

Mode การทำงานเมื่อ Controller ล่ม

- Standalone: Switch ทำงานเป็น Traditional Switch แม้ว่า controller down ก็จะยังงานได้ (Flow rules ยังอยู่)
- Secure: Switch พยายามเชื่อมต่อ Controller ตลอด ไม่ Forward packet (default) (ในกรณี flow timeout set)

1. ในโหมด Secure:

- Flow rules เดิมที่มีอยู่ใน table จะยังทำงานได้ (ถ้าไม่ได้กำหนด timeout)
- แต่ไม่สามารถสร้าง Flow rules ใหม่ได้เมื่อ Controller down
- ดังนั้นถ้ามีการสื่อสารระหว่าง hosts คู่ใหม่ที่ไม่เคยมี flow rules มาก่อน จะไม่สามารถสื่อสารกันได้

2. ในโหมด Standalone:

- Flow rules เดิมยังทำงานได้เหมือนกัน
- แต่สามารถสร้าง Flow rules ใหม่ได้เอง โดยทำงานเป็น traditional switch
- hosts คู่ใหม่สามารถสื่อสารกันได้ปกติ

sudo ovs-vsctl set-fail-mode <switch_name> standalone | secure

คำสั่งตรวจสอบ:

sudo ovs-vsctl show

sudo ovs-ofctl -O OpenFlow13 dump-flows s1

sudo ovs-ofctl -O OpenFlow13 dump-ports s1

sudo ovs-ofctl -O OpenFlow13 show s1

sudo ovs-appctl fdb/show s1 // Forwarding Database (FDB) หรือตาราง MAC Address

sudo ovs-ofctl -O OpenFlow13 dump-groups

sudo ovs-ofctl -O OpenFlow13 ***del-groups*** *s5 group_id=0 /// **ลบ***

sudo ovs-ofctl -O OpenFlow13 dump-meters s1

sudo ovs-ofctl -O OpenFlow13 meter-stats s1

คำสั่งพื้นฐานเกี่ยวกับ arp ประกอบไปด้วย

arp -a. แสดงรายละเอียดข้อมูลใน ARP Table

arp -d 10.1.1.2 ลบข้อมูลใน ARP Table

arp -s [ip_dest] [mac]

Clear config mininet:

sudo mn -c

mininet commands:

links, pingall, h1 ping h2, h1 arp -a, ***net****, xterm h1, h1 ifconfig, h1 ip route, link s1 s2 down*

h1 python -m http.server (http server on host 1, use curl to fetch data: curl [ip]:[port] หรือใช้ ApacheBench),

h1 ps aux | grep iperf //ตรวจสอบว่า iperf server ทำงานอยู่บน host1 หรือไม่

h1 kill $(ps aux | grep '[i]perf' | awk '{print $2}') // terminate iperf

nodes, dump , **h1 arp -a -s 192.168.1.2 00:00:00:00:00:02**

iperf:

h4 iperf -s & : -s หมายถึง การกำหนดให้เป็น Server Mode ,& : Run in background

h1 iperf -c -s & เป็นได้ทั้ง server & client

h1 iperf -c h4 -i 10 -P 10 -t 10:

-c หมายถึง การกำหนดให้เป็น Client Mode

-i หมายถึง ช่วงเวลาในการรายงานผล เช่น -i 10 คือ รายงานผลทุก 10 วินาที

-t หมายถึง ช่วงเวลาในการทดสอบในหน่วยวินาที -t 30 คือ ช่วงเวลาทั้งหมดในการทดสอบเท่ากับ 30 วินาที

-b หมายถึง การกำหนดแบนด์วิดท์ เช่น -b 10m คือ แบนด์วิดท์ขนาด 10 Mbps

-P หมายถึง การเชื่อมต่อแบบขนาน (Parallel) คือการสร้าง Connection เชื่อมต่อระหว่าง Client และ Server ขึ้นมาพร้อมๆ กัน เช่น -P 10 คือ สร้าง Connection ขึ้นมา 10 Connections แล้วส่งข้อมูลออกไปพร้อมๆ กัน

Ipetf UDP: (ใช้ keyword optional ได้เหมือน tcp)

h1 iperf -u -s &

h4 iperf -u -c h1

ApacheBench(http test traffic)

ab -n 500 -c 50 http://10.1.1.4:8000/

- c 50 หมายถึง จำนวนของ Client ที่ร้องขอไปยัง Server เท่ากับ 50 Clients

- n 500 หมายถึง จำนวนการร้องขอจาก Client 1 ตัว ไปยัง Server 500 ครั้ง

Curl Methods & REST API FOR Controller (before start controller add this *ryu.app.ofctl_rest)*

GET Methos:

- curl http://localhost:8080/stats/switches | jq //ดู switches ทั้งหมด
- curl http://localhost:8080/stats/desc/1 | jq //ดู Details switch 1
- curl http://localhost:8080/stats/flow/1 | jq //ดู flows switch 1
- curl http://localhost:8080/stats/port/1 | jq //ดู port switch 1

POST Methos: // ใน windows ใช้ curl.exe และ Double-quotes

- curl -X POST http://localhost:8080/stats/flowentry/add -d '@hub_flow.json'//ส่ง flowrule ให้ controller
- curl -X POST http://localhost:8080/stats/groupentry/add -d '@hub_flow.json'//ส่ง group ให้ controller

- curl.exe -X POST http://10.0.0.8:8080/stats/meterentry/add -d "@addmeter.json" //ส่ง meter limit

DELETE Methods:

- curl -X DELETE http://localhost:8080/stats/flowentry/clear/1 //ลบ flow rules เดิมทั้งหมด

Code python build topo (Run miniter topo by “sudo python [filename.py])

1. Simple = single,4

```python
from mininet.topo import Topo
from mininet.net import Mininet
from mininet.log import setLogLevel
from mininet.cli import CLI
from mininet.node import OVSSwitch, Controller, RemoteController

...
class SingleSwitchTopo(Topo):
    "Single switch connected to n hosts."
    def build(self):
        s1 = self.addSwitch('s1', failMode='standalone')
        h1 = self.addHost('h1', mac="00:00:00:00:00:01", ip="192.168.1.1/24")
        h2 = self.addHost('h2', mac="00:00:00:00:00:02", ip="192.168.1.2/24")
        h3 = self.addHost('h3', mac="00:00:00:00:00:03", ip="192.168.1.3/24")
        h4 = self.addHost('h4', mac="00:00:00:00:00:04", ip="192.168.1.4/24")
        self.addLink(h1, s1)
        self.addLink(h2, s1)
        self.addLink(h3, s1)
        self.addLink(h4, s1)

if __name__ == '__main__':
    setLogLevel('info')
    topo = SingleSwitchTopo()
    c1 = RemoteController('c1', ip='127.0.0.1')
    net = Mininet(topo=topo, controller=c1)
    net.start()
    #net.pingAll()
    CLI(net)
    net.stop()

# Topology 1: Ring Topology (วงแหวน)
class RingTopo(Topo):
    "Ring topology with 4 switches and 4 hosts"
    def build(self):
        # Add switches
        switches = []
        for i in range(4):
            switches.append(self.addSwitch(f's{i+1}', failMode='standalone'))

        # Add hosts and connect to switches
        for i in range(4):
            host = self.addHost(f'h{i+1}',
                                mac=f"00:00:00:00:00:0{i+1}",
                                ip=f"192.168.1.{i+1}/24")
            self.addLink(host, switches[i])

        # Create ring connections between switches
        for i in range(4):
            self.addLink(switches[i], switches[(i+1)%4])
```

```python
# Topology 2: Hierarchical Tree (ต้นไม้แบบลำดับชั้น)
class HierarchicalTopo(Topo):
    "Hierarchical topology with core, distribution and access layers"
    def build(self):
        # Core layer
        core = self.addSwitch('s1', failMode='standalone')

        # Distribution layer
        dist1 = self.addSwitch('s2', failMode='standalone')
        dist2 = self.addSwitch('s3', failMode='standalone')

        # Access layer
        access1 = self.addSwitch('s4', failMode='standalone')
        access2 = self.addSwitch('s5', failMode='standalone')

        # Connect core to distribution
        self.addLink(core, dist1)
        self.addLink(core, dist2)

        # Connect distribution to access
        self.addLink(dist1, access1)
        self.addLink(dist2, access2)

        # Add hosts
        h1 = self.addHost('h1', mac="00:00:00:00:00:01", ip="192.168.1.1/24")
        h2 = self.addHost('h2', mac="00:00:00:00:00:02", ip="192.168.1.2/24")
        h3 = self.addHost('h3', mac="00:00:00:00:00:03", ip="192.168.1.3/24")
        h4 = self.addHost('h4', mac="00:00:00:00:00:04", ip="192.168.1.4/24")

        # Connect hosts to access switches
        self.addLink(h1, access1)
        self.addLink(h2, access1)
        self.addLink(h3, access2)
        self.addLink(h4, access2)

# Topology 3: Mesh Topology (เมช)
class MeshTopo(Topo):
    "Partial mesh topology with 4 switches and 4 hosts"
    def build(self):
        # Add switches
        s1 = self.addSwitch('s1', failMode='standalone')
        s2 = self.addSwitch('s2', failMode='standalone')
        s3 = self.addSwitch('s3', failMode='standalone')
        s4 = self.addSwitch('s4', failMode='standalone')

        # Add hosts
        h1 = self.addHost('h1', mac="00:00:00:00:00:01", ip="192.168.1.1/24")
        h2 = self.addHost('h2', mac="00:00:00:00:00:02", ip="192.168.1.2/24")
        h3 = self.addHost('h3', mac="00:00:00:00:00:03", ip="192.168.1.3/24")
        h4 = self.addHost('h4', mac="00:00:00:00:00:04", ip="192.168.1.4/24")

        # Connect hosts to switches
        self.addLink(h1, s1)
        self.addLink(h2, s2)
        self.addLink(h3, s3)
        self.addLink(h4, s4)

        # Create mesh connections between switches
        self.addLink(s1, s2)
        self.addLink(s1, s3)
        self.addLink(s1, s4)
        self.addLink(s2, s3)
        self.addLink(s2, s4)
        self.addLink(s3, s4)

# Main function to run different topologies
def runTopology(topoClass):
    setLogLevel('info')
    topo = topoClass()
    c1 = RemoteController('c1', ip='127.0.0.1')
    net = Mininet(topo=topo, controller=c1)
    net.start()
    CLI(net)
    net.stop()

if __name__ == '__main__':
    # Uncomment the topology you want to run:
    # runTopology(RingTopo)
    # runTopology(HierarchicalTopo)
    # runTopology(MeshTopo)
    pass
```

ตัวอย่างการสร้าง Topo แบบกำหนด port การเชื่อมต่อได้

สังเกตว่ากำหนด mode = secure

```python
class TriangleOfficeTopo(Topo):
    "Triangle topology connecting 3 buildings with 5 hosts"
    def build(self):
        # Add switches (one per building)
        s1 = self.addSwitch('s1', failMode='secure')  # Building A
        s2 = self.addSwitch('s2', failMode='secure')  # Building B
        s3 = self.addSwitch('s3', failMode='secure')  # Building C

        # Add hosts with specific IP and MAC addresses
        # Building A devices
        h1 = self.addHost('h1', mac="00:00:00:00:00:01", ip="192.168.1.1/24")  # Security Camera
        h2 = self.addHost('h2', mac="00:00:00:00:00:02", ip="192.168.1.2/24")  # Access Control

        # Building B devices
        h3 = self.addHost('h3', mac="00:00:00:00:00:03", ip="192.168.1.3/24")  # File Server

        # Building C devices
        h4 = self.addHost('h4', mac="00:00:00:00:00:04", ip="192.168.1.4/24")  # Monitoring Syst
        h5 = self.addHost('h5', mac="00:00:00:00:00:05", ip="192.168.1.5/24")  # Backup Server

        # Connect hosts to their respective switches
        self.addLink(h1, s1, port2=1)
        self.addLink(h2, s1, port2=2)
        self.addLink(h3, s2, port2=1)
        self.addLink(h4, s3, port2=1)
        self.addLink(h5, s3, port2=2)

        # Create triangle topology between switches
        self.addLink(s1, s2, port1=3, port2=2)
        self.addLink(s2, s3, port1=3, port2=3)
        self.addLink(s3, s1, port1=4, port2=4))
```

Code python build controller (Run controller by “ryu-manager [filename.py])

2. Hub controller (For ryu-manager: ryu-manager hub.py)

```python
from ryu.base import app_manager
from ryu.controller import ofp_event
from ryu.controller.handler import CONFIG_DISPATCHER, MAIN_DISPATCHER
from ryu.controller.handler import set_ev_cls
from ryu.ofproto import ofproto_v1_3
from ryu.lib.packet import packet
from ryu.lib.packet import ethernet
from ryu.lib.packet import ether_types


You, 4 weeks ago | 1 author (You)
class SimpleSwitch13(app_manager.RyuApp):
    OFP_VERSIONS = [ofproto_v1_3.OFP_VERSION]

    def __init__(self, *args, **kwargs):
        super(SimpleSwitch13, self).__init__(*args, **kwargs)
        self.mac_to_port = {}

    @set_ev_cls(ofp_event.EventOFPSwitchFeatures, CONFIG_DISPATCHER)
    def switch_features_handler(self, ev):
        datapath = ev.msg.datapath
        ofproto = datapath.ofproto
        parser = datapath.ofproto_parser

        # writing flood entry
        match = parser.OFPMatch()
        actions = [parser.OFPActionOutput(port=ofproto.OFPP_FLOOD)]
        self.add_flow(datapath, 0, match, actions)

    def add_flow(self, datapath, priority, match, actions, buffer_id=None):
        ofproto = datapath.ofproto
        parser = datapath.ofproto_parser

        inst = [parser.OFPInstructionActions(ofproto.OFPIT_APPLY_ACTIONS,
                                             actions)]
        if buffer_id:
            mod = parser.OFPFlowMod(datapath=datapath, buffer_id=buffer_id,
                                    priority=priority, match=match,
                                    instructions=inst)
        else:
            mod = parser.OFPFlowMod(datapath=datapath, priority=priority,
                                    match=match, instructions=inst)
        datapath.send_msg(mod)

```

3. L3 switch controller (ryu-manager l3_switch.py)

```
65          datapath.send_msg(mod)
66      #from ryu.lib.packet import ipv4 เพิ่มโค้ดด่านล่างหลังจาก def add_flow **********
67      @set_ev_cls(ofp_event.EventOFPPacketIn, MAIN_DISPATCHER)
68      def _packet_in_handler(self, ev):
69          if ev.msg.msg_len < ev.msg.total_len:
70              self.logger.debug("packet truncated: only %s of %s bytes",
71                                ev.msg.msg_len, ev.msg.total_len)
72          msg = ev.msg
73          datapath = msg.datapath
74          ofproto = datapath.ofproto
75          parser = datapath.ofproto_parser
76          in_port = msg.match['in_port']
77          pkt = packet.Packet(msg.data)
78          eth = pkt.get_protocols(ethernet.ethernet)[0]
79          if eth.ethertype == ether_types.ETH_TYPE_LLDP:
80              return
81          dst = eth.dst
82          src = eth.src
83          dpid = datapath.id
84          self.mac_to_port.setdefault(dpid, {})
85          self.logger.info("packet in %s %s %s %s", dpid, src, dst, in_port)
86          self.mac_to_port[dpid][src] = in_port
87          if dst in self.mac_to_port[dpid]:
88              out_port = self.mac_to_port[dpid][dst]
89          else:
90              out_port = ofproto.OFPP_FLOOD
91          actions = [parser.OFPActionOutput(out_port)]
92          if out_port != ofproto.OFPP_FLOOD:
93              if eth.ethertype == ether_types.ETH_TYPE_IP:
94                  ip = pkt.get_protocol(ipv4.ipv4)
95                  srcip = ip.src
96                  dstip = ip.dst
97                  match = parser.OFPMatch(eth_type=ether_types.ETH_TYPE_IP,
98                                          ipv4_src=srcip,
99                                          ipv4_dst=dstip
100                                         )
101                 if msg.buffer_id != ofproto.OFP_NO_BUFFER:
102                     self.add_flow(datapath, 1, match, actions, msg.buffer_id)
103                     return
104                 else:
105                     self.add_flow(datapath, 1, match, actions)
106         data = None
107         if msg.buffer_id == ofproto.OFP_NO_BUFFER:
108             data = msg.data
109         out = parser.OFPPacketOut(datapath=datapath, buffer_id=msg.buffer_id,
110                                   in_port=in_port, actions=actions, data=data)
111         datapath.send_msg(out)
112
```

4. L4_Switch (port) สามารถใช้โค้ดจาก L3 แต่แก้โค้ดและ import เพิ่ม

SDN ch3.pdf | l4_switch.py 9+

ch3 > l4_switch.py > SimpleSwitch13 > _packet_in_handler

```
106             actions = [parser.OFPActionOutput(out_port)]
107             '''
108             from ryu.lib.packet import icmp
109             from ryu.lib.packet import tcp
110             from ryu.lib.packet import udp  เพิ่มและแก้โค้ดเพื่อกรอก L4
111             '''
112             if out_port != ofproto.OFPP_FLOOD:
113
114                 # check IP Protocol and create a match for IP
115                 if eth.ethertype == ether_types.ETH_TYPE_IP:
116                     ip = pkt.get_protocol(ipv4.ipv4)
117                     srcip = ip.src
118                     dstip = ip.dst
119                     protocol = ip.proto
120                     # if ICMP Protocol
121                     if protocol == in_proto.IPPROTO_ICMP:
122                         match = parser.OFPMatch(eth_type=ether_types.ETH_TYPE_IP, ipv4_src=srcip, ipv4_dst=dstip,
123                                                 ip_proto=protocol)
124
125                     #  if TCP Protocol
126                     elif protocol == in_proto.IPPROTO_TCP:
127                         t = pkt.get_protocol(tcp.tcp)
128                         match = parser.OFPMatch(eth_type=ether_types.ETH_TYPE_IP, ipv4_src=srcip, ipv4_dst=dstip,
129                                                 ip_proto=protocol, tcp_src=t.src_port, tcp_dst=t.dst_port,)
130
131                     #  If UDP Protocol
132                     elif protocol == in_proto.IPPROTO_UDP:
133                         u = pkt.get_protocol(udp.udp)
134                         match = parser.OFPMatch(eth_type=ether_types.ETH_TYPE_IP, ipv4_src=srcip, ipv4_dst=dstip,
135                                                 ip_proto=protocol, udp_src=u.src_port, udp_dst=u.dst_port,)
136
137                     # verify if we have a valid buffer_id, if yes avoid to send both
138                     # flow_mod & packet_out
139                     if msg.buffer_id != ofproto.OFP_NO_BUFFER:
140                         self.add_flow(datapath, 1, match, actions, msg.buffer_id)
141                         return
142                     else:
143                         self.add_flow(datapath, 1, match, actions)
144             data = None
145             if msg.buffer_id == ofproto.OFP_NO_BUFFER:
146                 data = msg.data
147
148             out = parser.OFPPacketOut(datapath=datapath, buffer_id=msg.buffer_id,
149                                       in_port=in_port, actions=actions, data=data)
150             datapath.send_msg(out)
151
```

5. Flow timeout :

```
    def add_flow(self, datapath, priority, match, actions, buffer_id=None, idle=0, hard=0):
    '''
    ไม่ต้อง import อะไรเพิ่ม ใช้จาก hub.py ได้เลย
    สังเกต idle, hard สำหรับ flow timeout
    '''
    @set_ev_cls(ofp_event.EventOFPPacketIn, MAIN_DISPATCHER)
    def _packet_in_handler(self, ev):
        if ev.msg.msg_len < ev.msg.total_len:
            self.logger.debug("packet truncated: only %s of %s bytes",
                              ev.msg.msg_len, ev.msg.total_len)
        msg = ev.msg
        datapath = msg.datapath
        ofproto = datapath.ofproto
        parser = datapath.ofproto_parser
        in_port = msg.match['in_port']
        pkt = packet.Packet(msg.data)
        eth = pkt.get_protocols(ethernet.ethernet)[0]
        if eth.ethertype == ether_types.ETH_TYPE_LLDP:
            return
        dst = eth.dst
        src = eth.src
        dpid = datapath.id
        self.mac_to_port.setdefault(dpid, {})
        self.logger.info("packet in %s %s %s %s", dpid, src, dst, in_port)
        self.mac_to_port[dpid][src] = in_port
        if dst in self.mac_to_port[dpid]:
            out_port = self.mac_to_port[dpid][dst]
        else:
            out_port = ofproto.OFPP_FLOOD
        actions = [parser.OFPActionOutput(out_port)]
        if out_port != ofproto.OFPP_FLOOD:
            match = parser.OFPMatch(in_port=in_port, eth_dst=dst, eth_src=src)
            if msg.buffer_id != ofproto.OFP_NO_BUFFER:
                self.add_flow(datapath, 1, match, actions, msg.buffer_id, idle=10, hard=30)
                return
            else:
                self.add_flow(datapath, 1, match, actions, idle=10, hard=30)
        data = None
        if msg.buffer_id == ofproto.OFP_NO_BUFFER:
            data = msg.data
        out = parser.OFPPacketOut(datapath=datapath, buffer_id=msg.buffer_id,
                                  in_port=in_port, actions=actions, data=data)
        datapath.send_msg(out)
```

Code for REST API to push in flow of controller (ส่ง flow rule ให้ controller)

ความหมายค่า Port ตรง Action ใน Flow rule สามารถใช้คำแทนได้ "port": "CONTROLLER"

- ✓ OFPP_FLOOD (0xFFFFFFFB) = 4294967291 //packet ออกทุก port ยกเว้น port ที่ packet เข้ามา
- ✓ OFPP_ALL (0xFFFFFFFC) = 4294967292 ส่ง //packet ออกทุก port
- ✓ OFPP_CONTROLLER (0xFFFFFFFD) = 4294967293 //packet ไปที่ controller
- ✓ OFPP_TABLE (0xFFFFFFFA) = 4294967290 //packet เข้า flow table
- ✓ OFPP_IN_PORT (0xFFFFFFF8) = 4294967288 //packet กลับออกไปทาง port ที่เข้ามา
- ✓ OFPP_NORMAL (0xFFFFFFFA) = 4294967290 //ให้ switch จัดการ packet ตามการทำงานปกติ

OFPP_TABLE และ OFPP_NORMAL มีค่าเท่ากัน (4294967290) เพราะทั้งสองค่านี้ใช้แทนพฤติกรรมเดียวกันคือการให้ switch จัดการ packet ตามการทำงานปกติผ่าน flow table

1. Hub.js //วิธีส่งให้ controller ใช้ curl -X POST (stats/flowentry/add) ดูในสรุปด้านบน

```
{
    "dpid": 1,
    "table_id": 0,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 100,
    "match":{
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 4294967291
        }
    ]
}
```

2. L2

2.1 ARP & Flow1 (ของ host1) // ARP ถ้าไม่ได้ให้แก้เป็น 2054 (dl_type หรือ "eth_type": 2054

```
{   // ARP
    "dpid": 1,
    "table_id": 0,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 100,
    "match":{
    "dl_dst": "ff:ff:ff:ff:ff:ff"
    //    "dl_type": 2054 ARP
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 4294967291
        }
    ]
}
```

```
{   //flow 1 For h1
    "dpid": 1,
    "table_id": 0,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 100,
    "match":{
    "dl_dst": "00:00:00:00:00:01"
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 1
        }
    ]
}
```

```
{
    "dpid": 1, //switch
    "table_id": 0,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 100,
    "match":{
    "dl_dst": "00:00:00:00:00:02"
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 2 //host 2
        }
    ]
}
```

h2

switch_1.json ...\sw2 U × switch_2.json

test > test_l2_REST2 > sw2 > switch_1.json >

```
{
    "dpid": 2,
    "table_id": 0,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 100,
    "match":{
        "eth_type": 2048,
        "ipv4_dst": "10.0.0.1"
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 2
        }
    ]
}
```

L3 ต้องระบุ eth_type ด้วย

3. Multitable

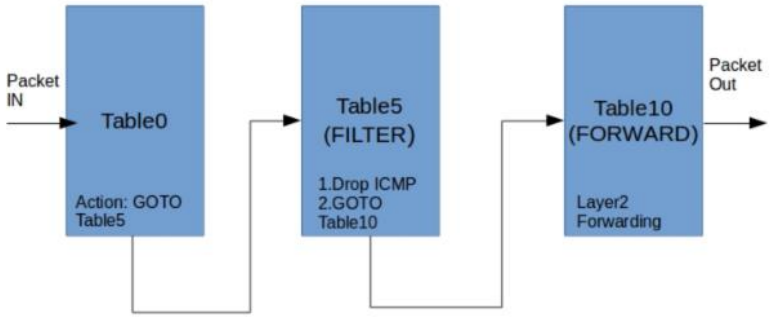
eth_type (EtherType) มีค่าหลักๆ ที่ใช้บ่อยดังนี้:

1. 0x0800 (2048) - IPv4
2. 0x0806 (2054) - ARP
3. 0x86DD (34525) - IPv6
4. 0x8100 (33024) - VLAN-tagged frame (802.1Q)
5. 0x88CC (35020) - LLDP (Link Layer Discovery Protocol)

ip_proto (IP Protocol Number) มีค่าหลักๆ ที่ใช้บ่อยดังนี้:

1. 1 - ICMP (Internet Control Message Protocol)
2. 6 - TCP (Transmission Control Protocol)
3. 17 - UDP (User Datagram Protocol)
4. 2 - IGMP (Internet Group Management Protocol)
5. 50 - ESP (Encapsulating Security Payload - IPsec)
6. 51 - AH (Authentication Header - IPsec)
7. 89 - OSPF (Open Shortest Path First)
8. 47 - GRE (Generic Routing Encapsulation)

ตัวอย่าง (Single,4)



SDN ch4.pdf | table0_flow1.json

document > ch4 > ofctl > multitable > table0_flow

You, 4 weeks ago | 1 author (You)

```
{
    "dpid": 1,
    "table_id": 0,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 0,
    "match":{
    },
    "actions":[
        {
            "type":"GOTO_TABLE",
            "table_id": 5
        }
    ]
}
```

table5_flow1.json

document > ch4 > ofctl > multitable > table5_flow

You, 4 weeks ago | 1 author (You)

```
{
    "dpid": 1,
    "table_id": 5,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 0,
    "match":{
    },
    "actions":[
        {
            "type":"GOTO_TABLE",
            "table_id": 10
        }
    ]
}
```

table5_flow2.json

document > ch4 > ofctl > multitable > table5_flow

You, 4 weeks ago | 1 author (You)

```
{
    "dpid": 1,
    "table_id": 5,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 100,
    "match":{
        "eth_type": 2048,
        "ipv4_dst": "10.0.0.4",
        "ip_proto": 1
    },
    "actions":[
    ]
}
```

SDN ch4.pdf | table10_arp.json

document > ch4 > ofctl > multitable > table10_arp.json

You, 4 weeks ago | 1 author (You)

```
{
    "dpid": 1,
    "table_id": 10,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 0,
    "match":{
    "dl_dst": "ff:ff:ff:ff:ff:ff"
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 4294967291
        }
    ]
}
```

table10_fl

document > ch4 > ofctl > multitable > table10_flow

You, 4 weeks ago | 1 author (You)

```
{
    "dpid": 1,
    "table_id": 10,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 0,
    "match":{
    "dl_dst": "00:00:00:00:00:01"
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 1
        }
    ]
}
```

table10_flow2.json

document > ch4 > ofctl > multitable > table10_flow2.json

You, 4 weeks ago | 1 author (You)

```
{
    "dpid": 1,
    "table_id": 10,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 0,
    "match":{
    "dl_dst": "00:00:00:00:00:02"
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 2
        }
    ]
}
```

SDN ch4.pdf | table10_flow3.json

document > ch4 > ofctl > multitable > table10_flow3.jso

You, 4 weeks ago | 1 author (You)

```
{
    "dpid": 1,
    "table_id": 10,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 0,
    "match":{
    "dl_dst": "00:00:00:00:00:03"
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 3
        }
    ]
}
```

table10_flow4.json

document > ch4 > ofctl > multitable > table10_flow

You, 4 weeks ago | 1 author (You)

```
{
    "dpid": 1,
    "table_id": 10,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 0,
    "match":{
    "dl_dst": "00:00:00:00:00:04"
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 4
        }
    ]
}
```

ดูตรง actions [port/ table_id] ดีๆ

4. Group Table

Multi-table workflow:

h1 -> s1 (เข้าสู่ switch)

↓

Table 0 (ตรวจสอบพื้นฐาน)

↓

Table 5 (block ICMP - ถ้าเป็น ICMP จะถูก drop)

↓

Table 10 (forward - ส่งต่อไปยังพอร์ตปลายทาง)

- ทำงานเป็นลำดับขั้น (pipeline)
- แต่ละ table มีหน้าที่เฉพาะ
- packet ต้องผ่านทุก table ตามลำดับ

Group Table workflow

sudo ovs-ofctl -O OpenFlow13 del-groups s5 group_id=0 // ลบ group id ในกรณี /add ผิด

h1 -> s1 (เข้าสู่ switch)

↓

Group Table (มี bucket หลายตัว)

↙ ↓ ↘

Bucket1 Bucket2 Bucket3

(ICMP) (TCP) (Forward)

กรณี ALL Group:

- packet จะถูกทำสำเนาและส่งไปทุก bucket
- แต่ละ bucket ทำงานแยกกัน

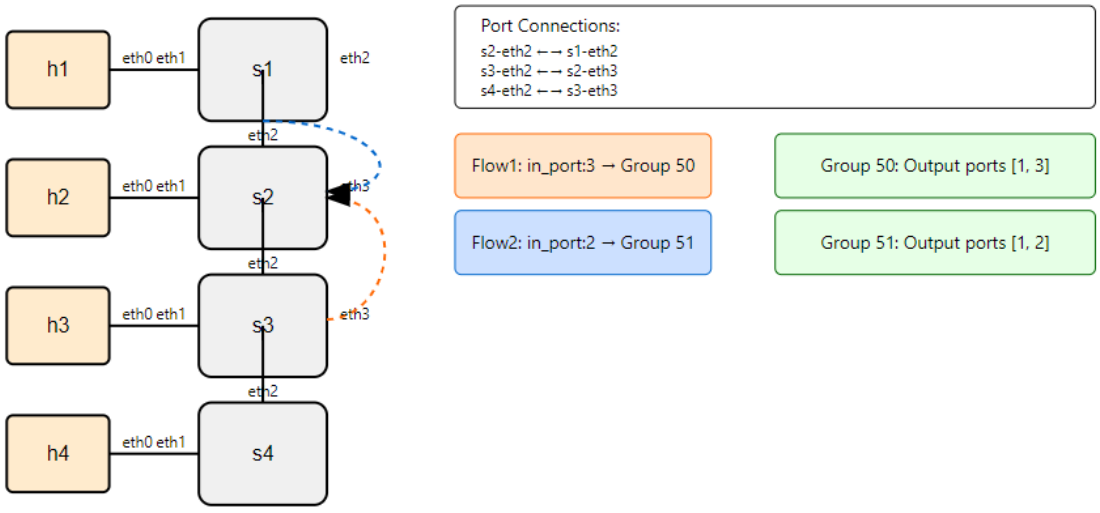
กรณี SELECT Group:

- packet จะถูกส่งไปเพียง bucket เดียว
- เลือก bucket ตามเงื่อนไขที่กำหนด (เช่น load balancing)

ความแตกต่างหลัก:

1. Multi-table ทำงานเป็นลำดับขั้นตอน แต่ Group Table ทำงานแบบขนานหรือเลือกทำอันใดอันหนึ่ง
2. Multi-table แยกตามประเภทการทำงาน แต่ Group Table รวมกลุ่มการทำงานที่เกี่ยวข้องกัน

4.1 Sniffer (linear,4 & ryu.app.simple_switch_13 ryu.app.ofctl_rest) ต้องส่ง Group ก่อน



1. Flow1 (เมื่อ packet เข้ามาที่ port 3 sw2):
    - Match condition: in_port = 3 (packet มาจาก s3)
    - Action: ส่งไปที่ Group 50
    - Group 50 จะทำการ multicast packet ไปที่:

        - Output port 1 (ไปที่ h2)
        - Output port 3 (ส่งกลับไปที่ s3)
2. Flow2 (เมื่อ packet เข้ามาที่ port 2):
    - Match condition: in_port = 2 (packet มาจาก s1)
    - Action: ส่งไปที่ Group 51
    - Group 51 จะทำการ multicast packet ไปที่:
        - Output port 1 (ไปที่ h2)
        - Output port 2 (ส่งกลับไปที่ s1)

1. เมื่อ packet เข้ามาที่ s2 ระบบจะเช็ค incoming port
2. ถ้าเข้ามาที่ port 3 จะเข้า Flow1 -> Group 50
3. ถ้าเข้ามาที่ port 2 จะเข้า Flow2 -> Group 51
4. จากนั้น Group จะทำการ multicast packet ไปยัง output ports ที่กำหนดไว้

   หมายเหตุ: ทั้ง Group 50 และ 51 เป็น type "ALL" ซึ่งหมายถึงจะทำการ multicast packet ไปยังทุก output ports ที่กำหนดไว้ในกลุ่มนั้นๆ

group50.json M

document > ch4 > ofctl > sniffer > group50.json > ...

You, 50 minutes ago | 1 author (You)

```
{
    "dpid": 2,
    "type": "ALL",
    "group_id": 50,
    "buckets": [
        {
            "actions": [
                {
                    "type": "OUTPUT",
                    "port": 1
                }
            ]
        },
        {
            "actions": [
                {
                    "type": "OUTPUT",
                    "port": 3
                }
            ]
        }
    ]
}
```

group51.json M

document > ch4 > ofctl > sniffer > group51.json > ...

You, 50 minutes ago | 1 author (You)

```
{
    "dpid": 2,
    "type": "ALL",
    "group_id": 51,
    "buckets": [
        {
            "actions": [
                {
                    "type": "OUTPUT",
                    "port": 1
                }
            ]
        },
        {
            "actions": [
                {
                    "type": "OUTPUT",
                    "port": 2
                }
            ]
        }
    ]
}
```

You, 4 weeks ago • add_ch4_files

flow1.json

document > ch4 > ofctl > sniffer > flow1.jsc

You, 4 weeks ago | 1 author (You)

```
{
    "dpid": 2,
    "table_id": 0,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 100,
    "match":{
        "in_port":3
    },
    "actions":[
        {
            "type":"GROUP",
            "group_id": 50
        }
    ]
}
```

flow2.json

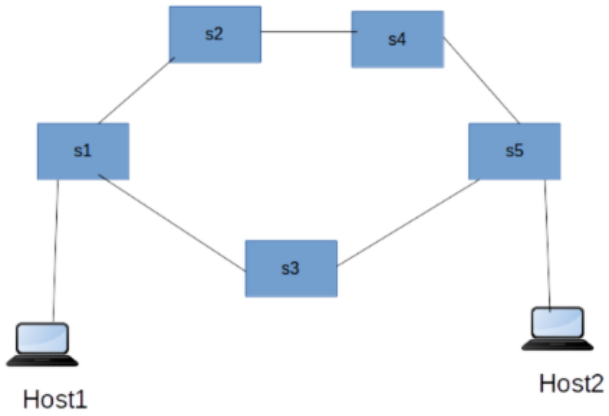
document > ch4 > ofctl > sniffer > flow2.jsc

You, 4 weeks ago | 1 author (You)

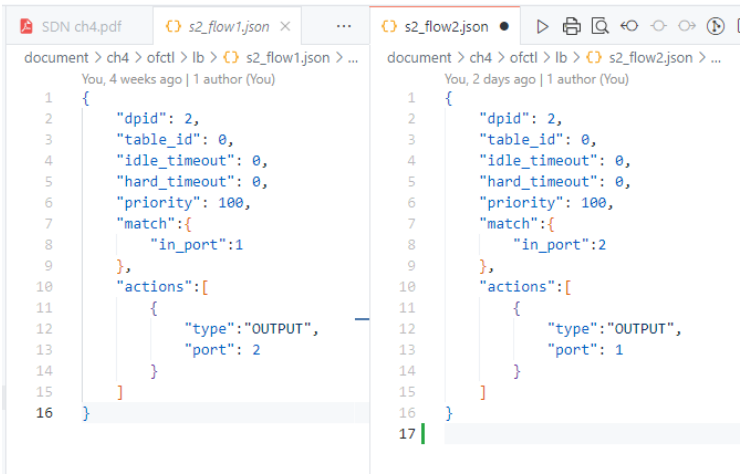
```
{
    "dpid": 2,
    "table_id": 0,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 100,
    "match":{
        "in_port":2
    },
    "actions":[
        {
            "type":"GROUP",
            "group_id": 51
        }
    ]
}
```

You, 4 weeks ago • ad

4.2 Load balancing



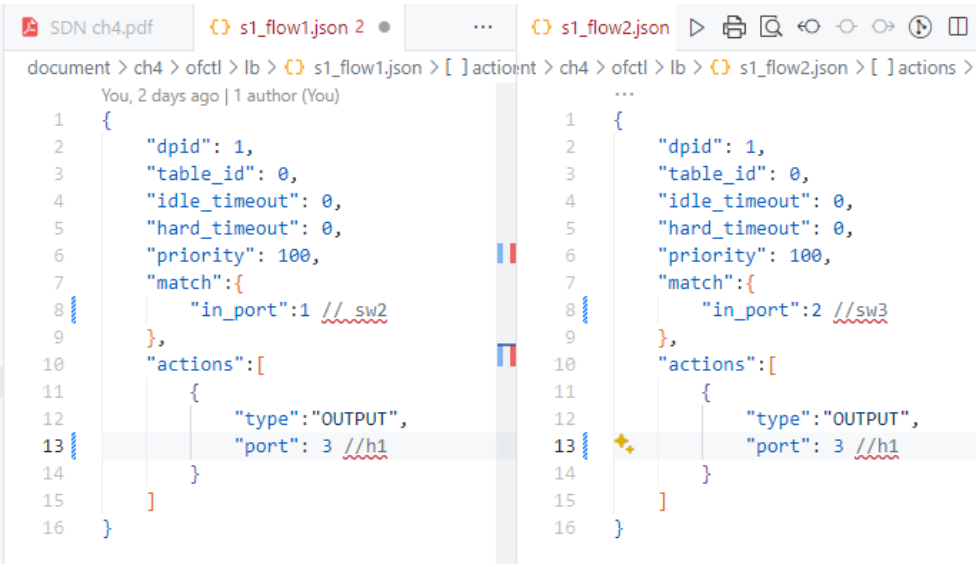
h1 arp -a -s 192.168.1.2 00:00:00:00:00:02 // set static host



```
{
    "dpid": 2,
    "table_id": 0,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 100,
    "match":{
        "in_port":1
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 2
        }
    ]
}
```

```
{
    "dpid": 2,
    "table_id": 0,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 100,
    "match":{
        "in_port":2
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 1
        }
    ]
}
```

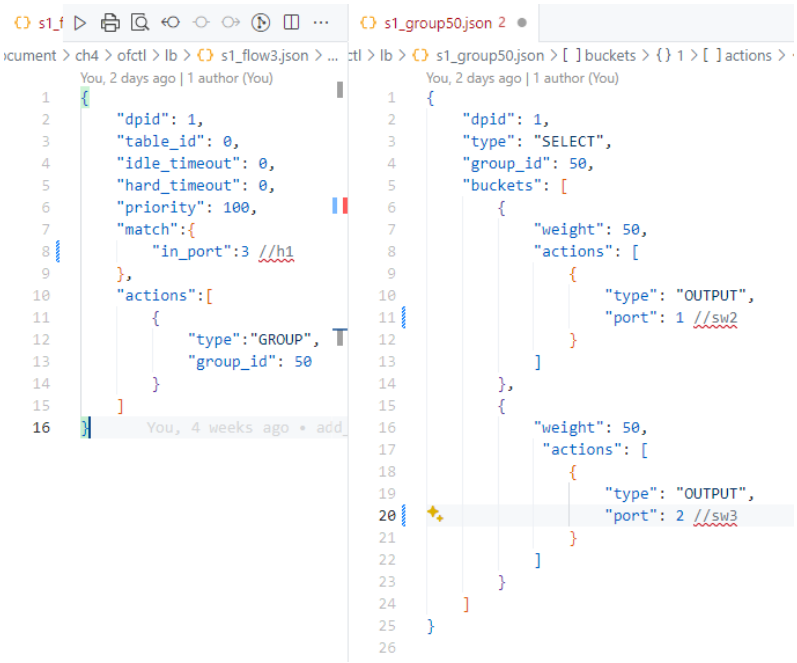
สร้าง Flow rules ไปกลับของ sw2, sw3, sw4



```
{
    "dpid": 1,
    "table_id": 0,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 100,
    "match":{
        "in_port":1 // sw2
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 3 //h1
        }
    ]
}
```

```
{
    "dpid": 1,
    "table_id": 0,
    "idle_timeout": 0,
    "hard_timeout": 0,
    "priority": 100,
    "match":{
        "in_port":2 //sw3
    },
    "actions":[
        {
            "type":"OUTPUT",
            "port": 3 //h1
        }
    ]
}
```

Flow rules sw1 สำหรับรับมาจาก sw2,sw3 (ทำสำหรับ switch5 ด้วย)



Flow rules sw1 สำหรับขาออกจาก h1 โดยส่งไปให้ group 50 เพื่อทำ load balance (ทำสำหรับ sw5ด้วย)

5. Statistics

5.1 Create simple TOPO (single,2 with -I [IP])

5.2 ryu-manager ryu.app.simple_monitor_13

5.3 perform TCP traffic

5.4 result will show in ryu terminal

6. Meter Table

6.1 sudo ovs-ofctl -O OpenFlow13 meter-stats s1

6.2 curl ..... /stats/meterentry/add -d “.....”

Add flow ตามปกติ (arp, des_mac,)

Xterm commands

- tcpdump -i any -v หรือ **tcpdump -i s1-eth3 ผ่าน terminal ไม่ต้อง xterm ############**
- tcpdump -i any -v udp, tcpdump -i any -v host 10.0.0.1, tcpdump -i any -v port 5001
- tcpdump -i h1-eth0 -v, tcpdump -i any -vvv

Flow Manager:

1. clone git repo,
2. ryu-manager -- observe-links ~/flowmanager/flowmanager.py ryu.app.simple_switch_13
3. sudo mn -- controller=remote,ip=127.0.0.1 -- mac -i 10.1.1.0/24 -- topo=tree,depth=2,fanout=2
4. http://localhost:8080/home/index.html
5. Pingall

Statistics Collection (ch5)

1. flow statistics

```python
from ryu.base import app_manager
from ryu.controller import ofp_event
from ryu.controller.handler import CONFIG_DISPATCHER, MAIN_DISPATCHER, set_ev_cls
from ryu.ofproto import ofproto_v1_3
from ryu.lib.packet import packet, ethernet, ether_types
from ryu.lib import hub

class SimpleSwitch13(app_manager.RyuApp):
    OFP_VERSIONS = [ofproto_v1_3.OFP_VERSION]

    def __init__(self, *args, **kwargs):
        super(SimpleSwitch13, self).__init__(*args, **kwargs)
        self.mac_to_port = {}
        self.datapaths = {}
        hub.spawn(self._monitor)

    def _monitor(self):
        while True:
            hub.sleep(10)
            [dp.send_msg(dp.ofproto_parser.OFPFlowStatsRequest(dp))
             for dp in self.datapaths.values()]

    @set_ev_cls(ofp_event.EventOFPFlowStatsReply, MAIN_DISPATCHER)
    def _stats_reply(self, ev):
        [self.logger.info(f"Flow: {stat}, bytes: {stat.byte_count}, "
                          f"packets: {stat.packet_count}") for stat in ev.msg.body]

    @set_ev_cls(ofp_event.EventOFPSwitchFeatures, CONFIG_DISPATCHER)
    def _switch_features(self, ev):
        dp = ev.msg.datapath
        self.datapaths[dp.id] = dp
        parser = dp.ofproto_parser
        match = parser.OFPMatch()
        actions = [parser.OFPActionOutput(dp.ofproto.OFPP_CONTROLLER,
                                          dp.ofproto.OFPCML_NO_BUFFER)]
        self._add_flow(dp, 0, match, actions)
```

```python
    def _add_flow(self, dp, priority, match, actions, buffer_id=None):
        ofproto = dp.ofproto
        parser = dp.ofproto_parser
        inst = [parser.OFPInstructionActions(ofproto.OFPIT_APPLY_ACTIONS, actions)]
        mod = parser.OFPFlowMod(
            datapath=dp, priority=priority, match=match, instructions=inst,
            buffer_id=buffer_id if buffer_id is not None else ofproto.OFP_NO_BUFFER
        )
        dp.send_msg(mod)

    @set_ev_cls(ofp_event.EventOFPPacketIn, MAIN_DISPATCHER)
    def _packet_in(self, ev):
        msg = ev.msg
        dp = msg.datapath
        ofproto = dp.ofproto
        parser = dp.ofproto_parser
        in_port = msg.match['in_port']

        pkt = packet.Packet(msg.data)
        eth = pkt.get_protocols(ethernet.ethernet)[0]
        if eth.ethertype == ether_types.ETH_TYPE_LLDP:
            return

        dst, src = eth.dst, eth.src
        dpid = dp.id

        self.mac_to_port.setdefault(dpid, {})
        self.mac_to_port[dpid][src] = in_port
        out_port = self.mac_to_port[dpid].get(dst, ofproto.OFPP_FLOOD)
        actions = [parser.OFPActionOutput(out_port)]

        if out_port != ofproto.OFPP_FLOOD:
            match = parser.OFPMatch(in_port=in_port, eth_dst=dst, eth_src=src)
            if msg.buffer_id != ofproto.OFP_NO_BUFFER:
                self._add_flow(dp, 1, match, actions, msg.buffer_id)
                return
            self._add_flow(dp, 1, match, actions)

        data = None if msg.buffer_id != ofproto.OFP_NO_BUFFER else msg.data
        out = parser.OFPPacketOut(datapath=dp, buffer_id=msg.buffer_id,
                                  in_port=in_port, actions=actions, data=data)
        dp.send_msg(out)
```

2. Aggregate Stats (ใช้ของเดิม flow statistics)

```python
def _monitor(self):
    while True:
        hub.sleep(10)
        [dp.send_msg(dp.ofproto_parser.OFPAggregateStatsRequest(
            dp, 0, dp.ofproto.OFPTT_ALL,
            dp.ofproto.OFPP_ANY, dp.ofproto.OFPG_ANY,
            0, 0, dp.ofproto_parser.OFPMatch()
        )) for dp in self.datapaths.values()]

@set_ev_cls(ofp_event.EventOFPAggregateStatsReply, MAIN_DISPATCHER)
def _stats_reply(self, ev):
    body = ev.msg.body
    self.logger.info(f'AggregateStats: {body}, Flows: {body.flow_count}')
```

3. port statistics monitoring

```python
# ส่วนที่แตกต่างสำหรับ Port Stats:
def _monitor(self):
    while True:
        hub.sleep(10)
        [dp.send_msg(dp.ofproto_parser.OFPPortStatsRequest(dp))
         for dp in self.datapaths.values()]

@set_ev_cls(ofp_event.EventOFPPortStatsReply, MAIN_DISPATCHER)
def _stats_reply(self, ev):
    [self.logger.info(f"Port stats: {stat}") for stat in ev.msg.body]
```

Params (ch5) เรียกใช้ไฟล์ config จากข้างนอก

1. สร้างไฟล์ params.conf [DEFAULT] ขึ้นบรรทัดใหม่ INTERVAL = 5
2. Import ในโค้ด controller (ryu) from ryu import cfg
3. เรียกใช้ ryu-manager --config-file params.conf flow_stats_param.py

Group (ch5) ใช้โค้ด python (ryu) สร้าง Group แทน REST API บทที่ 4 (linear,4) (sniffer)

```python
from ryu.base import app_manager
from ryu.controller import ofp_event
from ryu.controller.handler import CONFIG_DISPATCHER, MAIN_DISPATCHER, set_ev_cls
from ryu.ofproto import ofproto_v1_3
from ryu.lib.packet import packet, ethernet, ether_types

class SimpleSwitch13(app_manager.RyuApp):
    OFP_VERSIONS = [ofproto_v1_3.OFP_VERSION]

    def __init__(self, *args, **kwargs):
        super(SimpleSwitch13, self).__init__(*args, **kwargs)
        self.mac_to_port = {}

    def _add_flow(self, dp, priority, match, actions, buffer_id=None):
        inst = [dp.ofproto_parser.OFPInstructionActions(
            dp.ofproto.OFPIT_APPLY_ACTIONS, actions)]
        dp.send_msg(dp.ofproto_parser.OFPFlowMod(
            datapath=dp, priority=priority, match=match,
            instructions=inst, buffer_id=buffer_id if buffer_id
            else dp.ofproto.OFP_NO_BUFFER))

    def _setup_group_tables(self, dp):
        p = dp.ofproto_parser
        groups = [
            (50, [(1,), (3,)]),  # group_id 50: output to ports 1 and 3
            (51, [(1,), (2,)])   # group_id 51: output to ports 1 and 2
        ]
        for group_id, ports in groups:
            buckets = [p.OFPBucket(actions=[p.OFPActionOutput(port)])
                       for port in [p[0] for p in ports]]
            dp.send_msg(p.OFPGroupMod(dp, dp.ofproto.OFPGC_ADD,
                                      dp.ofproto.OFPGT_ALL, group_id, buckets))
            self._add_flow(dp, 10, p.OFPMatch(in_port=ports[1][0]),
                           [p.OFPActionGroup(group_id=group_id)])

    @set_ev_cls(ofp_event.EventOFPSwitchFeatures, CONFIG_DISPATCHER)
    def _switch_features(self, ev):
        dp = ev.msg.datapath
        p = dp.ofproto_parser
        self._add_flow(dp, 0, p.OFPMatch(),
                       [p.OFPActionOutput(dp.ofproto.OFPP_CONTROLLER,
                                          dp.ofproto.OFPCML_NO_BUFFER)])
        if dp.id == 2:
            self._setup_group_tables(dp)
            self._setup_group_tables(dp)

    @set_ev_cls(ofp_event.EventOFPPacketIn, MAIN_DISPATCHER)
    def _packet_in(self, ev):
        msg = ev.msg
        dp = msg.datapath
        p = dp.ofproto_parser
        in_port = msg.match['in_port']
        pkt = packet.Packet(msg.data)
        eth = pkt.get_protocols(ethernet.ethernet)[0]

        if eth.ethertype == ether_types.ETH_TYPE_LLDP:
            return

        dpid = dp.id
        self.mac_to_port.setdefault(dpid, {})
        self.mac_to_port[dpid][eth.src] = in_port
        out_port = self.mac_to_port[dpid].get(eth.dst, dp.ofproto.OFPP_FLOOD)

        actions = [p.OFPActionOutput(out_port)]
        if out_port != dp.ofproto.OFPP_FLOOD:
            match = p.OFPMatch(in_port=in_port, eth_dst=eth.dst, eth_src=eth.src)
            if msg.buffer_id != dp.ofproto.OFP_NO_BUFFER:
                self._add_flow(dp, 1, match, actions, msg.buffer_id)
                return
            self._add_flow(dp, 1, match, actions)

        data = None if msg.buffer_id != dp.ofproto.OFP_NO_BUFFER else msg.data
        dp.send_msg(p.OFPPacketOut(datapath=dp, buffer_id=msg.buffer_id,
                                   in_port=in_port, actions=actions, data=data))
```

Group - Loadbalance

```python
from ryu.base import app_manager
from ryu.controller import ofp_event
from ryu.controller.handler import CONFIG_DISPATCHER, MAIN_DISPATCHER, set_ev_cls
from ryu.ofproto import ofproto_v1_3
from ryu.lib.packet import packet, ethernet, ether_types

class SimpleSwitch13(app_manager.RyuApp):
    OFP_VERSIONS = [ofproto_v1_3.OFP_VERSION]

    def __init__(self, *args, **kwargs):
        super(SimpleSwitch13, self).__init__(*args, **kwargs)
        self.mac_to_port = {}

    def _add_flow(self, dp, priority, match, actions, buffer_id=None):
        inst = [dp.ofproto_parser.OFPInstructionActions(
            dp.ofproto.OFPIT_APPLY_ACTIONS, actions)]
        dp.send_msg(dp.ofproto_parser.OFPFlowMod(
            datapath=dp, priority=priority, match=match,
            instructions=inst, buffer_id=buffer_id if buffer_id
            else dp.ofproto.OFP_NO_BUFFER))

    def _setup_lb(self, dp):
        p = dp.ofproto_parser
        # Create weighted group table (30% to port1, 70% to port2)
        buckets = [
            p.OFPBucket(30, dp.ofproto.OFPP_ANY, dp.ofproto.OFPQ_ALL,
                        actions=[p.OFPActionOutput(1)]),
            p.OFPBucket(70, dp.ofproto.OFPP_ANY, dp.ofproto.OFPQ_ALL,
                        actions=[p.OFPActionOutput(2)])
        ]

        dp.send_msg(p.OFPGroupMod(dp, dp.ofproto.OFPGC_ADD,
                                  dp.ofproto.OFPGT_SELECT, 50, buckets))

        # Add flows for switch
        self._add_flow(dp, 10, p.OFPMatch(in_port=3),
                       [p.OFPActionGroup(group_id=50)])

        # Return flows from switches to host
        for in_port in [1, 2]:
            self._add_flow(dp, 10, p.OFPMatch(in_port=in_port),
                           [p.OFPActionOutput(3)])

    @set_ev_cls(ofp_event.EventOFPSwitchFeatures, CONFIG_DISPATCHER)
    def _switch_features(self, ev):
        dp = ev.msg.datapath
        p = dp.ofproto_parser
        self._add_flow(dp, 0, p.OFPMatch(),
                       [p.OFPActionOutput(dp.ofproto.OFPP_CONTROLLER,
                                          dp.ofproto.OFPCML_NO_BUFFER)])
        if dp.id in [1, 5]:  # Setup load balancing for switches 1 and 5
            self._setup_lb(dp)

    @set_ev_cls(ofp_event.EventOFPPacketIn, MAIN_DISPATCHER)
    def _packet_in(self, ev):
        msg = ev.msg
        dp = msg.datapath
        p = dp.ofproto_parser
        in_port = msg.match['in_port']
        pkt = packet.Packet(msg.data)
        eth = pkt.get_protocols(ethernet.ethernet)[0]

        if eth.ethertype == ether_types.ETH_TYPE_LLDP:
            return

        dpid = dp.id
        self.mac_to_port.setdefault(dpid, {})
        self.mac_to_port[dpid][eth.src] = in_port
        out_port = self.mac_to_port[dpid].get(eth.dst, dp.ofproto.OFPP_FLOOD)

        actions = [p.OFPActionOutput(out_port)]
        if out_port != dp.ofproto.OFPP_FLOOD:
            match = p.OFPMatch(in_port=in_port, eth_dst=eth.dst, eth_src=eth.sr
            if msg.buffer_id != dp.ofproto.OFP_NO_BUFFER:
                self._add_flow(dp, 1, match, actions, msg.buffer_id)
                return
            self._add_flow(dp, 1, match, actions)

        data = None if msg.buffer_id != dp.ofproto.OFP_NO_BUFFER else msg.data
        dp.send_msg(p.OFPPacketOut(datapath=dp, buffer_id=msg.buffer_id,
                                   in_port=in_port, actions=actions, data=data))
```

Arp_proxy (เรียกใช้ arp dict python แทน)

```python
from ryu.lib.packet import arp

arp_table = {"10.1.1.1": "00:00:00:00:00:01",
             "10.1.1.2": "00:00:00:00:00:02",
             "10.1.1.3": "00:00:00:00:00:03",
             "10.1.1.4": "00:00:00:00:00:04"
             }

def arp_process(self, datapath, eth, a, in_port):
    r = arp_table.get(a.dst_ip)
    if r:
        self.logger.info("Matched MAC %s ", r)
        arp_resp = packet.Packet()
        arp_resp.add_protocol(ethernet.ethernet(ethertype=eth.ethertype,
                              dst=eth.src, src=r))
        arp_resp.add_protocol(arp.arp(opcode=arp.ARP_REPLY,
                              src_mac=r, src_ip=a.dst_ip,
                              dst_mac=a.src_mac,
                              dst_ip=a.src_ip))

        arp_resp.serialize()
        actions = []      You, 3 weeks ago • add_ch5
        actions.append(datapath.ofproto_parser.OFPActionOutput(in_port))
        parser = datapath.ofproto_parser
        ofproto = datapath.ofproto
        out = parser.OFPPacketOut(datapath=datapath, buffer_id=ofproto.OFP_NO_BUFFER,
                              in_port=ofproto.OFPP_CONTROLLER, actions=actions, data=arp_resp)
        datapath.send_msg(out)
        self.logger.info("Proxied ARP Response packet")
```

```
# learn a mac address to avoid FLOOD next time.
self.mac_to_port[dpid][src] = in_port

# Check whether is it arp packet
if eth.ethertype == ether_types.ETH_TYPE_ARP:
    self.logger.info("Received ARP Packet %s %s %s ", dpid, src, dst)
    a = pkt.get_protocol(arp.arp)
    self.arp_process(datapath, eth, a, in_port)
    return
```

```
if dst in self.mac_to_port[dpid]:        You, 3 weeks ago • add_ch5
    out_port = self.mac_to_port[dpid][dst]
```

เรียกใช้

Topodiscovery (ryu python)

1. Linear,4
2. ryu-manager **--observe-links** topology_discovery.py

```
from ryu.base import app_manager
from ryu.controller import ofp_event
from ryu.controller.handler import CONFIG_DISPATCHER, MAIN_DISPATCHER, set_ev_cls
from ryu.ofproto import ofproto_v1_3
from ryu.lib.packet import packet, ethernet, ether_types
from ryu.topology.api import get_switch, get_link, get_host
from ryu.lib import hub

class SimpleSwitch13(app_manager.RyuApp):
    OFP_VERSIONS = [ofproto_v1_3.OFP_VERSION]

    def __init__(self, *args, **kwargs):
        super(SimpleSwitch13, self).__init__(*args, **kwargs)
        self.mac_to_port = {}
        self.topology_api_app = self
        hub.spawn(self._discover_topology)

    def _discover_topology(self):
        hub.sleep(10)  # Wait for switches to connect
        switches = [switch.dp.id for switch in get_switch(self, None)]
        links = [(link.src.dpid, link.dst.dpid, {'port': link.src.port_no})
                 for link in get_link(self, None)]
        hosts = [(host.mac, host.port.dpid, {'port': host.port.port_no})
                 for host in get_host(self, None)]
        self.logger.info(f"Topology Info - Switches: {switches}, "
                         f"Links: {links}, Hosts: {hosts}")

    def _add_flow(self, dp, priority, match, actions, buffer_id=None):
        inst = [dp.ofproto_parser.OFPInstructionActions(
            dp.ofproto.OFPIT_APPLY_ACTIONS, actions)]
        dp.send_msg(dp.ofproto_parser.OFPFlowMod(
            datapath=dp, priority=priority, match=match,
            instructions=inst, buffer_id=buffer_id if buffer_id
            else dp.ofproto.OFP_NO_BUFFER))
```

```
@set_ev_cls(ofp_event.EventOFPSwitchFeatures, CONFIG_DISPATCHER)
def _switch_features(self, ev):
    dp = ev.msg.datapath
    self._add_flow(dp, 0, dp.ofproto_parser.OFPMatch(),
                   [dp.ofproto_parser.OFPActionOutput(
                       dp.ofproto.OFPP_CONTROLLER,
                       dp.ofproto.OFPCML_NO_BUFFER)])

@set_ev_cls(ofp_event.EventOFPPacketIn, MAIN_DISPATCHER)
def _packet_in(self, ev):
    msg = ev.msg
    dp = msg.datapath
    p = dp.ofproto_parser
    in_port = msg.match['in_port']
    pkt = packet.Packet(msg.data)
    eth = pkt.get_protocols(ethernet.ethernet)[0]

    if eth.ethertype == ether_types.ETH_TYPE_LLDP:
        return

    dpid = dp.id
    self.mac_to_port.setdefault(dpid, {})
    self.mac_to_port[dpid][eth.src] = in_port
    out_port = self.mac_to_port[dpid].get(eth.dst, dp.ofproto.OFPP_FLOOD)

    actions = [p.OFPActionOutput(out_port)]
    if out_port != dp.ofproto.OFPP_FLOOD:
        match = p.OFPMatch(in_port=in_port, eth_dst=eth.dst, eth_src=eth.src)
        if msg.buffer_id != dp.ofproto.OFP_NO_BUFFER:
            self._add_flow(dp, 1, match, actions, msg.buffer_id)
            return
        self._add_flow(dp, 1, match, actions)

    data = None if msg.buffer_id != dp.ofproto.OFP_NO_BUFFER else msg.data
    dp.send_msg(p.OFPPacketOut(datapath=dp, buffer_id=msg.buffer_id,
                               in_port=in_port, actions=actions, data=data))
```

Multicontroller (ryu python) (equal role)

1. สร้าง Topo ด้วยโค้ดปกติ แต่ว่าชี้ controller 2 ที่

```
if __name__ == '__main__':
    setLogLevel('info')
    topo = MyTopo()
    net = Mininet(topo=topo,  build=False)
    c0 = RemoteController('c0', ip='127.0.0.1', port=6653)
    c1 = RemoteController('c1', ip='127.0.0.1', port=6654)
    net.addController(c0)
    net.addController(c1)
    net.build()
    net.start()
    CLI(net)
    net.stop()
```

2. กำหนด Port ตอนรัน controller ryu-manager --ofp-tcp-listen-port 6554 .....py

Multicontroller (ryu python) (Master/Slave Role)

1. สร้าง Topo ด้วยโค้ดปกติ แต่ว่าชี้ controller 2 ที่
2. Master

```python
from ryu.base import app_manager
from ryu.controller import ofp_event
from ryu.controller.handler import CONFIG_DISPATCHER, MAIN_DISPATCHER, set_ev_cls
from ryu.ofproto import ofproto_v1_3
from ryu.lib.packet import packet, ethernet, ether_types, ipv4

class MasterController(app_manager.RyuApp):
    OFP_VERSIONS = [ofproto_v1_3.OFP_VERSION]

    def __init__(self, *args, **kwargs):
        super(MasterController, self).__init__(*args, **kwargs)
        self.mac_to_port = {}

    def _send_role_request(self, dp):
        dp.send_msg(dp.ofproto_parser.OFPRoleRequest(dp, dp.ofproto.OFPCR_ROLE_MASTER, 0))

    @set_ev_cls(ofp_event.EventOFPRoleReply, MAIN_DISPATCHER)
    def _role_reply(self, ev):
        if ev.msg.role == ev.msg.datapath.ofproto.OFPCR_ROLE_MASTER:
            self.logger.info('Controller is master')

    @set_ev_cls(ofp_event.EventOFPSwitchFeatures, CONFIG_DISPATCHER)
    def _switch_features(self, ev):
        dp = ev.msg.datapath
        self._send_role_request(dp)
        self._add_flow(dp, 0, dp.ofproto_parser.OFPMatch(),
                       [dp.ofproto_parser.OFPActionOutput(
                           dp.ofproto.OFPP_CONTROLLER,
                           dp.ofproto.OFPCML_NO_BUFFER)])

    def _add_flow(self, dp, priority, match, actions, buffer_id=None):
        inst = [dp.ofproto_parser.OFPInstructionActions(
            dp.ofproto.OFPIT_APPLY_ACTIONS, actions)]
        dp.send_msg(dp.ofproto_parser.OFPFlowMod(
            datapath=dp, priority=priority, match=match,
            instructions=inst, buffer_id=buffer_id if buffer_id
            else dp.ofproto.OFP_NO_BUFFER))
```

3. Slave

```python
from ryu.base import app_manager
from ryu.controller import ofp_event
from ryu.controller.handler import CONFIG_DISPATCHER, MAIN_DISPATCHER, set_ev_cls
from ryu.ofproto import ofproto_v1_3

class SlaveController(app_manager.RyuApp):
    OFP_VERSIONS = [ofproto_v1_3.OFP_VERSION]

    def __init__(self, *args, **kwargs):
        super(SlaveController, self).__init__(*args, **kwargs)

    def _send_role_request(self, dp):
        dp.send_msg(dp.ofproto_parser.OFPRoleRequest(dp, dp.ofproto.OFPCR_ROLE_SLAVE, 0))

    @set_ev_cls(ofp_event.EventOFPRoleReply, MAIN_DISPATCHER)
    def _role_reply(self, ev):
        if ev.msg.role == ev.msg.datapath.ofproto.OFPCR_ROLE_SLAVE:
            self.logger.info('Controller is slave')
```