SUSTech_CS305-Network_2023s_Project-Ryu

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> The source code is hosted on GitHub and will be open-sourced based on **MIT License** after the project deadline. The access link is:
>
> **https://github.com/OctCarp/SUSTech_CS305-Network_2023s_Project-Ryu**

Developers

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Project Instruction

This project requires the use of **Mininet** for network topology simulation and **Ryu Controller** as the controller to implement a simple SDN simulation. DHCP and shortest path routing functions are required.

Function Display

DHCP

This software implements a simple DHCP server, allocates IP addresses to broadcast hosts from a given IP pool, and avoids duplication. A simple lease information feature is implemented as well.

Utils

First, we use two function to implement conversion between IP address string and 32-bit numbers

```python
def ip_to_int(ip_address):
    ip = ip_address.split('.')
    return (int(ip[0]) << 24) + (int(ip[1]) << 16) + (int(ip[2]) << 8) + int(ip[3])


def int_to_ip(num):
    return f"{num >> 24}.{(num >> 16) & 0xff}.{(num >> 8) & 0xff}.{num & 0xff}"
```

Thus, we can convert IP address strings like `'x.x.x.x'` to a 32 bit number and vice versa.

Static Info and fuction

Then, we set some informations for DHCP server:

```python
class DHCPServer():
    #  class variables
    hardware_addr = Config.controller_macAddr
    server_ip = Config.server_ip
    dns = Config.dns
    start_ip = Config.start_ip
    end_ip = Config.end_ip
    start_ip_i = ip_to_int(start_ip)  # 32 bits number for start IP
    end_ip_i = ip_to_int(end_ip)  # 32 bits number for start IP
    netmask = Config.netmask
    lease_time = Config.lease_time  # default lease time

    ip_mac = {}  # Map between IP and host MAC
    for i in range(start_ip_i, end_ip_i + 1):  # initialization
        ip_mac[i] = 'ok'  # If it is 'OK', meanings the IP is available

    # do some initialization for byte type data below
    server_ip_byte = addrconv.ipv4.text_to_bin(server_ip)
    netmask_byte = addrconv.ipv4.text_to_bin(netmask)
    dns_byte = addrconv.ipv4.text_to_bin(dns)
    lease_time_byte = struct.pack('>I', lease_time)

    offer_byte = struct.pack('>B', dhcp.DHCP_OFFER)
    ack_byte = struct.pack('>B', dhcp.DHCP_ACK)
```

We use this function below to check whether a new IP for new client is OK, or it is already exist a mapping. Then we return a IP address available, or `'0.0.0.0'` for not available.

```python
@classmethod
def check_ip_mac(cls, req_ip_i, client_mac):
    ip_return = '0.0.0.0'
    if (not req_ip_i == 0) and (cls.ip_mac[req_ip_i] == client_mac or cls.ip_mac[req_ip_i] == 'ok'):
        # if it has required IP and it is available
        for ip_i in cls.ip_mac:
            if cls.ip_mac[ip_i] == client_mac:
                cls.ip_mac[ip_i] = 'ok'  # clear the previous IP info for this client
        cls.ip_mac[req_ip_i] = client_mac
        ip_return = int_to_ip(req_ip_i)  # return the IP string
    else:
        has_mac = False
        for ip_i in cls.ip_mac:
            if cls.ip_mac[ip_i] == client_mac:
                ip_return = int_to_ip(ip_i)  # has previous IP information for the client
                has_mac = True
                break
        if not has_mac:
            for ip_i in cls.ip_mac:
                if cls.ip_mac[ip_i] == 'ok':  # has available IP for new MAC
                    cls.ip_mac[ip_i] = client_mac
                    ip_return = int_to_ip(ip_i)
                    break
    return ip_return  # return IP string in the end
```

Generate Offer and ACK packet

Then we handle the DHCP Offer Packet after DHCP Discover. The following code shows the details.

```python
@classmethod
def assemble_offer(cls, pkt):
    # get each layer for the packet
    c_eth = pkt.get_protocol(ethernet.ethernet)
    c_ipv4 = pkt.get_protocol(ipv4.ipv4)
    c_udp = pkt.get_protocol(udp.udp)
    c_dhcp = pkt.get_protocol(dhcp.dhcp)

    client_mac = c_eth.src  # get client MAC for IP-MAC mapping

    offer_pkt = packet.Packet()
    offer_pkt.add_protocol(ethernet.ethernet(
        ethertype=c_eth.ethertype,  # sync
        dst=client_mac,  # client mac
        src=cls.hardware_addr  # controller mac
    ))

    offer_pkt.add_protocol(ipv4.ipv4(
        version=c_ipv4.version,  # sync
        proto=c_ipv4.proto,  # sync
        src=cls.server_ip,  # dhcp server ip
        dst='255.255.255.255'  # broadcast addr
    ))

    offer_pkt.add_protocol(udp.udp(
        src_port=c_udp.dst_port,  # port 67
        dst_port=c_udp.src_port  # port 68
    ))

    req_ip_i = 0

    for opt in c_dhcp.options.option_list:
        if opt.tag == dhcp.DHCP_REQUESTED_IP_ADDR_OPT:  # if it has required IP address
            req_ip_i = int.from_bytes(opt.value, byteorder='big')  # unpack IP information

    offer_return_ip = cls.check_ip_mac(req_ip_i, client_mac)  # get IP for client

    offer_pkt.add_protocol(dhcp.dhcp(
        op=dhcp.DHCP_BOOT_REPLY,  # 2
        htype=1,  # ethernet
        hlen=c_dhcp.hlen,
        xid=c_dhcp.xid,  # random transaction id, define by client
        flags=0,  # unicast
        ciaddr='0.0.0.0',
        yiaddr=offer_return_ip,  # Your (client) IP address
        siaddr=cls.server_ip,  # Server IP address
        chaddr=c_dhcp.chaddr,  # Client hardware address (MAC addr)
        options=dhcp.options([
            dhcp.option(tag=dhcp.DHCP_MESSAGE_TYPE_OPT,  # set message type as offer
                        value=cls.offer_byte  # byte for number 2
                        ),
            dhcp.option(tag=dhcp.DHCP_IP_ADDR_LEASE_TIME_OPT,
                        value=cls.lease_time_byte  # add lease time info
                        ),
            dhcp.option(tag=dhcp.DHCP_SERVER_IDENTIFIER_OPT,
                        value=cls.server_ip_byte  # add server identifier
                        ),
            dhcp.option(tag=dhcp.DHCP_SUBNET_MASK_OPT,
                        value=cls.netmask_byte  # add subnet info
                        ),
            dhcp.option(tag=dhcp.DHCP_DNS_SERVER_ADDR_OPT,
                        value=cls.dns_byte  # add DNS info
                        )
        ])
    ))

    return offer_pkt  # return the packet finally
```

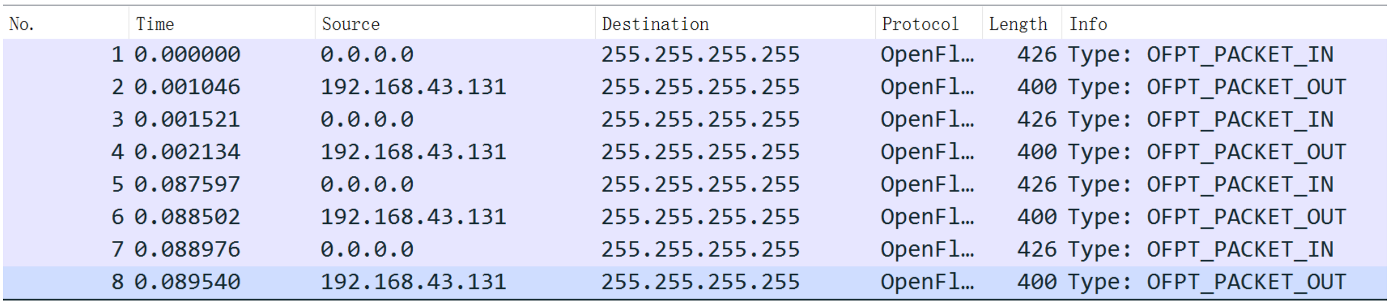
Because we handle the `DHCP_REQUESTED_IP_ADDR_OPT`, so the implementation of DHCP ACK is very similar to DHCP Offer, we just need to change `DHCP_MESSAGE_TYPE_OPT` to `5` in byte, which means this packet is a DHCP ACK. For brevity, we will not show the code this time.

DHCP Test

Basic 1

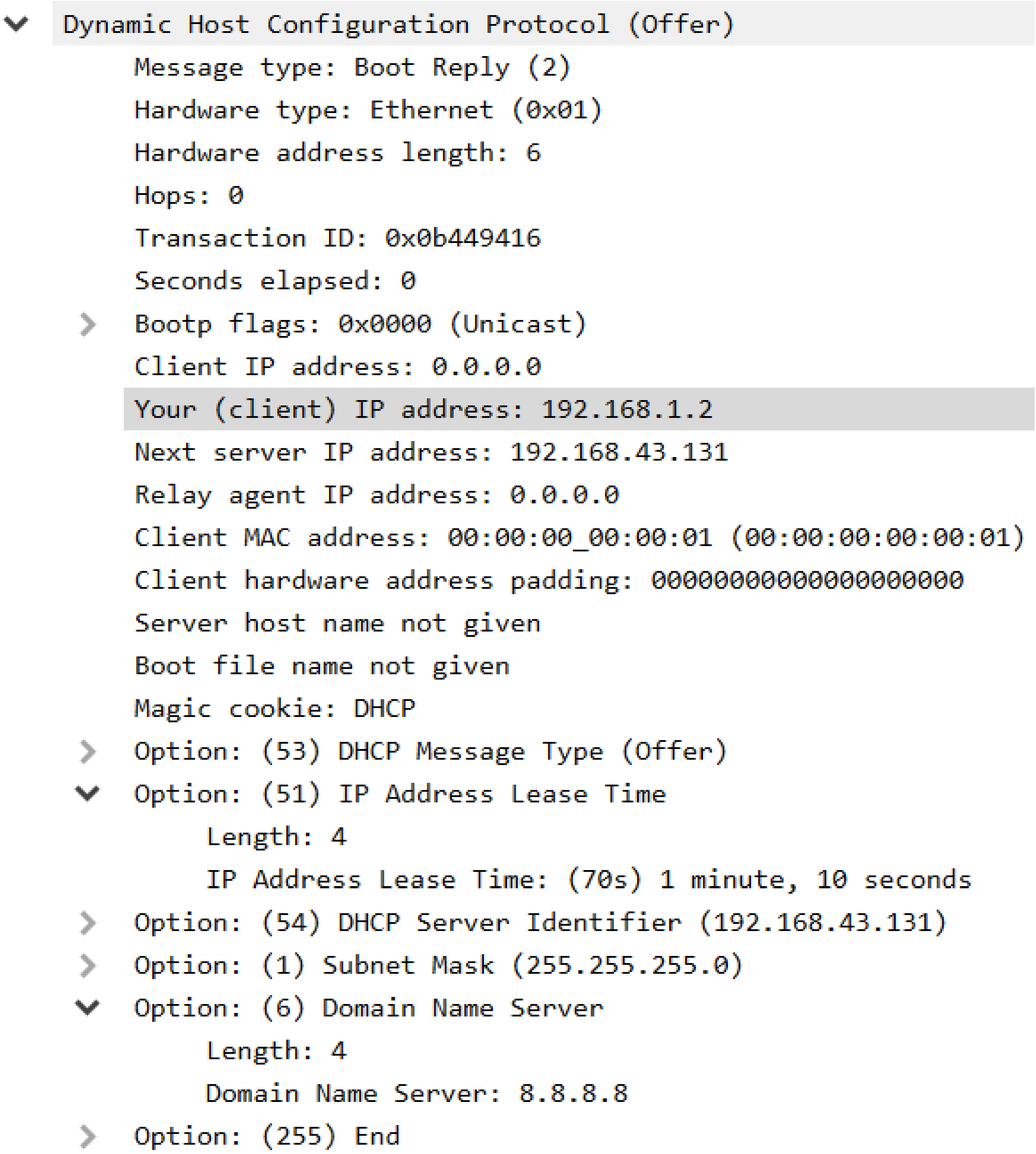
We use wireshark with GUI to capture the DHCP packets.

For basic test, we have two host, need 8 packets in total to complete IP allocation twice.



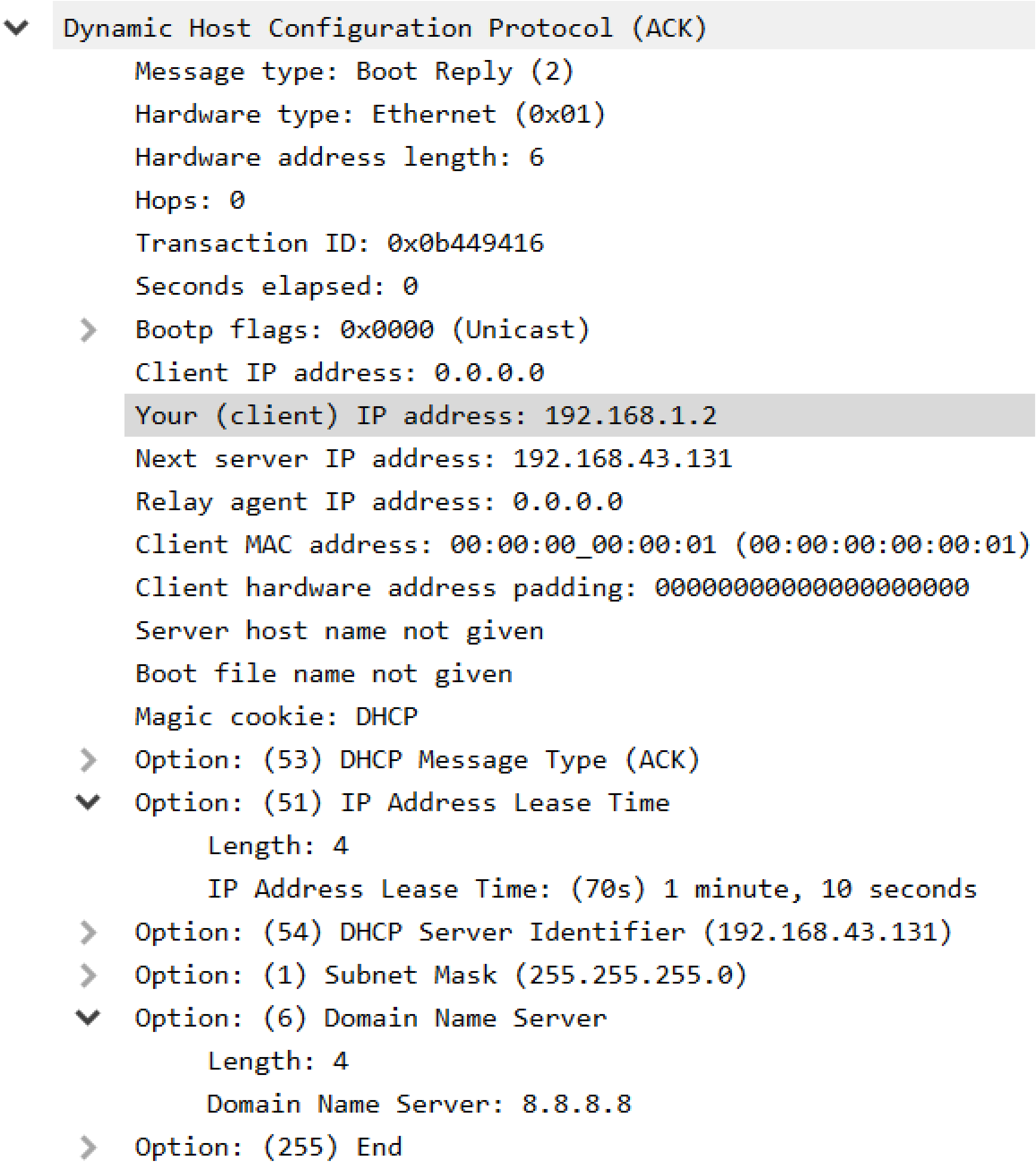
No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
2	0.001046	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
3	0.001521	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
4	0.002134	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
5	0.087597	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
6	0.088502	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
7	0.088976	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
8	0.089540	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT

Packet 2 in detail, this is a valid DHCP offer package:



```
⌄ Dynamic Host Configuration Protocol (Offer)
      Message type: Boot Reply (2)
      Hardware type: Ethernet (0x01)
      Hardware address length: 6
      Hops: 0
      Transaction ID: 0x0b449416
      Seconds elapsed: 0
    › Bootp flags: 0x0000 (Unicast)
      Client IP address: 0.0.0.0
      Your (client) IP address: 192.168.1.2
      Next server IP address: 192.168.43.131
      Relay agent IP address: 0.0.0.0
      Client MAC address: 00:00:00_00:00:01 (00:00:00:00:00:01)
      Client hardware address padding: 00000000000000000000
      Server host name not given
      Boot file name not given
      Magic cookie: DHCP
    › Option: (53) DHCP Message Type (Offer)
    ⌄ Option: (51) IP Address Lease Time
          Length: 4
          IP Address Lease Time: (70s) 1 minute, 10 seconds
    › Option: (54) DHCP Server Identifier (192.168.43.131)
    › Option: (1) Subnet Mask (255.255.255.0)
    ⌄ Option: (6) Domain Name Server
          Length: 4
          Domain Name Server: 8.8.8.8
    › Option: (255) End
```

Packet 4 in detail, this is a valid DHCP ACK package, including the lease time information:

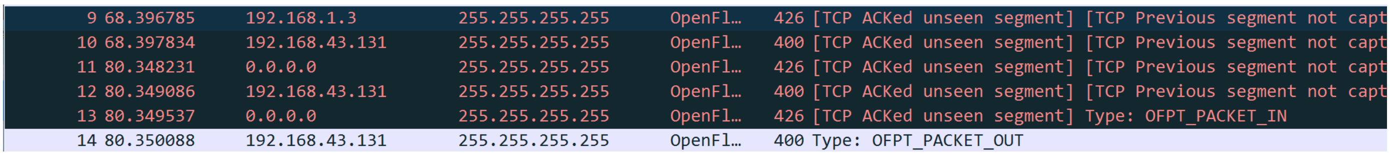


```
Dynamic Host Configuration Protocol (ACK)
    Message type: Boot Reply (2)
    Hardware type: Ethernet (0x01)
    Hardware address length: 6
    Hops: 0
    Transaction ID: 0x0b449416
    Seconds elapsed: 0
  > Bootp flags: 0x0000 (Unicast)
    Client IP address: 0.0.0.0
    Your (client) IP address: 192.168.1.2
    Next server IP address: 192.168.43.131
    Relay agent IP address: 0.0.0.0
    Client MAC address: 00:00:00_00:00:01 (00:00:00:00:00:01)
    Client hardware address padding: 00000000000000000000
    Server host name not given
    Boot file name not given
    Magic cookie: DHCP
  > Option: (53) DHCP Message Type (ACK)
  v Option: (51) IP Address Lease Time
        Length: 4
        IP Address Lease Time: (70s) 1 minute, 10 seconds
  > Option: (54) DHCP Server Identifier (192.168.43.131)
  > Option: (1) Subnet Mask (255.255.255.0)
  v Option: (6) Domain Name Server
        Length: 4
        Domain Name Server: 8.8.8.8
  > Option: (255) End
```

And it is the same for client 2.

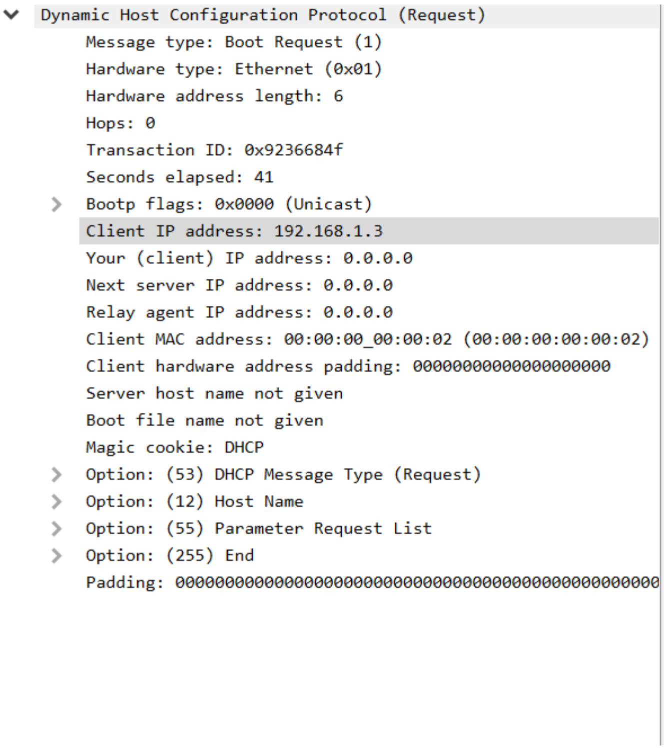
Lease Time

And we implement DHCP lease time. About 70 s. The error is about TCP caputure, it doesn't matter,

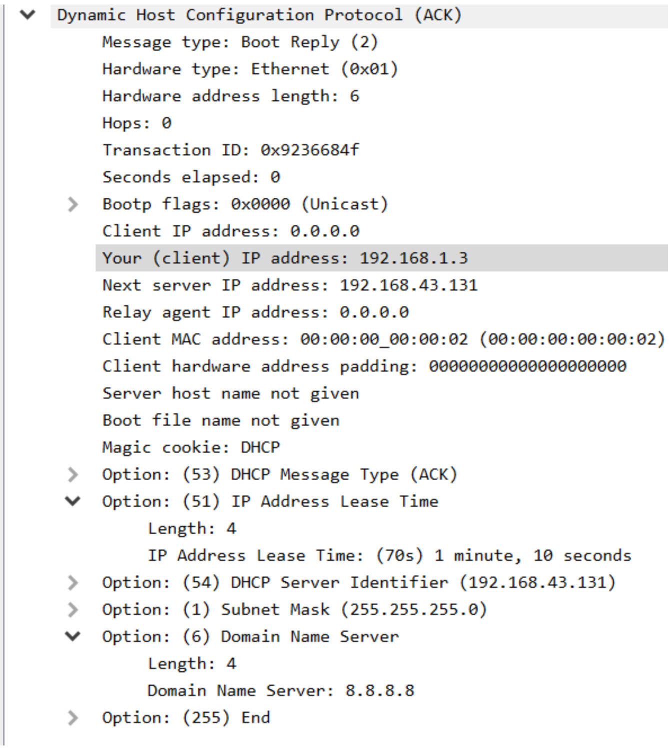


```
 9 68.396785   192.168.1.3      255.255.255.255   OpenFl…   426 [TCP ACKed unseen segment] [TCP Previous segment not capt
10 68.397834   192.168.43.131   255.255.255.255   OpenFl…   400 [TCP ACKed unseen segment] [TCP Previous segment not capt
11 80.348231   0.0.0.0          255.255.255.255   OpenFl…   426 [TCP ACKed unseen segment] [TCP Previous segment not capt
12 80.349086   192.168.43.131   255.255.255.255   OpenFl…   400 [TCP ACKed unseen segment] [TCP Previous segment not capt
13 80.349537   0.0.0.0          255.255.255.255   OpenFl…   426 [TCP ACKed unseen segment] Type: OFPT_PACKET_IN
14 80.350088   192.168.43.131   255.255.255.255   OpenFl…   400 Type: OFPT_PACKET_OUT
```

By the time is reached, the client will send a renewal DHCP Request packet, and the server will renew and give feedback with the correct IP, like packet 9 and 10:

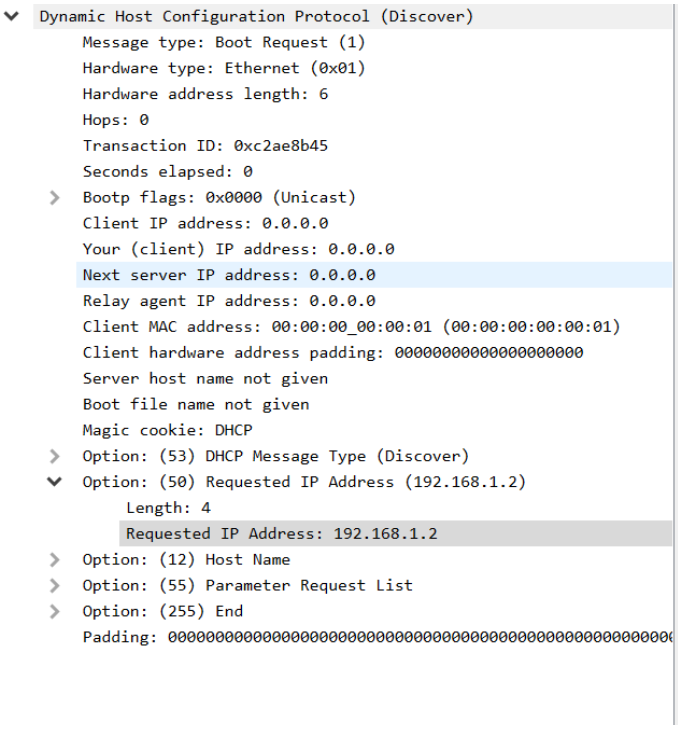


```
Dynamic Host Configuration Protocol (Request)
    Message type: Boot Request (1)
    Hardware type: Ethernet (0x01)
    Hardware address length: 6
    Hops: 0
    Transaction ID: 0x9236684f
    Seconds elapsed: 41
  > Bootp flags: 0x0000 (Unicast)
    Client IP address: 192.168.1.3
    Your (client) IP address: 0.0.0.0
    Next server IP address: 0.0.0.0
    Relay agent IP address: 0.0.0.0
    Client MAC address: 00:00:00_00:00:02 (00:00:00:00:00:02)
    Client hardware address padding: 00000000000000000000
    Server host name not given
    Boot file name not given
    Magic cookie: DHCP
  > Option: (53) DHCP Message Type (Request)
  > Option: (12) Host Name
  > Option: (55) Parameter Request List
  > Option: (255) End
    Padding: 0000000000000000000000000000000000000000000000000
```

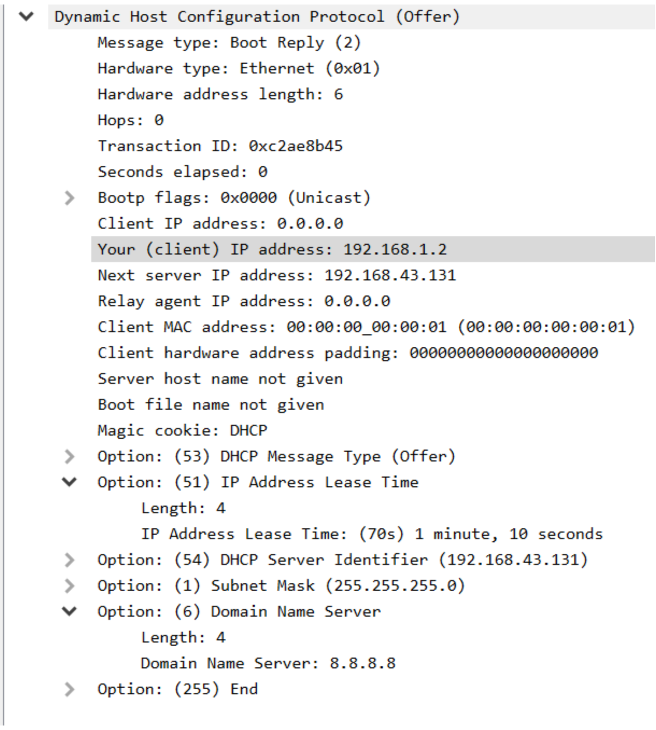


```
Dynamic Host Configuration Protocol (ACK)
    Message type: Boot Reply (2)
    Hardware type: Ethernet (0x01)
    Hardware address length: 6
    Hops: 0
    Transaction ID: 0x9236684f
    Seconds elapsed: 0
  > Bootp flags: 0x0000 (Unicast)
    Client IP address: 0.0.0.0
    Your (client) IP address: 192.168.1.3
    Next server IP address: 192.168.43.131
    Relay agent IP address: 0.0.0.0
    Client MAC address: 00:00:00_00:00:02 (00:00:00:00:00:02)
    Client hardware address padding: 00000000000000000000
    Server host name not given
    Boot file name not given
    Magic cookie: DHCP
  > Option: (53) DHCP Message Type (ACK)
  v Option: (51) IP Address Lease Time
        Length: 4
        IP Address Lease Time: (70s) 1 minute, 10 seconds
  > Option: (54) DHCP Server Identifier (192.168.43.131)
  > Option: (1) Subnet Mask (255.255.255.0)
  v Option: (6) Domain Name Server
        Length: 4
        Domain Name Server: 8.8.8.8
  > Option: (255) End
```

If the lease end time has already passed, the client will send a DHCP Discover with request IP, and the server will renew and give feedback with the correct IP as well, like packet 11 and 12:



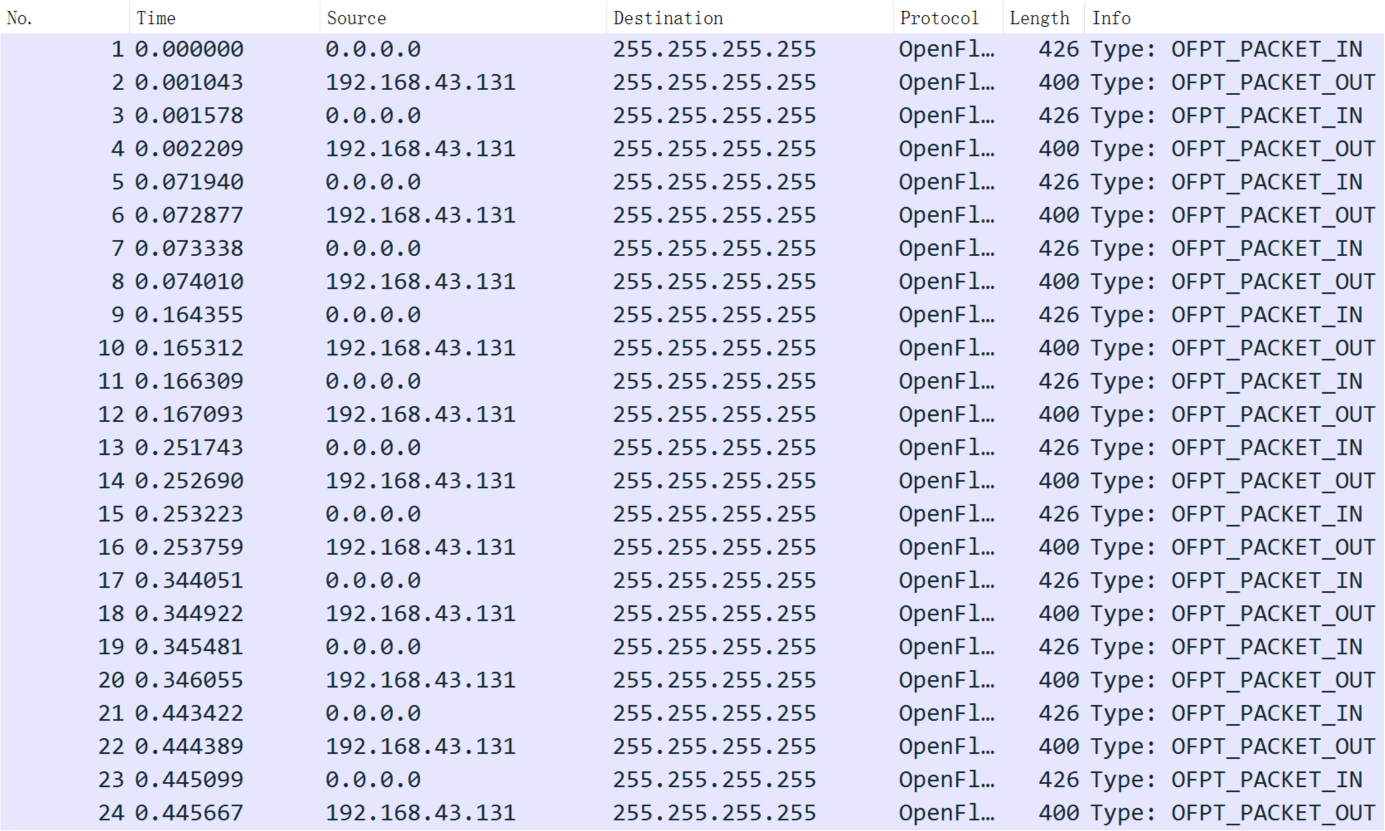
```
Dynamic Host Configuration Protocol (Discover)
    Message type: Boot Request (1)
    Hardware type: Ethernet (0x01)
    Hardware address length: 6
    Hops: 0
    Transaction ID: 0xc2ae8b45
    Seconds elapsed: 0
  > Bootp flags: 0x0000 (Unicast)
    Client IP address: 0.0.0.0
    Your (client) IP address: 0.0.0.0
    Next server IP address: 0.0.0.0
    Relay agent IP address: 0.0.0.0
    Client MAC address: 00:00:00_00:00:01 (00:00:00:00:00:01)
    Client hardware address padding: 00000000000000000000
    Server host name not given
    Boot file name not given
    Magic cookie: DHCP
  > Option: (53) DHCP Message Type (Discover)
  v Option: (50) Requested IP Address (192.168.1.2)
        Length: 4
        Requested IP Address: 192.168.1.2
  > Option: (12) Host Name
  > Option: (55) Parameter Request List
  > Option: (255) End
    Padding: 00000000000000000000000000000000000000000000000000000
```



```
Dynamic Host Configuration Protocol (Offer)
    Message type: Boot Reply (2)
    Hardware type: Ethernet (0x01)
    Hardware address length: 6
    Hops: 0
    Transaction ID: 0xc2ae8b45
    Seconds elapsed: 0
  > Bootp flags: 0x0000 (Unicast)
    Client IP address: 0.0.0.0
    Your (client) IP address: 192.168.1.2
    Next server IP address: 192.168.43.131
    Relay agent IP address: 0.0.0.0
    Client MAC address: 00:00:00_00:00:01 (00:00:00:00:00:01)
    Client hardware address padding: 00000000000000000000
    Server host name not given
    Boot file name not given
    Magic cookie: DHCP
  > Option: (53) DHCP Message Type (Offer)
  v Option: (51) IP Address Lease Time
        Length: 4
        IP Address Lease Time: (70s) 1 minute, 10 seconds
  > Option: (54) DHCP Server Identifier (192.168.43.131)
  > Option: (1) Subnet Mask (255.255.255.0)
  v Option: (6) Domain Name Server
        Length: 4
        Domain Name Server: 8.8.8.8
  > Option: (255) End
```

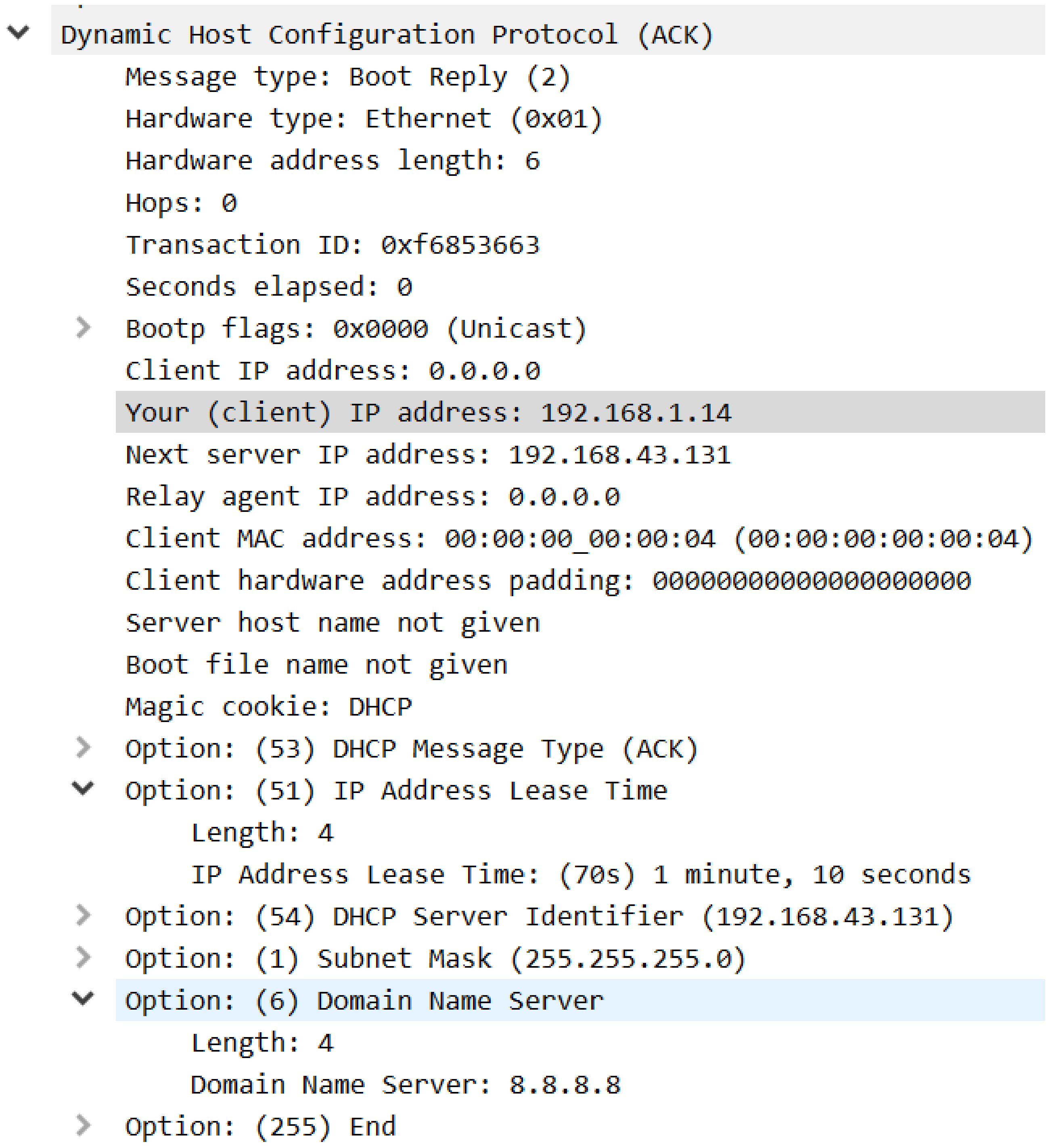
Basic 2

We created 6 DHCP clients, but only assigned the start and end IP of `192.168.1.11` - `192.168.1.14` for the IP pool, which means two client will not have a available IP.



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
2	0.001043	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
3	0.001578	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
4	0.002209	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
5	0.071940	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
6	0.072877	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
7	0.073338	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
8	0.074010	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
9	0.164355	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
10	0.165312	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
11	0.166309	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
12	0.167093	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
13	0.251743	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
14	0.252690	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
15	0.253223	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
16	0.253759	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
17	0.344051	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
18	0.344922	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
19	0.345481	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
20	0.346055	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
21	0.443422	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
22	0.444389	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT
23	0.445099	0.0.0.0	255.255.255.255	OpenFl…	426	Type: OFPT_PACKET_IN
24	0.445667	192.168.43.131	255.255.255.255	OpenFl…	400	Type: OFPT_PACKET_OUT

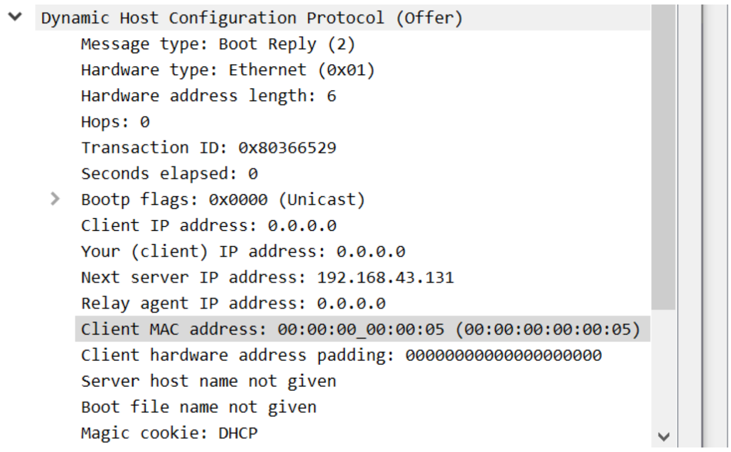
Packet 16, the ACK for the fourth client, is available.



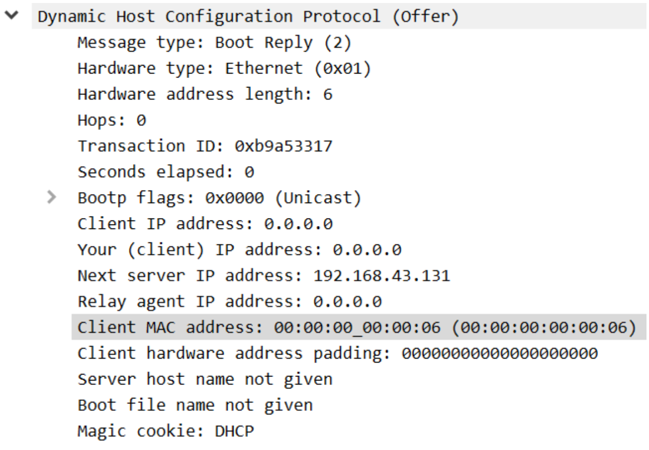
```
Dynamic Host Configuration Protocol (ACK)
    Message type: Boot Reply (2)
    Hardware type: Ethernet (0x01)
    Hardware address length: 6
    Hops: 0
    Transaction ID: 0xf6853663
    Seconds elapsed: 0
    Bootp flags: 0x0000 (Unicast)
    Client IP address: 0.0.0.0
    Your (client) IP address: 192.168.1.14
    Next server IP address: 192.168.43.131
    Relay agent IP address: 0.0.0.0
    Client MAC address: 00:00:00_00:00:04 (00:00:00:00:00:04)
    Client hardware address padding: 00000000000000000000
    Server host name not given
    Boot file name not given
    Magic cookie: DHCP
    Option: (53) DHCP Message Type (ACK)
    Option: (51) IP Address Lease Time
        Length: 4
        IP Address Lease Time: (70s) 1 minute, 10 seconds
    Option: (54) DHCP Server Identifier (192.168.43.131)
    Option: (1) Subnet Mask (255.255.255.0)
    Option: (6) Domain Name Server
        Length: 4
        Domain Name Server: 8.8.8.8
    Option: (255) End
```

But the fifth and sixth client will not have available IP, just `0.0.0.0` , because the IP pool has already full.

Replying the Offer packet is only for the display and endding the test, but in fact this IP is invalid.



```
Dynamic Host Configuration Protocol (Offer)
    Message type: Boot Reply (2)
    Hardware type: Ethernet (0x01)
    Hardware address length: 6
    Hops: 0
    Transaction ID: 0x80366529
    Seconds elapsed: 0
    Bootp flags: 0x0000 (Unicast)
    Client IP address: 0.0.0.0
    Your (client) IP address: 0.0.0.0
    Next server IP address: 192.168.43.131
    Relay agent IP address: 0.0.0.0
    Client MAC address: 00:00:00_00:00:05 (00:00:00:00:00:05)
    Client hardware address padding: 00000000000000000000
    Server host name not given
    Boot file name not given
    Magic cookie: DHCP
```



```
Dynamic Host Configuration Protocol (Offer)
    Message type: Boot Reply (2)
    Hardware type: Ethernet (0x01)
    Hardware address length: 6
    Hops: 0
    Transaction ID: 0xb9a53317
    Seconds elapsed: 0
    Bootp flags: 0x0000 (Unicast)
    Client IP address: 0.0.0.0
    Your (client) IP address: 0.0.0.0
    Next server IP address: 192.168.43.131
    Relay agent IP address: 0.0.0.0
    Client MAC address: 00:00:00_00:00:06 (00:00:00:00:00:06)
    Client hardware address padding: 00000000000000000000
    Server host name not given
    Boot file name not given
    Magic cookie: DHCP
```

In the above display, because of the mapping between IP and MAC, no duplicate IP will be allocated.

This is a brief demonstration of the DHCP function.

No Duplicate IP Allocation

By using the IP-MAC dic pool, we can guarantee each IP will only have one corresponding MAC, and there will be no duplication

Shortest path switching

Code

- function `update_topo`, update the topology structure each time wo do modification operations.

```
def update_topo(self):
    self.clear()  # init table
    self.swids = [sw.dp.id for sw in get_all_switch(self)]  #get all dpid

    links_list = get_all_link(self)
    for link in links_list:  #get all link
        self.adj[link.src.dpid][link.dst.dpid] = link.src.port_no
        self.adj[link.dst.dpid][link.src.dpid] = link.dst.port_no

    for cur_switch in self.swids:  # for each switch
        for host_mac in self.host_port.keys():  # then for each host mac
            host_swid = self.host_port[host_mac][0]
            host_port_no = self.host_port[host_mac][1]
            sw_port = self.shortest(cur_switch, host_swid, host_port_no)  # find sp
            if sw_port:  # has path
                for sw_id, out_port in sw_port:
                    dp = get_switch(self, sw_id)[0].dp
                    match = dp.ofproto_parser.OFPMatch(dl_dst=host_mac)
                    actions = [dp.ofproto_parser.OFPActionOutput(out_port)]
                    mod = dp.ofproto_parser.OFPFlowMod(datapath=dp, match=match,
                                                       priority=1, actions=actions)
                    dp.send_msg(mod)  # send flow table

            for src_mac in self.host_port.keys():
                if self.host_port[src_mac][0] == cur_switch:  # src host
                    src_port = self.host_port[src_mac]
                    if sw_port and self.port_state[(src_port[0], src_port[1])]:
                        self.print_path(sw_port=sw_port, src_mac=src_mac, dst_mac=host_mac)
                    elif src_mac != host_mac:
                        print(f"Net is break for {src_mac} to {host_mac}")
```

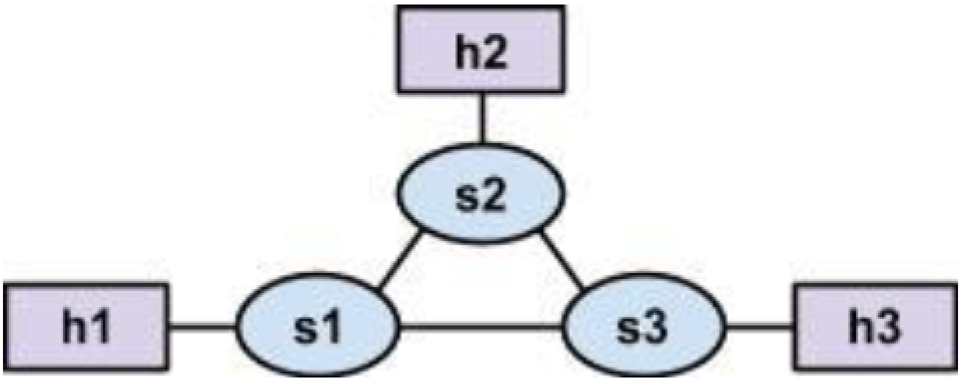
- function `shortest`, get shortest path according to the given src and dst, containing the `switch id` and the `port` it send packet out of each switch in the shortest path. We use simple BFS, and get each switch and its output port.

```
def shortest(self, src_sw, dst_sw, dst_port):
    if not self.port_state[(dst_sw, dst_port)]:
        return None  # host port shut down, None

    if src_sw == dst_sw: # dst switch to host
        return [(dst_sw, dst_port)]

    dis = {}  # distance
    fa = {}  # father node

    nodes = self.swids
    for node in nodes:
        dis[node] = float('inf')  # init
        fa[node] = None

    que = Queue()
    que.put(src_sw)
    dis[src_sw] = 0
    while not que.empty():
        cur = que.get()  # BFS
        for sw in nodes:
            if self.adj[cur][sw] is not None and dis[sw] > dis[cur] + 1:
                dis[sw] = dis[cur] + 1
                fa[sw] = cur
                que.put(sw)

    path_ids = []
    if dst_sw not in fa.keys():
        return None  # can not reach host

    father = fa[dst_sw]
    cur = dst_sw
    while True:  # find the father node
        if cur == src_sw:
            path_ids.append(src_sw)
            break
        elif father is None:
            return None
        else:
            path_ids.append(cur)
            father = fa[cur]
            cur = father
    path_ids.reverse()  # we get the switch ID in this path
```

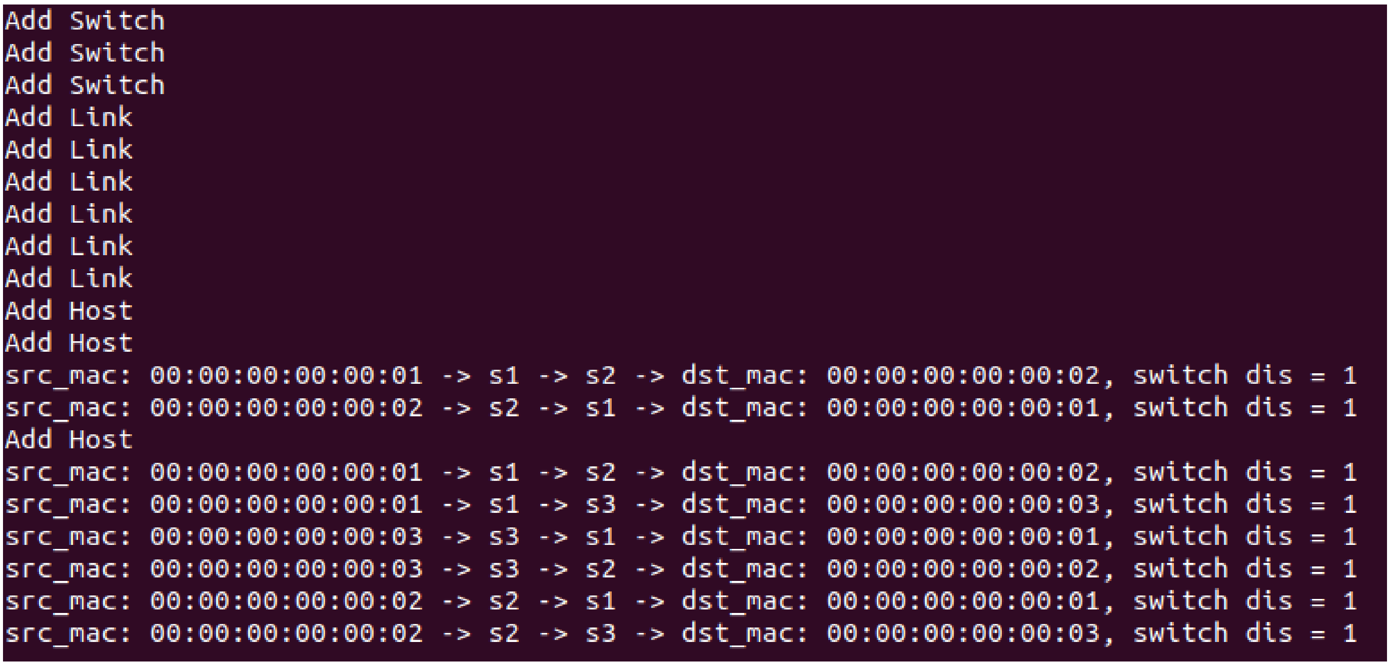
Test

basic test case

1.initial topology structure

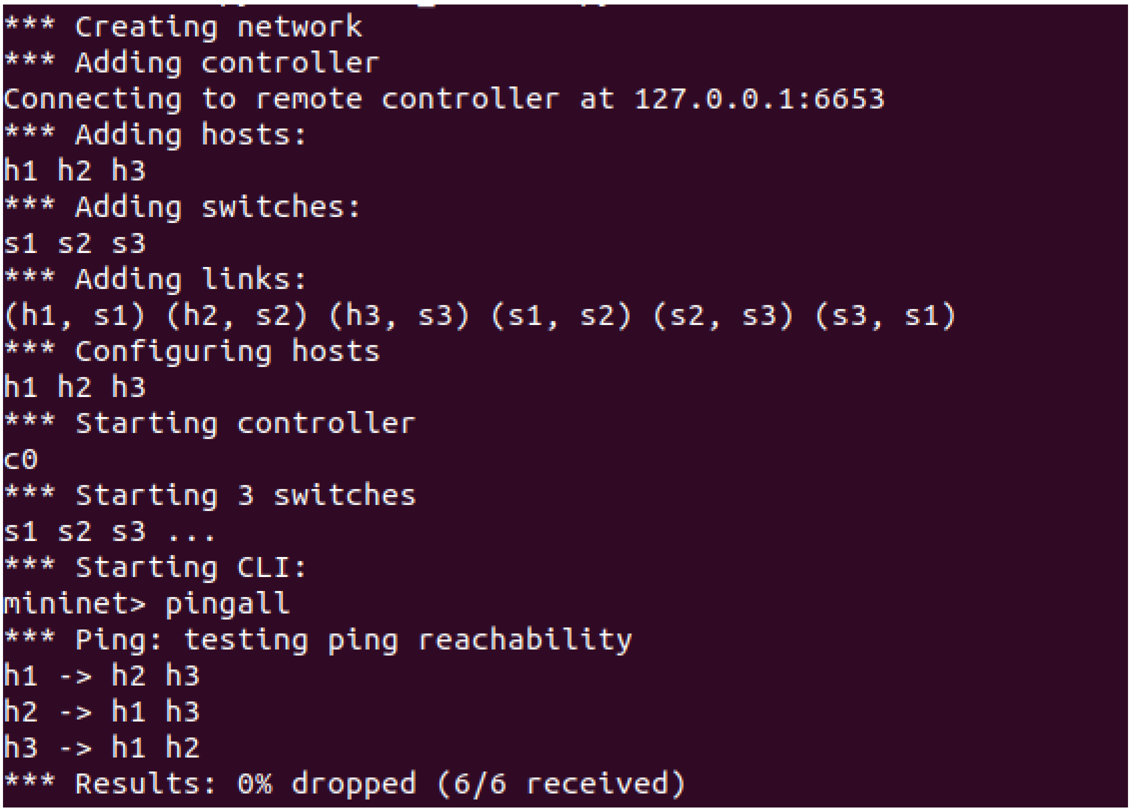


2.the shortest path between any two hosts and length between any two switches



```
Add Switch
Add Switch
Add Switch
Add Link
Add Link
Add Link
Add Link
Add Link
Add Link
Add Host
Add Host
src_mac: 00:00:00:00:00:01 -> s1 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 1
src_mac: 00:00:00:00:00:02 -> s2 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 1
Add Host
src_mac: 00:00:00:00:00:01 -> s1 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 1
src_mac: 00:00:00:00:00:01 -> s1 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 1
src_mac: 00:00:00:00:00:02 -> s2 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 1
src_mac: 00:00:00:00:00:02 -> s2 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 1
```

3.use `pingall` to verify connectivity between all hosts

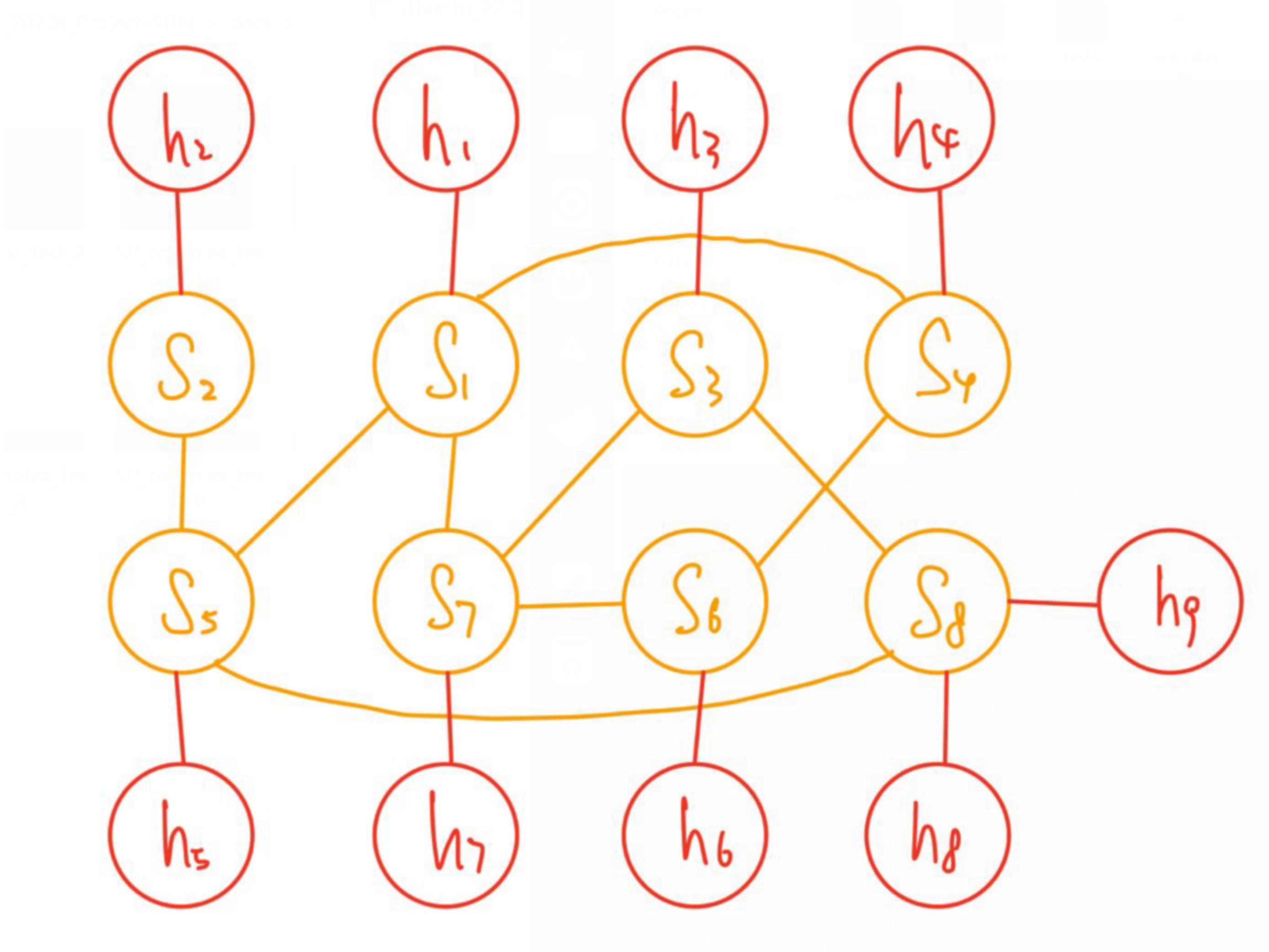


```
*** Creating network
*** Adding controller
Connecting to remote controller at 127.0.0.1:6653
*** Adding hosts:
h1 h2 h3
*** Adding switches:
s1 s2 s3
*** Adding links:
(h1, s1) (h2, s2) (h3, s3) (s1, s2) (s2, s3) (s3, s1)
*** Configuring hosts
h1 h2 h3
*** Starting controller
c0
*** Starting 3 switches
s1 s2 s3 ...
*** Starting CLI:
mininet> pingall
*** Ping: testing ping reachability
h1 -> h2 h3
h2 -> h1 h3
h3 -> h1 h2
*** Results: 0% dropped (6/6 received)
```

complex test case

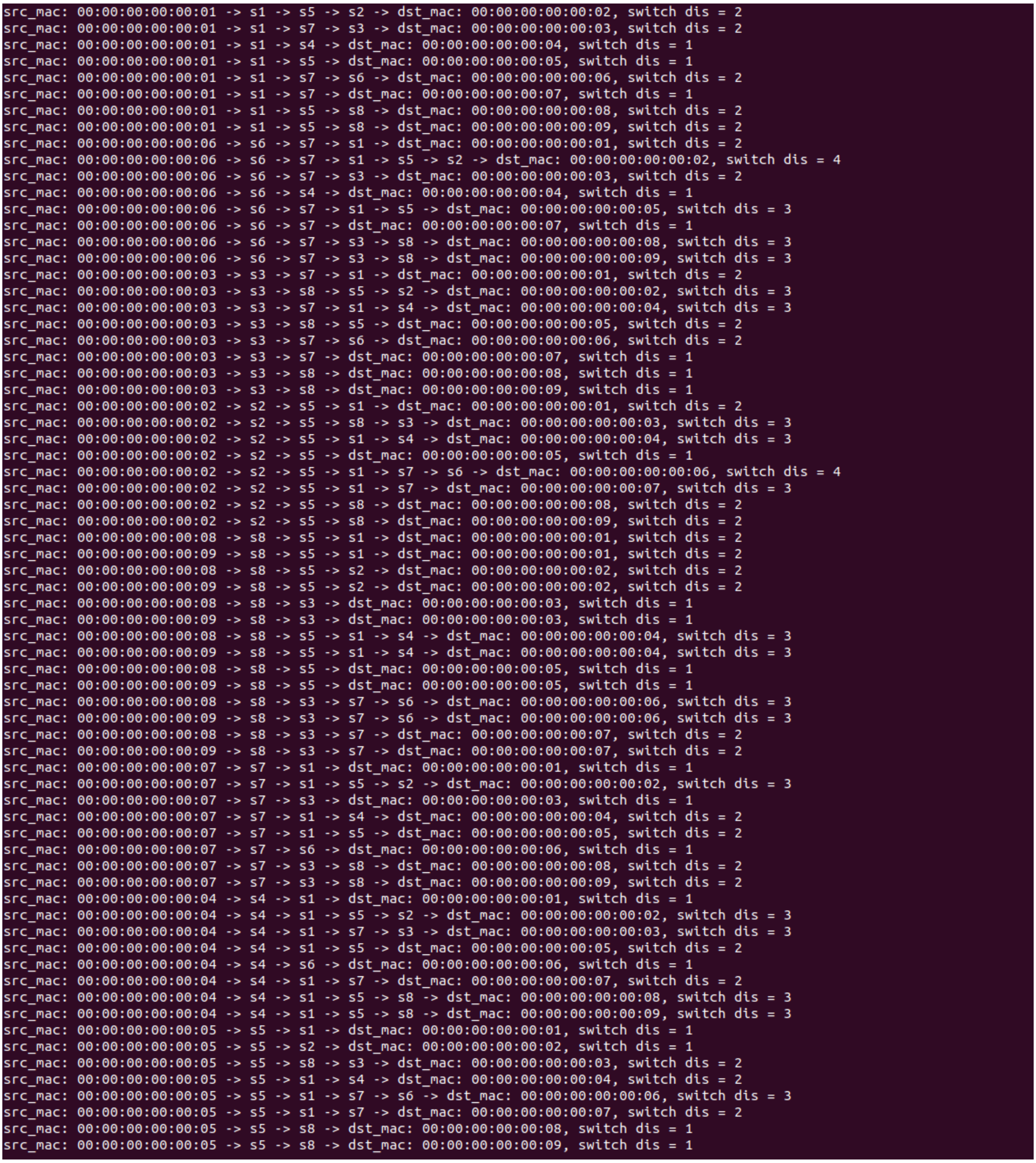
You can check **switching_test/test_network.py** `class ComplexTopo` for original information.

1.initial topology structure



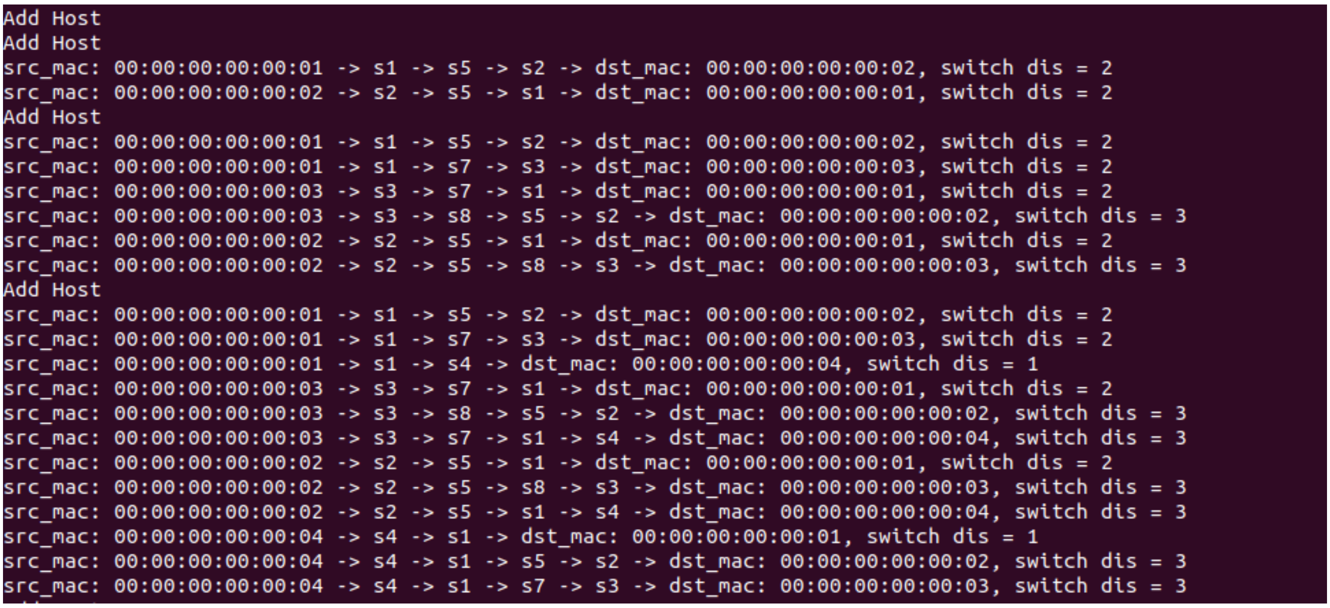
2.the shortest path between any two hosts and length between any two switches

- Overall



```
src_mac: 00:00:00:00:00:01 -> s1 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 2
src_mac: 00:00:00:00:00:01 -> s1 -> s7 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 2
src_mac: 00:00:00:00:00:01 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 1
src_mac: 00:00:00:00:00:01 -> s1 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 1
src_mac: 00:00:00:00:00:01 -> s1 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 2
src_mac: 00:00:00:00:00:01 -> s1 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 1
src_mac: 00:00:00:00:00:01 -> s1 -> s5 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 2
src_mac: 00:00:00:00:00:01 -> s1 -> s5 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 2
src_mac: 00:00:00:00:00:06 -> s6 -> s7 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:06 -> s6 -> s7 -> s1 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 4
src_mac: 00:00:00:00:00:06 -> s6 -> s7 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 2
src_mac: 00:00:00:00:00:06 -> s6 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 1
src_mac: 00:00:00:00:00:06 -> s6 -> s7 -> s1 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 3
src_mac: 00:00:00:00:00:06 -> s6 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 1
src_mac: 00:00:00:00:00:06 -> s6 -> s7 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 3
src_mac: 00:00:00:00:00:06 -> s6 -> s7 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 1
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> s8 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 3
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 3
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 1
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> s1 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 4
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> s1 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 3
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 2
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 2
src_mac: 00:00:00:00:00:08 -> s8 -> s5 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:09 -> s8 -> s5 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:08 -> s8 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 2
src_mac: 00:00:00:00:00:09 -> s8 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 2
src_mac: 00:00:00:00:00:08 -> s8 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 1
src_mac: 00:00:00:00:00:09 -> s8 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 1
src_mac: 00:00:00:00:00:08 -> s8 -> s5 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 3
src_mac: 00:00:00:00:00:09 -> s8 -> s5 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 3
src_mac: 00:00:00:00:00:08 -> s8 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 1
src_mac: 00:00:00:00:00:09 -> s8 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 1
src_mac: 00:00:00:00:00:08 -> s8 -> s3 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 3
src_mac: 00:00:00:00:00:09 -> s8 -> s3 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 3
src_mac: 00:00:00:00:00:08 -> s8 -> s3 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 2
src_mac: 00:00:00:00:00:09 -> s8 -> s3 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 2
src_mac: 00:00:00:00:00:07 -> s7 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 1
src_mac: 00:00:00:00:00:07 -> s7 -> s1 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 3
src_mac: 00:00:00:00:00:07 -> s7 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 1
src_mac: 00:00:00:00:00:07 -> s7 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 2
src_mac: 00:00:00:00:00:07 -> s7 -> s1 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 2
src_mac: 00:00:00:00:00:07 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 1
src_mac: 00:00:00:00:00:07 -> s7 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 2
src_mac: 00:00:00:00:00:07 -> s7 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 2
src_mac: 00:00:00:00:00:04 -> s4 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 1
src_mac: 00:00:00:00:00:04 -> s4 -> s1 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 3
src_mac: 00:00:00:00:00:04 -> s4 -> s1 -> s7 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 3
src_mac: 00:00:00:00:00:04 -> s4 -> s1 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 2
src_mac: 00:00:00:00:00:04 -> s4 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 1
src_mac: 00:00:00:00:00:04 -> s4 -> s1 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 2
src_mac: 00:00:00:00:00:04 -> s4 -> s1 -> s5 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 3
src_mac: 00:00:00:00:00:04 -> s4 -> s1 -> s5 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 3
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 1
src_mac: 00:00:00:00:00:05 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 1
src_mac: 00:00:00:00:00:05 -> s5 -> s8 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 2
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 2
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 3
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 2
src_mac: 00:00:00:00:00:05 -> s5 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 1
src_mac: 00:00:00:00:00:05 -> s5 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 1
```

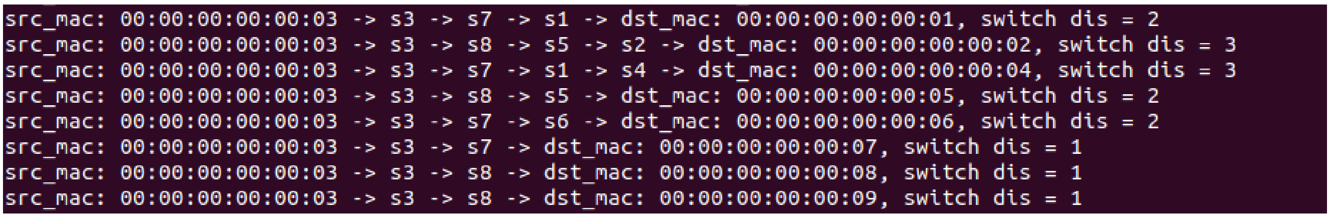
- Add Host (Initial)



```
Add Host
Add Host
src_mac: 00:00:00:00:00:01 -> s1 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 2
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
Add Host
src_mac: 00:00:00:00:00:01 -> s1 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 2
src_mac: 00:00:00:00:00:01 -> s1 -> s7 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 3
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> s8 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 3
Add Host
src_mac: 00:00:00:00:00:01 -> s1 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 2
src_mac: 00:00:00:00:00:01 -> s1 -> s7 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 2
src_mac: 00:00:00:00:00:01 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 3
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> s8 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 3
src_mac: 00:00:00:00:00:02 -> s2 -> s5 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 3
src_mac: 00:00:00:00:00:04 -> s4 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 1
src_mac: 00:00:00:00:00:04 -> s4 -> s1 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 3
src_mac: 00:00:00:00:00:04 -> s4 -> s1 -> s7 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 3
```

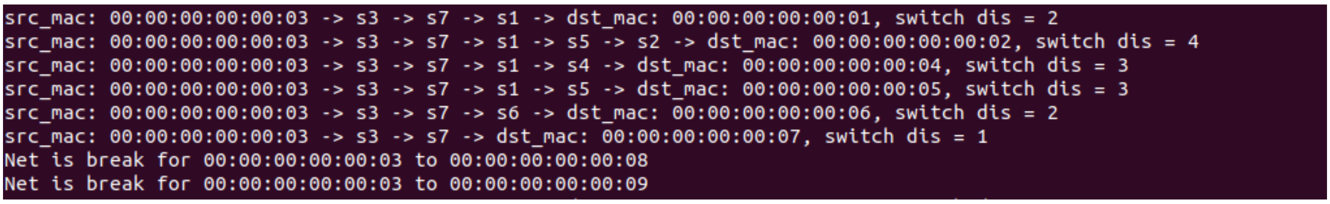
- Delete Switch

  before delete switch s8:



```
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 1
```

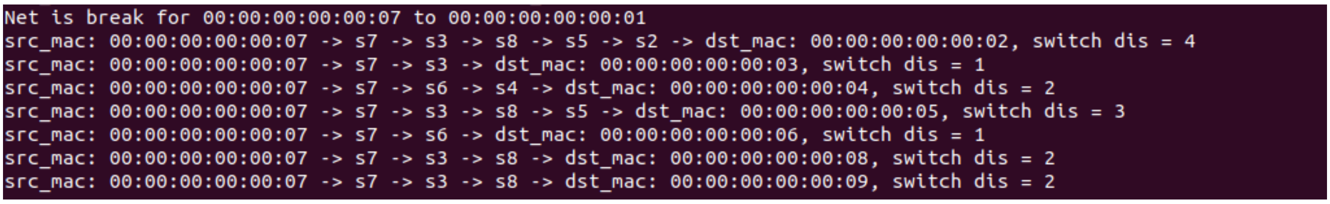
  after delete switch s8:



```
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 4
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 1
Net is break for 00:00:00:00:00:03 to 00:00:00:00:00:08
Net is break for 00:00:00:00:00:03 to 00:00:00:00:00:09
```

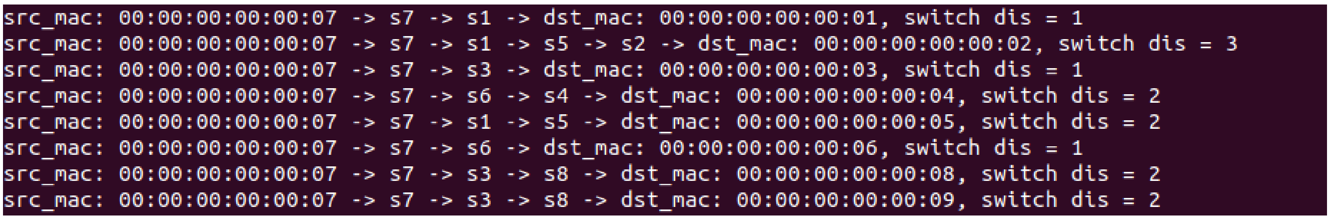
- Add Switch

  before add switch s1:



```
Net is break for 00:00:00:00:00:07 to 00:00:00:00:00:01
src_mac: 00:00:00:00:00:07 -> s7 -> s3 -> s8 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 4
src_mac: 00:00:00:00:00:07 -> s7 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 1
src_mac: 00:00:00:00:00:07 -> s7 -> s6 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 2
src_mac: 00:00:00:00:00:07 -> s7 -> s3 -> s8 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 3
src_mac: 00:00:00:00:00:07 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 1
src_mac: 00:00:00:00:00:07 -> s7 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 2
src_mac: 00:00:00:00:00:07 -> s7 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 2
```

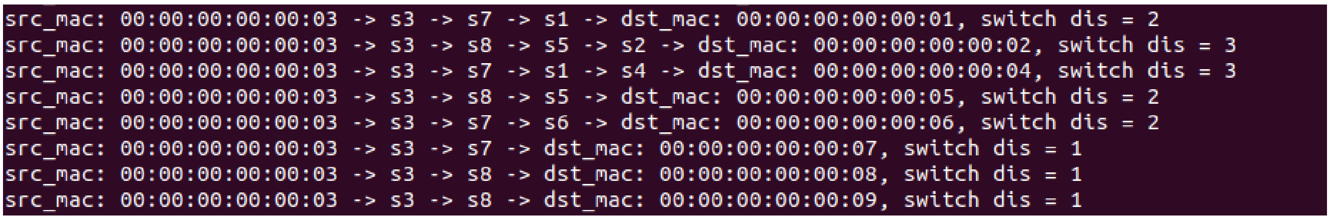
  after add switch s1:



```
src_mac: 00:00:00:00:00:07 -> s7 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 1
src_mac: 00:00:00:00:00:07 -> s7 -> s1 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 3
src_mac: 00:00:00:00:00:07 -> s7 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 1
src_mac: 00:00:00:00:00:07 -> s7 -> s6 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 2
src_mac: 00:00:00:00:00:07 -> s7 -> s1 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 2
src_mac: 00:00:00:00:00:07 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 1
src_mac: 00:00:00:00:00:07 -> s7 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 2
src_mac: 00:00:00:00:00:07 -> s7 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 2
```

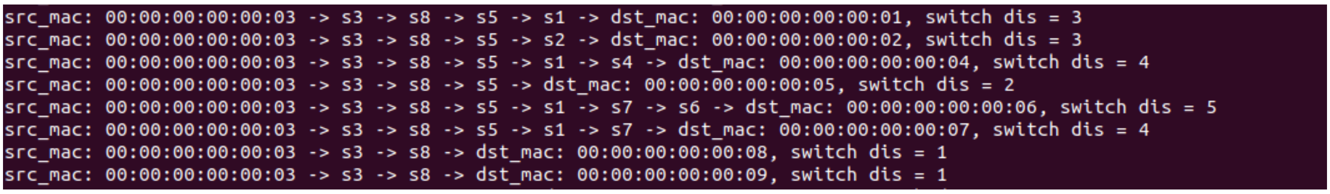
- Delete Link

  before delete link s3->s7:



```
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 1
```

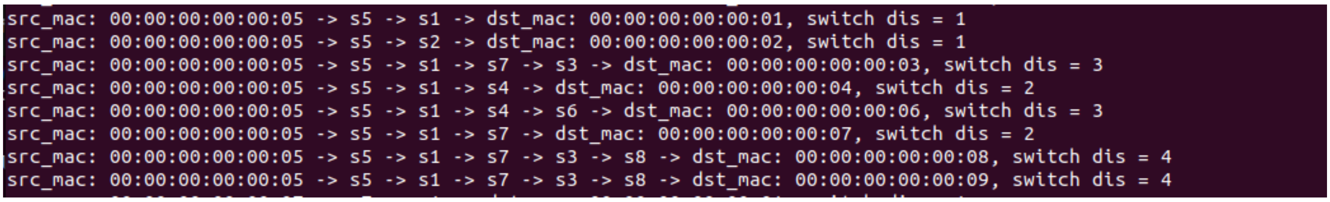
after delete link s3->s7：



```
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 4
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> s1 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 5
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> s1 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 4
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 1
```

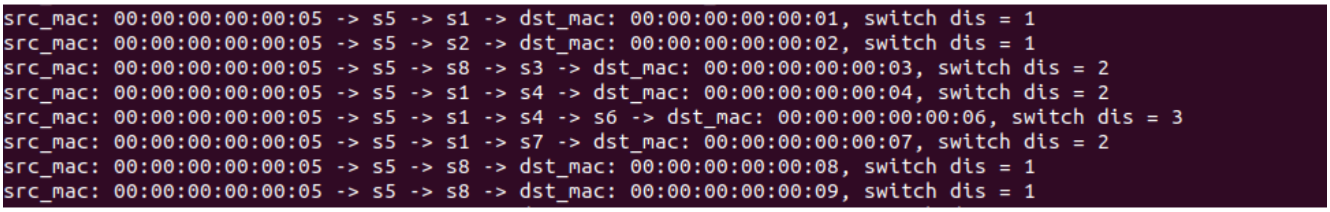
- Add Link

before add link s5->s8：



```
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 1
src_mac: 00:00:00:00:00:05 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 1
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> s7 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 3
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 2
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> s4 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 3
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 2
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> s7 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 4
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> s7 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 4
```

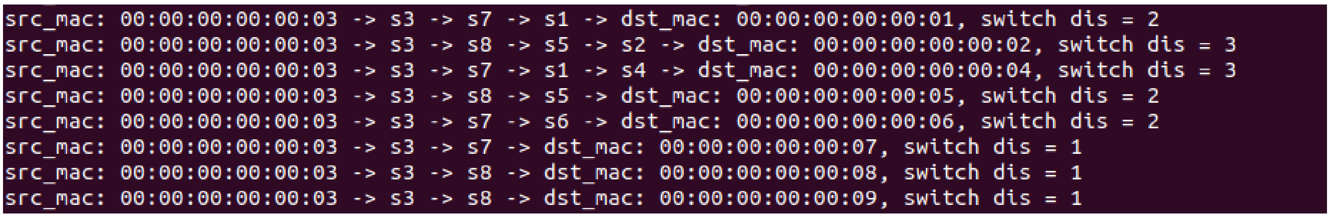
after add link s5->s8：



```
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 1
src_mac: 00:00:00:00:00:05 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 1
src_mac: 00:00:00:00:00:05 -> s5 -> s8 -> s3 -> dst_mac: 00:00:00:00:00:03, switch dis = 2
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 2
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> s4 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 3
src_mac: 00:00:00:00:00:05 -> s5 -> s1 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 2
src_mac: 00:00:00:00:00:05 -> s5 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 1
src_mac: 00:00:00:00:00:05 -> s5 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 1
```

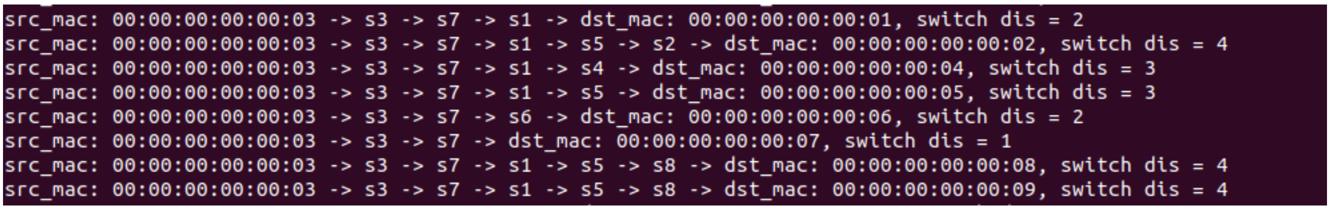
- Modify Port

before disable port 3 in switch 3（to switch 8）：



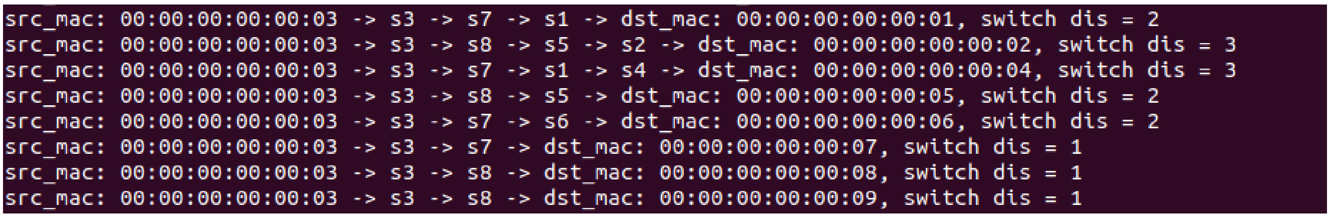
```
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 1
```

after disable port 3 in switch 3：



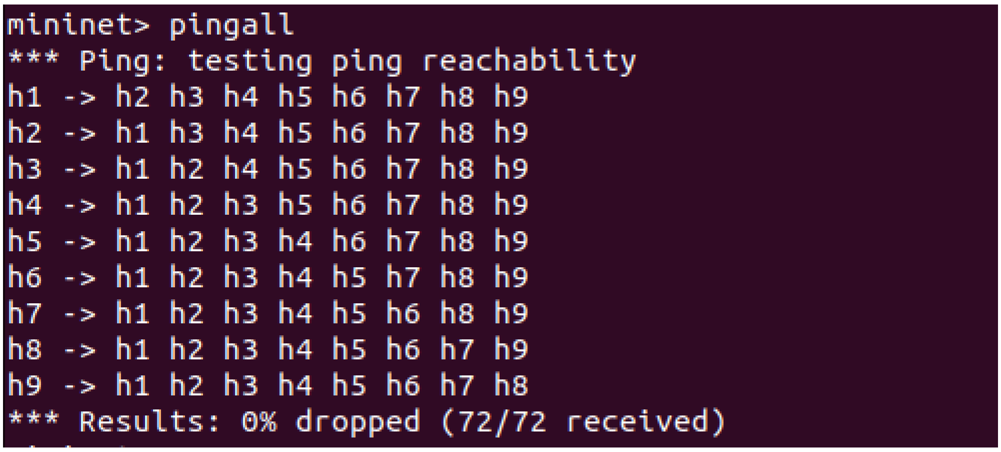
```
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 4
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s5 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 4
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s5 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 4
```

after enable port 3 in switch 3 again：



```
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> dst_mac: 00:00:00:00:00:01, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> s2 -> dst_mac: 00:00:00:00:00:02, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s1 -> s4 -> dst_mac: 00:00:00:00:00:04, switch dis = 3
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> s5 -> dst_mac: 00:00:00:00:00:05, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> s6 -> dst_mac: 00:00:00:00:00:06, switch dis = 2
src_mac: 00:00:00:00:00:03 -> s3 -> s7 -> dst_mac: 00:00:00:00:00:07, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:08, switch dis = 1
src_mac: 00:00:00:00:00:03 -> s3 -> s8 -> dst_mac: 00:00:00:00:00:09, switch dis = 1
```

3.use `pingall` to verify connectivity between all hosts



```
mininet> pingall
*** Ping: testing ping reachability
h1 -> h2 h3 h4 h5 h6 h7 h8 h9
h2 -> h1 h3 h4 h5 h6 h7 h8 h9
h3 -> h1 h2 h4 h5 h6 h7 h8 h9
h4 -> h1 h2 h3 h5 h6 h7 h8 h9
h5 -> h1 h2 h3 h4 h6 h7 h8 h9
h6 -> h1 h2 h3 h4 h5 h7 h8 h9
h7 -> h1 h2 h3 h4 h5 h6 h8 h9
h8 -> h1 h2 h3 h4 h5 h6 h7 h9
h9 -> h1 h2 h3 h4 h5 h6 h7 h8
*** Results: 0% dropped (72/72 received)
```

Bonus

Firewall

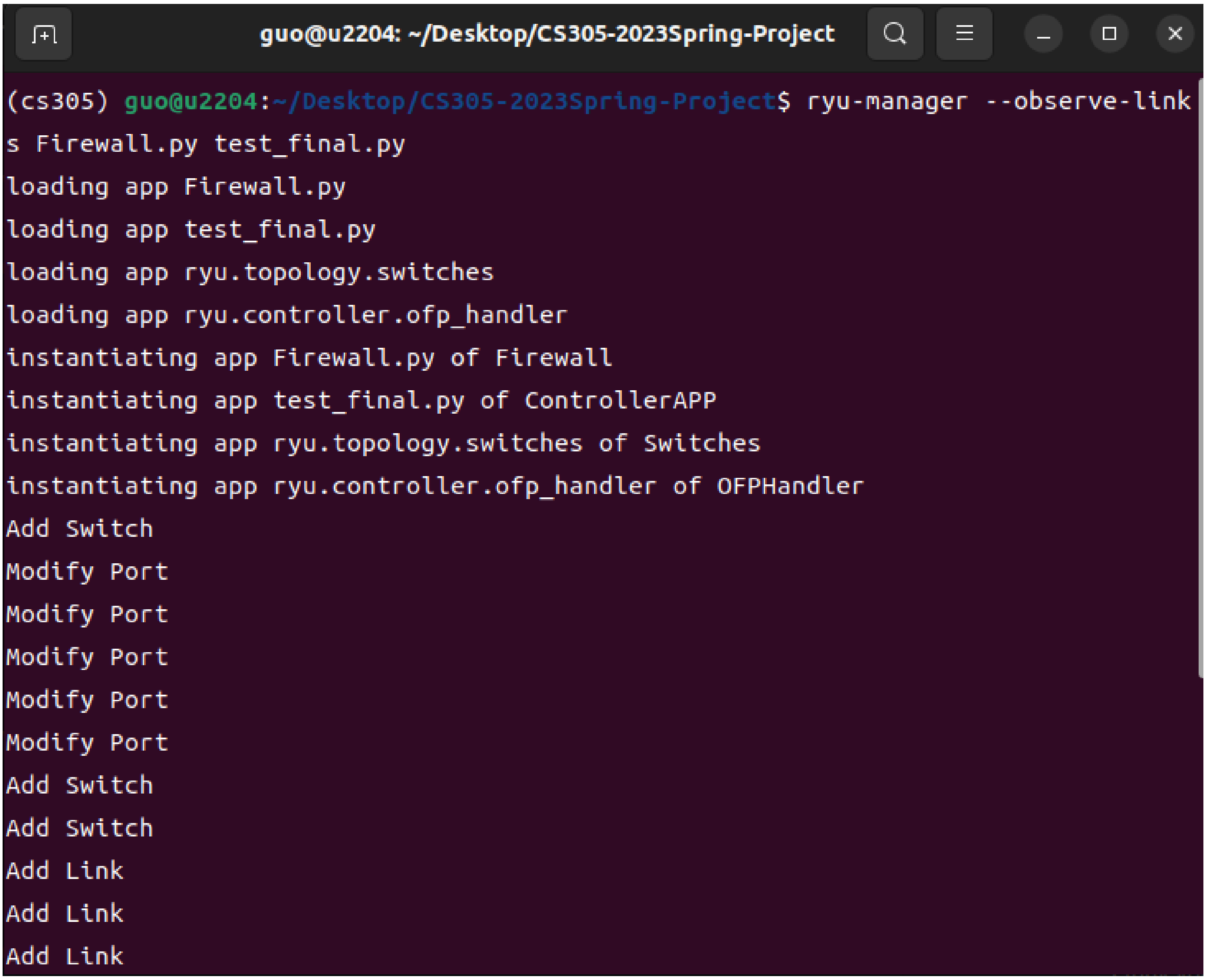
Code

- We block packet to host which mac address is `00:00:00:00:00:01`
- This is our new firewall code.

```
from ryu.controller.handler import set_ev_cls
from ryu.ofproto import ofproto_v1_0, ofproto_v1_0_parser
from ryu.topology.api import *


class Firewall(app_manager.RyuApp):
    OFP_VERSIONS = [ofproto_v1_0.OFP_VERSION]

    def __init__(self, *args, **kwargs):
        super(Firewall, self).__init__(*args, **kwargs)
        self.target = []
        self.target.append('00:00:00:00:00:01')

    @set_ev_cls(event.EventSwitchEnter)
    def switch_features_handler(self, ev):
        for drop_mac in self.target:
            match = ofproto_v1_0_parser.OFPMatch(dl_dst=drop_mac)
            command = ofproto_v1_0.OFPFC_ADD
            drop = ofproto_v1_0.OFPP_NONE
            actions = None
            req = ofproto_v1_0_parser.OFPFlowMod(datapath=ev.switch.dp, command=command, idle_timeout=0,                                        hard_timeout=0,priority=600, match=match, actions=actions)
            ev.switch.dp.send_msg(req)

```

Test

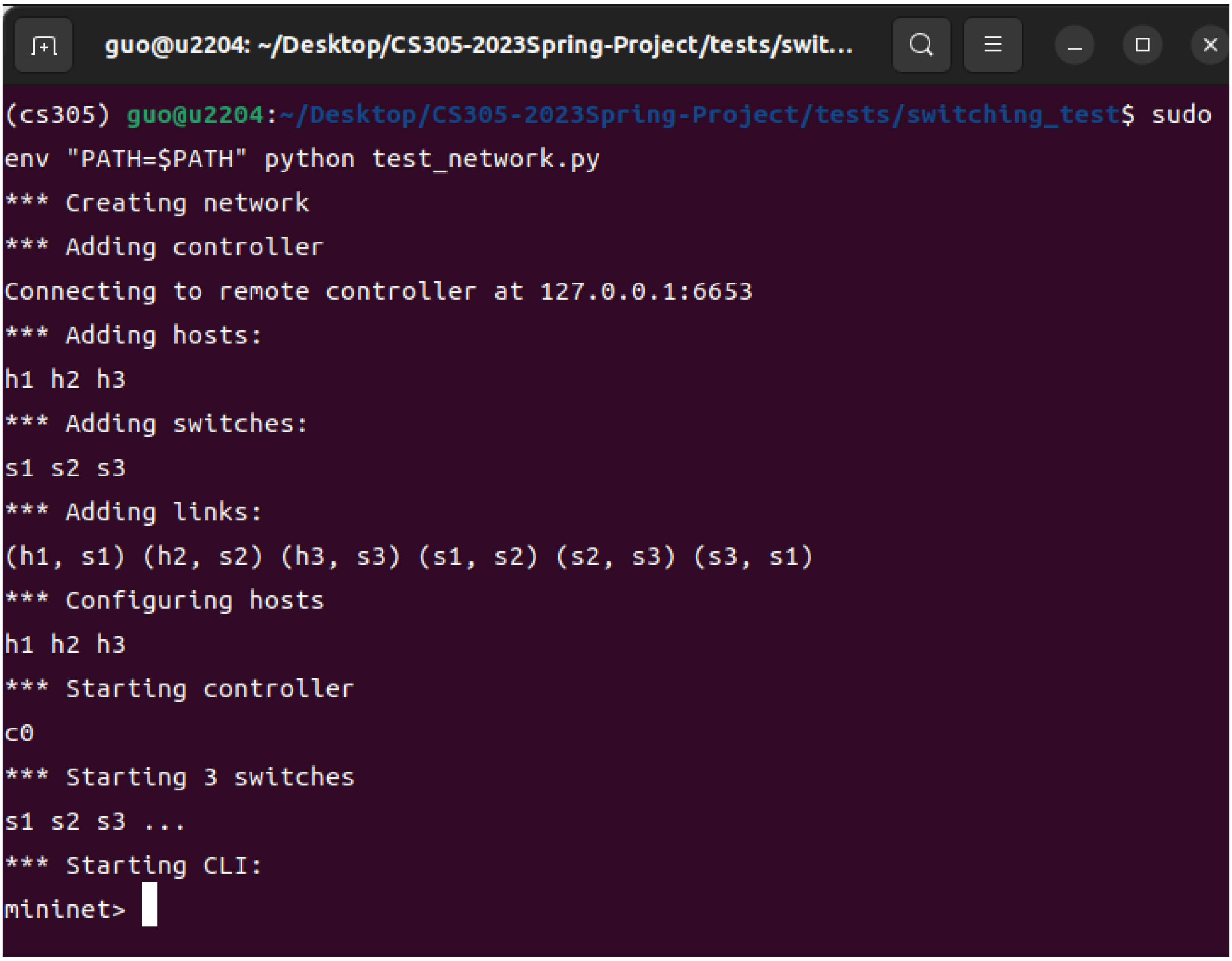
- Using `ryu-manager --observe-links` to run `firewall.py` and `test_final.py` .



guo@u2204: ~/Desktop/CS305-2023Spring-Project

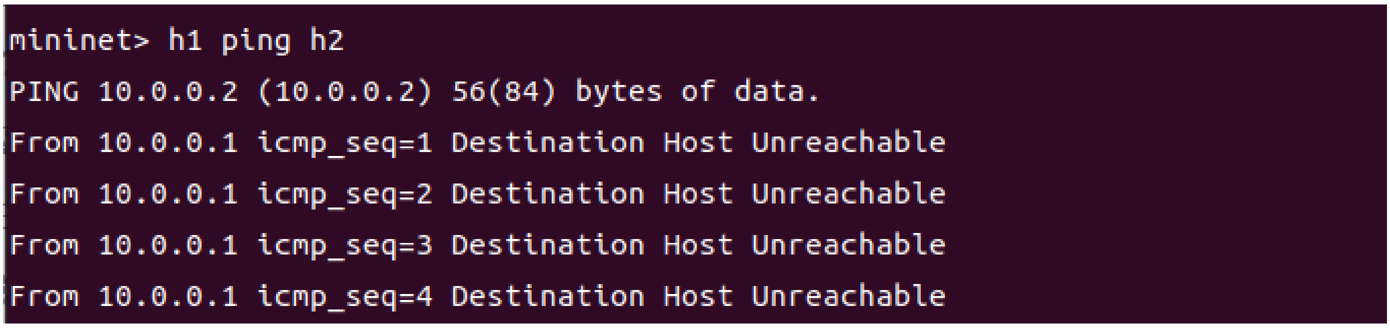
```
(cs305) guo@u2204:~/Desktop/CS305-2023Spring-Project$ ryu-manager --observe-link
s Firewall.py test_final.py
loading app Firewall.py
loading app test_final.py
loading app ryu.topology.switches
loading app ryu.controller.ofp_handler
instantiating app Firewall.py of Firewall
instantiating app test_final.py of ControllerAPP
instantiating app ryu.topology.switches of Switches
instantiating app ryu.controller.ofp_handler of OFPHandler
Add Switch
Modify Port
Modify Port
Modify Port
Modify Port
Modify Port
Add Switch
Add Switch
Add Link
Add Link
Add Link
```

- Run `test_network.py` which also use to check shortest path to build network topology.

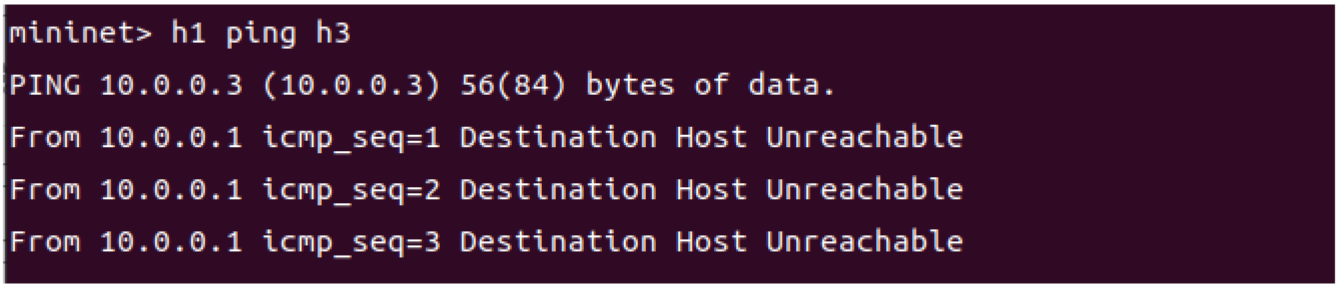


```
(cs305) guo@u2204:~/Desktop/CS305-2023Spring-Project/tests/switching_test$ sudo
env "PATH=$PATH" python test_network.py
*** Creating network
*** Adding controller
Connecting to remote controller at 127.0.0.1:6653
*** Adding hosts:
h1 h2 h3
*** Adding switches:
s1 s2 s3
*** Adding links:
(h1, s1) (h2, s2) (h3, s3) (s1, s2) (s2, s3) (s3, s1)
*** Configuring hosts
h1 h2 h3
*** Starting controller
c0
*** Starting 3 switches
s1 s2 s3 ...
*** Starting CLI:
mininet>
```

- h1'packet was blocked by firewall. Because h1's mac address is `00:00:00:00:00:01` .

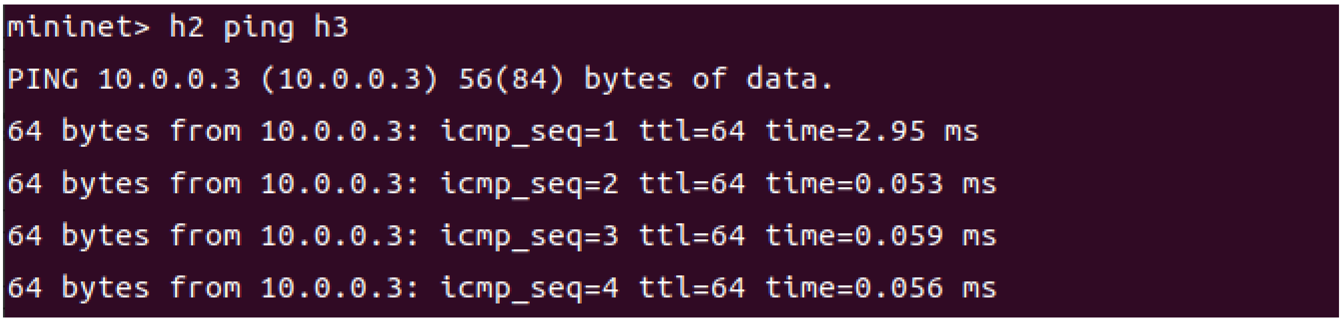


```
mininet> h1 ping h2
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.
From 10.0.0.1 icmp_seq=1 Destination Host Unreachable
From 10.0.0.1 icmp_seq=2 Destination Host Unreachable
From 10.0.0.1 icmp_seq=3 Destination Host Unreachable
From 10.0.0.1 icmp_seq=4 Destination Host Unreachable
```



```
mininet> h1 ping h3
PING 10.0.0.3 (10.0.0.3) 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
```

- h2 and h3 can send packet to each other.



```
mininet> h2 ping h3
PING 10.0.0.3 (10.0.0.3) 56(84) bytes of data.
64 bytes from 10.0.0.3: icmp_seq=1 ttl=64 time=2.95 ms
64 bytes from 10.0.0.3: icmp_seq=2 ttl=64 time=0.053 ms
64 bytes from 10.0.0.3: icmp_seq=3 ttl=64 time=0.059 ms
64 bytes from 10.0.0.3: icmp_seq=4 ttl=64 time=0.056 ms
```

- This our original firewall code. But we find `EventOFPSwitchFeatures` in `@set_ev_cls(ofp_event.EventOFPSwitchFeatures, CONFIG_DISPATCHER)` and `EventOFPPacketIn` in `@set_ev_cls(ofp_event.EventOFPPacketIn, MAIN_DISPATCHER)` are not exist. So we rewrite our firewall code.

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


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

    def __init__(self, *args, **kwargs):
        super(FirewallApp, 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

        # Add default flow table rules to forward all packets to the controller for processing
        match = parser.OFPMatch()
        actions = [parser.OFPActionOutput(ofproto.OFPP_CONTROLLER,
                                          ofproto.OFPCML_NO_BUFFER)]
        self. add_flow(datapath, 0, match, actions)

    def add_flow(self, datapath, priority, match, actions):
        ofproto = datapath.ofproto
        parser = datapath.ofproto_parser

        # Create flow table rules
        inst = [parser.OFPInstructionActions(ofproto.OFPIT_APPLY_ACTIONS,
                                             actions)]
        mod = parser.OFPFlowMod(datapath=datapath, priority=priority,
                                match=match, instructions=inst)
        datapath. send_msg(mod)

    @set_ev_cls(ofp_event.EventOFPPacketIn, MAIN_DISPATCHER)
    def packet_in_handler(self, ev):
        # Parse the received packet
        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 = pkt.get_protocol(ethernet.ethernet)

        # ignore non-Ethernet packets
        if not eth_pkt:
            return

        # Get the source MAC address and destination MAC address
        src_mac = eth_pkt.src
        dst_mac = eth_pkt.dst

        # Record the mapping relationship between source MAC address and port in the mac_to_port dictionary
        if datapath.id not in self.mac_to_port:
            self.mac_to_port[datapath.id] = {}
        self.mac_to_port[datapath.id][src_mac] = in_port

        # Check firewall rules and decide whether to block packets
        if self.firewall_check(src_mac, dst_mac):
            # block packets
            return

        # Find the port based on the destination MAC address and send the packet
        if dst_mac in self.mac_to_port[datapath.id]:
            out_port = self.mac_to_port[datapath.id][dst_mac]
        else:
            # If the destination MAC address is unknown, send packets to all ports (broadcast)
            out_port = ofproto.OFPP_FLOOD

        # Create a flow table rule to forward the packet to the corresponding port
        actions = [parser. OFPActionOutput(out_port)]
        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)

    def firewall_check(self, src_mac, dst_mac):


        # Example rule: Block packets with source MAC address 00:00:00:00:00:01
        if src_mac == '00:00:00:00:00:01':
            return True

        return False
```

DNS

Originally implemented an independent DNS server, but later found that it was necessary to implement DNS based on Ryu, but due to time constraints, it was not completed.

Implementation idea: The implementation idea of this function is similar to that of a DHCP server. It is necessary to first use `getProtocol()` identify whether there is a DNS protocol packet in the application layer, and then reply the corresponding DNS data packet according to the protocol content.

We can use tuples to store static DNS information in DNS Server for DNS response, such as `('www.google.com', '162.125.6.1', 'A')`, if we match the correct records in DNS, we can use a new packet to host to give response.

This is our DNS code originally.

```
from dnslib import *
from dnslib.server import DNSServer, DNSHandler, BaseResolver


class MyHandler(DNSHandler):

    def __init__(self, request, client_address, server):
        super().__init__(request, client_address, server)

    def handle(self):
        # 'handle DNS logic'
        data = self.request[0]  # get request data

        # resolve DNS requests
        request = DNSRecord.parse(data)

        qname = request.q.qname
        qtype = request.q.qtype

        # print DNS info
        print(f"Received DNS query for {qname} ({QTYPE[qtype]}) from {self.client_address[0]}")

        # manage DNS response
        reply = request.reply()

        # reply = request.reply()

        if qtype == QTYPE.A:
            # handle type A request
            # insert DNS A query logic
            reply.add_answer(RR(qname, qtype, rdata=A("127.0.0.1")))
        elif qtype == QTYPE.AAAA:
            # handle type AAAA request
            # insert DNS AAAA query logic
            reply.add_answer(RR(qname, qtype, rdata=AAAA("::1")))
        elif qtype == QTYPE.NS:
            # handle NS request
            # insert NS query logic
            reply.add_answer(RR(qname, qtype, rdata=A("ns.example.com")))
            pass
        elif qtype == QTYPE.CNAME:
            # handle CNAME request
            # insert CNAME query logic
            reply.add_answer(RR(qname, qtype, rdata=A("cname.example.com")))
            pass
        elif qtype == QTYPE.MX:
            # handle MX request
            # handle MX query logic
            reply.add_answer(RR(qname, qtype, rdata=A("mail.example.com")))
            pass
        else:
            # for unsupported query types, return an error response
            reply.header.rcode = RCODE.NXDOMAIN
        # send DNS response to client
        self.send_response(reply)

    def send_response(self, reply):
        # send DNS response to client
        self.server.socket.sendto(reply.pack(), self.client_address)


MyDNSserver = DNSServer(resolver=BaseResolver, handler=MyHandler, port=53, address="0.0.0.0")


if __name__ == '__main__':

    try:
        print("Starting DNS server...")
        print("Starting DNS server successfully.")
        MyDNSserver.start()
        while True:
            pass
    except KeyboardInterrupt:
        pass
    finally:
        print("Closing DNS server...")
        MyDNSserver.stop()
        print("Closing DNS server successfully.")
```

This is our new code. But we have not finish DNS controller part. In our new DNS Server version we try to complete DNS Server with Ryu. We get packet from DNS controller and handle packet data. Then generate reply packet and send to DNS controller. This DNS Server uses static response but we can also use dynamic response by creating a RRs list to save some RRs. Then if matched `qname` and `qtype` we can send `RR` in `RRs` list back.

```
from ryu.lib import addrconv
from ryu.lib.packet import packet
from ryu.lib.packet import ethernet
from ryu.lib.packet import ipv4
from dnslib import DNSRecord, RR, QTYPE, A, CNAME
from dnslib import *
from dnslib.server import DNSServer, DNSHandler, BaseResolver


class DNS_Server():

    def reply_packet(self, request):

        r = request.reply()

        if not request.querys:
            print("ERROR: Blank request.")
            return r

        for query in request.querys:
            name = query.get_qname
            type = query.qtype
            print(f"Received DNS query for {name} ({QTYPE[type]}) from {query.client_address[0]}")

            if type == QTYPE.A:
                # Handle A record query
                # Add your A record query logic here
                r.add_answer(RR(name, type, rdata=A("127.0.0.1")))
            elif type == QTYPE.AAAA:
                # Handle AAAA record query
                # Add your AAAA record query logic here
                r.add_answer(RR(name, type, rdata=AAAA("::1")))
            elif type == QTYPE.NS:
                # Handle NS record query
                # Add your NS record query logic here
                r.add_answer(RR(name, type, rdata=A("ns.example.com")))
                pass
            elif type == QTYPE.CNAME:
                # Handle CNAME record lookups
                # Add your CNAME record query logic here
                r.add_answer(RR(name, type, rdata=A("cname.example.com")))
                pass
            elif type == QTYPE.MX:
                # Handle MX record lookups
                # Add your MX record query logic here
                r.add_answer(RR(name, type, rdata=A("mail.example.com")))
                pass
            else:
                # For unsupported query types, return the corresponding error response
                r.header.rcode = RCODE.NXDOMAIN
            # Send DNS response to client

        return r

    def dns_handler(self, datapath, pkt, port):
        ether_c = pkt.get_protocol(ethernet.ethernet)
        ip_c = pkt.get_protocol(ipv4.ipv4)

        request = DNSRecord.parse(pkt.protocols[-1])

        if request.questions:
            pkt_ethernet = ether_c
            pkt_ethernet.src = pkt_ethernet.dst
            pkt_ethernet.dst = pkt_ethernet.src

            pkt_ip = ip_c
            pkt_ip.src = pkt_ip.dst,
            pkt_ip.dst = pkt_ip.src

            response = packet.Packet()
            response.add_protocol(pkt_ethernet)
            response.add_protocol(pkt_ip)
            response.add_protocol(self.reply_packet(request))

            return response
```

That's the end of our project report, thanks for reading!