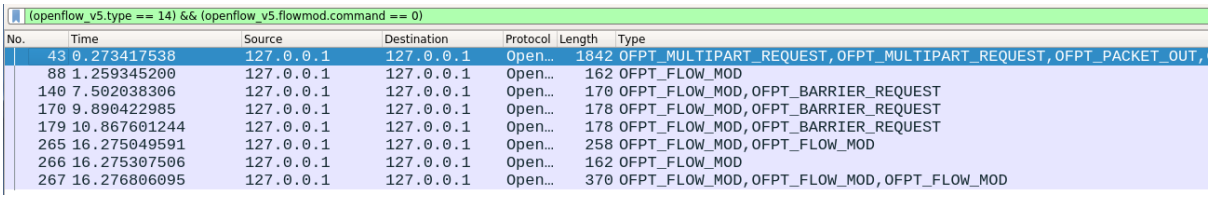
Part1

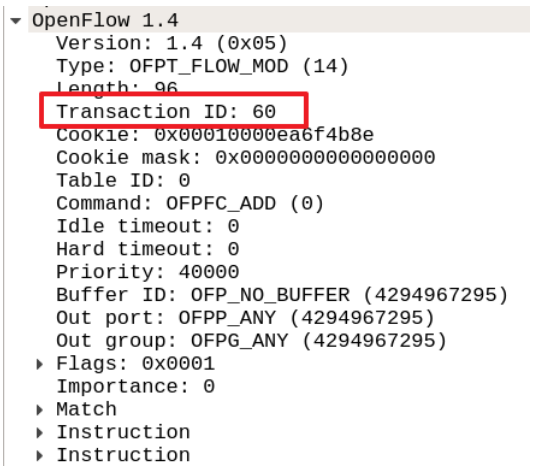
1. How many OpenFlow headers with type “OFPT_FLOW_MOD” and command “OFPFC_ADD” are there among all the packets?

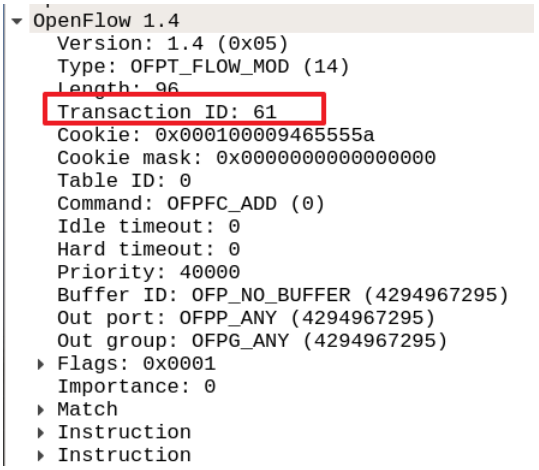
Answer:

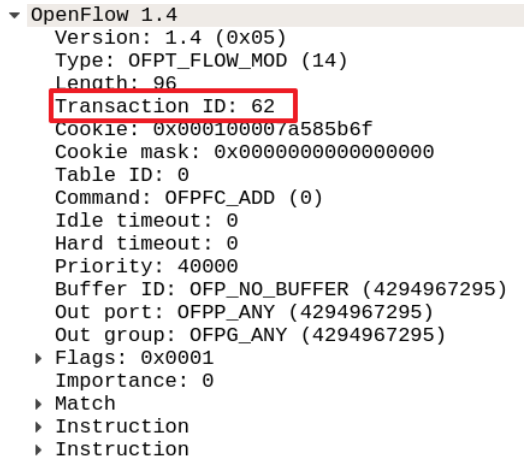
Using filters with this condition: (openflow_v5.type == 14) && (openflow_v5.flowmod.command == 0), and get 8 packets in the following picture.



1) packets No.43 - 3 headers







2) packets No.88 - 1 header

```
OpenFlow 1.4
    Version: 1.4 (0x05)
    Type: OFPT_FLOW_MOD (14)
    Length: 96
    Transaction ID: 0
    Cookie: 0x00010000021b41dc
    Cookie mask: 0x0000000000000000
    Table ID: 0
    Command: OFPFC_ADD (0)
    Idle timeout: 0
    Hard timeout: 0
    Priority: 5
    Buffer ID: OFP_NO_BUFFER (4294967295)
    Out port: OFPP_ANY (4294967295)
    Out group: OFPG_ANY (4294967295)
  ▸ Flags: 0x0001
    Importance: 0
  ▸ Match
  ▸ Instruction
  ▸ Instruction
```

3) packets No.140 - 1 header

```
OpenFlow 1.4
    Version: 1.4 (0x05)
    Type: OFPT_FLOW_MOD (14)
    Length: 96
    Transaction ID: 63
    Cookie: 0x00010000021b41dc
    Cookie mask: 0x0000000000000000
    Table ID: 0
    Command: OFPFC_ADD (0)
    Idle timeout: 0
    Hard timeout: 0
    Priority: 5
    Buffer ID: OFP_NO_BUFFER (4294967295)
    Out port: OFPP_ANY (4294967295)
    Out group: OFPG_ANY (4294967295)
  ▸ Flags: 0x0001
    Importance: 0
  ▸ Match
  ▸ Instruction
  ▸ Instruction
```

4) packets No.170 - 1 header

```
OpenFlow 1.4
    Version: 1.4 (0x05)
    Type: OFPT_FLOW_MOD (14)
    Length: 104
    Transaction ID: 66
    Cookie: 0x00500000eb219b61
    Cookie mask: 0x0000000000000000
    Table ID: 0
    Command: OFPFC_ADD (0)
    Idle timeout: 0
    Hard timeout: 0
    Priority: 10
    Buffer ID: OFP_NO_BUFFER (4294967295)
    Out port: OFPP_ANY (4294967295)
    Out group: OFPG_ANY (4294967295)
  ▸ Flags: 0x0001
    Importance: 0
  ▸ Match
  ▸ Instruction
```

5) packets No.179 - 1 header

```
OpenFlow 1.4
  Version: 1.4 (0x05)
  Type: OFPT_FLOW_MOD (14)
  Length: 104
  Transaction ID: 67
  Cookie: 0x005000001bac7760
  Cookie mask: 0x0000000000000000
  Table ID: 0
  Command: OFPFC_ADD (0)
  Idle timeout: 0
  Hard timeout: 0
  Priority: 10
  Buffer ID: OFP_NO_BUFFER (4294967295)
  Out port: OFPP_ANY (4294967295)
  Out group: OFPG_ANY (4294967295)
▸ Flags: 0x0001
  Importance: 0
▸ Match
▸ Instruction
```

6) packets No.265 - 2 headers

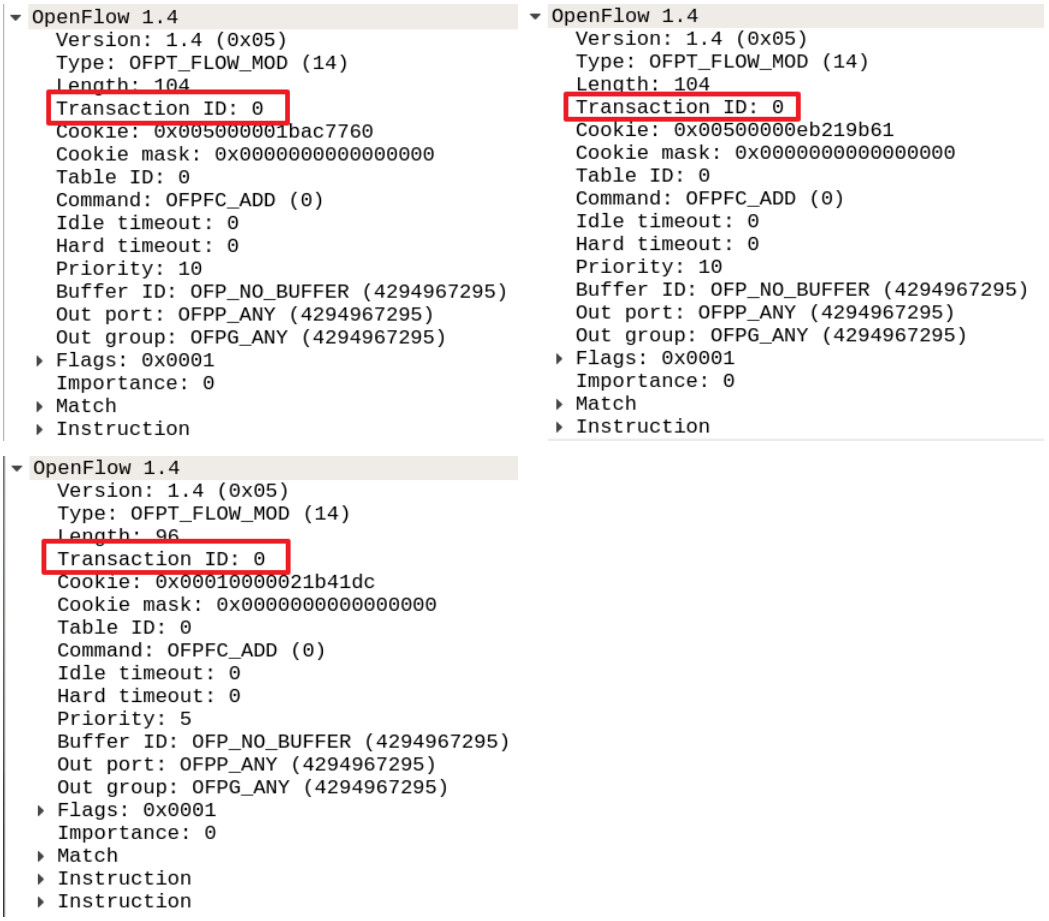
```
OpenFlow 1.4
  Version: 1.4 (0x05)
  Type: OFPT_FLOW_MOD (14)
  Length: 96
  Transaction ID: 0
  Cookie: 0x000100009465555a
  Cookie mask: 0x0000000000000000
  Table ID: 0
  Command: OFPFC_ADD (0)
  Idle timeout: 0
  Hard timeout: 0
  Priority: 40000
  Buffer ID: OFP_NO_BUFFER (4294967295)
  Out port: OFPP_ANY (4294967295)
  Out group: OFPG_ANY (4294967295)
▸ Flags: 0x0001
  Importance: 0
▸ Match
▸ Instruction
▸ Instruction
```

```
OpenFlow 1.4
  Version: 1.4 (0x05)
  Type: OFPT_FLOW_MOD (14)
  Length: 96
  Transaction ID: 0
  Cookie: 0x00010000ea6f4b8e
  Cookie mask: 0x0000000000000000
  Table ID: 0
  Command: OFPFC_ADD (0)
  Idle timeout: 0
  Hard timeout: 0
  Priority: 40000
  Buffer ID: OFP_NO_BUFFER (4294967295)
  Out port: OFPP_ANY (4294967295)
  Out group: OFPG_ANY (4294967295)
▸ Flags: 0x0001
  Importance: 0
▸ Match
▸ Instruction
▸ Instruction
```

7) packets No.266 - 1 header

```
OpenFlow 1.4
  Version: 1.4 (0x05)
  Type: OFPT_FLOW_MOD (14)
  Length: 96
  Transaction ID: 0
  Cookie: 0x000100007a585b6f
  Cookie mask: 0x0000000000000000
  Table ID: 0
  Command: OFPFC_ADD (0)
  Idle timeout: 0
  Hard timeout: 0
  Priority: 40000
  Buffer ID: OFP_NO_BUFFER (4294967295)
  Out port: OFPP_ANY (4294967295)
  Out group: OFPG_ANY (4294967295)
▸ Flags: 0x0001
  Importance: 0
▸ Match
▸ Instruction
▸ Instruction
```

8) packets No.267 - 3 headers



3 + 1 + 1 + 1 + 1 + 2 + 1 + 3 = 13

So, it has 13 headers that include the same match fields value among all the packets.

2. What are the match fields and the corresponding actions in each “OFPT_FLOW_MOD” message?

Answer:

1) **packets No.43**

```
Type: OFPT_FLOW_MOD (14)
Length: 96
Transaction ID: 60
Cookie: 0x00010000ea6f4b8e
Cookie mask: 0x0000000000000000
Table ID: 0
Command: OFPFC_ADD (0)
Idle timeout: 0
Hard timeout: 0
Priority: 40000
Buffer ID: OFP_NO_BUFFER (4294967295)
Out port: OFPP_ANY (4294967295)
Out group: OFPG_ANY (4294967295)
▸ Flags: 0x0001
Importance: 0
▾ Match
    Type: OFPMT_OXM (1)
    Length: 10
  ▾ OXM field
      Class: OFPXMC_OPENFLOW_BASIC (0x8000)
      0000 101. = Field: OFPXMT_OFB_ETH_TYPE (5)
      .... ...0 = Has mask: False
      Length: 2
      Value: ARP (0x0806)
    Pad: 000000000000
▾ Instruction
    Type: OFPIT_CLEAR_ACTIONS (5)
    Length: 8
    Pad: 00000000
▾ Instruction
    Type: OFPIT_APPLY_ACTIONS (4)
    Length: 24
    Pad: 00000000
  ▾ Action
      Type: OFPAT_OUTPUT (0)
      Length: 16
      Port: OFPP_CONTROLLER (4294967293)
      Max length: OFPCML_NO_BUFFER (65535)
      Pad: 000000000000
```

```
Type: OFPT_FLOW_MOD (14)
Length: 96
Transaction ID: 61
Cookie: 0x000100009465555a
Cookie mask: 0x0000000000000000
Table ID: 0
Command: OFPFC_ADD (0)
Idle timeout: 0
Hard timeout: 0
Priority: 40000
Buffer ID: OFP_NO_BUFFER (4294967295)
Out port: OFPP_ANY (4294967295)
Out group: OFPG_ANY (4294967295)
▸ Flags: 0x0001
Importance: 0
▾ Match
    Type: OFPMT_OXM (1)
    Length: 10
  ▾ OXM field
      Class: OFPXMC_OPENFLOW_BASIC (0x8000)
      0000 101. = Field: OFPXMT_OFB_ETH_TYPE (5)
      .... ...0 = Has mask: False
      Length: 2
      Value: 802.1 Link Layer Discovery Protocol (LLDP) (0x88cc)
    Pad: 000000000000
▾ Instruction
    Type: OFPIT_CLEAR_ACTIONS (5)
    Length: 8
    Pad: 00000000
▾ Instruction
    Type: OFPIT_APPLY_ACTIONS (4)
    Length: 24
    Pad: 00000000
  ▾ Action
      Type: OFPAT_OUTPUT (0)
      Length: 16
      Port: OFPP_CONTROLLER (4294967293)
      Max length: OFPCML_NO_BUFFER (65535)
      Pad: 000000000000
```

```
Type: OFPT_FLOW_MOD (14)
Length: 96
Transaction ID: 62
Cookie: 0x000100007a585b6f
Cookie mask: 0x0000000000000000
Table ID: 0
Command: OFPFC_ADD (0)
Idle timeout: 0
Hard timeout: 0
Priority: 40000
Buffer ID: OFP_NO_BUFFER (4294967295)
Out port: OFPP_ANY (4294967295)
Out group: OFPG_ANY (4294967295)
▸ Flags: 0x0001
Importance: 0
▾ Match
    Type: OFPMT_OXM (1)
    Length: 10
  ▾ OXM field
      Class: OFPXMC_OPENFLOW_BASIC (0x8000)
      0000 101. = Field: OFPXMT_OFB_ETH_TYPE (5)
      .... ...0 = Has mask: False
      Length: 2
      Value: Unknown (0x8942)
    Pad: 000000000000
▾ Instruction
    Type: OFPIT_CLEAR_ACTIONS (5)
    Length: 8
    Pad: 00000000
▾ Instruction
    Type: OFPIT_APPLY_ACTIONS (4)
    Length: 24
    Pad: 00000000
  ▾ Action
      Type: OFPAT_OUTPUT (0)
      Length: 16
      Port: OFPP_CONTROLLER (4294967293)
      Max length: OFPCML_NO_BUFFER (65535)
      Pad: 000000000000
```

2) packets No.88

```
Type: OFPT_FLOW_MOD (14)
Length: 96
Transaction ID: 0
Cookie: 0x00010000021b41dc
Cookie mask: 0x0000000000000000
Table ID: 0
Command: OFPFC_ADD (0)
Idle timeout: 0
Hard timeout: 0
Priority: 5
Buffer ID: OFP_NO_BUFFER (4294967295)
Out port: OFPP_ANY (4294967295)
Out group: OFPG_ANY (4294967295)
▸ Flags: 0x0001
Importance: 0
▾ Match
    Type: OFPMT_OXM (1)
    Length: 10
  ▾ OXM field
      Class: OFPXMC_OPENFLOW_BASIC (0x8000)
      0000 101. = Field: OFPXMT_OFB_ETH_TYPE (5)
      .... ...0 = Has mask: False
      Length: 2
      Value: IPv4 (0x0800)
    Pad: 000000000000
▾ Instruction
    Type: OFPIT_CLEAR_ACTIONS (5)
    Length: 8
    Pad: 00000000
▾ Instruction
    Type: OFPIT_APPLY_ACTIONS (4)
    Length: 24
    Pad: 00000000
  ▾ Action
      Type: OFPAT_OUTPUT (0)
      Length: 16
      Port: OFPP_CONTROLLER (4294967293)
      Max length: OFPCML_NO_BUFFER (65535)
      Pad: 000000000000
```

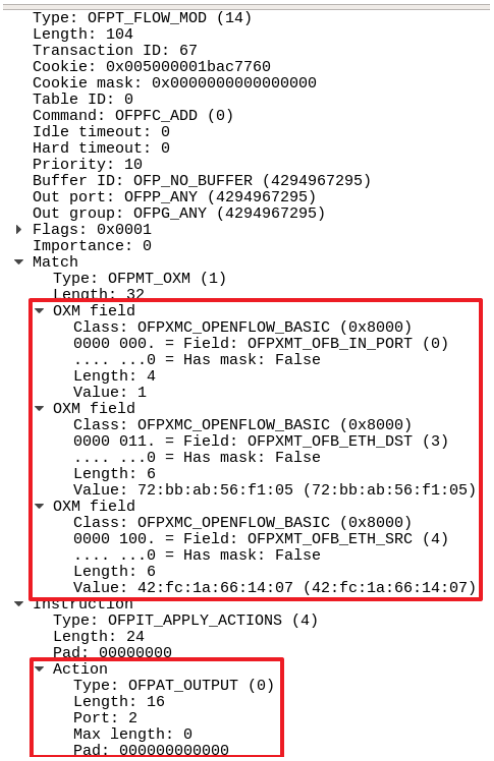
3) packets No.140

This packet has 1 header but the match field value is the same as the No.88 header, so skipped.

4) packets No.170

```
Type: OFPT_FLOW_MOD (14)
Length: 104
Transaction ID: 66
Cookie: 0x00500000eb219b61
Cookie mask: 0x0000000000000000
Table ID: 0
Command: OFPFC_ADD (0)
Idle timeout: 0
Hard timeout: 0
Priority: 10
Buffer ID: OFP_NO_BUFFER (4294967295)
Out port: OFPP_ANY (4294967295)
Out group: OFPG_ANY (4294967295)
▸ Flags: 0x0001
Importance: 0
▾ Match
    Type: OFPMT_OXM (1)
    Length: 32
  ▾ OXM field
      Class: OFPXMC_OPENFLOW_BASIC (0x8000)
      0000 000. = Field: OFPXMT_OFB_IN_PORT (0)
      .... ...0 = Has mask: False
      Length: 4
      Value: 2
  ▾ OXM field
      Class: OFPXMC_OPENFLOW_BASIC (0x8000)
      0000 011. = Field: OFPXMT_OFB_ETH_DST (3)
      .... ...0 = Has mask: False
      Length: 6
      Value: 42:fc:1a:66:14:07 (42:fc:1a:66:14:07)
  ▾ OXM field
      Class: OFPXMC_OPENFLOW_BASIC (0x8000)
      0000 100. = Field: OFPXMT_OFB_ETH_SRC (4)
      .... ...0 = Has mask: False
      Length: 6
      Value: 72:bb:ab:56:f1:05 (72:bb:ab:56:f1:05)
▾ Instruction
    Type: OFPIT_APPLY_ACTIONS (4)
    Length: 24
    Pad: 00000000
  ▾ Action
      Type: OFPAT_OUTPUT (0)
      Length: 16
      Port: 1
      Max length: 0
      Pad: 000000000000
```

5) packets No.179



6) packets No.265

This packet has 2 headers but the match field value is all the same as the No.43 headers, so skipped.

7) packets No.266

This packet has 1 header but the match field value is the same as the No.43 header, so skipped.

8) packets No.267

This packet has 3 headers but the match field value is the same as the No.179, No.170 , No. 88 headers, so skipped.

3. What is the value of timeout for each flow rule installed in s1?

Answer:
The device id of S1(switch1) is “of:0000000000000001”.
To get the flow rules of s1, the api response data from url:
http://localhost:8181/onos/v1/flows/of:0000000000000001 is as below.


```
{
  "flows": [
    {
      "id": "281477029321583",
      "tableId": "0",
      "appId": "org.onosproject.core",
      "groupId": 0,
      "priority": 40000,
      "timeout": 0,
      "isPermanent": true,
      "deviceId": "of:0000000000000001",
      "state": "ADDED",
      "life": 0,
      "packets": 0,
      "bytes": 0,
      "liveType": "UNKNOWN",
      "lastSeen": 1633928395238,
      "treatment": {
        "instructions": [
          {
            "type": "OUTPUT",
            "port": "CONTROLLER"
          }
        ],
        "clearDeferred": true,
        "deferred": []
      },
      "selector": {
        "criteria": [
          {
            "type": "ETH_TYPE",
            "ethType": "0x8942"
          }
        ]
      }
    },
    {
      "id": "22517999380834791",
      "tableId": "0",
      "appId": "org.onosproject.fwd",
      "groupId": 0,
      "priority": 10,
      "timeout": 10,
      "isPermanent": false,
      "deviceId": "of:0000000000000001",
      "state": "ADDED",
      "life": 17,
      "packets": 4,
      "bytes": 392,
```

```
    "liveType": "UNKNOWN",
    "lastSeen": 1633928339633,
    "treatment": {
      "instructions": [
        {
          "type": "OUTPUT",
          "port": "1"
        }
      ],
      "deferred": []
    },
    "selector": {
      "criteria": [
        {
          "type": "IN_PORT",
          "port": 2
        },
        {
          "type": "ETH_DST",
          "mac": "E2:ED:61:90:3D:B7"
        },
        {
          "type": "ETH_SRC",
          "mac": "C6:2C:B8:45:27:E9"
        }
      ]
    }
  },
  {
    "id": "281478909873038",
    "tableId": "0",
    "appId": "org.onosproject.core",
    "groupId": 0,
    "priority": 40000,
    "timeout": 0,
    "isPermanent": true,
    "deviceId": "of:0000000000000001",
    "state": "ADDED",
    "life": 0,
    "packets": 0,
    "bytes": 0,
    "liveType": "UNKNOWN",
    "lastSeen": 1633928395238,
    "treatment": {
      "instructions": [
        {
          "type": "OUTPUT",
          "port": "CONTROLLER"
        }
      ],
      "clearDeferred": true,
      "deferred": []
    },
    "selector": {
      "criteria": [
        {
```

```
          "type": "ETH_TYPE",
          "ethType": "0x806"
        }
      ]
    }
  },
  {
    "id": "22518001178099892",
    "tableId": "0",
    "appId": "org.onosproject.fwd",
    "groupId": 0,
    "priority": 10,
    "timeout": 10,
    "isPermanent": false,
    "deviceId": "of:0000000000000001",
    "state": "ADDED",
    "life": 17,
    "packets": 4,
    "bytes": 392,
    "liveType": "UNKNOWN",
    "lastSeen": 1633928339633,
    "treatment": {
      "instructions": [
        {
          "type": "OUTPUT",
          "port": "2"
        }
      ],
      "deferred": []
    },
    "selector": {
      "criteria": [
        {
          "type": "IN_PORT",
          "port": 1
        },
        {
          "type": "ETH_DST",
          "mac": "C6:2C:B8:45:27:E9"
        },
        {
          "type": "ETH_SRC",
          "mac": "E2:ED:61:90:3D:B7"
        }
      ]
    }
  },
  {
    "id": "281477466379610",
    "tableId": "0",
    "appId": "org.onosproject.core",
    "groupId": 0,
    "priority": 40000,
    "timeout": 0,
    "isPermanent": true,
    "deviceId": "of:0000000000000001",
```

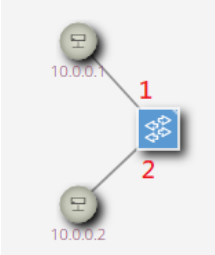
```
      "state": "ADDED",
      "life": 0,
      "packets": 0,
      "bytes": 0,
      "liveType": "UNKNOWN",
      "lastSeen": 1633928395238,
      "treatment": {
        "instructions": [
          {
            "type": "OUTPUT",
            "port": "CONTROLLER"
          }
        ],
        "clearDeferred": true,
        "deferred": []
      },
      "selector": {
        "criteria": [
          {
            "type": "ETH_TYPE",
            "ethType": "0x88cc"
          }
        ]
      }
    },
    {
      "id": "281475012051420",
      "tableId": "0",
      "appId": "org.onosproject.core",
      "groupId": 0,
      "priority": 5,
      "timeout": 0,
      "isPermanent": true,
      "deviceId": "of:0000000000000001",
      "state": "ADDED",
      "life": 0,
      "packets": 0,
      "bytes": 0,
      "liveType": "UNKNOWN",
      "lastSeen": 1633928395238,
      "treatment": {
        "instructions": [
          {
            "type": "OUTPUT",
            "port": "CONTROLLER"
          }
        ],
        "clearDeferred": true,
        "deferred": []
      },
      "selector": {
        "criteria": [
          {
            "type": "ETH_TYPE",
            "ethType": "0x800"
          }
```

```
        ]
      }
    }
  ]
}
```

Part2

- Install following flow rules to forward ARP packets
  - Match Fields
    - Ethernet type (ARP)
  - Actions
    - Output from port, forwarding ARP packets to hosts

The corresponding flow rule setting:



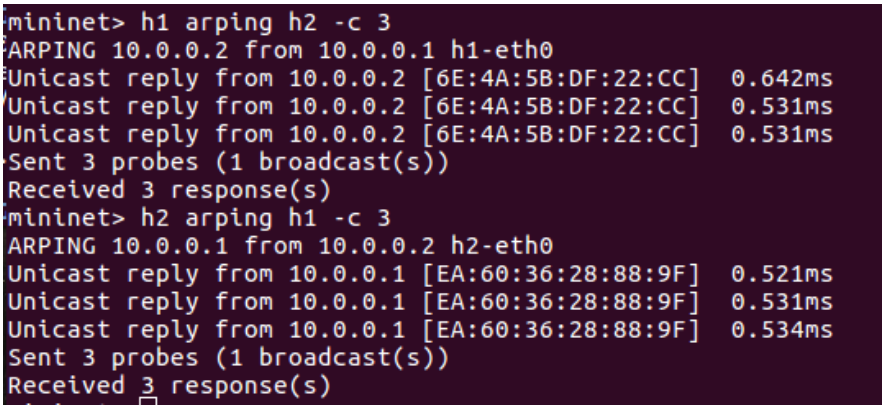
1) Set the flow rule from in port 1 and ethernet type equals ARP value 0x806, then forward ARP packets to output port 2.


```
{
    "id": "54043199018136292",
    "tableId": "0",
    "appId": "org.onosproject.rest",
    "groupId": 0,
    "priority": 50000,
    "timeout": 0,
    "isPermanent": true,
    "deviceId": "of:0000000000000001",
    "state": "ADDED",
    "life": 5,
    "packets": 0,
    "bytes": 0,
    "liveType": "UNKNOWN",
    "lastSeen": 1634350332754,
  ▼ "treatment": {
    ▼ "instructions": [
      ▼ {
            "type": "OUTPUT",
            "port": "2"
        }
      ],
      "deferred": []
    },
  ▼ "selector": {
    ▼ "criteria": [
      ▼ {
            "type": "IN_PORT",
            "port": 1
        },
      ▼ {
            "type": "ETH_TYPE",
            "ethType": "0x806"
        }
      ]
    }
},
```

2) Set the flow rule from in port 2 and ethernet type equals with ARP value 0x806, then forwarding ARP packets to output port 1.


```
{
    "id": "54043199619047884",
    "tableId": "0",
    "appId": "org.onosproject.rest",
    "groupId": 0,
    "priority": 50000,
    "timeout": 0,
    "isPermanent": true,
    "deviceId": "of:0000000000000001",
    "state": "ADDED",
    "life": 2,
    "packets": 0,
    "bytes": 0,
    "liveType": "UNKNOWN",
    "lastSeen": 1634350332754,
  "treatment": {
    "instructions": [
      {
        "type": "OUTPUT",
        "port": "1"
      }
    ],
    "deferred": []
  },
  "selector": {
    "criteria": [
      {
        "type": "IN_PORT",
        "port": 2
      },
      {
        "type": "ETH_TYPE",
        "ethType": "0x806"
      }
    ]
  }
},
```


After setting above flow rules, hosts can arping each other.



- Install flow rules to forward IPv4 packets
  - Match Fields
    - IPv4 destination address
  - Actions
    - Output from port, forwarding IPv4 packets to hosts

1) Set the flow rule from in port 1 and ethernet type equals IPv4 value 0x800 and IPv4 destination address set to fixed 10.0.0.2 , then forward IPv4 packets to output port 2.


```
{
    "id": "54043199496433760",
    "tableId": "0",
    "appId": "org.onosproject.rest",
    "groupId": 0,
    "priority": 50000,
    "timeout": 0,
    "isPermanent": true,
    "deviceId": "of:0000000000000001",
    "state": "ADDED",
    "life": 24,
    "packets": 0,
    "bytes": 0,
    "liveType": "UNKNOWN",
    "lastSeen": 1634351012758,
    "treatment": {
        "instructions": [
            {
                "type": "OUTPUT",
                "port": "2"
            }
        ],
        "deferred": []
    },
    "selector": {
        "criteria": [
            {
                "type": "IN_PORT",
                "port": 1
            },
            {
                "type": "ETH_TYPE",
                "ethType": "0x800"
            },
            {
                "type": "IPV4_DST",
                "ip": "10.0.0.2/32"
            }
        ]
    }
},
```

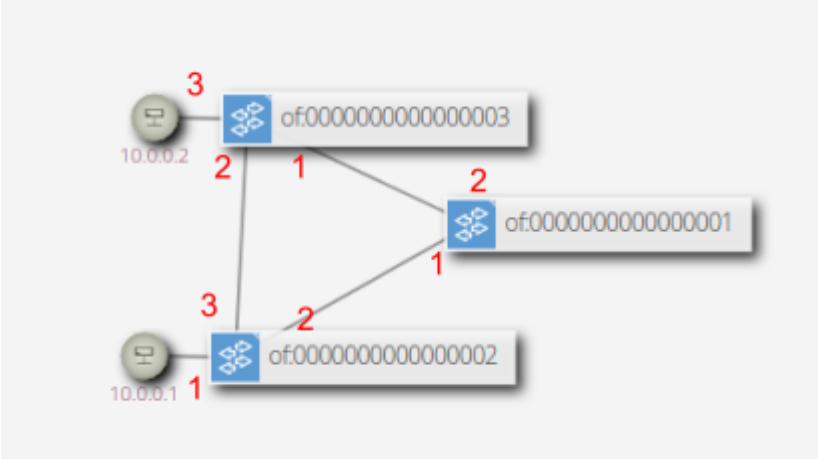
2) Set the flow rule from in port 2 and ethernet type equals IPv4 value 0x800 and IPv4 destination address set to fixed 10.0.0.1 , then forward IPv4 packets to output port 1.


```
{
    "id": "54043196625883669",
    "tableId": "0",
    "appId": "org.onosproject.rest",
    "groupId": 0,
    "priority": 50000,
    "timeout": 0,
    "isPermanent": true,
    "deviceId": "of:0000000000000001",
    "state": "ADDED",
    "life": 0,
    "packets": 0,
    "bytes": 0,
    "liveType": "UNKNOWN",
    "lastSeen": 1634351012761,
    "treatment": {
        "instructions": [
            {
                "type": "OUTPUT",
                "port": "1"
            }
        ],
        "deferred": []
    },
    "selector": {
        "criteria": [
            {
                "type": "IN_PORT",
                "port": 2
            },
            {
                "type": "ETH_TYPE",
                "ethType": "0x800"
            },
            {
                "type": "IPV4_DST",
                "ip": "10.0.0.1/32"
            }
        ]
    }
}
```

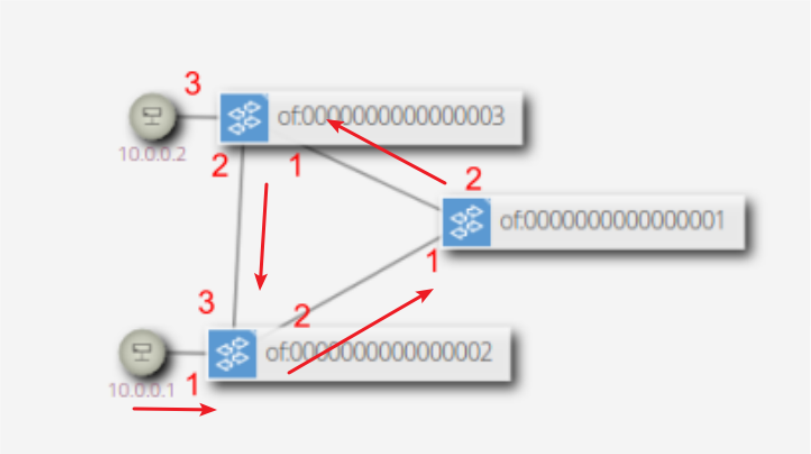

After setting above flow rules, hosts can ping each other.

```
mininet> h1 ping h2 -c 3
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=0.027 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.175 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.028 ms

--- 10.0.0.2 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2047ms
rtt min/avg/max/mdev = 0.027/0.076/0.175/0.070 ms
mininet> h2 ping h1 -c 3
PING 10.0.0.1 (10.0.0.1) 56(84) bytes of data.
64 bytes from 10.0.0.1: icmp_seq=1 ttl=64 time=0.026 ms
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=0.049 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=0.037 ms

--- 10.0.0.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2047ms
rtt min/avg/max/mdev = 0.026/0.037/0.049/0.010 ms
```

Part3



Broadcast Storm topology as shown picture below:



1) set s2 flow rule from: input port 1 to port 2 , input port 3 to port 2

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

```
  }
}
```

```
{
  "priority": 50000,
  "timeout": 0,
  "isPermanent": true,
  "selector": {
    "criteria": [
      {
        "type": "IN_PORT",
        "port": "3"
      }
    ]
  },
  "treatment": {
    "instructions": [
      {
        "type": "OUTPUT",
        "port": "2"
      }
    ]
  }
}
```

2) set s1 flow rule from input port 1 to port 2

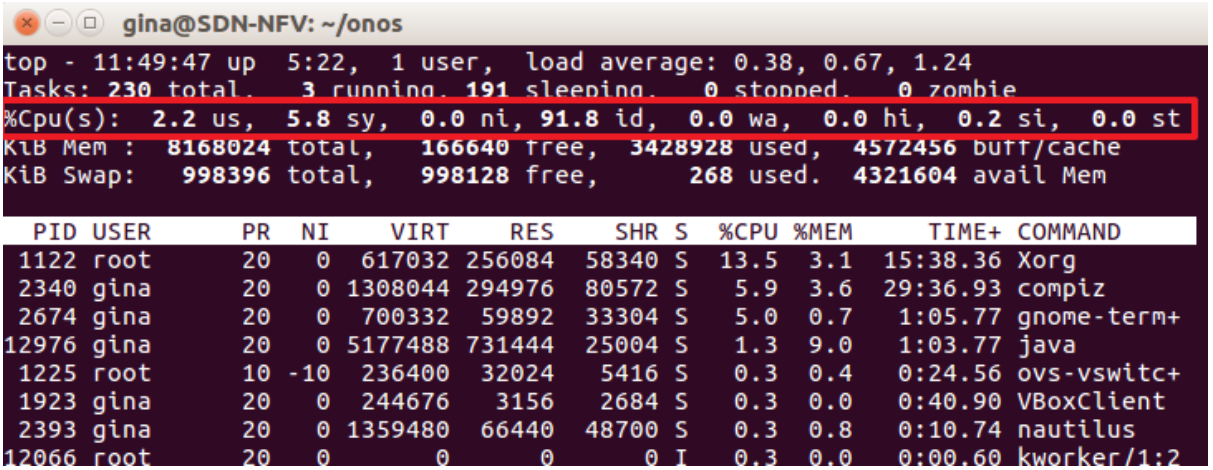
```
{
  "priority": 50000,
  "timeout": 0,
  "isPermanent": true,
  "selector": {
    "criteria": [
      {
        "type": "IN_PORT",
        "port": "1"
      }
    ]
  },
  "treatment": {
    "instructions": [
      {
        "type": "OUTPUT",
        "port": "2"
      }
    ]
  }
}
```

3) set s3 flow rule from input port 1 to port 2

```
{
  "priority": 50000,
```

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

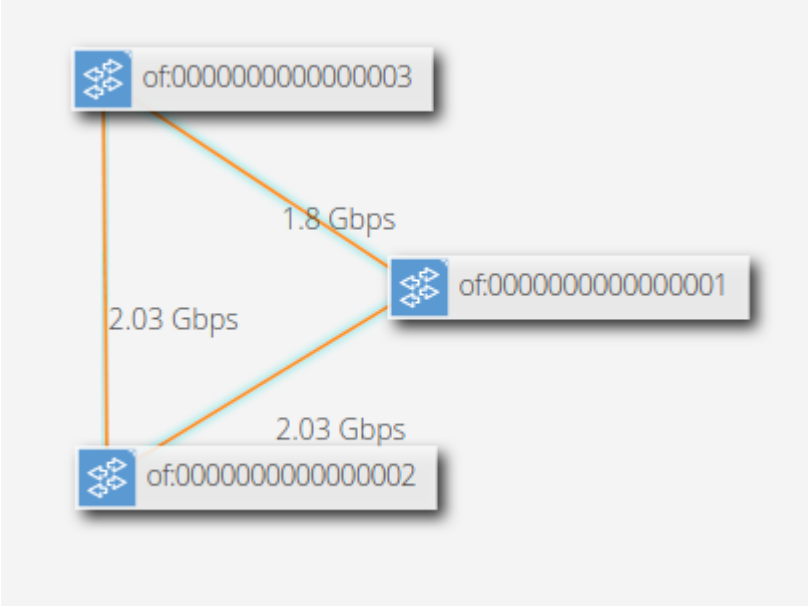
Before installing flow rules, the CPU usage is shown as below.



After installing flow rules, the CPU usage is shown as below.
It can be observed that the CPU usage has increased significantly.

```
gina@SDN-NFV: ~/onos
top - 11:55:47 up  5:28,  1 user,  load average: 7.90, 3.01, 1.86
Tasks: 230 total,   4 running, 189 sleeping,   0 stopped,   0 zombie
%Cpu(s):  1.9 us,  5.4 sy,  0.0 ni,  0.0 id,  0.0 wa,  0.0 hi, 92.6 si,  0.0 st
KiB Mem :  8168024 total,   148480 free,  3446140 used,  4573404 buff/cache
KiB Swap:   998396 total,   998128 free,      268 used.  4304020 avail Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU %MEM     TIME+ COMMAND
    7 root      20   0       0      0      0 R  96.0  0.0   5:25.70 ksoftirqd/0
   16 root      20   0       0      0      0 R  94.7  0.0   5:29.73 ksoftirqd/1
 1122 root      20   0  617032 256084  58340 R   5.0  3.1  15:50.12 Xorg
 2674 gina      20   0  700660  60216  33384 S   2.0  0.7   1:07.39 gnome-term+
12976 gina      20   0 5182628 740852  25004 S   1.7  9.1   1:16.05 java
 2340 gina      20   0 1308044 294976  80572 S   1.0  3.6  29:48.83 compiz
    8 root      20   0       0      0      0 I   0.3  0.0   0:14.23 rcu_sched
13740 gina      20   0   42188   4116   3408 R   0.3  0.1   0:00.59 top
    1 root      20   0  185232   5800   3932 S   0.0  0.1   0:02.42 systemd
    2 root      20   0       0      0      0 S   0.0  0.0   0:00.02 kthreadd
    4 root       0 -20       0      0      0 I   0.0  0.0   0:00.00 kworker/0:+
    6 root       0 -20       0      0      0 I   0.0  0.0   0:00.00 mm_percpu_+
    9 root      20   0       0      0      0 I   0.0  0.0   0:00.00 rcu_bh
   10 root      rt   0       0      0      0 S   0.0  0.0   0:00.03 migration/0
```

And observe the link status. The packet bytes have increased significantly.



Part4

Compared with “org.onosproject.fwd” app by activated and deactivated, then letting h1 ping h2 can describe that it would append 3 flow rules as following setting.

rule 1:
Control planes will generate the related fow rules(rule 2&3) and control the forwarding of IPv4 packets in the data plane because the OUTPUT was set to CONTROLLER.


```
{
      "id": "281475012051420",
      "tableId": "0",
      "appId": "org.onosproject.core",
      "groupId": 0,
      "priority": 5,
      "timeout": 0,
      "isPermanent": true,
      "deviceId": "of:0000000000000001",
      "state": "ADDED",
      "life": 21,
      "packets": 3,
      "bytes": 294,
      "liveType": "UNKNOWN",
      "lastSeen": 1634459119651,
      "treatment": {
        "instructions": [
          {
            "type": "OUTPUT",
            "port": "CONTROLLER"
          }
        ],
        "clearDeferred": true,
        "deferred": []
      },
      "selector": {
        "criteria": [
          {
            "type": "ETH_TYPE",
            "ethType": "0x800"
          }
        ]
      }
    }
```


These 2 flow rules were generated only when the fwd app was activated and after the control plane received the packets. The flow rules defined how packets send/receive port and MAC source/destination address.

rule 2:


```
{
      "id": "22518002394889381",
      "tableId": "0",
      "appId": "org.onosproject.fwd",
      "groupId": 0,
```

```
      "priority": 10,
      "timeout": 10,
      "isPermanent": false,
      "deviceId": "of:0000000000000001",
      "state": "ADDED",
      "life": 9,
      "packets": 3,
      "bytes": 294,
      "liveType": "UNKNOWN",
      "lastSeen": 1634459119651,
      "treatment": {
        "instructions": [
          {
            "type": "OUTPUT",
            "port": "1"
          }
        ],
        "deferred": []
      },
      "selector": {
        "criteria": [
          {
            "type": "IN_PORT",
            "port": 2
          },
          {
            "type": "ETH_DST",
            "mac": "9A:DC:8B:B6:69:EA"
          },
          {
            "type": "ETH_SRC",
            "mac": "52:22:33:84:37:7E"
          }
        ]
      }
    }
```


rule 3:


```
{
      "id": "22518000840009943",
      "tableId": "0",
      "appId": "org.onosproject.fwd",
      "groupId": 0,
      "priority": 10,
      "timeout": 10,
      "isPermanent": false,
      "deviceId": "of:0000000000000001",
      "state": "ADDED",
      "life": 9,
      "packets": 4,
      "bytes": 392,
      "liveType": "UNKNOWN",
      "lastSeen": 1634459119651,
      "treatment": {
        "instructions": [
```

```
        {
          "type": "OUTPUT",
          "port": "2"
        }
      ],
      "deferred": []
    },
    "selector": {
      "criteria": [
        {
          "type": "IN_PORT",
          "port": 1
        },
        {
          "type": "ETH_DST",
          "mac": "52:22:33:84:37:7E"
        },
        {
          "type": "ETH_SRC",
          "mac": "9A:DC:8B:B6:69:EA"
        }
      ]
    }
  }
```


And catching the packets as below picture when h1 ping h2 until h2 receives the first ICMP request.

No.	Source	Destination	Protocol	Length	Protocol	Type	Field	Value	Address Resolution Protocol	Info
587	127.0.0.1	127.0.0.1	OpenFlow	150	TCP	IPv4,ARP	OFPXMT_OFB_IN_PORT	1 ✓		Type: OFPT_PACKET_IN
590	127.0.0.1	127.0.0.1	OpenFlow	150	TCP	IPv4,ARP	OFPXMT_OFB_IN_PORT	2 ✓		Type: OFPT_PACKET_IN
592	127.0.0.1	127.0.0.1	OpenFlow	206	TCP,ICMP	IPv4,IPv4	OFPXMT_OFB_IN_PORT	1		Type: OFPT_PACKET_IN
594	127.0.0.1	127.0.0.1	OpenFlow	206	TCP,ICMP	IPv4,IPv4	OFPXMT_OFB_IN_PORT	2		Type: OFPT_PACKET_IN

At first, IN_PORT 1 sent the requested ARP packet.

```
▾ Match
    Type: OFPMT_OXM (1)
    Length: 12
  ▾ OXM field
      Class: OFPXMC_OPENFLOW_BASIC (0x8000)
      0000 000. = Field: OFPXMT_OFB_IN_PORT (0)
      .... ...0 = Has mask: False
      Length: 4
      Value: 1
    Pad: 00000000
  Pad: 0000
▾ Data
  ▾ Ethernet II, Src: 9a:dc:8b:b6:69:ea (9a:dc:8b:b6:69:ea), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
    ▸ Destination: Broadcast (ff:ff:ff:ff:ff:ff)
    ▸ Source: 9a:dc:8b:b6:69:ea (9a:dc:8b:b6:69:ea)
      Type: ARP (0x0806)
  ▾ Address Resolution Protocol (request)
      Hardware type: Ethernet (1)
      Protocol type: IPv4 (0x0800)
      Hardware size: 6
      Protocol size: 4
      Opcode: request (1)
      Sender MAC address: 9a:dc:8b:b6:69:ea (9a:dc:8b:b6:69:ea)
      Sender IP address: 10.0.0.1
      Target MAC address: 00:00:00_00:00:00 (00:00:00:00:00:00)
      Target IP address: 10.0.0.2
```

Then, IN_PORT 2 got the reply IN_PORT 1 ARP packet.

```
▾ Match
    Type: OFPMT_OXM (1)
    Length: 12
  ▾ OXM field
      Class: OFPXMC_OPENFLOW_BASIC (0x8000)
      0000 000. = Field: OFPXMT_OFB_IN_PORT (0)
      .... ...0 = Has mask: False
      Length: 4
      Value: 2
    Pad: 00000000
  Pad: 0000
▾ Data
  ▾ Ethernet II, Src: 52:22:33:84:37:7e (52:22:33:84:37:7e), Dst: 9a:dc:8b:b6:69:ea (9a:dc:8b:b6:69:ea)
    ▸ Destination: 9a:dc:8b:b6:69:ea (9a:dc:8b:b6:69:ea)
    ▸ Source: 52:22:33:84:37:7e (52:22:33:84:37:7e)
      Type: ARP (0x0806)
  ▾ Address Resolution Protocol (reply)
      Hardware type: Ethernet (1)
      Protocol type: IPv4 (0x0800)
      Hardware size: 6
      Protocol size: 4
      Opcode: reply (2)
      Sender MAC address: 52:22:33:84:37:7e (52:22:33:84:37:7e)
      Sender IP address: 10.0.0.2
      Target MAC address: 9a:dc:8b:b6:69:ea (9a:dc:8b:b6:69:ea)
      Target IP address: 10.0.0.1
```

And Second, IN_PORT 1 sent the requested IPv4 packet.

```
▾ Match
    Type: OFPMT_OXM (1)
    Length: 12
  ▾ OXM field
      Class: OFPXMC_OPENFLOW_BASIC (0x8000)
      0000 000. = Field: OFPXMT_OFB_IN_PORT (0)
      .... ...0 = Has mask: False
      Length: 4
      Value: 1
    Pad: 00000000
  Pad: 0000
▾ Data
  ▾ Ethernet II, Src: 9a:dc:8b:b6:69:ea (9a:dc:8b:b6:69:ea), Dst: 52:22:33:84:37:7e (52:22:33:84:37:7e)
    ▸ Destination: 52:22:33:84:37:7e (52:22:33:84:37:7e)
    ▸ Source: 9a:dc:8b:b6:69:ea (9a:dc:8b:b6:69:ea)
      Type: IPv4 (0x0800)
  ▾ Internet Protocol Version 4, Src: 10.0.0.1, Dst: 10.0.0.2
      0100 .... = Version: 4
      .... 0101 = Header Length: 20 bytes (5)
    ▸ Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
      Total Length: 84
      Identification: 0xa89c (43164)
    ▸ Flags: 0x4000, Don't fragment
      Time to live: 64
      Protocol: ICMP (1)
      Header checksum: 0x7e0a [validation disabled]
      [Header checksum status: Unverified]
      Source: 10.0.0.1
      Destination: 10.0.0.2
  ▾ Internet Control Message Protocol
      Type: 8 (Echo (ping) request)
```

Then, IN_PORT 2 got the reply IN_PORT 1 IPv4 packet.

```
▾ Match
    Type: OFPMT_OXM (1)
    Length: 12
  ▾ OXM field
      Class: OFPXMC_OPENFLOW_BASIC (0x8000)
      0000 000. = Field: OFPXMT_OFB_IN_PORT (0)
      .... ...0 = Has mask: False
      Length: 4
      Value: 2
    Pad: 00000000
  Pad: 0000
▾ Data
  ▾ Ethernet II, Src: 52:22:33:84:37:7e (52:22:33:84:37:7e), Dst: 9a:dc:8b:b6:69:ea (9a:dc:8b:b6:69:ea)
    ▸ Destination: 9a:dc:8b:b6:69:ea (9a:dc:8b:b6:69:ea)
    ▸ Source: 52:22:33:84:37:7e (52:22:33:84:37:7e)
      Type: IPv4 (0x0800)
  ▾ Internet Protocol Version 4, Src: 10.0.0.2, Dst: 10.0.0.1
      0100 .... = Version: 4
      .... 0101 = Header Length: 20 bytes (5)
    ▸ Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
      Total Length: 84
      Identification: 0x6518 (25880)
    ▸ Flags: 0x0000
      Time to live: 64
      Protocol: ICMP (1)
      Header checksum: 0x018f [validation disabled]
      [Header checksum status: Unverified]
      Source: 10.0.0.2
      Destination: 10.0.0.1
  ▾ Internet Control Message Protocol
      Type: 0 (Echo (ping) reply)
```